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Oklahoma Scenic Rivers Joint Phosphorus Criteria Study

A Team Qualifications Statement to

Shellie Chard-McClary
Water Quality Division Director
Oklahoma Department of Environmental Quality; 707 N Robinson, Oklahoma City, 73102

Presented on

December 27, 2013

Introduction to the Project Team

The Project Team of Kieser & Associates, LLC (K&A) and Versar, Inc. (Versar) is responding to a Request for Qualifications for consideration as experienced researchers for a joint study to determine a total phosphorus threshold response level(s) in Oklahoma's designated Scenic Rivers. These thresholds are expected to be protective of the aesthetics beneficial use and scenic river designations. They will also be based on overall stream health for "Outstanding Resource Waters". In these regards, our firms bring both relevant and unique experience and expertise to this project.

K&A is a specialty firm based in Kalamazoo, Michigan focused on water resources management, watershed protection and innovative water quality program implementation. Key staff members have experience relevant to the application of water quality criteria as well as the unique settings and circumstances in Oklahoma to be examined in this project. Dr. "Andrew" Feng Fang, Senior Project Scientist at K&A, for example served six years with Oklahoma DEQ (2006-2013) as a TMDL engineer. He thus brings extensive familiarity with Oklahoma's water quality standards and its development process. Particularly when developing TMDLs, Dr. Fang frequently consulted the Oklahoma Water Quality Standards. His section at DEQ also worked with the Oklahoma Water Resources Board, the agency responsible of developing the standards, to make changes and revisions to these. Other relevant K&A project experience that will support joint Oklahoma/Arkansas phosphorus threshold development includes: applied research on thermal response stressors in coldwater trout streams, TMDL assessment (monitoring, modeling and allocations), technical assessment and management of multi-state water quality programs, intensive water quality monitoring program development and implementation, and nutrient criteria assessment review.

Versar's Ecological Sciences and Applications service area combines its scientific research with a range of services to develop innovative and practical solutions for resource management, ecosystem restoration, watershed planning, and program decision support. They offer a wide array of ecological assessments, statistical analyses, and modeling services that provide a scientifically sound and defensible basis for their clients' environmental management decisions. Their scientists work closely with clients to develop practical, cost-effective solutions to environmental monitoring, data interpretation, and regulatory compliance needs. Versar scientists have a nationally demonstrated ability for designing, conducting, and interpreting long-term studies requiring extended commitments of resources, as well as short-term studies where quick mobilization and deployment of people and equipment are paramount.

Although our two firms have not formally worked together in the past, we both serve on a much broader team of engineers, scientists and technicians supporting U.S.EPA's Office of Water contract for Technical Support for Assessment and Watershed Protection (TSAWP) (under RTI International). We believe that our collective experience in understanding the setting, working with challenging multi-state water quality issues, assessing stressor-responses and recommending threshold levels will provide unbiased and independent assessment capabilities. For this project, both firms will share technical roles while administratively, K&A will serve as the prime contractor and Versar as a subcontractor to K&A. Additional details about each firm are provided as follows.

Kieser & Associates, LLC

Based in Kalamazoo, Michigan, K&A (www.kieser-associates.com) provides scientific research and environmental consulting services to federal, state and local agencies, industry, commercial businesses, municipalities, legal counsel and private clients across North America and internationally. The firm was established in March 1992 by Mark S. Kieser, Senior Scientist and owner. Our efforts frequently involve a balance between environmental improvements and economic realities. We strive for sustainable approaches incorporating environmentally sound actions that are economically viable.

K&A staff offer multi-disciplinary expertise in areas of water resource science, civil and environmental engineering, hydrogeology, resource management, risk assessment, aquatic ecology, biology, chemistry and regulatory policy development. Our combined experience includes studies covering a range of environmental topics and issues from traditional engineering to remedial investigation and surface water projects. The diverse experience of K&A project managers and highly qualified technical staff with advanced degrees provides the continuity necessary to direct and conduct projects from initial developmental stages through completion. Such continuity is a critical component to successful project management, investigation and problem resolution.

K&A's staff of nine has been and continue to be on the cutting edge of water resource assessment and management, particularly market-based environmental programs. K&A projects typically involve identifying and quantifying point source and nonpoint source pollutant loads, monitoring surface water and groundwater, developing watershed management plans, conducting water quality modeling and GIS analyses, implementing BMPs and aquatic/wetland restoration projects, and applying various watershed assessment techniques. Staff expertise includes design of non-point source BMPs and quantification of efficiencies, lake and river assessments, waste load allocations, TMDL development, and NPDES permitting services. For TMDL applications, staff experience with development and/or assessment of TMDLs has focused on streams, lakes, rivers and impoundments addressing impairments associated with eutrophication (nutrients, BOD and dissolved oxygen), bacteria, turbidity and habitat disruption.

Water quality trading program and policy development has been a core area of K&A's expertise since 1995. The firm is one of only a few in the U.S. that has such broad and successful experience in the development of a variety of market-based watershed incentive programs that respond to TMDL, nutrient standard and WQBEL load reduction requirements. The focus of these programs has included: watershed, state-wide, and regional trading program development; agricultural credit calculation and banking schemes; urban stormwater; electronic water quality trading registries and infrastructure; water quantity market structures for water offsets; restoration of natural flow regimes in Great Lakes tributaries; and, development of ecosystem service markets. K&A has been a partner on several US EPA Targeted Watershed Grant projects and USDA Conservation Innovation Grants related to water quality trading.

These efforts have included watershed-based nutrient trading programs at the local level (such as the Great Miami River basin of Ohio – the largest and most successful point source/non-point trading program to date), and multi-state trading programs such as the eight-state Ohio River Basin (which will be the largest program of its kind in the world). A watershed assessment for water quality trading in the Wabash River basin (5,746 mi^2 and 503 miles in length), covering most of the state of Indiana and parts of Ohio and Illinois, is indicative of K&A capabilities to evaluate water quality needs and opportunities across multiple state jurisdictions. Parallel K&A experience with multi-state water quality management is exemplified with development of the first Michigan/Indiana bi-state Watershed Management Plan approved by U.S.EPA in the 4,000 mi^2 St. Joseph River Basin. These projects illustrate K&A's ability to understand, assess and manage an array of water quality issues at scale as will be required for Oklahoma's Designated Scenic Rivers.

Versar, Inc.

Versar, Inc. a publicly-held, full-service, environmental, engineering, and professional services firm headquartered in Springfield, Virginia (www.versar.com), has provided support to governmental and commercial clients since 1969. With 600 staff in 15 domestic and 5 international offices, Versar offers a full range of professional capabilities to support our clients. The majority of our technical staff have advanced degrees and include scientists (biologists, computer scientists, chemists, toxicologists, ecologists, exposure and risk assessors), engineers (chemical, mechanical, civil, environmental, electrical), industrial hygienists, hydrogeologists, geologists, meteorologists, policy and regulatory analysts, and communications experts. Versar's commitment to excellence in program design, execution, and management has resulted in corporate growth through performance and client satisfaction. The degree of client satisfaction is epitomized by Versar having maintained its position as a major U.S.EPA contractor continuously since the early 1970s.

Versar's Ecological Sciences and Applications clients include local, state and federal agencies, with extensive current work being conducted in watershed-level monitoring, assessment, and restoration. We regularly provide support in highly contested issues (such as preparing the risk assessment and EIS for introduction of the Asian oyster to the Chesapeake Bay) and expert testimony before the Maryland Public Service Commission and legal proceedings (e.g., Smithfield Clean Water Act compliance and City of Norfolk King William reservoir project). We are proud of our reputation as objective arbiters of controversial scientific issues. Our importance to the K&A/Versar Project Team can be summarized as follows.

- Versar has unique experience working on state-level CWA programs to support listing of impaired waters, stressor identification, and TMDL development. Specifically, Versar developed the biological listing methodology for Maryland Department of the Environment, their Biological Stressor Identification (BSID) methodology, and their framework for urban TMDLs based on flow and impervious cover targets.
- Versar is the pre-eminent firm for monitoring and assessing the condition of waters in the Mid-Atlantic region. We have monitored the Chesapeake Bay since 1972, and our indicators and methods for assessment in both coastal (EMAP Coastal, Chesapeake Bay, Coastal Bays, and Hudson Estuary IBIs) and inland waters (Maryland Biological Stream Survey IBIs for fish, benthic invertebrates, and salamanders) are nationally known.
- Versar has unparalleled experience supporting the watershed planning for local jurisdictions in the Mid-Atlantic region. Through our support for nine counties in Maryland and Virginia, Versar has helped local governments monitor, assess, and restore their watersheds. Specifically, we identify healthy watersheds for preservation and degraded watersheds needing BMPs and other restoration actions. Working with stakeholders (including public outreach) to ensure successful implementation of these watershed restoration plans is a key component of our support.

Statement of Project Understanding

The Project Team recognizes that the primary purpose of the Joint Study is to determine the total phosphorus threshold response level in designated Scenic Rivers of Oklahoma. This level will represent a concentration where a statistically significant shift will occur for species composition of algae, or where algal biomass production results in undesirable aesthetic or water quality conditions. The Joint Study commission expects that the assessment will be in accordance with U.S.EPA's Rapid Bio-assessment Protocols. The project must also include U.S.EPA QAPP provisions and adhere to recent U.S.EPA guidance set forth in EPA's 2010 "Using Stressor-response Relationships to Derive Numeric Nutrient Criteria" documentation. Any collection or use of reference stream data in this project shall come from streams or rivers within the same EPA eco-region comparable to designated Scenic River watershed stream order and watershed land uses.

The following section of the Request for Qualifications response describes a proposed approach to accomplish these efforts. It is understood by the Project Team that if selected, a detailed proposal for such tasks will be required as a next step in the researcher selection process.

Project Approach

The goal of establishing appropriate nutrient criteria considering the diversity of natural ecosystems is an essential element for successful water resource management across the country. It is especially challenging when the protection of high quality waters, such as Scenic Rivers, is at stake. We recognize that the study goal is to identify a numerical TP criterion for the Scenic Rivers, focusing on algal species/mass production shift and considering frequency and duration.

The preliminarily proposed Project Team approach to this study will be based on team's broad experience and understanding of the specific project setting. In particular, the team will rely upon Versar's 40 years of scientific research for U.S.EPA and state agencies addressing challenging water quality issues, and K&A's 20 years of rigorous monitoring assessments to quantify watershed impacts and management program benefits. Versar's national reputation for rigorous scientific analysis includes field collection, data analysis, and expert interpretation. K&A's intensive water quality and biological monitoring experience has focused on applied water quality research for CWA and related program implementation; specifically on Best Management Practice quantification ranging from the site-scale to basin-wide conditions. Such program applications have been used by K&A to assess stormwater thermal enrichment on trout streams, and water quality improvements in both urban and agricultural stream settings under varying improvement program efforts. Both sets of experience will be essential for project success.

Of particular note is Versar's lead role in the development of the Chesapeake Bay benthic monitoring program and the EPA Environmental Monitoring and Assessment Program (EMAP). Their experience includes developing guidance for U.S.EPA and state agencies to create the sampling protocols, indicator development, and quality assurance that will be employed in this study. Most recently, Versar has been on the forefront of using stressor-response relationships to shape water quality programs. Specifically, Versar has (1) chaired the peer-review of the U.S.EPA Causal Analysis/Diagnosis Decision Information System (CADDIS), (2) developed the Biological Stressor Identification methodology for Maryland's water quality program, and (3) recently completed three projects in the states of Kansas, Missouri, Nebraska, and Iowa to identify stressors through field sampling and apply stressor-response relationships to impairment listings and management decisions.

Overall, the Project Team envisions employing the following steps in our technical approach to this study:

1. Gather existing data: the Project Team will compile existing data from both regular and special monitoring programs in the targeted scenic rivers and potential reference streams. The goal will be to achieve a minimum of ten independent samples (and a desired 40 samples) for each location. The team will work with local agencies and stakeholders to confirm that all relevant data have been obtained.

2. Conceptualize a TP-algal response model(s): the team will use existing data, literature, and experience to develop a TP-algal model that includes both anthropogenic and natural factors (e.g., light, temperature and watershed characteristics).

3. Identify data gaps needed for model: Existing and local data will be reviewed to determine if and where new data are needed to support the TP-algal model.

4. Conduct field work: the Project Team will design a sampling program using power analysis to obtain the remaining data needed to provide definitive results. All sampling will be conducted according to EPA's Rapid Bioassessment Protocols (1999) and other applicable methods.

5. Conduct statistical analysis: project data will be analyzed by the Project Team using standard statistical tests appropriate for the distribution of data obtained. The choice of test methods will be justified and may include the results of other tests for comparison.

6. Propose TP criterion: the team will propose a TP criterion that would be protective of water quality in the scenic rivers, given natural conditions. The proposal will conform to EPA guidance and may include varying criteria if appropriate.

7. Report results: the Project Team will participate in committee and public meetings, as needed, and provide both draft and final reports to document the findings and recommendations. All methods and reporting will adhere to EPA Guidance on Quality Assurance and Quality Control provisions and follow EPA's most recent guidance, "Using Stressor-response Relationships to Derive Numeric Nutrient Criteria" (EPA 820-S-IO-001, November 2010).

Preliminary assignments/roles of the Project Team to address these tasks include:

K&A:

- Project administration and related communications
- Coordinate technical activities
- Collect existing data and reports
- Support and review Versar work on statistical data analysis for stressor-response relationship and proposed criterion
- Attend and present at public meetings
- Primary responsibility for all reporting

Versar:

- Review existing data to determine completeness and/or gaps
- Model conceptualization
- Field work
- Lead statistical data analysis for stressor-response relationships

- Propose a TP criterion through appropriate analysis and modeling
- Attend and present at meetings
- Technical report writing

Descriptions of Project Team Experience with Similar Projects

This section provides a summary and descriptions of various K&A and Versar projects that identify relevant experience to perform this work.

K&A Experience

K&A's relevant water quality assessment experience for the proposed project focuses on:

- Oklahoma watershed assessment and TMDL development (K&A Project #1)
- Multi-state water quality assessment and management (Midwest) (K&A Project #s 2-3)
- Assessment of nutrient, sediment and biological criteria in Minnesota (K&A Project #4)

K&A Project #1: Oklahoma Watershed Assessment and TMDL Development

Client Name and Address:	Watershed Planning and Stormwater Permitting section Water Quality Division, Oklahoma DEQ 707 N Robinson Oklahoma City, OK 73102
Client Point of Contact:	Mr. Mark Derichsweiler, Manager 405-702-8188 mark.derichsweiler@deq.ok.gov
Period of Performance:	2008-2013

We cite here, the experience of Dr. Andrew Fang in his previous position with Oklahoma DEQ as this relates to water quality issues in the state. His experience, and non-conflicting relationship with DEQ and other regional agency staff will provide an opportunity for the Project Team to work closely with agencies for clear communication, data gathering and reporting. His Oklahoma project experience includes the following.

Lake Thunderbird TMDL development: 2009-2013

Lake Thunderbird, a 6,070-acre reservoir, is the main drinking water source for nearly 200,000 people in and near the Oklahoma City Metro Area. The lake was on Oklahoma's 303(d) list for high turbidity, low DO and high chlorophyll-a levels. As the project manager for developing TMDLs for the lake, Andrew was involved in all aspects of the TMDL process, from developing the highly technical HSPF watershed water quality model to conducting watershed stakeholder meetings, including participating in DEQ legal team's defense preparation against a lawsuit related to the TMDL development.

For the TMDLs, Andrew developed the HSPF watershed water quality model to quantify and project sediment and nutrient loads to the lake from its entire watershed. During the process, Andrew led the design of an intensive one-year, 5-station stream flow and pollutant discharge monitoring program, which formed the basis for the watershed model framework and calibration. The monitoring design included location of the stations, sampling frequency, sample volumes, parameters measured, and program budget. Andrew processed the raw laboratory data and synthesized the flow and concentration values. Andrew then independently developed and calibrated HSPF model. DEQ contracted a consulting firm for the development of the lake water quality model. Andrew worked closely with the firm to integrate the two models while overseeing the development of the lake model.

Due to the importance of Lake Thunderbird as the main drinking water sources for a large population and its watershed being the fastest urbanization area in the state, stakeholder meetings were held to communicate the progress of the TMDL development and solicit suggestions. Andrew conducted those meetings and gave technical briefings on the progress of water quality model development.

During the TMDL development process, a lawsuit was filed by the lake's management agency, alleging DEQ's delay of the TMDL development breached an agreement between the two agencies. Andrew participated in the defense by DEQ's legal team, helping the team understand the technical specifics of the TMDL process, particularly the watershed and lake water quality models. Andrew also accompanied the attorneys to the court appearances and assisted in drafting correspondences with the plaintiff attorney. The lawsuit was successfully settled outside the court.

By the time Andrew left DEQ in early 2013, the draft TMDLs had been completed with most of the technical details finalized. The final TMDLs were approved by EPA Region 6 in November 2013.

<u>General statistical assistance to DEQ Water Quality Division: 2007-2012</u>

Although not an official role, Andrew was often asked by other sections at the water quality division for statistical questions. For example, the Industrial Permitting Section was challenged by a facility on the assumption of normality for its monitoring data on total dissolved solids and total sulfate, which became the basis for setting new permit limits. Andrew used a formal normality test to prove the assumption correct, leaving no doubt to the new limits.

<u>Development of bacteria and turbidity TMDLs: 2006-2013</u>

Andrew was one of three core team members at DEQ that developed the TMDL template for bacteria and turbidity TMDLs in corporation with a consulting firm. Using the template, DEQ and the consulting firm developed hundreds of bacteria and turbidity TMDLs for Oklahoma over the last five years that contributed to the bulk of annual TMDL completion by EPA Region 6. Andrew personally wrote over 30 of these TMDLs.

The development of the TMDL template was based on the load duration curve method and the Oklahoma Water Quality Standards for bacteria and turbidity. It involved the inclusion of all necessary elements of a TMDL according to EPA TMDL development guidance, the technical interpretation of monitoring data, allocation of load and waste load to various pollutant sources in the contributing watershed, and implementation requirements for discharge permittees. For the completion of the template and individual TMDL reports, all Oklahoma environmental agencies were consulted and their cooperation in providing data and comments was sought. Through leading the inter-agency TMDL workgroup and its quarterly meetings, Andrew successfully coordinated these TMDL efforts among the agencies.

Representing Oklahoma DEQ in assisting EPA Region 6 in developing a TMDL for the Illinois River: 2011-2012

The Illinois River watershed includes several Scenic River designated streams in Oklahoma. The end of the watershed is Lake Tenkiller, a reservoir in Oklahoma. Because it is an interstate watershed between Arkansas and Oklahoma, the development of a total phosphorus TMDL for the watershed was led by the EPA Region 6 office. Andrew was part of the Oklahoma team on the project technical advisory committee. Andrew collected and provided available watershed information and water quality data to the EPA contract firm for the development of watershed and lake water quality models, which would form the basis for the TMDL. Andrew also provided suggestions to the modeling process and participated in making key modeling decisions such as the selection of baseline condition simulation period. By the time Andrew left DEQ, this TMDL project was still on-going.

K&A Project #2: St. Joseph River Watershed SWAT Model for an EPA-Approved Watershed Management Plan

Client Name and Address:	Friends of the St. Joseph River P.O. Box 1794 South Bend, Indiana 46634
Client Point of Contact:	Mr. Matt Meersman Executive Director www.FotSJR.org
Period of Performance:	2002-2005
Contract Value:	$180,000

A Section 319 Watershed Management Planning grant from the Michigan Department of Environmental Quality, Water Division (MDEQ) was obtained by K&A on behalf of the Friends of the St. Joseph River. The grant was used to develop the first of its kind, bi-state Watershed Management Plan (WMP) for the St. Joseph River Watershed. The planning process began in November 2002 and culminated in an EPA-Approved, web-based WMP. The fundamental objective of the project was to provide the watershed community with a plan that would facilitate and guide implementation of desired goals for water quality improvements and protection, as well as a provide a consistent venue to communicate, adapt and revise the overall plan as new information was obtained and milestones were completed. The plan served as a template for established jurisdictions to adopt short-term and long-term goals that accommodate existing infrastructure and established community visions, as well as allowed growing areas of these subwatersheds to enact new policies and practices which better address water quality protection.

Coordinating a bi-state planning effort in a largely agricultural watershed was an unprecedented task for the region. Moreover, the MDEQ was for the first time, being required by EPA to add quantitative loading assessments ("EPA Nine Elements") to their funded planning projects. K&A developed and successfully negotiated with MDEQ, Indiana Department of Environmental Management and Region V EPA what these additional quantification efforts should include. As such, the various analyses summarized below were identified as the appropriate methods to achieve these new requirements, thus setting the precedent for all future WMPs in Michigan.

As one of the major contributors of sediments, nutrients and pesticides to Lake Michigan, this type of quantification was important to assess for a St. Joseph River WMP. Nonpoint source modeling efforts by K&A therefore initially targeted agriculture. To assess these, K&A calibrated and validated the Soil and Water Assessment Tool (SWAT) model for the St. Joseph River watershed. The model was used to simulate the current (baseline) loading conditions of TP, TN, and sediment for each of the 229 subwatersheds delineated in the watershed, and atrazine loads at the outlets of three major agricultural tributary watersheds. Five agricultural BMP scenarios were simulated for the three major tributary watersheds to derive effects that BMP implementation would have on water quality at their confluence with the main stem of the St. Joe (see: http://www.stjoeriver.net/wmp/docs/SWAT_final_report.pdf).

To address future concerns and to help define critical areas of the watershed for protection, a unique "build-out" analysis (http://www.stjoeriver.net/wmp/docs/landscape_analyst.pdf) identified sensitive and vulnerable areas of the watershed potentially subject to urban sprawl. Urban non-point source modeling analyses provided (http://www.stjoeriver.net/wmp/docs/Urban_BMP_Analysis.pdf) vital information to identify current and future impacts of growth as well as the costs for urban stormwater retrofits for five different BMPs.

K&A Project #3: Water Quality Trading Feasibility Study for the Wabash River of IN, OH and IL

Client Name and Address:	Conservation Technology Innovation Center 3495 Kent Avenue, Suite J100 West Lafayette, IN 47906 USA
Client Point of Contact:	Karen Scanlon Executive Director (765) 494-9555 scanlon@ctic.org
Period of Performance:	2009-2010
Contract Value:	$90,000

Under an EPA Targeted Watershed Grant to the Conservation Technology Innovation Technology Center (CTIC), K&A along with Tetra Tech, Inc. conducted watershed and river water quality modeling to assess water quality trading (WQT) supply and demand in the Wabash River basin. This watershed covers the majority of the state of Indiana (as well as portions of Ohio and Illinois) and is one of the largest contributors of nitrogen to the Gulf of Mexico. K&A used the Soil and Water Assessment Tool (SWAT) to model agricultural contributions to water quality from this land use that represents approximately 70% of the land cover in the basin. Water quality modeling conducted by Tetra Tech examined fate & transport characteristics that influence instream nutrient delivery to the Ohio River.

K&A was principally responsible for the supply side analysis. This included evaluation of farmer implementation and opportunity costs of BMPs, which was critical for determining the potential economic benefits of WQT and conveying these benefits to wastewater treatment facility representatives and farmers. These were assessed in the context of impaired and unimpaired waters relative to WQT credit baselines. K&A focused on an annual payment analysis for three different BMPs including cover crops, residue management and filter strips. Each BMP had a different life cycle, and each with associated opportunity costs, establishment costs, operation and maintenance (O&M) schedules and replacement costs. To overcome differences in schedules and pricing, a Life Cycle Cost (LCC) analysis used a present worth calculation providing present day equivalent costs for each BMP. The present worth analysis considered all expenditures made, including: 1) current investments, 2) annual payments, and 3) one-time future payments. This present worth analysis was performed using a three percent inflation factor and a 20-year BMP implementation period, including replacement costs if BMP design life is less than 20 years. The LCC analysis then converted the present worth into a 20-year annual payment assuming a five percent discount factor. This was the first such time that this level of cost analysis has been included in trading feasibility studies.

The feasibility study provided insight as to where WQT might encounter geographic barriers in select subwatersheds in the Wabash and what type of trading framework might be most appropriate based on the sources with the greatest potential for participation. It was an initial step in investigating the potential for WQT opportunities in Indiana. The Indiana Department of Environmental Management and the Department of Agriculture have since committed to participating in a broader regional WQT pilot project in the Ohio River Basin (ORB). Indiana will explore trading opportunities in the Wabash and other ORB tributaries in their state. K&A is the technical consultant for these ORB efforts working with the Electric Power Research Institute, other collaborators as well as Ohio and Kentucky.

K&A Project #4: Review and Assessment of the MPCA Nutrient and Total Suspended Solids Water Quality Standard Development in the Current Triennial Review

Client Name and Address:	Scott County, Watershed Management Organization 200 Fourth Avenue West Shakopee, MN 5379-1220
Client Point of Contact:	Mr. Paul Nelson pnelson@co.scott.mn.us (952) 496-8054
Period of Performance:	2011
Contract Value:	$10,000

The Minnesota Pollution Control Agency (MPCA) was conducting a 2008-2012 Proposed Water Quality Standards Rules Revision for the Triennial Water Quality Standards review process (Triennial Review). Scott County contracted Kieser & Associates, LLC (K&A) to perform a preliminary evaluation of the MPCA Triennial Review process as it might affect their planning, policy and budgeting. Findings provided critical insight into the beneficial attributes MPCA was employing as well as the data and methods limitations found in the Triennial Review documentation. The MPCA planned to promulgate the nutrient and Total Suspended

Solids (TSS) numeric criteria in 2012. K&A findings provided Scott County managers sufficient information to engage MPCA staff during the development of the numeric criteria and rollout of subsequent implementation requirements.

The evaluation of the Triennial Review technical documentation focused on the river and stream nutrient (phosphorus and nitrogen) and TSS numeric criteria development. The K&A evaluation identified how new criteria development should consider an assessment of attainability and delivery methods protective of appropriate aquatic life goals.

This K&A evaluation of MPCA's Triennial Review documentation was divided into four sections that examined linkages between water quality protection programs and MPCA's criteria development in these regards. These included:

- 40 CFR Overview: a brief explanation of how the required 40 CFR water quality programs interact with each other. Critical focus was placed on numeric criteria development requirements, and regulatory and non-regulatory actions as they may pertained to Scott County.
- Review of the Technical Justification: examination of the MPCA and EPA guidance and documentation materials to identify advantageous methods and findings used by MPCA, as well as, limitations (to date) that had potential for setting numeric criteria that were too onerous or confounding to pragmatically implement.
- Review of Other States' Nutrient and Sediment Criteria: benchmarking criteria development from neighboring EPA Region V states and other national examples to provide insights into possible alternative options that could be put forth by Scott County. The selected examples contained successful options for regulatory flexibility necessary to provide for criteria adjustments or implementation.
- Summary of Comments and Recommended Options: a summary of the benefits and limitations identified in the review written as draft comments to MPCA and options to further engage MPCA in the review process. Recommendations focused on Scott County's objective to advance the quality of methods and appropriate selection techniques for setting and then implementing numeric criteria to the public's benefit.

Versar Project Experience

Versar's unique skill sets for this project draw upon example projects that address:

- Water quality monitoring and stressor identification for listed waters in Iowa and Missouri as well as sampling for Consent Decree Waters in Missouri, and Central Great Plains Ecoregion Headwaters Assessment in Nebraska and Kansas (Versar Project #1-2)
- Urban Stormwater/Green Infrastructure/BMP Data Monitoring and Analysis in Clarksburg, MD (Versar Project #3)

These are illustrated in the following three project examples. Under the first summary, Versar expects to continue to provide exemplary support to U.S.EPA Region 7 in these areas as well as in other aspects of TMDL, NPS, Healthy Watersheds, and Technical and General Program Support. Lastly, we note that Versar has decades of experience in providing Peer Review Support for EPA OW and ORD, as well as other agencies.

Versar Project #1: Stressor Identification in Midwestern Streams and Central Great Plains Stream Assessment for U.S. Environmental Protection Agency, Region 7

Client Name and Address:	Environmental Protection Agency, Region 7 Water, Wetlands and Pesticides Division Mail Code 1.4-E54 11201 Renner Boulevard Lenexa, Kansas 66219
Client Point of Contact:	Debby White Environmental Protection Specialist Phone: 913-551-7886 Email: White.Debby@epa.gov
Period of Performance:	2008-present
Contract Value:	$400,000

Versar provided support to EPA Region 7 for chemical, physical, hydrologic, and biological water quality monitoring and assessment to identify the likely stressors for certain streams listed on the Iowa and Missouri Section 303(d) lists. Versar coordinated with EPA, Iowa Department of Natural Resources, and Missouri Department of Natural Resources to develop customized sampling plans consistent with monitoring and assessment methods employed by each state agency and that would support data analysis using EPA's Stressor Identification Guidance.


Versar field staff utilizing rapid biological assessment protocols to assess stream conditions in a Missouri stream.

In four Missouri watersheds, Versar conducted biological monitoring (benthic macroinvertebrates), water chemistry, and habitat assessments over three field seasons. Monitoring activities included field data collection and laboratory analysis of benthic and water samples at fifteen sites. Benthic laboratory procedures and taxonomy followed Missouri Department of Natural Resources protocols. GIS was used to characterize watershed land uses and likely pollutant sources, such as confined animal feeding operations. The study streams are located in two areas: Northern Missouri (Long Branch, Hickory Creek, and Willow Branch) and Indian Creek in Southwestern Missouri (Middle, North, and Mainstem Indian Creek). Indian Creek (Newton and McDonald Counties) is located in the Ozark Elk / Spring EDU and is a high-gradient, riffle/pool type stream within the Elk River watershed.

Versar also conducted monitoring in Honey Creek, Iowa, over two field seasons, including chemical, physical and other parameters, to identify the causes of low dissolved oxygen previously observed. Versar produced reports for each watershed, which followed EPA's Stressor Identification framework.

Beginning in 2011, Versar has been conducting an assessment of conditions and identification of stressors in headwater streams in the Central Great Plains ecoregion in Kansas and Nebraska. Data collection has included benthic macroinvertebrate, physical habitat assessment, water chemistry, and watershed reconnaissance. Analyses include application of EPA's Stressor Identification protocol and Bayesian statistical methods.

Versar Project #2: Biological Stressor Identification Methodology for Maryland Department of Environment

Client Name and Address:	Maryland Department of the Environment Science Services Administration 1800 Washington Blvd. Baltimore, MD 21230
Client Point of Contact:	Lee Currey Director of Science Services Administration Phone: 410-537-3913 Email: LCurrey@mde.state.md.us
Period of Performance:	2002-2007
Contract Value:	$250,000

For the Maryland Department of Natural Resources (DNR), Versar designs and implements the ongoing Maryland Biological Stream Survey (MBSS) that has characterized the physical, chemical, and biological condition of nontidal streams through the probabilistic sampling of more than 3,500 sites since 1994. Versar now supports Maryland Department of the Environment (MDE) by using MBSS data to (1) implement biological criteria as part of their water quality standards program and 303d listing effort, and (2) develop innovative models of likely stressor effects on Maryland Streams including nutrients. MDE needs to prepare many Total Maximum Daily Load (TMDL) analyses over the coming years for Maryland 8-digit watersheds listed as impaired on the State 303d list. MDE recognizes that the TMDLs will contain uncertainty, but that they will use the best available information and provide equitable treatment of all parties.

Versar completed a cooperative study to identify likely stressors affecting Maryland watersheds by using the suite of physical, chemical, and biological data available from the statewide MBSS. Specifically, Versar (1) reviewed non-biological data and certain biological data from the MBSS for likely candidate variables to act as stressor surrogates, (2) developed statistical models (e.g., logistic, quartile regression, and odds-ratio) using those variables that best predict biocriteria failure, and (3) determined which 8-digit watersheds sampled during the 2000-2004 Round of the MBSS are appropriate "reference" watersheds for determining the threshold of impairment (i.e., those watersheds that just meet water quality standards) for each stressor.

Versar has helped develop a conceptual model of stressors resulting from six candidate causes: flow regime, terrestrial sediment, energy source, oxygen consuming/thermal, organic contamination, and inorganic contamination. Each stressor has several predictions that were tested with MBSS data. Versar identified the following sets of variables that support candidate cause predictions by having distinctly different values in streams that pass biocriteria versus those that fail biocriteria:

- Flow Regime: Impervious surface, Channelization, Conductivity, Erosion extent, Temperature, Benthic dominants, and Erosion severity.
- Terrestrial sediment: Epifaunal Substrate, Total Buffer Width, Embeddedness, Instream Habitat, Riparian Urban
- Energy source: DOC, Shading, SAV presence, Temperature, Forest Buffer, Agriculture, DO, High Residential, No Buffer
- Oxygen consuming/thermal: SO_4, DOC, Urban, NH_3, HBI, Temperature, Agriculture, DO
- Organic contamination: Conductivity, Agriculture, High Commercial, Anomalies, pH
- Inorganic contamination: Agriculture, Anomalies, HBI

The Versar study formed the basis of the Biological Stressor Identification Methodology for Maryland Department of Environment that is being used on an annual basis to revise the 303d listing of impaired waters by removing those designations not supported by this methodology.

Versar Project #3: Monitoring and Management Study for Addressing Algal Blooms in Fountain Rock Park Quarry Pond, Frederick, MD, in 2010

Client Name and Address:	Frederick County Government Sustainable Development Community Development Division 30 N Market St. Frederick, MD 21701
Client Point of Contact:	Shannon Moore Manager, Sustainable Development Phone: 301-600-1413 Email: smoore@frederickcountymd.gov
Period of Performance:	2010-2012
Contract Value:	$100K

Versar and the Chesapeake Research Consortium provided monitoring and research services to Frederick County to address algal blooms in Fountain Rock Park Quarry Pond. The County needed a study to help reduce or eliminate the presence of a cyanobacteria bloom, provisionally identified as Planktothrix prolifica, which was overwhelming the surface waters of the quarry pond. Cyanobacteria (also known as blue-green algae) are generally associated with nutrient-rich (high concentrations of nitrogen and phosphorus), stable water bodies and occurs throughout the world's aquatic systems, fresh and salt waters. They are usually associated with warm waters as well, with freshwater ponds and lakes characterized by highest densities in summer months.

Because freshwater cyanobacteria blooms are generally associated with high nutrient systems, the most important control for these blooms is limiting the inflow of nitrogen (N) and phosphorus (P) into the potential bloom systems. The nutrients can come from a variety of sources, including runoff from farms, suburban/urban areas, point sources like waste water treatment facilities, industries, and the atmosphere. In some systems, however, dominant water supplies are subsurface, through either shallow groundwater or deeper aquifers, with these slowly moving waters carrying nutrients from the source area. If shallow subsurface groundwaters, these can be from fields forests, and local lands with travel times of months to years. Highly porous sandy soils or rocks with fractures might have rapid travel times with compacted, clay-rich, or unfractured rock with very slow transit times. For deeper groundwaters, water and dissolved constituents can travel many miles and require a decade or more to reach the receiving body.

In the summer of 2010, Frederick County began treating the pond with potassium permanganate to reduce or eliminate the cyanobacteria bloom the pond. To confirm its effectiveness, the Versar Team provided monitoring for microcystin and anatoxin-a. For each sampling event, field staff collected five samples from the quarry pond (surface or at a selected depth) and/or other nearby waters (e.g., fishing pond, Glade Creek, or raw water tap). The team also determined the proper depth of sample collection in the pond and verified the taxonomic identification. The field collections included 6 sampling events, with up to 5 samples collected per event. Toxin analyses were done for microcystin and anatoxin-a, at the University of Syracuse ESF toxin laboratory. Versar provided a summary of each sampling event to the County and helped devise future management ttechniques, such as placement of barley straw, circulation/aeration, nutrient reduction through floating islands, and nutrient management in the watershed, including management of local goose populations.

Example Reports

The K&A/Versar Project Team has appended two representative reports in Attachment A of this submittal. These Versar reports include:

Southerland, M., J.Vølstad, E. Weber, R. Morgan, L. Currey, J. Holt, C. Poukish, and M. Rowe. 2007. Using MBSS Data to Identify Stressors for Streams that Fail Biocriteria in Maryland. Maryland Department of the Environment, Baltimore. June.
(http://www.mde.state.md.us/assets/document/BSID_Methodology_Final.pdf)

Southerland, M.T., L.A. Erb, G.M. Rogers, R. Morgan, M. Kline, K. Kline, S. Stranko, P. Kazyak, J. Kilian, J. Ladell, and J. Thompson. 2005. Maryland Biological Stream Survey 2000-2004 Volume 14: Stressors Affecting Maryland Streams. Monitoring and Non-Tidal Assessment Division, Maryland Department of Natural Resources, Annapolis. DNR-12-0305-0101 EA-05-11.
(http://www.dnr.state.md.us/streams/pdfs/ea-05-11_stressors.pdf)

K&A also provides by weblink a representative report addressing issues of establishing biocriteria in Minnesota. This effort was cited earlier. The link here includes the Final K&A August 17, 2011 Technical Memorandum to Scott County *("Review and Assessment of the MPCA Nutrient and Total Suspended Solids Water Quality Standard Development in the Current Triennial*

Review") http://www.kieser-associates.com/uploaded/ka_and_scott_county_mpca_triennial_review_memo.pdf

Other reports and citations can be provided upon further request.

Resumes

The Project Team has identified staff that would most likely participate in this project with lead roles as applicable (*in italics*). For K&A, these staff include (see Attachment B for resumes):

- Mark S. Kieser, Senior Scientist/Principal – *Project Administrator*
- "Andrew" Feng Fang, Ph.D., P.E., Senior Project Scientist – *Co-Project Manager*
- James A. Klang, P.E., Senior Project Engineer
- Patricia Hoch-Melluish, Project Scientist

Specific qualifications of the research team for Versar include (see Attachment C):

- Mark Southerland, Ph.D., Project Manager and Principal Ecologist – *Co-Project Manager*
- Nancy Roth, Senior Watershed Scientist
- Brenda Morgan, Field Manager
- Lisa Methratta, Ph.D., Statistician
- Tom Jones, Chemist
- Roberto Llanso, Ph.D., Water Quality Specialist

ATTACHMENT A

Example Project Reports

Maryland Biological Stressor Identification Process

MARYLAND
DEPARTMENT OF THE ENVIRONMENT
1800 Washington Boulevard, Suite 540
Baltimore, Maryland 21230-1718

June 2009

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List of Abbreviations

AMD	Acid Mine Drainage
ANC	Acid Neutralizing Capacity
AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DO	Dissolved Oxygen
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
LULC	Land Use Land Cover
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MBSS	Maryland Biological Stream Survey
MSSCS	Maryland Synoptic Stream Chemistry
mg/L	Milligrams per liter
µeq/L	Micro equivalent per liter
µS/cm	Micro Seimens per centimeter
P/G/E	Pool/Glide/Eddy
QA/QC	Quality Assurance/Quality Control
RESAC	Regional Earth Science Applications
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
USEPA	United States Environmental Protection
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

Executive Summary

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS listed on the 303(d) List in the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a Water Quality Analysis (WQA) that water quality standards are being met.

Current Integrated Report listing categories are:

- Category 2 ("meeting some water quality standards, but with insufficient data to assess completely"), if the potential or relevant stressors were found not to be present or to have a limited association with biological integrity in the subject segments.
- Category 3 ("insufficient data to determine if any water quality standard is being attained"), if the potential or relevant stressors were identified as having insufficient data to directly link them to degrading biological conditions in the subject segments.
- Category 4c ("waterbody impairment is not caused by a pollutant"), when the only remedy for degraded biological conditions in the subject segments is a technical correction.
- Category 5 ("does not meet water quality standards"), if the potential or relevant stressors were degrading biological conditions in the subject segments.

In 2002, the State began listing biological impairments on the Integrated Report. The current Maryland Department of Environment (MDE) biological assessment methodology assesses and lists at the Maryland 8-digit watershed scale, which maintains consistency with how other listings on the Integrated Report are made, how TMDLs are developed, and how implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds with multiple impacted sites by measuring the percentage of stream miles that are degraded, and calculating whether they differ significantly from a reference condition watershed.

Maryland developed water quality standards to protect, maintain and improve the quality of Maryland surface waters. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life, primary or secondary contact recreation, drinking water supply, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. There are numerous 8-digit watersheds in Maryland that are not attaining there designated use because of biological impairments. As an indicator of designated use attainment, MDE uses Fish and Benthic Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause and source of degraded biological conditions, which will enable the Department to most effectively direct corrective management action(s).

MDE SSA generated a principal dataset after a quality assurance/quality control (QA/QC) review and vetting process of the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) round two data. Parameters were selected from the principal dataset to represent either specific "stressors" or potential "sources" of stressors. Stressors were grouped into categories representing sedimentation, habitat conditions or water chemistry.

The BSID analysis is a risk-based approach, adapted from the field of epidemiology, which estimates the strength of association between various stressors and the biological community, and the likely improvement of biology if a given stressor were removed. The assessment compares the likelihood that a stressor is present, given that there is a degraded biological condition, by using the ratio of the incidence within the case group as compared to the incidence in the control group. The case group is defined as the sites within the assessment unit with degraded biological conditions and the controls are sites with similar physiographic characteristics that have good biological conditions. In Maryland three physiographic eco-regions were identified from the MDDNR MBSS index of biotic integrity (IBI) metrics: Highland, Eastern Piedmont, and Coastal (Southerland et al. 2005b).

Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

1. Introduction

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS listed on the 303(d) List in the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a Water Quality Analysis (WQA) that water quality standards are being met.

In 2002, the State began listing biological impairments on the Integrated Report. The current Maryland Department of Environment (MDE) biological assessment methodology assesses and lists at the Maryland 8-digit watershed scale (average watershed size approximately 90 sq. mi.), which maintains consistency with how other listings on the Integrated Report are made, how TMDLs are developed, and how implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds with multiple impacted sites by measuring the percentage of stream miles that are degraded, and calculating whether they differ significantly from a reference condition watershed (i.e., healthy stream based on reference sites determined independent of biological condition).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determines the predominant cause of reduced biological conditions, which will enable the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors and the biological community, and the likely improvement of biology if a given stressor were removed.

2. Biological Impairments

MDE's Integrated Report listing methodology incorporates indices of biological integrity (IBI) to determine attainment of the designated use of aquatic life protection. IBIs are broad, comprehensive measures of biological condition that represent numerous individual metrics which are scored based on comparison to reference conditions. An IBI score compares existing with expected conditions at sample sites using region specific baseline conditions that reflect little or no human impact. In Maryland three physiographic eco-regions were identified from the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) index of biotic integrity (IBI) metrics: Highland, Eastern Piedmont, and Coastal (Southerland et al. 2005a). The three eco-regions are identified in Figure 1.

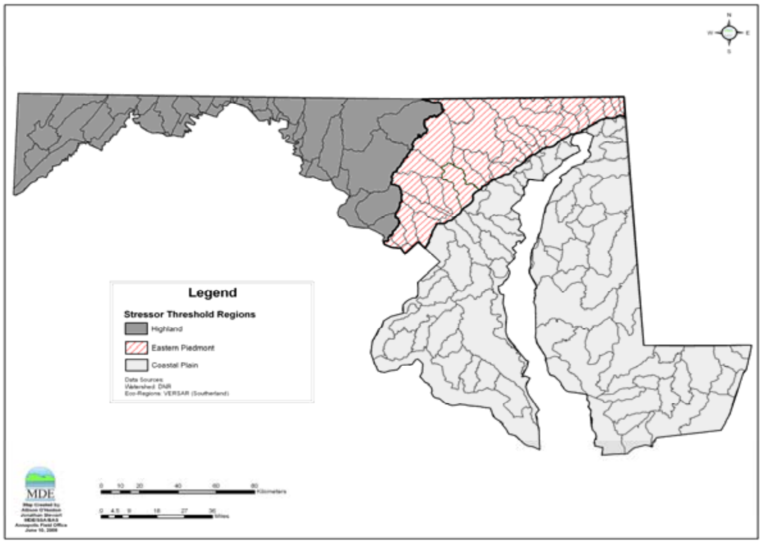

Figure 1. Eco-Region Map of Maryland

Benthic and fish IBIs (B-IBI and F-IBI, respectively) are quantitative ratings of the health of benthic macroinvertebrates and fish assemblages found at each site. Scores below the threshold value of 3 indicate poor biological conditions. Table 1 contains a more detailed description of each of the IBI categories developed.

Table 1. IBI Metrics

Narrative descriptions of stream biological integrity associated with each of the IBI categories. [a]		
Good	IBI score 4.0 - 5.0	Comparable to reference streams considered to be minimally impacted. Fall within the upper 50% of reference site conditions.
Fair	IBI score 3.0 - 3.9	Comparable to reference conditions, but some aspects of biological integrity may not resemble the qualities of these minimally impacted streams. Fall within the lower portion of the range of reference sites (10th to 50th percentile).
Poor	IBI score 2.0 - 2.9	Significant deviation from reference conditions, with many aspects of biological integrity not resembling the qualities of these minimally impacted streams, indicating some degradation.
Very Poor	IBI score 1.0 - 1.9	Strong deviation from reference conditions, with most aspects of biological integrity not resembling the qualities of these minimally impacted streams, indicating severe degradation.

a. Mercurio et al. 1999

Maryland's IBI(s) assesses biological integrity by comparing the community structure of streams to that of high quality (or reference) streams. Biological integrity is influenced by five broad factors; biological interactions, flow regime, energy source, water chemistry, and physical habitat (Karr 1991). Biological impairments could result from the influence of one or any combination of factors. All stream parameters available to diagnose the cause of biological impairments were carefully reviewed to generate the best possible representation of each factor to ensure the most comprehensive stressor identification.

Biological interactions such as competition and predation are dynamic controls for species population sizes within any community. Anthropogenic influences such as the inadvertent or intentional introduction (e.g., fish stocking) of exotic species may amplify the divergence of community structure from reference condition, thus indicate biological impairment.

The biota of aquatic systems is dependent on a recurring flow pattern including both high and low flow conditions to sustain functions such as feeding, reproduction, and dispersal. Altered flow regimes that either homogenize flow conditions (e.g., dams) or exaggerate extreme conditions (e.g., increased surface flow from impervious surface) may not provide adequate conditions to sustain populations (e.g., periodic flush of sediment from interstitial spaces, sustained current to support feeding strategy) or diversity.

Aquatic community structure reflects the mosaic of energy inputs into each stream system due to the association of organisms with unique feeding strategies. The proportion of allochthonous inputs (originating from outside the aquatic system) or autochthonous inputs (originating within the aquatic system) as well as the size of available organic materials (e.g., coarse or fine particulates) may determine which species proliferates in a community. Any modifications that could effect a change in the energy source of a system (e.g., increased nutrients, increased fine particulate organics, increased sunlight, increased temperature, decreased leaf litter or woody debris) could alter community composition, thus biological integrity.

Water chemistry is the most commonly considered factor controlling biological integrity because we have long recognized that biological organisms have specific tolerances and requirements. Exceedance of species tolerances (e.g., dissolved oxygen, pH) may reduce or eliminate populations thus altering biological integrity.

Proliferation of aquatic organisms is dependent on adequate physical habitat, including substrate, current, and temperature. Diversity of physical habitat generally supports larger number of community members. If the diversity of physical habitat is reduced (e.g., channel widened, channel straightened, woody debris removed, etc.) fewer species may find suitable conditions for feeding and reproduction, thus altering community structure.

3. Data Used in Stressor Identification

The BSID analysis is based primarily on the MDDNR MBSS round two dataset. This principal dataset uses a statewide probability-based sampling design to assess the biological condition of first-, second-, third-, and fourth-order non-tidal streams (determination based on the solid blue line shown on U.S. Geological Survey 1:100,000-scale maps) within Maryland's 8-digit watersheds (Klauda et al. 1998, Roth et al. 2005). MDDNR MBSS sites are sampled within a 75-meter segment of stream length. The MDDNR MBSS conducted two rounds of sampling between 1995 and 2004. BSID analysis was constrained to the round two MDDNR MDSS dataset (2000 -2004) because it provides a broad spectrum of paired data variables (i.e., in-stream biological data are paired with chemical, physical, and land use variables).

MDE conducted a thorough data quality review and vetting process of all MDDNR MBSS round two data to ensure that they meet the biological listing methodology criteria of the Integrated Report (MDE 2008). The final master dataset contains all round two biological sites considered valid for use as the principal dataset for BSID analysis and the listing process.

The round two dataset contains counts from numerous taxonomic groups (i.e., fish, macroinvertebrates, reptiles, amphibians), has more than 190 abiotic parameters, and identifies upstream drainage areas for calculation of spatial information (e.g., land use proportions). Each abiotic parameter represents a specific ecosystem component within the watershed (i.e., physical habitat, water chemistry, and land use sources).

The MDDNR MBSS dataset has three data types for abiotic parameters. First, there are quantitative parameters (e.g. chemical data) that can be classified as continuous as they have a wide range of numerical values. Next, there are qualitative habitat parameters that can be classified as ordinal as these are typically integer values with a logical numerical order (scale 20-0). Finally, there are binary variables that have a logical present or absent (yes/no) value.

MDE reviewed the abiotic information from the principal dataset and selected parameters that represent stressors causing biological degradation (i.e. sediment, habitat conditions, and water chemistry), and sources of stressors (i.e. land use and sources of acidity). Target values for these parameters were established to indicate a threshold above which degradation to biological communities will likely occur.

The State of Maryland is required to consider all readily available data for listing impairments in the Integrated Report; therefore, relevant data from federal, state, and county environmental programs, and from private organizations, will be reviewed for possible inclusion into the principal dataset. For inclusion in the principal dataset, all relevant data must incorporate all MDDNR MBSS round two parameters and be consistent with all MDDNR MBSS protocols.

4. Stressors and Sources

Parameters were selected from the principal dataset to represent either specific "stressors" or potential "sources" of stressors causing biological degradation. Parameters representing stressors are grouped into four categories: 1) sediment transport and deposition, 2) habitat condition, 3) riparian habitat condition, and 4) water chemistry. Parameters representing potential sources of stressors are grouped into two categories: land uses within a watershed and potential sources of acidity.

4.1. Stressors

4.1.1 Indicators of Sediment Transport and Deposition

MDE selected several parameters from the principal dataset that evaluates the overall amount of sedimentation in the stream and provides information about the hydrologic regime of the watershed. The sedimentation parameters used in the BSID analysis are: bar formation, channel alteration, embeddedness, epifaunal substrate, presence of erosion, bank stability, and presence of silt/clay. Each of these parameters is measured once during summer index period.

Bar Formation

Bar Formation represents deposition of sand, gravel, and small stones in an area of the stream with a gentle slope and an elevation very close to the stream's water level. Bar formation typically reflects the overall sediment transport capacity of the stream with observed categories of moderate to extensive or extensive bar formation present. Moderate to extensive bar formation indicates channel instability related to frequent and intense high stream velocities that quickly dissipate and rapidly lose the capacity to transport excessive sediment loads downstream.

Sediment loads may originate from terrestrial (surface) erosion or from in-stream channel/bank erosion. Excessive sediment loading is expected to reduce and homogenize available feeding and reproductive habitat, degrading biological conditions. Distinguishing between terrestrial or aquatic sources of sediment is not possible from this measure. Since many pollutants readily attach to sediment particles, it is possible that this parameter may also represent the presence of pollutants other than sediment. For example, sediment loads from terrestrial erosion may also introduce phosphorus into the stream segment. Conditions indicating biological degradation are *bar formation present*, *moderate bar formation present* and *extensive bar formation present.*

Channel Alteration

Channel Alteration is a rating of large-scale changes in the shape of a stream channel. This rating addresses deliberate stream manipulations within a 75-meter sample station (e.g., concrete channels, artificial embankments, obvious straightening of the natural channel, rip-rap, or other structures), as well as stream alterations resulting from large changes in hydrologic energy (e.g., recent bar development). Deliberate alterations typically result in higher velocities by smoothing channel surfaces, straightening channels, or raising/steepening banks. Thus, the presence of alterations assessed in this rating is considered to demonstrate increased probability that the stream is prone to frequent high velocities. The corresponding occurrence of more frequent low discharges is also expected, due to reduced base flow resulting from rapid exit of water from a watershed. Many channel alterations may also directly reduce habitat heterogeneity.

Channel alteration is described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels. The first level, *poor channel alteration*, is defined as heavy deposits of fine material and/or extensive bar development, or recent channelization, or evidence of dredging, or greater than 80% of the banks artificially armored. The second level, marginal channel alteration, is defined as recent but moderate deposition of gravel and sand on bars and/or embankments; and/or 40% to 80% of banks artificially armored or channel lined in concrete. Conditions indicating biological degradation for the BSID analysis are *channel alteration marginal to poor* and *channel alteration poor*.

Embeddedness

Embeddedness is determined by the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed. Embeddedness is categorized as a percentage from 0% to 100% with low values as optimal and high values as poor. High embeddedness is a result of excessive sediment deposition.

High embeddedness suggests that sediment may interfere with feeding or reproductive processes and result in biological impairment. Although embeddedness is confounded by natural variability (e.g., Coastal Plain streams will naturally have more embeddedness than Highlands streams), embeddedness values higher than reference streams are indicative of anthropogenic sediment inputs from overland flow or stream channel erosion.

Embeddedness threshold values are determined by comparing the 90^{th} percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. A final threshold value is set based on review of the results. Levels above the threshold percentages may indicate biological degradation.

Threshold values indicating embeddedness were identified for two regions, the Highland (50%) and Eastern Piedmont (50%) (see Appendix A: Table A-1). Because the Coastal Plain is naturally embedded, there was no significant difference between 90^{th} percentile embeddedness values for very poor and good sites. Based on the results, the threshold value set for the Highland and Eastern Piedmont is 50% embedded. A threshold of 100% was applied to the Coastal Plain, as embeddedness is not a good indicator in this region. Applying these thresholds value to individual sites allows the determination of the *high embeddedness* condition considered for the BSID.

Epifaunal Substrate Condition

Epifaunal Substrate is a visual observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. The varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates. Like embeddedness, epifaunal substrate is confounded by natural variability (i.e., streams will naturally have more or less available productive substrate). Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates.

Epifaunal substrate conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, where stable substrate is lacking, or particles are over 75% surrounded by fine sediment and/or flocculent material; and 2) marginal, where large boulders and/or bedrock are prevalent and cobble, woody debris, or other preferred surfaces are uncommon. Conditions considered for the BSID analysis are *epifaunal substrate marginal to poor* and *epifaunal substrate poor.*

Erosion Severity

Erosion Severity represents a visual observation that the stream discharge is frequently exceeding the ability of the channel and/or floodplain to attenuate flow energy, resulting in channel instability, which in turn affects bank stability. Where such conditions are observed, flow energy is considered to have increased in frequency or intensity, accelerating channel and bank erosion. Increased flow energy suggested by this measure is also expected to negatively influence stream biology.

Erosion severity is described categorically as minimal, moderate, or severe. Conditions indicating biological degradation are set at two levels, moderate and severe. A level of *severe* indicates that a substantial amount of stream banks show severe erosion and the stream segment exhibits high levels of instability due to erosion. A level of moderate indicates that a marginal amount of stream banks show erosion and the stream segment shows elevated levels of instability due to erosion. Conditions considered for the BSID analysis are *moderate to severe erosion present* and *severe erosion present.*

Bank Stability Index

Bank stability index is a composite score that combines a visual rating based on the presence or absence of riparian vegetation and other stabilizing bank materials (e.g., boulders, root-wads) with quantitative measures of erosion extent and erosion severity. Banks Stability Index is based on a numeric score from 0-20, with low values as poor and high values as optimal. A poor bank stability index score indicates that the amount of stream bank soil that is being eroded and deposited in the stream is likely different from sites with fair to good biological conditions.

Bank stability index converts the MDDNR MBSS 2000 erosion extent into a numeric score from 0 – 20 using the following formula (source):

$$\text{Bank Stability Index} = \left[\frac{\text{Erosion Extent}}{-15} \cdot \text{Severity}\right]_{\text{Left bank}} + \left[\frac{\text{Erosion Extent}}{-15} \cdot \text{Severity}\right]_{\text{Right bank}} + 20$$

In short, bank stability is a measure of channel erosion. Lower scores on this index are considered to demonstrate that discharge is frequently exceeding the ability of the channel and/or floodplain to attenuate flow energy. The index may further identify conditions, in which stream banks are vulnerable regardless of flood severity or frequency, thus demonstrate increased probability of high sediment loadings.

Bank stability index threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont, and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation due to bank stability were identified for two regions; the Highland (10) and Eastern Piedmont (6) (see Appendix A: Table A-2). The Coastal Plain region did not show any statistically significant difference between 90th percentile bank stability index values for very poor and good sites. Based on the results, the threshold value set for the Highland is (10), Eastern Piedmont (6) and the Coastal Plain (10). The Coastal Plain threshold was applied since this is the middle point of the metric (e.g. 1 to 20). Applying these threshold values to individual sites allows the determination of the *poor bank stability index* condition considered for the BSID.

Silt/Clay

Silt/Clay represents indications of the obvious presence of silt and/or clay in a stream channel, suggesting that sediment loading exceeds the transport capacity of the stream. Accumulations of sediment may interfere with feeding or reproductive processes, which may eliminate or reduce species occurrence, resulting in community structure alteration. Silt/clay is a presence/absence binary data result. The condition considered for the BSID analysis is *silt/clay present.*

4.1.2 Indicators of In-stream Habitat Conditions

MDE selected several qualitative parameters from the principal dataset that evaluate the overall physical in-stream habitat conditions of the watershed. The habitat parameters used in the BSID analysis are: presence of channelization, in-stream habitat, pool/glide/eddy quality, riffle/run quality, velocity/depth diversity, presence of concrete/gabion, and presence of beaver ponds. Each of these parameters is measured during spring and/or summer index period.

Channelization

Channelized describes a condition determined by visual observation of the presence or absence of the channelization of the stream segment and the extent of the channelization. Channelization is the human alteration of the natural stream morphology by altering the stream banks, (i.e., concrete, rip rap, and ditching). Streams are channelized to increase the efficiency of the downstream flow of water. Channelization likely inhibits heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities. The condition considered for the BSID analysis is *channelization present.*

In-stream Habitat Condition

In-stream Habitat is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. High in-stream habitat scores are evidence of the lack of sediment deposition. Like embeddedness, in-stream habitat is confounded by natural variability (i.e., some streams will naturally have more or less in-stream habitat). Low in-stream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats.

In-stream habitat conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, which is defined as less than 10% stable habit where lack of habitat is obvious; and 2) marginal, where there is a 10-30% mix of stable habitat but habitat availability is less than desirable. 'Marginal' and/or 'poor' ratings of this measure indicate excessive erosion and/or sedimentation. Conditions considered for the BSID analysis are and *in-stream habitat structure marginal to poor* and *in-stream habitat structure poor*.

Pool/glide/eddy Quality

Pool/glide/eddy (P/G/E) quality is a visual observation and quantitative measurement of the variety and spatial complexity of slow or still water habitat and cover within a stream segment. Stream morphology complexity directly increases the diversity and abundance of fish species found within the stream segment. The increase in heterogeneous habitat such as a variety in depths of pools, slow moving water, and complex covers likely provide valuable habitat for fish species; conversely, a lack of heterogeneity within the P/G/E habitat decreases valuable habitat for fish species.

P/G/E quality conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels 1) poor, defined as minimal heterogeneous habitat with a max depth of <0.2 meters or being absent completely; and 2) marginal, defined as <10% heterogeneous habitat with shallow areas (<0.2 m) prevalent and slow moving water areas with little cover. Conditions considered for the BSID analysis are *pool/glide/eddy quality marginal to poor* and *pool/glide/eddy quality poor.*

Riffle/Run Quality

Riffle/Run Quality is a visual observation and quantitative measurement based on the depth, complexity, and functional importance of riffle/run habitat within the stream segment. Like P/G/E quality, an increase of heterogeneity of riffle/run habitat within the stream segment likely increases the abundance and diversity of fish species, while a decrease in heterogeneity likely decreases abundance and diversity.

Riffle/run quality conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, defined as riffle/run depths < 1 cm or riffle/run substrates concreted; and 2) marginal, defined as riffle/run depths generally 1 – 5 cm with a primarily single current velocity. Conditions considered for the BSID analysis are *riffle/run quality marginal to poor* and *riffle/run quality poor*.

Velocity Depth Diversity

Velocity/Depth Diversity is a visual observation and quantitative measurement based on the variety of velocity/depth regimes present at a site (i.e., slow-shallow, slow-deep, fast-shallow, and fast-deep). Like riffle/run quality, the increase in the number of different velocity/depth regimes likely increases the abundance and diversity of fish species within the stream segment. The decrease in the number of different velocity/depth regimes likely decreases the abundance and diversity of fish species within the stream segment. The 'marginal' or 'poor' diversity categories could identify the absence of available habitat to sustain a diverse aquatic community. This measure may reflect natural conditions (e.g., bedrock), anthropogenic conditions (e.g., widened channels, dams, channel dredging, etc.), or excessive erosional conditions (e.g., bar formation, entrenchment, etc.).

Velocity/depth diversity conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, defined as the stream segment being dominated by one velocity/depth regime, usually pools; and 2) marginal, defined as having only two out of the four velocity/depth diversity regimes present with in the stream segment. Conditions considered for the BSID analysis are *velocity/depth diversity marginal to poor* and *velocity/depth diversity poor*.

Concrete

The presence or absence of concrete is determined by a visual observation within the stream segment, resulting from the field description of the types of channelization. Like the parameter channelization, concrete inhibits the heterogeneity of stream morphology needed for colonization, abundance, and diversity of fish and benthic communities. Concrete channelization increases flow and provides a homogeneous substrate, conditions which are detrimental to diverse and abundant colonization. The condition considered for the BSID analysis is *concrete/gabion present.*

Beaver Dam

The presence or absence of a beaver pond within the stream segment is determined from a visual observation. Beaver dams often create stream impoundments causing numerous physical and chemical changes of a free flowing stream resulting in a more lentic environment. These impoundments create a physical barrier within the stream preventing fish migration. Natural biological response to beaver activity may appear to suggest that a stream's biological community is 'impaired' because the biotic composition differs from regional reference stations. The presence of beaver pond at a station will demonstrate the potential for natural community alteration to explain low IBI scoring. Beaver pond is categorized as a presence/absence binary data result. The condition considered for the BSID analysis is *beaver pond present.*

4.1.3 Indicators of Riparian Habitat Condition

MDE selected two parameters from the principal dataset that evaluate the overall riparian habitat conditions of the watershed. The riparian habitat parameters used in the BSID analysis are: riparian buffer width and shading. Each of these parameters is measured once during summer index period.

Riparian Buffer Width

Riparian Buffer Width represents the minimum width of vegetated buffer in meters, looking at both sides of the stream. Riparian buffer width is measured from 0 m to 50 m, with 0 m having no buffer and 50 m having a full buffer. Riparian buffers serve a number of critical ecological functions. They control erosion and sedimentation, modulate stream temperature, provide organic matter, and maintain benthic macroinvertebrate communities and fish assemblages (Lee et al. 2004).

Riparian buffer threshold values are determined by comparing the 10th percentile width among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont, and Coastal Plain physiographic regions. Threshold values are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results. Levels below the threshold may indicate biological degradation.

A statistically significant minimum riparian buffer threshold value was not identified when considering data statewide or within any of the three eco-regions. It was decided that a stream segment having no (zero meters) riparian buffer width would indicate a potential impact to biological degradation (see Appendix A: Table A-3). The condition considered for the BSID Analysis is *no riparian buffer.*

Shading

Shading is a metric indicating the percentage of the stream segment that is shaded, taking duration into account. Because solar radiation increases the temperature of the stream segment, causing thermal stress on fish and invertebrates, shading is important in protecting the stream from this impact. Other impacts from increased water temperature are decreased dissolved oxygen, and increased bacterial and algal growth.

Shading threshold values are determined by comparing the 10th percentile value among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont, and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation for shading were identified for the State (50%) and in one region, Coastal Plain (55%) (see Appendix A: Table A-4). The Highland and Eastern Piedmont did not show any statistically significant difference between 90th percentile shading values for very poor and good sites. Based on the results, a threshold was set for the state at 50%. Applying the aforementioned thresholds to individual sites allow the determination of the *low shading* condition considered for the BSID.

4.1.4 Indicators of Water Chemistry Conditions

MDE selected several quantitative parameters from the principal dataset that evaluates the overall water quality of a stream and provides information about nutrient and inorganic loading. The water quality parameters used in the BSID analysis are: total phosphorus, ortho-phosphate, total nitrogen, dissolved nitrogen, ammonia, pH (lab), ANC, chlorides, conductivity (lab), and sulfates. Each of these parameters is measured once during the spring index period. In addition, in situ measurements of dissolved oxygen, pH (field), conductivity (field), and temperature are taken once during the summer index period.

Total Phosphorus

Total phosphorus (TP) is a measure of the amount of TP in the water column. Phosphorus forms the basis of a very large number of compounds, the most important class of which is the phosphates. For every form of life, phosphates play an essential role in all energy-transfer processes such as metabolism and photosynthesis. About three-quarters of the TP (in all of its chemical forms) used in the United States goes into fertilizers. Other important uses are as builders for detergents and nutrient supplements for animal feeds. Phosphorus plays a crucial role in primary production. Elevated levels of phosphorus can lead to excessive growth of filamentous algae and aquatic plants. Excessive phosphorus input can also lead to increased primary production, which potentially results in species tolerance exceedances of dissolved oxygen and pH levels. TP input to surface waters typically increases in watersheds where urban and agricultural developments are predominant.

TP threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont, and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation for TP were identified for the State and all three regions (see Appendix A: Table A-5). Based on the results, threshold concentrations were set for the three regions at 0.06 mg/L (Highland), 0.06 mg/L (Eastern Piedmont), and 0.14 mg/L (Coastal Plain). Applying these thresholds to individual sites allow the determination of the *high total phosphorus* condition considered for the BSID.

Orthophosphate

Orthophosphate (OP) is a measure of the amount of OP in the water column. OP is the most readily available form of phosphorus for uptake by aquatic organisms (see 'Total Phosphorus' above). OP threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont, and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation for OP were identified for the State (0.02 mg/L) and one region, the Highland (0.02 mg/L) (see Appendix A: Table A-6). The Eastern Piedmont and Coastal Plain regions did not show any statistically significant difference between 90th percentile OP values for very poor and good sites. Based on the results, threshold concentrations were set for the state at 0.02 mg/L. Applying the threshold to individual sites will allow the determination of the *high orthophosphate* condition considered for the BSID.

Total Nitrogen

Total nitrogen (TN) is a measure of the amount of TN in the water column. TN is comprised of organic nitrogen, ammonia nitrogen, nitrite and nitrate. Nitrogen plays a crucial role in primary production. Elevated levels of nitrogen can lead to excessive growth of filamentous algae and aquatic plants. Excessive nitrogen input also can lead to increased primary production, which potentially results in species tolerance exceedances of dissolved oxygen and pH levels. Runoff and leaching from agricultural land can generate high in-stream levels of nitrogen.

TN threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont, and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results and consideration of other information.

A threshold value indicating potentially significant biological degradation for TN was identified for only one region, Highland (3.0 mg/L) (see Appendix A: Table A-7). The Statewide, Eastern Piedmont, and Coastal Plain regions did not show any statistically significant difference between 90th percentile TN values for very poor and good sites. It is also important to note that in the Eastern Piedmont that higher levels of TN were found in Good sites, when compared to the Poor sites. The threshold is also the same as the Enhanced Nutrient Removal (ENR) threshold for wastewater treatment plants in Maryland. Based on the results, threshold concentrations were set for the three regions at 3.0 mg/L. Applying the threshold to individual sites will allow the determination of the *high total nitrogen* condition considered for the BSID.

Total Dissolved Nitrogen

Total dissolved nitrogen (TDN) is a measure of the amount of dissolved nitrogen in the water column. Nitrogen plays a crucial in primary production. Dissolved nitrogen is the most readily available form of phosphorus for uptake by aquatic organisms (see 'Total Nitrogen' above).

TDN threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont, and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results and consideration of other information.

A threshold value indicating potentially significant biological degradation for TDN was identified for only one region, Highland (3.0 mg/L) (see Appendix A: Table A-8). This is the same threshold used for TN (see section 3.2.1). Based on the results and using the same rationale as applied in setting the TN threshold, threshold concentrations were set for the three regions at 3.0 mg/L. Applying the threshold to individual sites to allow the determination of the *high total dissolved nitrogen* condition considered for the BSID.

Dissolved Oxygen

Dissolved Oxygen (DO) is a measure of the amount of oxygen dissolved in the water as a function of variables such as water temperature, atmospheric pressure, physical aeration, and chemical/biological oxygen demand. DO is generally reported as a concentration (mg/L). MDDNR MBSS measures DO in situ once during the summer. Low DO concentrations may indicate organic pollution due to heterotrophic oxygen consumption and may stress aquatic organisms. Low DO concentrations are considered to demonstrate excessive oxygen demand, primarily from decomposition of organic material. Sources are agricultural, forested, and urban land uses.

The DO threshold value, at which concentrations below 5.0 mg/L may indicate biological degradation, is established by COMAR 2007. Applying the threshold of 5.0 mg/L to individual sites will allow the determination of the *low dissolved oxygen* condition considered for the BSID.

<u>Dissolved Oxygen Saturation</u>

DO saturation accounts for physical solubility limitations of oxygen in water and provides a more targeted assessment of oxygen dynamics than concentration alone. Percent saturation is relative to the amount of oxygen that water can hold, as determined by temperature and atmospheric pressure. MDDNR MBSS only measures DO concentrations expressed in mg/L; therefore, MDE calculated DO saturation percentages. DO saturation, expressed in mg/L, depends on water temperature and salinity. Percent saturation is the ratio of observed DO to DO saturation value, expressed as a percent.

$$T_a = \text{temp\_fld} + 273.15$$

where temp_fld is the DNRMBSS recorded temperature at a specified station and T_a = absolute temperature (K).

$$\ln O_{sf} = -139.34411 + \frac{1.575701 * 10^5}{T_a} - \frac{6.642308 * 10^7}{T_a^2} + \frac{1.243800 * 10^{10}}{T_a^3} - \frac{8.621949 * 10^{11}}{T_a^4}$$

$$O_{sf} = e^{\ln O_{sf}}$$

where O_{sf} = saturation concentration of dissolved oxygen in fresh water at 1 atm (mg L^{-1}) and e is the irrational constant = 2.718281828459.

$$O_{sp} = O_{sf} * (1 - .000035 * \text{altitude\_f})$$

where O_{sp} = saturation concentration of dissolved oxygen at a specified elevation and altitude_f is the altitude of a specified DNRMBSS station.

$$\text{dosat\_fld} = \frac{\text{do\_fld}}{O_{sf}}$$

where dosat_fld is the percent DO saturation and do_fld is the DNRMBSS recorded Dissolved Oxygen in situ at a specified station.

Natural diurnal fluctuations can become exaggerated in streams with excessive primary production, enabling stressor risk analyses. DO saturation levels less than 60% saturation (like DO concentrations <5mg/L) are considered to demonstrate high respiration associated with excessive decomposition of organic material. Additionally, DO saturation greater than 125% is considered to demonstrate oxygen production associated with high levels of photosynthesis. Sources are agricultural, forested and urban land uses.

The DO saturation threshold values, at which concentrations below 60% and above 125% may indicate biological degradation are established from peer-reviewed literature (CIESE 2008). Applying the thresholds of 60% and 125% to individual sites will allow the determination of the *low dissolved oxygen saturation* and *high dissolved oxygen saturation* conditions considered for the BSID.

Ammonia

Ammonia (NH_3) is a measure of the amount of NH_3 in the water column. NH_3 is a nitrogen nutrient species; in excessive amounts it has potential toxic effects on aquatic life. Increased nutrient loads from urban and agricultural development are a source of NH_3. Ammonia is associated with increased primary production, increased pH, increased sunlight exposure, and high water temperature.

Ammonia toxicity is reported in four categories: ammonia acute with salmonid present, ammonia acute with salmonid absent, ammonia chronic with salmonid present, and ammonia chronic with salmonid absent. Ammonia acute toxicity with salmonid present or absent refers to potential exceedences of species tolerance caused by a one-time, sudden, high exposure of ammonia. Chronic ammonia toxicity refers to potential exceedences of species tolerance caused by repeated exposure over a long period of time.

MDDNR MBSS collects water chemistry samples for un-ionized ammonia (NH_3) and pH during the spring index period. The USEPA numeric criterion for ammonia is reported for total ammonia in N mg/l and is pH, temperature, and life stage dependent. NH_3 threshold values are determined by using USEPA ammonia criteria (USEPA 2006) for freshwater with appropriate conversion. Concentrations above the threshold value may indicate biological degradation.

In surface water, un-ionized ammonia exists in equilibrium with ammonium and hydroxide ions. The equilibrium constant for this reaction is dependent on temperature and pH values of the stream segment. Thus, if temperature and pH are known for a stream segment, the fraction of un-ionized ammonia can be calculated. Then, if ammonia in N mg/l is known from USEPA numeric criteria, the un-ionized ammonia numeric criteria can be calculated.

The ammonia criteria in COMAR is calculated as follows:

1. The one-hour average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than every three years on the average, the acute criterion (CMC) calculated using equations:

    a. Where salmonid fish are present:
    $CMC = (0.275/(1 + 10^{7.204-pH})) + (39.0/(1 + 10^{pH-7.204}))$

    b. Where salmonid fish are absent:
    $CMC = (0.411/(1 + 10^{7.204-pH})) + (58.4/(1 + 10^{pH-7.204}))$

2. The thirty-day average concentration of total ammonia nitrogen (in mg N/L) does not exceed, more than once every three years on the average, the chronic criterion (CCC) calculated using equations:

    a. Where salmonid fish are present:
    $CCC = ((0.0577/(1 + 10^{7.688-pH})) + (2.487/(1 + 10^{pH-7.688}))) \text{ x MIN } (2.85, 1.45\cdot 10^{0.028\cdot(25-T)})$

    b. Where salmonid fish are absent:
    $CCC = ((0.0577/(1 + 10^{7.688-pH})) + (2.487/(1 + 10^{pH-7.688}))) \text{ x } 1.45\cdot 10^{0.028\cdot(25-MAX(T,7))}$

3. In addition, the highest four-day average within the thirty-day period should not exceed 2.5 times the CCC.

The conversion from ammonia in mg N mg/l, which is reported in COMAR, to un-ionized ammonia, which is collected by MDNR MBSS in the spring index period, is required for comparison of MBSS to the water quality criteria.

The conversion begins with specifying a pH within the valid range of the criteria. While the equation developed by EPA, and presented in COMAR, is valid for a pH range between 6.0 and 10.0, a pH range between 6.5 and 9.0 was selected for consistency with the pH tables listed in COMAR (COMAR 2007a). Therefore if the pH is less than 6.5 it is adjusted up to 6.5 and if the pH is greater than 9.0 it is adjusted down to 9.0.

Next, an equilibrium constant is defined ad follows:

$$pK_a = 0.09018 + 2729.92 / (273.2 + T_k)$$

where

pKa = equilibrium constant
T_k = average water temperature in degrees C.

Because water temperature is not collected in the MBSS spring index period (i.e. with ammonia samples) an average water temperature was estimated for each physiographic region using data from a representative Maryland CORE/Trend station. The water temperatures applied in the three regions were 7.0º C (Highland), 7.0º C (Eastern Piedmont), and 10.0º C (Coastal Plain).

Once the equilibrium constant and pH are specified for a site, the mole fraction of un-ionized ammonia is calculated by the following equation:

$$f = \frac{1}{(10^{(pK_a - pH)} + 1)}$$

Finally, the amount of total ammonia (expressed in mg N/l) for the COMAR criteria can be converted to total un-ionized ammonia (expressed in mg N/l), which is the same for of ammonia reported by MDNR MBSS for the spring index period, using the following equation:

$$NH_3 = \mathrm{NH}_4 * f * \left(17/14\right),$$

where

NH^3 = un-ionized ammonia mg/l
NH^4 = ammonia mg N/l
f = mole fraction of un-ionized ammonia17/14 is the formula weight of NH^3 divided by the formula weight of N

Applying the criteria to individual sites allows the determination of the a*mmonia chronic with salmonid present, ammonia chronic with salmonid absent, ammonia acute with salmonid present* and a*mmonia acute with salmonid absent* conditions considered for the BSID.

pH

pH is a measure of the acid balance of a stream and uses a logarithmic scale range from 0 to 14, with 7 being neutral. MDDNR MBSS collects pH samples once during the spring, which are analyzed in the laboratory (*pH lab*), and measured once in situ during the summer (*pH field*). Most stream organisms prefer a pH range of 6.5 to 8.5. Values of less than 6.5 for pH are considered to demonstrate acidity, which can be damaging to aquatic life. Intermittent high pH (greater than 8.5) is often associated with eutrophication related to increased algal blooms. Exceedances of pH may allow concentrations of toxic elements (such as ammonia, nitrite, and aluminum) and high amounts of dissolved heavy metals (such as copper and zinc) to be mobilized for uptake by aquatic plants and animals.

The pH threshold values, at which levels below 6.5 and above 8.5 may indicate biological degradation, are established from state regulations (COMAR 2007a). Low stream pH results from agricultural land use, acid mine drainage, atmospheric deposition and organic sources. High stream pH results from agricultural and urban land uses. Applying the low and high thresholds to individual sites will allow the determination of the *low lab pH, high lab pH, low field pH, and high field pH* conditions considered for the BSID.

Acid Neutralizing Capacity

Acid Neutralizing Capacity (ANC) is a measure of the capacity of dissolved constituents in the water to react with and neutralize acids. MDDNR MBSS measures ANC in the spring and reports it as µeq/L. ANC can be used as an index of the sensitivity of surface waters to acidification. The higher the ANC, the more acid a system can assimilate before experiencing a decrease in pH. An ANC value above 200µeq/l is considered normal (Southerland et al 2007). Repeated additions of acidic materials may cause a decrease in ANC. ANC values less than 50µeq/l are considered to demonstrate chronic (highly sensitive to acidification) exposures for aquatic organisms, and less than 200 are considered to demonstrate episodic (sensitive to acidification) exposures.

The ANC threshold values, at which levels below 50 (chronic) and below 200 (episodic) may indicate biological degradation, are established from peer-reviewed literature (Kazyak et al 2005, Southerland et al 2007). Low ANC results from agricultural land use, acid mine drainage, atmospheric deposition and organic sources. Applying the thresholds to individual sites will allow the determination of the *acid neutralizing capacity below chronic level* and *acid neutralizing capacity below episodic level* conditions considered for the BSID.

Chlorides

Chloride is a measure of the amount of dissolved chloride (CL^-) in the water column. MDDNR MBSS measures chlorides during the spring index period and reports it as mg/L. Chlorides can play a critical role in the elevation of conductivity (an indicator of the presence of dissolved substances). Most fish and benthic communities cannot survive in waters with high levels of chlorides. Excessive chloride concentrations indicate a potentially damaging chemical content to stream biology.

High concentrations of chlorides can be due to several types of pollution, including industrial discharges, leaking wastewater infrastructure, metals contamination, and application of road salts in urban landscapes. Although chloride can originate from natural sources, most of the chloride that enters the environment is associated with the storage and application of road salt. Road salt accumulation and persistence in watersheds poses risks to aquatic ecosystems and to water quality. Approximately 55% of road-salt chlorides are transported in surface runoff, with the remaining 45% infiltrating through soils and into groundwater aquifers (Church and Friesz, 1993).

Chloride threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont, and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation for CL^- were identified for the State and all three regions (see Appendix A: Table A-9). Based on the results, threshold concentrations were set for the three regions at 50.0 mg/L (Highland), 50.0 mg/L (Eastern Piedmont), and 50.0 mg/L (Coastal Plain). Since analysis for all regions resulted in a threshold value 50.0mg/L, this threshold was applied to all sites.
Applying these thresholds to individual sites allow the determination of the *high chlorides* condition considered for the BSID.

Conductivity

Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. MDDNR MBSS collects conductivity samples once during the spring, which is analyzed in the laboratory (*conductivity lab*), and measured once in situ during the summer (*conductivity field*).

Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate. Stream conductivity is determined primarily by the geology of the area through which the stream flows. Streams supporting fish assemblages usually have a range between 150 and 500 µS/cm; conductivity outside this range may indicate that the water is unsuitable for certain species of fish and/or macroinvertebrates resulting a shift to more salinity-tolerant species.

Conductivity threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont, and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation for conductivity were identified for the State and all three regions (see Appendix A: Table A-11). Based on the results, threshold concentrations were set for the three regions at 500 µS/cm (Highland), 300µS/cm (Eastern Piedmont), and 300 µS/cm (Coastal Plain). Applying these thresholds to individual sites allow the determination of the *high conductivity* condition considered for the BSID.

Sulfates

Sulfate is the amount of dissolved sulfate (SO_4^{2-}) in the water column. MDDNR MBSS measures sulfate once in the spring and reports it as mg/L. Sulfur is an essential plant nutrient. Sulfates can play a critical role in the elevation of conductivity. Other detrimental impacts of elevated sulfates are their ability to form strong acids, which can lead to changes of pH levels in surface waters.

Sulfate loads to surface waters can be naturally occurring or originate from urban runoff, agricultural runoff, acid mine drainage, atmospheric deposition, and wastewater dischargers. When naturally occurring, they are often the result of the breakdown of leaves that fall into a stream, of water passing through rock or soil containing gypsum and other common minerals.

Sulfate threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation for sulfate were identified for the State and all three regions (see Appendix A: Table A-11). Based on the results, threshold concentrations were set for the three regions at 32.0 mg/L (Highland), 21.0 mg/L (Eastern Piedmont), and 28.0 mg/L (Coastal Plain). Applying these thresholds to individual sites allow the determination of the *high sulfate* condition considered for the BSID.

4.2. Sources

MDE selected parameters from the principal dataset to represent potential "sources" of stressors. Parameters representing sources of stressors are grouped into two categories: land uses within a watershed and potential sources of acidity.

The majority of landscape data evaluated in BSID analysis is land use land cover (LULC) data that was developed by MDE for each MDDNR MBSS site, and enabled calculation of LULC proportions for the 60-meter riparian areas upstream of the site as well as whole watershed areas upstream of the site. ArcGIS and Spatial Analyst (ESRI, 1999) were used to identify and quantify LULC categories from the 2000 RESAC dataset. The datasets was derived from LandSat imagery and have a resolution of 900m^2. Land use parameters used in the BSID analysis were grouped into four categories: urban, agricultural, barren, and anthropogenic.

As anthropogenic disturbance increases, biological condition in our rivers and streams generally decreases. However, land use is broadly associated with the biological condition of aquatic systems and does not provide the specificity to isolate and identify in-stream stressors responsible for observed biological conditions. While not independently useful in identifying biological stressors, land use data does enhance understanding of the influence of in-stream chemical and physical stressors. Land uses are considered sources of many biological stressors, for example pH, ammonia, and chlorides. However, causal sources are given far less weight than in-stream stressors in the final interpretation of causation in the risk analyses results.

MDE also selected numerous parameters within the principle dataset that represent sources of acidity to be included as causal sources. Increased acidity within a stream, resulting in levels that exceed species tolerance, may indicate biological degradation to biological communities. Sources of acidity represent acidic conditions due to loads from land use and chemical sources (i.e., atmospheric deposition, acid mine drainage, organic sources, and agricultural influences). MDNR MBSS derived the possible sources of acidification from analyzing water chemistry data collected by the Maryland Synoptic Stream Chemistry Survey (MSSCS) and other regional data (Southerland et al. 2005a).

4.2.1 Urban Land Use

Impervious Surface in Watershed

Impervious surface is any land area that does not permit precipitation to percolate into the ground, including natural and anthropogenic surfaces. Human development typically increases the amount of impervious surface in a watershed by replacing natural vegetation and soils with buildings and pavement. A high proportion of impervious surface will result in increased surface flow and more rapid transport of precipitation out of a watershed. Increased surface flows to streams can result in more pollutant transport that may exceed species tolerances. The increased speed of runoff also overpowers any natural stream morphology formed to attenuate flow energy, such as meanders and floodplains. As streams adjust to changes in flow energy, they are unstable and are subject to rapid changes in morphology that could episodically displace aquatic organisms as habitats are gained and lost. Aquatic organisms may also be repeatedly scoured from stream channels where high flows are experienced more frequently than in watersheds with low amounts of impervious surface.

Impervious surface land use threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation were identified for the state and all three regions (see Appendix A: Table A-12). Based on results, thresholds were set for the three regions at 5% (Highland), 5% (Eastern piedmont), and 10% (Coastal plain).

Applying these thresholds value to individual sites allows the determination of the *high % of impervious surface in watershed* condition considered for the BSID.

High Intensity Urban in Watershed

Watershed high intensity urban represents the proportion of medium and high intensity developed land as well as transportation area within the entire drainage basin for each stream station. As with measures of impervious surface, high intensity urban increases surface water flow, or otherwise speeds water delivery to stream channels (e.g., storm water pipes), increasing the energy of flowing water and the potential to erode soils (on the terrain and in stream channels), carry pollutants, and displace organisms. Expedited transport of water from a basin decreases groundwater recharge and amplifies both high and low flow extremes. Increased pollutant transport could include nutrients, organics, and/or inorganics from residential, commercial, and/or industrial activities associated with this land usage. Reduction of available heterotrophic material could also shift trophic conditions in aquatic systems to more autotrophic that could also alter biological community structure.

High Intensity land use threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation were identified for the state and all three regions (see Appendix A: Table A-13). Based on results, thresholds were set for the three regions at 6% (Highland), 10% (Eastern piedmont), and 10% (Coastal plain). Applying these thresholds value to individual sites allows the determination of the *high % of high intensity urban in watershed* condition considered for the BSID.

High Intensity Urban in 60m Stream Buffer

Stream buffer high intensity urban represents the proportion of medium and high intensity developed land and transportation area within 60 meters of streams upstream from sample stations. This measure does not convey the total system flow energy potential or whole basin high intensity urban proportions. Instead, it demonstrates the increased potential for pollutants to enter streams due to proximity and the corresponding lack of natural buffers to filter pollutants. High proportions also demonstrate the increased potential for encroachment of urban development on floodplains, which could reduce flow attenuation properties thereby increasing storm flow velocity and channel erosion.

High Intensity within 60m stream buffer threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating

biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.
Threshold values indicating potentially significant biological degradation were identified for the state and all three regions (see Appendix A: Table A-14). Based on results, thresholds were set for the three regions at 6% (Highland), 6% (Eastern piedmont), and 7% (Coastal plain). Applying these thresholds value to individual sites allows the determination of the *high % of high intensity urban 60m stream buffer* condition considered for the BSID.

Low Intensity Urban in Watershed

Watershed low intensity urban represents the proportion of low intensity developed land as well as urban/residential land areas dominated by deciduous trees, evergreen trees, mixed trees/forest, or recreational grasses within the entire drainage basin for each stream station. While impervious surface is expected in this land use classification, it is considered to be less extensive than in high intensity urban areas. Pollutant types are expected to be similar to those associated with high intensity urban. Episodic acute loads may equal the magnitude of high intensity area due, for example, to potential seasonal application of lawn fertilizers/pesticides or random illegal dumping of pollutants. However, chronic pollutant loads are expected to be less than those in high intensity settings due to the implied presence of natural vegetation associated with this land use classification.

Low Intensity land use threshold values are determined by comparing the 90^{th} percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation were identified for the state and all three regions (see Appendix A: Table A-15). Based on results, thresholds were set for the three regions at 20% (Highland), 50% (Eastern piedmont), and 55% (Coastal plain). Applying these threshold values to individual sites allows the determination of the *high % of low intensity urban in watershed* condition considered for the BSID.

Low Intensity Urban in 60m Stream Buffer

Stream buffer low intensity urban represents the proportion of low intensity developed land as well as urban/residential land areas dominated by deciduous trees, evergreen trees, mixed trees/forest, or recreational grasses within 60 meters of streams upstream from sample stations. Episodic pollutant loads from this primarily residential land use have increased potential compared to whole basin classifications due to the proximity to streams.

Low Intensity within 60m stream buffer threshold values are determined by comparing the 90^{th} percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation were identified for the state and all three regions (see Appendix A: Table A-16). Based on results, thresholds were set for the three regions at 20% (Highland), 35% (Eastern piedmont), and 40% (Coastal plain). Applying these threshold values to individual sites allows the determination of the *high % of low intensity urban land 60m stream buffer* condition considered for the BSID.

Transportation Land Use in Watershed

This land use classification is a subset of high intensity urban because it one of the original RESAC categories that were reclassified to create the high intensity classification. Independently, it generally conveys the potential for increased surface runoff and transport of pollutants due to the largely impervious nature of roadways and railways.

Transportation land use threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation were identified for the state and all three regions (see Appendix A: Table A-17). Based on results, thresholds were set for the three regions at 4% (Highland), 6% (Eastern piedmont), and 6% (Coastal plain). Applying these threshold values to individual sites allows the determination of the *high % of transportation in watershed* condition considered for the BSID.

Transportation Land Use in 60m Stream Buffer

Roadways and railways within 60 meters of streams upstream from sample stations is a subset of high intensity urban within buffers. Independently, this land use measure demonstrates the exaggerated potential of channel modifying encroachments of paved surfaces, walls, culverts, and bridges into flood plains. Reduced flow attenuation properties of floodplains as well as rapid delivery of surface flow and pollutants are potential effects associated with high proportions of this measure.

Transportation within 60m stream buffer threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation were identified for the state and all three regions (see Appendix A: Table A-18). Based on results, thresholds were set for the three regions at 5% (Highland), 5% (Eastern piedmont), and 3% (Coastal plain). Applying these threshold values to individual sites allows the determination of the *high % of transportation 60m stream buffer* condition considered for the BSID.

4.2.2 Agricultural Land Use

Total Agricultural Land in Watershed

Watershed agricultural land represents the proportion of land area used for pasture/hay as well as for production of row crops within the entire drainage basin upstream of sample stations. Possible stream consequences to large proportions of agricultural land may include increased loads of sediment, nutrients, and/or pesticides. This is an extremely variable land use classification that could represent conditions ranging from dense livestock feeding lots to broad hay fields with no exposed soils.

Agricultural land use threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

A threshold value indicating potentially significant biological degradation was identified for one region, Highland (55%) (see Appendix A: Table A-19). No statistically significant barren land in watershed threshold values was determined for the Eastern Piedmont and Coastal Plain physiographic region. Since only the Highland analysis resulted in a threshold value (55%), this threshold was applied to all sites. Applying the threshold to individual sites will allow the determination of the *high % of agriculture in watershed* condition considered for the BSID.

Total Agricultural Land in 60m Stream Buffer

This measure represents the proportion agriculture land area used for pasture/hay, livestock, and production of row crops within 60 meters of streams upstream from sample stations. Possible stream consequences to large proportions of agricultural land may include increased loads of sediment, nutrients, and/or pesticides. This is an extremely variable land use classification that could represent conditions ranging from dense livestock feeding lots to broad hay fields with no exposed soils.

Agriculture within 60m stream buffer threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation were identified for the state (45%) and two regions, the Highland (45%) and Coastal Plains (45%) (see Appendix A: Table A-20). No statistically significant agriculture 60m stream buffer threshold values were determined for the Eastern Piedmont physiographic region. Because the statewide, Highland, and Coastal Plains analysis resulted in the same threshold value (45%), this threshold was applied to all sites. Applying these thresholds to individual sites allows the determination of the *high % of agriculture 60m stream buffer* condition considered for the BSID.

Cropland in Watershed

The proportion of cropland in the whole drainage basin above is a subset of total agriculture in the basin. This measure provides limited refinement of the diversity of land condition represented by agriculture. However, it is still a very broad classification that includes a wide range of nutrient and soil loading potential. Worst case scenarios may include the presence of exposed soils for extended, possibly wet, periods and broadcast spreading of fertilizers.

Cropland land use threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

A threshold value indicating potentially significant biological degradation was identified for one region, Highland (25%) (see Appendix A: Table A-21). No statistically significant threshold values for cropland in watershed were determined for the state, Eastern Piedmont and Coastal Plain physiographic region. Since only the Highland analysis resulted in a threshold value (25%), this threshold was applied to all sites. Applying the threshold to individual sites will allow the determination of the *high % of cropland in watershed* condition considered for the BSID.

Crop Land in 60m Stream Buffer

This measure represents the proportion row crops within 60 meters of streams upstream from sample stations. High proportions demonstrate the increased potential to transport sediment from exposed soils and nutrients from fertilizers into streams. However, the presence of exposed soils and application of fertilizers is extremely variable within this land use classification.

Cropland land use within 60m stream buffer threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation were identified for the state (25%) and only one region, the Highland (20%) (see Appendix A: Table A-22). No statistically significant cropland 60m stream buffer threshold values were determined for the Eastern Piedmont and Coastal Plain physiographic region. Since only the Highland analysis resulted in a threshold value (20%), this threshold was applied to all sites. Applying these thresholds to individual sites allows the determination of the *high % of cropland 60m stream buffer* condition considered for the BSID.

Pasture/Hay in Watershed

The proportion of pasture/hay in the whole drainage basin above is also a subset of total agriculture in the basin. This measure also provides limited refinement of the diversity of land condition represented by agriculture because it still involves possibly the highest (dense animal feed lots) and lowest potential (hay fields) for nutrient and sediment loads.

Pasture/Hay land use threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

A threshold value indicating potentially significant biological degradation was identified for one region, Highland (35%) (see Appendix A: Table A-23). No statistically significant pasture/hay in watershed threshold values was determined for the Eastern Piedmont and Coastal Plain physiographic region. Since only the Highland analysis resulted in a threshold value (35%), this threshold was applied to all sites. Applying the threshold to individual sites will allow the determination of the *high % of pasture/hay in watershed* condition considered for the BSID.

Pasture/Hay in 60m Stream Buffer

This measure represents the proportion pasture/hay land use within 60 meters of streams upstream from sample stations. High proportions demonstrate the increased potential to transport sediment from exposed soils and nutrients from fertilizers due to proximity to streams. However, the presence of nutrients and exposed soil is extremely variable within this land use classification.

Pasture/Hay within 60m stream buffer threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

Threshold values indicating potentially significant biological degradation were identified for the state (30%) and two regions, the Highland (30%) and Coastal Plains (20%) (see Appendix A: Table A-24). No statistically significant pasture/hay 60m stream buffer threshold value was determined for the Eastern Piedmont physiographic region. Because the statewide analysis and Highland analysis resulted in the same threshold value (30%), this threshold was applied to Eastern Piedmont region. Applying these threshold values to individual sites allows the determination of the *high % of pasture/hay 60m stream buffer* condition considered for the BSID.

4.2.3 Barren Land Use

Barren Land in Watershed

This measure represents the proportion of exposed rock, clay, sand, surfacing mining activities, etc within the entire drainage basin upstream of sample stations. Streams below barren areas could potentially experience altered flow regimes and increased sediment loads.

Barren land use threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

A threshold value indicating potentially significant biological degradation was identified for one region, Highland (1%) (see Appendix A: Table A-25). No statistically significant barren land in watershed threshold values was determined for the Eastern Piedmont and Coastal Plain physiographic region. Since only the Highland analysis resulted in a threshold value (1%), this threshold was applied to all sites. Applying the threshold to individual sites will allow the determination of the *high % of barren land in watershed* condition considered for the BSID.

Barren Land in 60m Stream Buffer

This measure represents the proportion of exposed rock, clay, sand, surface mining activities, etc within 60 meters of streams upstream from sample stations. Streams below barren areas, particularly in close proximity, could potentially experience altered flow regimes and increased sediment loads.

Barren land within 60m stream buffer threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results.

A threshold value indicating potentially significant biological degradation was identified for one region, Highland (1%) (see Appendix A: Table A-26). No statistically significant barren land 60m stream buffer threshold values were determined for the Eastern Piedmont and Coastal Plain physiographic region. Since only the Highland analysis resulted in a threshold value (1%), this threshold was applied to all sites. Applying the threshold to individual sites will allow the determination of the *high % of barren land 60m stream buffer* condition considered for the BSID.

4.2.4 Anthropogenic Land Use

Forest Land in Watershed

The amount of forested land reveals the general extent of urban and agricultural development within a watershed. Forested land use is natural areas dominated by tree cover with an understory of natural plant material or ground cover. Due to processes such as evaporation, water uptake, and transpiration, watersheds with high forest proportions demonstrate natural hydrological regimes. High forest proportions also suggest that erosion will be limited due to canopies that reduce the impact of heavy rain events, along with roots and leaf litter that secure soils from transport in any overland water flow. Due to the retention of precipitation by living vegetation and leaf litter, less surface water flow will means less chance for transport of pollutants (e.g., nutrients, organic, and inorganic contaminants). High forest proportion also suggests that heterotrophic material will be in abundance, and that autochthonous production will be minimal due to the presence of canopies over small water bodies. Thus, decreased amounts of forested land use within a watershed will affect hydrological regimes, nutrient loads, trophic conditions, and inorganic pollutant contaminants on surface waters.

Forested land use threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results. Proportions below the threshold percentages may indicate biological degradation.

Threshold values indicating potentially significant biological degradation were identified for the state and all three regions (see Appendix A: Table A-27). Based on results, thresholds were set for the three regions at 25% (Highland), 15% (Eastern Piedmont), and 15% (Coastal Plain). Applying these thresholds value to individual sites allows the determination of the *low % of forested land in watershed* condition considered for the BSID.

Forest Land in 60m Stream Buffer

This measure represents the proportion forested land use within 60 meters of streams upstream from sample stations. Low forest riparian proportions should associate with higher anthropogenic disturbances and pollutant loadings to surface waters. Riparian zones serve a number of critical ecological functions. They control erosion and sedimentation, modulate stream temperature, provide organic matter, and maintain benthic macroinvertebrate communities and fish assemblages (Lee et al. 2004).

Forested land within 60m stream buffer threshold values are determined by comparing the 90th percentile concentration among very poor, poor, fair, and good biological conditions (fish and benthic separately). The comparison is made statewide and also separately for the Highland, Eastern Piedmont and Coastal Plain physiographic regions. Threshold values, indicating biological degradation, are set by determining if there is a statistically significant difference between the poor and fair group, and then between the very poor and good group of sites. A final threshold value is set based on review of the results. Proportions below the threshold percentages may indicate biological degradation.

Threshold values indicating potentially significant biological degradation were identified for the state and all three regions (see Appendix A: Table A-28). Based on results, thresholds were set for the three regions at 35% (Highland), 35% (Eastern piedmont), and 30% (Coastal plain). Applying these threshold values to individual sites allows the determination of the *low % of forested land 60m stream buffer* condition considered for the BSID.

4.2.5 Sources of Acidity - Atmospheric Deposition

Acidity is a problematic aspect of atmospheric deposition, with the pH of rain often in the range of 3.5 to 5.0. Acidic deposition is the contribution of material from atmospheric sources, both as wet precipitation (wet) and particulate (dry) deposition. Atmospheric deposition is generally associated with elevated concentrations of sulfates and nitrates. Atmospheric deposition reflects a binary response (i.e., yes/no) for presence in a watershed and is contained in the principal dataset. The condition considered for the BSID analysis is *atmospheric deposition present.*

4.2.6 Sources of Acidity - Acid Mine Drainage

Acid mine drainage (AMD) results from the oxidation of mineral pyrite, which is found in mine spoils and abandoned mine shafts, and is known to cause extreme acidification of surface waters as well as affect stream physical substrate. Streams strongly affected by AMD exhibit high levels of sulfate, manganese, iron, aluminum, and conductivity. Highly acidic waters ($pH < 3$) can solubilise heavy metals and other toxic elements from soil and cause them to be transported into nearby surface waters. The high acidity of acid mine drainage and the high amounts of dissolved heavy metals (such as copper and zinc) generally make acid mine drainage extremely toxic to most organisms (Penreath, 1994). AMD reflects a binary response (i.e., yes/no) for presence in a watershed and is contained in the principal dataset. The condition considered for the BSID analysis is *AMD present.*

4.2.7 Sources of Acidity – Organic Acid Source

Natural decay of organic materials may contribute acidity in the form of organic anions, as in blackwater streams associated with bald cypress wetlands and boreal bogs. Streams dominated by organic sources are often characterized by high concentrations of dissolved organic carbon ($DOC > 8$ mg/L) and organic anions. Organic acid source reflect a binary response (i.e., yes/no) for presence in a watershed and is contained in the principal dataset. The condition considered for the BSID analysis is *organic acid source present.*

4.2.8 Sources of Acidity – Agricultural Acid Source

Agricultural lands fertilized with high levels of nitrogen, or other acidifying compounds are a source of acidification in surface waters. Agricultural activities in watersheds effect stream chemistry, adding both ANC, from soil liming practices, and strong acid anions from nitrogen fertilizers. Agricultural acid source reflect a binary response (i.e., yes/no) for presence in a watershed and is contained in the principal dataset. The condition considered for the BSID analysis is *agricultural acid source present.*

5. Statistical Methods

MDE has adopted a case-control, risk-based approach to identify and support the stressors and sources of biological impairments. The BSID analysis tests for the strength of association between stressors and degraded biological conditions by determining if there is an increased risk associated with the stressor being present. More specifically, the assessment compares the likelihood that a stressor is present, given that there is a degraded biological condition, by using the ratio of the incidence within the case group as compared to the incidence in the control group. The case group is defined as the sites within the assessment unit with degraded biological conditions and the controls are sites with similar physiographic characteristics that have good biological conditions. In Maryland three physiographic eco-regions were identified from the MDDNR MBSS index of biotic integrity (IBI) metrics: Highland, Eastern Piedmont, and Coastal (Southerland et al. 2005b).

Measures of association statistics are applied to assess the influence of stressors on degraded biological conditions. It was determined that, given the binary structure (i.e., present/absent, yes/no) of the biological response and stressor/source data, the most appropriate statistical method was to report the data in a 2-way contingency table and evaluate the strength of association using the odds ratio. Table 2 provides an example of a 2-way contingency table.

Table 2. Example 2-way Contingency Table

	Degraded Cases (Sites with very poor to poor biological communities in assessment unit)	Controls (Sites with fair to good biological communities in similar physiographic region)	Total
Stressor/Source Present	a	b	m_1
Stressor/Source Absent	c	d	m_0
Total	n_1	n_0	n

where,

a = # of sites with very poor to poor biological condition and stressor/source present
b = # of sites with fair to good biological condition and stressor/source present
c = # of sites with poor to very poor biological condition and stressor/source absent
d = # of sites with fair to good biological condition and stressor/source absent
n_1 = Total # of cases
n_0 = Total # of controls
m_1 = Total # of case and control sites with stressor present
m_0 = Total # of case and control sites with stressor absent
n = Total # of case and control sites

The odds ratio is calculated as

Odds Ratio = $\frac{a}{b} \Big/ \frac{c}{d}$, which is also equivalent to $\frac{a}{c} \Big/ \frac{b}{d}$ and $\frac{ad}{cb}$

When case sites span multiple geographic strata it is important to compare cases with controls from the appropriate strata. In this scenario a common odds ratio is calculated by developing a separate 2x2 table for each physiographic region. The combined or common odds ratio is then calculated using the Mantel-Haenszel (MH) approach. The MH odds ratio is calculated as follows:

$$\text{Odds Ratio}_{MH} = \sum_{g=1}^{G} \frac{a_g d_g}{n_g} \Bigg/ \sum_{g=1}^{G} \frac{b_g c_g}{n_g}$$

Where

Odds Ratio_{MH} = the Mantel-Haenszel common odds ratio
g = identifier used to denote the stratum
G = the total number of strata

In addition to the three physiographic strata defined by the BIBI, habitat parameters were also grouped into two additional strata defined by sites in first order streams and sites in second through fourth order streams. The rationale for this was that the extent or quality of habitat can vary naturally with stream order and it is more appropriate to compare streams of similar size. The division of these two stream order strata resulted in approximately equal number of control sites per strata. Also, due to sample size limitations, the second through fourth order streams were not subdivided into small groups.

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the MH (1959) approach and based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are poor to very poor biological conditions (cases) than when there are fair to good biological conditions (controls). This result suggests a statistically significant positive association between the stressor and poor to very poor biological conditions and is used to identify potential stressors.

Once potential stressors are identified (i.e., odds ratio significantly greater than one), the risk attributable to each stressor is quantified for all sites with poor to very poor biological conditions within the watershed (i.e. cases). The attributable risk (AR) defined herein is the portion of the cases with poor to very poor biological conditions that are a result of the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present. The equation is as follows.

$$AR = R_{cases} - R_{controls}$$

where

AR = attributable risk
R_{cases} = absolute risk (proportion) of stressor among cases
$R_{controls}$ = absolute risk (proportion) of stressor among controls

When multiple strata are present and the data are from a case control study, Bruzzi et al. (1985) stated that the AR can be estimated using the cases alone once the relative risk is known. Instead of using the relative risk, it is possible to sum the AR for each case over all the cases. The assumption is that each case site has its own absolute risk. If the stressor is present the absolute risk is unity whereas if the stressor is absent the absolute risk is zero. The absolute risk of the stressor among the controls, for the specific case site, is determined based on the physiographic region of the case site and includes stream order if the stressor is related to habitat condition. The following equation is used to determine the AR when considering multiple strata:

$$AR = \frac{\sum_{g=1}^{G} \sum_{i=1}^{n_{ig}} \left[Rcase_{ig} - Rcontrols_{g} \right]}{G \cdot n_g}$$

where

AR = Attributable risk for a population of sites within a watershed
$Rcase_{ig}$ = absolute risk of stressor for case i in stratum g (0 or 1)
$Rcontrols_g$ = absolute risk of stressor among controls for stratum g
G = total number of strata
n_g = number of cases within stratum g
$G \cdot n_g$ = total number of cases

Once the AR is defined for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR calculation for each stressor, the AR calculation for a group of stressors is also summed over the case sites using the individual site characteristics (i.e., stressors present at that site). The only difference is that the absolute risk for the controls at each site is estimated based on the stressor present at the site that has the lowest absolute risk among the controls. For example, if high embeddedness and poor epifaunal substrate were present at the site and the absolute risk among the controls were 0.25 and 0.15 respectively, then a value of 0.15 would be used since it has the lowest risk among the controls and would produce the highest AR. The equation for estimating AR for groups of stressors is as follows:

$$AR = \frac{\sum_{g=1}^{G} \sum_{i=1}^{n_{ig}} \max_j \left[Rcase_{jig} - Rcontrols_{jg} \right]}{G \cdot n_g}$$

where

AR = Attributable risk for a population of sites within a watershed
$Rcase_{jig}$ = absolute risk of stressor j for case i in stratum g (0 or 1)
$Rcontrols_{jg}$ = absolute risk of stressor j among controls for stratum g
G = total number of strata
n_g = number of cases within stratum g
$G \cdot n_g$ = total number of cases

After determining the AR for each stressor and the AR for groups of stressors, the AR for all potential stressors is calculated. This value represents the proportion of cases, sites in the watershed with poor to very poor biological conditions, which would be improved if the potential stressors were eliminated. The purpose of this metric is to determine if stressors have been identified for an acceptable proportion of cases. While there is not a reported acceptable value for this metric, it is recommended that a limit be selected based on the number of cases in the watershed and consideration for the biological listing methodology.

To assist in determining potential sources of the stressors, the above described statistical methods are applied to all source parameters (e.g. land use, AMD, etc.).

6. Conclusion

The BSID process will use results from the BSID analysis to evaluate each biologically impaired watershed and determine potential stressors and sources. Interpretation of the BSID analysis results is based upon components of Hill's Postulates (1965), which propose a set of standards that could be used to judge when an association might be causal. The components applied are: 1) the strength of association which is assessed using the odds ratio; 2) the specificity of the association for a specific stressor (risk among controls); 3) the presence of a biological gradient; 4) ecological plausibility which is illustrated through final causal models; and 5) experimental evidence gathered through literature reviews to help support the causal linkage.

BSID process uses general causal scenarios to aide in the interpretation of how land-use conditions might generate in-stream stressors and how the resulting impacts can alter the biological community and structure. Appendix B contains four general causal scenario models MDE uses to aide in the interpretation of results from the BSID analysis. With the general understanding of ecological processes within casual scenarios and knowledge of impaired watersheds, MDE can determine likely causes of degraded biological conditions.

Ecologically plausible causal models will be developed specifically for a watershed based on BSID analysis results. Once the BSID analysis is completed and a final causal model is developed, a number of stressors (pollutants) may be identified as the cause of the poor to very poor biological condition within the Maryland 8-digit watershed. If there are multiple stressors (pollutants) then the process will evaluate the AR for each stressor and rank them appropriately.

Finally, water quality limited segments with degraded biological condition caused by specific stressor(s) (e.g., sediment, nutrients) are compared to the current Integrated Report listing categories for the 8 digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

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Appendix A

Table A-1 Statewide and Physiographic Eco-region Analysis for Embeddedness

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	100 (97,100)	174
Poor (2-3)	100 (100,100)	286
Fair (3-4)	100 (100,100)	292
Good (4-5)	100 (90,100)	322
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	100 (100,100)	110
Poor (2-3)	100 (100,100)	173
Fair (3-4)	100 (90,100)	291
Good (4-5)	100 (100,100)	317
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	85 (80,90)	56
Poor (2-3)	65 (57,75)	107
Fair (3-4)	49 (45,50)	103
Good (4-5)	35 (35,40)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	49
Very Poor vs. Good	Yes	57

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	86 (75,90)	39
Poor (2-3)	65 (55,80)	66
Fair (3-4)	55 (49.5,65)	92
Good (4-5)	40 (40,45)	101
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	60

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	55.4 (50.2,61)	79
Poor (2-3)	78 (54,90)	73
Fair (3-4)	55 (45,60)	68
Good (4-5)	40 (39.6,45)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	66.5

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	57 (50,90)	31
Poor (2-3)	45.5 (40.5,50.5)	40
Fair (3-4)	55 (50,60)	95
Good (4-5)	40 (38.9,45)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	50.25

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	100 (100,100)	39
Poor (2-3)	100 (100,100)	106
Fair (3-4)	100 (100,100)	121
Good (4-5)	100 (100,100)	121
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	100 (100,100)	40
Poor (2-3)	100 (100,100)	67
Fair (3-4)	100 (100,100)	104
Good (4-5)	100 (100,100)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-2 Statewide and Physiographic Eco-region Analysis for Bank Stability Index

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	6.3 (5.1,10.0)	175
Poor (2-3)	8.0 (7.0,8.9)	286
Fair (3-4)	8.3 (7.3,9.2)	293
Good (4-5)	7.0 (6.3,8.3)	322
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	7.9 (5.0,9.9)	110
Poor (2-3)	6.6 (5.3,9.0)	173
Fair (3-4)	7.0 (6.4,8.3)	291
Good (4-5)	8.3 (7.0,9.0)	318
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	8.8 (5.0,10.5)	56
Poor (2-3)	7.0 (6.0,8.8)	107
Fair (3-4)	11.7 (9.2,13.0)	104
Good (4-5)	14.7 (14.1,16.0)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	11.7
Very Poor vs. Good	Yes	9.4

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	9.6 (5.0,12.0)	39
Poor (2-3)	8.8 (6.3,11.5)	66
Fair (3-4)	8.2 (7.0,10.0)	92
Good (4-5)	10.0 (8.9,12.1)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	7.7 (5.2,11.8)	79
Poor (2-3)	8.1 (5.8,9.5)	73
Fair (3-4)	7.7 (6.2,9.6)	68
Good (4-5)	7.8 (6.3,8.5)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	8.3 (7.5,13.3)	31
Poor (2-3)	5.0 (4.9,6.2)	40
Fair (3-4)	8.2 (6.5,9.7)	95
Good (4-5)	8.7 (6.7,9.9)	112
Group	Significant	Target Value
Poor vs. Fair	Yes	6.4
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	5.5 (3.1,12.3)	40
Poor (2-3)	9.2 (7.3,10.5)	106
Fair (3-4)	6.8 (5.0,9.0)	121
Good (4-5)	5.0 (3.5,6.5)	121
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	3.4 (2.0,10.3)	40
Poor (2-3)	9.2 (7.3,10.4)	67
Fair (3-4)	5.7 (3.5,8.0)	104
Good (4-5)	6.2 (5.5,7.2)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-3 Statewide and Physiographic Eco-region Analysis for Riparian Buffer Width

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.0 (0.0,0.0)	182
Poor (2-3)	0.0 (0.0,0.0)	300
Fair (3-4)	0.0 (0.0,0.0)	306
Good (4-5)	0.0 (0.0,0.0)	325
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.0 (0.0,0.0)	110
Poor (2-3)	0.0 (0.0,0.0)	172
Fair (3-4)	0.0 (0.0,0.0)	290
Good (4-5)	0.0 (0.0,0.0)	313
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.0 (0.0,0.0)	57
Poor (2-3)	0.0 (0.0,0.0)	115
Fair (3-4)	0.0 (0.0,0.0)	110
Good (4-5)	0.0 (0.0,0.0)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.0 (0.0,0.0)	39
Poor (2-3)	0.0 (0.0,0.0)	66
Fair (3-4)	0.0 (0.0,0.0)	92
Good (4-5)	0.0 (0.0,0.0)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.0 (0.0,0.0)	80
Poor (2-3)	0.0 (0.0,0.0)	74
Fair (3-4)	0.0 (0.0,0.0)	69
Good (4-5)	0.0 (0.0,0.0)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.0 (0.0,0.0)	31
Poor (2-3)	0.0 (0.0,0.0)	40
Fair (3-4)	0.0 (0.0,0.0)	95
Good (4-5)	0.0 (0.0,0.0)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.0 (0.0,0.0)	45
Poor (2-3)	0.0 (0.0,0.0)	111
Fair (3-4)	0.0 (0.0,14.6)	127
Good (4-5)	28.6 (0.0,35.0)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.0 (0.0,0.0)	40
Poor (2-3)	0.0 (0.0,0.0)	66
Fair (3-4)	0.0 (0.0,20.0)	103
Good (4-5)	0.0 (0.0,27.4)	99
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-4 Statewide and Physiographic Eco-region Analysis for Shading

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	30 (20,45)	174
Poor (2-3)	45 (40,60)	286
Fair (3-4)	50 (45,60)	293
Good (4-5)	57.3 (45.5,60.3)	322
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	47.5

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	65 (60,65)	110
Poor (2-3)	47 (40,60)	173
Fair (3-4)	50 (40,60)	291
Good (4-5)	40 (35,45)	318
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	27.5 (20,37.5)	56
Poor (2-3)	38 (25.30098272,54)	107
Fair (3-4)	45 (45,60)	104
Good (4-5)	40 (37.5,56)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	65 (34,69)	39
Poor (2-3)	35 (25,45)	66
Fair (3-4)	45 (35,60)	92
Good (4-5)	40 (35,40.5)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	62.4 (60,65)	79
Poor (2-3)	60 (47,65)	73
Fair (3-4)	65 (35,70)	68
Good (4-5)	60 (50,62)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	63.33333333 (30,70)	31
Poor (2-3)	60 (55.5,69.5)	40
Fair (3-4)	60 (52,65)	95
Good (4-5)	46 (35.3,60.3)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	16.6 (6.8,42)	39
Poor (2-3)	55 (35,65)	106
Fair (3-4)	55 (30,65)	121
Good (4-5)	65 (63,75)	121
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	55

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	74.5 (64.5,85)	40
Poor (2-3)	73 (56,78)	67
Fair (3-4)	40 (30,65)	104
Good (4-5)	42.1 (25,57.4)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-5 Statewide and Physiographic Eco-region Analysis for Total Phosphorous

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.10 (0.09,0.12)	182
Poor (2-3)	0.11 (0.10,0.13)	300
Fair (3-4)	0.09 (0.08,0.10)	307
Good (4-5)	0.06 (0.05,0.07)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	0.09
Very Poor vs. Good	Yes	0.10

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.10 (0.08,0.11)	110
Poor (2-3)	0.10 (0.08,0.11)	172
Fair (3-4)	0.09 (0.08,0.10)	290
Good (4-5)	0.07 (0.06,0.07)	313
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	0.09

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.09 (0.07,0.14)	57
Poor (2-3)	0.08 (0.06,0.10)	115
Fair (3-4)	0.05 (0.03,0.06)	110
Good (4-5)	0.02 (0.02,0.02)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	0.06

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.07 (0.05,0.09)	39
Poor (2-3)	0.07 (0.05,0.10)	66
Fair (3-4)	0.06 (0.04,0.06)	92
Good (4-5)	0.03 (0.03,0.04)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	0.06

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.06 (0.05,0.09)	80
Poor (2-3)	0.07 (0.05,0.13)	74
Fair (3-4)	0.05 (0.04,0.08)	69
Good (4-5)	0.04 (0.04,0.05)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	0.06

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.06 (0.04,0.07)	31
Poor (2-3)	0.04 (0.03,0.05)	40
Fair (3-4)	0.04 (0.03,0.06)	95
Good (4-5)	0.05 (0.05,0.07)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.14 (0.11,0.17)	45
Poor (2-3)	0.16 (0.12,0.19)	111
Fair (3-4)	0.11 (0.10,0.13)	128
Good (4-5)	0.09 (0.08,0.09)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	0.14

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.12 (0.10,0.14)	40
Poor (2-3)	0.12 (0.10,0.18)	66
Fair (3-4)	0.13 (0.10,0.16)	103
Good (4-5)	0.10 (0.08,0.11)	99
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-6 Statewide and Physiographic Eco-region Analysis for Ortho Phosphate

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.03 (0.02,0.04)	182
Poor (2-3)	0.03 (0.03,0.04)	300
Fair (3-4)	0.02 (0.01,0.02)	307
Good (4-5)	0.02 (0.01,0.02)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	0.02
Very Poor vs. Good	Yes	0.02

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.02 (0.01,0.04)	110
Poor (2-3)	0.02 (0.02,0.03)	172
Fair (3-4)	0.02 (0.01,0.03)	290
Good (4-5)	0.02 (0.02,0.02)	313
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.04 (0.02,0.07)	57
Poor (2-3)	0.03 (0.02,0.04)	115
Fair (3-4)	0.01 (0.01,0.02)	110
Good (4-5)	0.01 (0.01,0.01)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	0.01
Very Poor vs. Good	Yes	0.02

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.02 (0.01,0.06)	39
Poor (2-3)	0.02 (0.02,0.03)	66
Fair (3-4)	0.02 (0.01,0.03)	92
Good (4-5)	0.01 (0.01,0.01)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	0.02

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.01 (0.01,0.02)	80
Poor (2-3)	0.03 (0.01,0.04)	74
Fair (3-4)	0.02 (0.01,0.02)	69
Good (4-5)	0.02 (0.01,0.02)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.01 (0.01,0.04)	31
Poor (2-3)	0.01 (0.01,0.02)	40
Fair (3-4)	0.01 (0.01,0.02)	95
Good (4-5)	0.02 (0.02,0.03)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.04 (0.03,0.05)	45
Poor (2-3)	0.04 (0.02,0.04)	111
Fair (3-4)	0.02 (0.02,0.03)	128
Good (4-5)	0.02 (0.02,0.03)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.03 (0.01,0.04)	40
Poor (2-3)	0.04 (0.02,0.06)	66
Fair (3-4)	0.03 (0.02,0.04)	103
Good (4-5)	0.03 (0.02,0.03)	99
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-7 Statewide and Physiographic Eco-region Analysis for Total Nitrogen

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	5.44 (4.53,5.92)	182
Poor (2-3)	4.99 (4.63,5.50)	300
Fair (3-4)	4.68 (4.35,4.87)	307
Good (4-5)	4.80 (4.37,5.05)	325
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	5.91 (4.60,6.07)	110
Poor (2-3)	4.61 (4.08,4.98)	172
Fair (3-4)	4.69 (4.38,4.76)	290
Good (4-5)	5.22 (4.83,5.52)	313
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	7.35 (5.93,8.83)	57
Poor (2-3)	4.72 (4.46,4.98)	115
Fair (3-4)	2.96 (2.64,4.23)	110
Good (4-5)	1.68 (1.47,1.80)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	2.96
Very Poor vs. Good	Yes	3.84

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	6.52 (5.57,8.68)	39
Poor (2-3)	4.40 (3.54,4.94)	66
Fair (3-4)	4.43 (4.04,4.69)	92
Good (4-5)	3.01 (2.77,3.76)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	4.42

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	3.26 (2.92,4.45)	80
Poor (2-3)	4.75 (3.88,5.85)	74
Fair (3-4)	5.13 (4.40,5.90)	69
Good (4-5)	5.08 (4.77,5.49)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	5.91 (4.55,6.04)	31
Poor (2-3)	3.54 (2.99,4.90)	40
Fair (3-4)	4.14 (3.99,4.69)	95
Good (4-5)	5.27 (4.84,5.77)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	3.64 (2.45,4.29)	45
Poor (2-3)	6.18 (4.66,7.02)	111
Fair (3-4)	4.80 (4.53,5.51)	128
Good (4-5)	5.31 (4.77,5.89)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1.70 (1.39,1.85)	40
Poor (2-3)	5.38 (3.96,6.28)	66
Fair (3-4)	5.81 (4.71,7.22)	103
Good (4-5)	6.01 (5.28,6.97)	99
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-8 Statewide and Physiographic Eco-region Analysis for Total Dissolved Nitrogen

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	3.97 (2.94,7.40)	39
Poor (2-3)	4.74 (4.29,5.42)	52
Fair (3-4)	4.38 (3.62,4.68)	70
Good (4-5)	4.64 (3.96,5.14)	100
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	5.77 (1.66,6.97)	22
Poor (2-3)	3.58 (2.36,4.85)	28
Fair (3-4)	4.52 (3.84,4.65)	75
Good (4-5)	4.95 (4.29,5.41)	96
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	8.05 (4.02,9.90)	16
Poor (2-3)	3.65 (2.57,4.34)	22
Fair (3-4)	2.74 (1.79,3.44)	29
Good (4-5)	1.17 (0.76,2.12)	28
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	3.20

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	6.97 (1.55,9.12)	11
Poor (2-3)	1.65 (1.26,3.01)	13
Fair (3-4)	4.57 (3.67,6.62)	24
Good (4-5)	2.50 (1.88,2.80)	33
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	2.02 (1.65,3.08)	13
Poor (2-3)	6.02 (4.41,6.28)	17
Fair (3-4)	4.73 (4.38,6.21)	21
Good (4-5)	5.15 (4.35,5.65)	40
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	4.30 (1.50,6.11)	5
Poor (2-3)	4.95 (4.13,5.03)	5
Fair (3-4)	4.02 (3.48,4.73)	28
Good (4-5)	5.82 (5.23,6.25)	40
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1.43 (1.22,2.01)	10
Poor (2-3)	4.73 (3.66,5.29)	13
Fair (3-4)	3.67 (2.03,4.43)	20
Good (4-5)	4.60 (3.41,5.24)	32
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1.26 (0.62,1.70)	6
Poor (2-3)	2.27 (1.29,4.15)	10
Fair (3-4)	4.43 (2.76,4.64)	23
Good (4-5)	4.63 (4.10,5.31)	23
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-9 Statewide and Physiographic Eco-region Analysis for Chlorides

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	148.4 (113.5,158.9)	181
Poor (2-3)	77.3 (73.1,84.4)	300
Fair (3-4)	49.0 (45.3,58.9)	307
Good (4-5)	30.4 (28.1,32.6)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	49.0
Very Poor vs. Good	Yes	63.1

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	99.1 (82.5,122.0)	109
Poor (2-3)	106.6 (85.6,144.2)	172
Fair (3-4)	61.1 (56.5,68.3)	290
Good (4-5)	55.2 (47.2,62.9)	313
Group	Significant	Target Value
Poor vs. Fair	Yes	61.1
Very Poor vs. Good	Yes	83.9

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	90.7 (71.7,113.5)	57
Poor (2-3)	64.0 (54.8,70.9)	115
Fair (3-4)	50.5 (38.5,77.8)	110
Good (4-5)	14.6 (12.7,27.5)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	57.2

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	60.9 (55.5,73.6)	39
Poor (2-3)	126.1 (77.7,174.2)	66
Fair (3-4)	49.1 (46.2,67.6)	92
Good (4-5)	60.2 (45.9,71.7)	102
Group	Significant	Target Value
Poor vs. Fair	Yes	49.1
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	152.4 (141.4,179.2)	80
Poor (2-3)	92.6 (84.3,137.1)	74
Fair (3-4)	48.2 (38.4,68.8)	69
Good (4-5)	33.0 (31.3,39.8)	115
Group	Significant	Target Value
Poor vs. Fair	Yes	48.2
Very Poor vs. Good	Yes	70.4

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	141.3 (119.3,190.4)	31
Poor (2-3)	144.5 (82.5,160.5)	40
Fair (3-4)	75.5 (64.6,86.8)	95
Good (4-5)	55.2 (46.9,67.2)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	110.0

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	143.6 (93.9,262.8)	44
Poor (2-3)	71.0 (65.4,87.2)	111
Fair (3-4)	47.6 (42.2,54.7)	128
Good (4-5)	27.8 (24.8,30.9)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	47.6
Very Poor vs. Good	Yes	59.3

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	68.1 (59.6,76.1)	39
Poor (2-3)	83.0 (53.9,103.1)	66
Fair (3-4)	55.9 (40.7,59.8)	103
Good (4-5)	47.4 (37.0,57.7)	99
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	69.5

Table A-10 Statewide and Physiographic Eco-region Analysis for Conductivity

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.772 (0.748,0.861)	182
Poor (2-3)	0.560 (0.496,0.577)	300
Fair (3-4)	0.311 (0.290,0.349)	307
Good (4-5)	0.220 (0.207,0.240)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	0.311
Very Poor vs. Good	Yes	0.435

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.708 (0.634,0.762)	110
Poor (2-3)	0.656 (0.578,0.731)	172
Fair (3-4)	0.450 (0.411,0.491)	290
Good (4-5)	0.347 (0.317,0.381)	313
Group	Significant	Target Value
Poor vs. Fair	Yes	0.450
Very Poor vs. Good	Yes	0.553

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.773 (0.735,0.805)	57
Poor (2-3)	0.595 (0.513,0.645)	115
Fair (3-4)	0.406 (0.300,0.519)	110
Good (4-5)	0.183 (0.149,0.220)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	0.501

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.751 (0.627,0.778)	39
Poor (2-3)	0.770 (0.648,0.795)	66
Fair (3-4)	0.566 (0.481,0.606)	92
Good (4-5)	0.402 (0.340,0.504)	102
Group	Significant	Target Value
Poor vs. Fair	Yes	0.566
Very Poor vs. Good	Yes	0.668

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.758 (0.703,0.894)	80
Poor (2-3)	0.623 (0.506,0.723)	74
Fair (3-4)	0.314 (0.293,0.369)	69
Good (4-5)	0.238 (0.216,0.266)	115
Group	Significant	Target Value
Poor vs. Fair	Yes	0.314
Very Poor vs. Good	Yes	0.469

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.708 (0.690,0.938)	31
Poor (2-3)	0.711 (0.523,0.795)	40
Fair (3-4)	0.477 (0.398,0.504)	95
Good (4-5)	0.342 (0.308,0.385)	112
Group	Significant	Target Value
Poor vs. Fair	Yes	0.477
Very Poor vs. Good	Yes	0.594

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.853 (0.616,1.390)	45
Poor (2-3)	0.415 (0.375,0.495)	111
Fair (3-4)	0.271 (0.260,0.308)	128
Good (4-5)	0.209 (0.192,0.243)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	0.271
Very Poor vs. Good	Yes	0.343

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0.408 (0.366,0.693)	40
Poor (2-3)	0.511 (0.350,0.571)	66
Fair (3-4)	0.314 (0.270,0.363)	103
Good (4-5)	0.270 (0.247,0.350)	99
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	0.412

Table A-11 Statewide and Physiographic Eco-region Analysis for Sulfate

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	39.0 (35.6,42.0)	182
Poor (2-3)	33.8 (31.3,36.7)	300
Fair (3-4)	25.1 (24.3,26.1)	307
Good (4-5)	17.6 (17.1,19.1)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	25.1
Very Poor vs. Good	Yes	29.5

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	44.4 (37.4,48.8)	110
Poor (2-3)	35.8 (31.5,43.9)	172
Fair (3-4)	24.5 (23.4,25.9)	290
Good (4-5)	20.5 (19.0,23.2)	313
Group	Significant	Target Value
Poor vs. Fair	Yes	24.5
Very Poor vs. Good	Yes	30.1

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	72.1 (40.4,208.8)	57
Poor (2-3)	36.8 (29.4,57.1)	115
Fair (3-4)	25.2 (23.5,28.4)	110
Good (4-5)	21.2 (17.0,31.3)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	25.2
Very Poor vs. Good	Yes	31.0

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	83.4 (45.9,108.6)	39
Poor (2-3)	59.9 (44.9,90.9)	66
Fair (3-4)	26.6 (24.5,30.4)	92
Good (4-5)	24.1 (20.0,25.8)	102
Group	Significant	Target Value
Poor vs. Fair	Yes	26.6
Very Poor vs. Good	Yes	43.3

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	33.5 (28.0,34.6)	80
Poor (2-3)	23.5 (19.9,27.0)	74
Fair (3-4)	13.7 (13.1,24.3)	69
Good (4-5)	11.9 (11.1,15.5)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	18.6

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	35.0 (33.5,42.0)	31
Poor (2-3)	25.4 (21.3,29.9)	40
Fair (3-4)	19.4 (15.2,22.0)	95
Good (4-5)	14.0 (13.7,17.1)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	22.4

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	39.0 (34.5,48.2)	45
Poor (2-3)	37.1 (33.4,48.3)	111
Fair (3-4)	26.2 (24.8,27.3)	128
Good (4-5)	18.9 (17.5,22.8)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	26.2
Very Poor vs. Good	Yes	31.7

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	37.9 (29.9,47.5)	40
Poor (2-3)	32.9 (27.4,35.1)	66
Fair (3-4)	24.6 (22.3,27.3)	103
Good (4-5)	23.6 (20.8,26.0)	99
Group	Significant	Target Value
Poor vs. Fair	Yes	24.6
Very Poor vs. Good	Yes	28.8

Table A-12 Statewide and Physiographic Eco-region Analysis for Impervious Surface Land Use in Watershed

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	21% (20%,23%)	181
Poor (2-3)	14% (12%,17%)	300
Fair (3-4)	4% (4%,6%)	303
Good (4-5)	3% (2%,3%)	324
Group	Significant	Target Value
Poor vs. Fair	Yes	4%
Very Poor vs. Good	Yes	9%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	20% (18%,21%)	110
Poor (2-3)	18% (15%,21%)	173
Fair (3-4)	8% (6%,11%)	287
Good (4-5)	6% (4%,6%)	318
Group	Significant	Target Value
Poor vs. Fair	Yes	8%
Very Poor vs. Good	Yes	13%

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	5% (4%,6%)	57
Poor (2-3)	4% (3%,6%)	115
Fair (3-4)	1% (1%,2%)	107
Good (4-5)	0% (0%,0%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	1%
Very Poor vs. Good	Yes	3%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	4% (3%,6%)	39
Poor (2-3)	4% (3%,5%)	66
Fair (3-4)	2% (1%,3%)	90
Good (4-5)	2% (1%,3%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	23% (21%,24%)	80
Poor (2-3)	18% (15%,20%)	74
Fair (3-4)	4% (3%,5%)	69
Good (4-5)	1% (1%,2%)	114
Group	Significant	Target Value
Poor vs. Fair	Yes	4%
Very Poor vs. Good	Yes	11%

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	24% (20%,26%)	31
Poor (2-3)	27% (19%,29%)	40
Fair (3-4)	11% (9%,13%)	94
Good (4-5)	5% (4%,6%)	112
Group	Significant	Target Value
Poor vs. Fair	Yes	11%
Very Poor vs. Good	Yes	19%

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	23% (20%,24%)	44
Poor (2-3)	21% (15%,23%)	111
Fair (3-4)	8% (6%,10%)	127
Good (4-5)	4% (3%,6%)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	8%
Very Poor vs. Good	Yes	14%

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	20% (15%,21%)	40
Poor (2-3)	20% (15%,25%)	67
Fair (3-4)	13% (7%,14%)	103
Good (4-5)	9% (7%,13%)	104
Group	Significant	Target Value
Poor vs. Fair	Yes	13%
Very Poor vs. Good	Yes	17%

Table A-13 Statewide and Physiographic Eco-region Analysis for High Intensity Urban Land Use in Watershed

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	27% (25%,32%)	182
Poor (2-3)	21% (20%,24%)	300
Fair (3-4)	9% (8%,10%)	306
Good (4-5)	6% (6%,6%)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	9%
Very Poor vs. Good	Yes	15%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	27% (23%,34%)	110
Poor (2-3)	23% (20%,25%)	173
Fair (3-4)	15% (12%,16%)	291
Good (4-5)	11% (9%,13%)	318
Group	Significant	Target Value
Poor vs. Fair	Yes	15%
Very Poor vs. Good	Yes	19%

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	12% (10%,14%)	57
Poor (2-3)	11% (9%,13%)	115
Fair (3-4)	6% (5%,6%)	110
Good (4-5)	3% (2%,4%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	6%
Very Poor vs. Good	Yes	9%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	10% (9%,11%)	39
Poor (2-3)	9% (8%,12%)	66
Fair (3-4)	8% (7%,9%)	92
Good (4-5)	7% (6%,9%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	33% (27%,36%)	80
Poor (2-3)	27% (23%,29%)	74
Fair (3-4)	10% (9%,12%)	69
Good (4-5)	7% (6%,8%)	115
Group	Significant	Target Value
Poor vs. Fair	Yes	10%
Very Poor vs. Good	Yes	18%

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	46% (27%,48%)	31
Poor (2-3)	30% (25%,36%)	40
Fair (3-4)	18% (15%,19%)	95
Good (4-5)	12% (10%,14%)	112
Group	Significant	Target Value
Poor vs. Fair	Yes	18%
Very Poor vs. Good	Yes	24%

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	32% (25%,34%)	45
Poor (2-3)	27% (21%,33%)	111
Fair (3-4)	11% (8%,13%)	127
Good (4-5)	7% (6%,8%)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	11%
Very Poor vs. Good	Yes	19%

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	31% (20%,35%)	40
Poor (2-3)	25% (20%,33%)	67
Fair (3-4)	15% (12%,19%)	104
Good (4-5)	14% (10%,17%)	104
Group	Significant	Target Value
Poor vs. Fair	Yes	15%
Very Poor vs. Good	Yes	20%

Table A-14 Statewide and Physiographic Eco-region Analysis for High Intensity Urban Land Use in 60 m Buffer

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	23% (19%,28%)	180
Poor (2-3)	13% (12%,15%)	299
Fair (3-4)	6% (6%,7%)	303
Good (4-5)	4% (4%,5%)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	6%
Very Poor vs. Good	Yes	10%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	18% (16%,21%)	109
Poor (2-3)	13% (12%,19%)	173
Fair (3-4)	8% (7%,9%)	291
Good (4-5)	7% (6%,7%)	318
Group	Significant	Target Value
Poor vs. Fair	Yes	8%
Very Poor vs. Good	Yes	11%

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	19% (15%,26%)	56
Poor (2-3)	8% (8%,9%)	115
Fair (3-4)	6% (5%,7%)	110
Good (4-5)	5% (4%,5%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	6%
Very Poor vs. Good	Yes	7%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	14% (7%,15%)	39
Poor (2-3)	12% (8%,16%)	66
Fair (3-4)	6% (5%,7%)	92
Good (4-5)	7% (6%,8%)	102
Group	Significant	Target Value
Poor vs. Fair	Yes	6%
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	25% (19%,33%)	80
Poor (2-3)	18% (14%,27%)	74
Fair (3-4)	6% (4%,7%)	68
Good (4-5)	4% (4%,5%)	115
Group	Significant	Target Value
Poor vs. Fair	Yes	6%
Very Poor vs. Good	Yes	12%

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	40% (19%,50%)	31
Poor (2-3)	19% (13%,24%)	40
Fair (3-4)	12% (9%,14%)	95
Good (4-5)	6% (5%,7%)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	15%

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	25% (20%,31%)	44
Poor (2-3)	13% (10%,16%)	110
Fair (3-4)	7% (5%,9%)	125
Good (4-5)	3% (3%,5%)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	7%
Very Poor vs. Good	Yes	10%

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	13% (6%,21%)	39
Poor (2-3)	13% (12%,21%)	67
Fair (3-4)	6% (4%,9%)	104
Good (4-5)	7% (6%,9%)	104
Group	Significant	Target Value
Poor vs. Fair	Yes	6%
Very Poor vs. Good	No	NA

Table A-15 Statewide and Physiographic Eco-region Analysis for Low Intensity Urban Land Use in Watershed

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	74% (71%,76%)	182
Poor (2-3)	60% (59%,62%)	300
Fair (3-4)	44% (40%,49%)	306
Good (4-5)	32% (28%,35%)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	44%
Very Poor vs. Good	Yes	52%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	71% (67%,74%)	110
Poor (2-3)	64% (61%,72%)	173
Fair (3-4)	53% (50%,57%)	291
Good (4-5)	42% (39%,48%)	318
Group	Significant	Target Value
Poor vs. Fair	Yes	53%
Very Poor vs. Good	Yes	58%

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	42% (33%,56%)	57
Poor (2-3)	35% (30%,52%)	115
Fair (3-4)	19% (17%,28%)	110
Good (4-5)	13% (10%,18%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	19%
Very Poor vs. Good	Yes	27%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	25% (19%,28%)	39
Poor (2-3)	31% (27%,44%)	66
Fair (3-4)	33% (28%,41%)	92
Good (4-5)	25% (20%,30%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	79% (74%,82%)	80
Poor (2-3)	74% (67%,76%)	74
Fair (3-4)	52% (48%,58%)	69
Good (4-5)	35% (33%,40%)	115
Group	Significant	Target Value
Poor vs. Fair	Yes	52%
Very Poor vs. Good	Yes	63%

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	82% (73%,85%)	31
Poor (2-3)	74% (73%,81%)	40
Fair (3-4)	61% (58%,63%)	95
Good (4-5)	46% (40%,51%)	112
Group	Significant	Target Value
Poor vs. Fair	Yes	61%
Very Poor vs. Good	Yes	68%

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	68% (63%,73%)	45
Poor (2-3)	60% (53%,62%)	111
Fair (3-4)	50% (43%,57%)	127
Good (4-5)	33% (28%,35%)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	55%

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	67% (63%,74%)	40
Poor (2-3)	59% (50%,63%)	67
Fair (3-4)	52% (46%,59%)	104
Good (4-5)	47% (38%,51%)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	56%

Table A-16 Statewide and Physiographic Eco-region Analysis for Low Intensity Urban Land Use in 60 m Buffer

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	71% (68%,74%)	180
Poor (2-3)	63% (56%,66%)	299
Fair (3-4)	29% (26%,33%)	303
Good (4-5)	22% (19%,24%)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	29%
Very Poor vs. Good	Yes	46%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	68% (62%,71%)	109
Poor (2-3)	70% (64%,73%)	173
Fair (3-4)	40% (38%,42%)	291
Good (4-5)	29% (26%,33%)	318
Group	Significant	Target Value
Poor vs. Fair	Yes	40%
Very Poor vs. Good	Yes	55%

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	41% (36%,45%)	56
Poor (2-3)	41% (36%,45%)	115
Fair (3-4)	21% (17%,24%)	110
Good (4-5)	13% (11%,16%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	21%
Very Poor vs. Good	Yes	31%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	23% (18%,27%)	39
Poor (2-3)	41% (30%,58%)	66
Fair (3-4)	33% (25%,39%)	92
Good (4-5)	21% (18%,28%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	78% (72%,79%)	80
Poor (2-3)	80% (67%,87%)	74
Fair (3-4)	35% (28%,40%)	68
Good (4-5)	27% (23%,35%)	115
Group	Significant	Target Value
Poor vs. Fair	Yes	35%
Very Poor vs. Good	Yes	58%

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	79% (70%,79%)	31
Poor (2-3)	78% (71%,84%)	40
Fair (3-4)	48% (40%,55%)	95
Good (4-5)	30% (26%,37%)	112
Group	Significant	Target Value
Poor vs. Fair	Yes	48%
Very Poor vs. Good	Yes	63%

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	66% (60%,71%)	44
Poor (2-3)	65% (51%,68%)	110
Fair (3-4)	38% (28%,42%)	125
Good (4-5)	22% (18%,27%)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	38%
Very Poor vs. Good	Yes	51%

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	65% (57%,71%)	39
Poor (2-3)	67% (45%,79%)	67
Fair (3-4)	38% (31%,40%)	104
Good (4-5)	30% (26%,40%)	104
Group	Significant	Target Value
Poor vs. Fair	Yes	38%
Very Poor vs. Good	Yes	53%

Table A-17 Statewide and Physiographic Eco-region Analysis for Transportation Land Use in Watershed

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	10% (9%,11%)	182
Poor (2-3)	9% (8%,9%)	300
Fair (3-4)	6% (5%,6%)	306
Good (4-5)	5% (4%,5%)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	6%
Very Poor vs. Good	Yes	7%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	9% (8%,10%)	110
Poor (2-3)	9% (8%,10%)	173
Fair (3-4)	7% (6%,7%)	291
Good (4-5)	6% (6%,6%)	318
Group	Significant	Target Value
Poor vs. Fair	Yes	7%
Very Poor vs. Good	Yes	8%

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	9% (8%,10%)	57
Poor (2-3)	7% (5%,7%)	115
Fair (3-4)	4% (4%,5%)	110
Good (4-5)	3% (2%,3%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	4%
Very Poor vs. Good	Yes	6%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	8% (6%,9%)	39
Poor (2-3)	8% (6%,10%)	66
Fair (3-4)	5% (4%,5%)	92
Good (4-5)	5% (5%,6%)	102
Group	Significant	Target Value
Poor vs. Fair	Yes	5%
Very Poor vs. Good	Yes	6%

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	11% (10%,12%)	80
Poor (2-3)	12% (9%,13%)	74
Fair (3-4)	7% (6%,8%)	69
Good (4-5)	6% (5%,7%)	115
Group	Significant	Target Value
Poor vs. Fair	Yes	7%
Very Poor vs. Good	Yes	9%

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	9% (8%,10%)	31
Poor (2-3)	11% (9%,12%)	40
Fair (3-4)	7% (7%,8%)	95
Good (4-5)	6% (6%,7%)	112
Group	Significant	Target Value
Poor vs. Fair	Yes	7%
Very Poor vs. Good	Yes	9%

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	9% (8%,10%)	45
Poor (2-3)	9% (8%,10%)	111
Fair (3-4)	6% (6%,7%)	127
Good (4-5)	4% (4%,5%)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	6%
Very Poor vs. Good	Yes	8%

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	9% (6%,10%)	40
Poor (2-3)	7% (6%,9%)	67
Fair (3-4)	6% (5%,8%)	104
Good (4-5)	6% (5%,6%)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-18 Statewide and Physiographic Eco-region Analysis for Transportation Land Use in 60 m Buffer

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	13% (10%,16%)	180
Poor (2-3)	8% (6%,8%)	299
Fair (3-4)	4% (4%,5%)	303
Good (4-5)	4% (3%,4%)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	4%
Very Poor vs. Good	Yes	6%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	10% (7%,12%)	109
Poor (2-3)	9% (8%,12%)	173
Fair (3-4)	5% (4%,6%)	291
Good (4-5)	5% (4%,5%)	318
Group	Significant	Target Value
Poor vs. Fair	Yes	5%
Very Poor vs. Good	Yes	7%

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	18% (10%,21%)	56
Poor (2-3)	6% (6%,8%)	115
Fair (3-4)	6% (4%,7%)	110
Good (4-5)	4% (4%,5%)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	6%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	10% (7%,11%)	39
Poor (2-3)	9% (8%,15%)	66
Fair (3-4)	5% (4%,6%)	92
Good (4-5)	6% (5%,6%)	102
Group	Significant	Target Value
Poor vs. Fair	Yes	5%
Very Poor vs. Good	Yes	7%

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	11% (9%,14%)	80
Poor (2-3)	12% (8%,14%)	74
Fair (3-4)	5% (3%,5%)	68
Good (4-5)	4% (3%,5%)	115
Group	Significant	Target Value
Poor vs. Fair	Yes	5%
Very Poor vs. Good	Yes	8%

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	11% (7%,14%)	31
Poor (2-3)	10% (6%,12%)	40
Fair (3-4)	6% (5%,9%)	95
Good (4-5)	4% (4%,5%)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	8%

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	10% (4%,15%)	44
Poor (2-3)	6% (5%,7%)	110
Fair (3-4)	3% (3%,5%)	125
Good (4-5)	3% (2%,3%)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	3%
Very Poor vs. Good	Yes	5%

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	5% (3%,13%)	39
Poor (2-3)	7% (5%,13%)	67
Fair (3-4)	3% (2%,3%)	104
Good (4-5)	4% (3%,4%)	104
Group	Significant	Target Value
Poor vs. Fair	Yes	3%
Very Poor vs. Good	No	NA

Table A-19 Statewide and Physiographic Eco-region Analysis for Agricultural Land Use in Watershed

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	63% (53%,66%)	182
Poor (2-3)	64% (60%,65%)	300
Fair (3-4)	63% (61%,65%)	306
Good (4-5)	59% (56%,60%)	325
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	61% (45%,65%)	110
Poor (2-3)	59% (52%,60%)	173
Fair (3-4)	62% (59%,64%)	291
Good (4-5)	61% (59%,62%)	318
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	71% (67%,76%)	57
Poor (2-3)	60% (58%,64%)	115
Fair (3-4)	54% (49%,60%)	110
Good (4-5)	25% (22%,33%)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	57%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	67% (63%,71%)	39
Poor (2-3)	52% (45%,59%)	66
Fair (3-4)	57% (51%,60%)	92
Good (4-5)	54% (45%,58%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	55%

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	35% (27%,39%)	80
Poor (2-3)	54% (49%,56%)	74
Fair (3-4)	63% (60%,65%)	69
Good (4-5)	62% (61%,64%)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	29% (7%,41%)	31
Poor (2-3)	37% (31%,52%)	40
Fair (3-4)	60% (55%,62%)	95
Good (4-5)	62% (59%,62%)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	51% (39%,57%)	45
Poor (2-3)	71% (64%,73%)	111
Fair (3-4)	68% (63%,72%)	127
Good (4-5)	58% (55%,61%)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	49% (28%,62%)	40
Poor (2-3)	63% (58%,73%)	67
Fair (3-4)	67% (64%,71%)	104
Good (4-5)	63% (60%,71%)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-20 Statewide and Physiographic Eco-region Analysis for Agricultural Land Use in 60 m Buffer

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	54% (49%,68%)	180
Poor (2-3)	56% (52%,60%)	299
Fair (3-4)	46% (44%,51%)	303
Good (4-5)	40% (36%,42%)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	46%
Very Poor vs. Good	Yes	51%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	53% (37%,58%)	109
Poor (2-3)	50% (45%,54%)	173
Fair (3-4)	43% (42%,47%)	291
Good (4-5)	45% (42%,46%)	318
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	76% (69%,77%)	56
Poor (2-3)	59% (51%,64%)	115
Fair (3-4)	45% (41%,51%)	110
Good (4-5)	17% (12%,22%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	45%
Very Poor vs. Good	Yes	52%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	68% (56%,73%)	39
Poor (2-3)	48% (38%,54%)	66
Fair (3-4)	54% (42%,60%)	92
Good (4-5)	45% (37%,49%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	51%

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	27% (18%,36%)	80
Poor (2-3)	38% (35%,49%)	74
Fair (3-4)	47% (43%,51%)	68
Good (4-5)	47% (42%,49%)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	16% (4%,26%)	31
Poor (2-3)	30% (28%,36%)	40
Fair (3-4)	41% (37%,47%)	95
Good (4-5)	45% (42%,47%)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	44% (36%,49%)	44
Poor (2-3)	62% (53%,66%)	110
Fair (3-4)	46% (40%,52%)	125
Good (4-5)	33% (29%,39%)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	46%
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	37% (20%,53%)	39
Poor (2-3)	61% (50%,65%)	67
Fair (3-4)	42% (37%,45%)	104
Good (4-5)	41% (36%,46%)	104
Group	Significant	Target Value
Poor vs. Fair	Yes	42%
Very Poor vs. Good	No	NA

Table A-21 Statewide and Physiographic Eco-region Analysis for Cropland Land Use in Watershed

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	30% (22%,37%)	182
Poor (2-3)	32% (28%,40%)	300
Fair (3-4)	35% (31%,41%)	306
Good (4-5)	27% (24%,30%)	325
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	27% (19%,39%)	110
Poor (2-3)	32% (25%,42%)	173
Fair (3-4)	29% (27%,31%)	291
Good (4-5)	33% (29%,36%)	318
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	41% (36%,49%)	57
Poor (2-3)	26% (25%,31%)	115
Fair (3-4)	23% (18%,29%)	110
Good (4-5)	18% (16%,20%)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	25%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	39% (32%,46%)	39
Poor (2-3)	30% (23%,38%)	66
Fair (3-4)	26% (22%,28%)	92
Good (4-5)	19% (17%,22%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	28%

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	8% (6%,9%)	80
Poor (2-3)	14% (12%,21%)	74
Fair (3-4)	16% (14%,22%)	69
Good (4-5)	22% (21%,24%)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	8% (1%,19%)	31
Poor (2-3)	6% (5%,10%)	40
Fair (3-4)	20% (15%,22%)	95
Good (4-5)	21% (17%,22%)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	35% (19%,43%)	45
Poor (2-3)	51% (45%,55%)	111
Fair (3-4)	52% (49%,56%)	127
Good (4-5)	37% (34%,40%)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	12% (5%,42%)	40
Poor (2-3)	46% (35%,54%)	67
Fair (3-4)	51% (49%,55%)	104
Good (4-5)	50% (40%,52%)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-22 Statewide and Physiographic Eco-region Analysis for Cropland Land Use in 60 m Buffer

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	25% (19%,30%)	180
Poor (2-3)	24% (20%,26%)	299
Fair (3-4)	24% (21%,27%)	303
Good (4-5)	14% (12%,17%)	325
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	24%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	25% (15%,32%)	109
Poor (2-3)	25% (21%,30%)	173
Fair (3-4)	20% (18%,23%)	291
Good (4-5)	18% (15%,21%)	318
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	43% (30%,49%)	56
Poor (2-3)	17% (15%,25%)	115
Fair (3-4)	19% (16%,22%)	110
Good (4-5)	10% (8%,14%)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	18%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	41% (27%,46%)	39
Poor (2-3)	28% (20%,35%)	66
Fair (3-4)	17% (15%,21%)	92
Good (4-5)	14% (11%,16%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	22%

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	2% (2%,3%)	80
Poor (2-3)	8% (6%,10%)	74
Fair (3-4)	10% (9%,11%)	68
Good (4-5)	11% (9%,12%)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (0%,2%)	31
Poor (2-3)	3% (3%,6%)	40
Fair (3-4)	10% (8%,11%)	95
Good (4-5)	11% (10%,12%)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	30% (5%,40%)	44
Poor (2-3)	31% (27%,36%)	110
Fair (3-4)	30% (27%,33%)	125
Good (4-5)	22% (15%,24%)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	17% (3%,27%)	39
Poor (2-3)	29% (25%,46%)	67
Fair (3-4)	28% (23%,31%)	104
Good (4-5)	26% (23%,30%)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-23 Statewide and Physiographic Eco-region Analysis for Pasture/Hay Land Use in Watershed

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	34% (32%,38%)	182
Poor (2-3)	38% (37%,41%)	300
Fair (3-4)	39% (36%,43%)	306
Good (4-5)	38% (35%,39%)	325
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	26% (20%,36%)	110
Poor (2-3)	33% (30%,38%)	173
Fair (3-4)	37% (33%,38%)	291
Good (4-5)	40% (38%,44%)	318
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	51% (39%,59%)	57
Poor (2-3)	45% (39%,54%)	115
Fair (3-4)	34% (30%,39%)	110
Good (4-5)	7% (5%,10%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	34%
Very Poor vs. Good	Yes	40%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	32% (20%,52%)	39
Poor (2-3)	32% (27%,38%)	66
Fair (3-4)	37% (33%,50%)	92
Good (4-5)	43% (32%,47%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	33% (20%,35%)	80
Poor (2-3)	40% (35%,42%)	74
Fair (3-4)	50% (49%,52%)	69
Good (4-5)	47% (45%,50%)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	17% (6%,29%)	31
Poor (2-3)	33% (30%,47%)	40
Fair (3-4)	44% (38%,48%)	95
Good (4-5)	47% (43%,49%)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	22% (17%,23%)	45
Poor (2-3)	32% (29%,36%)	111
Fair (3-4)	33% (24%,38%)	127
Good (4-5)	28% (26%,31%)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	27% (14%,36%)	40
Poor (2-3)	32% (25%,39%)	67
Fair (3-4)	28% (26%,29%)	104
Good (4-5)	25% (24%,28%)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-24 Statewide and Physiographic Eco-region Analysis for Pasture/Hay Land Use in 60 m Buffer

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	39% (31%,43%)	180
Poor (2-3)	36% (32%,45%)	299
Fair (3-4)	31% (29%,35%)	303
Good (4-5)	27% (26%,30%)	325
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	33%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	21% (17%,27%)	109
Poor (2-3)	27% (25%,32%)	173
Fair (3-4)	31% (29%,35%)	291
Good (4-5)	32% (30%,35%)	318
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	54% (43%,63%)	56
Poor (2-3)	46% (39%,51%)	115
Fair (3-4)	31% (25%,36%)	110
Good (4-5)	6% (3%,9%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	31%
Very Poor vs. Good	Yes	38%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	33% (19%,45%)	39
Poor (2-3)	27% (20%,34%)	66
Fair (3-4)	40% (31%,49%)	92
Good (4-5)	35% (25%,37%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	25% (17%,32%)	80
Poor (2-3)	31% (27%,36%)	74
Fair (3-4)	40% (37%,41%)	68
Good (4-5)	38% (35%,41%)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	16% (4%,24%)	31
Poor (2-3)	28% (25%,34%)	40
Fair (3-4)	33% (28%,37%)	95
Good (4-5)	38% (35%,40%)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	24% (14%,29%)	44
Poor (2-3)	32% (30%,35%)	110
Fair (3-4)	21% (16%,24%)	125
Good (4-5)	17% (15%,19%)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	21%
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	18% (9%,26%)	39
Poor (2-3)	27% (17%,32%)	67
Fair (3-4)	20% (15%,26%)	104
Good (4-5)	19% (16%,20%)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-25 Statewide and Physiographic Eco-region Analysis for Barren Land Land Use in Watershed

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (1%,2%)	182
Poor (2-3)	1% (1%,1%)	300
Fair (3-4)	1% (1%,1%)	306
Good (4-5)	1% (1%,2%)	325
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (1%,1%)	110
Poor (2-3)	1% (1%,2%)	173
Fair (3-4)	1% (1%,1%)	291
Good (4-5)	1% (1%,1%)	318
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	2% (1%,2%)	57
Poor (2-3)	1% (1%,1%)	115
Fair (3-4)	1% (1%,1%)	110
Good (4-5)	0% (0%,1%)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	1%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (1%,2%)	39
Poor (2-3)	1% (0%,1%)	66
Fair (3-4)	1% (1%,1%)	92
Good (4-5)	1% (1%,1%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	1%

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (1%,1%)	80
Poor (2-3)	1% (1%,1%)	74
Fair (3-4)	1% (1%,2%)	69
Good (4-5)	1% (1%,2%)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0% (0%,0%)	31
Poor (2-3)	2% (1%,3%)	40
Fair (3-4)	1% (1%,2%)	95
Good (4-5)	1% (1%,1%)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (1%,1%)	45
Poor (2-3)	1% (1%,1%)	111
Fair (3-4)	1% (1%,1%)	127
Good (4-5)	2% (2%,2%)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (1%,2%)	40
Poor (2-3)	2% (1%,3%)	67
Fair (3-4)	1% (1%,2%)	104
Good (4-5)	1% (1%,2%)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-26 Statewide and Physiographic Eco-region Analysis for Barren Land Land Use in 60 m Buffer

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (0%,1%)	180
Poor (2-3)	1% (1%,1%)	299
Fair (3-4)	1% (1%,1%)	303
Good (4-5)	1% (1%,1%)	325
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (0%,1%)	109
Poor (2-3)	1% (0%,1%)	173
Fair (3-4)	1% (1%,1%)	291
Good (4-5)	1% (1%,1%)	318
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (1%,2%)	56
Poor (2-3)	1% (1%,1%)	115
Fair (3-4)	1% (1%,1%)	110
Good (4-5)	0% (0%,0%)	86
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	1%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (0%,2%)	39
Poor (2-3)	0% (0%,1%)	66
Fair (3-4)	1% (1%,1%)	92
Good (4-5)	1% (1%,1%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (0%,1%)	80
Poor (2-3)	0% (0%,1%)	74
Fair (3-4)	1% (0%,1%)	68
Good (4-5)	1% (1%,2%)	115
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	0% (0%,0%)	31
Poor (2-3)	1% (0%,2%)	40
Fair (3-4)	1% (0%,1%)	95
Good (4-5)	1% (0%,1%)	112
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (0%,1%)	44
Poor (2-3)	1% (0%,1%)	110
Fair (3-4)	1% (1%,1%)	125
Good (4-5)	1% (1%,1%)	124
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (0%,1%)	39
Poor (2-3)	1% (1%,2%)	67
Fair (3-4)	1% (1%,1%)	104
Good (4-5)	1% (1%,1%)	104
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Table A-27 Statewide and Physiographic Eco-region Analysis for Forest Land Use in Watershed

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	4% (2%,5%)	182
Poor (2-3)	9% (8%,11%)	300
Fair (3-4)	17% (15%,19%)	306
Good (4-5)	24% (23%,24%)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	17%
Very Poor vs. Good	Yes	13%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	4% (2%,6%)	110
Poor (2-3)	6% (4%,9%)	173
Fair (3-4)	15% (13%,17%)	291
Good (4-5)	20% (18%,21%)	318
Group	Significant	Target Value
Poor vs. Fair	Yes	11%
Very Poor vs. Good	Yes	10%

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	8% (6%,11%)	57
Poor (2-3)	13% (13%,17%)	115
Fair (3-4)	28% (25%,35%)	110
Good (4-5)	56% (50%,65%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	28%
Very Poor vs. Good	Yes	21%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	13% (9%,19%)	39
Poor (2-3)	14% (7%,21%)	66
Fair (3-4)	17% (13%,19%)	92
Good (4-5)	22% (18%,26%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	No	NA

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	2% (1%,4%)	80
Poor (2-3)	4% (2%,8%)	74
Fair (3-4)	14% (14%,16%)	69
Good (4-5)	22% (17%,22%)	115
Group	Significant	Target Value
Poor vs. Fair	Yes	14%
Very Poor vs. Good	Yes	9%

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (0%,2%)	31
Poor (2-3)	2% (2%,4%)	40
Fair (3-4)	14% (12%,16%)	95
Good (4-5)	20% (15%,21%)	112
Group	Significant	Target Value
Poor vs. Fair	Yes	8%
Very Poor vs. Good	Yes	8%

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	4% (2%,11%)	45
Poor (2-3)	8% (7%,12%)	111
Fair (3-4)	18% (14%,20%)	127
Good (4-5)	24% (22%,27%)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	18%
Very Poor vs. Good	Yes	13%

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	8% (5%,16%)	40
Poor (2-3)	6% (2%,13%)	67
Fair (3-4)	17% (15%,19%)	104
Good (4-5)	20% (18%,22%)	104
Group	Significant	Target Value
Poor vs. Fair	Yes	14%
Very Poor vs. Good	Yes	11%

Table A-28 Statewide and Physiographic Eco-region Analysis for Forest Land Use in 60 m Buffer

Statewide Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	3% (2%,6%)	180
Poor (2-3)	10% (7%,16%)	299
Fair (3-4)	34% (30%,36%)	303
Good (4-5)	45% (41%,47%)	325
Group	Significant	Target Value
Poor vs. Fair	Yes	34%
Very Poor vs. Good	Yes	22%

Statewide Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	5% (3%,12%)	109
Poor (2-3)	6% (2%,12%)	173
Fair (3-4)	27% (24%,30%)	291
Good (4-5)	36% (34%,39%)	318
Group	Significant	Target Value
Poor vs. Fair	Yes	18%
Very Poor vs. Good	Yes	17%

Highland Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	9% (3%,12%)	56
Poor (2-3)	20% (19%,22%)	115
Fair (3-4)	37% (33%,42%)	110
Good (4-5)	64% (60%,70%)	86
Group	Significant	Target Value
Poor vs. Fair	Yes	37%
Very Poor vs. Good	Yes	28%

Highland Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	19% (12%,24%)	39
Poor (2-3)	15% (12%,20%)	66
Fair (3-4)	22% (15%,27%)	92
Good (4-5)	37% (35%,41%)	102
Group	Significant	Target Value
Poor vs. Fair	No	NA
Very Poor vs. Good	Yes	19%

Eastern Piedmont Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	2% (1%,4%)	80
Poor (2-3)	3% (0%,9%)	74
Fair (3-4)	36% (33%,40%)	68
Good (4-5)	38% (34%,44%)	115
Group	Significant	Target Value
Poor vs. Fair	Yes	36%
Very Poor vs. Good	Yes	19%

Eastern Piedmont Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	1% (0%,3%)	31
Poor (2-3)	3% (2%,9%)	40
Fair (3-4)	26% (23%,31%)	95
Good (4-5)	37% (33%,43%)	112
Group	Significant	Target Value
Poor vs. Fair	Yes	16%
Very Poor vs. Good	Yes	14%

Coastal Plain Benthic		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	3% (0%,9%)	44
Poor (2-3)	8% (5%,16%)	110
Fair (3-4)	30% (25%,34%)	125
Good (4-5)	45% (41%,53%)	124
Group	Significant	Target Value
Poor vs. Fair	Yes	30%
Very Poor vs. Good	Yes	19%

Coastal Plain Fish		
Biological Condition	90th Percentile (80% CI)	Number of Sites
Very Poor (1-2)	12% (7%,27%)	39
Poor (2-3)	3% (2%,16%)	67
Fair (3-4)	33% (31%,40%)	104
Good (4-5)	36% (31%,42%)	104
Group	Significant	Target Value
Poor vs. Fair	Yes	23%
Very Poor vs. Good	Yes	18%

Appendix B: General Causal Scenario Models

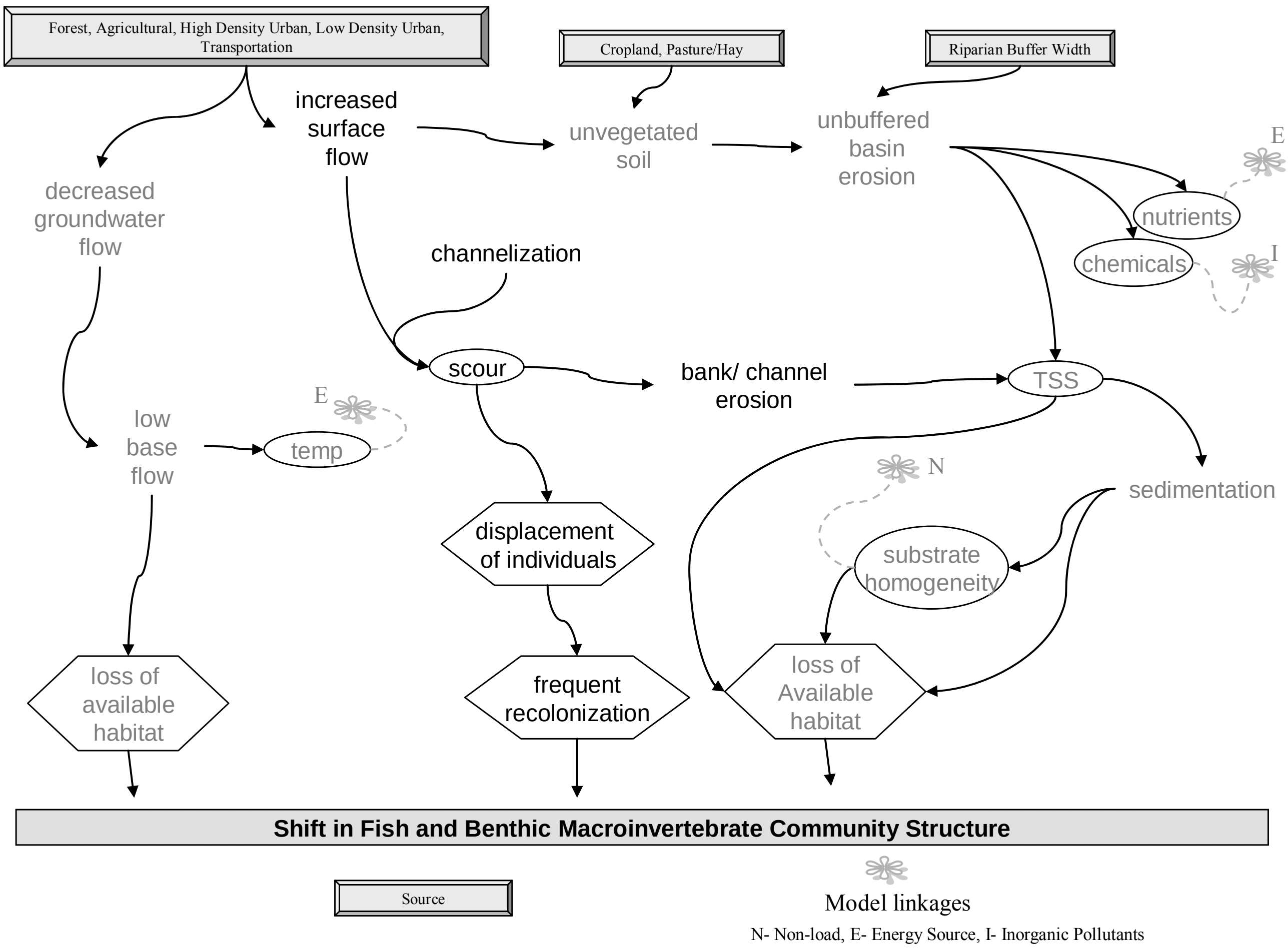

Figure B-1 Flow/Sediment Causal Scenario

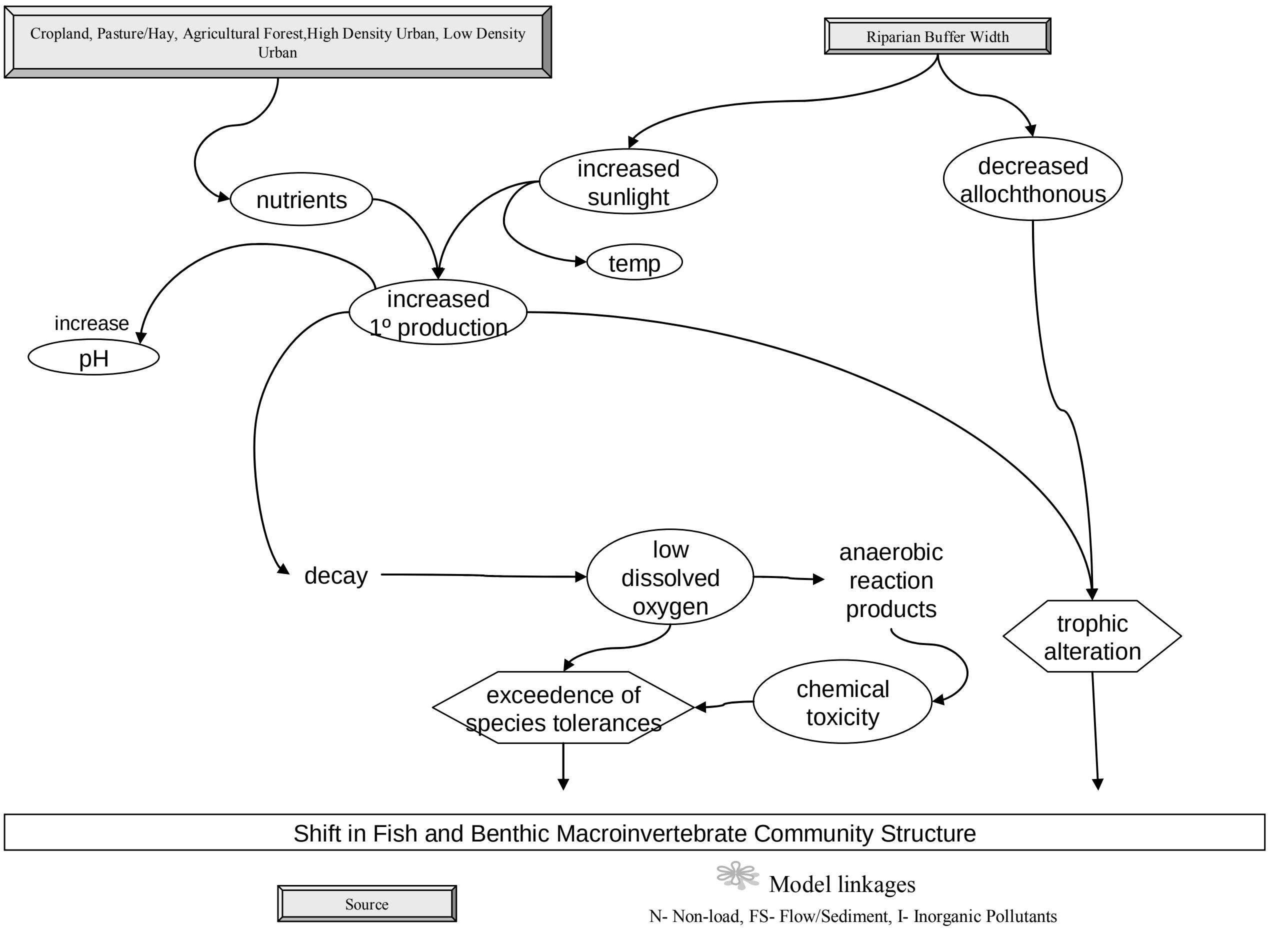

Figure B-2 Energy Source Causal Scenario

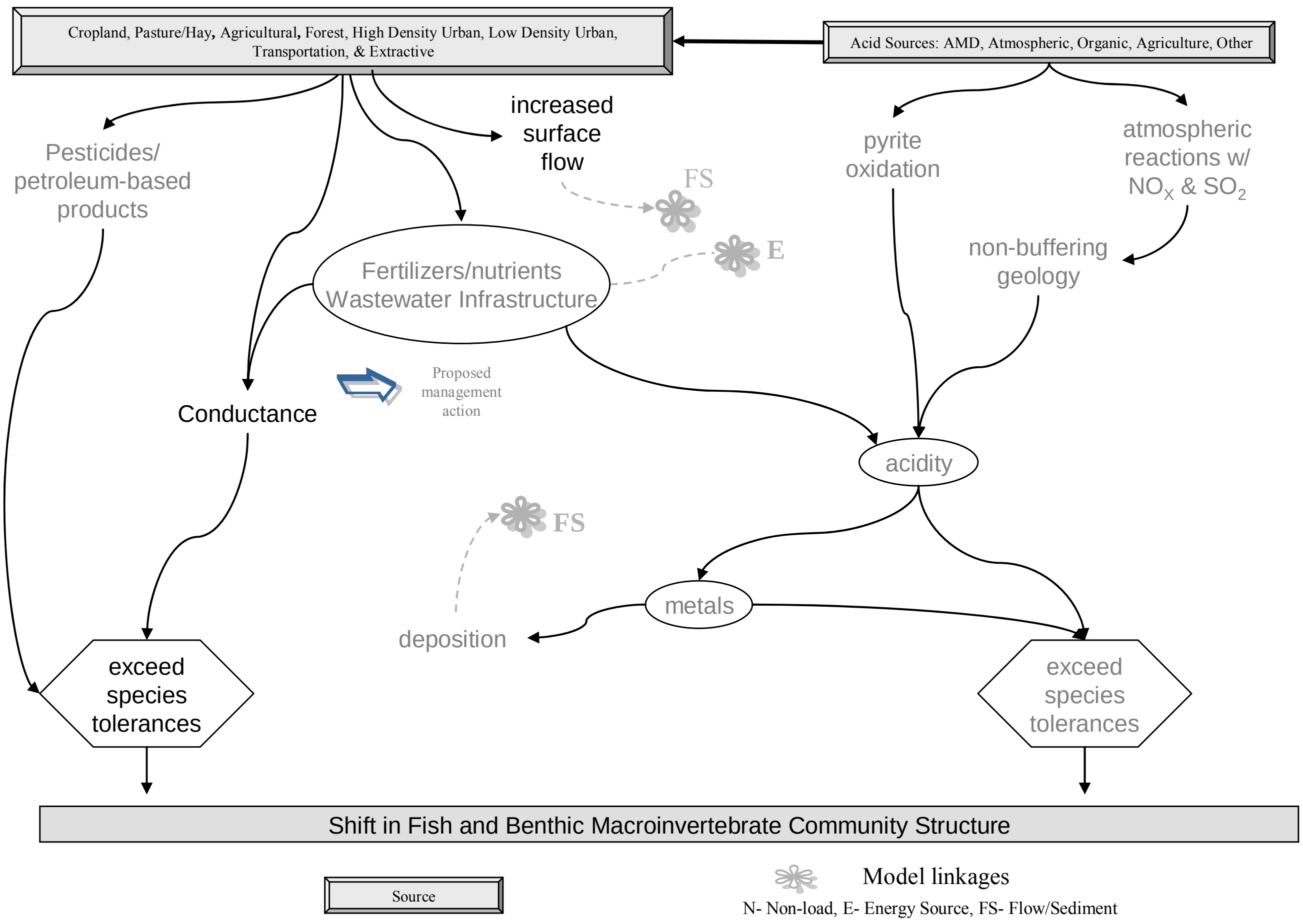

Figure B-3 Inorganic Pollutant Causal Scenario

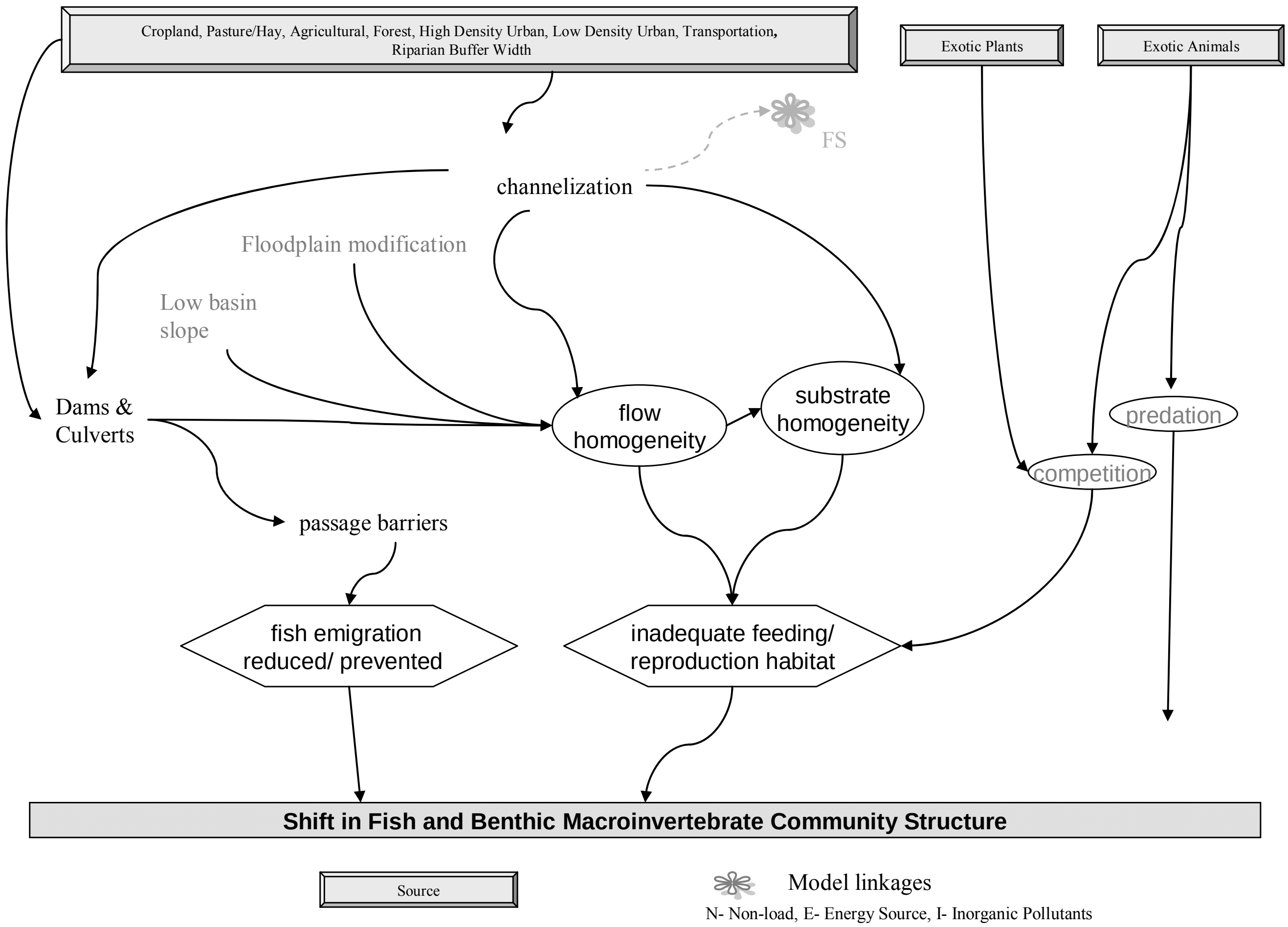

Figure B-4 Non-Load Causal Scenario

MARYLAND BIOLOGICAL STREAM SURVEY 2000-2004

Volume XIV

Stressors Affecting Maryland Streams

MARYLAND
DEPARTMENT OF
NATURAL RESOURCES

CHESAPEAKE BAY AND
WATERSHED PROGRAMS
MONITORING AND
NON-TIDAL ASSESSMENT

CBWP-MANTA-EA-05-11

Robert L. Ehrlich, Jr.
Governor

Michael S. Steele
Lt. Governor

A message to Maryland's citizens

The Maryland Department of Natural Resources (DNR) seeks to preserve, protect and enhance the living resources of the state. Working in partnership with the citizens of Maryland, this worthwhile goal will become a reality. This publication provides information that will increase your understanding of how DNR strives to reach that goal through its many diverse programs.

C. Ronald Franks
Secretary

MARYLAND
DEPARTMENT OF
NATURAL RESOURCES

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Publication # DNR-12-0305-0101

Published July 2005

PRINTED ON RECYCLED PAPER

Maryland Biological Stream Survey 2000-2004

Volume 14: Stressors Affecting Maryland Streams

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July 2005

PUB # DNR-12-0305-0101
EA-05-11

FOREWORD

This report, *Maryland Biological Stream Survey 2000-2004 Volume14: Stressors Affecting Maryland Streams*, was prepared by Versar, Inc., as a combined effort of several authors from Versar, University of Maryland, and Maryland DNR, for the Maryland Department of Natural Resources' Monitoring and Non-Tidal Assessment Division. It was supported by Maryland's Power Plant Research Program (Contract No. K00B0200109 to Versar, Inc.).

ACKNOWLEDGMENTS

All aspects of the Maryland Biological Stream Survey have been a cooperative effort among Maryland DNR, several academic institutions, and consulting firms, as listed in the acknowledgments sections of each volume. For this volume, the authors would like to acknowledge the following individuals who contributed data analysis, graphical support, editing, or other talents:

Versar
Allison Brindley
Beth Franks
Gail Lucas
Sherian George
Don Strebel
Ed Weber

We'd also like to thank Bob Hilderbrand, Bill Kimmel, and Lester Yuan for taking the time to review this volume.

ABSTRACT

This volume uses the data collected by the MBSS since 1994 to identify the stressors (e.g., individual pollutants, physical habitat changes, invasive species, and general factors such as land use) that are affecting Maryland's streams. To the surprise of no one, a large proportion of our streams are in poor condition and many more are in worse condition than we desire. The first step in "fixing" these streams is determining why they are "broken." Identifying stressors is critical to meeting Clean Water Act mandates and developing management actions that can restore or protect the desired condition of streams. Stressor identification, or the diagnosis of stream problems, is an emerging field that draws on the approaches of traditional risk assessment while using new metrics derived from more sophisticated monitoring data. Relative risk assessment and cumulative impact analyses are another approach useful for setting management priorities. This volume uses both approaches to investigate which stressors are responsible for degradation of Maryland streams.

Stressors can be organized according to the five major determinants of biological integrity in aquatic ecosystems: water chemistry, energy source, habitat structure, flow regime, and biotic interactions. Water chemistry comprises acidity, dissolved oxygen, and contaminants. Energy source describes the size, abundance, and nutritional quality of food from both primary production and allochthonous inputs. Habitat structure encompasses physical features such as water depth, current velocity, substrate composition, and morphology of the stream channel. Flow regime refers to seasonal, annual, and altered patterns in water quantity and delivery. Biotic interactions include competition, predation, and parasitism, from both native and introduced species. The MBSS directly measures many of these stressors and ancillary information, such as land use, can be used to evaluate others. Some stressors, such as pesticides, currently are not considered in MBSS analyses. This volume includes detailed analysis of five important stressor categories: acidification, nutrients, physical habitat, biotic interactions, and land use. It also discusses the relative contributions of each stressor and their cumulative impact on stream resources. Lastly, it provides basin and site examples of stressor identification.

Important results include the strong effect that acidification (especially low acid neutralizing capacity, ANC) has on both fish and benthic macroinvertebrate communities. While acid mine drainage is among the most severe stressors (producing a strong effect when present), the extent of streams affected by AMD (1% of all stream miles) is small compared to other stressors, including acidic deposition. Aquatic non-natives and invasive plants are the stressors affecting the greatest number of stream miles statewide (more than 50%). Nutrient pollution also affects Maryland streams as evidenced by the strong relationship between sensitive benthic taxa (Ephemeroptera, Plecoptera, and Trichoptera) and the ratio of total nitrogen (TN) to total phosphorus (TP). The percentage of agricultural land use is a good predictor of nitrate levels in streams. Degradation of instream physical habitat is the stressor most often resulting in the loss of individual fish species. Urban land use and its concomitant impervious surfaces strongly affect the fish, benthic, and salamander communities in streams to the point that other stressors are obscured and management solutions may be limited.

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14.1 BACKGROUND

The Maryland Biological Stream Survey (MBSS) provides State agencies and the public with a comprehensive assessment of the condition of Maryland's streams. To the surprise of no one, a large proportion of our streams are in poor condition and many more are in worse condition than we desire. The first step in "fixing" these streams is determining why they are "broken."

Identifying stressors is critical to the development of management actions that can restore or protect the desired condition of streams. To implement Section 303(d) of the Clean Water Act, the Maryland Department of the Environment (MDE) must identify stressors ("pollutants") for impaired waters so that Total Maximum Daily Loads (TMDLs) can be developed. These TMDLs are the State's mechanism for maintaining water quality standards. Stressor identification also supports Clean Water Act implementation through 305(b) Water Quality Reports, 319 Nonpoint Source Control, 402 Point Source Permitting, and 401 Water Quality Certifications. In addition, the Maryland Department of Natural Resources (DNR) and other agencies maintain active restoration programs for Maryland's streams. Programs, such as Watershed Restoration Action Strategies (WRAS) use MBSS and other data (e.g., Stream Corridor Assessment) to identify stressors. The Chesapeake Bay Program, as well as other governmental and private programs, also must identify stressors to implement their restoration initiatives. This volume uses the data collected by the MBSS since 1994 to summarize the severity and geographic extent of stressors (individual pollutants, physical habitat changes, and general factors such as land use) that are affecting Maryland's streams. It does not provide a complete characteristic of stressors in Maryland (additional analyses will be conducted in the future) nor is it a formal stressor identification as described by EPA (see below) to support regulatory decisions.

14.1.1 Stressor Identification

Stressor identification, or the diagnosis of stream problems, is an emerging field that draws on the approaches of traditional risk assessment while using new metrics derived from more sophisticated monitoring data. The U.S. Environmental Protection Agency (2000a,b,c) has published a stressor identification process that includes three steps (Figure 14-1):

- Listing candidate causes
- Analyzing new and previously existing data to generate evidence for each candidate cause
- Producing a causal characterization using the evidence generated to draw conclusions about the stressors that are most likely to have caused the impairment.

Critical to characterizing causes are the three approaches of eliminate, diagnose, and strength of evidence.

Stressors can be organized according to the five major determinants of biological integrity in aquatic ecosystems (Figure 14-2): water chemistry, energy source, habitat structure, flow regime, and biotic interactions (Angermeier and Karr 1994, Karr and Chu 1998). Water chemistry comprises acidity, dissolved oxygen, and contaminants. Energy source describes the size, abundance, and nutritional quality of food from both primary production and allochthonous inputs. Habitat structure encompasses physical features such as water depth, current velocity, substrate composition, and morphology of the stream channel. Flow regime refers to seasonal, annual, and altered patterns in water quantity and delivery. Biotic interactions include competition, predation, and parasitism, from both native and introduced species.

The MDE is considering individual candidate causes as a means of addressing specific problems within these five factors:

- Chemical
  - Chemical toxicity
  - Low dissolved oxygen
  - pH
- Energy source
  - Increased primary production
  - Decreased allochthonous input
- Physical habitat
  - Sediment
  - Channel modification
  - Temperature
- Flow regime
  - High discharge
  - Low discharge
- Biotic interactions
  - Exotics
  - Pathogens
  - Exploitation

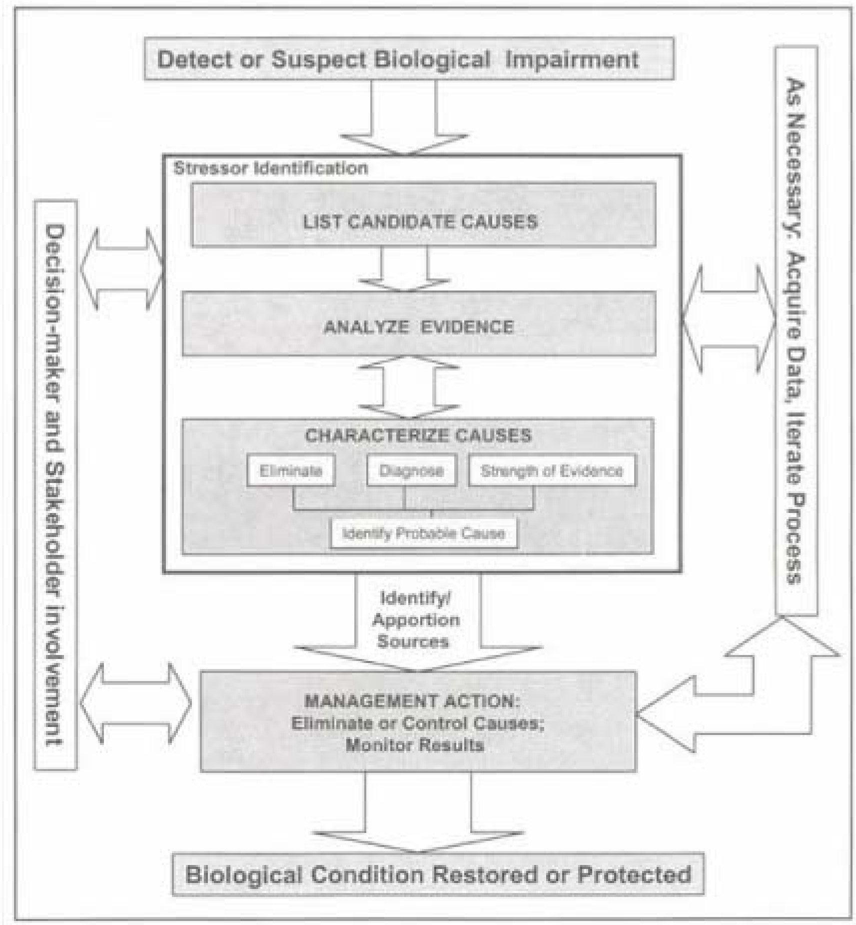


Figure 14-1. The management context of the stressor identification process. (The stressor identification process is shown in the center box with bold line. Stressor identification is initiated with the detection of a biological impairment Decision-maker and stakeholder involvement is particularly important in defining the scope of the investigation and listing candidate causes. Data can be acquired at any time during the process. The accurate characterization of the probable cause allows managers to identify appropriate management action to restore or protect biological condition.)

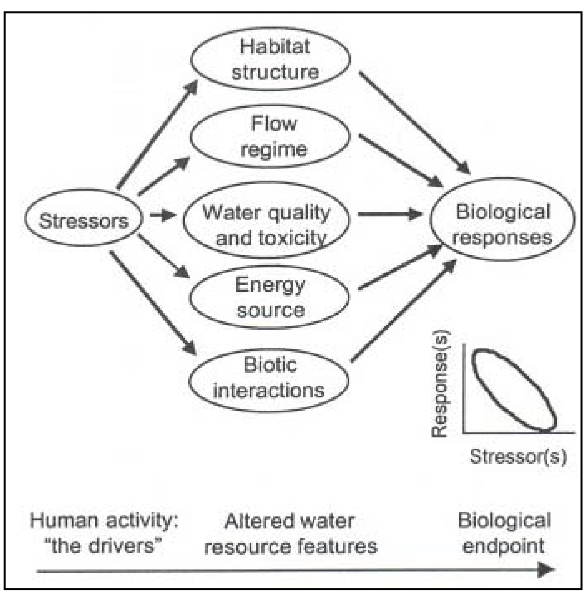


Figure 14-2. Linkages from human activity (the stressors or drivers of system change) through the five major water resource features altered by human activity, to the biological responses producing ambient condition, i.e., the biological endpoints of primary interest in biological assessment programs. This model illustrates the multiple causes of water resource changes associated with human activity. Insert illustrates the relationship between stressor dose and the gradient of biological responses that signal a good biological metric. (Source: Karr and Yoder 2005).

Stressor identification requires that each candidate cause have a conceptual model that shows the relevant cause-and-effect relationships. The MDE has developed preliminary conceptual models of the 13 candidate causes, though these models are still evolving. Compiling and interpreting evidence on which cause is affecting stream condition is the most critical part of stressor identification. This is analogous to diagnosing the illness of a patient. The accuracy and precision of the diagnosis depends on the relevance and sophistication of the evidence that can be obtained, including whether the evidence describes the effect directly, the exposure to a stressor, the cause of that stressor, or the original source of the stressor.

The MBSS collects a core of site data on biological assemblages, physical habitat, and water chemistry in all of Maryland's watershed basins (Figure 14-3). This information is supplemented with land use and other area-wide data from many sources. This combination of data can be used to identify specific stressors at individual sites and predominant stressors at the basin, tributary basin, or statewide level. In some cases, stressor identification in streams can be straightforward, as when pH levels are below thresholds known to adversely affect fish survival. In other cases, the evidence is a mixture of habitat changes (embedded substrate) and indirect causes (stormwater runoff from impervious surfaces). A promising method of stressor identification is the use of biological data when consistent thresholds of tolerance have been determined. The large number of sites sampled by the MBSS across the full range of human disturbance allowed Stranko et al. (2005a) to develop a Prediction and Diagnosis Model that can be used to identify likely stressors when fish species are absent. All of these methods are used in this volume to identify which stressors are affecting Maryland streams, and to characterize their severity and geographic extent.

14.1.2 What's in This Volume?

This volume attempts to look broadly at what stressors may be affecting Maryland streams, but it cannot be comprehensive because evidence for some stressors are not available. For example, migration barriers to fish have an important affect on fish communities but many such barriers cannot be identified during site visits or from currently available data sources. Similarly, many upstream effects are also not discernible at the site level nor can they be determined with large-scale ancillary data. Local assessment data (such as Stream Corridor Assessment data) are very helpful at fine scales, but will be introduced here only. The range of evidence that is available from the MBSS and separate landscape data are powerful, however, and will be used in the sections that follow.

To limit the size and complexity of this volume and increase readability, all methods used to prepare and analyze data for this volume are presented in 2000-2004 Maryland Biological Stream Survey Volume 6: Laboratory, Field, and Analytical Methods. This volume can be downloaded from http://www.dnr.Maryland.gov/streams/pubs.

Another caution about stressor identification is the difficulty in determining when individual stressors interact to produce synergistic (or antagonistic) effects on biota. To some extent, land use reflects a suite of stressors

STREAM CORRIDOR ASSESSMENTS

The MBSS provides excellent coverage of the State at the scale of the Maryland 8-digit basins (approximately 50 mi^2). The mean IBIs for fish and benthic macroinvertebrate assemblages (and the proportion of stream miles in each IBI class) provide robust measures of the cumulative stress on biological communities, at this scale. In addition, stressor and stressor-surrogate variables sampled at MBSS sites provide areawide estimates of the extent and severity of water quality and physical habitat conditions. MBSS data do not, however, provide coverage of stressor presence at the next larger stream reach scale. For example, when evaluating the stressors potentially affecting biological condition at an individual MBSS site, the presence of an adequate riparian buffer along the 75-m sample segment could be misleading if the riparian buffer has been removed along the entire reach upstream of the site. Stressor identification in Maryland streams would be greatly enhanced if data on the reach level could be combined with MBSS data collected at the segment level. Fortunately, Maryland DNR is conducting reach-level Stream Corridor Assessments (SCAs) as part of the State's Watershed Restoration Action Strategies (WRASs) in selected 8-digit basins (Yetman 2001). Analysis is underway to evaluate how MBSS and SCA data might be combined for improved stressor identification.

What is SCA? SCA data are intensive, covering the entire stream network of selected 8-digit basins through "stream walks," which inventory each individual problem site along a stream, and "representative sites," which document the instream and riparian habitat conditions along small stretches of a stream (approximately 300 feet in length). These habitat assessments are based on an array of habitat metrics similar to those used in the MBSS summer habitat assessment. Currently, SCA data are available for the Ballenger Creek, Breton Bay, Georges Creek, Liberty Reservoir and Upper Patuxent River basins. Additional basins will be added on a regular basis.

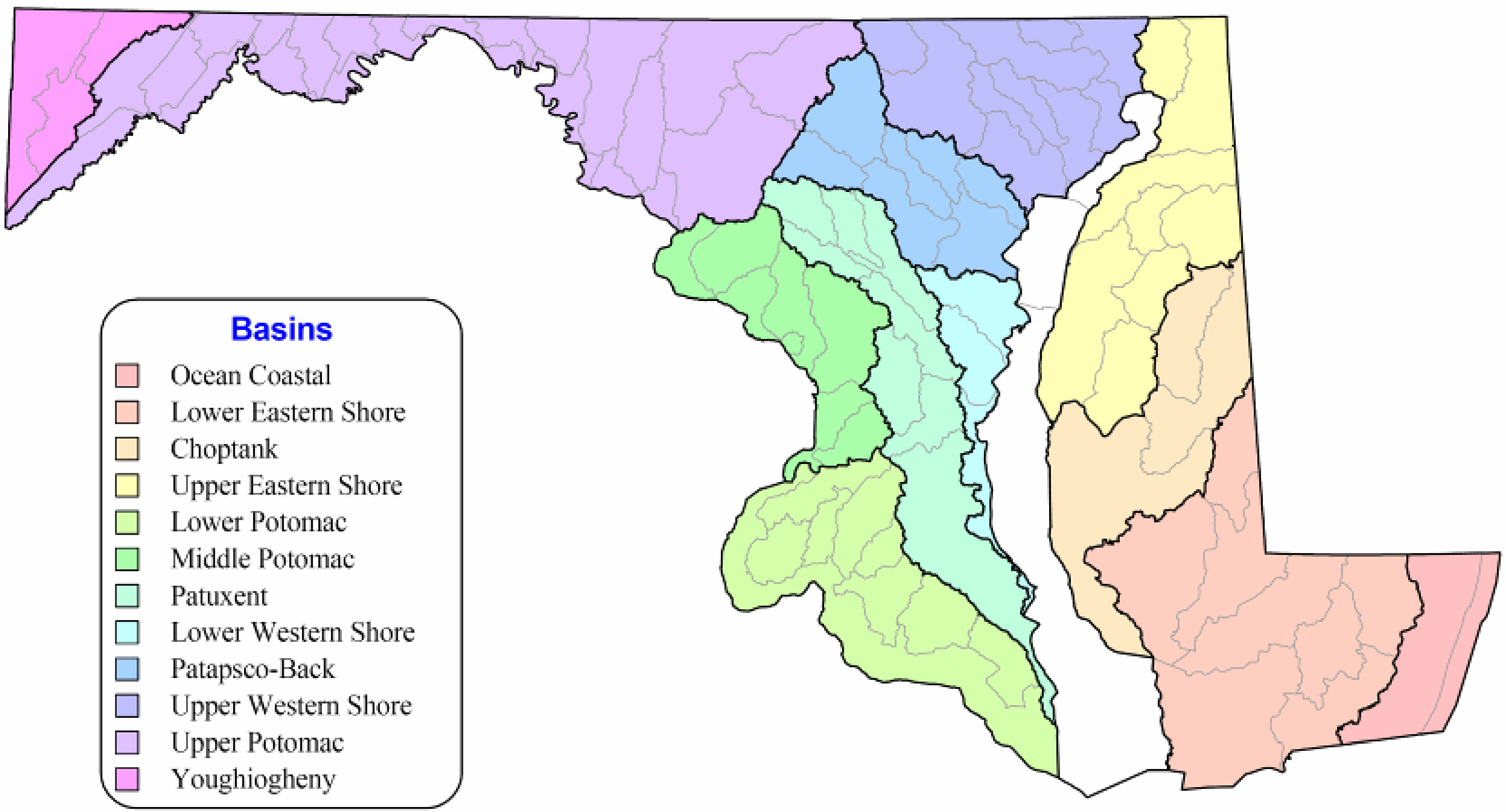


Figure 14-3. Maryland Tributary Strategy Basins with their constituent Maryland 8-digit basins.

resulting from human activities and can help address this issue. More importantly, when biological data themselves can be used, they integrate the cumulative effects of many stressors and are the best evidence of adverse impacts. Investigation into interactions among stressors remains an important area for further research.

The next five sections in this volume address the following important stressor categories:

- Acidification
- Nutrients
- Physical habitat
- Biotic interactions (non-native and invasive aquatic biota)
- Land use

Subsequent sections discuss the relative contributions of each stressor and their cumulative impact on stream resources, and provide basin and site examples of stressor identification.

14.2 Acidification

One of the primary objectives of the MBSS is to assess the effect of acidic deposition on biological resources of Maryland streams–an objective driven by previous studies that document effects on ecologically and economically important species in Maryland's tidal and freshwater ecosystems. Acidification is well known to have detrimental effects on fish assemblages and other aquatic biota (Baker and Christensen 1991, Baker et al. 1990a, 1996) both from the direct effects of low pH and through toxic effects resulting from increases in elemental concentrations (e.g., aluminum, zinc, and mercury) that leach from soils.

In the early 1980s, DNR recognized that atmospheric deposition resulting from the generation of electric power is one of the State's most important environmental problems. The link between acidification of surface waters and acidic deposition resulting from pollutant emissions is well established. To determine the spatial extent of acidification of Maryland streams resulting from acidic deposition, DNR conducted the Maryland Synoptic Stream Chemistry Survey (MSSCS) in 1987 (Knapp et al. 1988). The MSSCS estimated the number of streams affected by, or sensitive to, acidification statewide, and concluded that the greatest concentration of fishery resources at risk may be in streams throughout the Appalachian Plateau and the Southern Coastal Plain physiographic provinces, as well as certain portions of the Blue Ridge.

Because the MBSS collects both biological and water chemistry data, it has the ability to measure not only the spatial extent of acidification in Maryland but also the severity and extent of potential adverse effects on aquatic biological communities.

14.2.1 Background

Acidic deposition occurs as wet deposition (rain, snow, sleet, or hail), dry deposition (particles or vapor), and cloud or fog deposition (common at high elevations and coastal areas). Cloud and fog deposition may significantly contribute to the total deposition of sulfate and nitrogen to high-elevation sites in the northeastern United States (Anderson et al. 1999). Prevailing winds from west to east cause pollutants to be deposited in the mid-Atlantic and Northeast regions. During atmospheric transport, some SO_2 and NO_x will be converted to sulfuric and nitric acids or to ammonium sulfate and ammonium nitrate, all with significant residence times in the atmosphere (Lovett 1994).

The effects of acidic deposition on stream chemistry are well documented (Baker et al., 1990b, 1996, Bricker and Rice 1989, Schindler 1988, Wigington et al. 1996a,b). Conducted in 1987, the MSSCS concluded that approximately one-third of all headwater streams in Maryland are sensitive to acidification or are already acidic (Knapp et al. 1988). Research has demonstrated that the vulnerability of stream systems to acidic deposition depends on basin hydrology and the ability of the vegetation, soils, and bedrock within the basin to buffer acidic inputs.

Defining characteristics of surface waters sensitive to acidification are low to moderate pH and acid neutralizing capacity (ANC), where pH is a measure of the acid balance of a stream. The pH scale ranges from 0 to 14, with pH 7 as neutral. Low to moderate pH (< 6) signifies acidity. ANC is a measure of the capacity of dissolved constituents in the water to react with and neutralize acids, and is used as an index of the sensitivity of surface water to acidification. The higher the ANC, the more acid a system can assimilate before experiencing a decrease in pH. Repeated additions of acidic materials may cause a decrease in ANC. In many acidic deposition studies (e.g., Schindler 1988, Roth et al. 1999), an ANC of 200 µeq/L is considered the threshold for defining acid-sensitive streams and lakes.

In a recent study of acid deposition impacts in Maryland streams (Janicki et al. 1991, Sverdrup et al. 1992), the sensitivity of an indicator species was expressed as the critical pH at which half or more of the population experiences acute or chronic effects (Janicki et al. 1991, Sverdrup et al. 1992, Morgan 1995). The level of acid deposition that results in the critical pH is known as the "critical load". In the critical loads study, information on soil buffering ability was combined with MSSCS ANC values to estimate critical loads at specific sites across the state. Critical load results revealed wide differences in the sensitivity of Maryland streams in different provinces:

- The Appalachian Plateau, Coastal Plain, and portions of the Blue Ridge are very sensitive with critical load values < 0.5 keq SO_4/ha/year (24 kg SO_4/ha/year).
- In contrast, the Valley and Ridge, Piedmont, and portions of the Blue Ridge exhibit critical loads well over 2.0 keq SO_4/ha/year (96 kg SO_4/ha/year). In these regions, limestone bedrock and derived soils are prevalent.

These critical load values provided the basis for a reassessment of acidic deposition in 1998 (Miller et al. 1998). When measured sulfate deposition was compared with critical loads, the results suggested that streams continue to be affected in some areas of Maryland despite recent reductions in industrial sulfate emissions. This was a finding consistent with stream chemistry measured in the 1995-1997 MBSS.

Acidification is known to cause declines in both diversity and abundance of fish populations. Current evidence indicates that the number of aquatic taxa in an ecosystem usually declines with increasing acidity (Eilers et al. 1984, Mills and Schindler 1986, Stephenson and Mackie 1986). In a review of pH effects on aquatic biota, Baker and Christensen (1991) report a number of critical thresholds at which certain fish populations are affected. Many streams in Maryland have pH values below critical levels, with critical pH values for inland species ranging from 5.0 to 6.5 (Baker et al. 1990a; Morgan et al. 1991, Pinder and Morgan 1995). For instance, several bass and trout species have a reported critical threshold of pH 5.0-5.5, while a number of more sensitive cyprinid and darter species are adversely affected at pH 5.5-6.0. Acid-tolerant species, such as the yellow perch *(Perca flavescens),* can survive at pH levels of 4.5 or lower. Eastern mudminnow (*Umbra pygmaea*) have been found in waters with a pH 4.0 or lower (Jenkins and Burkhead 1993), although the acidity may be partially derived from weak organic acids.

The primary mechanisms for fish population declines under acidic conditions include both recruitment failure (owing to an increased mortality of early life stages) and direct effects on adult survival. One of the physiological effects observed when pH decreases is the disruption of the normal internal ionic salt balance, which causes the fish to lose salt to the surrounding water. If the salt losses exceed intake, fish go into shock, lose equilibrium and eventually die from circulatory collapse-an osmoregulatory process. Acidic waters may also inhibit development of fish reproductive organs and facilitate development of a mucous that suffocates eggs and fry (Eno and Di Silvestro 1985). The loss of entire fish populations in abnormally acidic streams or lakes usually occurs because of successive failures in the reproductive cycle (Baker 1996, Carline et al. 1992, 1994). Other detrimental effects are caused by the increased concentrations of metal ions resulting from acidification (e.g., from the leaching of aluminum and the formation of methylmercury).

In addition to potential long-term (chronic) acidification, streams in Maryland are susceptible to rapid, short-term increases in acidity (episodic acidification) related to precipitation, snowmelt, and stormflow events (Greening et al. 1989, Gerritsen et al. 1992, Wigington et al. 1993, Eshleman et al. 2000). One study estimates that 50% more streams in the northern Appalachian Plateau of Western Maryland probably experience the deleterious effects of episodic acidification than are chronically acidified (Eshleman 1995). Spatial and temporal variability of acidic conditions are important to the magnitude of effects on aquatic biota. For example, a pulse of episodic acidification during juvenile recruitment could have a greater effect on a fish population than it would at other times of the year. The highest levels of acidity in Maryland streams have been recorded in the spring, when many fish, including economically important anadromous fish species of the Chesapeake Bay, enter the freshwater portions of coastal streams to spawn. Large-scale fish kills frequently result when snowmelts and large quantities of acidic materials are released into rivers and streams (Eno and Di Silvestro 1985, Molot et al. 1989, Baker et al. 1996, Carline et al. 1992).

Because many invertebrate taxa are also sensitive to acidification, detrimental effects on food webs may occur well before direct toxicity to fish is evident (Schindler et al. 1989, Gill 1993). Benthic invertebrate taxa richness may be reduced as a result of acidification (Ford 1988), but this loss may be compensated for by an increase in numbers of acid-tolerant species resulting in little or no decrease in overall biomass (Eriksson et al. 1980, Dixit and Smol 1989). Some invertebrate taxa-notably mollusks, crustaceans, leeches, mayflies, some species of water striders, caddisflies, damselflies, dragonflies, and cladocerans-are sensitive to acidification and become scarce or disappear between pH 5.0 and 6.0 (Havas and Hutchinson 1982, Eilers et al. 1984, Raddum and Fjelheim 1984, Ormerod and Tyler 1986, Bendell 1988, Bendell and McNicol 1987).

14.2.2 Extent of the Acidification Problem

Both rounds of the MBSS measured several water quality parameters related to acidification during both the spring baseflow index and summer baseflow index periods (see Volume 6: Laboratory, Field, and Analytical Methods). Thresholds for pH and ANC were defined using U.S. NAPAP (1991) conventions and statistical distributions of each water quality parameter (Table 14-1). The high pH

Table 14-1. MBSS water quality thresholds for pH and ANC as measured in the first and second rounds of the MBSS.

Parameter		**Low**	**Moderate**	**High**
pH		< 5.5	5.5 - 6.5	> 6.5
ANC	**Acidic**	**Chronic**	**Episodic**	**Normal**
μeq/L	< 0	0 – 50	50 - 200	> 200

and normal ANC thresholds were broken down further into very high for a pH greater than 7.5, and high for an ANC greater than 750 μeq/L. This was done for acidification analyses by the ten Maryland tributary strategy basins (plus the Youghiogheny and Ocean Coastal basins) and for testing biotic relationships.

14.2.2.1 Low pH

In the MBSS, pH was measured in the spring index period as closed pH (measured in the laboratory), and during the summer index period using field meters. There is a strong correlation (r^2 = 0.60) between spring and summer pH (Figure 14-4). However, the relationship is not as robust at the lower pH levels (< 6.0), where field pH and closed pH diverge. Closed pH predicts a lower spring index pH for the MBSS sites than in the summer index period sampling. At pH above 6.5, the regression fit is very good, although there is some scatter above pH 8.0.

2000-2004 MBSS Spatial Extent - In Round 2 of the MBSS, five basins – the Lower Eastern Shore, Lower Western Shore, Lower Potomac, Youghiogheny, and Ocean Coastal–had greater than 10% of stream km below a pH of 5.5, the low pH threshold (Table 14-2). However, five basins exceeded 40% of stream km in the pH 5.5–6.5 category, and five basins had greater than 85% of their stream km in the pH greater than 6.5 category, reflecting both their geology and land use. The difference in mean pH among basins is shown in Figure 14-5. Three basins had a mean pH less than 6.5 – Lower Potomac, Lower Eastern Shore, and Choptank. The Ocean Coastal basin

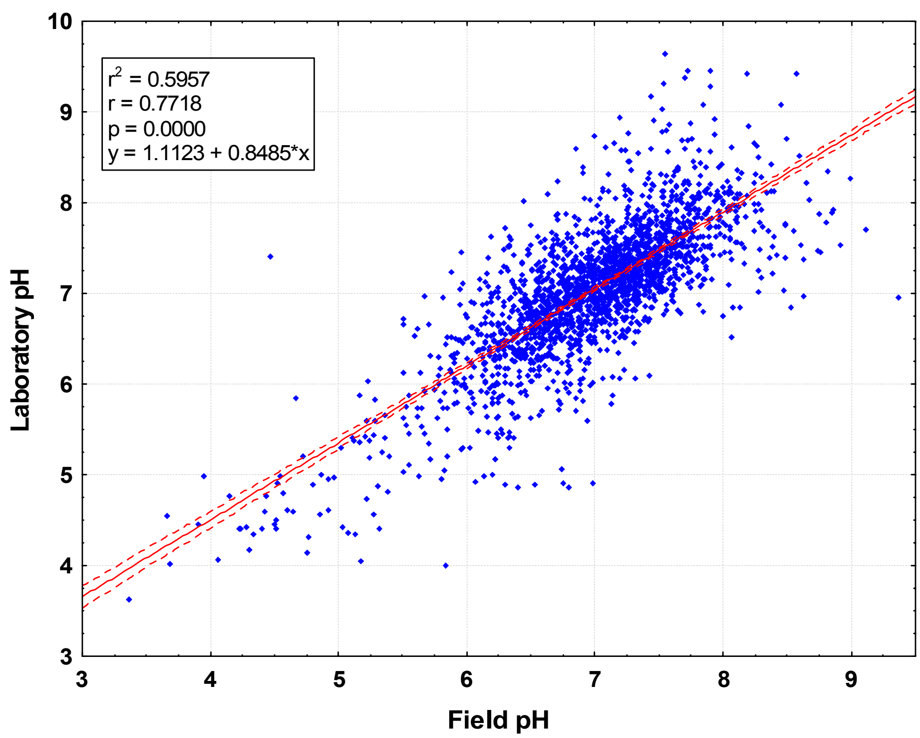


Figure 14-4. Relationship of field pH (summer index period) with laboratory pH (closed pH taken during spring index period).

Table 14-2. Percentage of stream km within each threshold category as defined in Table 14-1 for pH (standard units) and ANC (μeq/L) for all tributary strategy basins. The Youghiogheny and Ocean Coastal basins are included but their drainages are not part of the Chesapeake Bay basin.

		Basin											
Analyte	**Threshold**	**Lower Eastern Shore**	**Choptank**	**Upper Eastern Shore**	**Upper Western Shore**	**Patapsco/ Back River**	**Lower Western Shore**	**Patuxent**	**Lower Potomac**	**Middle Potomac**	**Upper Potomac**	**Youghio-gheny**	**Ocean Coastal**
pH	< 5.5	26.2	4.0	1.3	0.8	1.6	10.0	2.7	14.4	0.5	3.4	16.1	11.1
	5.5 – 6.5	40.0	43.9	20.9	4.2	1.6	43.5	12.3	42.2	3.9	4.1	11.9	55.6
	> 6.5	33.7	52.1	77.8	95.0	96.9	46.5	85.0	43.4	95.6	92.4	72.0	33.3
ANC	< 0	12.2	2.7	1.3	0	0	3.0	2.7	4.3	0.5	2.1	10.2	11.1
	0 – 50	11.8	1.3	0	0.8	1.6	7.0	2.2	23.2	0	3.9	9.2	0
	50 - 200	37.5	40.4	16.6	8.1	3.4	39.9	13.8	47.7	6.6	15.5	59.5	11.1
	> 200	38.6	55.7	82.1	91.1	95.0	50.1	81.3	24.7	92.9	78.5	21.1	77.8

consists of only eight samples, collected in the second round in the large pH sampling effect. This reflects the difficulty in site selection due to the tidal influence of the Maryland coastal bays and the small basin.

The spatial extent of pH in MBSS streams is depicted in Figure 14-6. Four clusters of low and moderate pH values stand out – the Eastern Shore, the southern western Coastal Plain, portions of the Blue Ridge associated with the Catoctin Mountains, and true western Maryland, in both the Youghiogheny and western North Branch drainage. For the latter two basins, acid mine drainage (AMD) is a confounding factor in acidification assessment.

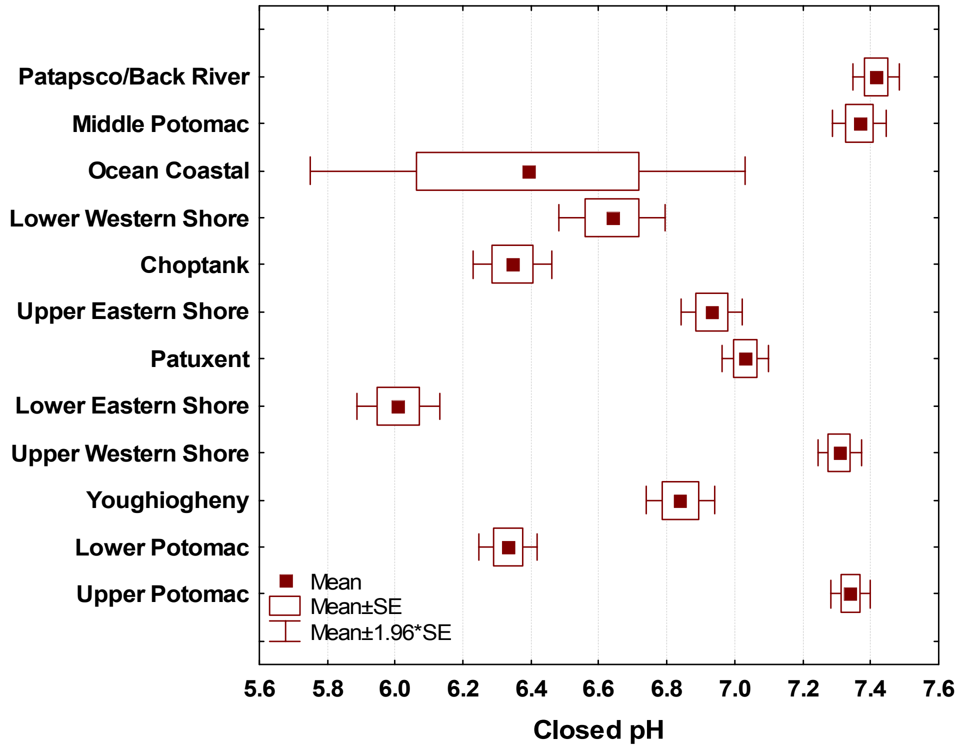


Figure 14-5. Closed pH for all Tributary Strategy Basins (includes Youghiogheny and Ocean Coastal) of Maryland.

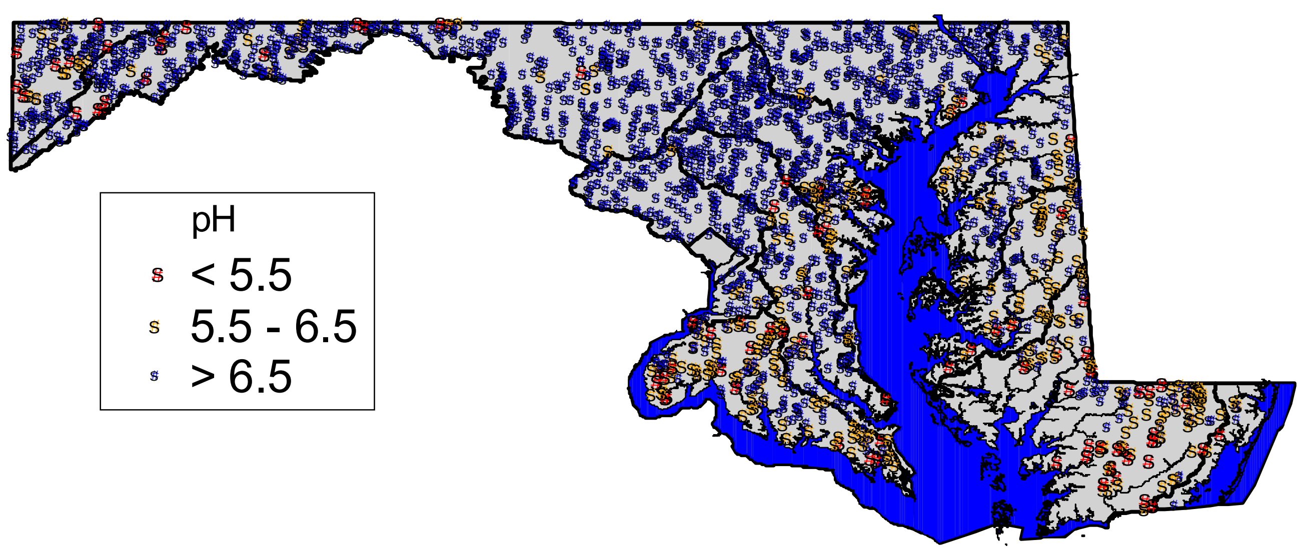


Figure 14-6. Spatial distribution of MBSS sites for pH values taken during the MBSS spring index period.

<u>1995-1997 MBSS Spatial Extent</u> - During spring sampling, an estimated 2.6% of the stream km sampled in the 1995-1997 MBSS had a pH less than 5, while another 6.4% had a pH of 5-6. Low spring pH was most common in the Pocomoke, where about 34% of stream km had a pH less than 5 and 28% of stream km had a pH of 5-6. Summer field sampling results were similar. An estimated 1.8% of the stream km had a pH less than 5, while 4.1% had a pH of 5-6. The lowest summer pH was in the North Branch Potomac, where about 16% of the stream miles had summer pH less than 5 and 1% had summer pH 5-6. Small streams appear to be most susceptible to low pH conditions; first-order streams have the highest percentage of stream km in the low pH classes. None of the third-order sites sampled had spring pH < 5. During spring, only 2.7% of third-order stream km had a pH of 5-6, compared to 8.4% of first-order stream km. Likewise, only 1.6% of third-order stream km sampled in summer had pH <6 as compared to 7.3% of first-order stream km.

14.2.2.2 Low Acid Neutralizing Capacity (ANC)

In the MBSS, ANC is measured in the spring index period. The definition of ANC, from Stumm and Morgan (1996), is:

ANC is the concentration of proton acceptors in solution minus the concentration of proton donors

or,

$$ANC = [HCO_3^-] + 2[CO_3^{2-}] + [OH^-] + [\text{other H+ acceptors}] - [\text{H+ donors}] \quad (1)$$

where, HCO_3^- is the bicarbonate ion, CO_3^{2-} is the carbonate ion, and OH^- is the hydroxide ion - all measured in molar concentrations. An alterative equation, simply the summation of all base cation concentrations minus the summation of all strong acid anion concentrations, is:

$$ANC = \Sigma C_B - \Sigma C_A$$

For most lakes and streams, all terms except bicarbonate are insignificant. In low ANC waters, the concentration of other hydrogen acceptors becomes important, including organic substances and aluminum species. Important noncarbonate contributors may include organic ligands (especially acetate and propionate) as well as hydroxide, silicate, borate, and less commonly ammonia and sulfide (Hem 1985); phosphate and arsenate may contribute to ANC as well (Stumm and Morgan 1996).

ANC is customarily determined for an unfiltered water sample composed of solute plus particulars. ANC is usually reported as either meq/L or µeq/L. An important point regarding the ANC unit is that it may be measured below zero since this analysis is done as a Gran titration. ANC is an important measure of acidification because it may be used as an index to estimate which aquatic systems may become acidified under either chronic or episodic conditions. Aquatic systems with an ANC < 0 µeq/L are acidic, 0 ≤ ANC < 50 µeq/L are highly sensitive to acidification (chronic), 50 ≤ ANC < 200 µeq/L are sensitive to acidification (episodic), and ANC > 200 µeq/L are not sensitive to acidification (Table 14-1).

There is a strong curvilinear relationship of pH versus ANC (Wigington et al. 1990, 1993, U.S. National Acid Precipitation Assessment Program – NAPAP 1991). This common ANC pattern is present for both MBSS rounds (Figure 14-7). Above an ANC of 200 µeq/L, pH is generally greater than 6.5, and slowly increases with rising ANC up to about pH 8.3 (bicarbonate saturation) for aquatic systems (Allan 1995). Below an ANC of 100, pH drops rapidly and falls to about pH 5.0 at 0 µeq/L, and continues to drop below 0 µeq/L. At low ANC levels, dissolved organic carbon (DOC) may be an important acid contributor, having a contribution of weak organic acids (Figure 14-7). DOC concentrations greater than 5.0 mg/l may contribute to low ANC levels, and high DOC levels (> 10 mg/l) obviously contribute.

<u>2000-2004 MBSS Spatial Extent</u> – Three basins–the Lower Eastern Shore, Youghiogheny and Ocean Coastal–had greater than 10% of stream km with an ANC < 0 µeq/L, indicating acidic conditions (Table 14-2). In addition, the Lower Eastern Shore, Lower Potomac and Youghiogheny also had significant stream km in the 0-50 µeq/L ANC range. The Upper Western Shore, Patapsco/Back River, and Middle Potomac had greater than 90% of stream km with an ANC greater than 200 µeq/L. Six basins had a mean ANC greater than 500 µeq/L and another three basins had a mean ANC between 200-400 µeq/L (Figure 14-8). The Lower Potomac, Lower Eastern Shore, and Youghiogheny basins had a mean ANC less than 200 µeq/L, with a significant number of stream km with ANC < 0 µeq/L in the Lower Eastern Shore and Youghiogheny.

The spatial extent of low ANC MBSS streams is depicted in Figure 14-9. Four clusters of acidic and low ANC values stand out: the lower Eastern Shore, the southern Coastal Plain, portions of the Blue Ridge associated with the Catoctin Mountains, and true western Maryland, in both the Youghiogheny and western North Branch drainage.

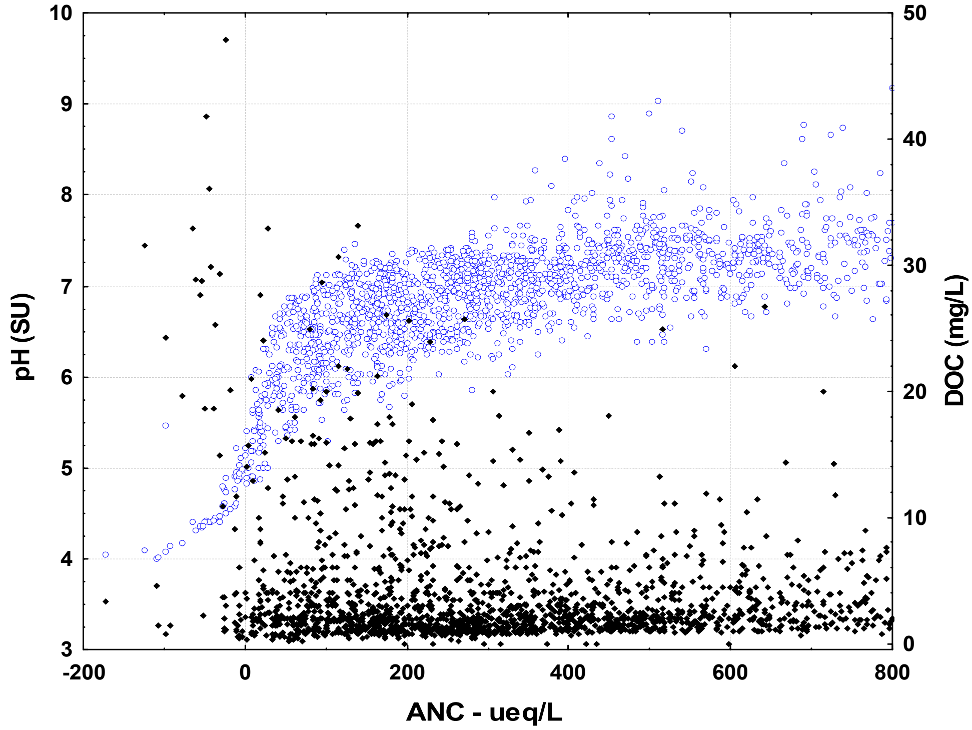


Figure 14-7. Relationship of pH (blue dots) and DOC (black diamonds) with ANC for all MBSS sites.

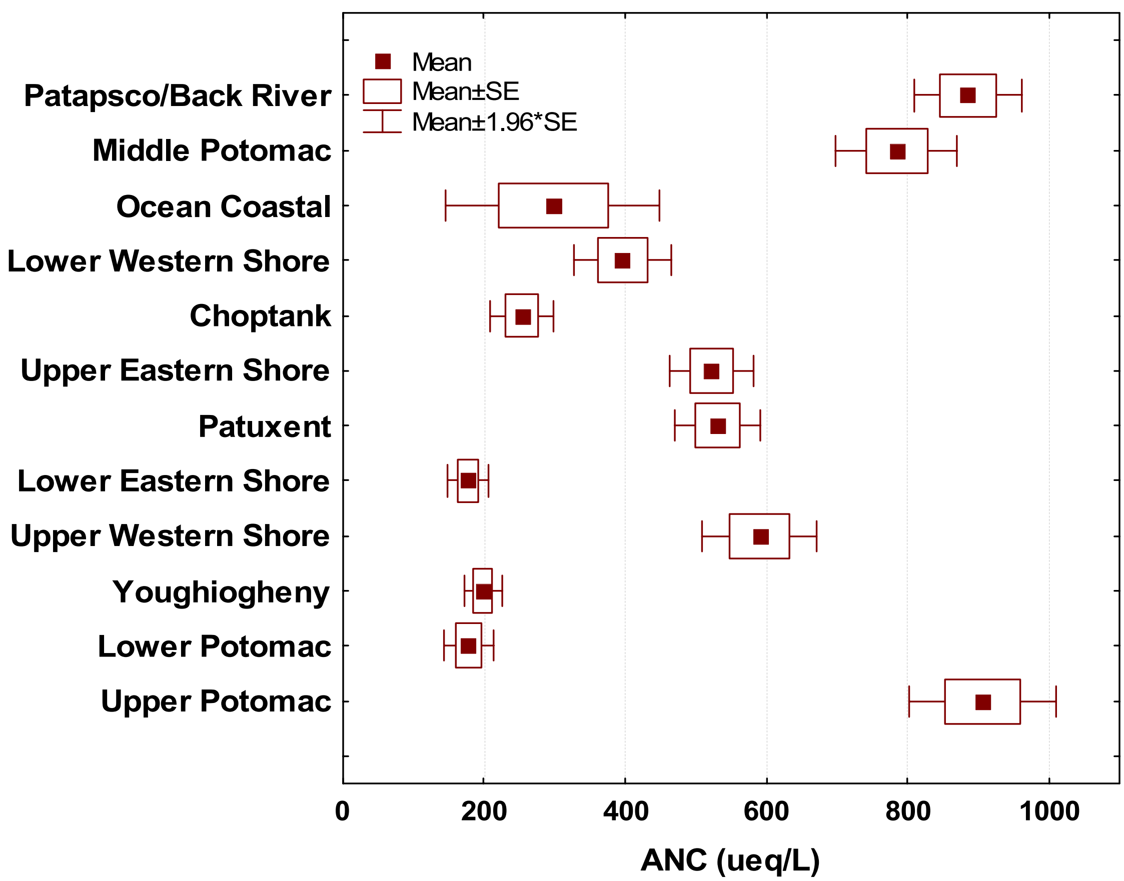


Figure 14-8. ANC (μeq/L) for all Tributary Strategy Basins (includes Youghiogheny and Ocean Coastal) of Maryland.

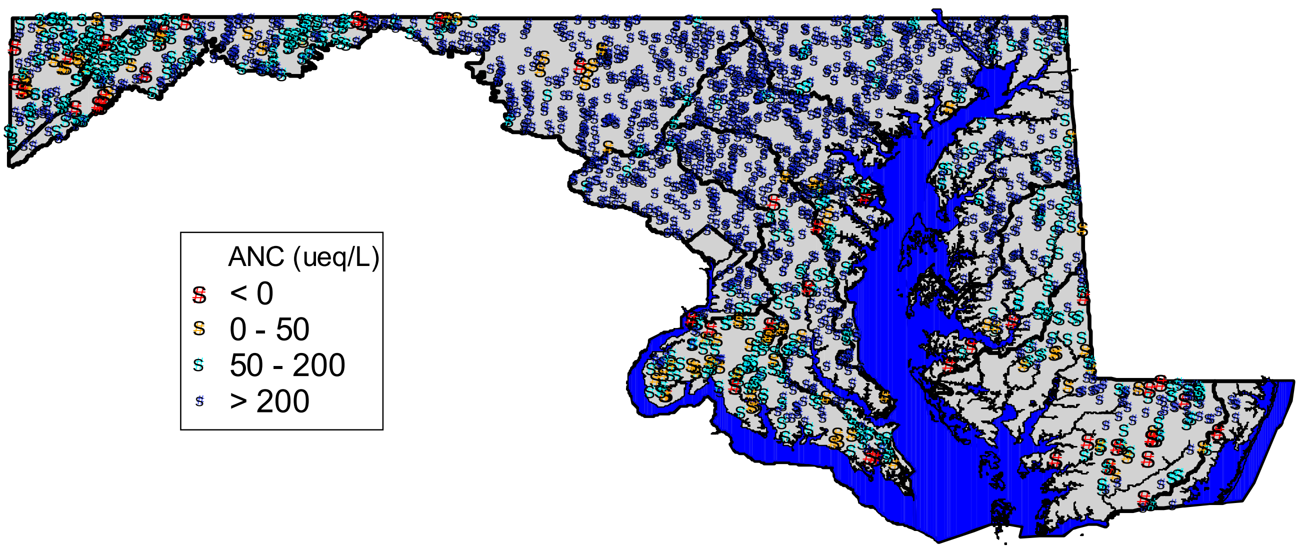


Figure 14-9. Spatial distribution of MBSS sites for ANC taken during the MBSS spring index period.

1995-1997 MBSS Spatial Extent - Statewide, an estimated 28% of the stream km were acidic or acid-sensitive, including about 2% acidic, 4% highly sensitive, and 22% sensitive to acidification in the first round of the MBSS. Statewide, the estimated percentage of stream km with ANC < 0 is 3% of first-order, 2% of second-order, and 0% of third-order stream km. The estimated percentage of stream km with ANC < 200 is 31% of first-order, 21% of second-order, and 20% of third-order stream km.

14.2.3 Sources of Acidity

Acidic deposition, acid mine drainage, agricultural runoff, and natural organic materials all contribute to the observed acidification of Maryland streams. Acidic deposition is the contribution of material from atmospheric sources, both as precipitation (wet) and particulate (dry) deposition. Acidic deposition is generally associated with elevated concentrations of sulfate and nitrate in precipitation (Wigington et al. 1990, 1993, 1996a,b). Acid mine drainage (AMD) results from pyrite oxidation - from mine spoils and abandoned mine shafts - and is known to cause extreme acidification of surface waters, as well as to affect stream physical substrate. Streams strongly affected by AMD exhibit high levels of sulfate, manganese, iron, aluminum, and conductivity. A third source of acidification is surface runoff from agricultural lands fertilized with high levels of nitrogen, or other acidifying compounds. Lastly, the natural decay of organic materials may contribute acidity in the form of organic anions, as in blackwater streams associated with bald cypress wetlands or boreal bogs. Streams dominated by organic sources of acidity are often characterized by high concentrations of dissolved organic carbon (DOC > 8 mg/l) and organic anions.

Acidification sources in Maryland streams have been examined in previous DNR studies using water chemistry data from the MSSCS and other regional surveys. In a study of Maryland Coastal Plain streams, Janicki (1991) reported a predominance of low ANC conditions, and found that differences in stream chemistry within the region were related to land use. In particular, ANC tends to be higher in basins dominated by agriculture. Agricultural activities in Coastal Plain basins may have different effects on stream chemistry, adding both ANC, from soil liming practices, and strong acid anions from nitrogen fertilizers (Janicki et al. 1995). Janicki and Wilson (1994) estimate that acidic deposition is the dominant source of acidity in about 45% of the low ANC streams in the Maryland Coastal Plain, while combined inputs from acidic deposition and agricultural sources affect about 55% of the streams. In Maryland's Appalachian Plateau and Blue Ridge regions, where there are also a significant number of acidic and acid-sensitive streams, bedrock geology is an important factor in determining stream response to acidic deposition, according to analyses by Janicki (1995). Atmospheric deposition is identified as the major source of acidification in the Appalachian Plateau and Blue Ridge streams. Organic acids and agricultural sources did not appear to be major contributors to acidification in western Maryland streams. The analyses by Janicki (1995) did not include any AMD effects.

For the MBSS, a new analysis was conducted to estimate the extent of impacts by acidic deposition, acid mine drainage, agricultural runoff and organic sources. Water chemistry data from sites with low ANC (< 200 μeq/L) were examined to identify dominant sources of acidi-ication and to estimate the percentage of stream km impacted by each according to the flow chart in Figure 14-10. This data set was compared by basins because different acidity sources were expected to be important in the eastern and western parts of Maryland.

Instream concentrations of sulfate and nitrate ions are important indicators of acid sources. For areas near the ocean, however, analyses of stream chemistry need to account for sulfate contributions from airborne sea salts. In this analysis, measured instream sulfate concentrations are corrected for sea salt influence, which decreases with distance from the coast. The amount of marine sulfate is related to levels of marine chloride, which can be estimated from a site's distance from the coast. Because the MBSS does not directly measure chloride concentrations, estimates of sea salt sulfate and chloride concentrations are made using the following relationships derived for mid-Atlantic streams by the National Stream Survey (Baker et al. 1990b, Kaufmann et al. 1992):

$$\ln(Cl^{-}_{sea}) = 5.4328 - 0.0180*Dist + 0.00004*Dist^{2}$$

$$\text{sea salt corrected } SO_4 = SO_4^{2-}\text{ (observed)} - 0.013*Cl^{-}_{sea}$$

where Cl^{-}_{sea}= concentration of sea salt derived chloride (μeq/L), Dist = distance from the coast (km), and SO_4^{2-} (observed) = observed sulfate concentration (μeq/L). The sea salt correction is made only for MBSS sites within 200 km of the ocean. Beyond 200 km, streams are assumed to have no sea salt contributions (Baker et al. 1990b).

In Western Maryland streams, sulfate concentrations are used to distinguish MBSS sites having AMD as the dominant source of acidification from those dominated by acidic deposition (Figure 14-10). Based on results of previous studies in the Mid-Atlantic Highlands streams (Kaufmann et al. 1992, Herlihy et al. 1990), thresholds were established to distinguish which sites were affected by AMD. For all sites in the Youghiogheny and North Branch Potomac River basins with ANC less than 200 μeq/L, those with sulfate concentrations greater than 500 μeq/L are designated as dominated by AMD. Sites with sulfate in the 300-500 μeq/L (~ 14 to 24 mg/l) range are considered affected by both AMD and acidic deposition (Figure 14-10).

Assessment of acidity sources is critical to understanding stream chemistry, especially in regions affected by both acid mine drainage (AMD) and acidic deposition (Kaufmann et al. 1991, Herlihy et al. 1991, Roth et al. 1999). Synoptic water quality investigations are extremely important in describing a population of streams that may be influenced by either acidic deposition or AMD. However, these types of surveys may not fully address the causal mechanisms of acidification (Herlihy et al. 1991) requiring a more extensive set of water quality measurements.

The categories of acid sources described in Figure 14-10 were used to estimate the extent of each source affecting Maryland streams. An estimated 27% (SE = 1.2%) of Maryland stream km had an ANC < 200 μeq/L. Statewide, acidic deposition is by far the most common source of acidifying compounds, being the dominant source at about 21.2% of stream km. AMD is the dominant source at only 1.4% of stream km (only found in the Youghiogheny and Upper Potomac basins), while an additional 3.9% of stream km are affected by agricultural inputs of acidity. Organic sources account for less than 1% of the stream km in Maryland.

As expected, acid sources vary considerably among basins (Table 14-3). In the Lower Potomac and Youghiogheny basins, for example, acidic deposition is the only major source of acidity, accounting for 74.4% and 65%, respectively, of stream km with ANC < 200 μeq/L. The Lower Western Shore and the Lower Eastern Shore also had significant stream km affected by acidic deposition (Table 14-3).

Acid mine drainage is only present in the Youghiogheny (10.9%) and Upper Potomac (2.9%) basins (Table 14-3). AMD is not a problem throughout the Upper Potomac, but is restricted to just the Georges Creek basin and the upper North Branch of the Potomac River (above Westernport).

Statewide, less than 1% of all stream km were dominated by organic sources. These sources were present in the Lower Eastern Shore (7%), Choptank (4%) and Ocean Coastal (11%) basins (Table 14-3) and three other basins with 1% or less. The small number of organically dominated streams led to large standard errors (SE > 100%) in estimating the number of stream km that were organically influenced. Twenty-five sites (76%) had a DOC > 8 mg/l, a level commonly used to characterize blackwater streams (streams rich in organic material and typically acid due to the presence of weakly-dissociated fulvic and humic acids).

Across Maryland, 3.9% of acid affected stream km are classified as agriculturally influenced. Agricultural influences on acidity are most extensive in the Lower Eastern Shore, Upper Eastern Shore and Choptank basins (Table 14-3). Smaller percentages (1.0 to 4.2%) are observed in the Upper Western Shore, Patapsco/Back River, Middle Potomac, Upper Potomac, and Ocean Coastal basins. Agriculture is rarely responsible for extreme acidification: only two agriculturally influenced sites had an ANC < 50 μeq/L, the rest had values of 51-200 μeq/L.

Water Chemistry Measurement (Other Parameters)		Source or Type of Acidification
ANC < 200 µeq/L	No →	None
Yes ↓		
Agriculture > 50% of Catchment Area and NO_3-N > 100 µeq/L (1.4 mg/l NO_3-N)	Yes →	Possible Agricultural Influence (AG)
No ↓		
SO_4 ≥ 500 µeq/L (~24 mg/l) and BASIN = North Branch Potomac or Youghiogheny[1]	Yes →	Dominated by Acid Mine Drainage (AMD)
No ↓		
SO_4 ≥ 300 µeq/L (~14 mg/l) and BASIN = North Branch Potomac or Youghiogheny[1]	Yes →	Mixed – Affected by both AMD and Acidic Deposition (ACID DEP)
No ↓		
Organic Ions > NO_3 + SO_4	Yes →	Dominated by organic sources (ORG)
No ↓		
DOC > 8 mg/l	Yes →	Mixed: Affected by both ORG and ACID DEP
No ↓		
Baseflow ANC 50 - 200 µeq/L[2]	Yes →	Stream vulnerable to episodic acidification
No ↓		
Baseflow ANC < 50 µeq/L[2]	Yes →	Chronic acidification – baseflow ANC may be less than 0 µeq/L[2]

Figure 14-10. Diagnosis of stream acidification sources and types for Maryland streams based on MBSS spring index period water chemistry. Note that more than one water chemistry situation (and acidification source or type) may apply.

Table 14-3. Percentage of stream km for each acid source category as defined for all tributary strategy basins. The Youghiogheny and Ocean Coastal are included but their drainages are not part of the Chesapeake Bay basin.

	Basin											
Acid Source	**Lower Eastern Shore**	**Choptank**	**Upper Eastern Shore**	**Upper Western Shore**	**Patapsco/ Back River**	**Lower Western Shore**	**Patuxent**	**Lower Potomac**	**Middle Potomac**	**Upper Potomac**	**Youghio-gheny**	**Ocean Coastal**
Acidic Deposition	38.1	21.0	9.8	4.3	4.0	49.9	15.0	74.4	3.2	17.6	65.0	11.1
Agriculture	16.5	19.1	7.0	4.2	1.0	0	3.7	0	3.9	1.0	3.0	0
Acid Mine Drainage	0	0	0	0	0	0	0	0	0	2.9	10.9	0
Organic	6.9	4.2	1.1	0.4	0	0	0	0.9	0	0	0	11.1
None	38.6	55.7	82.1	91.1	95.0	50.1	81.3	24.7	92.9	78.5	21.1	77.8

The distribution of acidic sources by stream order (for those streams with less than 200 μeq/L) shows some differences in sources (Figure 14-11). Acidic deposition was the major acid source in all stream orders, influencing 63% to 80%. Agricultural acid sources were associated with 14% of first-order streams, 8% of second-order and third-order streams, and 20% of fourth-order streams. AMD affected between 2 to 7 % of first to third-order streams, but these effects are only present in western Maryland (western Allegany and Garrett Counties).

The percentage of stream miles (ANC < 200 μeq/L) that were associated with each acidic source also varied by basin (Figure 14-12). Among low ANC streams, acidic deposition was the dominant source in all basins (and statewide), either singly or in combination with organic acids and AMD. The Choptank, Lower Eastern Shore, Middle Potomac, and Patapsco/Back River all have high levels of agriculturally produced acidic sources in these basins. AMD is present only in the Upper Potomac and Youghiogheny basins. Organic acids are a major source of acidification in the Lower Eastern Shore, Ocean Coastal, Upper Western Shore, Choptank, and Upper Eastern Shore.

14.2.4 Comparison with the 1987 Maryland Synoptic Stream Chemistry Survey

MBSS results from 2000-2004 may be compared with the previous characterization of low ANC in Maryland streams by the 1987 MSSCS (Knapp et al. 1988; Table 14-4). The MSSCS estimated the percentage of stream miles below certain threshold levels of ANC across Maryland, within MSSCS sampling strata derived from physiographic provinces for Maryland. MSSCS measurements were taken in 1987, a dry year that received an average of 11% less rainfall than normal (NOAA 1987). The MSSCS estimated that the greatest concentrations of acidic or acid-sensitive streams were in the Southern Coastal Plain (74% of stream miles) and the Appalachian Plateau (53%), with a statewide estimate of 33.3% of all stream miles below an ANC of 200 μeq/L, 10% below 50 μeq/L, and 3.6% below 0 μeq/L.

There are some important methodological differences between the 1987 MSSCS and the 2000-2004 MBSS. For example, MSSCS sampling was conducted statewide in a single year, while MBSS basins, in the second round, were sampled over a five-year period. Also, the sample frame for the MSSCS specifically excluded streams known to be affected by acid mine drainage, while the MBSS does not exclude these streams. To rectify these differences, the MBSS data were re-stratified by sampling strata, excluding sites that showed AMD as a contributing source of acidity (Table 14-4).

Among basins sampled in the MBSS, ANC patterns are generally consistent with the results of the earlier MSSCS. Sites in the Appalachian Plateau and Valley and Ridge sampling strata had a higher occurrence of acidic or acid-sensitive stream miles, compared to findings from 1987 for these regions. For example, 76% of streams in the Appalachian Plateau category had an ANC below 200 μeq/L in the second round MBSS, versus 53% in the MSSCS. There was an increase in the number of stream miles (30% versus 1.5%) with an ANC less than 200 μeq/L for the Valley and Ridge sampling strata.

These differences may be attributable to the greater number of small streams sampled by the MBSS than MSSCS. These results are consistent with low critical loads estimated for these provinces by Janicki et al. (1995), based on basin hydrology, and the buffering abilities of soils and parent material. Sites in the Piedmont had a low occurrence of low ANC streams in both MSSCS and MBSS sampling; these regions are thought to have higher critical loads values (Janicki et al. 1995). The Blue Ridge province showed a significant difference in ANC results between the MSSCS and MBSS sampling. This difference should be interpreted with caution, because the Blue Ridge is a small region and naturally has large statistical variation in results. The Northern Coastal Plain had similar values between the MSSCS and the second round of the MBSS, while the Southern Coastal Plain showed a drop (74% versus 56%) in streams with ANC less than 200 μeq/L. Across all provinces, the MBSS results show a lower percentage of low ANC sites than do the MSSCS results (from 33% to 27%). This suggests an overall improvement in the acidic condition of Maryland streams from 1987 to 2004. This, however, may be confounded by the design differences described above.

14.2.5 Associations Between Acidification and Biological Condition

Biological data for MBSS sites within designated pH and ANC classes were compared to determine the effect of acidic conditions (primarily acidic deposition) on Maryland stream communities. Acidification of streams may cause declines in the biotic integrity of fish assemblages, as a result of the loss of fish species sensitive to acidification, increases in acid-tolerant species, or the total elimination or reduction in the overall abundance of biota (Baker et al. 1990a, Carline et al. 1992, Van Sickle et al. 1996, Webb et al. 1989, Gagen et al. 1994, Heard et al. 1997).

Streams sensitive to acidification may experience intermittent periods of low pH that may be harmful to fish populations. In particular, streams may be subject to

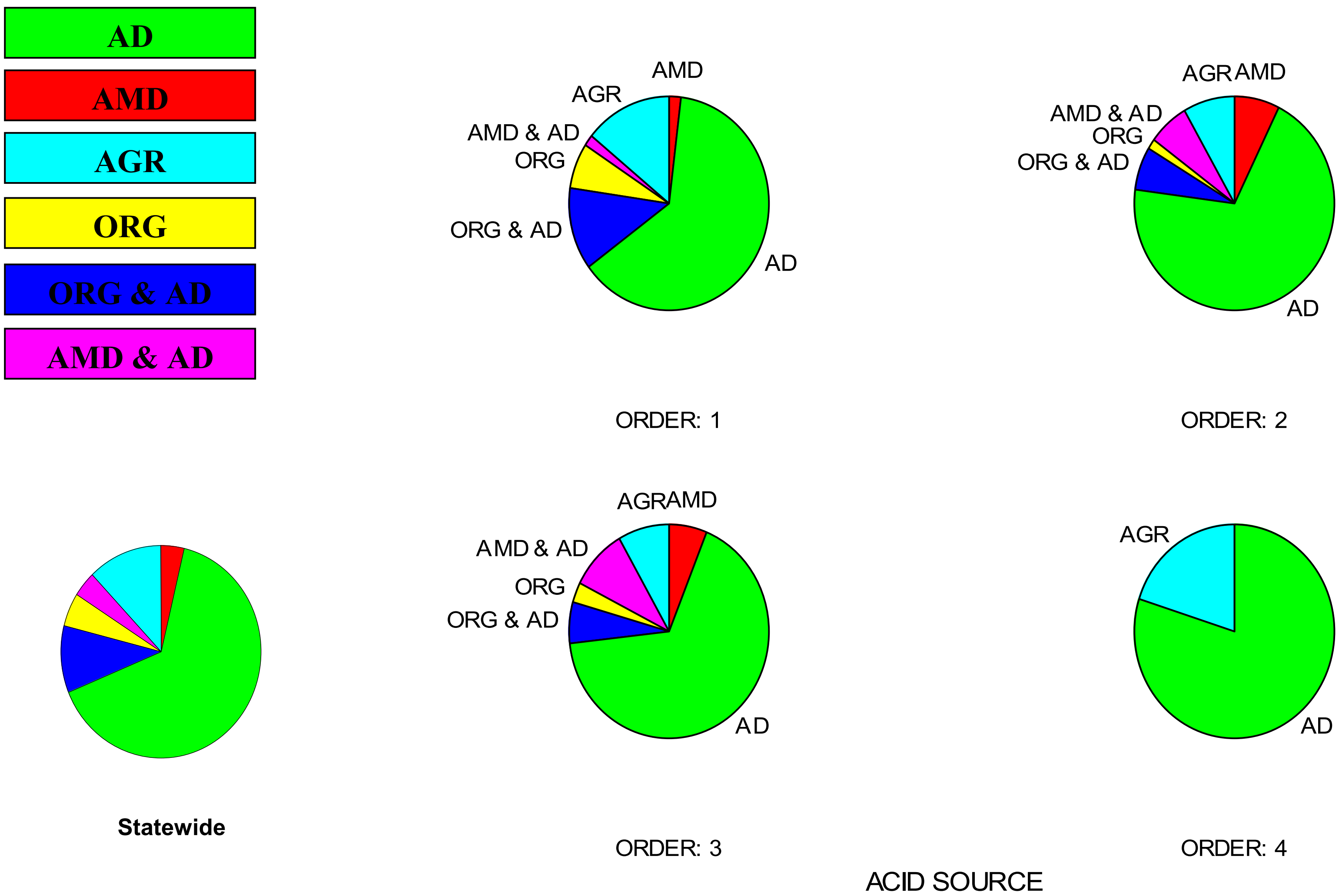


Figure 14-11. Summary of acid sources statewide and by stream order for MBSS sites having an ANC less than 200 µeq/L. (AMD = acid mine drainage; AD = acid deposition; AGR = agriculture; ORG = organic; AMD & AD = mixed sources of acid deposition and acid mine drainage; and ORG & AD = mixed sources of organic and acid deposition).

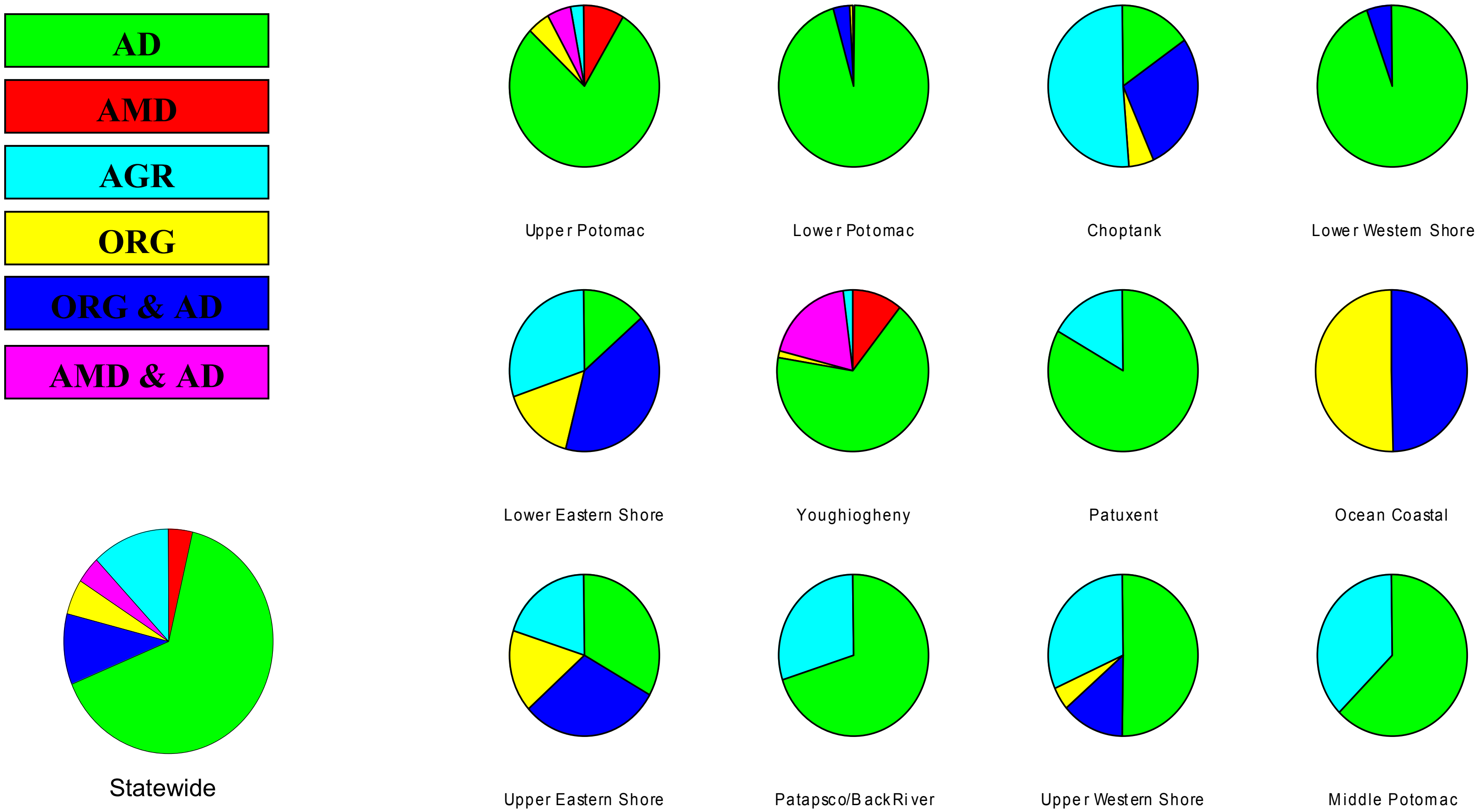


Figure 14-12. Summary of acid sources statewide and by Tributary Strategy Basin (including the Youghiogheny and Ocean Coastal) for MBSS sites having an ANC less than 200 µeq/L. (AMD = acid mine drainage; AD = acid deposition; AGR = agriculture; ORG = organic; AMD & AD = mixed sources of acid deposition and acid mine drainage; and ORG & AD = mixed sources of organic and acid deposition).

Table 14-4. Percentage (and SE) of acidic and acid-sensitive stream miles, as estimated by the 1987 Maryland Synoptic Stream Chemistry Survey (MSSCS) and 2000-2004 MBSS. Estimates are the percentage of stream miles below threshold ANC values, by MSSCS sampling strata.

ANC (μeq/L)	MSSCS SAMPLING STRATA													
	Appalachian Plateau		Valley and Ridge		Blue Ridge		Piedmont		Northern Coastal Plain		Southern Coastal Plain		All	
	N = 139		N = 47		N = 50		N = 125		N = 99		N = 99		N = 559	
	Percent	SE	Percent	SE	Percent	SE	Percent	SE	Percent	SE	Percent	SE	Percent	SE
<0	10.7	3.6	0	0	0	0	0	0	2.1	1.5	7.6	2.9	3.6	0.9
<50	15.7	3.9	0	0	5.8	2.5	0.9	1.0	4.7	2.8	29.3	4.7	10.0	1.4
<200	53.3	4.6	1.5	1.3	26.0	5.7	8.9	3.6	28.3	5.2	74.4	5.0	33.4	2.2
	N = 95		N = 135		N = 124		N = 438		N =		N =		N = 1,387	
<0	9.1	3.9	2.2	1.3	2.6	2.6	0.0	0.0	1.8	1.0	6.9	1.5	2.8	0.5
<50	19.5	4.5	4.3	1.7	8.8	3.6	0.2	0.2	2.8	1.1	20.8	2.6	7.5	0.8
<200	75.8	4.8	30.0	3.7	14.2	6.4	5.8	1.6	27.6	3.8	56.4	3.0	27.3	1.2

episodic acidification during springtime, when larval and juvenile fish are particularly vulnerable to adverse changes in water quality (Carline et al. 1992, Gagen et al. 1994, Heard et al. 1997). The MBSS study design did not focus on sampling during high stream flow events that may have produced low pH episodes. Instead, the MBSS results reflect an indirect relationship between episodic acidification and loss of biotic integrity.

Fish IBI and Fish Biomass - The fish index of biotic integrity (FIBI), recently re-developed (Southerland et al. 2005), provides a quantitative (scores of 1 to 5 with < 3 reflecting degradation) biological indicator based on reference conditions. Different fish IBIs were developed for Coastal Plain, Eastern Piedmont, warmwater Highlands, and Coldwater Highlands, and include 4 to 6 metrics each (e.g., number of benthic species). An analysis of FIBI scores shows a significant decline ($p = 0.001$) at both low pH and low ANC classes (Figure 14-13). The low pH (< 5.5) and low ANC class (< 0) have very low FIBI scores, with both mean FIBI scores below 2.0. As pH and ANC increase, by class, the FIBI improves. The highest ANC class (> 750 μeq/L) had a mean FIBI below 3.0.

Fish biomass (g) varied significantly ($p < 0.001$) with both pH and ANC classes (Figure 14-14). For MBSS sites in the low pH and low ANC classes, mean fish biomass was less than 500 g. As pH and ANC increase, fish biomass increases. In the high pH class and the normal and high ANC classes, fish biomass averages over 3000 g/MBSS site. Normally, gamefish, including brook trout, do not persist where ANC is < 0, therefore their biomass drops to zero in that class.

The MBSS results are merely a snapshot of acidity (pH and ANC) and biological condition at one point in time and do not capture episodic acidification contributing to the uncertainty in the relationship among pH-ANC, the FIBI, and fish biomass.

Benthic IBI, Benthic Taxa, and Ephemoptera, Plecoptera, and Trichoptera (EPT) Taxa - Three measures of the benthic macroinvertebrate community, the benthic IBI (BIBI), also re-developed (Southerland et al. 2005), the number of benthic taxa, and the number of EPT taxa were compared among pH and ANC classes. The BIBI combines 6 to 8 metrics separately for Coastal Plain, Eastern Piedmont, and Highlands, but the number of benthic taxa and EPT taxa are themselves robust indicators of stream condition (Resh and Jackson 1993, Stribling et al. 1998).

The response pattern for the BIBI versus pH and ANC shows declines of both high and low values (Figure 14-15). As expected, the mean BIBI is below 3.0 for the low pH and acidic ANC classes, indicating an acidification effect on the benthic community, above 3.0 for the moderate and high pH classes, and above 3.0 for the chronic, episodic and normal ANC classes. However, for the very high pH class (greater than 7.5) and the high ANC class (greater than 750 μeq/L) the BIBI is well below the 3.0 threshold. This BIBI response may indicate species shifts at higher ANC and pH, not captured by BIBI reference conditions, or it may indicate that there are confounding factors operating at these higher pH and ANC levels.

This same relationship of low benthic scores within both low and high values of pH and ANC is duplicated for both the number of benthic taxa and the number of EPT taxa.

An analysis of the new Physical Habitat Index (PHI) (Paul et al. 2003) indicates that the very high pH class (PHI = 63.1) is significantly lower than observed in the low (74.8), moderate (69.2), and high (68.1) pH classes. For PHI, the high ANC class (60.6) is also significantly lower than the acidic (75.9), chronic (76.2), episodic (71.9) and normal ANC (67.3) classes. This suggests that there are confounding factors influencing biotic responses to acidification in the very high pH and high ANC classes.

Based on comparing pH and ANC to the FIBI, biomass, BIBI, number of benthic taxa, and number of EPT taxa, an ANC threshold of 50 μeq/L (pH = 6.16) is adequate for defining acute and chronic effects of acidification (MacAvoy and Bulger 1995). However, other investigators propose an ANC of 20 μeq/L (pH = 5.72) as a critical tolerance level for fish and invertebrates (Lien et al. 1996).

14.2.6 Fish Tolerance to Low pH Conditions

The presence of fish species at low summer pH (pH < 6.5) MBSS sites indicates which species were most tolerant of summer acidic conditions (Table 14-5). Many of these species were previously reported as tolerant to low pH conditions (Graham 1993, Baker and Christensen 1991, Baker et al. 1990), although not all Maryland fish species were covered by these earlier studies. Interestingly, brook trout are not present below a summer pH of 6.0; this species is often considered to be acid tolerant, being found at pH values as low as 5.2 – 5.3 (Baker et al. 1990, 1996; Carline et al. 1992, Webb et al. 1989). In general, the results for rare species should be interpreted with caution as geographic or other factors may be limiting their occurrence in some pH classes.

Of the 66 species listed (*Lepomis* hybrid is not included in percentages), 12% of the species are found at a summer pH < 5.0, 34% in the pH range of 5.0 to 5.5, 65% in the pH 5.5 to 6.0 range, and 98% in the pH range of 6.0 to 6.5. Low pH tolerant species, for summer MBSS collections, include a number of species such as pirate perch, bluespotted sunfish, and mud sunfish that are

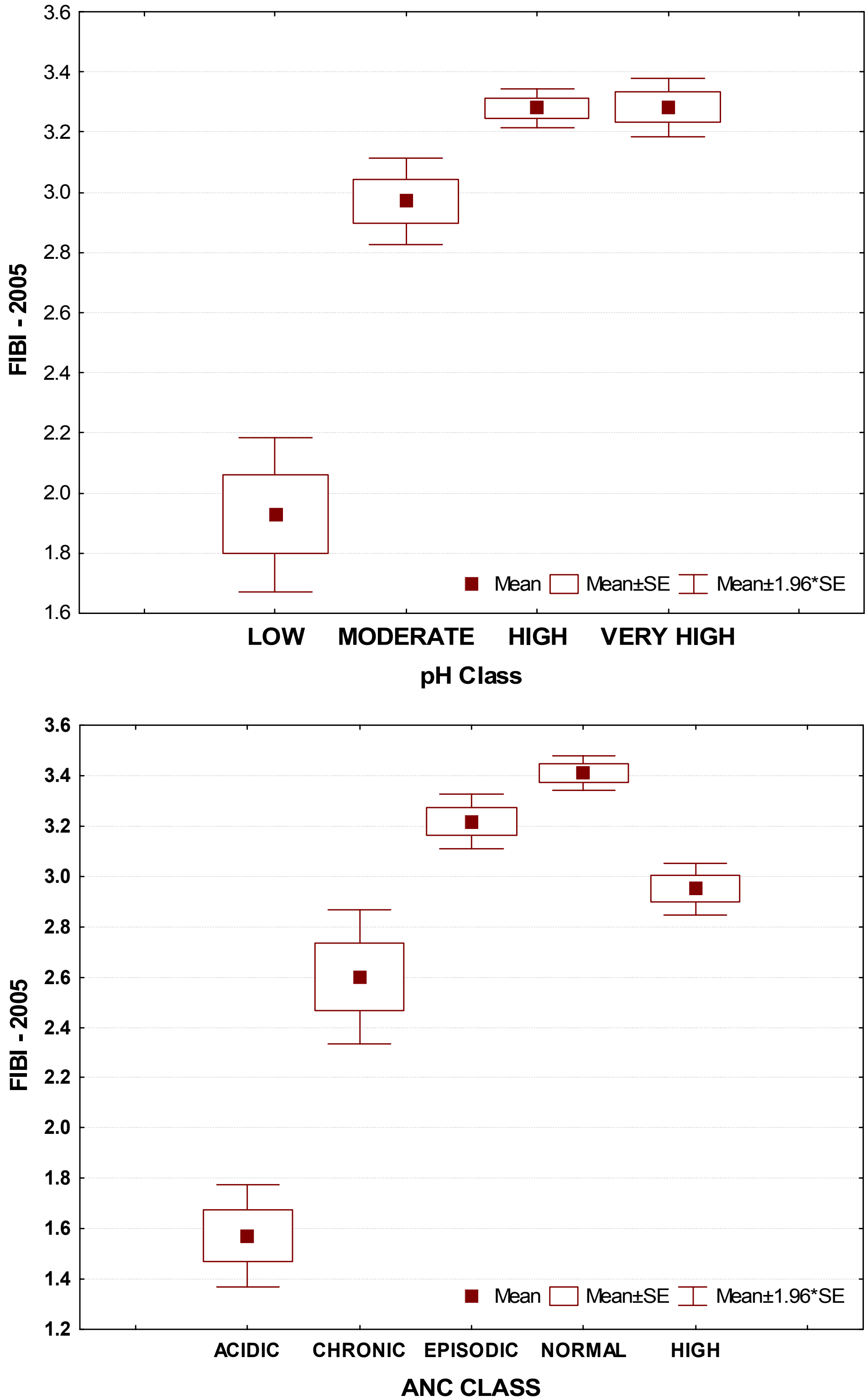


Figure 14-13. Summary of FIBI (2005) for four pH classes (upper) and five ANC classes (below) for MBSS sites. Classes are described in Table 14-1 with the addition of very high pH > 7.5 and high ANC > 750 µeq/L classes.

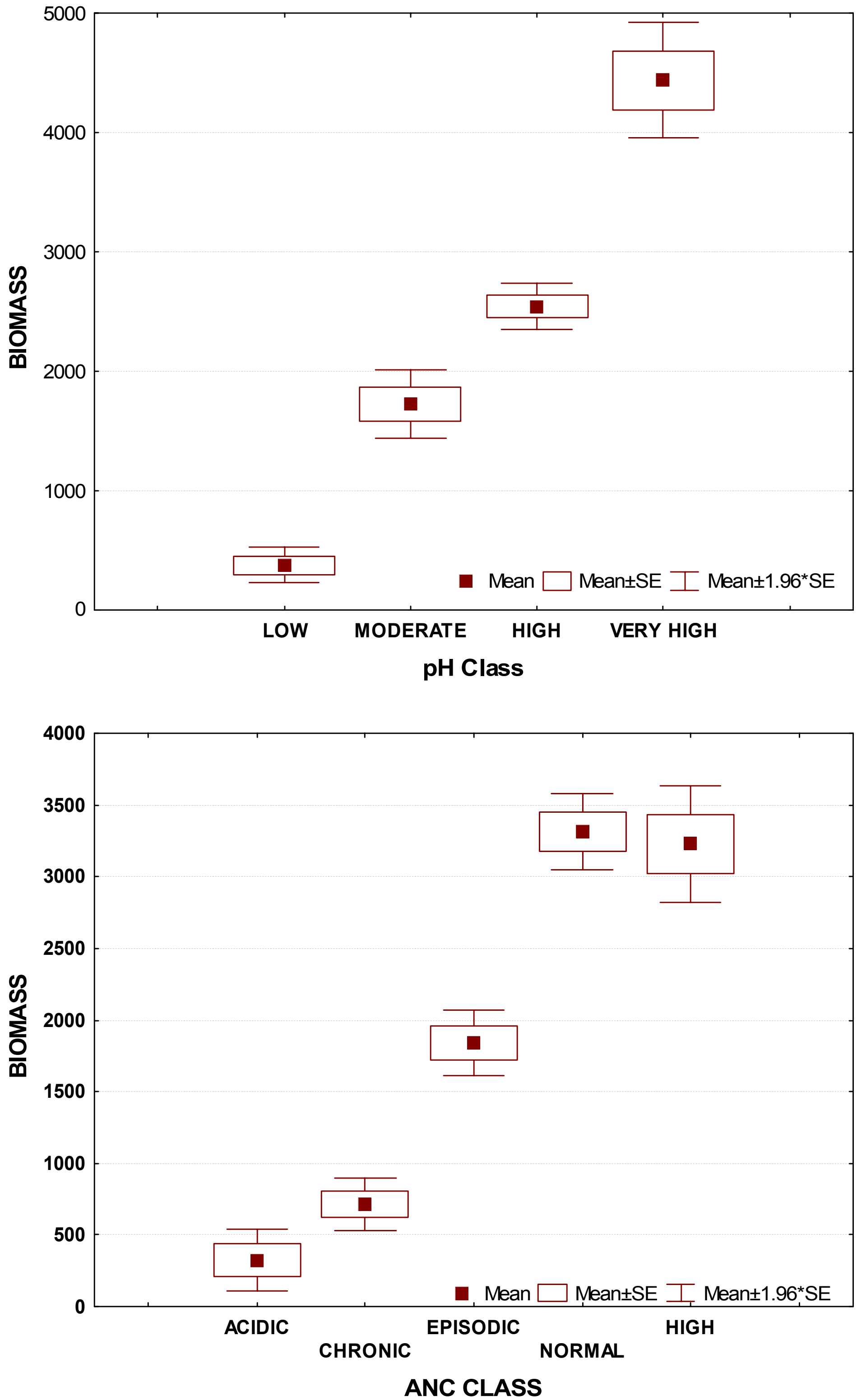


Figure 14-14. Summary of fish biomass (g) for four pH classes (upper) and five ANC classes (below) for MBSS sites. Classes are as described in Table 14-1, with the addition of very high pH > 7.5 and high ANC > 750 µeq/L classes.

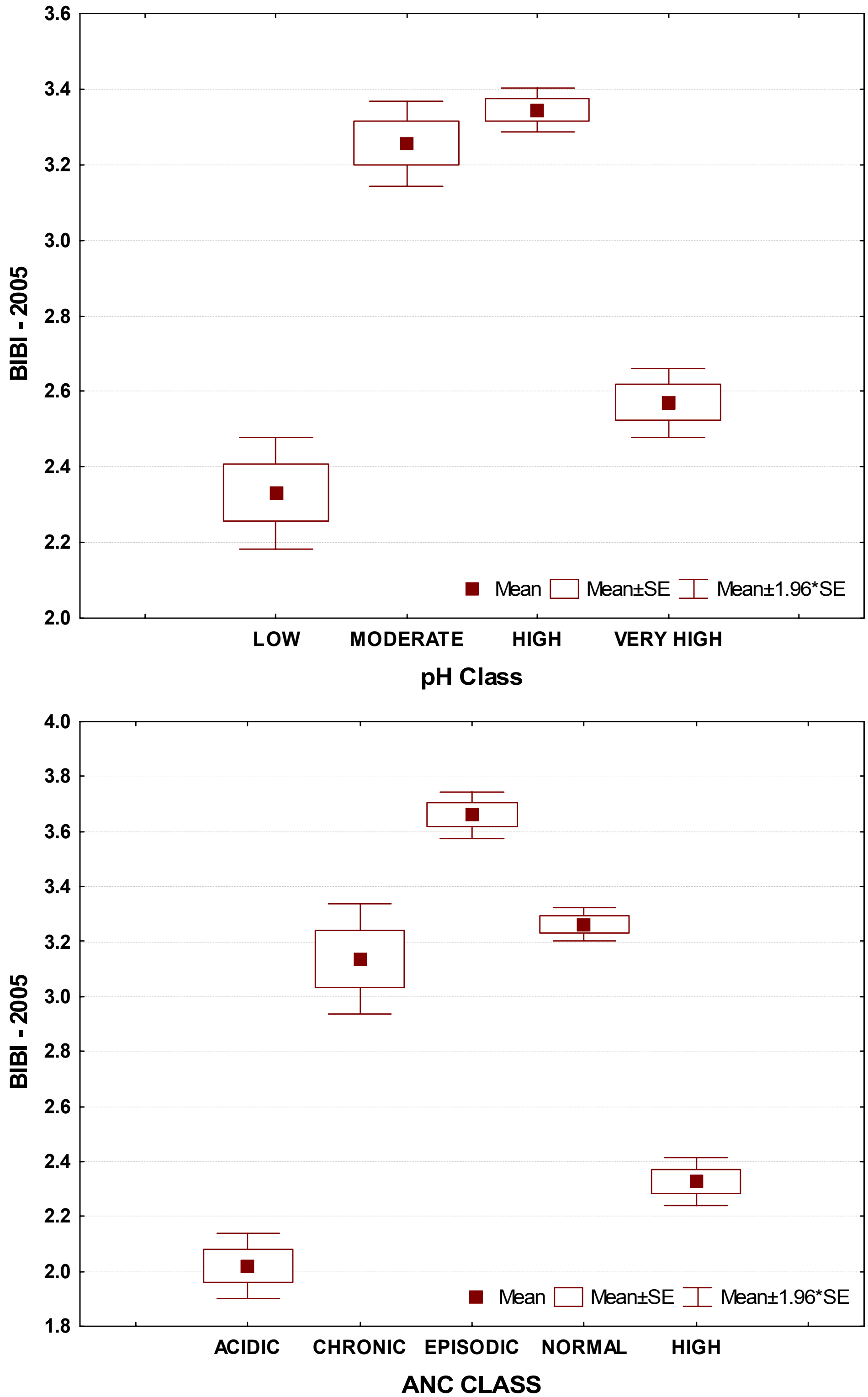


Figure 14-15. Summary of BIBI (2005) for four pH classes (upper) and five ANC classes (below) for MBSS sites. Classes are as described in Table 14-1 with the addition of very high pH > 7.5 and high ANC > 750 μeq/L classes.

Table 14-5. Fish species found at 2000-2004 MBSS sites by summer pH. *Species considered to be game species.

Species	pH < 5	pH 5.0-5.5	pH 5.5-6.0	pH 6.0-6.5
ALEWIFE				X
AMERICAN EEL	X	X	X	X
BANDED KILLIFISH				X
BANDED SUNFISH	X	X	X	X
BLACK CRAPPIE		X	X	X
BLACKNOSE DACE		X	X	X
BLUE RIDGE SCULPIN			X	X
BLUEGILL		X	X	X
BLUESPOTTED SUNFISH	X	X	X	X
BLUNTNOSE MINNOW				X
BROOK TROUT*				X
BROWN BULLHEAD		X	X	X
BROWN TROUT*				X
CENTRAL STONEROLLER				X
CHAIN PICKEREL*		X	X	X
COMELY SHINER			X	
COMMON CARP				X
COMMON SHINER			X	X
CREEK CHUB		X	X	X
CREEK CHUBSUCKER		X	X	X
CUTLIPS MINNOW			X	X
EASTERN MUDMINNOW	X	X	X	X
FALLFISH			X	X
FANTAIL DARTER				X
FATHEAD MINNOW			X	X
FLIER			X	X
GLASSY DARTER				X
GOLDEN REDHORSE				X
GOLDEN SHINER		X	X	X
GOLDFISH				X
GREEN SUNFISH		X	X	X
GREENSIDE DARTER				X
IRONCOLOR SHINER				X
LARGEMOUTH BASS*		X	X	X
LEAST BROOK LAMPREY		X	X	X
LEPOMIS HYBRID				X
LONGNOSE DACE				X
MARGINED MADTOM		X	X	X
MOSQUITOFISH			X	X
MOTTLED SCULPIN				X
MUD SUNFISH	X	X	X	X
NORTHERN HOGSUCKER				X
PIRATE PERCH	X	X	X	X
POTOMAC SCULPIN				X
PUMPKINSEED	X	X	X	X

Table 14-5. (Continued)				
Species	**pH < 5**	**pH 5.0-5.5**	**pH 5.5-6.0**	**pH 6.0-6.5**
RAINBOW TROUT				**X**
REDBREAST SUNFISH		**X**	**X**	**X**
REDFIN PICKEREL	**X**	**X**	**X**	**X**
RIVER CHUB				**X**
ROCK BASS				**X**
ROSYSIDE DACE			**X**	**X**
SATINFIN SHINER			**X**	**X**
SEA LAMPREY			**X**	**X**
SMALLMOUTH BASS				**X**
SPOTFIN SHINER				**X**
SPOTTAIL SHINER			**X**	**X**
STRIPED BASS				**X**
SWALLOWTAIL SHINER			**X**	**X**
SWAMP DARTER			**X**	**X**
TADPOLE MADTOM			**X**	**X**
TESSELLATED DARTER			**X**	**X**
WARMOUTH			**X**	**X**
WHITE PERCH			**X**	
WHITE SUCKER			**X**	**X**
YELLOW BULLHEAD			**X**	**X**
YELLOW PERCH		**X**	**X**	**X**
TOTAL	**8**	**22**	**42**	**64**

found frequently in association with organically enriched acidic streams.

14.2.7 Fish Abundance Under Acidified or Acid Sensitive Conditions

The estimated density of fish (mean number of fish per stream mile) varied by species under acidified and acid-sensitive conditions (Table 14-6). Statewide estimates were calculated for the number of individual fish per stream mile within each of four ANC classes (< 0, 0-50, 50-200, and > 200 µeq/L). Estimates reported here were not adjusted for capture efficiency; it should be noted that the ANC measurement was done during the spring index and fish collection during the summer index period. Across all sites, the number of fish per stream mile declined with low ANC.

Thirty-seven fish species were found in all four of the ANC classes. Dramatic differences were seen in fish species composition and abundance above and below the threshold for acid sensitivity (ANC – 200 µeq/L). For many species, the highest number of stream miles fall into the highest ANC class, although 41 species were collected in the lowest ANC class (Table 14-6). Many species were collected in very low numbers so estimates of individual fish per stream mile are often less than zero.

Given that an estimated 27% of stream miles in the study area had an ANC less than 200 µeq/L, the effects of acidification on many fish populations appear to be significant. It is important to note that this analysis considered only acidification, not other natural (e.g., geographic) or anthropogenic effects on fish abundance. For example, brook trout tend to favor the high-gradient streams of western Maryland, where ANC conditions < 200 µeq/L are common. This geographic difference would explain the apparent increase in brook trout abundance in streams with ANC 50-200 µeq/L, compared to streams in other parts of the state that have ANC > 200 µeq/L but lack suitable habitat for brook trout.

Table 14-6. Mean number of fish per stream mile within each acid neutralizing capacity (ANC - μeq/L) class by species, 2000-2004 MBSS.

Species	ANC ≤ 0	SE	ANC 0 to 50	SE	ANC 50 to 200	SE	ANC > 200	SE
ALEWIFE	0	0	0	0	0	0	4	3
AMERICAN BROOK LAMPREY	0	0	0	0	0	0	2	1
AMERICAN EEL	7	2	8	2	47	8	143	19
BANDED KILLIFISH	0	0	0	0	1	0	10	5
BANDED SUNFISH	2	1	1	1	3	1	3	2
BLACK CRAPPIE	0	0	0	0	1	0	1	1
BLACKNOSE DACE	21	4	45	5	192	17	1,301	77
BLUE RIDGE SCULPIN	9	3	12	4	128	35	649	70
BLUEBACK HERRING	0	0	0	0	0	0	0	0
BLUEGILL	6	2	9	2	41	7	122	20
BLUESPOTTED SUNFISH	6	2	6	2	19	4	22	6
BLUNTNOSE MINNOW	6	4	13	8	24	5	667	285
BROOK TROUT	4	1	3	1	21	4	16	3
BROWN BULLHEAD	9	16	4	5	12	11	25	22
BROWN TROUT	0	0	0	0	2	1	24	10
CENTRAL STONEROLLER	2	1	5	3	32	10	100	25
CHAIN PICKEREL	1	0	1	0	3	1	3	0
CHANNEL CATFISH	0	0	0	0	0	0	0	0
CHECKERED SCULPIN	0	0	0	0	0	0	6	4
COMELY SHINER	0	0	0	0	0	0	1	1
COMMON CARP	0	0	0	0	0	0	0	0
COMMON SHINER	2	1	0	0	9	2	95	18
CREEK CHUB	12	3	15	5	64	10	292	22
CREEK CHUBSUCKER	3	1	6	1	26	5	40	8
CUTLIPS MINNOW	1	0	0	0	4	1	50	7
CUTTHROAT TROUT	0	0	0	0	0	0	0	0
CYPRINID (UNKNOWN)	0	0	0	0	0	0	0	0
CYPRINID HYBRID	0	0	0	0	0	0	0	0
EASTERN MUDMINNOW	71	14	77	13	460	72	750	176
EASTERN SILVERY MINNOW	0	0	0	0	0	0	7	6
FALLFISH	2	1	2	1	20	5	105	30
FANTAIL DARTER	4	2	9	4	35	11	184	39
FATHEAD MINNOW	0	0	0	0	1	1	8	3
FLIER	0	0	0	0	0	0	0	0
GIZZARD SHAD	0	0	0	0	0	0	2	1
GLASSY DARTER	0	0	0	0	0	0	3	3
GOLDEN REDHORSE	0	0	0	0	0	0	1	1
GOLDEN SHINER	6	3	6	2	30	8	39	8
GOLDFISH	0	0	0	0	0	0	0	0
GREEN SUNFISH	2	1	5	2	13	4	88	25
GREENSIDE DARTER	2	1	3	2	8	2	276	518
INLAND SILVERSIDE	0	0	0	0	0	0	0	0
IRONCOLOR SHINER	0	0	0	0	0	0	0	0
JOHNNY DARTER	0	0	1	0	2	1	1	0

Table 14-6. (Continued)								
Species	**ANC ≤ 0**	**SE**	**ANC 0 to 50**	**SE**	**ANC 50 to 200**	**SE**	**ANC > 200**	**SE**
LARGEMOUTH BASS	1	0	1	0	4	1	20	3
LEAST BROOK LAMPREY	3	1	9	3	39	14	81	38
LEPOMIS HYBRID	0	0	0	0	0	0	0	0
LOGPERCH	0	0	0	0	0	0	0	0
LONGEAR SUNFISH	0	0	0	0	1	0	1	0
LONGNOSE DACE	2	1	3	1	38	13	231	28
MARGINED MADTOM	1	1	1	1	17	10	61	35
MOSQUITOFISH	1	1	2	1	7	5	30	12
MOTTLED SCULPIN	9	2	9	3	44	12	13	4
MUD SUNFISH	0	0	0	0	0	0	0	0
MUMMICHOG	0	0	0	0	1	1	21	10
NORTHERN HOGSUCKER	0	0	1	0	3	1	25	6
NOTROPIS SP.	0	0	0	0	0	0	0	0
PEARL DACE	0	0	1	1	0	0	14	11
PIRATE PERCH	10	4	10	4	60	22	88	84
POTOMAC SCULPIN	1	0	2	1	21	6	140	38
PUMPKINSEED	5	2	4	1	23	4	65	14
RAINBOW DARTER	0	0	0	0	17	7	10	3
RAINBOW TROUT	0	0	0	0	0	0	1	0
REDBREAST SUNFISH	1	0	2	1	14	2	67	10
REDFIN PICKEREL	6	2	7	3	29	9	21	4
RIVER CHUB	0	0	0	0	26	17	105	68
ROCK BASS	0	0	1	0	10	3	10	2
ROSYFACE SHINER	0	0	0	0	2	1	18	9
ROSYSIDE DACE	5	1	3	1	25	4	267	25
SATINFIN SHINER	1	1	0	0	4	1	35	9
SEA LAMPREY	0	0	0	0	4	2	30	14
SHIELD DARTER	0	0	0	0	0	0	6	2
SHORTHEAD REDHORSE	0	0	0	0	0	0	0	0
SILVERJAW MINNOW	1	1	2	2	0	0	53	33
SMALLMOUTH BASS	0	0	0	0	9	2	21	4
SPOTFIN SHINER	0	0	0	0	7	3	41	21
SPOTTAIL SHINER	2	1	3	2	2	1	260	192
STRIPED BASS	0	0	0	0	0	0	0	0
STRIPED SHINER	0	0	0	0	0	0	0	0
SUNFISH (UNKNOWN)	0	0	0	0	0	0	0	0
SUNFISH HYBRID	0	0	0	0	0	0	0	0
SWALLOWTAIL SHINER	1	1	1	0	6	2	90	20
SWAMP DARTER	0	0	0	0	1	0	0	0
TADPOLE MADTOM	2	1	2	2	11	8	7	7
TESSELLATED DARTER	18	9	9	3	77	12	429	56
WARMOUTH	0	0	1	0	2	1	1	1
WHITE CATFISH	0	0	0	0	0	0	0	0
WHITE PERCH	0	0	0	0	0	0	0	0

Table 14-6. (Continued)

Species	ANC ≤ 0	SE	ANC 0 to 50	SE	ANC 50 to 200	SE	ANC > 200	SE
WHITE SUCKER	7	1	5	1	31	6	280	27
YELLOW BULLHEAD	1	1	1	1	5	2	21	9
YELLOW PERCH	0	0	0	0	0	0	1	1
Species Number	**41**		**42**		**57**		**69**	

14.3 NUTRIENTS

This section presents water quality results relating to nutrient and dissolved oxygen concentrations from the 1995-1997 and 2000-2004 MBSS. Levels of nitrate (as NO_3-N), nitrite (as NO_2-N), ammonia (as NH_3-N), total nitrogen, total phosphorus, ortho-phosphate, and dissolved oxygen (DO) are examined for first- (N = 845), second- (N = 265) and third-order (N = 140) streams in each basin sampled in the 2000-2004 MBSS (in the second MBSS round, only 39 fourth-order sites were sampled). In addition, the 1995-1997 MBSS sampled 325 first-order, 332 second-order, and 297 third-order streams for water quality for a total of 2243 streams sampled over eight years.

14.3.1 Background Information on Nutrients

In aquatic systems, nutrients such as nitrogen and phosphorus (and major elements such as carbon, oxygen and sulfur and trace elements such as calcium, magnesium, potassium, sodium, etc.) are essential for life (Allan 1995). Without human influence, streams contain background levels of nitrogen and phosphorus essential to the survival of autotrophic, and also heterotrophic, organisms within that basin. However, over the last four hundred years, nutrient loading in many stream systems increased, resulting from anthropogenic influences such as agricultural runoff, wastewater discharge, atmospheric deposition, and urban/suburban point and non-point sources (Galloway et al. 2003). Increased sediment loading and elevated stream temperatures affect nutrient processing in aquatic systems (Walters 1995).

Elevated nitrogen concentrations contribute to nutrient enrichment in aquatic systems, with reactive nitrogen accumulating at all spatial scales (Galloway et al. 2003). Excessive nitrogen loading may lead to the eutrophication of water bodies, particularly in lakes or downstream estuaries. Eutrophication often decreases the level of dissolved oxygen available to aquatic organisms, with a prolonged exposure to low dissolved oxygen values suffocating adult fish or leading to reduced recruitment. Increased nutrient loads are also thought to be harmful to humans by causing toxic algal blooms and contributing to outbreaks of toxic organisms such as *Pfiesteria piscicida* in the Chesapeake Bay. Besides contributing to a loss of biodiversity and habitat degradation in coastal ecosystems, reactive nitrogen also contributes to impacts on human and ecosystem health (Galloway et al. 2003). There is a constant biotic struggle to capture phosphorus, an element that is limiting in freshwater systems (Allan 1995). Although the phosphorus cycle is not nearly as complex as stream nitrogen dynamics, it is important to consider in freshwater systems, where excessive total phosphorus may be present, since it may accelerate eutrophication, and alter stream processing of materials.

In Maryland, concern for nutrient loadings to the Chesapeake Bay has drawn attention to the amounts of materials transported throughout the basin by stream tributaries. In the Chesapeake Bay basin, the largest source of nitrogen is from agriculture (estimated as 39% of total nitrogen). Other contributors include point sources (23%), runoff from developed areas (9%) and forests (18%), and direct atmospheric deposition to the Chesapeake Bay (11%). The total contribution of atmospheric deposition is higher (27%), including amounts deposited to the basin and subsequently entering the Chesapeake Bay as runoff (Chesapeake Bay Program 1995). Atmospheric deposition is therefore recognized as a significant contributor of nitrogen to the Chesapeake Bay, including deposition reaching the basin from power plants and other distant sources within the airshed (Dennis 1996).

The MBSS provides a large dataset for assessing nutrient concentrations under spring baseflow conditions. Although a full understanding of nutrient loadings also requires data collected over multiple years and seasons, the MBSS water chemistry results provide extensive spatial coverage (with nearly 2250 sites sampled), enabling nutrient concentrations to be compared among basins statewide. In the 2000-2004 MBSS, the more complete set of nutrient analyses allows for a more intensive and extensive assessment.

14.3.2 Results of Nutrient Assessment

In the 2000-2004 MBSS, concentrations of several nutrients were determined during the spring baseflow period, as well as summer stream dissolved oxygen (Table 14-7). Thresholds for these nutrients and dissolved oxygen were estimated by examining statistical

Table 14-7. MBSS water quality thresholds for nutrients and dissolved oxygen measured in 2000-2004 MBSS. Both nitrate and dissolved oxygen were also measured in 1995-1997. All units are in mg/l.

Parameter	Low	Moderate	High
Nitrate–N	< 1.0	1.0 – 5.0	> 5.0
Nitrite–N	< 0.0025	0.0025 – 0.01	> 0.01
Ammonia-N	< 0.03	0.03 – 0.07	> 0.07
TN	< 1.5	1.5 – 7.0	>7.0
TP	< 0.025	0.025 – 0.070	> 0.070
Othro-PO_4	< 0.008	0.008 – 0.03	> 0.03
Dissolved Oxygen	< 3	3-5	> 5

distributions of each nutrient, employing basins with greater than 90% forest as a reference – the thresholds for dissolved oxygen are identical to those used in 1995-1997. For all box and whisker plots, the absence of a mean box indicates that no samples were collected for that basin-stream order combination; a mean box without the mean ± SE box or whiskers indicates that a single sample was collected for that basin-stream order combination. For the ten Maryland tributary strategy basins (excluding the Youghiogheny and Ocean Coastal basins), nutrient analyses were broken down by seven basin areas: < 500 acres (202 ha); 500-1,000 acres (202-405 ha); 1,000-2,500 acres (405–1,012 ha); 2,500-5,000 acres (1,012-2,024 ha); 5,000-10,000 acres (2,024-4,047 ha); 10,000-20,000 acres (4,047-8,094 ha); and greater than 20,000 acres (>8,094 ha).

14.3.2.1 Nitrate

The majority of the MBSS basins, by stream order, have nitrate concentrations (all nitrate values measured as nitrate-nitrogen) greater than the threshold value between low (< 1.0 mg/l) and moderate (1-5 mg/l) nitrate concentrations (Table 14-7 and Figure 14-16). However, no basin had a mean nitrate concentration greater than 5 mg/l (Figure 14-16). For first-order MBSS streams, 14 basins had mean nitrate levels greater than 1 mg/l, with only the North Branch of the Potomac River, West Chesapeake, and Youghiogheny basins being less than the nitrate threshold value. In second-order MBSS streams, 14 basins had moderate nitrate levels and four basins had nitrate levels less than 1.0 mg/l (Figure 14-16), paralleling the same pattern seen in the third-order streams for the same basins (only one third-order stream sampled in the Nanticoke-Wicomico basin). Limited nitrate data exist for fourth-order streams in the MBSS, but the Gunpowder, Middle Potomac, Patuxent and Lower Susquehanna exceeded the 1.0 mg/l threshold (single point estimates not included). Three basins had mean nitrate levels greater than 4.0 mg/l – these include the second-order streams in the Nanticoke-Wicomico basin and third-order streams in the Chester and Lower Susquehanna basins (Figure 14-16). For all first- through third-order streams, there are four basins (Lower Potomac, North Branch, West Chesapeake, and Youghiogheny) with mean nitrate concentrations less than 1.0 mg/l (the North Branch and the Upper Potomac nitrate values are less than 1.0 mg/l for fourth-order streams).

Nitrate-nitrogen was measured in both MBSS rounds so comparisons may be made of nitrate concentration over time by 8 digit basin (Table 14-8 and Figure 14-18). There was a significant reduction in stream nitrate concentration from the first (2.4 mg/l) to the second round (1.8 mg/l), as reflected in the difference in median values (Table 14-8). This nitrate difference is better illustrated in Figure 14-17, where there is a significant difference in nitrate levels for the first- and third-order streams for each of the two MBSS rounds. Analysis by basin (Ocean Coastal was not sampled in 1995-1997 MBSS) for each MBSS round also reveals the same nitrate pattern (Figure 14-18). There were general declines in mean nitrate levels in all basins that had elevated mean nitrate concentrations (note that the North Branch, West Chesapeake, and Youghiogheny basins were less than 1.0 mg/l). Reasons for these decreases in nitrate may be related to decreased atmospheric nitrogen deposition, a reduction in fertilizer use (perhaps due to improved cover crop management, or implemented agricultural nutrient management plans with BMPs), remediation of septic systems, or restoration of riparian corridors (CREP program and others). They may also be an artifact of the greater number of small streams sampled in 2000-2004.

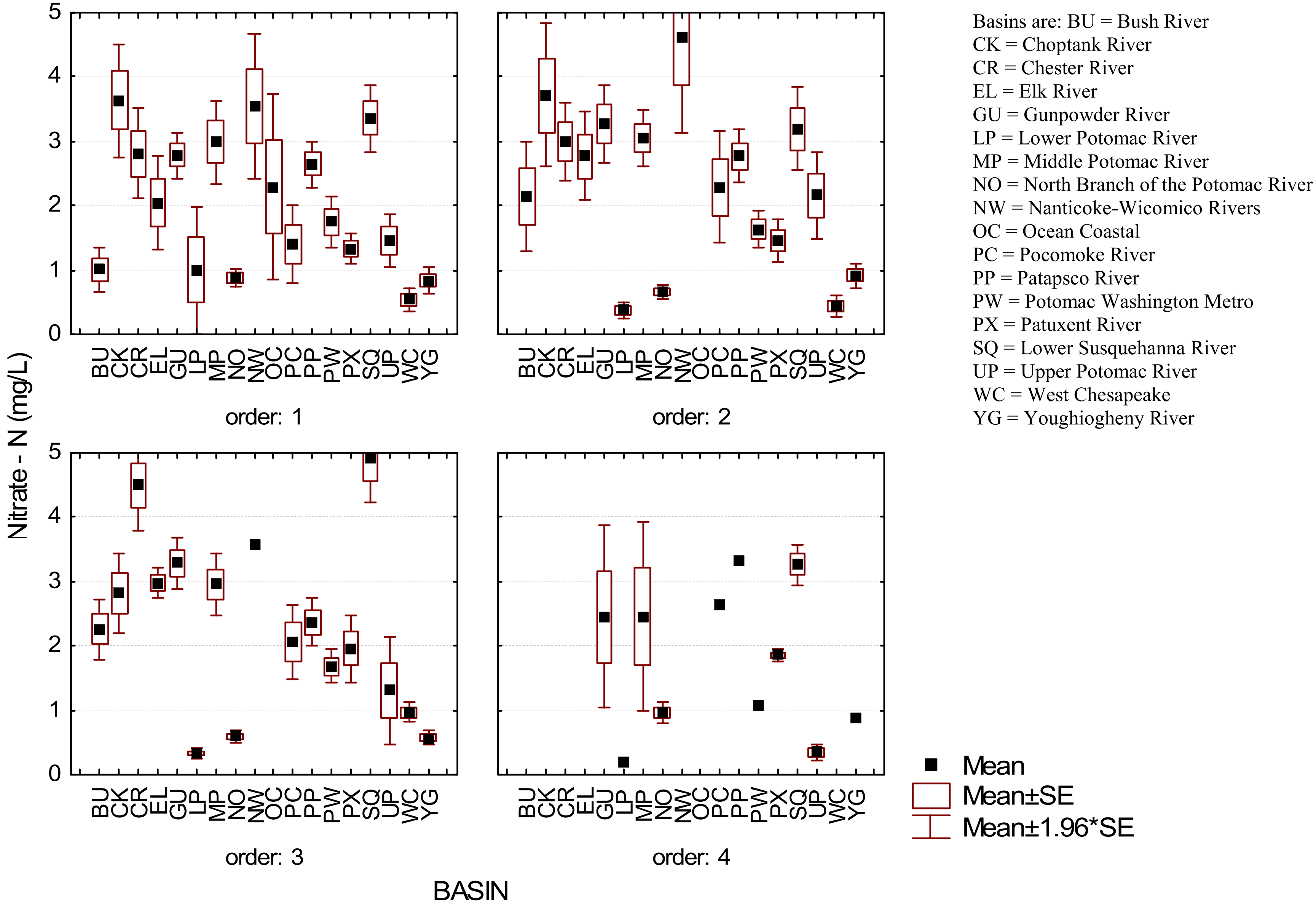


Figure 14-16. Nitrate-nitrogen (mg/l) concentration for all basins by stream order (1-4) for 1995-2004 MBSS

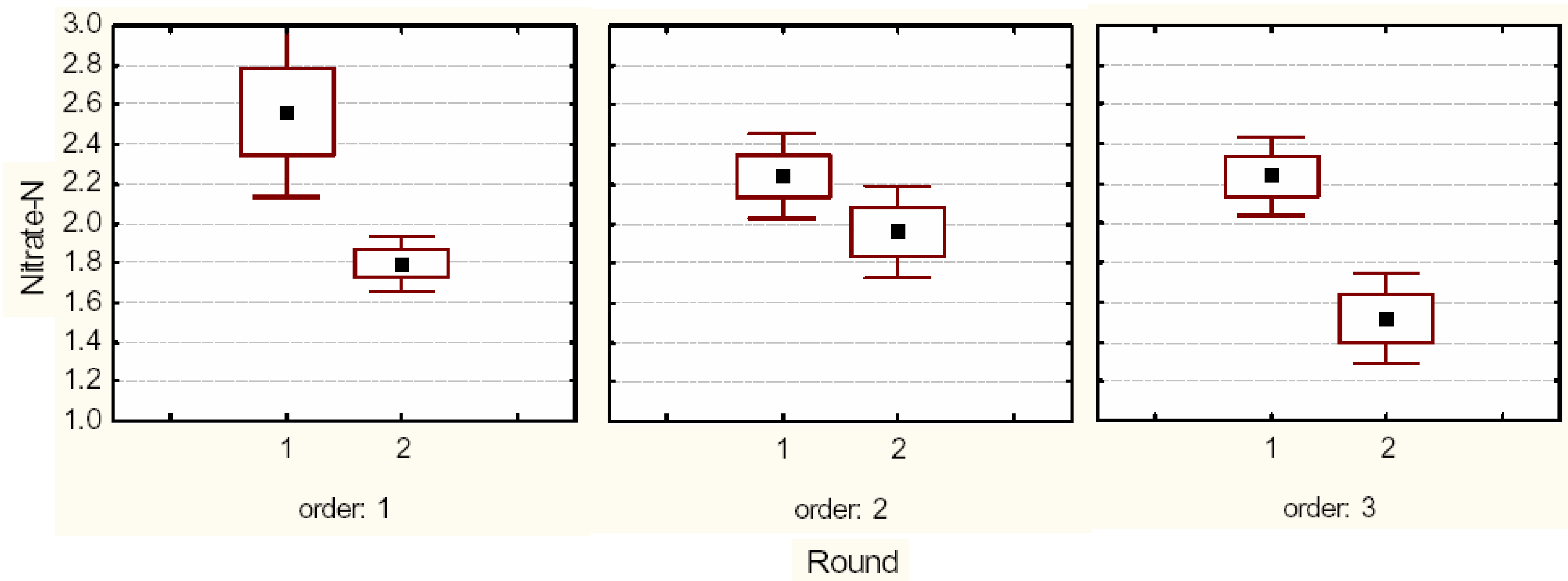
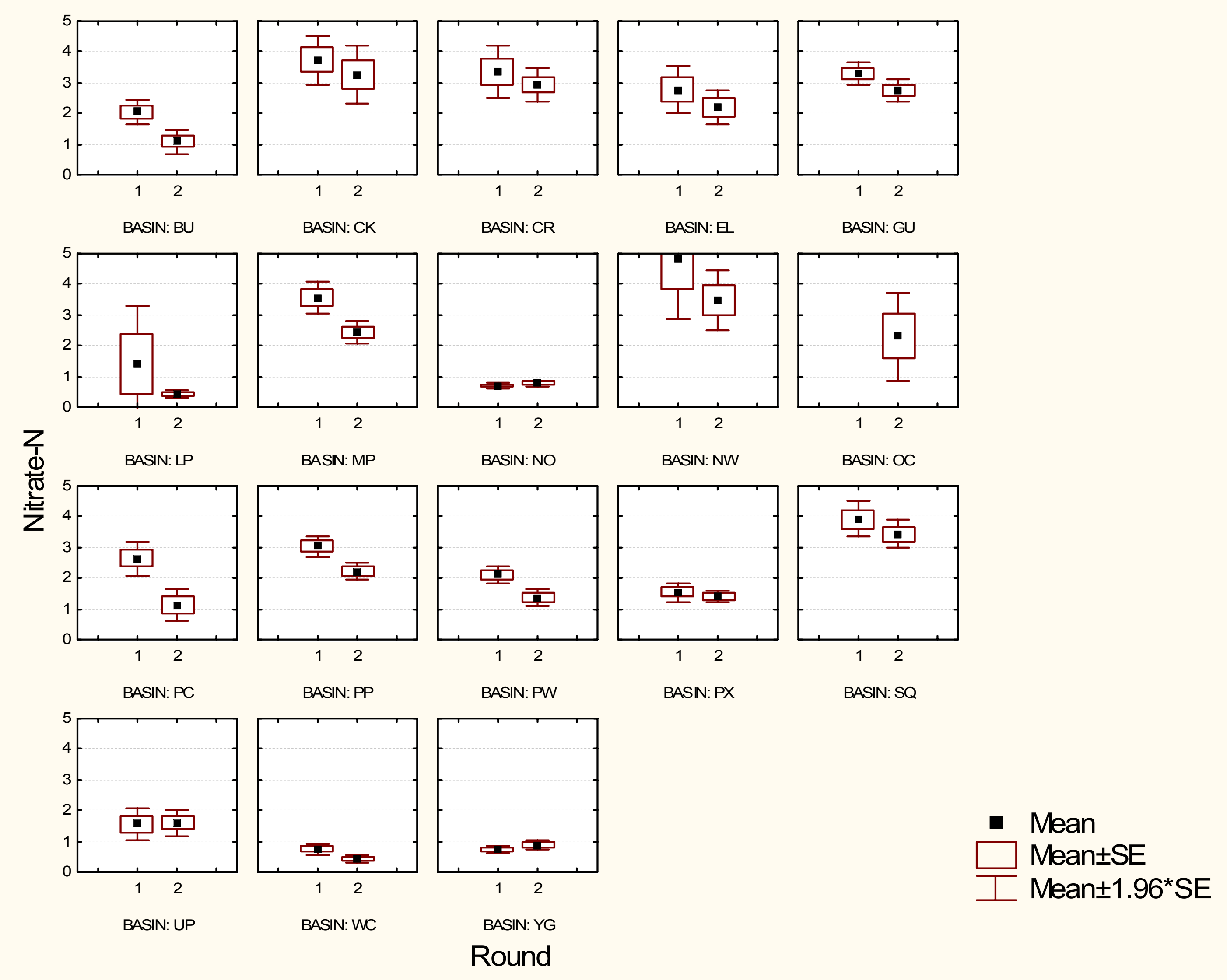


Figure 14-17. Nitrate-nitrogen (mg/l) concentration by MBSS round (Round 1 and Round 2) for stream order (1-3).



Basins are: BU = Bush River; CK = Choptank River; CR = Chester River; EL = Elk River; GU = Gunpowder River; LP = Lower Potomac River; MP = Middle Potomac River; NO = North Branch of the Potomac River; NW = Nanticoke-Wicomico Rivers; OC = Ocean Coastal; PC = Pocomoke River; PP = Patapsco River; PW = Potomac Washington Metro; PX = Patuxent River; SQ = Lower Susquehanna River; UP = Upper Potomac River; WC = West Chesapeake; and YG = Youghiogheny River.

Figure 14-18. Nitrate-nitrogen (mg/l) concentration by MBSS round (Round 1 and Round 2) for all basins.

Table 14-8. Summary of nutrient parameters for MBSS water quality collected during spring baseflow in first- through third-order streams (Round One = 1995-1997; Round Two = 2000-2004); all units = mg/l

Parameter	Mean	Median	SE	25% Percentile	75% Percentile	N
Nitrate-N	2.06	1.35	0.050	0.52	2.98	2190
Round One	2.36	1.65	0.089	0.63	3.38	949
Round Two	1.82	1.14	0.055	0.41	2.68	1241
Nitrite-N	0.0078	0.0046	0.00033	0.0016	0.0097	1140
Ammonia-N	0.049	0.015	0.0048	0.0065	0.039	1212
Total N	2.09	1.40	0.057	0.65	3.01	1266
Total P	0.041	0.020	0.0022	0.011	0.043	1266
Ortho-PO_4	0.012	0.0037	0.0015	0.00070	0.0088	1232

For all Chesapeake Bay tributary strategy basins, and the Youghiogheny and Ocean Coastal basins, four basins exceeded 10% of stream km for the high nitrate-nitrogen threshold of 5 mg/l (Table 14-9). The Lower Eastern Shore and the Choptank had greater than 15% of stream km above the high nitrate threshold, while all basins had greater than 50% of stream km above the moderate threshold. The Lower Eastern Shore, Lower Western Shore, and the Lower Potomac had the highest percentages (14.3 – 34.7) of stream km in the low category (Table 14-9).

In the 1995-1997 MBSS, the majority of stream km (59%) had NO_3-N concentrations greater than 1.0 mg/l. An estimated 41% of stream km had NO_3-N concentrations between 0.1 mg/l and 1.0 mg/l, and only 0.4% had concentrations that were less than 0.1 mg/l. Only three basins had any stream km (< 5%) with less than 0.1 mg/l of NO_3-N: the Upper Potomac, the Lower Potomac, and the West Chesapeake. An estimated 29% of stream km had a NO_3-N concentration greater than 3.0 mg/l and an estimated 5% of stream km had a NO_3-N concentration greater than 7.0 mg/l. Areas where the concentration is greater than 7.0 mg/l are places where NO_3-N may be especially detrimental to stream quality. These areas occurred in seven of the basins sampled: Upper Potomac, Middle Potomac, Lower Potomac, Patuxent and Patapsco (1995 and 1997 sampling).

Of 2190 nitrate-nitrogen measurements made in both MBSS rounds, only 0.87% (N = 19) exceeded the U. S. Environmental Protection Agency (EPA) Maximum Contaminant Level of 10 mg/l of nitrate-nitrogen (criteria for ground water and drinking water). The highest stream nitrate measured was 52.7 mg/l.

14.3.2.2 Nitrite

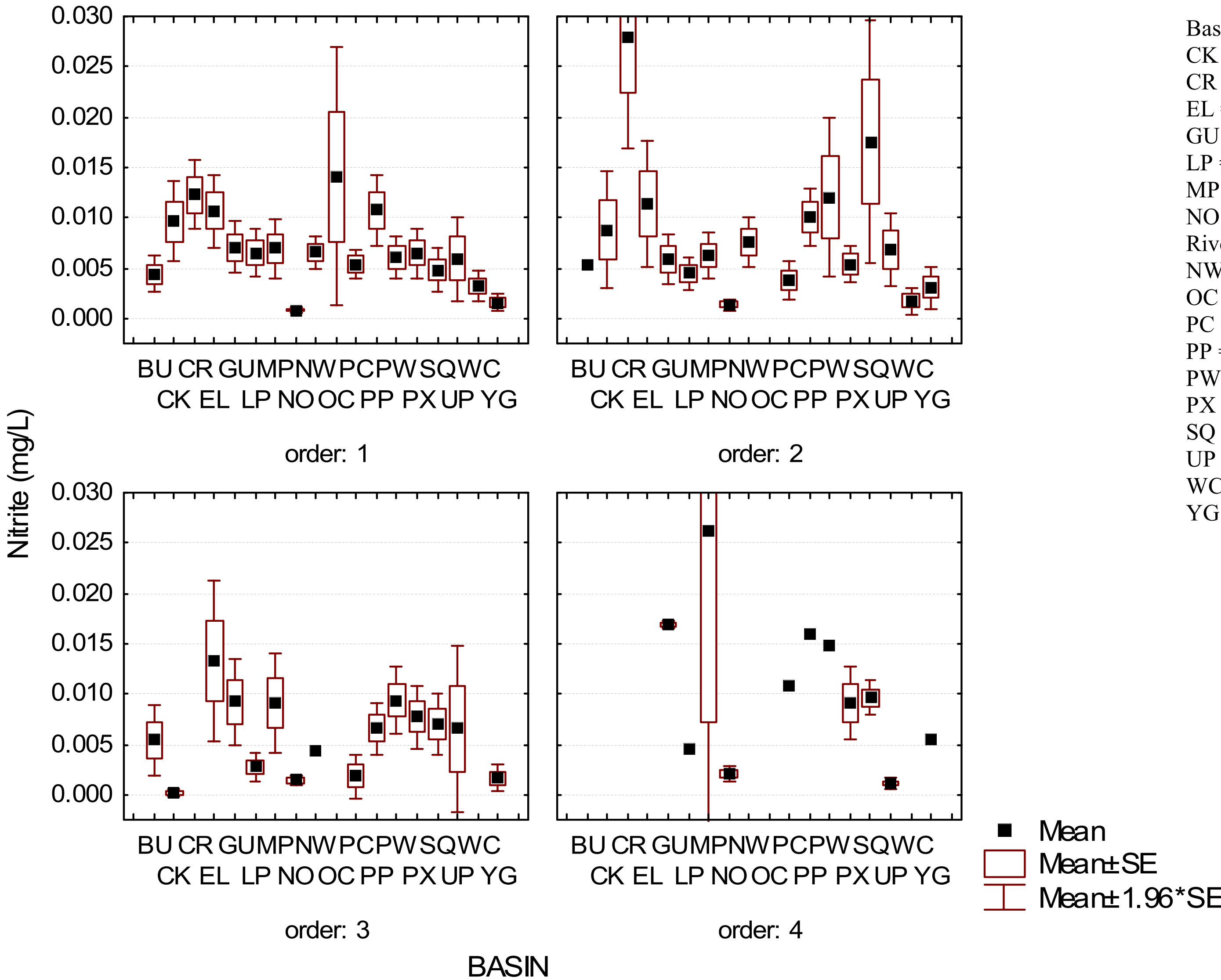
Nitrite (as nitrite-nitrogen) was first measured in the 2000-2004 MBSS, with values for many basins, by stream order, exceeding the low/moderate cutoff threshold of 0.0025 mg/l (Table 14-7). Five basins for first-order streams, six basins for second-order streams, three basins for third-order streams, and three fourth-order streams (only those with adequate sample size considered) exceeded the upper threshold of 0.010 mg/l (Figure 14-19). Of the 18 MBSS basins, only the North Branch and Youghiogheny had mean nitrite values less than 0.0025 mg/l in the first-order streams. For second-order streams, only the North Branch and West Chesapeake basins were below the 0.0025 mg/l threshold: for third-order streams, the North Branch, Pocomoke West Chesapeake and Youghiogheny basins had low nitrite levels. A limited number of fourth-order streams were sampled in the second MBSS round, but for those basins with adequate sample sizes (GU, MP, NO, PX, SQ, and UP – Figure 14-19), only the North Branch (NO) and the Upper Potomac (UP) were below the 0.0025 mg/l nitrite threshold.

For all Chesapeake Bay tributary strategy basins, and the Youghiogheny and Ocean Coastal basins, seven basins exceeded the high nitrite-nitrogen threshold of 0.01 mg/l with greater than 20% of stream km (Table 14-9). Two basins had > 50% of stream km in the moderate threshold. The Youghiogheny (81%) and Lower Western Shore (63%) had the highest percentages of stream km in the low threshold category (Table 14-9).

Of 1,140 nitrite-nitrogen measurements made in the 2000-2004 MBSS, no samples exceeded the U.S. Environmental Protection Agency Maximum Contaminant Level of 1 mg/l of nitrite-nitrogen (criteria for ground water and drinking water). The highest stream nitrite measured was 0.15 mg/l, with an overall mean nitrite of 0.0078 mg/l (Table 14-8).

Table 14-9. Percentage of stream km within each threshold category as defined in Table 14-7 for nutrients and dissolved oxygen for all tributary strategy basins. The Youghiogheny and Ocean Coastal basins are included but their drainages are not part of the Chesapeake Bay basin.

		Basin											
Analyte (mg/l)	**Threshold**	**Lower Eastern Shore**	**Choptank**	**Upper Eastern Shore**	**Upper Western Shore**	**Patapsco/ Back River**	**Lower Western Shore**	**Patuxent**	**Lower Potomac**	**Middle Potomac**	**Upper Potomac**	**Youghiogheny**	**Ocean Coastal**
Nitrate-N	Low	14.3	4.0	4.4	2.2	1.2	17.1	7.0	34.7	3.8	5.4	1.7	
	Moderate	65.8	67.6	87.1	87.8	92.6	82.9	93.0	65.3	90.3	90.2	98.3	88.9
	High	19.9	28.4	8.6	10.0	6.2				5.8	4.5		11.1
Nitrite-N	Low	26.2	33.7	9.5	21.7	13.5	62.7	31.0	37.9	19.2	54.9	80.7	
	Moderate	53.9	23.6	39.8	53.3	41.5	34.3	52.1	49.2	48.6	26.9	19.3	77.8
	High	19.9	42.7	50.7	25.0	45.0	3.0	16.9	12.9	32.2	18.2		22.2
Ammonia-N	Low	58.9	56.8	45.4	83.4	65.9	47.4	39.1	63.6	73.6	88.0	94.1	77.8
	Moderate	24.8	7.1	28.5	7.1	17.9	33.6	42.4	23.3	11.1	3.7	4.3	11.1
	High	16.3	36.2	26.1	9.6	16.2	19.0	18.5	13.1	15.2	8.3	1.7	11.1
TN	Low	46.9	15.6	20.8	14.1	27.5	96.4	65.3	89.0	46.4	49.9	82.1	33.3
	Moderate	39.0	65.7	72.5	81.8	71.5	3.6	34.7	11.0	51.6	47.0	17.9	55.6
	High	14.1	18.7	6.8	4.1	1.0				1.9	3.1		11.1
TP	Low	47.0	9.1	12.3	65.9	72.5	24.5	34.7	62.2	60.4	68.6	87.9	11.1
	Moderate	28.3	64.4	45.4	25.4	19.2	47.0	35.1	28.2	34.5	20.9	12.1	44.4
	High	24.7	26.5	42.3	8.8	8.3	28.4	30.2	9.7	5.1	10.6		44.4
Ortho-PO_4	Low	55.7	33.3	44.8	67.6	76.3	77.0	74.7	76.5	83.4	73.0	100	11.1
	Moderate	29.6	46.1	38.7	26.9	19.8	23.0	21.9	23.5	11.1	15.8		22.2
	High	14.7	20.5	16.6	5.6	3.9		3.4		5.5	11.2		66.7
DO	Low	21.4	16.4	7.0	1.2	2.1	7.5	2.0	10.8	0.5			
	Moderate	27.2	8.9	8.3	8.3	2.4	12.3	1.6	8.4	2.5	3.3	4.3	14.3
	High	51.3	74.8	84.7	90.5	95.5	80.2	96.4	80.8	96.9	96.7	95.7	85.7



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PP = Patapsco River
PW = Potomac Washington Metro
PX = Patuxent River
SQ = Lower Susquehanna River
UP = Upper Potomac River
WC = West Chesapeake
YG = Youghiogheny River

Figure 14-19. Nitrite-nitrogen (mg/l) concentration for all basins by stream order (1-4) for 1995-2004 MBSS.

14.3.2.3 Ammonia

Ammonia (as ammonia-nitrogen) was also measured in the 2000-2004 MBSS; values for ammonia for all basins and all four stream orders often exceeded the low/moderate cutoff concentration of 0.03 mg/l (Table 14-7 and Figure 14-20). For first-order streams, 13 basins exceeded the low threshold; five basins were below the low ammonia threshold (Figure 14-20). Eleven basins had ammonia levels above the threshold for second-order streams, with only three third-order streams exceeding the low threshold. For fourth-order streams (with adequate samples size), only the Middle Potomac exceeded the low ammonia threshold. There were several basins that exceeded the high cutoff (> 0.07) for ammonia; five basins were greater than the threshold for first-order streams, one for second order, none for third-order, and one – the Middle Potomac – for fourth-order streams. Of 1,212 ammonia-nitrogen measurements made in the 2000-2004 MBSS, the highest stream ammonia value measured was 2.8 mg/l, with overall mean ammonia of 0.049 mg/l (Table 14-8).

For all Chesapeake Bay tributary strategy basins, and the Youghiogheny and Ocean Coastal basins, seven basins had > 15% of stream km in the high ammonia threshold of 0.07 mg/l, with nine basins having greater than 50% of stream km in the low threshold category (Table 14-9). The Upper Potomac and Youghiogheny basins had > 80% of their stream km in the low category.

14.3.2.4 Total Nitrogen

Total nitrogen (TN), first measured in the 2000-2004 MBSS, varied over all basins for all stream orders (Figure 14-21). Eleven basins, for first-order streams, exceeded the TN threshold of 1.5 mg/l, with twelve basins (second-order streams) also greater than the low TN threshold. Eleven third-order stream basins exceeded the TN threshold, along with four fourth-order basins (Figure 14-21). No basin, for any stream order, was greater than the high threshold of 7.0 mg/l TN, although several basins were obviously elevated for TN (Figure 14-21). Of 1266 TN measurements made in the second MBSS round, the highest stream value measured was 15.5 mg/l, with an overall mean TN of 2.09 mg/l (Table 14-8).

In December 2000, the U.S. EPA published ambient water quality criteria recommendations (TP, TN, chlorophyll *a*, and turbidity) for rivers and streams in Nutrient Ecoregions (aggregated ecoregions throughout the United States). There are three Nutrient Ecoregions associated with Maryland (U.S. EPA 2000a, 2000b, 2000c); Nutrient Ecoregion IX is the Southeastern Temperate Forested Plains and Hills (equivalent to sections of the western Coastal Plain and the entire Piedmont), Nutrient Ecoregion XI is the Central and Eastern Forested Uplands (equivalent to the Blue Ridge, Ridge and Valley, and Allegheny Plateau), and Nutrient Ecoregion XIV is the Eastern Coastal Plain (equivalent to the Coastal Plain on the Eastern Shore, and a section of the western Coastal Plain). The TN criteria for Nutrient Ecoregion IX is 0.69 mg/l, XI 0.31 mg/l, and XIV 0.71 mg/l; all below the MBSS threshold of 1.5 mg/l.

For all Chesapeake Bay tributary strategy basins, and the Youghiogheny and Ocean Coastal basins, three basins exceeded 10% of stream km for the high total nitrogen threshold of 7.0 mg/l (Table 14-9). Several basins had high percentages (> 50%) of stream km in the moderate (1.5 – 7.0 mg/l) category, including the Choptank, Upper Eastern Shore, Upper Western Shore, Middle Potomac and Ocean Coastal. Only two basins, Lower Western Shore and Youghiogheny, had greater than 80% of stream km in the low threshold category (Table 14-9).

14.3.2.5 Total Phosphorus

Total phosphorus (TP), measured in the 2000-2004 MBSS, also varied over all basins for all stream orders (Figure 14-22). Several basins had mean TP levels over 0.025 mg/l. Fifteen basins (first-order streams) exceeded the low TP threshold, with only the Lower Susquehanna, Youghiogheny, and North Branch below the threshold value. Fourteen basins (second-order streams) were greater than the threshold value, with nine basins (third-order) also higher than the low TP threshold level. The Patuxent, for fourth-order streams, was greater than 0.025 mg/l TP (Figure 14-22). For all basin-stream order combinations, six basins had TP greater than 0.07 mg/l (the high threshold). In particular, the Ocean Coastal (first-order), Chester (second-order), and Middle Potomac (fourth-order) all were higher than 0.10 mg/l TP.

Of 1266 TP measurements made in the MBSS, the highest value measured was 1.52 mg/l, with an overall mean TP of 0.041 mg/l (Table 14-8). The TP criteria for Nutrient Ecoregion IX is 0.037 mg/l, XI 0.010 mg/l, and XIV 0.031 mg/l; these criteria are close to the low TP threshold in Table 14-7 except for the criteria for Nutrient Ecoregion XI (0.010 mg/l versus 0.070 mg/l).

For all Chesapeake Bay tributary strategy basins, and the Youghiogheny and Ocean Coastal basins, six basins exceeded 20% of stream km for the high total phosphorus threshold (Table 14-9). Three basins, in the moderate category, had stream km greater than 40%. One basin, the Youghiogheny, had greater than 80% of stream km in the low threshold category.

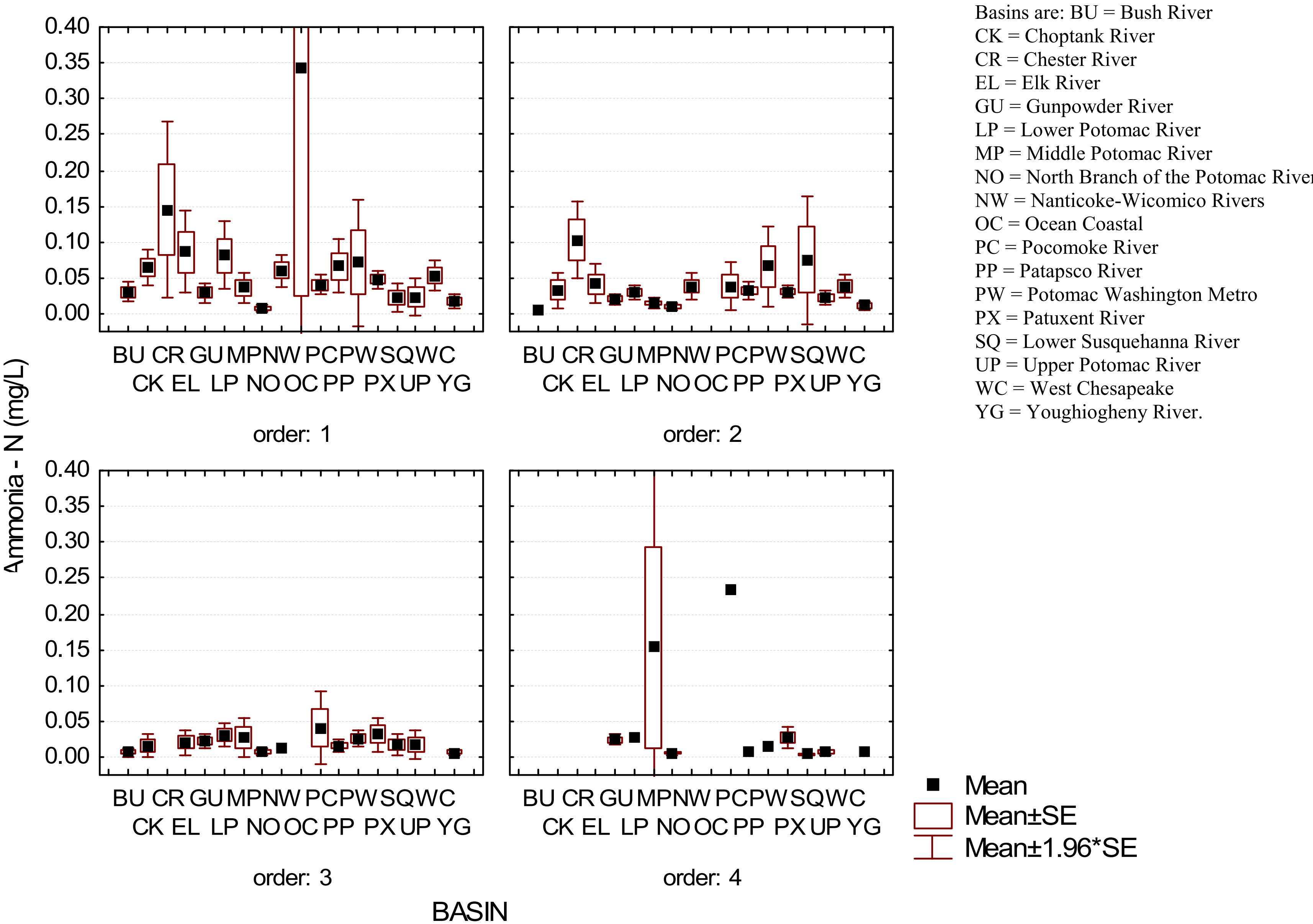


Figure 14-20. Ammonia (mg/l) concentration for all basins by stream order (1-4) for 1995-2004 MBSS.

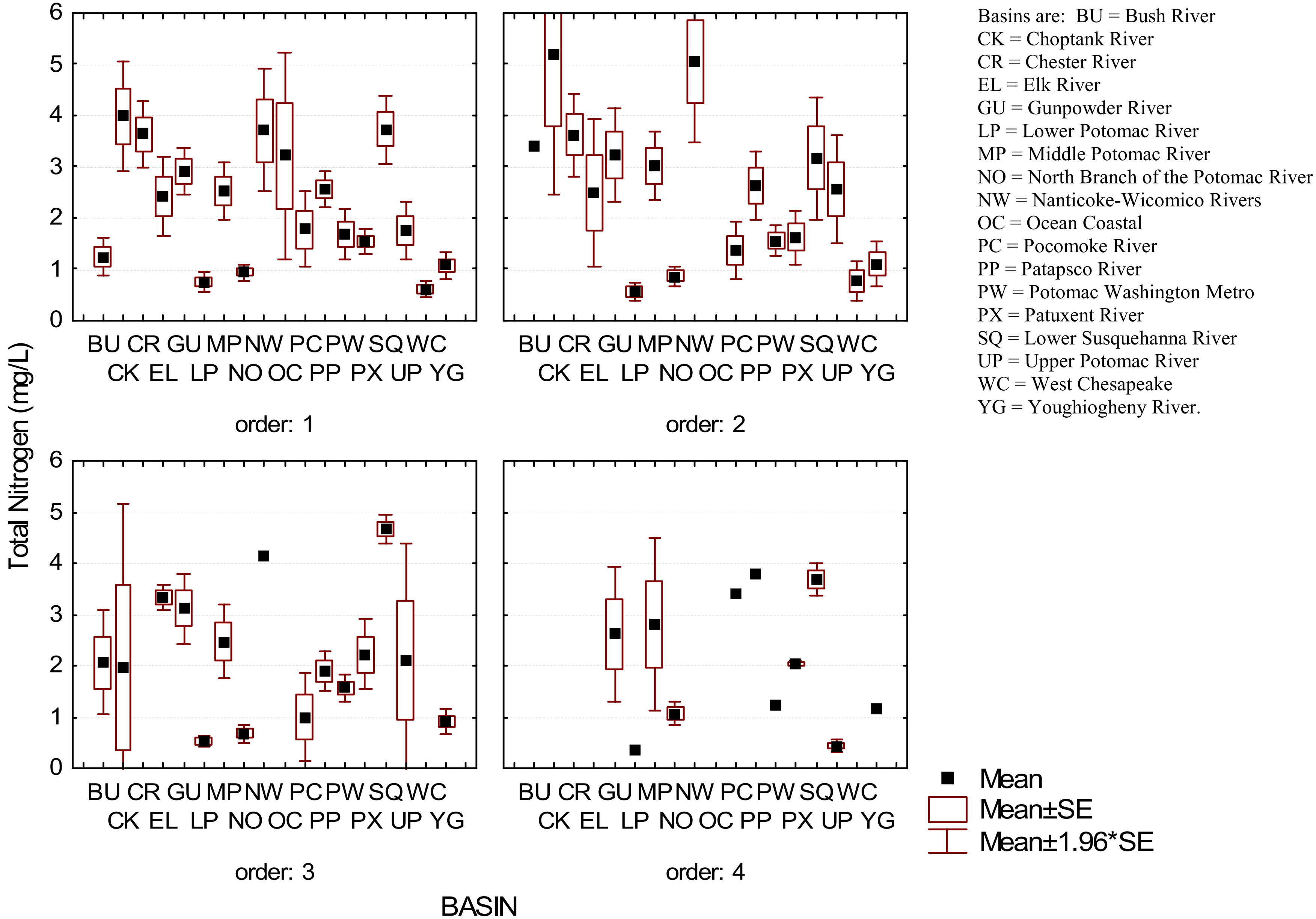
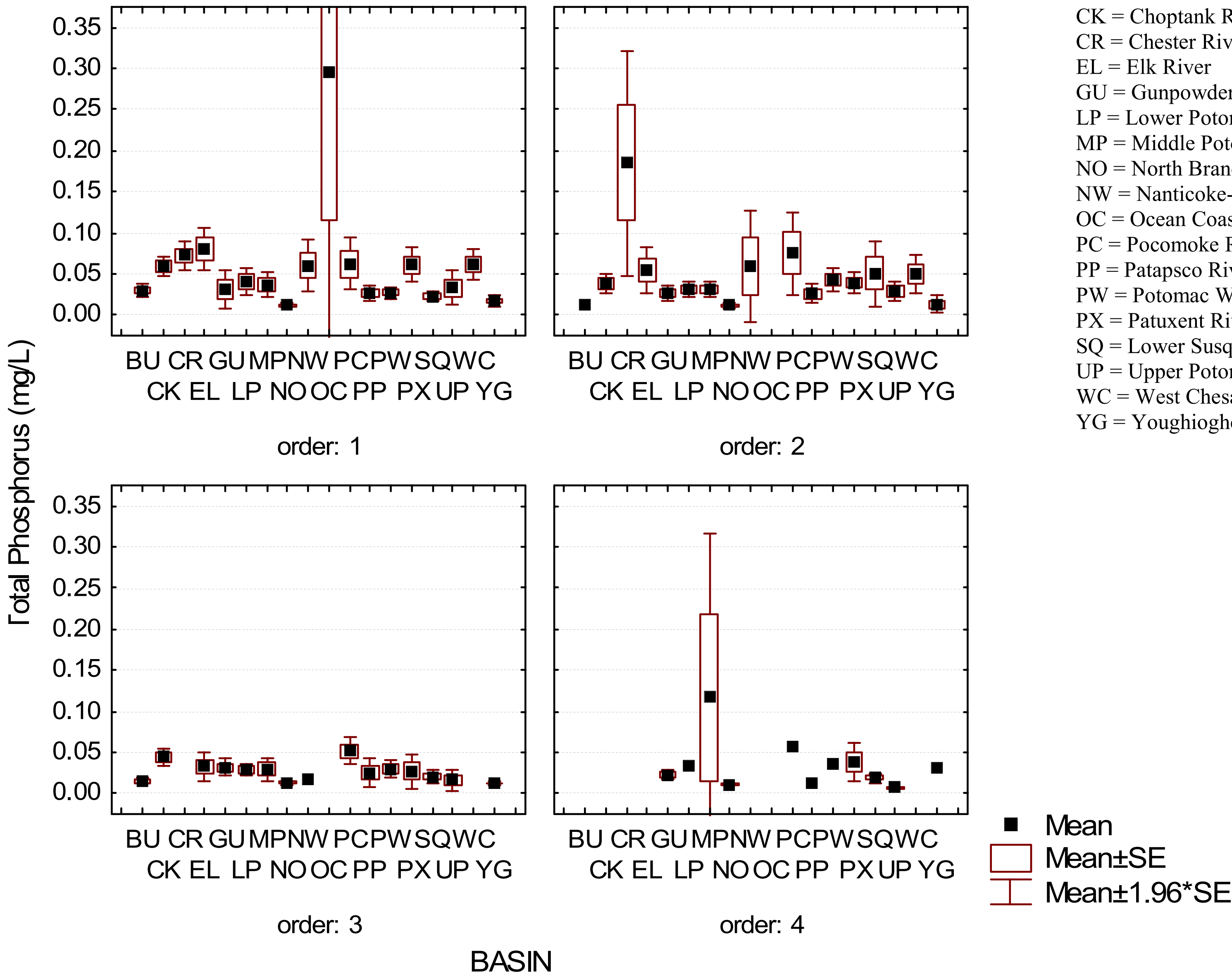


Figure 14-21. Total nitrogen (TN - mg/l) concentration for all basins by stream order (1-4) for 1995-2004 MBSS.



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WC = West Chesapeake
YG = Youghiogheny River.

Figure 14-22. Total phosphorus (TP - mg/l) concentration for all basins by stream order (1-4) for 1995-2004 MBSS.

14.3.2.6 Ortho-phosphate

Ortho-phosphate (OP_4), measured in the 2000-2004 MBSS, again varied over all basins for all stream orders (Figure 14-23). The first-order Ocean Coastal streams are not plotted in Figure 14-26 since the mean OP_4 was 0.22 mg/l; the OP_4 for the Middle Potomac was also not plotted since the mean was 0.071 mg/l. Twenty-five basin-stream order combinations had OP levels > 0.008 mg/l, with many basins greater than the upper threshold of 0.03 mg/l for high OP_4. Of 1232 OP_4 measurements made in the second MBSS round, the highest value measured was 1.20 mg/l, with an overall mean OP_4 of 0.012 mg/l (Table 14-8).

For all Chesapeake Bay tributary strategy basins, and the Youghiogheny and Ocean Coastal basins, five basins exceeded 10% of stream km for the high OP_4 threshold of 0.03 mg/l (Table 14-9), with four basins having 25% of stream km in the moderate OP_4 category. Four basins had greater than 75% of stream km in the low threshold category.

14.3.2.7 Dissolved Oxygen (DO)

Summer field DO normally exceeded the low threshold (Table 14-7) for all basin-stream order combinations (Figure 14-24). Only 4.3% of the 2176 summer DO measurements were below 3 mg/l, 6% between 3-5 mg/l, and 89.7% greater than 5.0 mg/l. Mean values for several basins, by stream order, were above 7 mg/l. The plot of field temperature versus DO (Figure 14-25) indicated that there is a subset of MBSS stations, with a field DO of less than 3 mg/l and a field temperature between 15-25 ºC, where the normal DO-temperature relationship is not present. Many of these stations are associated with basins having high nutrient loadings.

For all Chesapeake Bay tributary strategy basins, and the Youghiogheny and Ocean Coastal basins, there were three basins, Lower Eastern Shore, Choptank, and Lower Potomac, with greater than 10% of stream km in the low oxygen category of < 3 mg/l DO. All basins had > 50% of stream km in the high threshold category of > 5 mg/l DO, while five basins exceeded 90% (Table 14-9).

14.3.3 Tributary Strategy Basins

While nutrient increases can have deleterious effects on streams, eutrophication is often a bigger problem for receiving estuaries. For Maryland, there are ten large basins defined as Tributary Strategy Basins, essentially waters that eventually flow into tidal systems of the Chesapeake Bay. One large western Maryland basin, the Youghiogheny, flows into the Ohio basin, and eventually to the Mississippi River. A second drainage basin, the Ocean Coastal, drains into the Atlantic Ocean through tidal reaches of inland bays on the Atlantic Coast of Maryland.

Both TN and TP mean values were calculated for all ten Tributary Strategy Basins (Figures 14-26 and 14-27). For TN, there are three distinct groupings (Figure 14-26). The Lower Potomac and the Lower Western Shore had mean TN levels less than 1.0 mg/l (approximate to two eco-region values of 0.69 and 0.71 mg/l TN), indicating low TN in these two basins. A second grouping of the Upper Potomac, Middle Potomac, and Patuxent basins had mean TN values between 1-2 mg/l. The remaining five Tributary Strategy Basins, the Upper Western Shore, Choptank, Upper Eastern Shore, Lower Eastern Shore and Patapsco/Back River, all had TN concentrations over 2.0 mg/l. In particular, the Choptank (> 4.0 mg/l) and the Upper Eastern Shore (> 3.0 mg/l) basins were high in TN.

A similar pattern was observed for TP (Figure 14-27), with three distinct groups of mean TP values. The first group of five basins had TP levels below 0.040 mg/l (close to two ecoregion values of 0.037 and 0.031 mg/l) – this basin assemblage includes the Upper Western Shore, Lower Potomac, Upper Potomac, Patapsco/Back River and Middle Potomac. A second grouping of four basins had TP levels between 0.04 and 0.08 mg/l, and comprised the Choptank, Lower Eastern Shore, Patuxent and Lower Western Shore basins. Finally, the Upper Eastern Shore basin had a mean TP level over 0.08 mg/l – an exceptionally high TP level and of concern for Maryland nutrient strategies.

14.3.4 CORE/Trends Comparison

Fixed-site monitoring provides the best evidence of the link between nutrients in streams and receiving estuaries such as the Chesapeake Bay. The CORE/Trend program is a pre-selected, fixed station network sampled monthly to track statewide trends in water quality over time. This sampling program, started in 1974, visits 54 land-based and 3 boat sites (Sandy Point, Turkey Point -Elk River, and Kent Narrows) monthly in 12 major (6-digit) basins, year-round. Only the 54 land-based freshwater stations were considered. These fixed sites are located in 10 of the major basins, 37 of the 8-digit basins sampled by the MBSS. MBSS chemistry samples were collected during the Spring Index Period March and April, from 2000 through 2004 in all basins. Only the 560 regular and sentinel samples collected by MBSS common to the CORE/Trend were included in the comparison. Similarly, 528 CORE/Trend samples collected only during the same time period as covered by the MBSS sampling (March and April, 2000 through 2004) were considered. Chemistry analytes collected by both programs were nitrate (NO_3), total nitrogen (TN), ammonia (NH_3 as N, MBSS)/ammonium (NH_4 as N, CORE/Trend), orthophos-phate (PO_4), and total phosphorous (TP). Conductivity

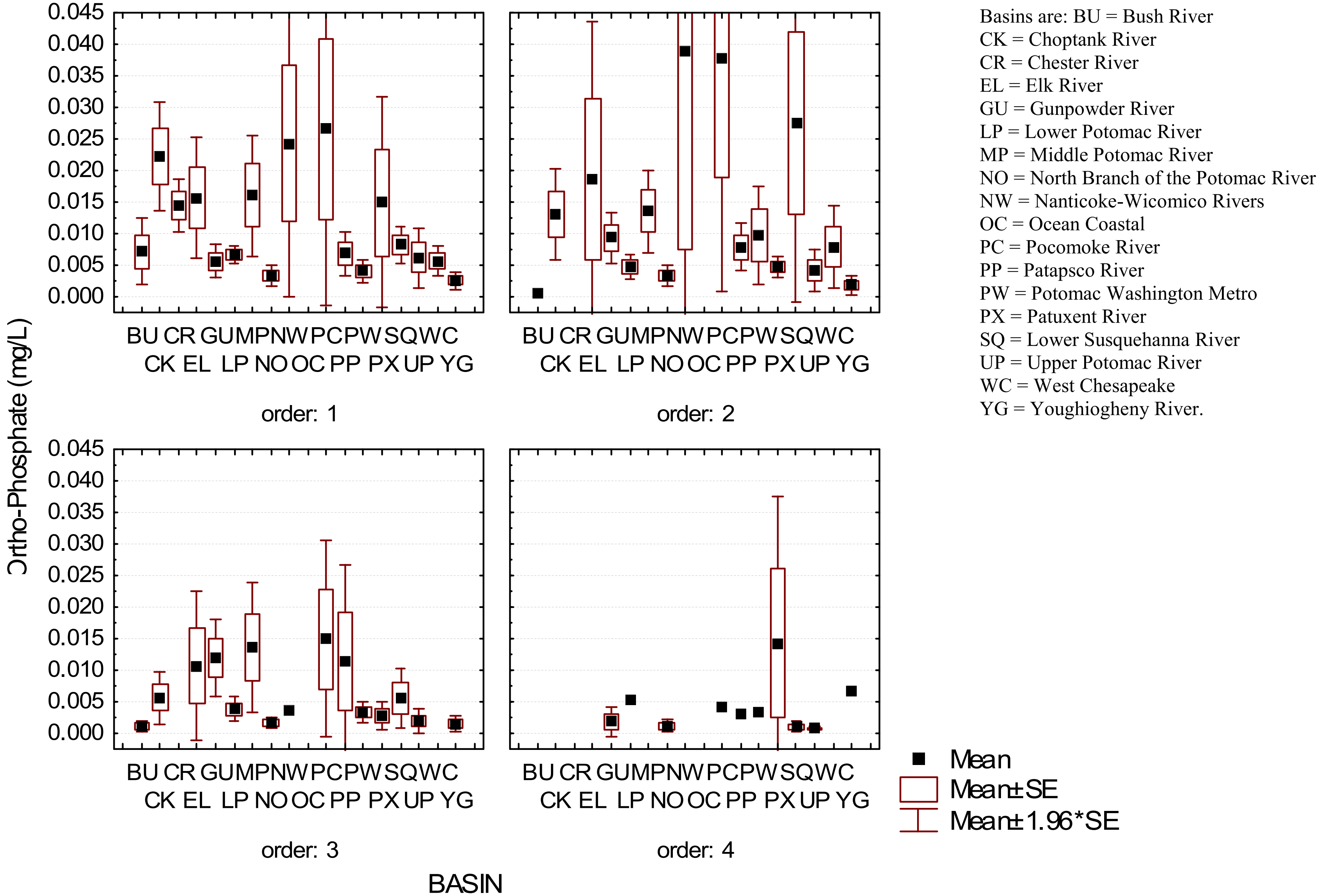


Figure 14-23. Ortho-phosphate (OP - mg/l) concentration for all basins by stream order (1-4) for 1995-2004 MBSS.

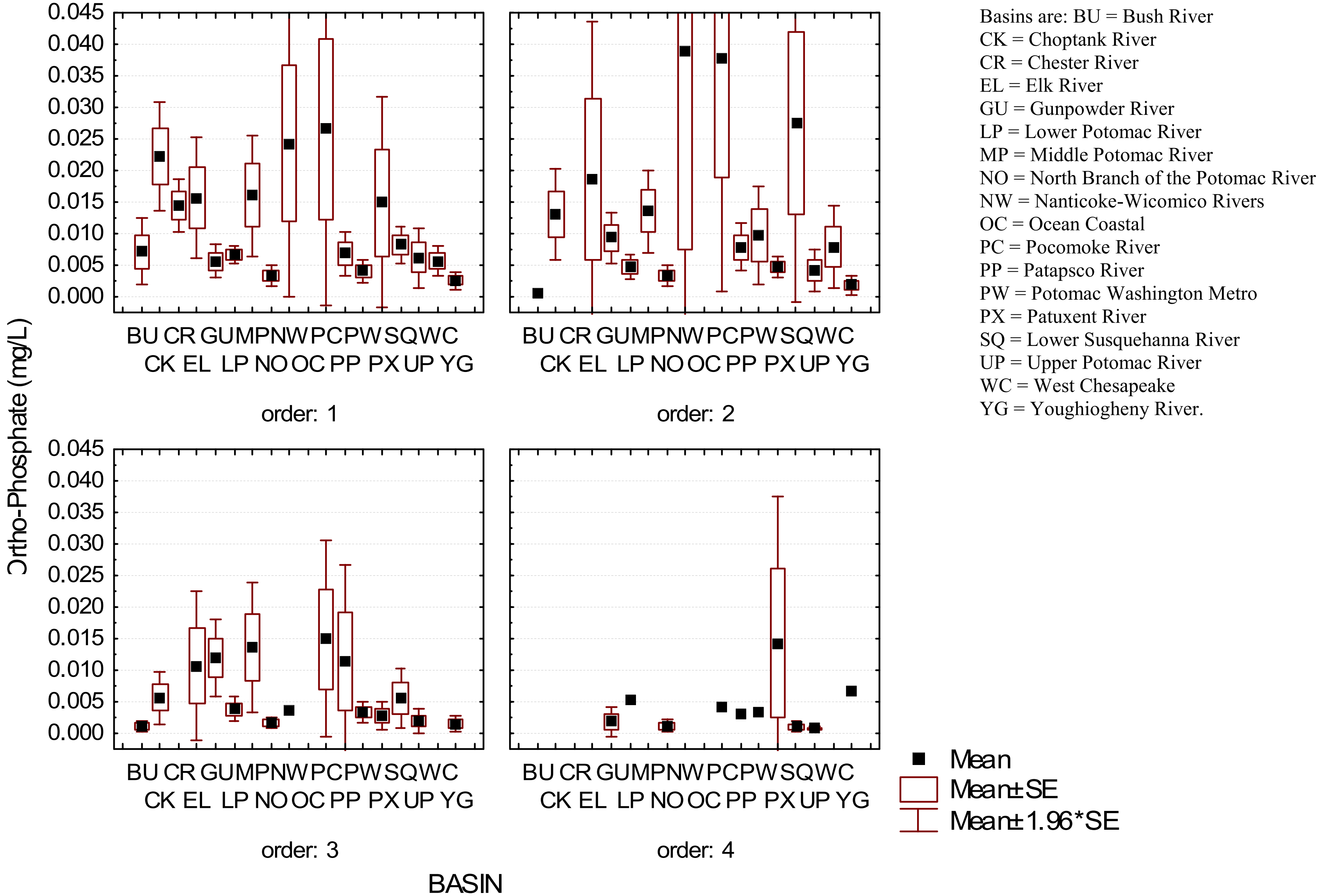


Figure 14-24. Dissolved oxygen (DO - mg/l) concentration for all basins by stream order (1-4) for 1995-2004 MBSS.

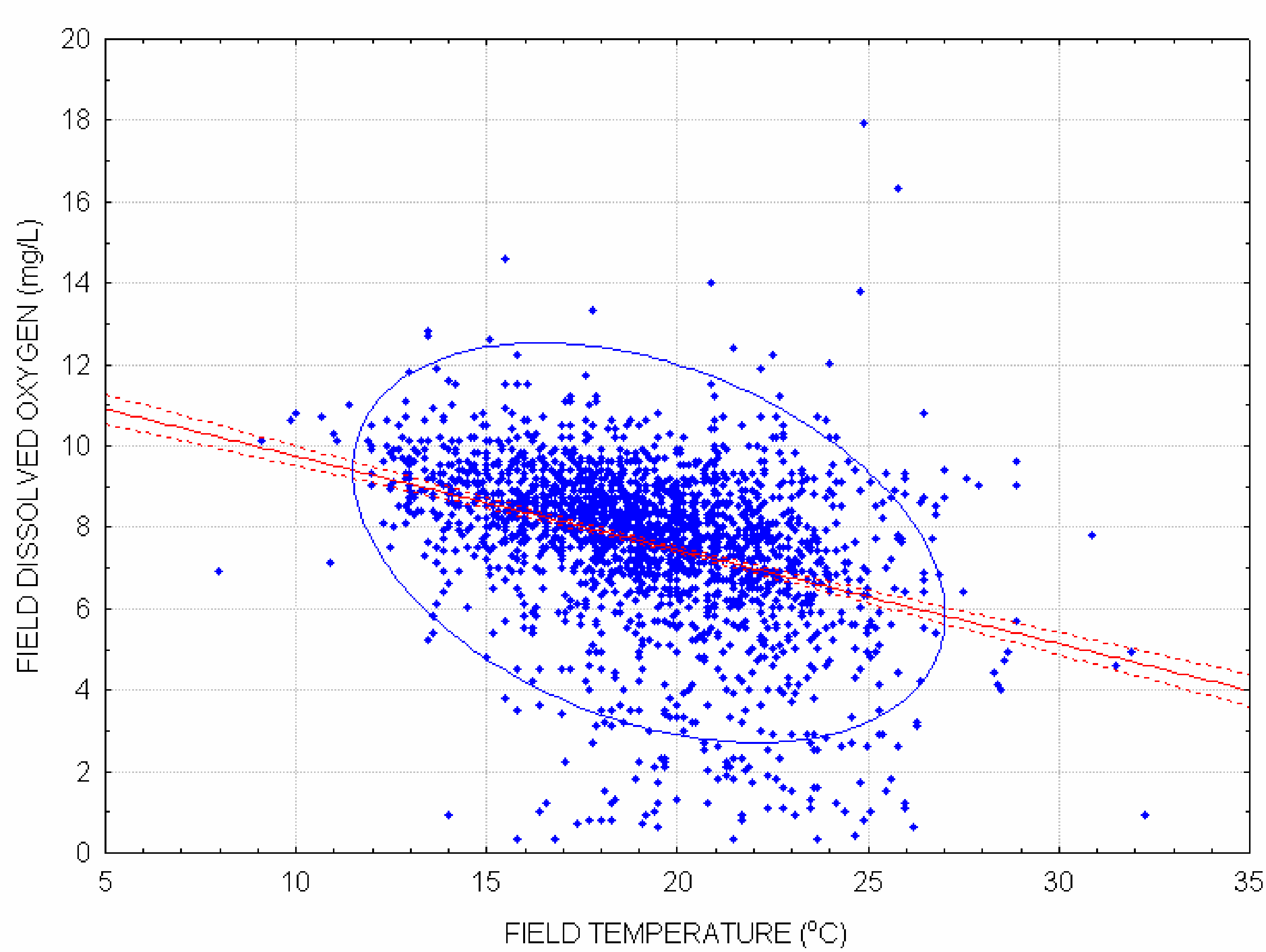


Figure 14-25. Dissolved oxygen versus field temperature for all basins by stream order (1-4) for 1995-2004 MBSS. Regression, 95% confidence interval, and 95% ellipse are shown.

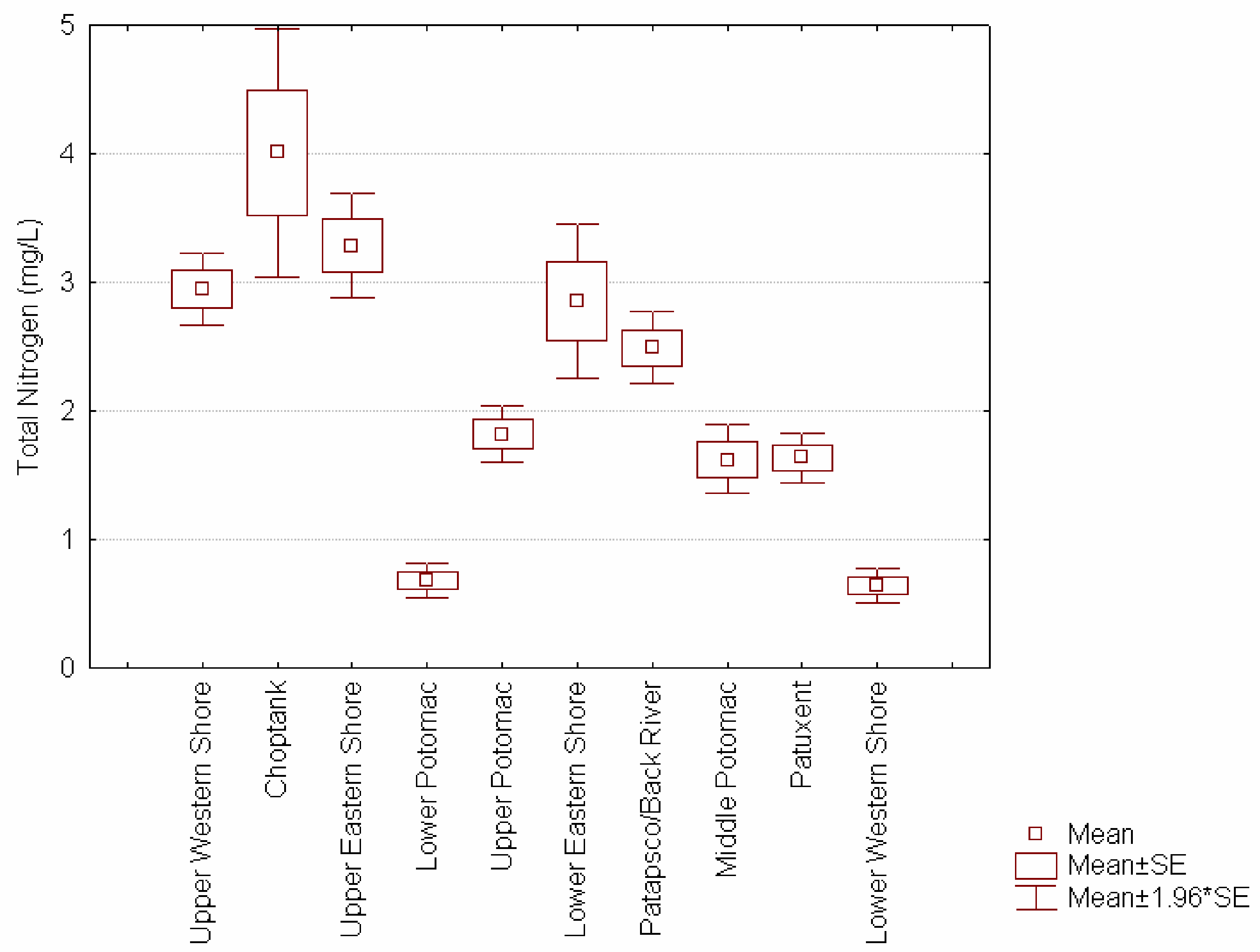


Figure 14-26. Total nitrogen (mg/l) concentration for all tributary strategy basins.

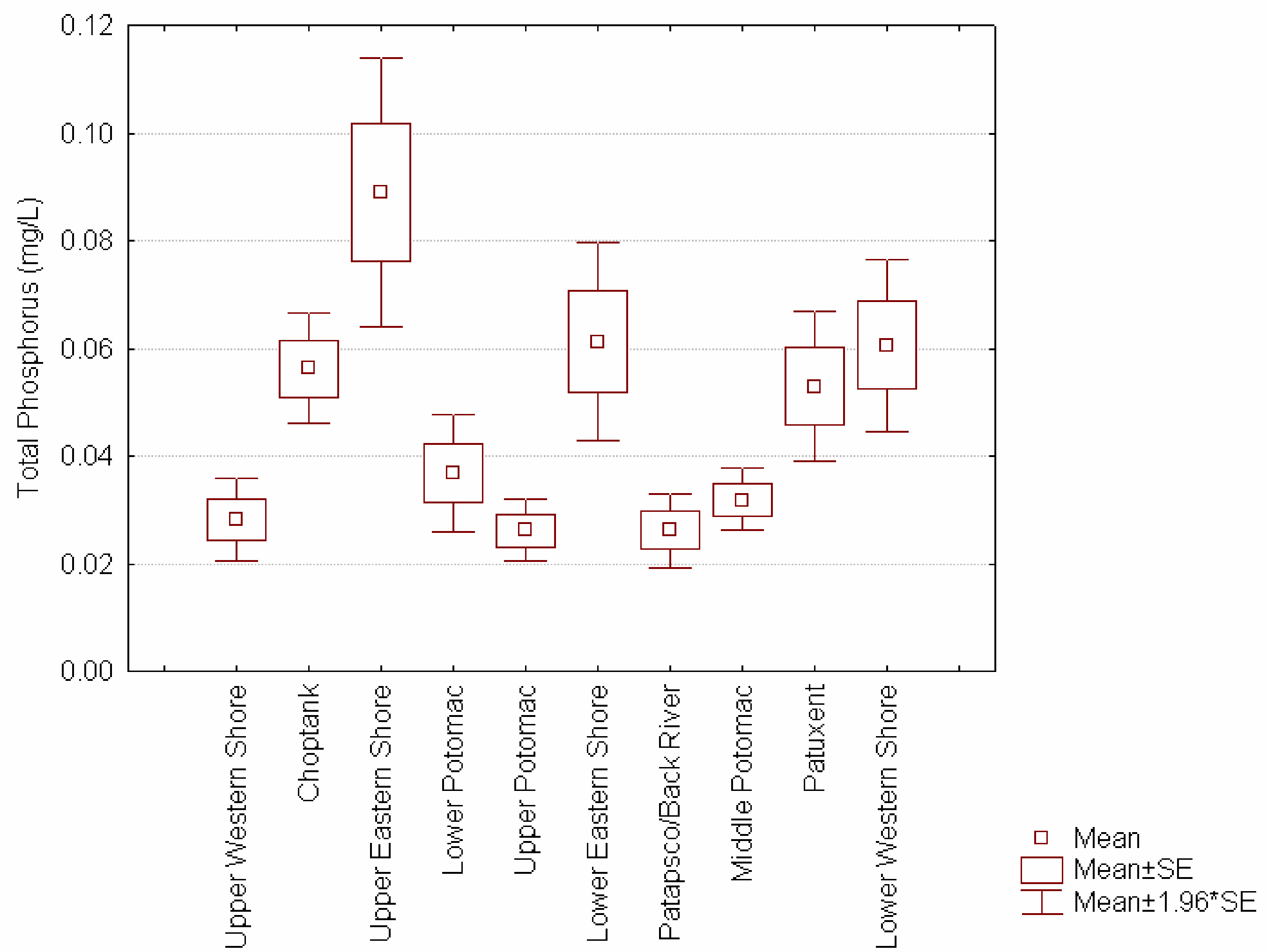


Figure 14-27. Total phosphorus (mg/l) concentration for all tributary strategy basins.

and pH were measured in-situ by the CORE/Trend program, but were lab-generated numbers for the Spring MBSS samples.

Three analyses were run: (1) included all common watersheds, (2) excluded watersheds with tidal sites, and (3) excluded sites with > 4th order streams. Rank correlations (Spearman correlation) were performed for each analyte to determine correlations between programs for each group of watersheds (Table 14-10). For all the common watersheds, TN showed the best correlation, possibly related to the oxidized forms of nitrogen (NO_x). Ammonia/ammonium had the lowest correlation values, probably due to the instability of this analyte. In the second analysis, the elimination of tidal-fresh CORE/Trend basins from the analysis did not appreciably improve the correlations and the NHx correlation decreased with the elimination of tidal areas. The third analysis allowed an examination of the effect of the stream order. All correlations based on the remaining basins increased except orthophosphate. An artifact of rank correlations is the "perfect score" shown in the pH correlation. The values were different, yet the *ranks* were the same.

Changes in correlations may be in part because CORE/Trend sites are targeted to capture specific areas or conditions, such as being downstream from major point-source discharges. There are also differences in sample processing in both the field and the laboratory that could make a difference. No laboratory QC check common to both processing labs was noted. Because the CORE/Trend program uses the same sampling points, there is less variation in these data than the corresponding MBSS data. Simple summary statistics also point out differences in the detection limits and data handling decisions that can skew comparisons in areas where a particular analyte detection value is higher. For example, the MBSS TP detection limit is 0.001 and the CORE/Trend detection limit is 0.01. Summary statistics for the MBSS indicate, from the median and modes, that many of the MBSS sample values are below the CORE/Trend detection limit. Overall, there is fairly good statewide agreement between the sampling programs based on the basins they have in common when analyzed at the area scales both programs were designed to cover. Stream order appears to have an effect more pronounced in the nutrient species than in the total nutrient analytes. This is expected, as nutrient cycling and dilution change with the size of the stream. CORE/Trend values are frequently higher than MBSS values, possibly due to a combination of the effects of stream order, lab detection limits, and the fact that CORE/Trend sites are deliberately chosen to monitor specific conditions. The large discrepancy in the ammonium values (Figure 14-28) in Conewago/Double Pipe Creek (CODP) values is the result of one sample where the ammonia ion constituted most of the total nitrogen of the sample. Examination of the records showed no problems in the field or laboratory, and 3/4" of rain during the two days previous to sampling. Total nitrogen was about 10 times the total phosphorous value, and all nutrients measured were substantially above other sites on this creek. The data are consistent with storm surge runoff traveling downstream.

14.3.5 Nutrients and Biological Characteristics

Nutrient relationships with stream biotic components, and their derived indices, are often difficult to isolate from complex data sets such as the MBSS, where multiple stressors may be working at the reach to landscape level. However, there are two examples-one of the relationship between the TN/TP ratio and number of EPT taxa and the other between total phosphorus and number of EPT taxa-that illustrate nutrient effects on stream biota (Figures 14-29 and 14-30). As the TN/TP ratio increases, there is a general decrease in the number of EPT taxa present in the stream sample (Figure 14-29). Benthic macroinvertebrates, and other stream biota, have this general pattern of decreasing taxa richness with increasing nutrient loading. Ephemeroptera, Plecoptera, and Trichoptera (EPT), all taxa generally sensitive to stream degradation, are excellent indicators of nutrient pollution, and are used extensively in assessing water quality. Another nutrient-biotic example is the relationship of the number of EPT taxa with total phosphorus (Figure 14-30). EPT richness decreases as TP increases, with the maximum number of EPT observed at TP concentrations less than 0.05 mg/l–very close to the ecoregion TP thresholds. The number of EPT taxa is normally less than four at TP levels greater than 0.1 mg/l.

Table 14-10. Summary of Spearman Rank Correlations for different groups of watersheds.

Correlation Summary:	NO_3	NHx	TN	PO_4	TP	pH	COND	MBSS Sample Count	CORE/ Trend Sample Count
All watersheds	0.622	0.045	0.784	0.545	0.480	0.714	0.541	560	528
Non-tidal watersheds	0.608	0.018	0.799	0.585	0.492	0.732	0.519	535	508
No watersheds with > 4th order sites	0.706	0.084	0.891	0.511	0.608	1.000	0.647	292	244

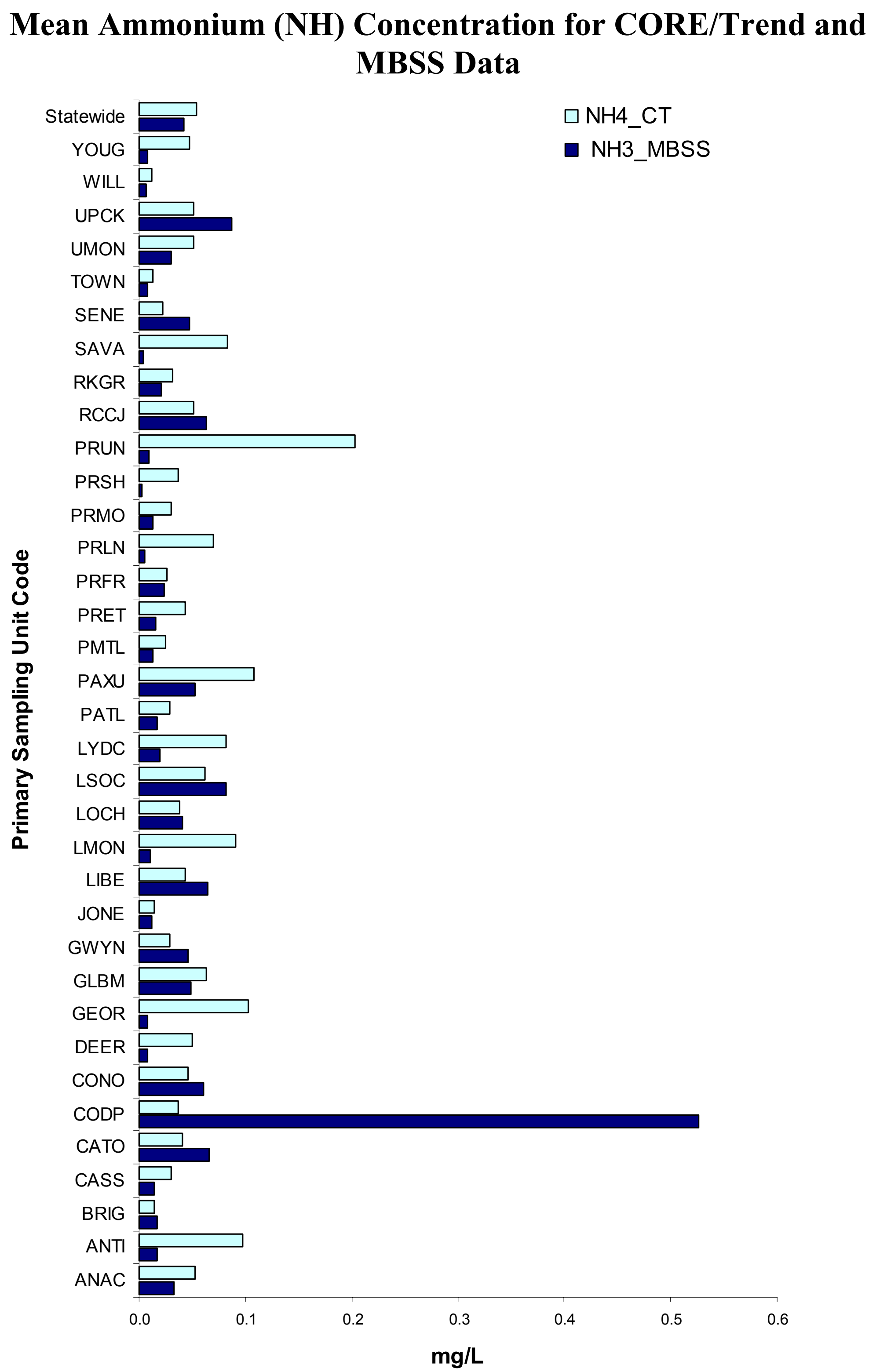


Figure 14-28. Mean ammonium concentration for CORE/Trend (NH_4) and MBSS (NH_3) stations sampled in March and April 2000 through 2004.

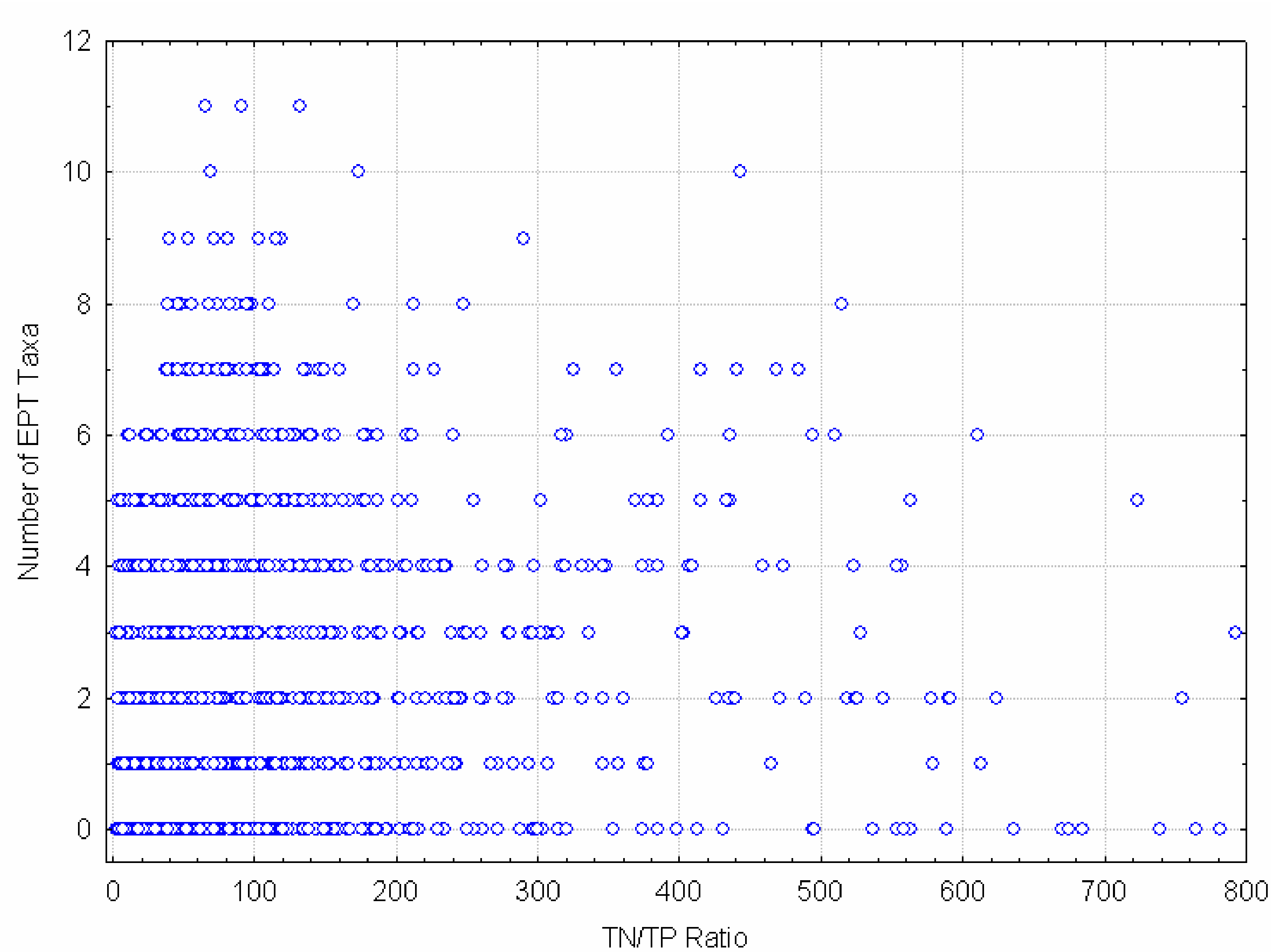


Figure 14-29. Number of EPT taxa as a function of the TN/TP ratio, 2000-2004 MBSS.

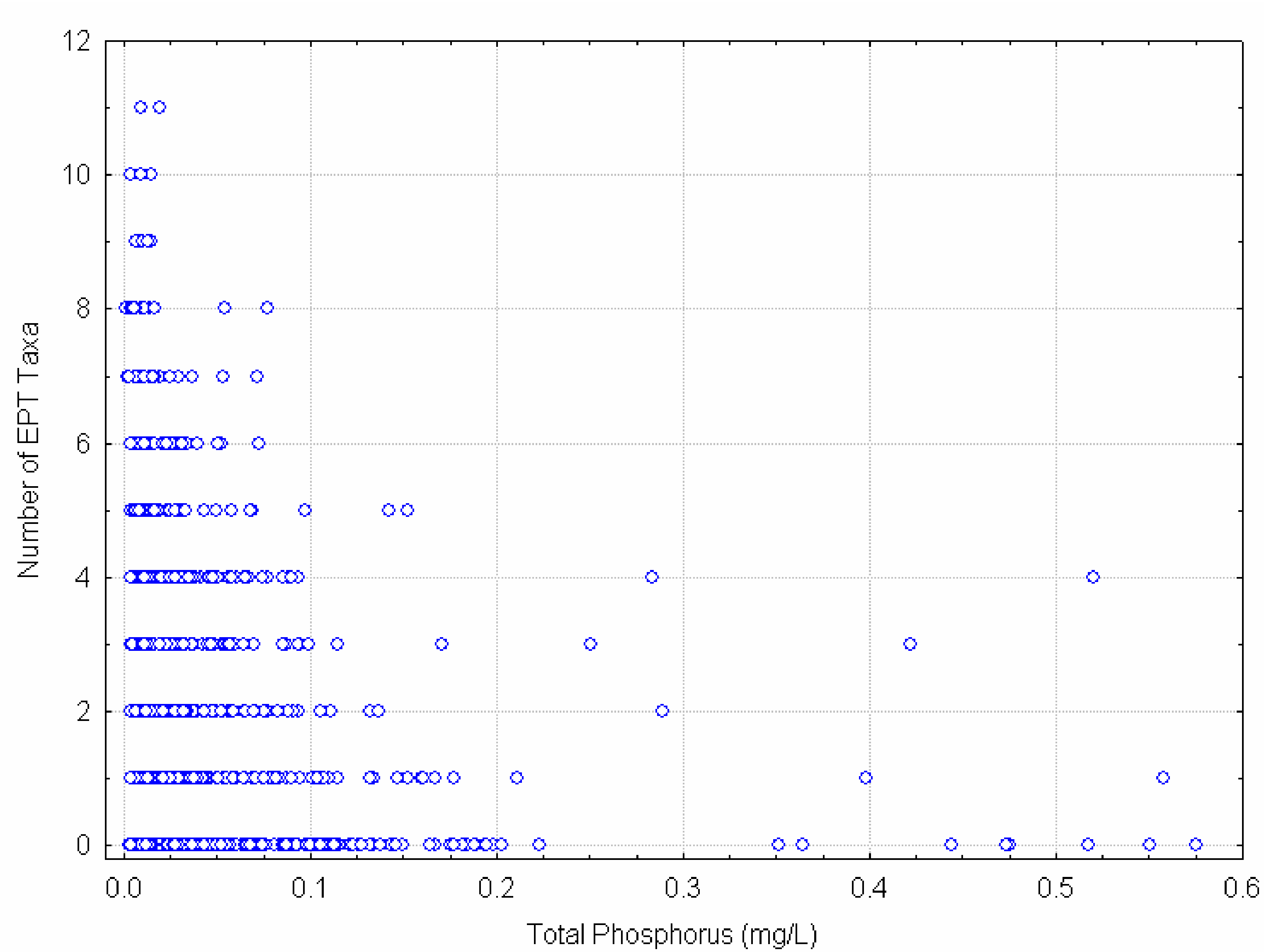


Figure 14-30. Number of EPT taxa as a function of stream total phosphorus (TP), 2000-2004 MBSS.

14.3.6 Storm Nutrient Dynamics

The MBSS samples water quality during the spring index period, corresponding to the spring baseflow for Maryland streams, with some additional field water quality taken during the summer index period sampling. Although the spring index sample is a point water quality sample taken during the year, the MBSS does represent a comprehensive spatial picture of first- through fourth-order non-tidal streams in Maryland. Of paramount interest to Maryland is stream nutrient dynamics, especially given the linkage between headwater systems (first- and second-order) and the tidal reaches of the Chesapeake Bay. In this regard, stream nutrient dynamics are important to consider in managing fluxes of organic and inorganic materials (Peterson et al. 2001, Gomi et al. 2002); including dynamics of riparian buffers in mitigating nutrient inputs (Sweeney et al. 2004). Small streams (comprising 76% of Maryland stream km) are responsible for the most rapid uptake and transformation of inorganic nitrogen (Peterson et al. 2001). Nutrient reduction is a goal of the Maryland Tributary Strategy, and this goal reflects a basin approach to cleaning up the Chesapeake Bay.

Both TN and TP (Figures 14-26 and 14-27) figure prominently in strategies to reduce nutrient loadings (U.S. EPA 2000a,b,c, Dodds and Welch 2000, Pinay et al. 2002, King and Richardson 2003), especially since the U.S. EPA is responsible for setting nutrient criteria for streams, rivers and lakes as part of the Clean Water Action Plan. TN and TP are relatively easy to measure, even at low levels, and eliminate certain analytical problems in measuring some nitrogen species (e.g. DIN) found in water. There is also a significant body of limnological literature that examines TN:TP ratios – known throughout the literature as the Redfield ratio, where C: N: P is found in the ratio of 106:16:1 in algal tissue, and serves as a model to examine nutrient limitations (Allan 1995, Dodds 2002). This concept of a 16:1 TN:TP ratio has been discussed extensively and stands as a nutrient paradigm, although there are questions as to its utility in lotic systems (Allan 1995, Dodds 2002). The classic work by Omernik (1977), done for small and relatively unpolluted streams throughout the U. S., serves as a benchmark to assess TN:TP ratios, where ratios of ~12:1 are associated with > 90% forest, 21:1 with > 50% forest, 26:1 with > 50-75% agriculture, and 60:1 with agriculture > 90%.

Maryland TN:TP ratios, as plotted for all tributary strategy basins and the Youghiogheny and Ocean Coastal basins, reveal some interesting results (Figure 14-31). Mean TN:TP ratios for the Lower Potomac, Ocean Coastal, and Lower Western Shore are all below a TN:TP ration of 40, with four basins ranging from a TN:TP ratio of 60-100 and five having ratios greater than 100. Since the average TP for the 2000-2004 MBSS is 0.041 mg/l (median = 0.020 mg/l), and the 75% percentile value is 0.043 mg/l TP, these TN:TP ratios > 60 indicate that there are basins leaking nitrogen into tidal reaches of the Chesapeake Bay, where nitrogen is a limiting nutrient for phytoplankton growth in mesohaline and coastal marine waters (Paerl et al. 1990). It appears that TP is being highly conserved, but TN is being leaked in MBSS streams. Using the U. S. EPA Aggregate Ecoregion approach for rivers and streams, the TN:TP ratio for Ecoregion IX is 19, for XI 31, and for XIV 23 – all MBSS basins are above these ecoregion threshold ratios.

To better illustrate nitrogen (TN) and phosphorus (TP) levels in Maryland, these two analytes were plotted, by percentiles, for all MBSS sites. There were a number of TN values that exceeded the 90th percentile on the Eastern Shore, and throughout Central Maryland. In concordance with these high TN, sites exceeding the 50-75th and 75-90th TN percentiles were common in Central Maryland. There were numerous MBSS sites in the TP 75-90th percentile, clustered on the upper Eastern Shore and Choptank, the lower Potomac River, the Lower Patuxent River and the Upper Potomac River. Few TP values exceeded the 90th percentile. It is obvious that nutrient reduction strategies should focus on these regions of Maryland.

14.4 PHYSICAL HABITAT

While acidification, nutrient enrichment, and other water pollution are well known causes of degradation, MBSS data consistently show that physical habitat changes are the primary cause of biotic impoverishment in Maryland streams (affecting more than 50% of stream miles based on Roth et al. 1999 and Volume 7 of this report). The MBSS Physical Habitat Index (PHI, Paul et al. 2003) is a measure of how much physical habitat in streams varies from reference condition; PHI scores by Tributary Basin and County are reported in Volumes 7 and 8 of this report, respectively. Individual metrics collected by the MBSS provide evidence of the specific physical habitat stressors and probable causes of degradation, and are the focus of this section.

Three candidate causes affect physical habitat in streams: temperature, channel alteration, and sediment. Temperature changes primarily result from (1) removal of canopy cover and direct heating of the stream and (2) heated runoff from impervious surfaces. Channel alteration includes direct channelization (often including armoring), creation of impoundments or fish barriers, and changes in fluvial geomorphology that result from altered flows. The input of terrestrial sediments results from changes in land use, especially in the riparian zone. Sediment impacts on the availability of instream habitat can also result from flow regime changes (higher or "flashier" flows) that erode stream banks. Separating the ultimate causes of sedimentation can be problematic. The role of riparian

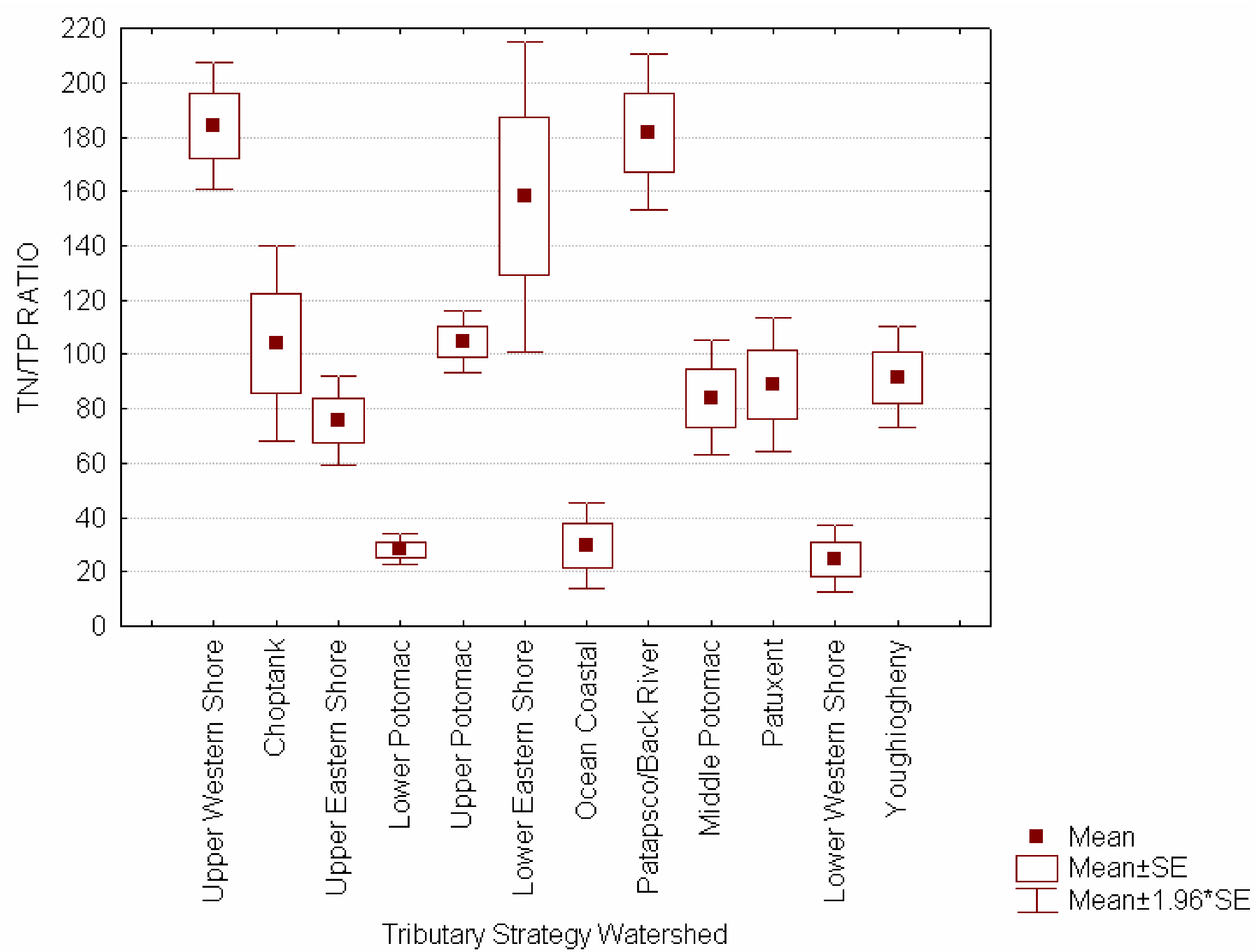


Figure 14-31. TN/TP ratios for all tributary strategy (Youghiogheny and Ocean Coastal) basins.

(streamside) vegetation in modifying stressors to streams is so important that it is addressed in detail in Volume 10.

14.4.1 Background

Stream health, as determined by the condition of biological communities, has been shown to be directly correlated to physical habitat quality (Richards et al. 1993, Rankin 1995, Roth et al. 1999). Habitat loss and degradation has been identified as one of six critical factors affecting biological diversity in streams worldwide; habitat alteration is cited as a leading cause of fish species extinctions, contributing to 73% of extinctions in North America during this century (Miller et al. 1989, Allan and Flecker 1993). Habitat degradation can result from a variety of human impacts occurring within the stream itself or in the surrounding basin. Urban development, agriculture, timber harvesting, livestock grazing, and the draining or filling of wetlands are the best known human activities affecting streams.

Alone or in combination, these human activities may cause changes in vegetative cover, sediment loads, hydrology, and other factors influencing stream habitat quality. The amount of vegetative cover in a basin regulates the flow of water, nutrients, and sediments to adjacent streams. In basins under anthropogenic stress, riparian forests can ameliorate inputs of nutrients, sediments, and other pollutants to streams. They also provide local benefits of shade, overhead cover, leaf litter to feed the aquatic food web (allochthonous input), and large woody debris, which in turn provides cover and forms pool and riffle microhabitats (Karr and Schlosser 1978, Gregory et al. 1991). Removal of riparian vegetation can increase stream temperatures, often with adverse effects on stream fish (Barton et al. 1985). The loss of basin or riparian vegetation increases the potential for overland and channel erosion, often increasing the siltation of stream bottoms and obliterating the clean gravel surfaces used by many fish species as spawning habitat (Berkman and Rabeni 1987). Stream bottoms that become embedded with increased sediment loads provide less habitat for many benthic macroinvertebrates. Stream channelization alters runoff patterns and creates "flashy" streams with more extreme high and low flows, increased scouring and streambank erosion. These altered flows accelerate downcutting and widening of stream channels. This increased hydrologic variability is exacerbated by urbanization, which increases the amount of impervious surface in a basin and causes higher overland flows to streams, especially during storm events. Streams with highly altered flow regimes often become wide, shallow, and homogeneous, resulting in poor habitat for many fish species (Schlosser 1991). Concrete-lined streams are perhaps the most severe example of habitat loss for fish, benthic macroinvertebrates, and other aquatic species.

14.4.2 Physical Habitat Index

The MBSS Physical Habitat Index (PHI) was developed to describe the physical habitat component of freshwater streams that strongly influences the composition and status of stream fish communities (Gorman and Karr 1978). As described in Volume 6: Laboratory, Field, and Analytical Methods, MBSS procedures for physical habitat assessment were derived from two sources: EPA's Rapid Bioassessment Protocols (RBPs) (Plafkin et al. 1989) as modified by Barbour and Stribling (1991), and the Ohio EPA's Qualitative Habitat Evaluation Index (Rankin 1989). In addition to the 13 qualitative physical habitat metrics derived from these methods, qualitative and quantitative stream characteristics (meandering, presence of emergent and submerged vegetation, presence of coarse woody debris, rootwad number, etc.) were recorded during MBSS field sampling. All of the measured parameters were considered in the development of a reference-based PHI for Maryland streams.

The revised PHI was developed using MBSS data through 2000 (Paul et al. 2003). Because of underlying differences in stream types, separate PHIs are developed for each of three geographic strata: the Highlands, Piedmont, and Coastal Plain. Four physical habitat variables are common to all three indices: (1) bank stability, (2) epifaunal substrate, (3) shading, and (4) remoteness. Five additional variables are included in one of two indices: (1) riparian buffer width, (2) riffle quality, (3) instream wood, (4) instream habitat quality, and (5) embeddedness.

Index scores were adjusted to a centile scale that rates each sample segment as follows:

- Scores of 81 to 100 are rated minimally degraded
- Scores of 66 to 80 are rated partially degraded
- Scores of 51 to 65 are degraded
- Scores of 0 to 50 are rated severely degraded

Figure 14-32 shows the PHI score for the 1,065 MBSS sites sampled from 2000-2004. The percentage of stream miles with each PHI rating are provided by Primary Sampling Unit (PSU) generally Maryland 8-digit watersheds) in Volumes 1 through 5, and for Tributary Basins and the entire State in Volume 6.

Stream mile estimates of PHI scores indicate that approximately one-third (33%) of Maryland streams have degraded to severely degraded physical habitat. Only 21% of streams have minimally degraded physical habitat. The extent of degraded physical habitat throughout Maryland is likely a result of several factors. The following sections discuss each of these factors and their candidate causes in turn.

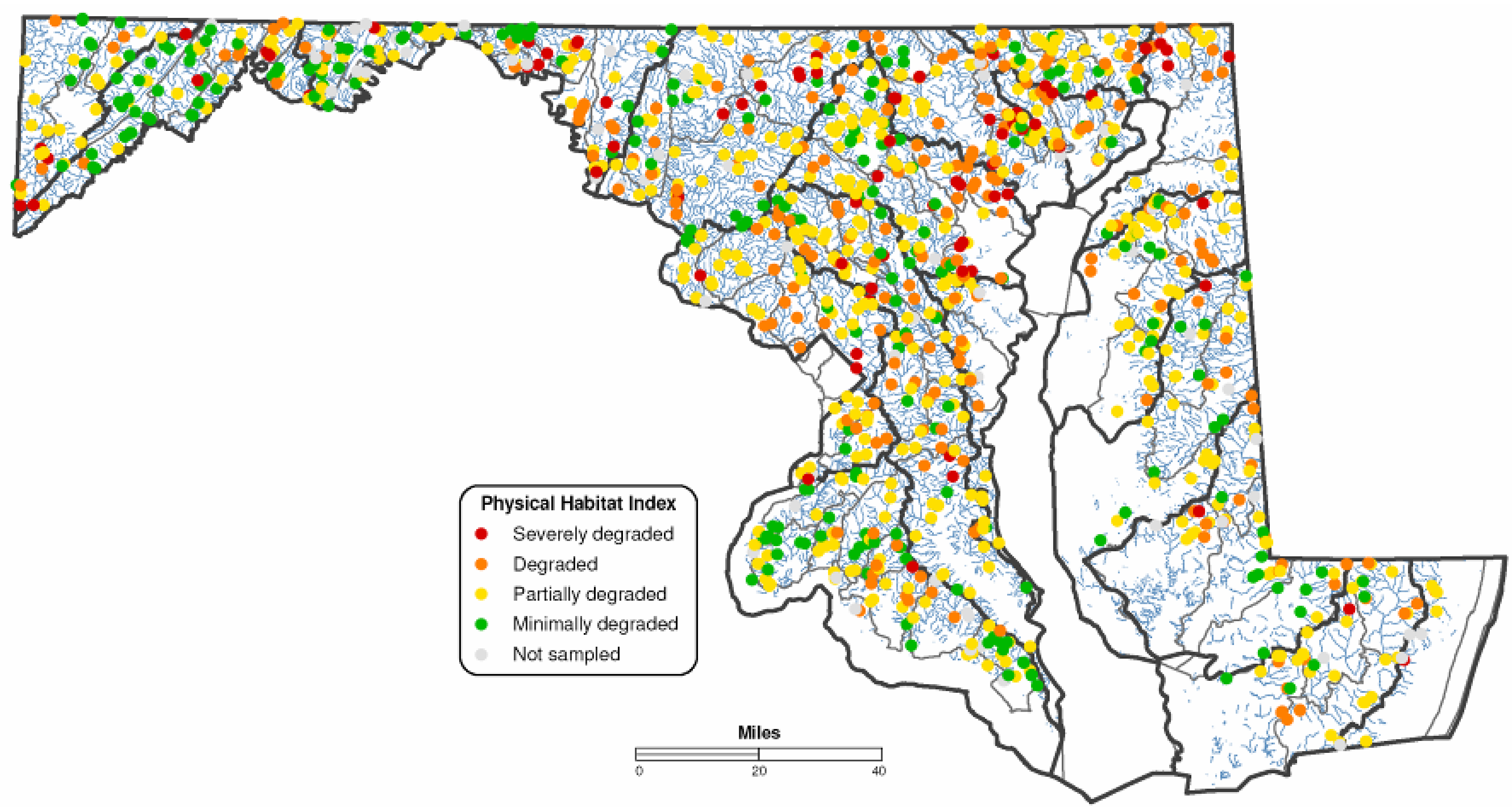


Figure 14-32. Geographic distribution of Physical Habitat Index (PHI) ratings for sites sampled in the 2000-2004 MBSS. Ratings are as follows: 81-100 good, 66-80 fair, 51-65 poor, and 0-50 very poor.

14.4.3 Riparian Buffer

The width and quality of riparian buffer strongly alters the amount of runoff into streams and the resultant stress from temperature, erosion, sediment, and flow regime. In addition, the presence of riparian vegetation affects the amount of woody debris and other allochthonous input (leaf fall) that affect stream structure and energy processing. Volume 10 discusses this topic in detail, so only a brief summary is provided below.

MBSS results describe both the type and extent of local riparian vegetation, estimated as the width of the riparian buffer along each 75-m sample segment. Statewide, an estimated 65% of stream miles had forested buffers on both sides of the stream, 12% had other kinds of vegetated buffers (wetland, old field, tall grass, or lawn) on both sides, and 10% had no buffer (sites were not included in the analysis if an outfall pipe was observed draining directly into the stream segment or if severe buffer breaks were present). An estimated 58% of stream miles had at least a 50-m riparian buffer on both sides of the stream (Figure 14-33). The data indicate that as buffer width increases, buffer type switches from roughly an even split between forest and other vegetation to nearly entirely forested buffer.

A statewide map (Figure 14-34) shows the distribution of riparian buffer widths observed at MBSS sites. Sites with at least a 50-m vegetated buffer were distributed throughout the state. The largest concentrations of sites with no buffer or buffer widths of less than 50-m were in the Lower Easter Shore basin and portions of the Baltimore-Washington corridor; other sites with less than a 50-m buffer were scattered throughout the state.

Estimates of the extent of stream miles lacking riparian buffer indicated that 10% of stream miles statewide had no buffer, while another 5% had only a vegetated buffer 1-5 m wide on the side with the least amount of buffer. The Lower Eastern Shore and Youghiogheny basins had the largest percentage of poorly buffered stream miles, with 18% lacking any buffer and 4% with 1-5 m of vegetation for each basin. Fifteen percent of stream miles in the Upper Potomac basin were unbuffered, while another 8% had 1-5 m of vegetation for the least buffered side of the stream. For all basins buffer width less than 5 meters on the least buffered side ranges between 6% (Lower Western Shore) to 25% (Lower Eastern Shore). The problem of insufficient riparian buffer is widespread throughout the State, presenting numerous opportunities for stream restoration through re-establishment of trees and other vegetation along riparian corridors. Riparian restoration efforts should be targeted to areas with the greatest potential for ecological benefit (e.g., reduced nutrient runoff, enhanced stream habitat, and improved water quality).

14.4.4 Temperature

Streams are adapted to their natural temperature regimes. Natural stream temperatures depend on climatic region, elevation, groundwater inputs, and riparian vegetation. Regular groundwater inputs and shading from riparian trees create cooler temperatures in any region. As Maryland's forests have been replaced with other land uses, riparian shading is frequently lost and groundwater inputs decrease as infiltration is reduced by less pervious surfaces. The water directly entering streams itself is warmed by the impervious surfaces and pipes that drain most urban areas (Walsh et al. 2004). The more open channels and shallower depths of urban streams also likely contribute to greater variation in stream temperatures between day and night. Warmer water can worsen the problems of algal growth, thereby affecting the natural energy processing in streams. Unnaturally warm water (thermal pollution) can also arise from small farm dams (Lessert and Hayes 2003) and constructed stormwater treatment ponds (Walsh et al. 2004).

Since 1997, the MBSS has deployed continuous reading temperature loggers at more than 2,000 sites. The long-term goal is to use temperature data to (1) better classify and characterize coldwater streams and (2) identify streams stressed by temperature changes, such as spikes from rapid inputs of warm water running off impervious surfaces during summer storms. Data were recorded at 20-minute intervals with loggers set to record the highest value observed during each 20-minute interval. Because temperature loggers are sometimes lost or not submerged in the stream during low flow periods, careful examination is needed to establish a consistent period of record and compute meaningful summary indicators such as:

- Mean average daily temperature
- Mean minimum and maximum daily temperatures
- Absolute maximum temperature
- 95th percentile temperature
- Percentage of readings exceeding thresholds in state water quality standards

Ultimately, the MBSS plans to analyze all MBSS temperature data and compare it to Maryland water quality standards for temperature, which state that the maximum temperature may not exceed 32 EC (90 °F) in most waters, 20 °C (68 °F) in Class III Natural Trout Waters, or 23.9 °C (75 °F) in Class IV Recreational Trout Waters (COMAR 1995). EPA criteria for growth and survival of brook trout (Maryland's only native salmonid) are maximum weekly means of 19 and 24 °C. Research has found that a still lower temperature of 14.4 °C is the maximum temperature for juvenile growth of brook trout (EPA 1976 and McCormick et al. 1972, as cited in Eaton 1995).

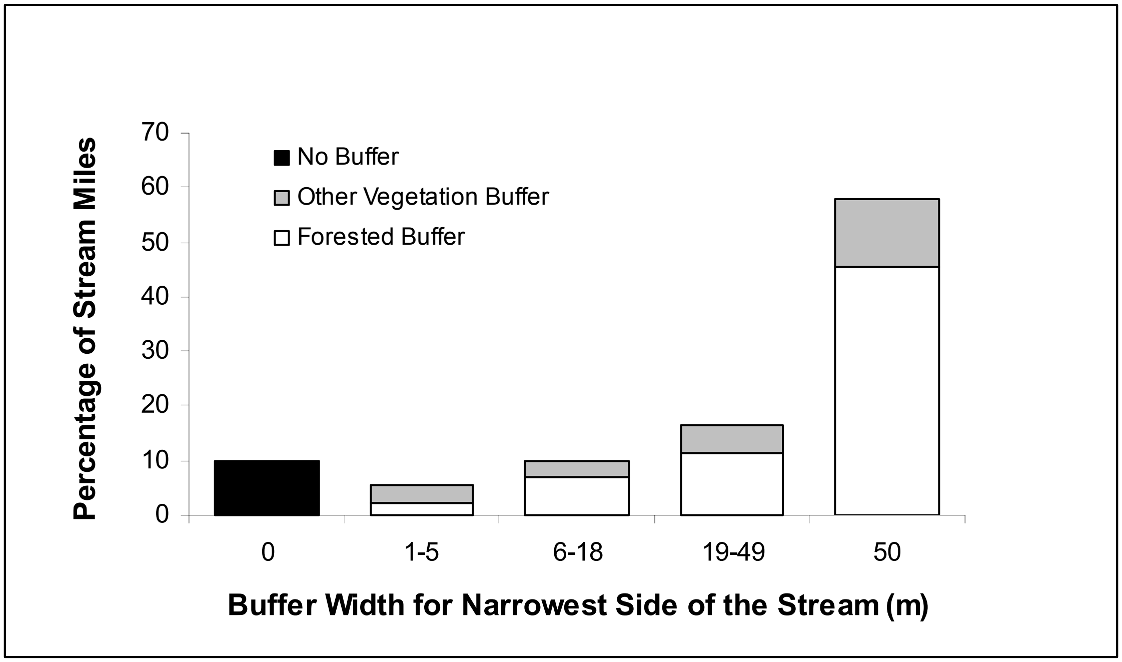


Figure 14-33. Percentage of stream miles by riparian buffer type and width for the 2000-2004 MBSS. The category "Other Vegetation Buffer" includes old field, emergent vegetation, mowed lawn, tall grass, and wetland vegetation. No (effective) buffer indicates that although some vegetation may be present, runoff (such as from an outfall pipe) occurs directly into the stream.

Figures 14-35 and 14-36 show the temperature records of typical warmwater and coldwater sites. Note that in both cases a significant proportion of days between June and September exceeded the respective temperature thresholds.

14.4.5 Channel Alteration

Dredging, filling, and construction in a stream channel are the most direct ways to affect physical habitat. Channelization refers to both the straightening of channels and their armoring with concrete or other hard materials. Dams alter upstream areas by converting lotic stream habitat to lentic (ponded) habitat, resulting in silt deposition, increased water temperature, and barriers to the movement of fish. Even small culverts or other structures (exposed sewer pipes) in the stream channel can block fish movement. In addition, beaver dams can flood large areas, dramatically changing stream character.

14.4.5.1 Stream Bockages as Stressors to Stream Communities in Maryland

Stream blockages such as dams, weirs, and culverts can prevent migratory fishes access to upstream habitats and have been responsible for the reduction or elimination of populations of migratory species throughout the world, including Chesapeake Bay. Reduction or the complete loss of populations of anadromous species (e.g., American shad, hickory shad, alewife herring, blueback herring, white perch, yellow perch, striped bass) and catadromous species (e.g., American eel) from many tributaries to Chesapeake Bay as a result of stream blockages have resulted in concerted efforts to restore fish passages and re-establish populations of these commercially important species.

The Maryland DNR Fisheries Service began surveying blockages to anadromous fish passage in the late 1960s and 1970s. Surveys documented more than 1,000 fish blockages to migratory species including dams, culverts, gauging weirs, and sewer lines (Figure 14-37). In 1987, the first Chesapeake Bay Agreement was signed by states within the basin, including Maryland, Pennsylvania, Virginia, and the District of Columbia. This landmark agreement included commitments within each state "to provide for fish passage at dams, and remove stream blockages wherever necessary to restore passage for migratory fish." The Bay states agreed to reopen 1,357 miles (thought to be the majority of historic stream miles available) of historical spawning grounds by the year 2003, of which Maryland's share was approximately 389 stream miles. In response to this commitment, the Maryland Department of Natural Resources created the Fish Passage Program in 1988.

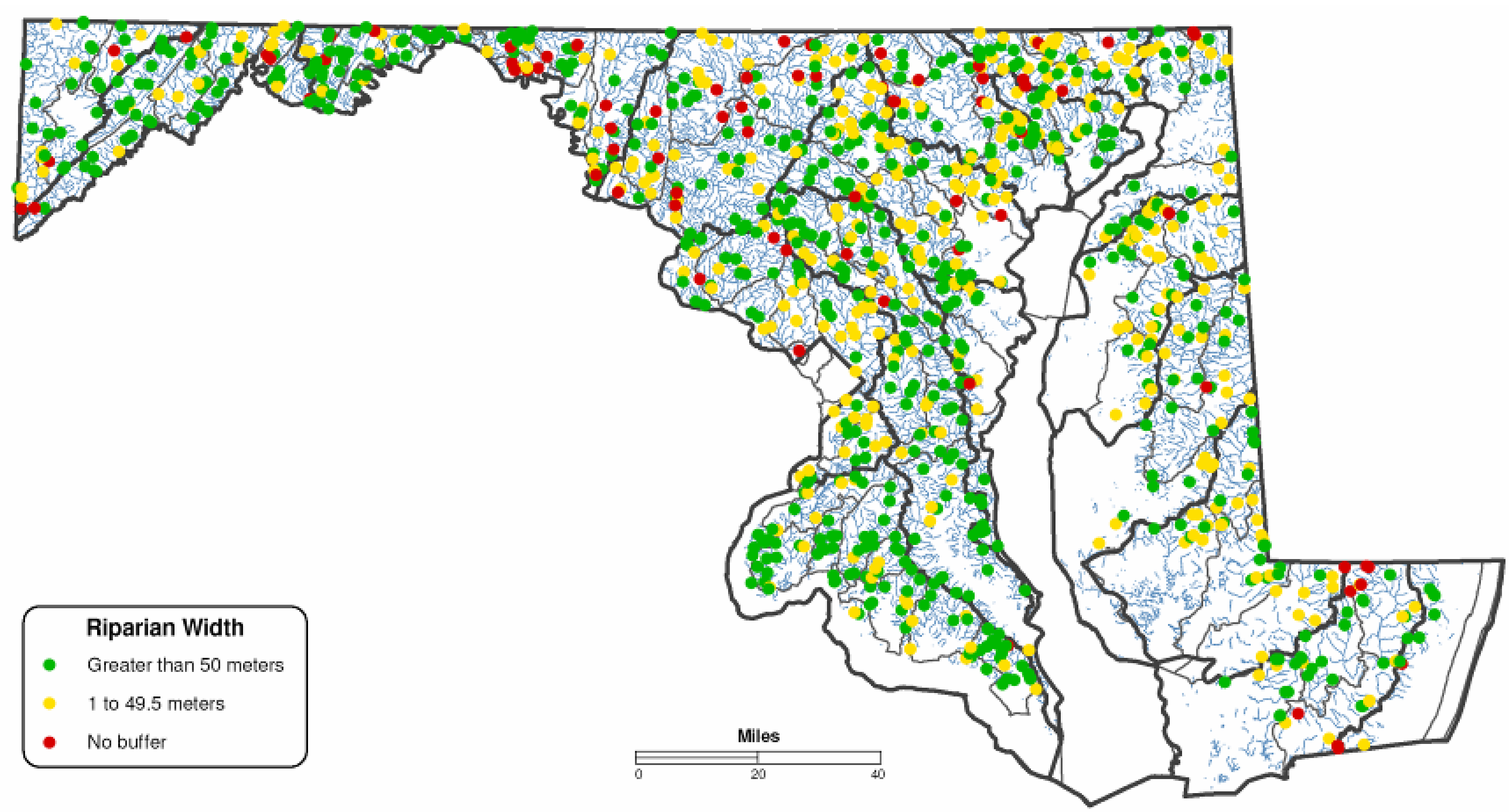


Figure 14-34. Riparian buffer width at sites sampled in the 2000-2004 MBSS.

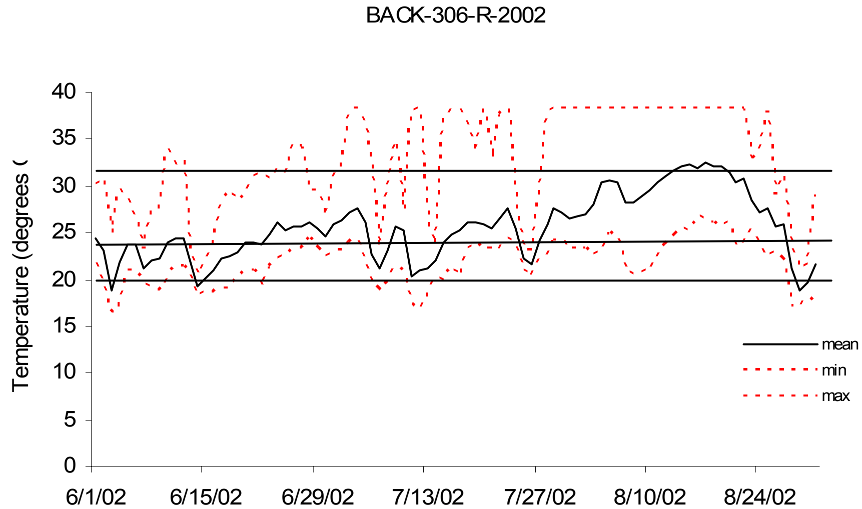


Figure 14-35. Mean, minimum and maximum daily temperatures (degrees Celsius) for a warmwater stream sampled in MBSS 2002, BACK-306-R-2002. Period of record was from June 1, 2002 to August 31, 2002. Horizontal threshold lines indicate Maryland water quality standards maximums for Class III, Class IV, and other waters.

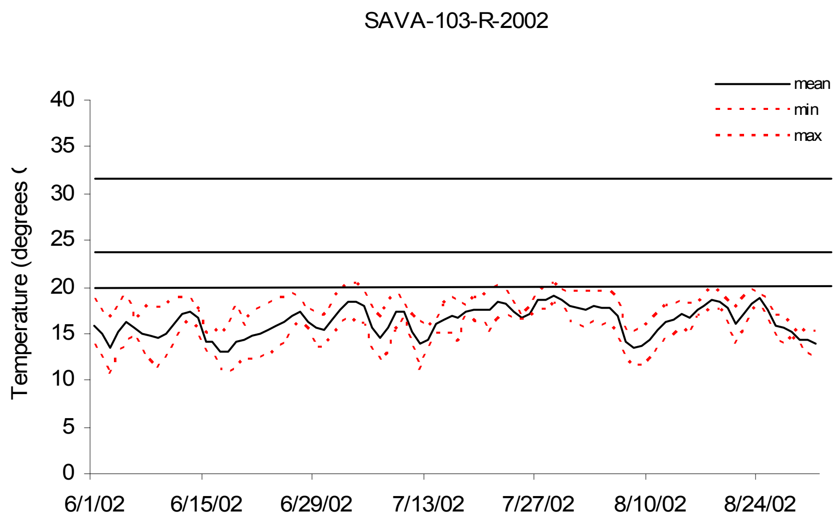


Figure 14-36. Mean, minimum and maximum daily temperatures (degrees Celsius) for a coldwater stream sampled in MBSS 2002, SAVA-103-R-2002. Period of record was from June 1, 2002 to August 31, 2002. Horizontal threshold lines indicate Maryland water quality standards maximums for Class III, Class IV, and other waters.

The Fish Passage Program's purpose is to restore migratory fish species to historic or near-historic levels of the 1950s. Since funding has been a limiting factor, the program has typically focused most of its attention on the larger blockages. With this in mind, fish passages have been provided at many of the larger blockages on Maryland waterways, including Conowingo Dam on the Susquehanna River, and Bloede, Simkins, and Daniels dams on the Patapsco River. They have also been provided at some of the smaller dams such as Fort Meade Dam on the Little Patuxent River, Van Bibber Dam on Winters Run, the dam at Elkton on Big Elk Creek, and the Tuckahoe Lake Dam in Tuckahoe State Park, as well as many others. The original goal of the Chesapeake Bay Agreement was surpassed in 2004 when the Bay states collectively opened 1,570 miles of historic spawning habitat. Installations of fish passages have reopened more than 400 miles of streams in Maryland to migratory species.

Many resident fishes are also known to move some distances to preferred seasonal habitats for spawning and feeding, and to refugia during times of stress. The

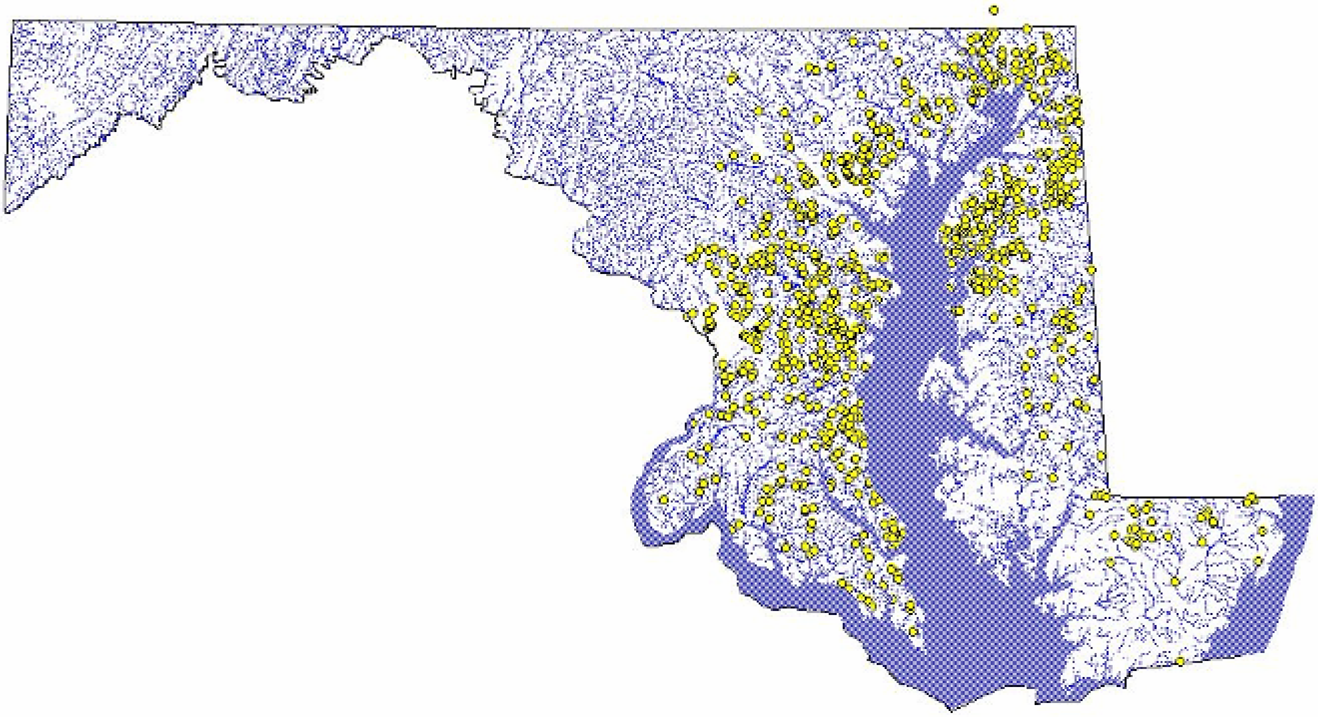


Figure 14-37. Stream blockages to the migration of anadromous fishes identified by MDNR Fisheries Service.

influence of blockages on resident fish populations and community structure can be profound. The most pervasive influence of blockages on resident fishes may be as barriers to upstream re-colonization. Blockages can interrupt pathways of immigration and emigration, and limit the exchange of individuals between populations. This change in metapopulation structure, culminating in fragmented and isolated populations upstream of a blockage, can result in local extinctions following catastrophic events (Winston et al. 1991, Dunham and Rieman 1999). These events may displace or eliminate all or part of a stream fish community, after which re-colonization is impossible. Stream blockages may more severely affect rare resident species by increasing the likelihood of local extinction (Fagan et al. 2002).

Although large stream blockages have received the most attention, small blockages such as box culverts, pipe culverts, gabion baskets, and sewer lines also are barriers to resident and migratory fish movement (e.g., Kenny et al. 1992; Gibson et al. 2005; Warren and Pardew 1998) and often degrade or reduce fish habitat (Harper and Quigley 2000). In Maryland, small blockages are numerous and widespread. For example, MBSS has identified 32 small blockages to fish passage at or near sites sampled from 1995-2004. These blockages included 16 dams, 6 pipe culverts, 4 box culverts, 3 pipeline crossings, 2 arch culverts, and 1 gauging weir (Figure 14-38). Since 1996, the MDNR Stream Corridor Assessment (SCA) has conducted stream walks within 23 Maryland 8-digit basins. In addition to documenting various aspects of stream condition, one of the goals of the SCA is to identify structures that may impede fish movement such as man-made dams, road crossings, pipe crossings, channelized stream sections, beaver dams, and natural falls (Figure 14-38). The State Highway Administration (SHA) also notes blockages to fish passage during their biannual inspection of bridges and large culverts (Figure14-38).

Poor design and/or improper installation of culverts and stream channel alterations associated with road crossings often cause complete or intermittent blockage to upstream fish movement. Culverts often result in insufficient stream depth, excluding certain species due to body size or shape. They also alter elevation of the streambed. Downstream outlets of culverts are often higher than the original streambed, creating a vertical drop that is often insurmountable. High water velocities produced by culverts may also exclude upstream movement by some species. Large cobbles, boulders, or gabion baskets placed at road crossings often create physical barriers to fish movement.

Kenny et al. (1992) surveyed 48 road crossings in Maryland during the period from 1988 to 1990. Twenty-eight (58%) were identified as being complete (15), seasonal (9), or frequent (4) barriers to fish passage. Surveys of road crossings by Gibson et al. (2005) and Langill and Zamora (2002) in Canada found that 53% and 58% served as complete or intermittent barriers to fish passage, respectively. If approximately 50% of road

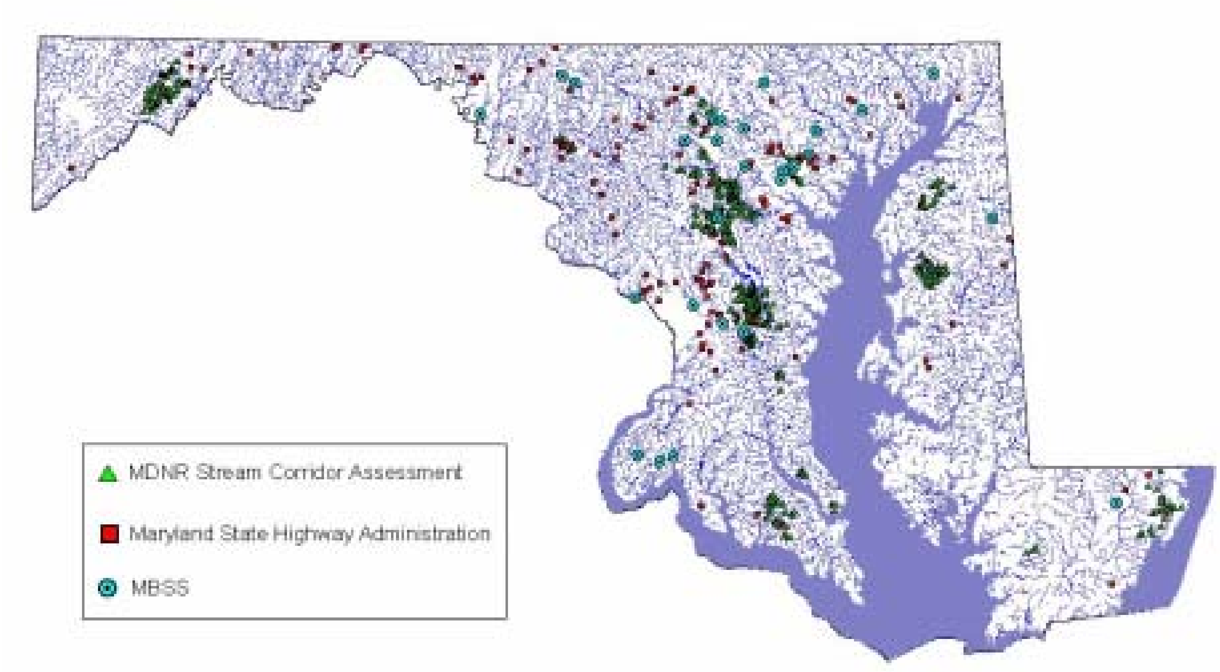


Figure 14-38. Stream blockages identified by the MBSS, MDNR Stream Corridor Assessment, and Maryland State Highway Administration.

crossings are barriers to fish migration, as found in these three studies, nearly 6,851 of an estimated 13,703 road crossings in Maryland (data from U.S. Department of Commerce Bureau of the Census Geography Division) are potentially complete or intermittent blockages.

In addition to permanent stream blockages, beaver ponds can also limit fish passage. Based on MBSS sites having beaver ponds or being unsampleable because of beaver activity, an estimated 6% of stream miles statewide had beaver ponds. The areas with the greatest extent of beaver ponds were the Lower Potomac (20%) and the Upper Eastern Shore (22%). No beaver activity was observed for Choptank, Lower Eastern Shore, and the Ocean Coastal basins. (Figure 14-39).

During 1995, fish sampling was conducted by MBSS upstream and downstream of a small blockage (1 ft. high) at a road crossing on Budd's Creek, a tributary to the Lower Potomac River basin, in Charles County, Maryland. Sampling was restricted to fish species presence or absence and equal sampling effort was used above and below the fish blockage. Eight species were collected downstream of the blockage including creek chub (*Semotilus atromaculatus*), eastern mudminnow (*Umbra pygmaea*), blacknose dace (*Rhinichthys atratulus*), tessellated darter (*Etheostoma olmstedi*), American eel (*Anguilla rostrata*), bluegill (*Lepomis macrochirus*), golden shiner (*Notemigonus crysoleucus*), and spottail shiner (*Notropis hudsonius*). Upstream of the blockage, only four of these species were collected: creek chub (*S. atromaculatus*), eastern mudminnow (*U. pygmaea*), tessellated darter (*E. olmstedi*), and golden shiner (*L. macrochirus*).

As part of a cooperative study with the U.S. Army Corps of Engineers in 1998, the MBSS sampled upstream and downstream of two concrete channels at road crossings in the Western Branch basin to determine whether the channels acted as barriers to the upstream migration of resident fishes. Despite suitable fish habitat conditions upstream and similarities in habitats upstream and downstream of the channels, species richness was lower upstream of both channels (Table 14-11).

In addition to declines in species richness, blockages can also alter fish abundance and density (Kenny et al. 1992). Recovery of pre-disturbance abundance and density in upstream species may be delayed as a result of a complete or intermittent downstream blockage (Detenbeck et al. 1992). Abundances of upstream species may also shift as a result of the exclusion of top predators by downstream barriers. For example, the exclusion of American eel (*A. rostrata*), a species known to prey upon benthic species such as cottids and percids (Jenkins and Burkhead 1994; Wiley et al. 2004), from much of its historic range as a result of stream blockages may partially explain high abundances of Blue Ridge sculpin (*Cottus caeruleomentum*) above many large dams in Maryland. Large dams (> 25 ft) are present in Patapsco River, Gunpowder River, and Bush River basins in the Piedmont of Maryland. These dams serve as complete or partial barriers to upstream migration of the catadromous American eel, resulting in high eel abundances and densities downstream (Wiley et al. 2004).

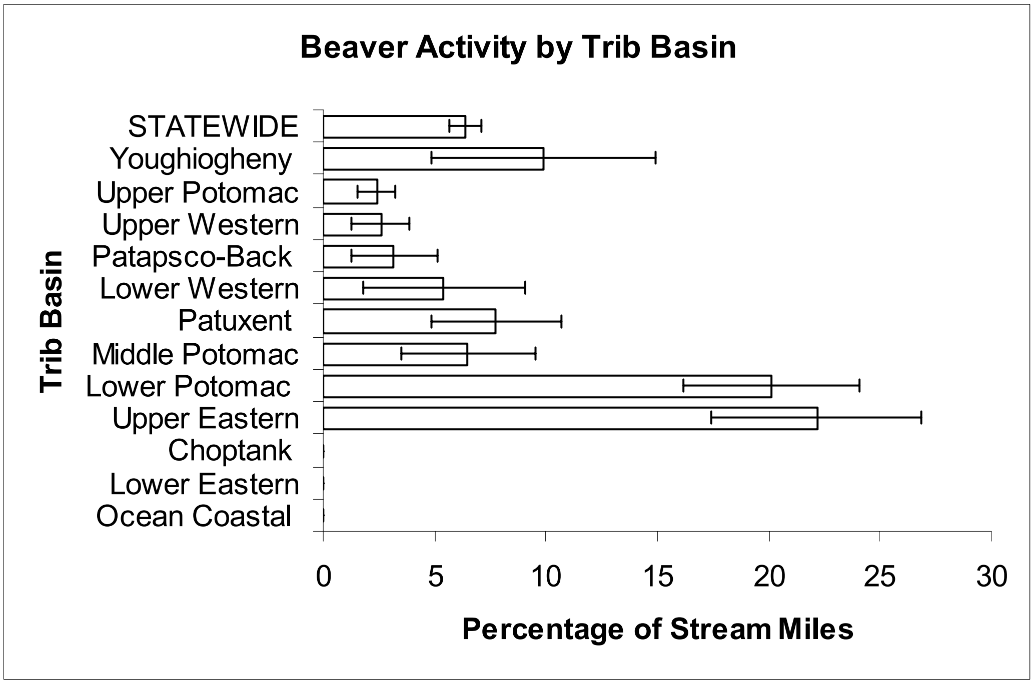


Figure 14-39. Percentage of stream miles (±SE) with beaver ponds, statewide and for the basins sampled in the 2000-2004 MBSS.

Table 14-11. Species present above and below fish blockages formed by concrete channels at sites sampled by MBSS in Bald Hill Branch and Unnamed Tributary (UT) to Southwest Branch in Western Branch basin.

Stream	Fish Species	Downstream of Barrier	Upstream of Barrier
Bald Hill Branch	Mummichog (*Fundulus heteroclitus*)	X	X
	Blacknose dace (*Rhinichthys atratulus*)	X	X
	Golden shiner (*Notemigonus crysoleucas*)	X	X
	Goldfish (*Carassius auratus*)	X	X
	Swallowtail shiner (*Notropis procne*)	X	
	Bluespotted sunfish (*Enneacanthus gloriosus*)	X	
	Redbreast sunfish (*Lepomis auritus*)	X	
	Creek chubsucker (*Erimyzon oblongus*)	X	
	Eastern mudminnow (*Umbra pygmaea*)	X	
	Pumpkinseed (*Lepomis gibbosus*)	X	
UT Southwest Branch	Blacknose dace (*Rhinichthys atratulus*)	X	X
	Least brook lamprey (*Lampetra aepyptera*)	X	X
	American eel (*Anguilla rostrata*)	X	X
	Rosyside dace (*Clinostomus funduloides*)	X	
	Fallfish (*Semotilus corporalis*)	X	
	Swallowtail shiner (*Notropis procne*)	X	
	Tessellated darter (*Etheostoma olmstedi*)	X	
	Cutlips minnow (*Exoglossum maxillingua*)	X	
	White sucker (*Catostomus commersoni*)	X	
	Common shiner (*Luxilus cornutus*)	X	
	American brook lamprey (*Lampetra appendix*)	X	
	Pumpkinseed (*Lepomis gibbosus*)	X	
	Bluegill (*Lepomis macrochirus*)	X	
	Satinfin shiner (*Cyprinella analostana*)	X	
	Redbreast sunfish (*Lepomis auritus*)	X	
	Eastern mosquitofish (*Gambrusia holbrooki*)	X	
	Creek chub (*Semotilus atromaculatus*)	X	
	Sea lamprey (*Petromyzon marinus*)	X	

An analysis of 47 MBSS sites in these basins was used to examine the possible influence of eel predation on sculpin abundance above and below large dams. Sites were selected based on the presence of preferred sculpin habitat and suitable eel habitat (Stranko et al. 2005b). Sculpin abundance was significantly higher in sites above dams compared to below (Table 14-12). In downstream sites where the two species co-existed, sculpin abundance was inversely related to eel abundance. This suggests that predation by eels may lower sculpin abundance where they co-occur. Exclusion of eels from streams above dams, therefore, results in higher sculpin abundance due to the absence of this important predator. Other variables (e.g., microhabitat) not measured by MBSS may be additional factors influencing sculpin abundance. However, the exclusion of eel from upstream habitats likely has cascading effects on fish community structure upstream of blockages.

Deleterious effects of stream blockages are not limited to stream fish communities. Barriers have also been implicated in the decline of freshwater unionid mussels throughout North America (Watters 1996). The parasitic larval stage of most unionids requires fishes as hosts. Stream barriers can indirectly result in declines of unionid populations by directly excluding host species upstream, and by altering upstream habitats such that unfavorable conditions reduce survival of host fishes (Bogan 1993). Therefore, stream blockages that serve as barriers to host fishes may cause isolation and fragmentation of unionid populations, leading to local extinctions (Watters 1992, 1996). Stream barriers may be partially responsible for the decline of rare unionids in Maryland. For example, the distribution of the federally endangered dwarf wedge-mussel (*Alasmidonta heterodon*) in certain streams is confined to stream reaches below road crossings. The downstream distribution of this species in relation to road crossings suggests that complete or partial blockages at these crossings may impede the upstream movement of anadromous and resident host fishes, thereby restricting dwarf wedgemussel to downstream habitats. The role of stream barriers in unionid distribution in Maryland requires further investigation.

A strong case can be made regarding the deleterious effects of blockages on fish communities. However, in some cases a blockage may be beneficial to upstream fish communities because it prevents the upstream introduce-tion of an invasive, non-indigenous fish species. For example, Timber Run, a tributary to Liberty Reservoir in Baltimore County, has been monitored annually as part of the MBSS sentinel site network. This tributary has supported a healthy population of native brook trout (*Salvelinus fontinalis*) due in part to a downstream blockage (road culvert) that excluded non-native brown trout (*Salmo trutta*) from upstream reaches. Since 2000, siltation below the road culvert has reduced the height of the blockage, ultimately allowing passage of brown trout into upstream habitats. Competition between brook trout and this non-native trout species may ultimately lead to the extirpation of brook trout from this tributary. In the large majority of circumstances, the removal of stream blockages will benefit stream communities. However, when planning fish passage projects in areas where non-native species are known to occur, the potential threats of non-native introductions to upstream areas should be considered.

Stressors to streams are often difficult to definitively diagnose. Disruptions to the connectivity of stream eco-systems may be responsible for stream degradation in more cases than are presently known even though extensive efforts have been made to restore access of anadromous fish species to their natal spawning areas, substantial amounts of stream habitat are still inaccessible. In particular, the distribution and effects of small blockages associated with road crossings on resident species in Maryland is not well understood and are not limited to fish and mussels.

14.4.5.2 Channelization

Channelization can dramatically change the character of a stream. Historically, streams were routinely channelized to drain fields and provide flood control. Today, streams in urban areas are often channelized to accommodate road building or to drain stormwater from developed areas. When previously meandering streams are straightened, they lose their natural connection to the floodplain, with adverse consequences for the stream ecosystem. For example, increased flows during storm events can lead to greater scouring, more bank instability, and disruption of the natural pattern of riffle and pool habitats. At other times, decreased base flows can result in stagnant ditches with substrates degraded by heavy sediment deposition. At the extreme, channelization replaces a diverse, meandering stream with a barren concrete trapezoid devoid of physical habitat.

Table 14-12. Above and below dam abundance of Blue Ridge sculpin and American eel.

Species	Above Dam (Mean abundance)	Below Dam (Mean abundance)
Blue Ridge sculpin (*C. caeruleomentum*)	260.7*	42.3*
American eel (*A. rostrata*)	0.25*	26.4*
*indicates significant difference (p<0.05)		

Figure 14-40 shows that channelized streams have lower BIBIs. This effect is widespread in Maryland (Figure 14-41). Statewide, an estimated 22% of stream miles are channelized. The greatest extent of channelization was observed in the Ocean Coastal basin (67%). Two additional basins had channelization in greater than 50% of the stream miles, Lower Eastern Shore (62%) and the Choptank (53%). The Lower Potomac River, Lower Western Shore, and the Youghiogheny had less than 10% of stream miles with channelization. All other basins had between 12-33% of stream mile channelized.

14.4.5.3 Altered Flow Regimes

As described above, increased runoff from impervious surfaces and increased flows in straightened and constrained channels can lead to greater scouring, greater bank instability, and disruption of the natural pattern of riffle and pool habitats. At other times, decreased base flows can result in stagnant ditches with substrates degraded by heavy sediment deposition. Therefore, both higher and lower than natural flows can have deleterious effects on stream biota.

Low Flows. For the years 2000-2004, 4% of streams were unsampleable due to low flows. Some of these low flows are attributable to natural conditions, but others may result from less infiltration in urban areas or from specific water withdrawals. Currently, the MDE maintains minimum flow-by requirements for surface water withdrawal permits to protect the State's aquatic resources. It is not known whether the permits are uniformly applied or whether they consider the potential cumulative effects of other permitted withdrawals on the same waterway. Preliminary analysis by the MBSS did not reveal evidence of water withdrawal effects on biological condition (see Volume 4 for more details). Figure 14-42 describes the regression relationship for catchment area and flow statewide. Certainly, different natural conditions (e.g., lower flows in rain shadow valleys and karst geology) account for most of this variability. The flow values are also one-time measurements, although most are taken during baseflow in the summer. Nonetheless, MBSS sites in the lower right corner (i.e., those departing most from the regression) may represent low flow resulting from human activities. For the six biggest outliers, FIBIs and BIBIs were not significantly lower than average.

In addition, MDE permit information in the Big Elk Creek basin was used to seek associations between the relationship of seven permitted withdrawals and eight MBSS sites (Figure 14-43). On four occasions between 1994 and 2001, stream flow in Big Elk Creek at Elk Mills dipped below 15.3 cubic feet per second (cfs), the minimum flow-by for the mill race diversion that feeds DNR's fish rearing ponds in Elkton. On two occasions, stream flow dipped below 11.9 cfs; the (waived) minimum flow-by requirement for the town of Elkton. These two low flow periods lasted for about 20 days in late summer 1995, and about 10 days in late summer 1999. An examination of the fish and benthic IBIs in the Big Elk Creek basin between 1996 and 2000, however, did not suggest that permitted surface water withdrawals operating during this time were a major stressor at these sites.

In the future, the MBSS plans to conduct a more thorough analysis with fortuitously "paired" water withdrawals and MBSS sampling sites. Stressor identification will be improved by choosing homogeneous geographic regions and focusing on especially low flow periods (e.g., drought summers). This will be possible when more of the 921 permitted surface water withdrawals are available as geographically referenced digital files.

High Flows and Bank Erosion. Bank erosion is a common symptom of stream flow problems. Erosion within the stream channel, often associated with "flashy" flow regimes in highly urbanized basins, can scour banks and mobilize sediment. In fact, much of the sediment transported and deposited within the stream often originates from in-channel erosion rather than overland flow. Bank erosion is a sign of channel instability (side-cutting and/or down-cutting). While the lack of streambank vegetation can contribute to bank erosion, severe erosion can, in turn, destabilize vegetation, causing even large tress to fall. In addition, sediments eroded from banks can become resuspended after initial settling, increasing turbidity and deposition in downstream areas. The effects of sedimentation are discussed in the next section.

Moderate to severe bank erosion occurs commonly in Maryland streams, as seen in Figure 14-44. Many basins had a high occurrence of bank erosion during the 2000-2004 MBSS. The greatest extent of moderate to severe bank erosion was estimated for the Patuxent basin (57% of stream miles). Within each 75-meter segment sampled, field estimates of the amount of eroded bank area were also made. Mean values by basin were used to estimate the extent of eroded area (square meters) per stream mile. The highest values were the Choptank (35%), Upper Eastern Shore (36%), Lower Western Shore (37%), and the Patuxent (39%) basins. Overall, moderate to severely eroded banks occurred on 23% of the State's stream miles.

As described above, channel alteration (generally) and changes to the flow regime (specifically) disrupt the natural pattern of riffles and pools in a stream. The MBSS assesses this effect with the velocity/depth diversity score. Figure 14-45 shows that lower velocity/depth diversity scores are correlated with lower FIBIs. Figure 14-46 shows the extent of this effect by tributary basin.

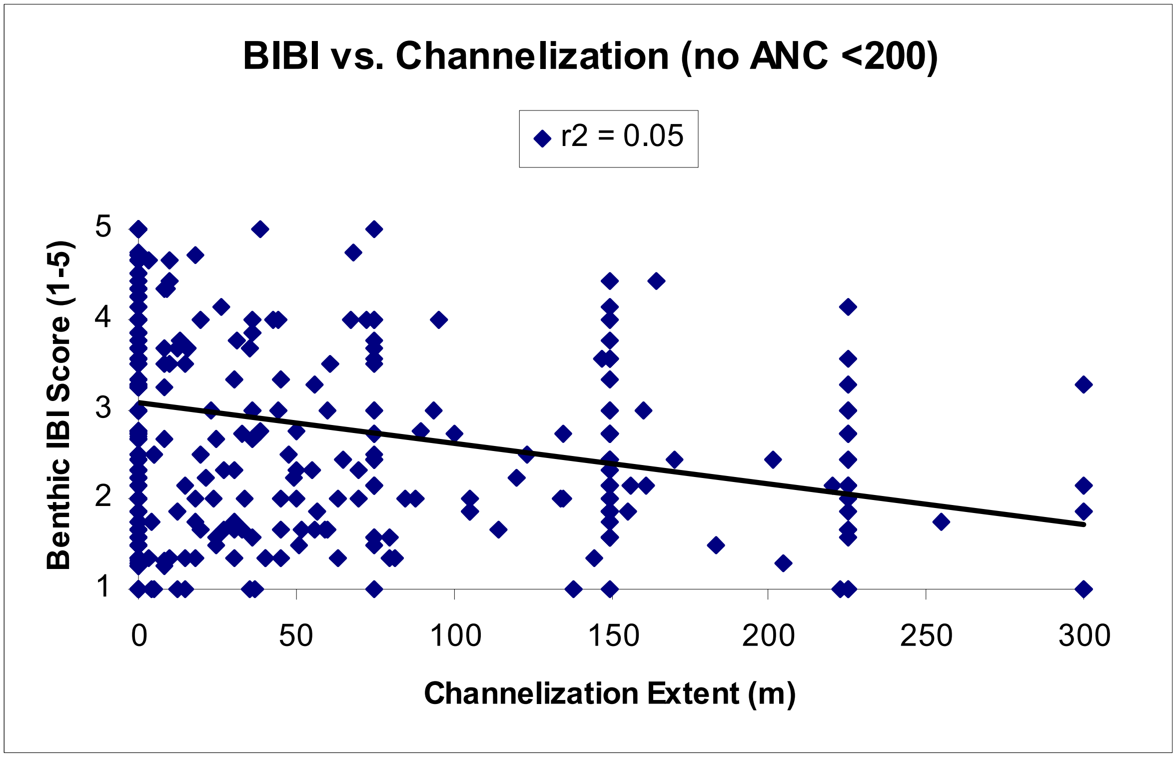


Figure 14-40. Relationship between benthic IBI and extent of channelization, statewide for the 1997-2004 MBSS sites with ANC > 200.

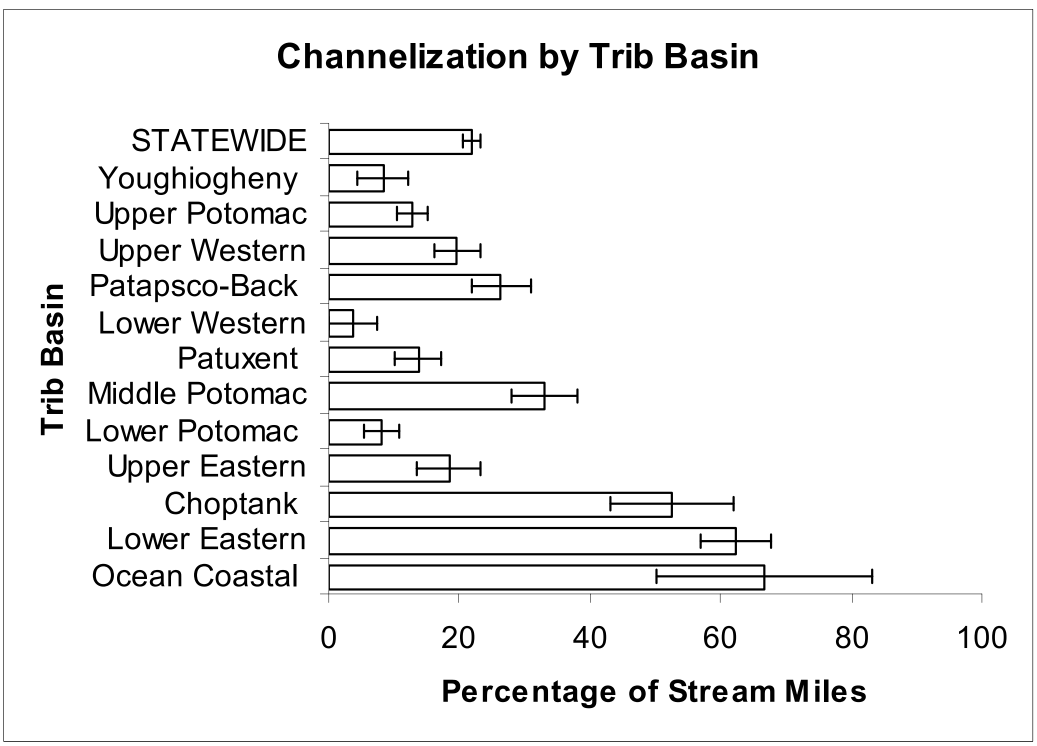


Figure 14-41. Percentage of stream miles (+SE) with evidence of channelization statewide and by basins for the 2000-2004 MBSS.

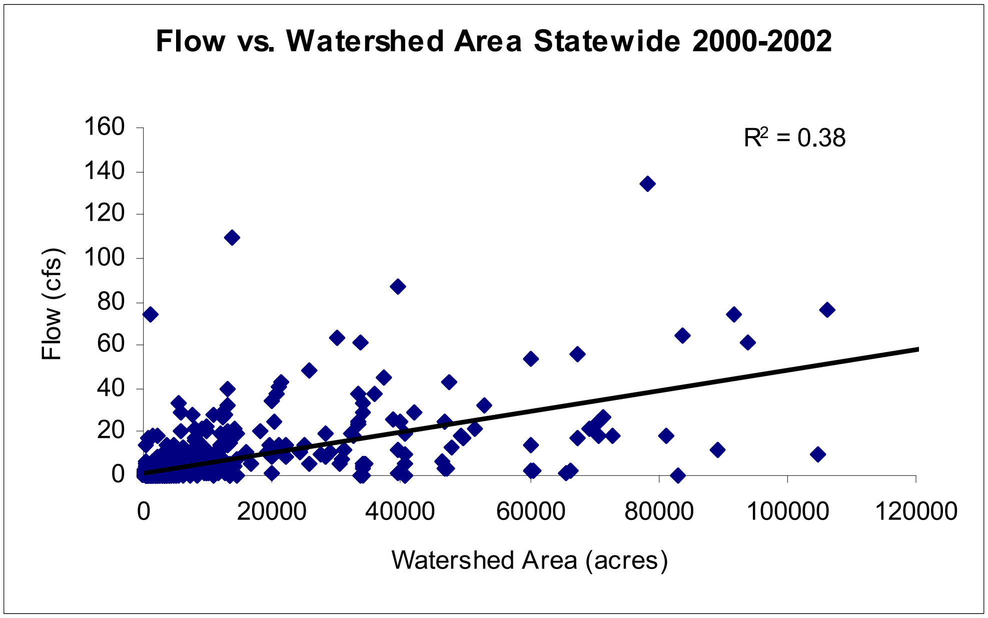


Figure 14-42. Relationship of flow and catchment (basin) area at MBSS sites (2000-2002) showing outliers with "apparent low flows."

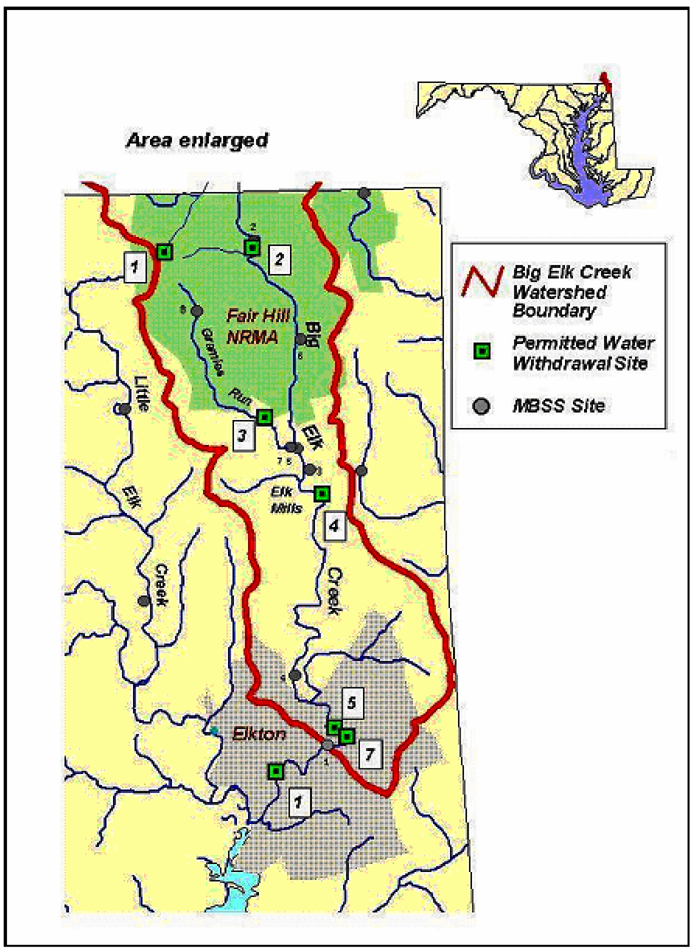


Figure 14-43. Big Elk Creek basin in Maryland showing permitted water withdrawal and MBSS sites.

14.4.6 Terrestrial and Channel Sediment

Sediment "pollution" is the number one impairment of streams nationwide. As described above, sediment within the water column and sediment within the streambed can come from both terrestrial and channel sources. Wolman (1967) described a cycle of sedimentation and erosion associated with urban development. Initially, cleared land produces large sediment loads into streams that can lead to an aggradation phase where the channels are filled with sediment. Following construction, sediment loads from the catchment are reduced and the increased high flows gradually remove the sediment so that the channel widens and deepens. During this erosional phase, most of the sediment carried by the stream comes from channel erosion rather than terrestrial sources.

Construction activities can affect aquatic biota directly and indirectly (Angermeier et al. 2004). Operating machinery in shallow-water habitats can destroy nests of animals and crush mollusks or other sedentary animals. However, more serious and common impacts result from the indirect effects of excessive fine sediment. Fine sediment can interfere with breathing, feeding, reproducing, and food production for many aquatic animals (Wood and Armitage 1997). Consequently, sediments can depress populations of invertebrates (e.g., Cline et al. 1982) and fishes (e.g., Whitney and Bailey 1959), and increase the dominance of silt-tolerant species. The deposition of fine sediments increases the embeddedness of the stream bed. Figure 14-47 shows the relationship of embeddedness with FIBI. Significant deposition of gravel and fine sediments can also lead to bar formation. Although some formation of bars is natural, severe bar formation can signal channel instability related to bank erosion and altered flow regimes. Exacerbated bar formation was observed in 48% (includes moderate bar formation in 32% of stream miles and severe in 16%) of stream miles statewide (Figure 14-48). Estimates of the percentage of stream miles experiencing moderate to severe bar formation were highest in Patuxent (62%), Lower Eastern Shore (59%), and the Lower Potomac (59%). Ocean Coastal had the lowest percent of stream miles with moderate to severe bar formation (14%). The other basins ranged between 32% and 52% for stream miles with exacerbated bar formation.

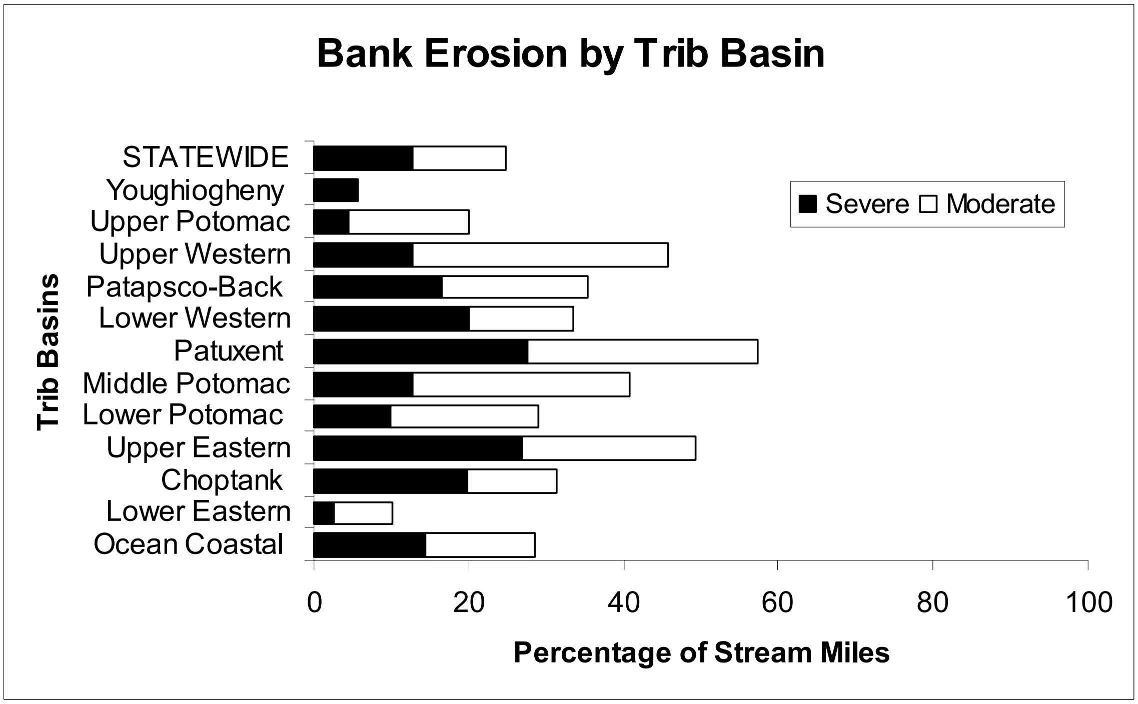


Figure 14-44. Percentage of stream miles with moderate to severe bank erosion, statewide and for the basins sampled in 2000-2004 MBSS.

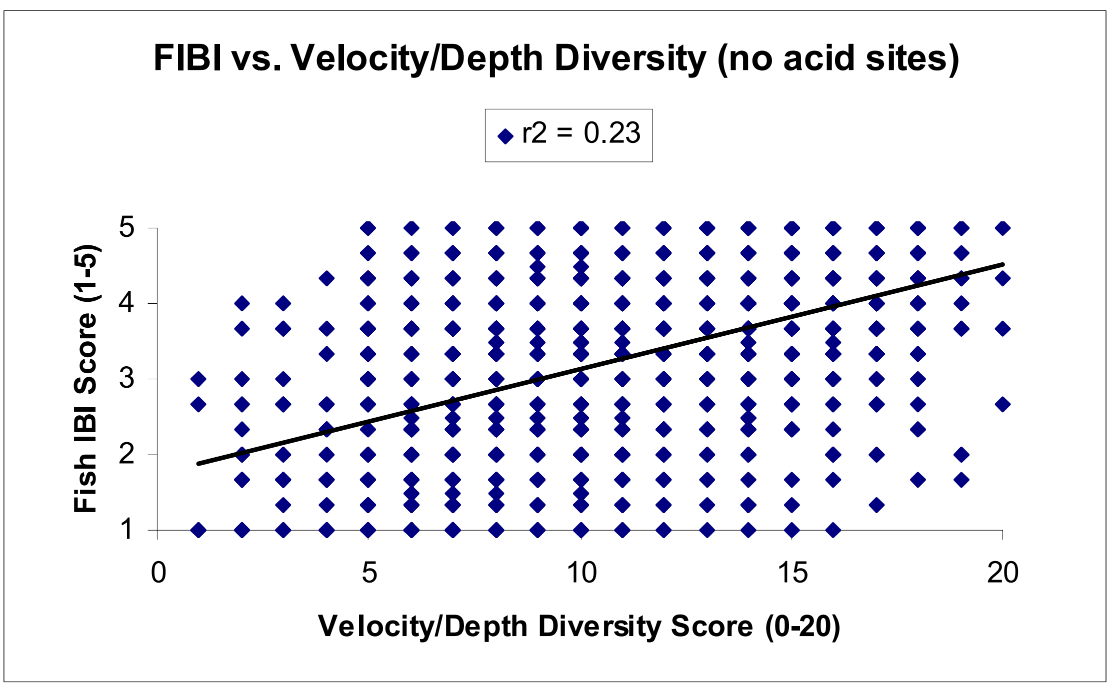


Figure 14-45. Relationship between the fish IBI and velocity/depth diversity scores, statewide for the 1995-2004 MBSS sites with ANC > 200.

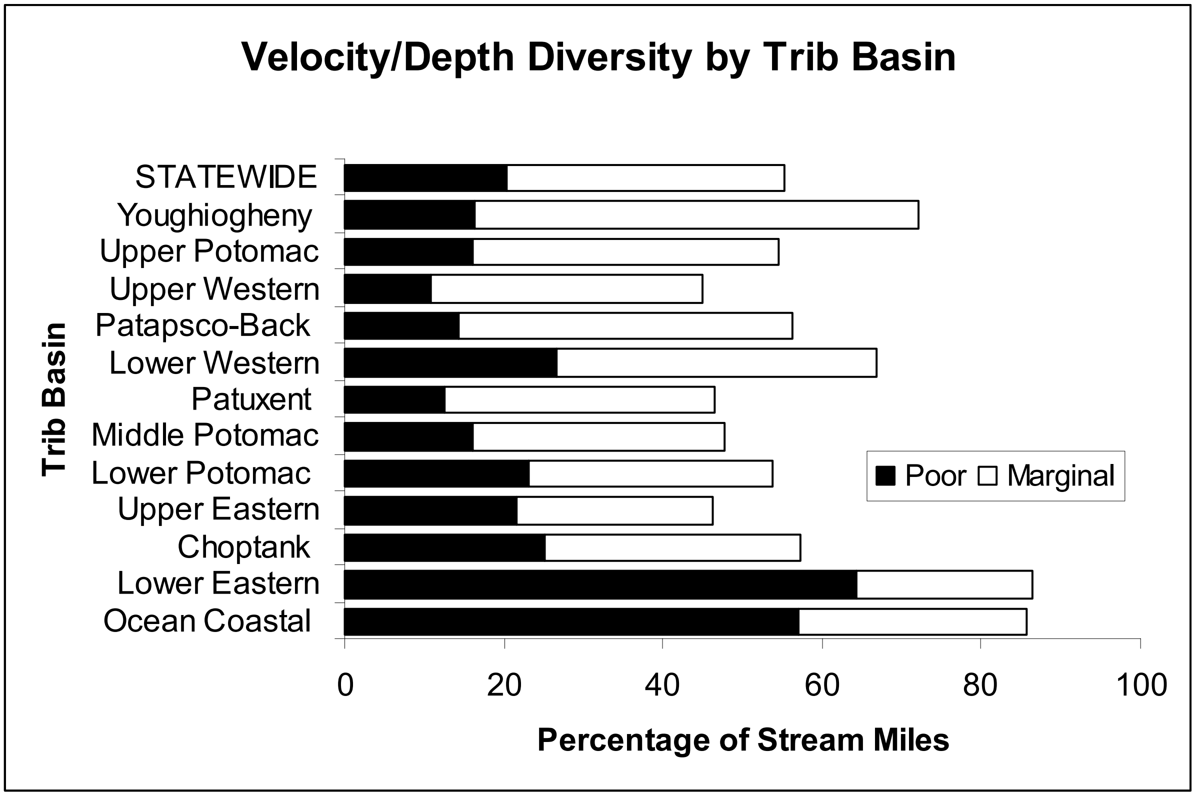


Figure 14-46. Percentage of stream miles with marginal and poor velocity/depth diversity scores, statewide and by basins sampled in 2000-2004 MBSS.

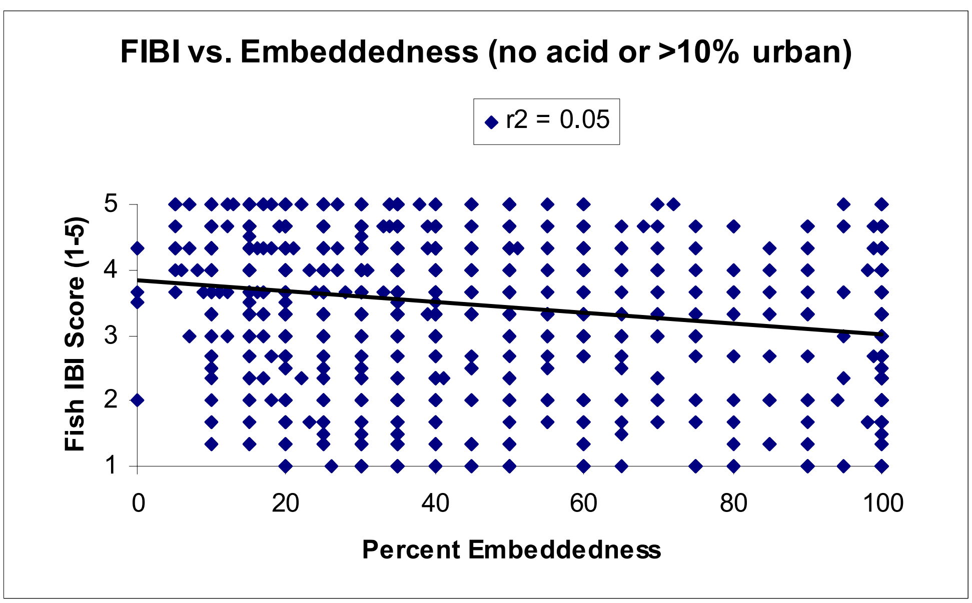


Figure 14-47. Relationship between fish IBI and embeddedness, statewide for the 1995-2004 MBSS sites with ANC > 200 and urban land < 10%.

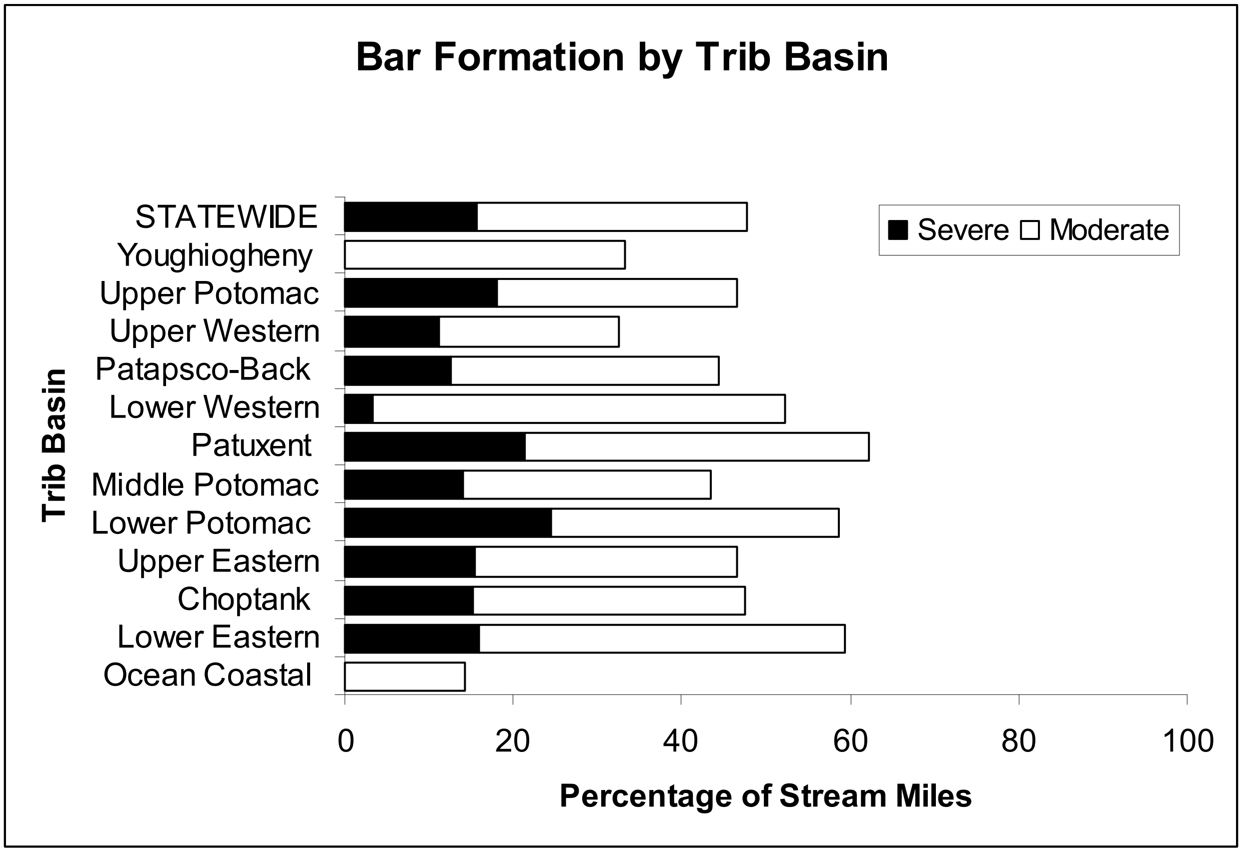


Figure 14-48. Percentage of stream miles with moderate to severe bar formation, statewide and for the basins sampled in the 2000-2004 MBSS.

SEDIMENT IMPAIRMENTS IN MARYLAND

The Maryland Department of the Environment (MDE) collaborated with Maryland DNR to develop a method for identifying sediment impairments in Maryland basins based on MBSS data. Specifically, MBSS data from 1995 to 2004 were used to identify likely sediment impairments based on sediment-related endpoints (i.e., stream habitat endpoints that best predict biological condition). This endpoint approach is consistent with U.S. Environmental Protection Agency (EPA) guidelines and uses Maryland biocriteria-based water quality standards.

To develop a model of sediment effects, the project first identified MBSS physical habitat parameters potentially influenced by sediment transport. The 27 parameters were grouped into five categories: riparian and upland zone, combined physical habitat, channel features, streambed, and water column. These parameters were reviewed and approved by a Technical Advisory Committee. Next, a subset of the parameters were selected that met the following criteria:

- Collected during both rounds of MBSS sampling (thus more sites can be analyzed)
- Useful range of values that provide discriminatory power (e.g., parameters scored as presence and absence would not meet this criterion)
- Not confounded by stream size and other critical natural variables, and
- Not completely redundant

Based on these criteria, six candidate parameters were available for analysis as potential surrogates for sediment impacts (see Table A).

The dataset was then refined by removing all MBSS sites affected by known, non-sediment related stressors (urban land use, high chloride levels, and acidification). Lastly, logistic regression was used to develop the best model (sediment indicator) for identifying sediment-related effects on "biocriteria failure" (i.e., degraded biological communities as represented by fish and benthic IBI scores). The modeling procedure is illustrated in Figure A.

Logistic regression models were developed at both the state and regional scale (i.e., for the Highlands, Eastern Piedmont, and Coastal Plain). Half of the original dataset was used for model development (based on random selection of stations) and the remaining half was used for model validation. Three to four parameters were selected per region based on model scores and parsimony (Table B). Table C provides the average rate of correct classification (ARCC) for both the development and validation results. MDE is evaluating different options for applying this sediment indicator at the Maryland 8-digit basin or other spatial scales. This model and methodology are currently under review and thus all results are draft.

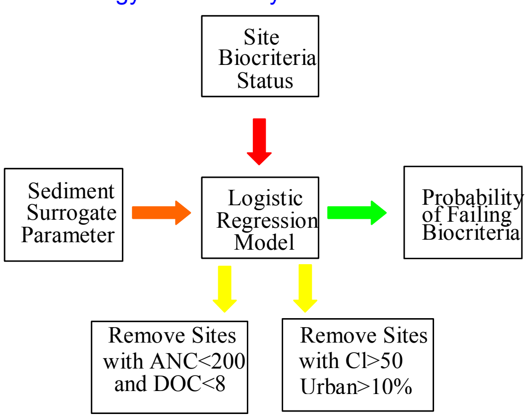


Figure A. Flow chart of logistic regression approach to developing a statistical model (sediment indicator) for predicting biocriteria failure.

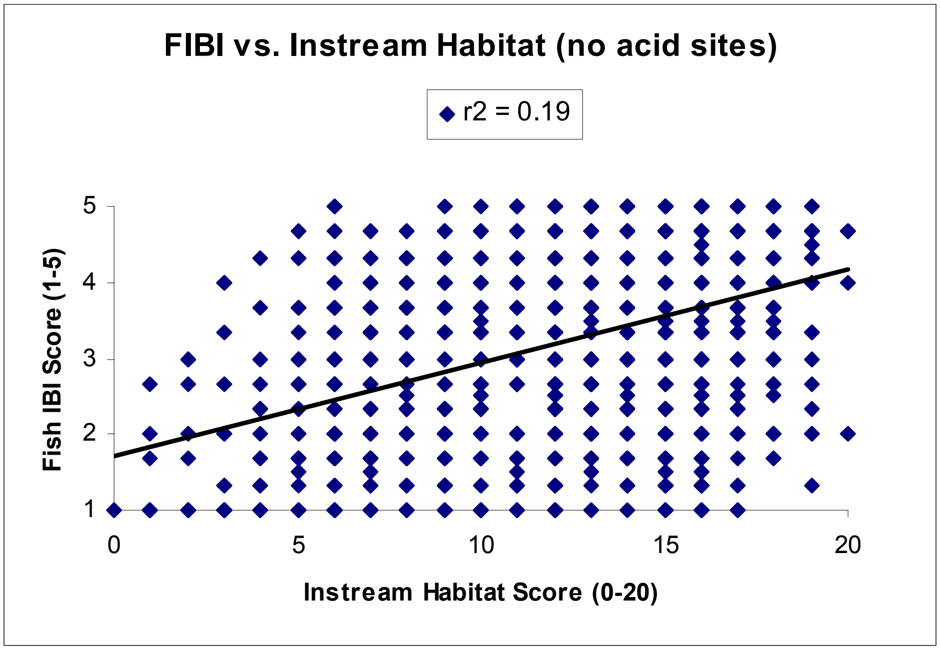
Table A. Six candidate parameters with identified relationships to sediment that may serve as useful surrogates for predicting stream impairment.			
Surrogate Variables	**Definition**	**Scoring**	**Relationship to Sediment**
Riffle/Run Quality	Visual rating based on the depth, complexity, and functional importance of riffle/run habitat, especially deeper riffle/run areas, stable substrates, and a variety of current velocities.	0 to 20	High quality riffle/run habitat is evidence of lack of sediment deposition. However, riffle/run quality is confounded by natural variability (i.e., some streams will naturally have different quality riffle/run habitat).
Bank Stability	Composite score combining visual rating based on the presence or absence of riparian vegetation and other stabilizing bank materials, such as boulders and rootwads, with quantitative measures of erosion extent and erosion severity.	0 to 100	Bank stability is evidence of lack of channel erosion, a major source of downstream sediment transport. Sediment loading may still occur through overland runoff.
Riparian Buffer Width	Width of vegetated (i.e., grass, shrubs, or trees) riparian buffer, estimated to a maximum distance of 50 meters from the stream channel.	0 to 50	Wide and well-vegetated riparian buffers are indirectly related to sedimentation as buffers remove sediment in runoff and protect banks from erosion. Riparian buffers also benefit aquatic communities by reducing stream temperature through shading, an effect unrelated to sediment.
Instream Habitat	Visual rating based on the perceived value of instream habitat to the fish community, including multiple habitat types, varied particle sizes, and uneven stream bottom.	0 to 20	High instream habitat scores are evidence of lack of sediment deposition. However, instream habitat is confounded by natural variability (i.e., some streams will naturally have more or less instream habitat).
Epifaunal Substrate	Visual rating based on the amount and variety of hard, stable substrates usable by benthic macroinvertebrates.	0 to 20	High epifaunal substrate scores are evidence of lack of sediment deposition. However, epifaunal substrate is confounded by natural variability (i.e., some streams will naturally have different kinds of epifaunal substrate).
Embeddedness	Percentage of gravel, cobble, and boulder particles in the streambed that are surrounded by fine sediment.	0 to 100	High embeddedness is direct evidence of sediment deposition. However, embeddedness is confounded by natural variability (e.g., Coastal Plain streams will naturally have more embeddedness than Highlands streams).

Table B. Significance of parameters and model predictive power (c)				
Parameter	**Highland**	**Piedmont**	**Coastal**	**Statewide**
Intercept	0.4110	0.1157	<0.0001	<0.0001
Riffle run	0.0194	-----	<0.0001	0.0003
Riparian width	0.0413	0.1306	0.0906	0.0016
Embeddedness	0.0006	0.1350	-----	0.0110
Instream habitat	-----	0.4332	0.0004	<0.0001
Epifaunal substrate	-----	0.1104	-----	-----
c (area ROC)	0.7	0.6	0.8	0.8

Table C. Model Average Rate of Correct Classification (ARCC) at 90% confidence interval					
	Rate of Correct Classification – Fail	**Rate of Correct Classification – Pass**	**Inconclusive**	**ARCC**	**Validation ARCC**
Highland	72%	78%	39%	74%	67%
Coastal	74%	88%	27%	78%	73%
State	73%	71%	23%	73%	67%

14.4.7 Habitat Quality

Sedimentation, channel alteration, low flow, and other kinds of physical habitat degradation are reflected in the instream habitat and epifaunal substrate scores at MBSS sites. Both are qualitative measures of the total available habitat preferred by fish (instream habitat) and benthic macroinvertebrates (epifaunal substrate). Figure 14-49 shows the relationship of instream habitat to FIBI and epifaunal substrate to BIBI. The extent of the effect is shown in Figures 14-50 and 14-51.



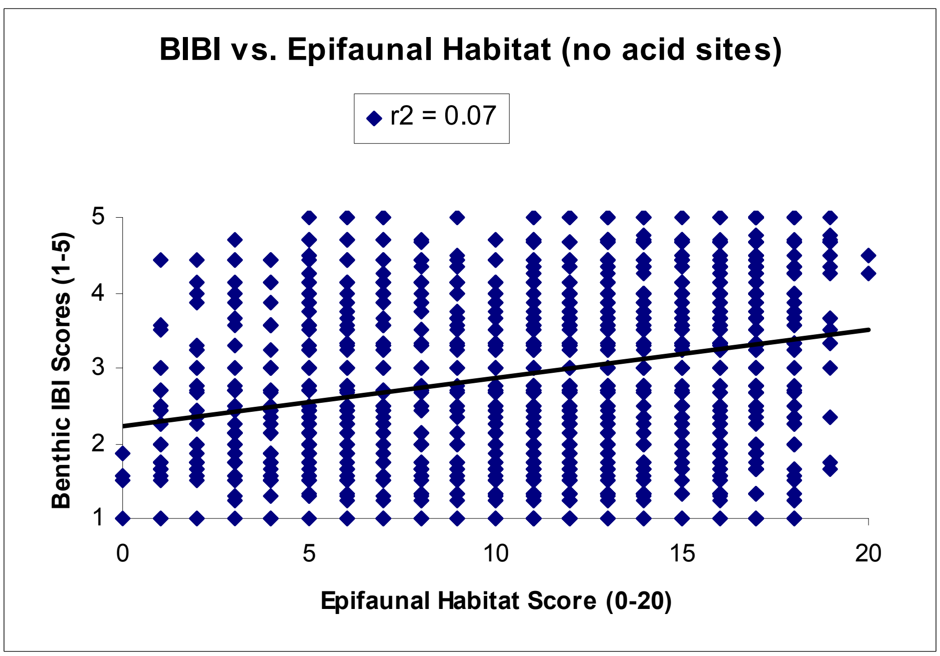


Figure 14-49. Relationship between the fish IBI and instream habitat, and benthic IBI and epifaunal substrate, statewide for the 1995-2004 MBSS.

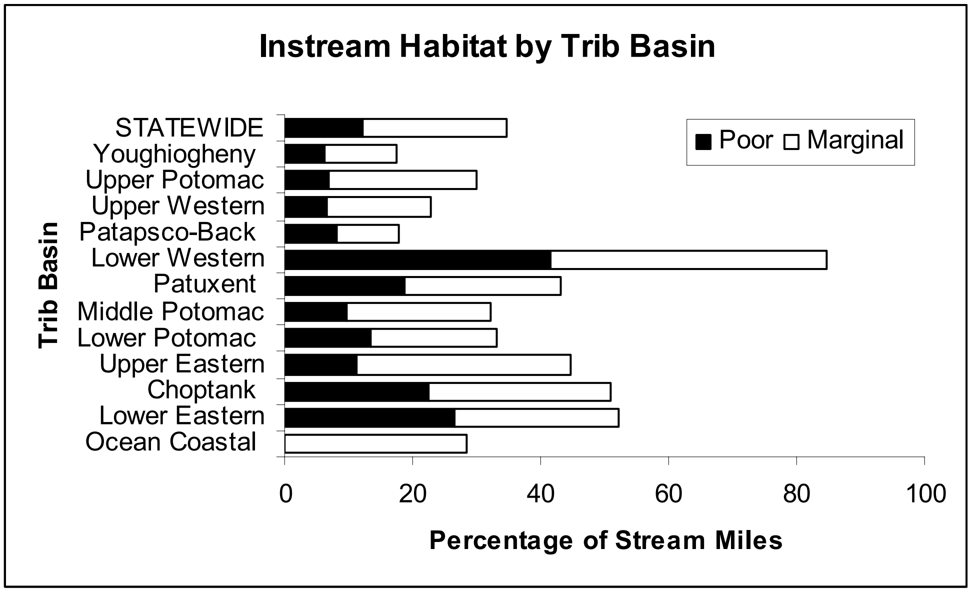


Figure 14-50. Percent of stream miles with marginal and poor instream substrate, statewide and for the basins sampled in the 2000-2004 MBSS.

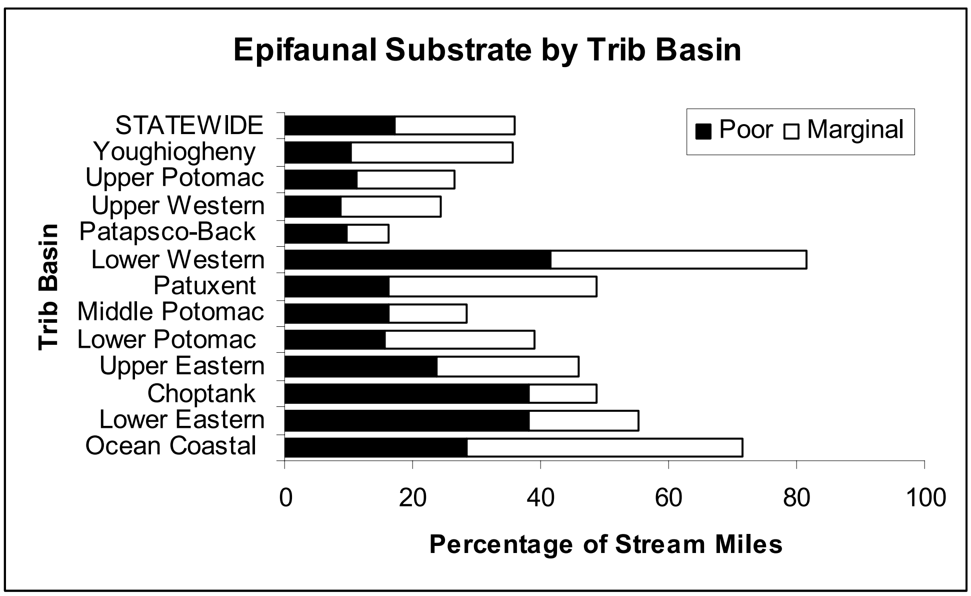


Figure 14-51. Percent of stream miles with marginal and poor epifaunal substrate, statewide and for the basins sampled in the 2000-2004 MBSS.

14.5 BIOTIC INTERACTIONS (*NON-NATIVE AND INVASIVE AQUATIC BIOTA*)

The intentional or unintentional introductions of non-native biota into streams and rivers pose potential risks to native assemblages. These risks include disease introduction, parasitism, and elimination of native species through predation, resource competition, and incidental harvest (bycatch). Table 14-13 lists the non-native species intentionally and unintentionally introduced into Maryland waters. Adverse effects can be severe, though for most species there is little documented evidence of impact to native assemblages. More details on the effects of non-native and invasive species (both aquatic and terrestrial) are provided in Volume 12: Stream and Riverine Biodiversity.

Based on historical data and survey work done by the MBSS, several non-native species of crayfish appear to be expanding in Maryland. The expansion of introduced crayfish and concomitant loss of two native crayfish from the same area strongly support the possibility of competitive or predatory exclusion. Available literature also indicates that introduced crayfish may play an important role in the elimination of freshwater mussels by preying on juveniles. The spread of non-native crayfish to additional basins in Maryland could have disastrous results for the remaining freshwater mussels in the state. The expansion of *Corbicula*, an introduced Asian clam, throughout Maryland waters may also be having a deleterious effect on native mussels.

Among the fishes, there is potential for high profile species such as northern snakehead to reduce or eliminate native fish populations. There is also a continuing risk from fish species stocked for recreational fishing, including brown trout. During 2001-2003, DNR Fisheries stocked approximately 5.4 million non-native fish, or about 1.8 million fish per year, to provide recreational fishing opportunities or enhance the forage base for gamefish (Rivers, personal communication). Eleven different species have been stocked, with life history stages ranging from adult to fry (Table 14-13). In addition, an unknown number of non-native fish and crayfish used as bait are released by anglers.

The risk of spreading non-native diseases to native biota via the culture of hatchery fish is currently unknown. A decade ago, the risk of transferring hatchery diseases to wild fish was thought to be very minimal, but the decimation of native rainbow trout in many areas of the western U.S. by whirling disease suggests that the potential for disease impacts exists. Diseases confirmed at one or more coldwater hatchery facilities or in their receiving streams during 2000-2004 included: the parasite *Ichthyophthirius multifilus* (Ich), bacterial gill disease, Columnaris, and whirling disease caused by the parasite *Myxobolus cerebralis* (Rivers, pers. comm.). It should be noted that no hatchery diseases have been determined to had a negative effect on native biota in Maryland, although no monitoring of native species for this purpose is conducted. The number of types of disease introduced from bait shops is unknown.

Results from MBSS surveys show that non-native species occur widely in Maryland. Five of the six most abundant non-native fish species found by the MBSS in 2000-2004 were members of the sunfish family. The most abundant was bluegill, followed by green sunfish, smallmouth bass, brown trout, largemouth bass, and rock bass. Another species, rainbow darter, has expanded in Maryland, and now occurs in four major basins. There is a well-established body of published literature on the negative effects of brown trout on brook trout (Fausch and White 1981; Waters 1983; Lasenby and Kerr 2001), Maryland's only native salmonid and a species designated as being in Greatest Conservation Need (GCN). Further, the lack of abundance of brook trout when brown trout were present at MBSS sites supports the concept that introduced brown trout can eliminate or greatly reduce brook trout populations (see more details in the following subsection).

14.5.1 Non-native Brown Trout as Stressors to Brook Trout in Maryland

Historically, brook trout probably inhabited much of Maryland, west of the Fall Line between the Piedmont and Coastal Plain, as well as the western border of the Coastal Plain (Boward et al. 1999). Currently, brook trout are restricted to relatively small streams (Morgan et al. 2005) and primarily occur in the westernmost portion of the State. Urban development and other abiotic variables have been shown to be associated with brook trout declines in Maryland (Morgan et al. 2005, Boward et al. 1999). However, biotic interactions with non-native salmonids have also likely influenced the current distribution of brook trout. Negative impacts of non-native salmonids on native brook trout populations have been demonstrated in other areas of eastern North America due to competition (Fausch and White 1981, Nyman 1970, Essington et al. 1998) and possibly predation (Nyman 1970).

First introduced into Maryland during the late 1800s, brown trout have become widely established in Maryland (Stinefelt et al. 1985). At present, the geographic distribution significantly overlaps that of the native brook trout (Figure 14-52). The two species prefer similar stream habitats that are dominated by cool water and abundant cover. In Maryland, it appears that many subpopulations of brook trout have become isolated into small tributaries as a result of brown trout in nearby stream reaches (Morgan et al. 2005).

Table 14-13. Non-native freshwater fish species known or thought to occur in Maryland.

Species	Status	Habitat and Extent	Impacts to Native Species
Brown trout	>50,000 stocked annually by DNR; numerous reproducing populations exist	Widely distributed in cool and coldwater habitats	Well documented impacts to brook trout; possible impacts to non-game fishes; possible disease introduction
Rainbow trout	>500,000 stocked annually by DNR; only two reproducing populations known to exist (Hoyes Run and Sang Run)	Widely distributed in cool and coldwater habitats; put and take stocking in Coastal Plain areas as well	Well documented impacts to brook trout; possible impacts to non-game fishes; possible disease introduction
Cutthroat trout	Periodically stocked by DNR; only two reproducing populations known to exist (Jennings Randolf tailrace and Murley Run)	Mostly restricted to North Branch Potomac River	Possible impacts to non-game fishes; possible disease introduction
Lake trout*	Last stocked in 1986, few reported caught in recent years	Stocked in Jennings Randolph Reservoir; not reported from outside the impoundment	None documented
Channel catfish	Reproducing populations known from most major Bay tributaries.	Widely distributed in impoundments, larger rivers, oligohaline water	Possible negative impact to white catfish
Blue catfish*	Reproducing population in the tidal Potomac River	Appears to prefer tidal oligohaline water	None documented
Flathead catfish*	Known from the Susquehanna River in Pennsylvania	Large river and impoundment species	None documented
Northern pike+	Reproducing population known from Deep Creek Lake; also stocked in other impoundments	Primarily impoundments; spawns in flooded wetlands and inlet streams	Predation likely on GCN species that occupy same habitat
Tiger muskie*	About 25,000 stocked annually by DNR, including Potomac River; hybrids are sterile	Large river and impoundment species	Predation likely on GCN species that occupy same habitat; potential disease introduction
Fathead minnow	Common bait fish species, stocked as forage by DNR; reproducing populations in some streams	Small-medium streams	None documented; may supplant native species in highly disturbed habitats; possible disease introduction
Goldfish	Sold as bait, also commonly released as pets; reproduce in ponds, reservoirs, and larger streams/rivers	Slow water habitat	None documented; possible disease introduction
Common carp	Introduced in 1870s; widespread reproducing populations	Slow water habitat in larger streams, rivers and impoundments	None documented
Grass carp*	Sold as SAV control for golf course ponds, etc. Likely in scattered ponds throughout the state	Slow water habitat in larger streams, rivers, and impoundments	None documented but pose significant threat to SAV; possible disease introduction from illegal shipments
Northern snakehead*	Released into Potomac River and Crofton Ponds from pet trade, food trade, and/or religious purposes; possible population in tidal Potomac	Slow water habitat in larger streams, rivers, and impoundments	None documented; possible disease introduction from illegal stocking
Banded darter*	Introduced into Susquehanna River; reproducing populations in MD; apparently declined in last several decades	Larger streams	None documented

Table 14-13. (Continued)			
Species	**Status**	**Habitat and Extent**	**Impacts to Native Species**
Rainbow darter	Likely introduced into MD portion of Potomac drainage; distribution expanding	Run habitat in larger streams and rivers	None documented
Walleye*	About 800,000 stocked annually by DNR, including Potomac River	Larger streams, rivers, and impoundments	None documented, but predation on native rare cyprinids likely; possible disease introduction
Largemouth bass	Introduced to MD in 1870s; now statewide reproducing populations	Slow water habitat in larger streams, rivers, ponds, and larger impoundments	Likely impacts to smaller non-game species, including GCN species
Smallmouth bass	Introduced to Atlantic slope; widespread reproducing populations throughout non-Coastal Plain	Medium and larger streams, rivers, and impoundments with coolwater habitat	Likely impacts to smaller non-game species, including GCN species
Bluegill	Introduced to Atlantic slope; widespread reproducing populations throughout MD	Slow water habitat in larger streams, rivers, ponds, and larger impoundments	Likely impacts to smaller non-game species, including GCN species
Rock bass	Introduced to Atlantic slope; widespread reproducing populations throughout non-Coastal Plain	Rocky habitat in streams, rivers, and larger impoundments	Likely impacts to smaller non-game species, including GCN species
Green sunfish	Introduced to Atlantic slope; reproducing populations throughout non-Coastal Plain	Slow water habitat in streams, rivers, ponds, and larger impoundments	Likely impacts to smaller non-game species, including GCN species
Longear sunfish	Introduced to Potomac River	Slow water habitat in larger streams and rivers	None documented
Black crappie	Introduced to Atlantic slope; widespread reproducing populations throughout MD	Slow water habitat in larger streams, rivers, ponds, and larger impoundments	Likely impacts to smaller non-game species, including GCN species
White crappie*	Introduced to Atlantic slope; widespread reproducing populations throughout MD	Slow water habitat in larger streams, rivers, ponds, and larger impoundments	Likely impacts to smaller non-game species, including GCN species
Redear sunfish*	Introduced via pond stocking	Slow water habitat in larger streams, rivers, ponds, and larger impoundments	Potential impacts to smaller non-game species, including GCN species
* Not collected during the 2000-2004 MBSS, but known or thought to occur in MD + Collected during rare species survey in the Potomac River, 2004			

Morgan et al. (2005) also showed that streams containing brook trout and non-native species had significantly lower densities of brook trout compared to brook trout-only streams. Overall brook trout abundance in Maryland was negatively correlated (Pearsons $r = -0.173$, $p = 0.001$) with brown trout abundance (Figure 14-53) and no brook trout has ever been collected at any MBSS site with more than about 0.5 brown trout per meter of stream. The highest abundances for brook trout and brown trout occurred at sites where the other species was absent. The apparent exclusion of brook trout from sites where brown trout have become established could be due to competitive exclusion or to inherent differences in the tolerances of the two species to natural and human-related stream conditions.

Brown trout occur in streams that are significantly (ANOVA, $p < 0.0001$) more biologically (Figure 14-54), physically (Figure 14-55), and chemically (Figure 14-56) degraded than do brook trout. Brown trout also tolerate significantly warmer temperatures (Figure 14-57) and larger amounts of basin urbanization (Figure 14-58). These results suggest that degradation of streams leads to a concomitant decline in brook trout with brown trout

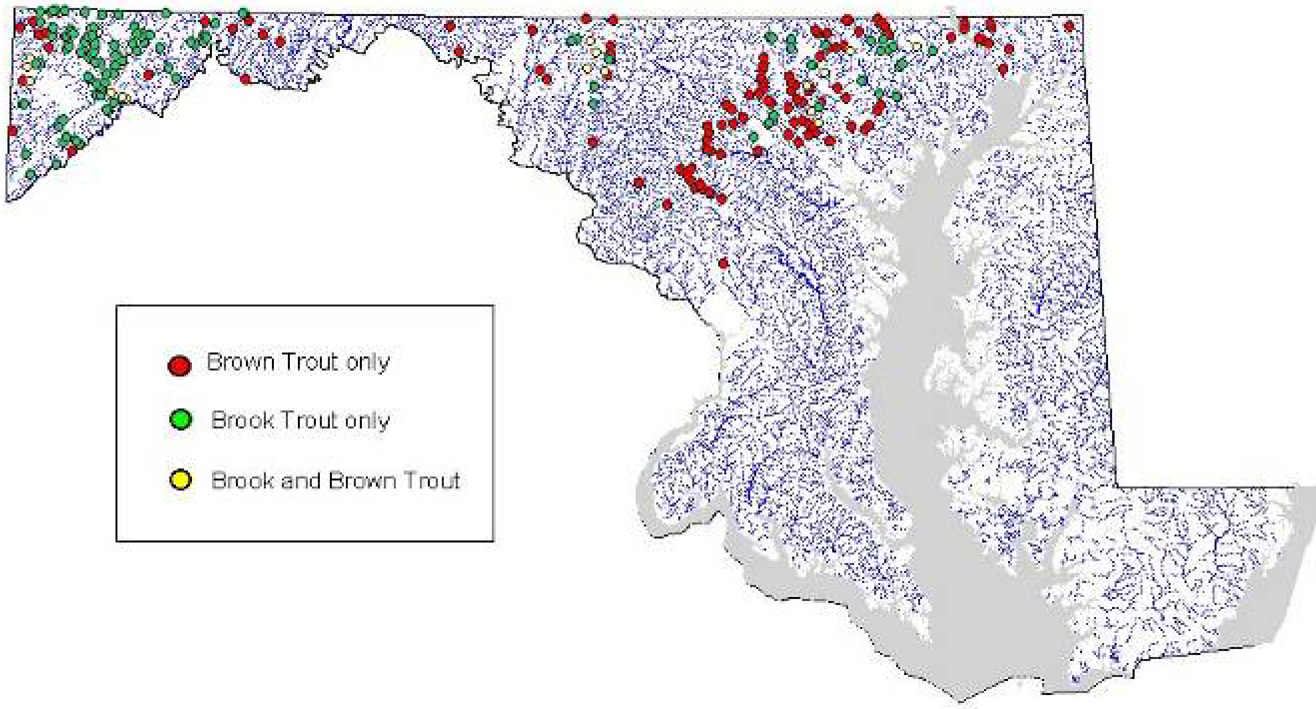


Figure 14-52. Location of sites where brook trout, brown trout, or both species were encountered in Maryland during MBSS 1994-2004.

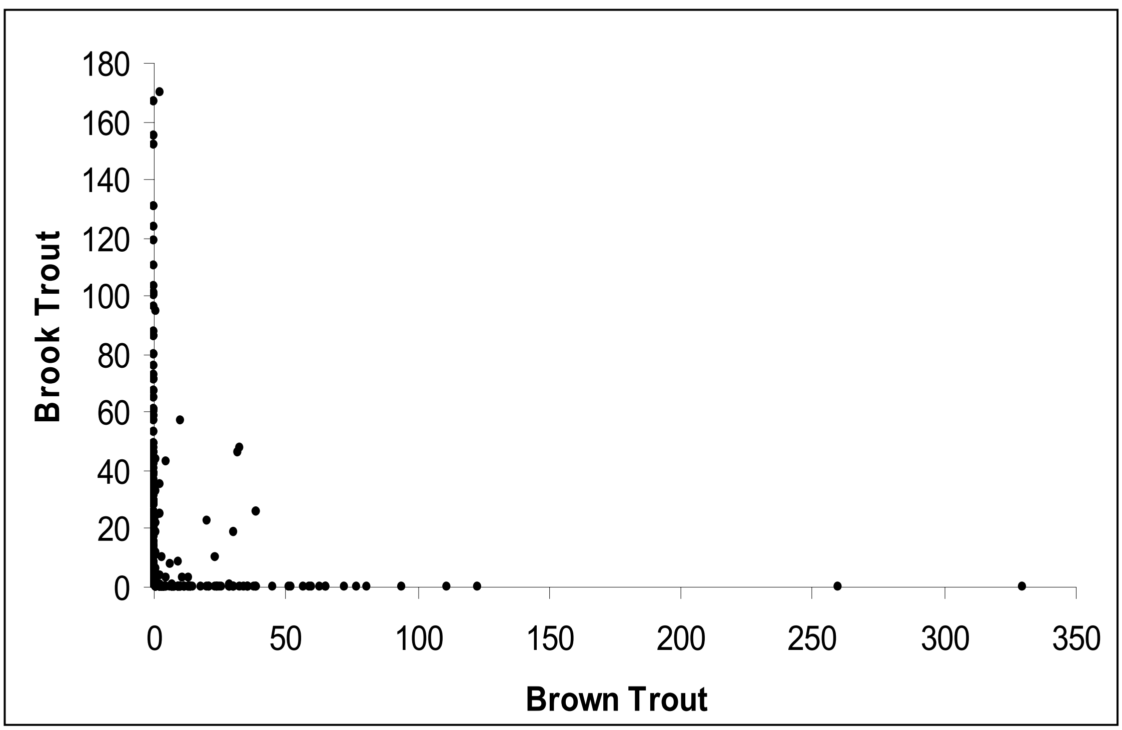


Figure 14-53. Brook trout abundance vs. brown trout abundance at 75 m stream sites for MBSS 1994-2004.

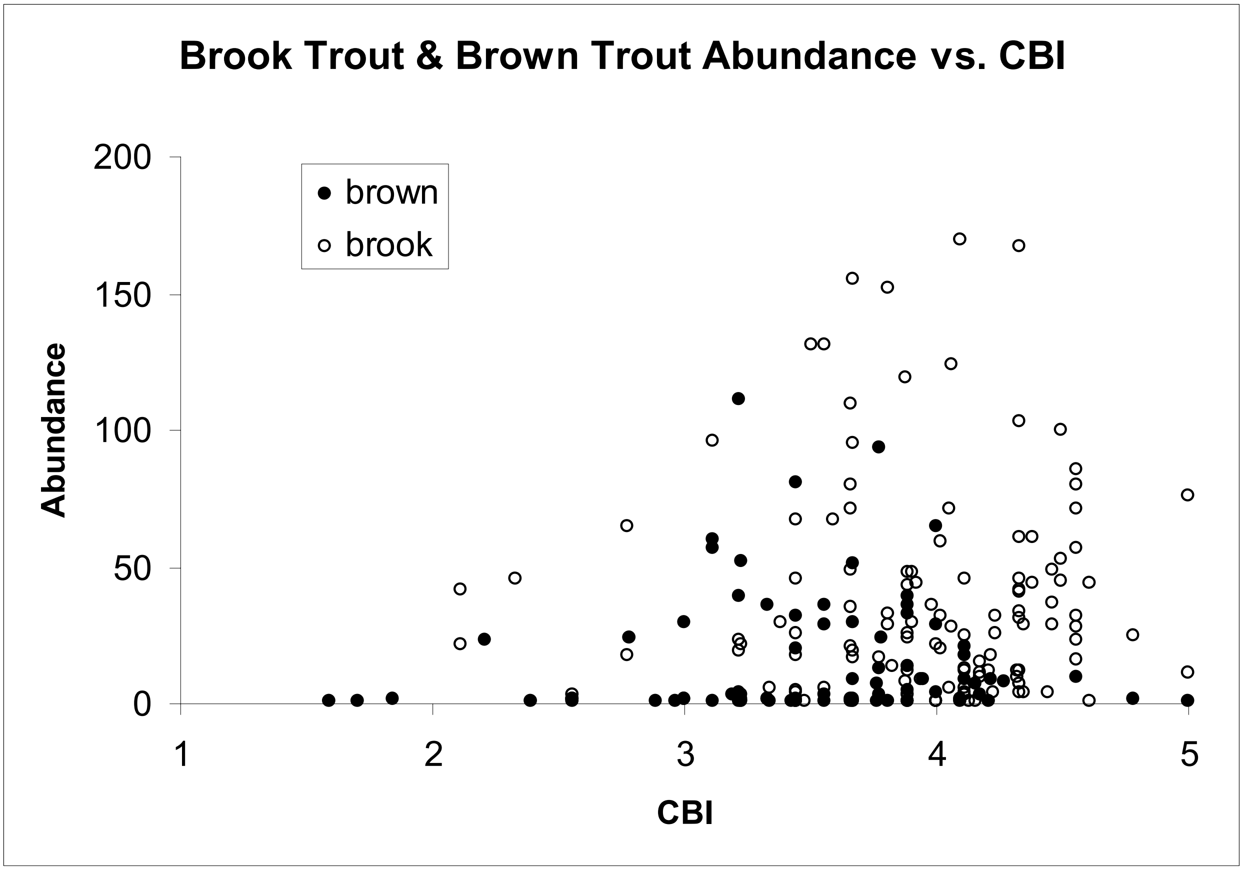


Figure 14-54. Combined Biotic Index (CBI) scores of sites containing brook trout or brown trout for MBSS 1994-2004.

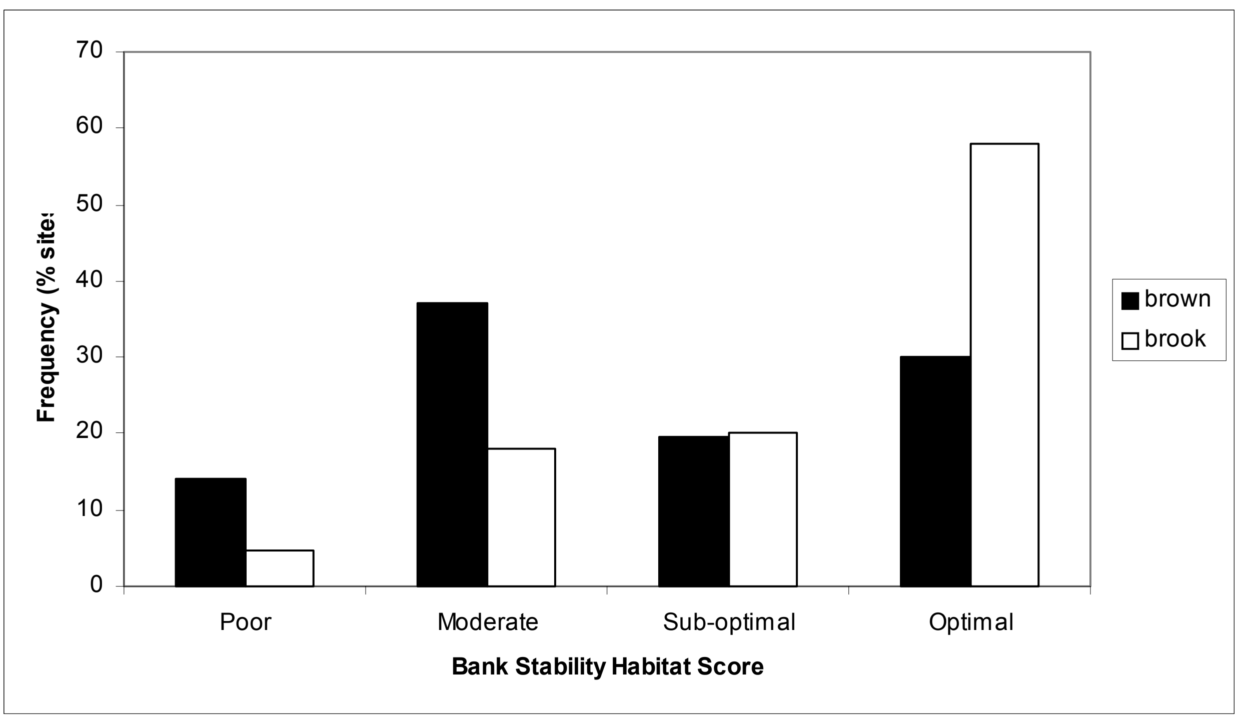


Figure 14-55. Bank stability scores of sites containing brook trout or brown trout for MBSS 1994-2004.

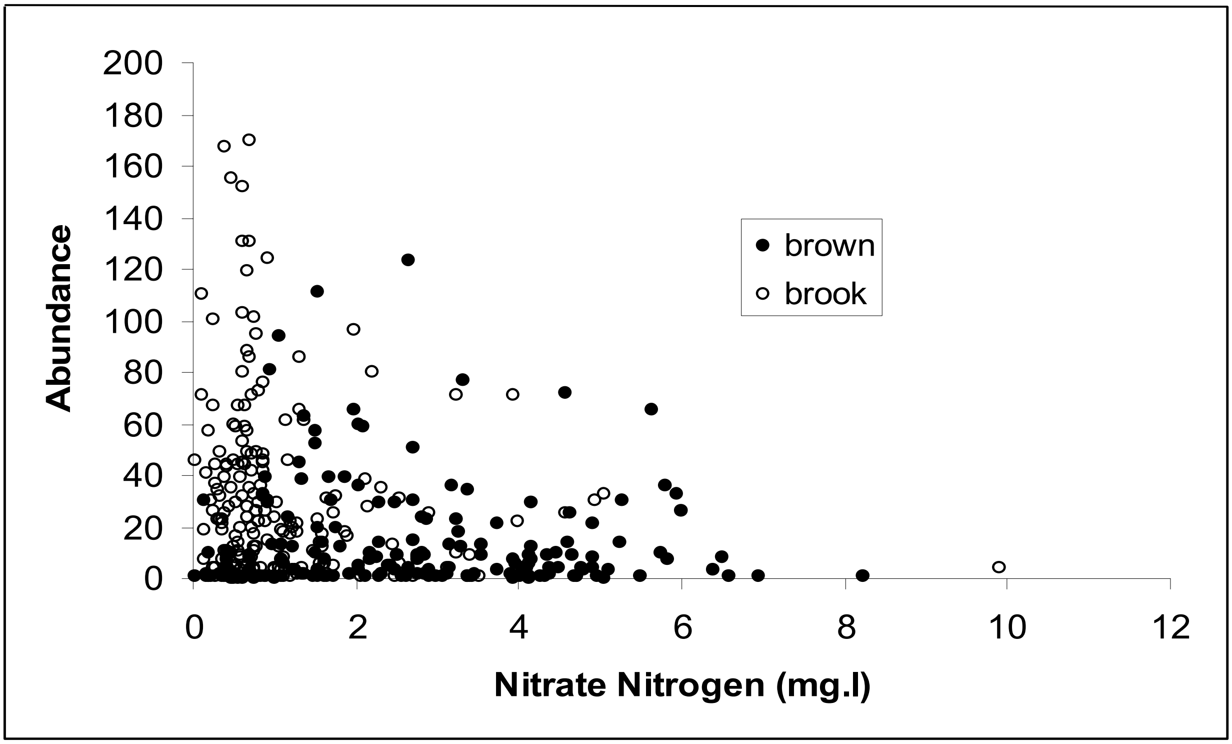


Figure 14-56. Nitrate measurements of sites containing brook trout or brown trout for MBSS 1994-2004.

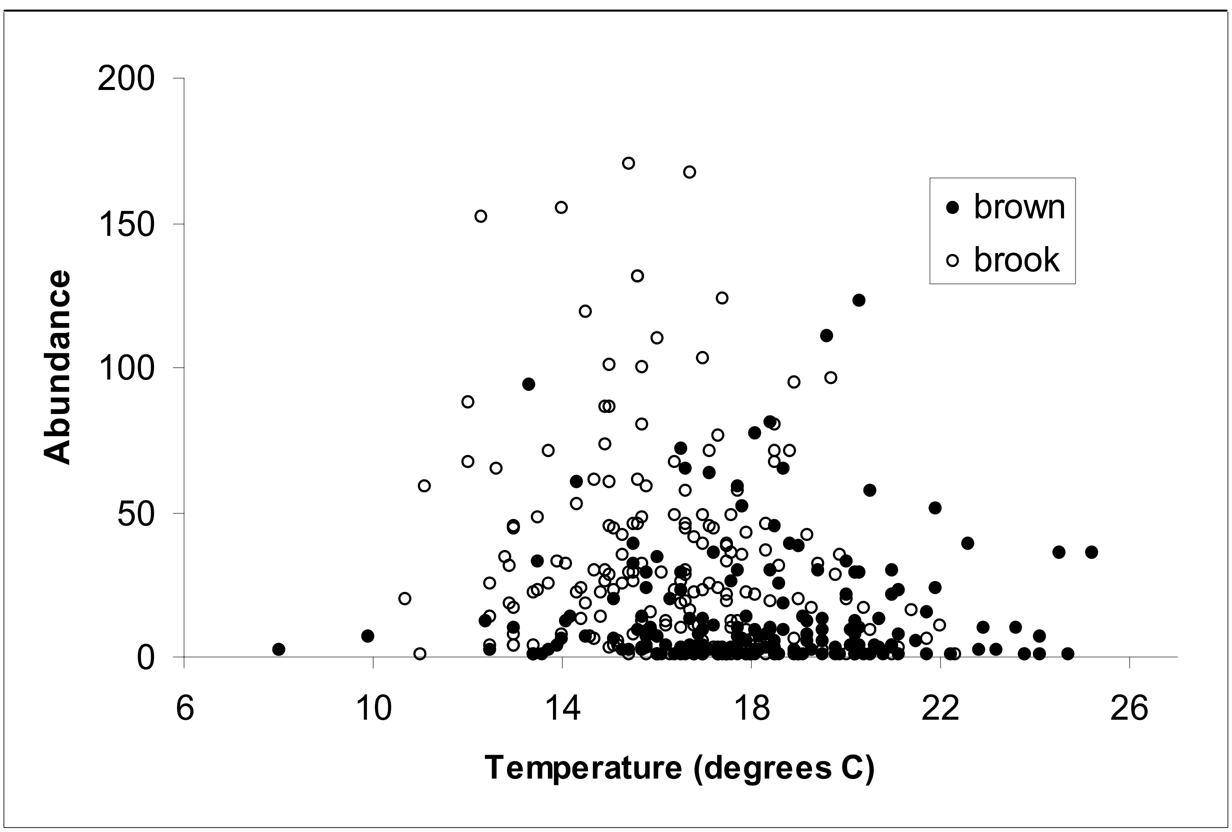


Figure 14-57. Summer water temperature (ºC) of sites containing brook trout or brown trout for MBSS 1994-2004.

gaining a competitive advantage. Table 14-14 lists thresholds for the five variables listed above at which brook trout appear to be excluded from Maryland Streams but where brown trout remain.

In addition to having a competitive advantage over brook trout in degraded streams, brown trout also appear to exclude brook trout from most streams draining more than 16,000 hectares of basin area even in the absence of major anthropogenic stressors. One exception is the Savage River in Western Maryland, which is heavily forested and remains cool throughout the summer (typically less than 18 ºC). It currently supports a fairly large brook trout population along with introduced brown trout. The only streams where brook trout presently occur in the absence of brown trout are those draining catchments of less than 14,000 hectares. Brook trout residing in these small, isolated stream reaches may still be at risk of extirpation, however, because the populations in most small reaches may be too small for long-term genetic sustainability, even if abiotic conditions in the streams remain suitable and brown trout remain excluded.

Table 14-14. Maximum thresholds where brook trout and brown trout have been collected in the MBSS data set (1994-2004).

Variable	Brook Trout Thresholds	Brown Trout Thresholds
Temperature (°C)	23.8	25.2
Bank Stability Score	2	0
Urban Land Cover (%)	10.9	40.7
Nitrate-Nitrogen (mg/l)	9.9	8.2
CBI Score *	2.1	1.6

* CBI score reflects an average of FIBI and BIBI scores

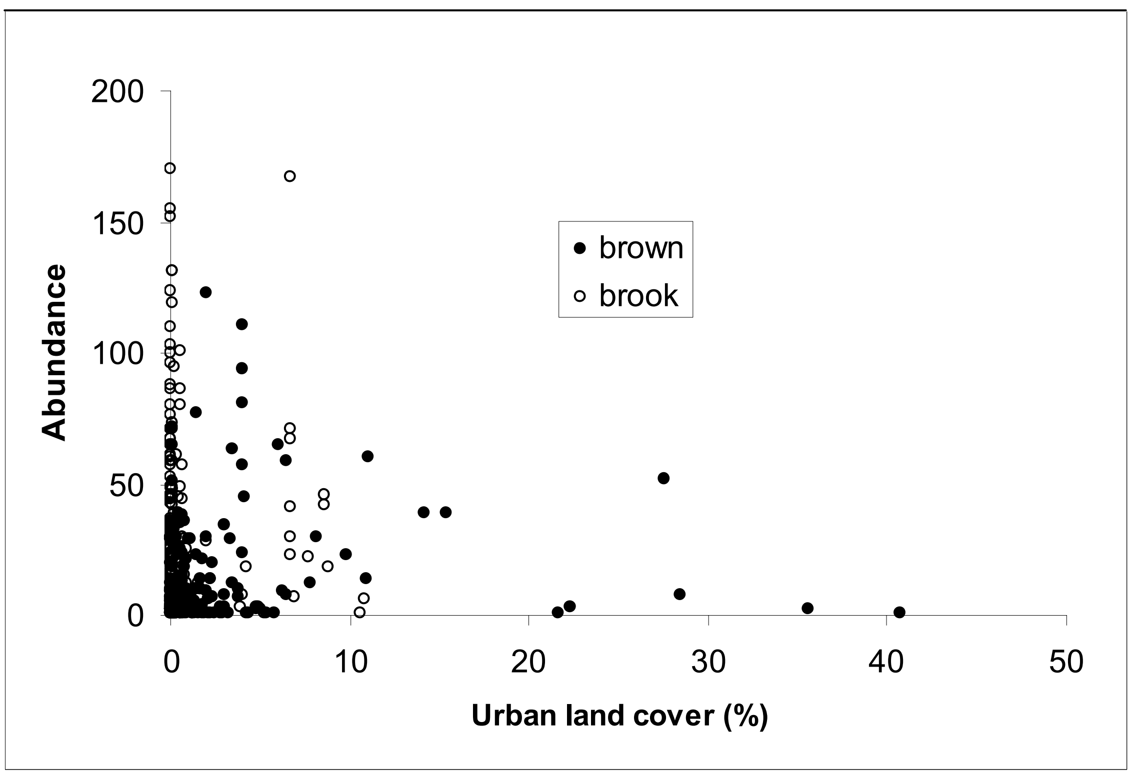


Figure 14-58. Percentage of urban land cover of sites containing brook trout or brown trout for MBSS 1994-2004.

14.6 LAND USE

Streams are affected by the full range of human activities, so it is often impossible to identify all the stressors and causes of degradation. In addition, rivers and streams are hierarchical systems wherein the stressors affecting a local stream may originate elsewhere in the basin. Therefore assessing basin land use is a necessary part of stressor identification. Solutions to stream problems also depend largely on the landscape context. Remediating individual stressors at the site level is of no value if it cannot be sustained within the existing and future land uses in the basin. Maryland and other states recognize that different water quality goals may be necessary where intensive human land uses predominate. Therefore, this section evaluates land use as a measure of anthropogenic influence at the landscape scale.

Basins form natural geographic units for assessing impacts on streams, because land use within the basin (or catchment) upstream of a specific stream site is representative of many of the human activities affecting the stream at that point. As such, land cover serves as a surrogate for a variety of stressors, some of which may be difficult to measure directly. Because no field sampling program will ever be able to visit all parts of all streams throughout the state, the "wall-to-wall" coverage provided by land cover data serves as a useful tool for predicting conditions at sites that cannot be sampled. Geographic information system (GIS) data may be used to develop predictive models linking land cover with instream biological or physical habitat conditions. In evaluating streams across a large area, GIS land cover information can be employed in an initial screening step to locate areas likely to exhibit either desired or degraded conditions and to then target subsequent field sampling to these streams. Depending on management goals, these more detailed investigations can provide the information needed to make informed conservation or restoration decisions.

14.6.1 Maryland Land Uses

Historically, much of Maryland was covered by forest, a sharp contrast to the variety of urban and agricultural uses presently dominating the landscape (Figure 14-59). In Maryland, as in much of the United States, conversions of naturally vegetated lands to urban and agricultural uses have resulted in serious impacts to streams and their inhabitants. Examining land uses as composite stressors, through analyses of relationships with ecological indicators, allows predictions to be made about the extent and severity of ecological impacts associated with varying levels of human use. Urban land produces impervious surfaces, such as roads, parking lots, sidewalks, and rooftops, that cause a rapid increase in the rate at which water is transported from the basin to its stream channels. Effects include more variable stream flows, increased erosion from runoff, habitat degradation caused by channel instability, increased nonpoint source pollutant loading, and elevated temperatures. Urban development of even small portions of a basin (less than 10%) may affect stream biota (Schueler 1994). [Agricultural lands are_strongly associated with high inputs of nutrients and sediment into receiving streams]. The presence of these land uses in the upstream catchment and in the riparian zone both have important, but sometimes differing, effects on stream condition. It is also critical to consider the "legacy" effects of earlier land uses whose effects may still continue long after the land use has changed (Harding et al. 1998). Investigators believe that the sediment loads in many Maryland Piedmont streams were delivered 50-100 years ago (Ray Morgan personal communication).

Associations between urban or agricultural land use and stream biota have been examined in a number of studies (e.g., Klein 1979, Steedman 1988, Richards et al. 1996, Roth et al. 1999). In this section, we report on the relationships observed between land use and several indicators of stream condition for sites sampled by the MBSS from 1995 to 2004, including the fish IBI, benthic macroinvertebrate IBI, and the number and distribution of stream salamanders. Because the MBSS employs a probability-based design, examining land use associations for the sampled sites allows us to make inferences about the effects of land use on biological resources, statewide and within individual basins.

In this section, we specifically examine urban land use, impervious surface, roads, and trash as surrogates for human activities that affect stream quality. In particular, impervious surface is a good surrogate for "flashy" stormwater flows that one-time MBSS sampling cannot capture. Note that the percent coverage by impervious surface for a catchment would be lower than the corresponding value for percent urban land assessed by the MBSS. According to the class definitions used in developing the land cover base data (MRLC 1996 a,b), impervious surfaces make up 30-80% of the low-intensity and 80-100% of high-intensity developed urban land classes. Other land cover classes contribute smaller but possibly significant proportions of impervious surface. Therefore, the values for percent urban land use associated with poor stream quality were expected to be somewhat higher than that for impervious surface effects.

LAND USE AS A BASIN, RIPARIAN, AND LOCAL SCALE STRESSOR ON STREAMS

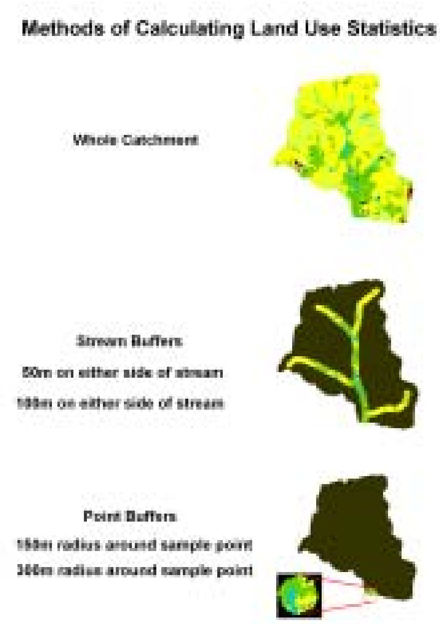
Since the advent of readily available GIS technologies and comprehensive land use coverages, investigators have shown that land use can alter the stream habitat and significantly affect the biotic integrity of streams (e.g., Richards and Host 1994, Wang et al. 1997). Specifically, farming and urbanization in basins are associated with degradation of the invertebrate (Klein 1979, Garie and McIntosh 1986, Jones and Clark 1987) and fish (Scott et al. 1986, Steedman 1988, Roth et al. 1999, Wang et al. 1997, Weaver and Garman 1994) communities in streams and rivers throughout North America. The effects of land use are significant at basin, riparian, and local scales, though the relative influence of land use at each scale varies among studies (Roth et al. 1999, Wang et al. 2001, Vølstad et al. 2003). As an example, the variance in biological indices explained by urban and agricultural land uses at basin and riparian scales in a Wisconsin study were 19% and 35%, respectively, with the interaction accounting for 26% (Wang et al. 2001).

In Maryland, Vølstad et al. (2003) found that urban land use at the catchment scale resulted in the highest coefficient of determination for the regressions of urban land use against fish and benthic IBIs. Land use data for the State of Maryland was extracted from the Federal Region III National Land Cover (NLCD) digital data set (Vogelmann et al. 1998). The percentage of land area in each land use class was calculated at three different spatial scales (see Figure):

- Catchment — includes the entire contiguous basin upstream of a MBSS sample site
- Riparian corridor — the streamside area within a 50-m distance on each side of the streams, for the entire length upstream of a site;
- Local area — area within a 300-m radius circle around a sample site

Of the six landscape classes evaluated, urban land was consistently selected in the one-variable "best" linear regression model (highest), and was included as a variable in all model selections using the maximum method for both fish and benthic IBIs. Linear regression models with one or more additional landscape classes only marginally improved the fit. In the Patapsco basin, the coefficient of determination for a regression of fish IBI against percent urban land use was 0.83 at the catchment scale, as compared with 0.41 at the riparian scale and 0.49 at the local scale; all regressions were highly significant ($p < 0.0001$).

In contrast, the MBSS data did not show a negative relationship between agricultural land use and IBIs, as has been the case in other states (e.g., Gordon and Majumder 2000, Wang et al. 2000). This may be an artifact of the interdependency between percent agricultural land and percent urban land use in the study basins (i.e., when one is low, the other is high). King et al. (2005) used MBSS data in the Coastal Plain of Maryland to investigate the following issues inherent in land use analyses: proportional interdependence , spatial autocor-relation, linkages with abiotic intermediaries, and spatial arrangement. They developed a distance-weighted method for analyzing land use effects to compensate for this spatial autocorrelation.



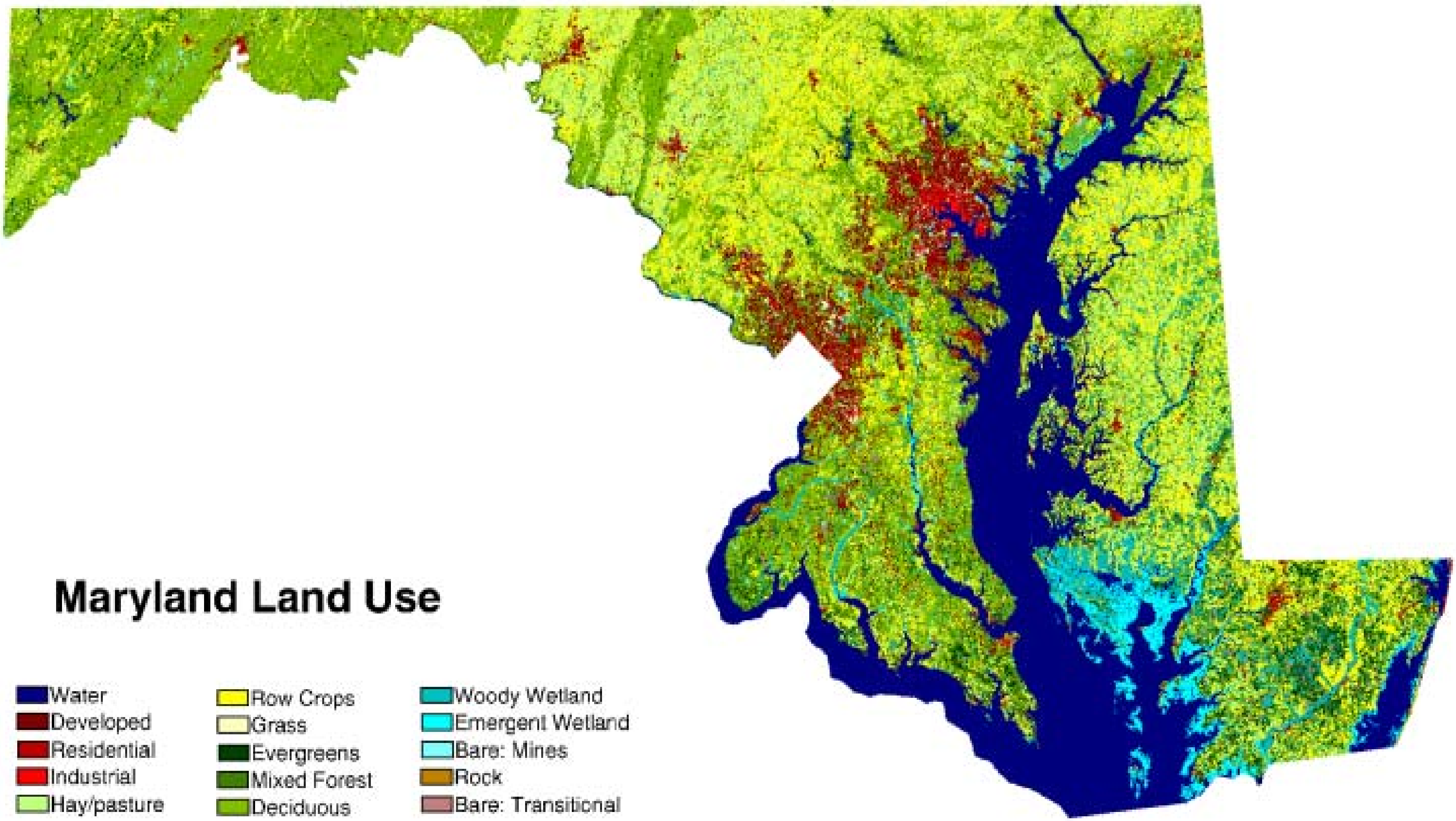


Figure 14-59. Map of land use in Maryland.

A characterization of catchment land use was developed for the basin upstream of each site sampled by the MBSS from 2000 to 2004 using the GIS methods described in Volume 6: Methods. Statewide, the dominant land use in site-specific catchments was forest (mean percent cover of 49%), followed by agriculture (43%) and urban (7%) (Figure 14-60). In individual basins, agricultural land use was greatest at sites in the Upper Eastern Shore basin, with a per-site mean of 67%. Agriculture also dominated in the Upper Western Shore, Ocean Coastal, and the Choptank basins, each with a per-site average of greater than 51%. Sites in the Lower Potomac had a mean of just 22%, while the mean in the remaining basins ranged from 27 to 45% agricultural land. Forest cover was most extensive for sites in the Youghiogheny basin (70%) and least extensive in the Upper Eastern Shore (30%) Patapsco basin (30%). As expected, urban land use was greatest in the Patapsco (23%) and Middle Potomac (21%) basins. Two of the remaining basins: the Lower Western Shore and Patuxent basins contained a mean percentage of urban land use between 10 and 20%. The remaining basins had a mean percentage of urban land use of less than 10%.

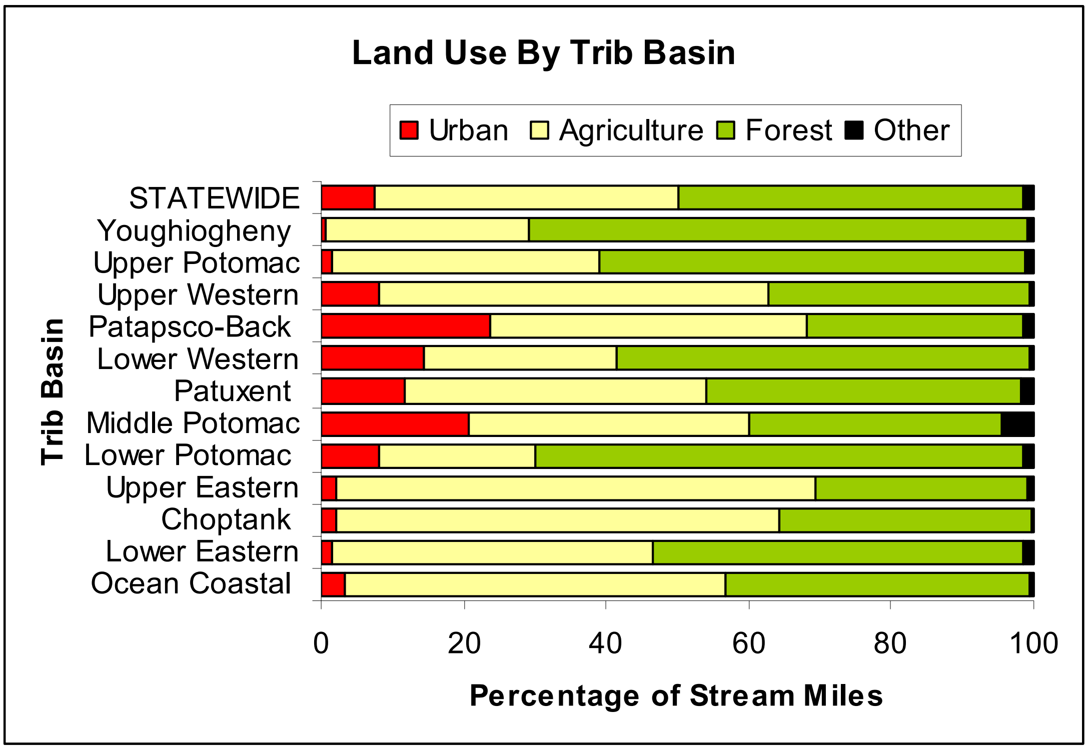
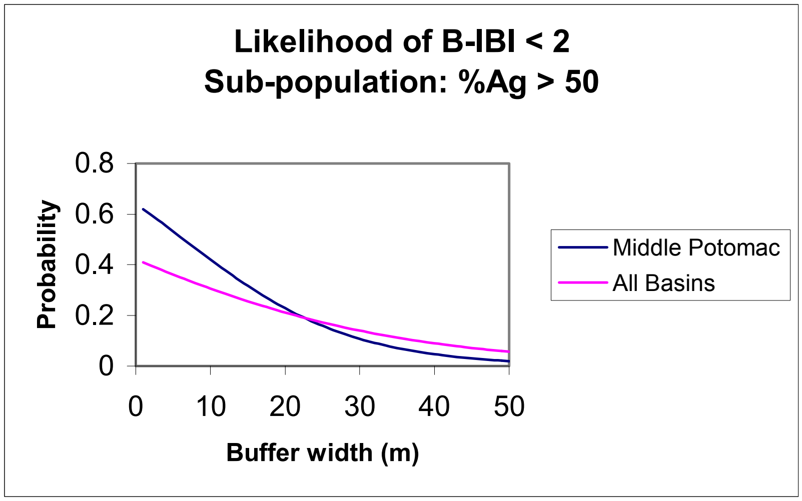


Figure 14-60. Percentage of stream miles by urban, agriculture, forest, and other land use types, statewide and by basins for the 2000-2004 MBSS.

EFFECT OF RIPARIAN BUFFERS ON AGRICULTURAL IMPACTS

Agricultural land uses predominate in much of Maryland, with expected adverse effects on stream condition. The presence of vegetated riparian buffers in agricultural lands varies, so the MBSS looked at the Middle Potomac basin and all Eastern Piedmont basins to determine if the presence of vegetated riparian buffers coincided with high quality streams. We determined that the expected likelihood of very poor condition (benthic index of biotic integrity, B-IBI<2) in catchments with more than 50% agricultural land is reduced from 64% for sites with no riparian buffer, to 11% for sites with 30-m riparian buffer along the streams (see below). This result supports the planting of riparian buffers to potentially mitigate the effects of agricultural land use. In addition to improving the condition of the local stream network and basin, the planting of riparian buffer would benefit the Chesapeake Bay by reducing nutrient loads.



14.6.2 Urbanization

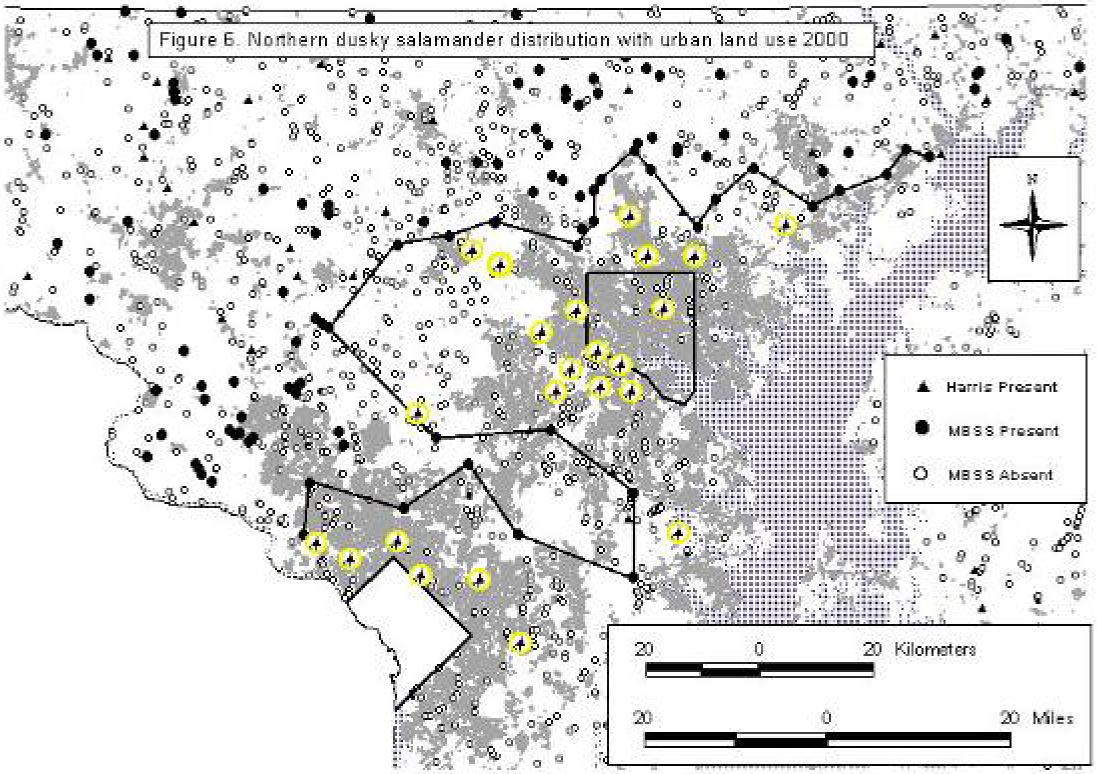
Urbanization is the transformation of rural environments to residential, commercial, or industrial land use, and includes prominent increases in impervious surfaces and roads (discussed below). The amount of land in urban use has accelerated in recent decades to the point that it is the leading cause of water-body impairment affecting more than 130,000 km of U.S. streams and rivers (USEPA 2000a,b,c). Urbanization is also the second-leading cause of species imperilment (next to nonnative species) in the United States (Czech et al. 2000).

Paul and Meyer (2001) describe the many ways that urbanization affects aquatic ecosystems. These include contributing 10,000 times as much fine sediment to streams as do forested basins (Wolman and Schick 1967), carrying higher concentrations of phosphorous and nitrogen than forested or agricultural streams (Osborne and Wiley 1988), and modifying physical habitat through hydrologic changes (Walsh et al. 2004). Although stream channels may ultimately adjust to the altered hydrology, such adjustments may take several decades following urbanization (Henshaw and Booth 2000). Habitat quality in urban streams is often further reduced by active removal of instream woody debris and riparian vegetation.

The physical and chemical changes associated with urbanization strongly influence aquatic biota. Fish and benthic macroinvertebrate communities in urbanized basins commonly exhibit less abundance and lower species diversity (Weaver and Garman 1994, Wang et al. 2000). Anadromous fishes are especially sensitive to urbanization (Limburg and Schmidt 1990). Biological impacts are detectable quite early in the urbanization process. Unlike most agricultural land cover, small amounts of urban land cover, especially near streams, can severely impair biota (Wang et al. 2001). Additional research is needed to determine the relative importance of physical versus chemical effects as the drivers of biological change during urbanization.

Figure 14-61 shows the common inverse relationship between the MBSS benthic IBI and urbanization. MBSS data also show that the percentage of urban land use is the best predictor of a stream failing biocriteria (i.e., being degraded). Specifically, Vølstad et al. (2003) applied logistic regression to quantify how the biotic integrity of streams (using MBSS IBI-based biocriteria) at a local scale is affected by cumulative effects resulting from catchment land uses, point sources, and nearby transmission line rights-of-way (see earlier side bar). Indicators for land use were developed from the remotely

LAND USE CHANGE FRAGMENTS MARYLAND SALAMANDER DISTRIBUTIONS



The advent of readily available land use maps for different time periods (usually from remote sensing) allowed the MBSS to evaluate the effect of urban sprawl occurring in Maryland since the 1960s (Southerland and Stranko, 2005). The map shows the distribution of northern dusky salamander records from both 1960s or earlier (Harris 1975) and the 1995-2004 MBSS in relation to land use in the Baltimore-Washington, D.C. urban corridor. Only presence records (solid triangles) are included from Harris (1975) as no absence records were reported. Both presence (solid circles) and absence (open circles) records are shown for the MBSS. The lack of presence records (and the large number of absence records) in the Baltimore-Washington, D.C. corridor is striking for this and other stream salamander species. Specifically, northern dusky salamander records are conspicuously absent (i.e., southeast of the connected line) in the areas of urban land use (shown as shading in the figure) surrounding both cities. There are substantial regions around the metropolitan areas of Baltimore and Washington, D.C., where long-tailed salamanders and northern red salamanders are also no longer found. Overall, a tally of records from areas that are now urban (based on 2000 land use) for both the 1960s survey and the current MBSS clearly shows that populations of these salamanders have been drastically reduced in urbanizing Maryland.

sensed National Land Cover Data and applied at different scales to three mixed land use drainage basins: Patapsco River, Patuxent River, and Potomac Washington Metro. They determined that the risk of local impairment in nontidal streams rapidly increases with increased urban land use in the catchment area (Figure 14-62). The average likelihood of failing biocriteria doubled with every 10% points increment in urban land, thus an increase in urban land use from 0 to 20% quadruples the risk of impairment. For the basins evaluated in this study, catchments with more than 40–50% urban land use had greater than 80% probability of failing biocriteria, on average. Inclusion of rights-of-way and point sources in the model did not significantly improve the fit for this data set, most likely because of their low numbers. The study indicates that urban land use is the strongest determinant of stream condition in central Maryland. Lastly, in combination with historical distribution information, MBSS sampling data illustrate the dramatic effect of urbanization on a stream salamander (see side bar).

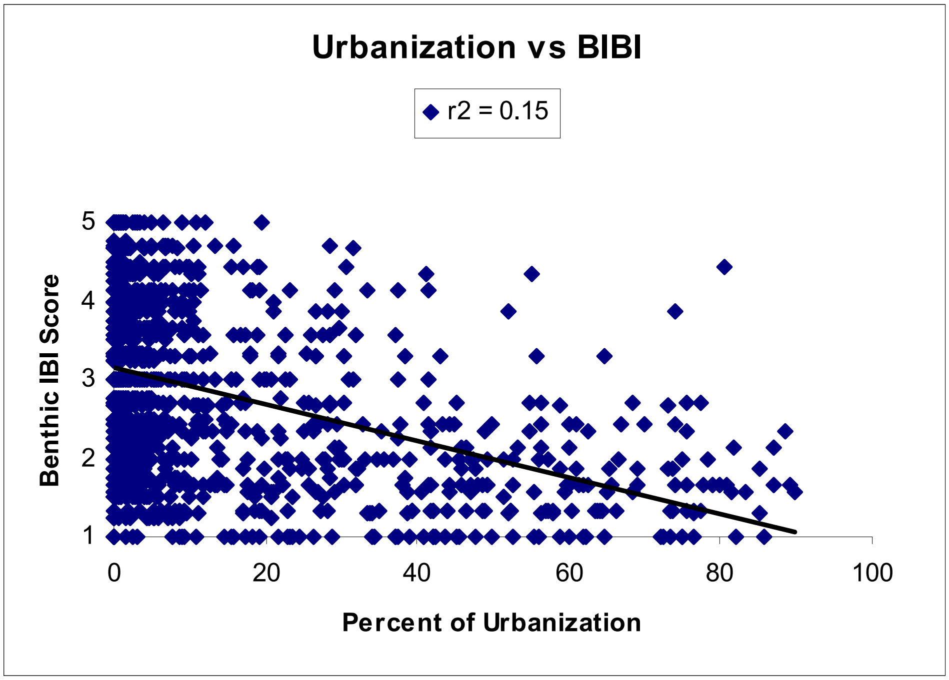


Figure 14-61. Relationship between percentage of urban land use and the benthic-macroinvertebrate index of biotic integrity, statewide for the 2000-2004 MBSS.

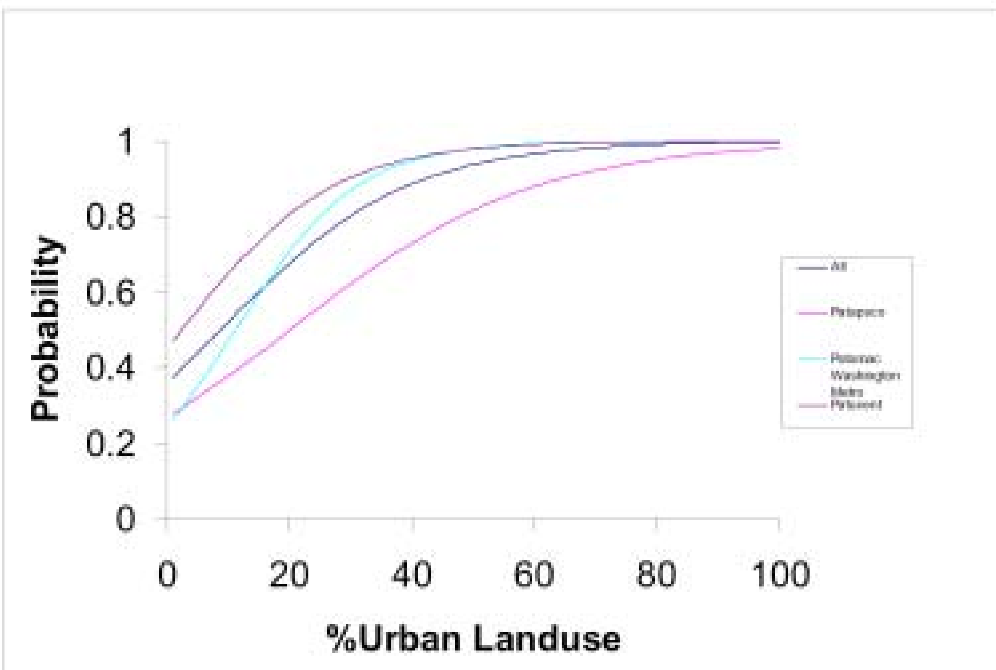


Figure 14-62. The probability of failing the Maryland biocriteria vs. percentage of land use in the catchments of MBSS sample sites for three central Maryland basins and across these basins.

14.6.3 Impervious Surfaces

The amount of imperviousness in a basin is the total contribution of paved surfaces, roofs, other solid structures, and less pervious soils found in sports fields and other hard packed areas. While imperviousness is highest in urban areas, it exists to varying degrees in suburban and rural environments as well. Roads are often the biggest contributor to impervious area (May et al. 1997). The proliferation of impervious surfaces fundamentally alters the timing of precipitation runoff, resulting in higher peak flows during storms and lower base flows (e.g., Wang et al. 2001, Walsh et al. 2004). During storm events, water on impervious surfaces is routed more quickly to the stream, resulting in current velocities unsuitable for many organisms. The energy associated with high flows also results in greater scouring and movement of bedload, increasing mortality of less mobile species. The extra energy associated with high flows may also precipitate channel incision through accelerated downcutting (Booth 1990). When downcutting occurs, the stream becomes less connected to its floodplain and streambank vegetation is less able to protect against bank erosion. When the energy of the stream is focused laterally, channel widening occurs, resulting in an increase in the width-to-depth ratio and a reduction in habitat quality for many species. During dry periods, the less water percolating into the soil during storms results in reductions in baseflow. This reduction further exacerbates the shallowing of habitat and may markedly slow current velocity. Consequently, urban streams tend to have wide, silty channels with relatively little water.

Higher flows during storms also more readily transport sediment, nutrient-laden surface runoff, toxic contaminants, large woody debris, rootwads, Coarse Fine Particulate Organic Matter (CPOM), Fine Particulate Organic Matter (FPOM), and Dissolved Organic Matter (DOM) downstream. These flows also result in decreased nutrient spiraling, increased turbidity/siltation, reduced amounts of habitat refugia, and potentially lethal contaminant concentrations. In urban areas such as Baltimore City that feature combined storm and sewer drains, high flow events result in elevated bacterial and nutrient levels, including potentially lethal concentrations of ammonia. When high flow events occur after extended periods of dry weather, a "first flush" of polycyclic aromatic hydrocarbons (PAHs) can kill many organisms. When high flow events occur during hot summer conditions, the heated water running off hot pavement and rooftops can result in unlivable stream temperatures. During and after winter storm events, concentrations of chlorides and heavy metals can far exceed tolerance limits for freshwater biota. In total, increased imperviousness from urbanization causes numerous deleterious changes to stream habitats, often resulting in severely impaired biological communities.

Tolerant macroinvertebrate and fish species quickly replace sensitive species as impervious surfaces cover 5 to 15% of a basin's area (Scheuler 1994, Klein 1979). However, Roth et al. (1999) found that significant loss of fish, benthic macroinvertebrate and aquatic herpetofauna species richness occurred at levels below this threshold. Biotic communities often change little after impervious land cover exceeds 20% of a basin (Booth and Jackson 1997; Wang et al. 2000; but see Morley and Karr 2002 for a biotic response when impervious land cover exceeds 50%).

As with urban land use, both fish and benthic IBIs decrease with increased impervious surface. Figures 14-63 and 14-64 illustrate poorer biological condition as the percentage of impervious surface exceed 5% and 20%. Figures 14-65 shows a similar decreasing relationship with the number of stream salamander species.

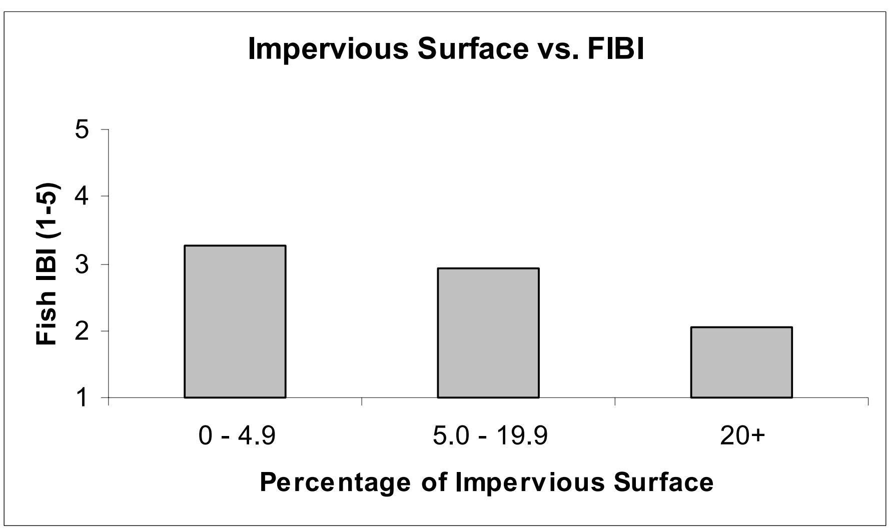


Figure 14-63. Relationship between impervious surface and the fish index of biotic integrity score (IBI), statewide for the 1994-2004 MBSS.

MAXIMUM IMPERVIOUS SURFACES TOLERATED BY FISH AND STREAM SALAMANDERS IN MARYLAND

Impervious land cover maximums for fish and stream salamander species collected by MBSS during 1994-2004. Maximums were not reported for estuarine, big river species, and species that occurred at less than 10 sites.

Common Name	Scientific Name	Impervious Maximum
***johnny darter	*Etheostoma nigrum*	0.1
***seal salamander	*Desmognathus monticola*	0.2
***mottled sculpin	*Cottus bairdi*	0.6
***Allegheny mountain dusky salamander	*Desmognathus ochrophaeus*	1.4
northern spring salamander	*Gyrinophilus p. porphyriticus*	1.9
checkered sculpin	*Cottus sp.*	2.0
mud sunfish	*Acantharchus pomotis*	2.5
***rainbow darter	*Etheostoma caeruleum*	2.6
swamp darter	*Etheostoma fusiforme*	3.0
brook trout	*Salvelinus fontinalis*	4.2
long-tailed salamander	*Eurycea longicauda*	4.8
rosyface shiner	*Notropis rubellus*	5.5
shield darter	*Percina peltata*	5.8
longear sunfish	*Lepomis megalotis*	7.1
warmouth	*Lepomis gulosus*	7.2
comely shiner	*Notropis amoenus*	8.7
banded sunfish	*Enneacanthus obesus*	9.2
river chub	*Nocomis micropogon*	11.5
glassy darter	*Etheostoma vitreum*	12.0
flier	*Centrarchus macropterus*	12.5
pirate perch	*Aphredoderus sayanus*	12.5
tadpole madtom	*Noturus gyrinus*	12.5
American brook lamprey	*Lampetra appendix*	12.9
blue ridge sculpin	*Cottus caeruleomentum*	13.7
*brown trout	*Salmo trutta*	14.3
greenside darter	*Etheostoma blennioides*	15.3
sea lamprey	*Petromyzon marinus*	15.3
spotfin shiner	*Cyprinella spiloptera*	15.3
fallfish	*Semotilus corporalis*	15.5
northern red salamander	*Pseudotriton ruber*	15.6
Potomac sculpin	*Cottus girardi*	16.1
margined madtom	*Noturus insignis*	16.1
northern hogsucker	*Hypentelium nigricans*	16.1
cutlips minnow	*Exoglossum maxillingua*	16.9
fantail darter	*Etheostoma flabellare*	20.2
northern dusky salamander	*Desmognathus fuscus*	20.2
silverjaw minnow	*Notropis buccatus*	20.2
**black crappie	*Pomoxis nigromaculatus*	22.1
rock bass	*Ambloplites rupestris*	22.1
bluntnose minnow	*Pimephales notatus*	24.3
**largemouth bass	*Micropterus salmoides*	24.3
smallmouth bass	*Micropterus dolomieu*	24.3
yellow bullhead	*Ameiurus natalis*	24.3
eastern silvery minnow	*Hybognathus regius*	24.5
mosquitofish	*Gambusia holbrooki*	24.5
pearl dace	*Margariscus margarita*	25.7
central stoneroller	*Campostoma anomalum*	26.7
spottail shiner	*Notropis hudsonius*	26.8
bluespotted sunfish	*Enneacanthus gloriosus*	27.1
chain pickerel	*Esox niger*	27.1
least brook lamprey	*Lampetra aepyptera*	27.1
redfin pickerel	*Esox americanus*	27.1
*rainbow trout	*Oncorhynchus mykiss*	27.5
satinfin shiner	*Cyprinella analostana*	28.0
swallowtail shiner	*Notropis procne*	28.0
bluegill	*Lepomis macrochirus*	28.9

Common Name	Scientific Name	Impervious Maximum
common shiner	*Luxilus cornutus*	28.9
green sunfish	*Lepomis cyanellus*	29.6
American eel	*Anguilla rostrata*	30.6
longnose dace	*Rhinichthys cataractae*	30.6
white sucker	*Catostomus commersoni*	30.6
tessellated darter	*Etheostoma olmstedi*	30.7
eastern mudminnow	*Umbra pygmaea*	31.6
golden shiner	*Notemigonus crysoleucas*	31.6
pumpkinseed	*Lepomis gibbosus*	31.6
blacknose dace	*Rhinichthys atratulus*	37.6
creek chub	*Semotilus atromaculatus*	37.6
creek chubsucker	*Erimyzon oblongus*	37.6
fathead minnow	*Pimephales promelas*	37.6
northern two-lined salamander	*Eurycea bislineata*	37.6
redbreast sunfish	*Lepomis auritus*	37.6
rosyside dace	*Clinostomus funduloides*	37.6
brown bullhead	*Ameiurus nebulosus*	41.2
goldfish	*Carassius auratus*	41.2

* Maximum tolerance is probably not this high because species is anually stocked into streams and may not be a long term resident

** Maximum tolerance is probably not this high because species is often displaced into streams from ponds and may not be a long term resident

***Maximum tolerance may not be this low because species is restricted to small portions of Maryland with little urbanization

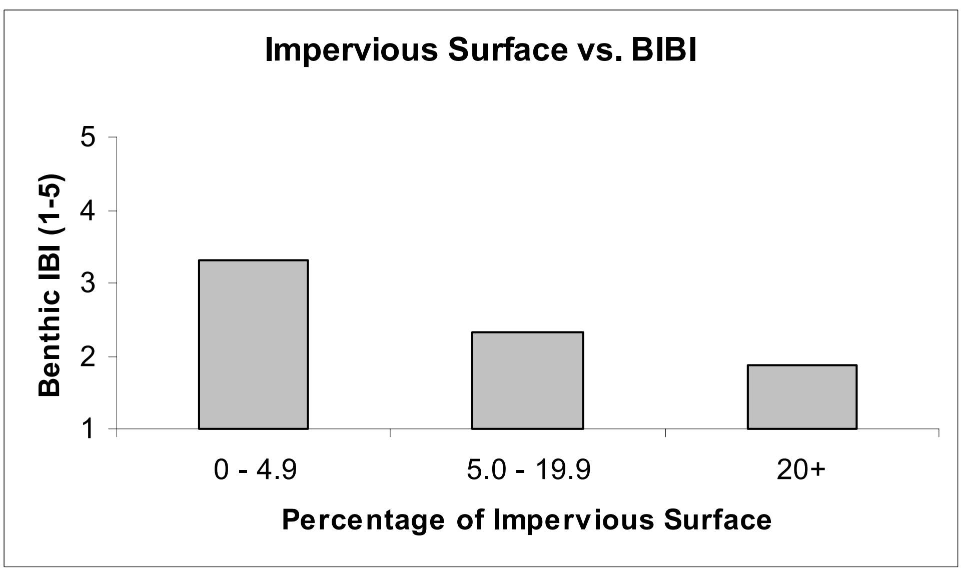


Figure 14-64. Relationship between impervious surface and the benthic-macroinvertebrate index of biotic integrity score (IBI), statewide for the 1994-2004 MBSS.

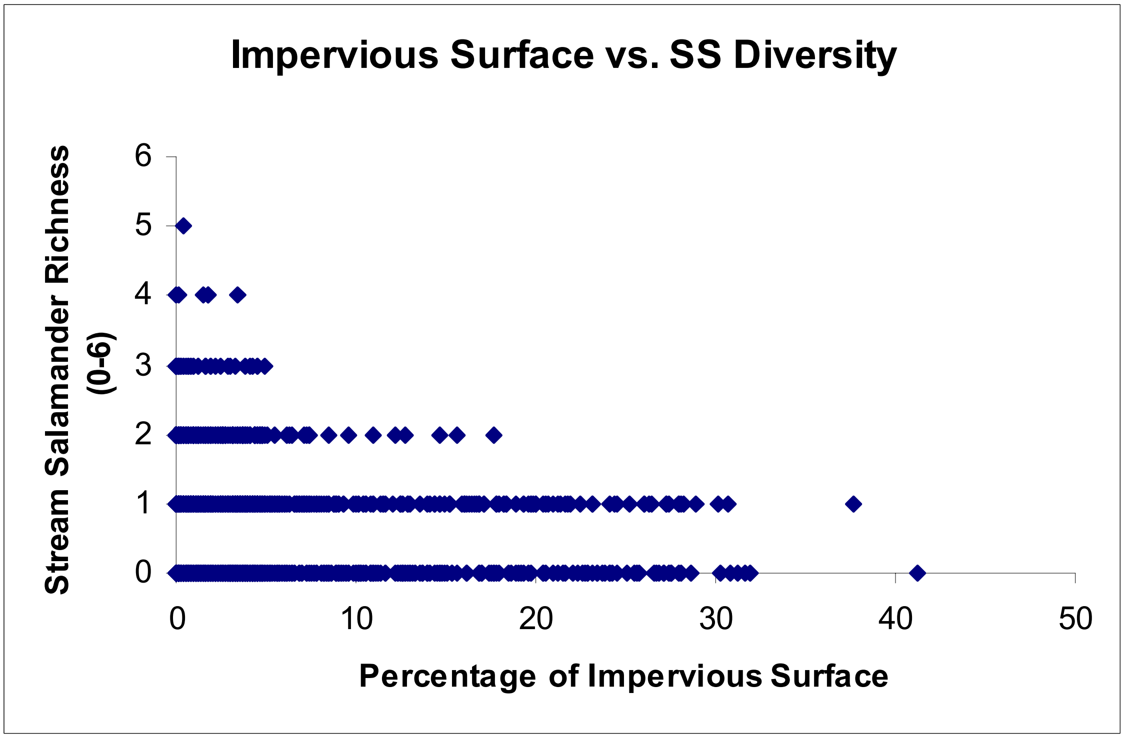


Figure 14-65. Relationship between impervious surface and the number of stream salamanders, statewide for the 1994-2004 MBSS.

14.6.4 Roads

While impervious surfaces are an excellent surrogate for hydrological changes affecting streams, roads may be the best surrogate of human activities across the entire landscape (Southerland 1995, Spellerberg 2002). The ecological effects of roads extend 100 to 1,000 m (average of 300 m) on each side of four-lane roads (Forman and Deblinger 2000). These effects, which stem from both construction and use, vary considerably in type and degree among regions and particular roads. Effects on biological populations and communities, as well as key ecological processes, can be dramatic and probably contribute to local extirpation and regional endangerment of many fishes (Angermeier et al. 2004).

The primary impacts of road construction are direct alteration of the stream channel and indirect acceleration of fine sediment loading from exposed soils. As described above, these alterations can change channel depth, pool-to-riffle ratio, percent fines in substrates, and cover availability. Once constructed, roads still have major effects on water quality (e.g., via toxic spills and runoff), habitat quality (via sediment loading and channel modification), and habitat connectivity (via barriers to movement). Many road crossings over streams constrain movements by small fishes that may be essential for individuals to complete their life cycles and for metapopulations to remain viable (Angermeier et al. 2004). To the extent that roads continue to contribute fine-sediment loading after construction, aquatic biota suffer (Waters 1995, Wood and Armitage 1997). Several studies have shown elevated concentrations of contaminants in aquatic animals near roads (Van Hassel et al. 1980, Stemberger and Chen 1998). Roads also provide human access to streams and can enhance the spread of non-native fishes, mollusks, and pathogens (Trombulak and Frissell 2000).

In Maryland, as in many other parts of the Country, vehicle miles traveled have increased in recent decades (Figure 14-66). This is a result of greater dispersed development (urban sprawl) and our automobile-based lifestyle. As the number of vehicle miles traveled increases, the road infrastructure grows and the impact of each segment (supporting more traffic) increase. Figure 14-67 shows the distribution of road crossings in Maryland.

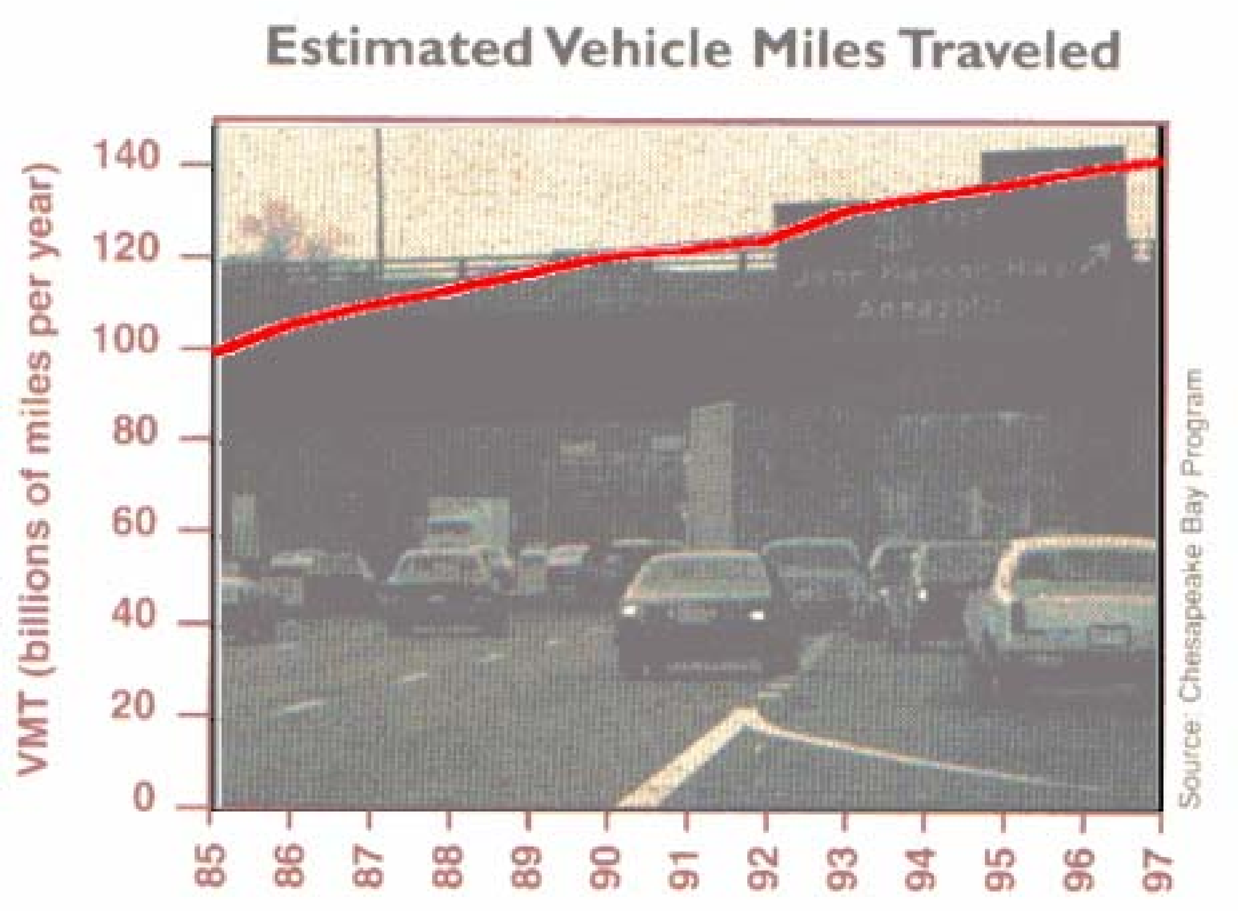


Figure 14-66. Vehicle miles traveled (VMT) in billions per year throughout the Chesapeake Bay basin.

14.6.5 Trash

Another useful surrogate for human activities at the scale of the MBSS site is the amount of trash. Originally called "aesthetics," this "absence of trash" score is based on a 0 to 20 scale that increases as the amount of trash decreases. A score of 20 is the complete absence of trash or other obvious evidence of human presence. Figures 14-68 and 14-69 show the increasing relationships between the absence of trash and benthic IBI and PHI, respectively.

14.7 RELATIVE RISKS AND CUMULATIVE IMPACTS OF STRESSORS ON MARYLAND STREAMS

Identifying stressors is critical to the development of management actions by the State and others to restore or protect the desired condition of streams. In particular, stressor identification is critical to implementing Total Maximum Daily Loads (TMDLs) developed by MDE to address streams impaired under CWA Section 303(d). Stressor information is also critical for active restoration programs for Maryland's streams such as Maryland DNR Watershed Restoration Action Strategies (WRAS) and Chesapeake Bay Program Tributary Strategies.

Identifying stressors, however, is not sufficient to guide effective management actions for Maryland streams. The State, Counties, and other natural resource stewards must assess the relative risks posed by different stressors at site, basin, and regional scales. Only by comparing these risks can effective stream restoration or protection be attained. Comparative risk assessment is an emerging discipline (U.S. Environmental Defense 2004) that tries to answer the question—Is one environmental problem worse than another? The search for this answer provides a good forum for discussing environmental issues. It also leads to better environmental management by weeding out obsolete programs, promoting efficiency, establishing credibility, improving relationships among stakeholders, and increasing awareness of the environment by the government and the public. Critical to comparative risk discussions is the understanding that better environmental conditions provide a better quality of life, and that preservation and protection are always more cost-effective than restoration. Determining the comparative risks facing Maryland streams involves assessing not only the severity, extent, and reversibility of risks, but

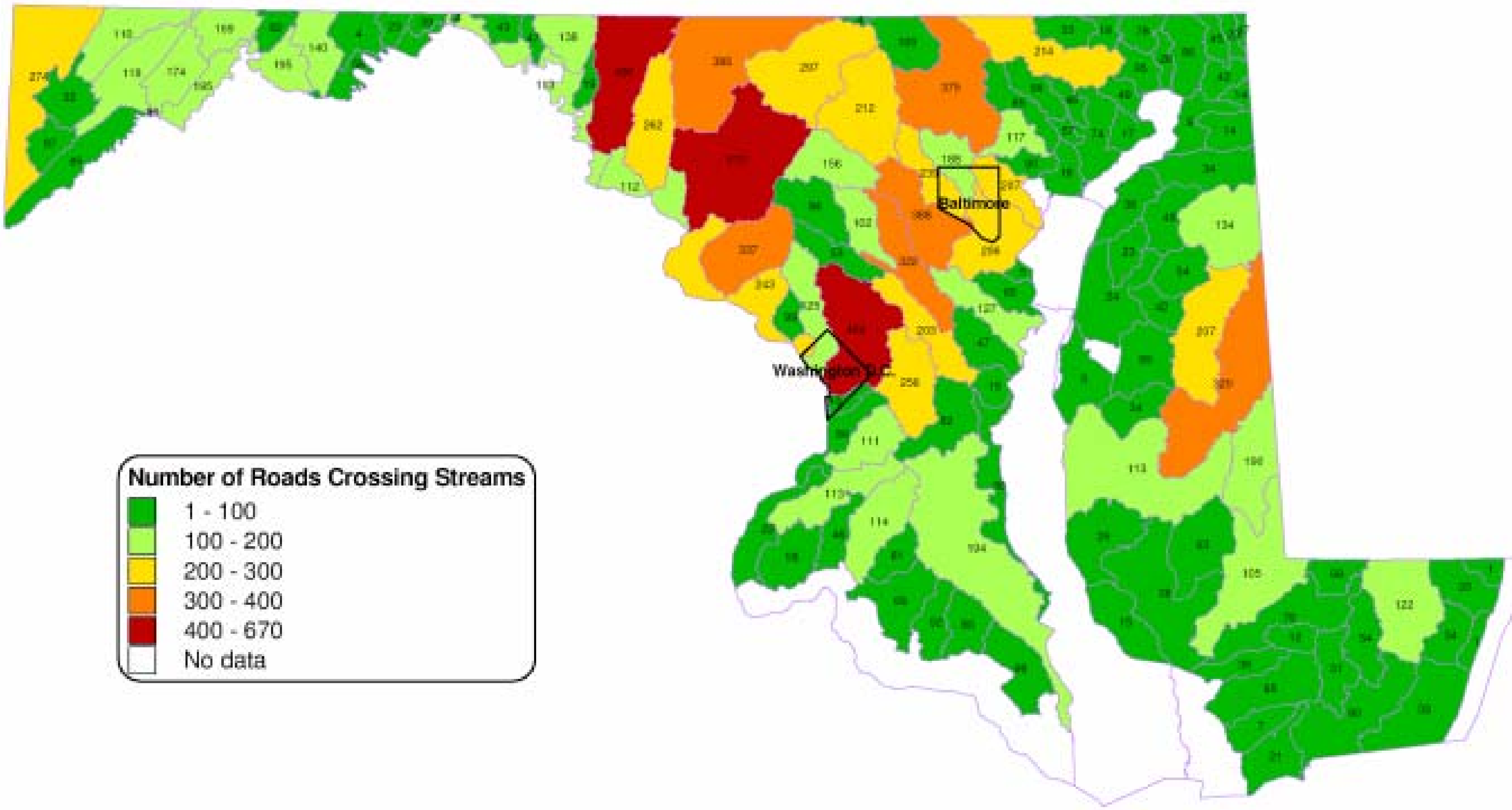


Figure 14-67. Number of road crossings of streams by basin in Maryland.

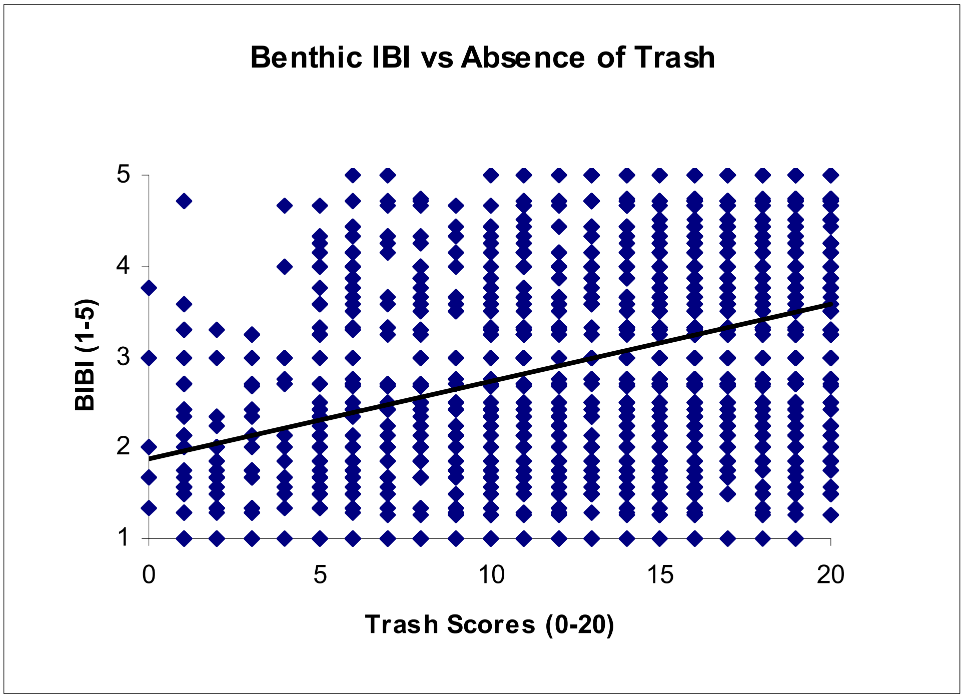


Figure 14-68. Relationship between the benthic index of biotic integrity (IBI) and the absence of trash score, statewide for the 1995-2004 MBSS.

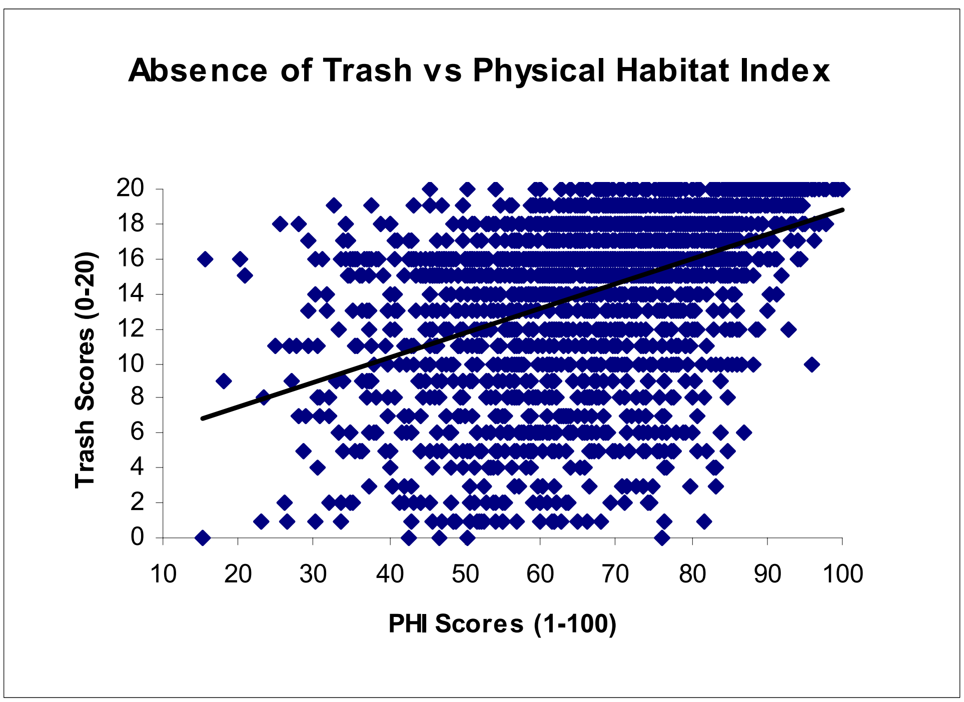


Figure 14-69. Relationship between the physical habitat index (PHI) and the absence of trash score, statewide for the 1995-2004 MBSS.

also the uncertainty associated with these risks. Ultimately, a comparative risk assessment will lead to a strategic plan for stream protection and restoration that includes priorities for action, resource needs and potential sources of funding, and a means of tracking and documenting success.

Comparisons of relative risks must be accompanied by assessments of the cumulative impacts that result. It is the total effect of stressors combined in space and time that degrade stream conditions. Odum (1982) aptly described degradation from cumulative impacts as "the tyranny of small decisions." Atmospheric deposition is a good example of cumulative impacts—natural resources in a stream become degraded when the total loading of acid exceeds the threshold assimilative capacity of the receiving basin. Complicating cumulative effects analysis for streams is the fact that streams and rivers are hierarchical systems wherein the character of a local stream site is affected by the larger stream network and basin to which it belongs. This means that to fully understand the multiple, cumulative impacts on stream systems, conditions at a broad landscape scale, as well as the local or site-specific scale, must be assessed. Equally important is the recognition that solutions to stream problems must consider the cumulative (and sometime synergistic effects) of multiple stressors. For example, while water chemistry results may indicate that acidic deposition is the likely cause of degraded fish communities at a particular site, there may be other stressors on that stream that would continue to inhibit fish even if the acidification was ameliorated. Loss of biota where riparian vegetation has been removed may be caused by hydrological changes (i.e., that accelerate bank erosion and sedimentation) or simply the loss of allochthonous inputs (e.g., leaf fall). In other cases, refugia within a local stream network may mitigate severe episodic stresses. This illustrates the need to include landscape-level information in the ecological assessment process. Only by using an integrated multiple-scale and multiple-stressor approach can the cumulative effects on streams be assessed and ameliorated.

Table 14-15 is an example from the first attempt to quantify relative risks posed by 22 stressors to Maryland streams, including some that are not monitored by the MBSS (see Volume 12: Stream and Riverine Biodiversity). This table includes a qualitative evaluation of the severity, extent, reversibility, trends, and degree of understanding (uncertainty) of each stressor. Refinement of this list of relative risks will occur as more MBSS analyses are conducted and as additional data from other sources are incorporated.

14.7.1 Most Severe Stressors Affecting Maryland Streams

Determining the relative risks posed by stressors is important at the scale of management actions. Relative risk includes two components: the importance (or severity) and the prevalence (or extent) of each stressor. We present the severity of ten stressors to Maryland streams as the probability of poor fish and benthic IBI scores given stressor scores above the threshold for degradation, divided by the probability of poor IBI scores given stressor scores below the threshold for degradation. Risk severity scores > 1 indicate which stressors have the strongest effect on streams statewide (Figure 14-70). For fish, acid mine drainage is the most severe stressor; for benthic macroinvertebrates, low dissolved oxygen is the most severe. Urban land use is the most severe stressor overall.

The analysis includes the following ten stressors (shown with the threshold values indicating degradation risk):

- Urban > 5%
- No Riparian Buffer
- Channelization
- NO3 > 5 mg/l
- DO < 3 mg/l
- Acid Deposition Present
- Acid Mine Drainage Present
- Bank Stability Sub-optimal or Poor (<= 11)
- Invasive Plants Present
- Invasive Fish or Mussels Present

These ten stressors are meant to be a representative but incomplete list. The thresholds of concern for each stressor were selected based on expert consensus and analyses to date on the MBSS data. In particular, stressor values that result in demonstratively lower fish or benthic IBI scores have been used as thresholds. Additional stressor analyses are being conducted with the MBSS data and thresholds may be revised in the future.

14.7.2 Extent of Major Stressors Affecting Maryland Streams

While acid mine drainage is a severe stressor, it has the smallest extent statewide (i.e., number of stream miles affected) of the ten major stressors (Figure 14-71). The presence of invasive plants and animals are the most extensive stressors statewide, at 85% and 52% of stream miles, respectively. Poor bank stability affects 25% of stream miles and acid deposition affect 21%, compared to 1% for acid mine drainage. Figure 14-72 shows the extent of each of these major stressors as the percentage of stream miles by each Maryland county with stressor values exceeding the threshold for degradation.

Table 14-15. Relative risks posed to an example Maryland basin (note that relative risks for all Maryland basins are in Volume 9: Stream and Riverine Biodiversity).

Basin: Gwynns Falls

Category	Subcategory	Name	Extent	Trend	Severity	Persistence	Reversibility
Chemical	Non-point Source	Organic Matter Retention	2	3	3	4	3
Chemical	Non-point Source	Acid Deposition/ Low pH	0	2	4	4	2
Chemical	Non-point Source	Acid Mine Drainage	0	1	5	5	1
Chemical	Non-point Source	Excess Nitrates	3	3	2	3	3
Chemical	Non-point Source	Excess Phosphorus	3	3	2	3	4
Chemical	Non-point Source	Mercury Deposition	2	3	2	4	2
Chemical	Point Source	Pathogens/Endocrine disruptors	3	3	4	2	3
Chemical	Point Source	Industrial (NPDES)	4	2	3	3	3
Chemical	Point Source	Agricultural Pesticides	2	2	2	3	3
Chemical	Point Source	Dissolved Oxygen	0	3	4	2	3
Future Changes		Land Conversion	1	3	4	5	2
Future Changes		Sea Level Rise	0	3	5	5	1
Habitat Alteration		Wetland Loss	2	3	3	4	2
Habitat Alteration		Channelization	4	2	3	3	3
Habitat Alteration		Forest Fragmentation	5	3	2	3	4
Habitat Alteration		Ground Water withdrawal	1	2	2	2	4
Habitat Alteration		Migration Barriers	3	2	3	3	2
Habitat Alteration		Runoff/Baseflow/Down Cutting	5	3	3	4	2
Habitat Alteration		Sedimentation	2	3	3	4	3
Habitat Alteration		Surface Water Withdrawal	4	2	2	2	4
Non-natives		Non-native Species (aquatic)	4	2	2	3	2
Non-natives		Invasive Plants (riparian)	4	3	2	3	2

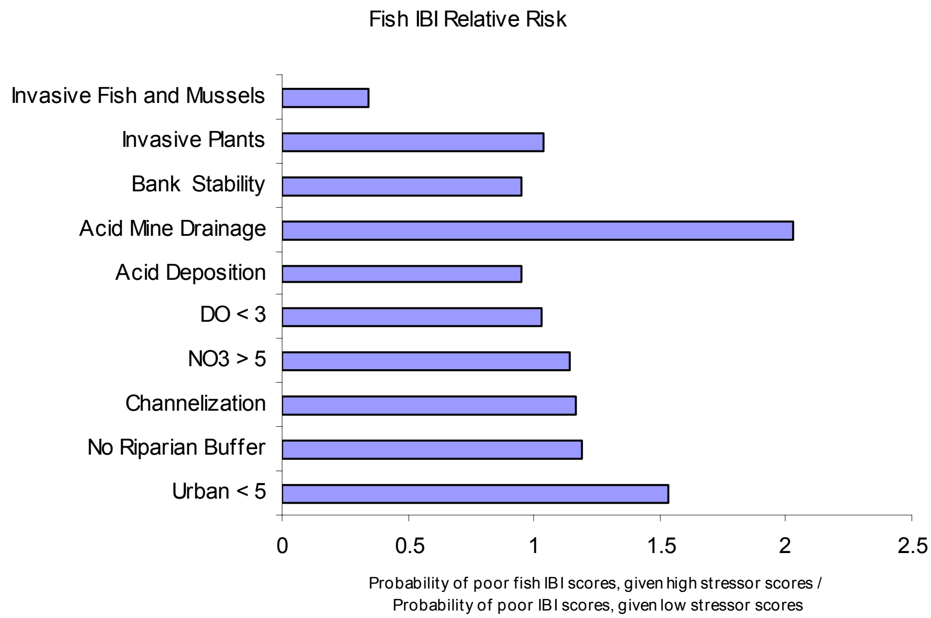
EXTENT (0-5) Based on the estimated percentage of stream miles or, in some cases, areas in the basin that are affected
0 = None or negligible
1 = 1-10%
2 = 11-20%
3 = 21-30%
4 = 31- 60%
5 = 61-100%

TREND (1-5) Based on the projected rate of change and immediacy of the impact
0 = Threat extent decreasing over time, either due to human intervention or natural rejuvenation
1 = Threat extent unchanging
2 = Threat slowly getting worse; up to 0.25% change per year
3 = Threat extent getting worse; up to 0.5% change per year
4 = Threat extent steadily growing, up to 2% change per year
5 = Threat extent rapidly growing, 2 or more percent change per year

SEVERITY (0-5) Based on the estimated or known impact to aquatic ecosystems
0 = No impact likely
1 = Mild
2 = Moderate; degradation of some forms of biological function; detectable shift in community structure and species loss
3 = Serious; significant loss of biological function, communities often dominated by tolerant generalists and/or richness declines
4 = Very serious; heavy loss of biological function; only tolerant species remain
5 = Catastrophic; near-total loss of biological function in affected areas

PERSISTANCE (1-5) Based on duration of impact
0 = Recovery nearly immediate
1 = Short duration, substantial recovery possible in less than 1 year
2 = Moderate duration, substantial recovery possible within 5 years
3 = Long duration, substantial recovery possible within 5-50 years with human remediation
4 = Extreme duration, substantial recovery not likely for 50 to 100s of years, even with intensive human intervention
5 = Essentially permanent environmental feature lasting hundreds of years, even with intensive human intervention

REVERSABILITY (1-5) Based on the degree of difficulty to reduce or eliminate the threat
1 = Only correctable using extreme or unproven measures and at extreme relative cost
2 = Mostly correctable, but at very high socioeconomic cost
3 = Correctable using existing technology, but at high relative cost (social or economic)
4 = Correctable with existing technology and moderate cost
5 = Readily remedied using existing technology



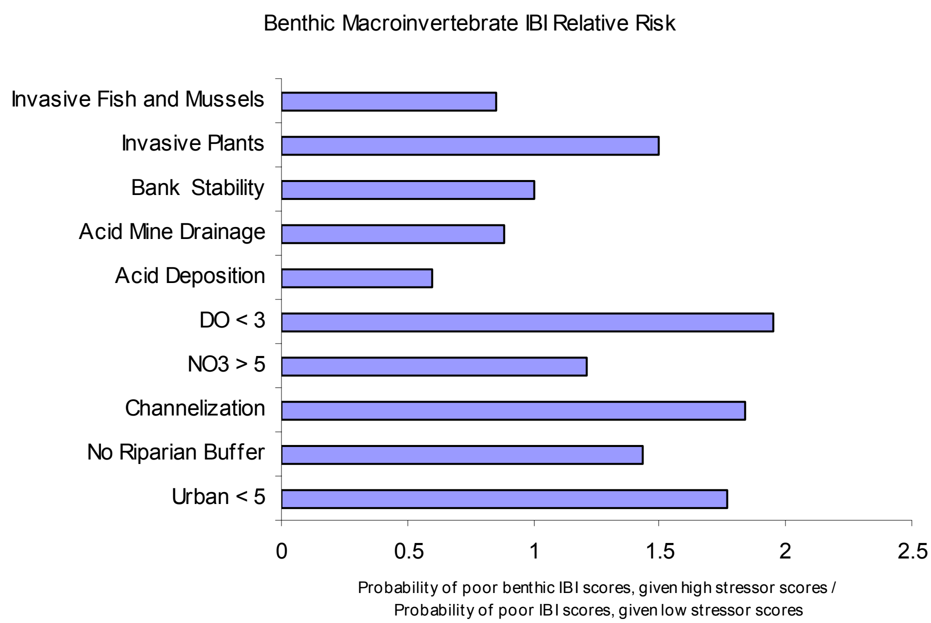


Figure 14-70. Importance of ten stressors to FIBI and BIBI scores.

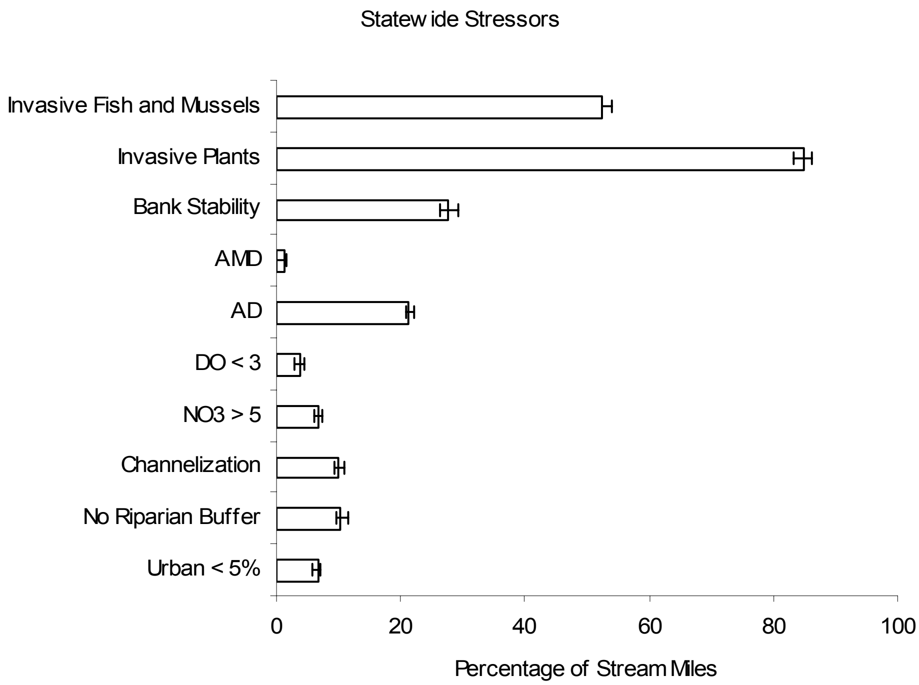


Figure 14-71. Statewide stressors extent for MBSS 2000-2004 data.

14.7.3 Stressor Identified by Loss of Fish Species

The combined effect of stressors can also be determined by identifying where individual fish species are lost. Table 14-16 lists the major stressors to fishes in Maryland streams based on the loss of fish species as determined by the Prediction and Diagnosis Model of Stranko et al. (2005). This model predicts species that should be present in the absence of major anthropogenic stress using variables that do not typically change with human influences (e.g., stream size, geology, altitude, gradient, drainage basin where species occurs). Conservative predictions were generated by only predicting that species should occur where conditions for all predictor variables are optimal. Where species were predicted to occur but were absent, stressors were identified. A stressor to a species was any value outside the tolerance thresholds for the species. The methods used apply this model are described in section 14.8.

In this analysis, a total of 398 MBSS sites had some stressor identified. This was 45% of the total sites the model was applied to and 51% of the sites with at least one predicted species absent. Exactly 71 sites had urban or impervious identified as a stressor; that is 8% of the 889 total sites used in the model and 18% of the 398 where stressors were identified.

Table 14-16 shows the percentage of stream miles where species were absent due to stressors. Statewide results indicate that physical habitat alterations are the most pervasive stressors responsible for fish species absences (17% of stream miles) with bank erosion the most pervasive physical habitat stressor (9% of stream miles). Acidity is also a widespread stressor (8% of stream miles affected), with acid deposition the most often diagnosed source of acidity. Urbanization and agricultural land use were also identified as important stressors responsible for fish species absences with both affecting more than 5% of stream miles.

Brook trout were most often absent due to physical habitat related stressors. Blacknose dace were rarely affected by urbanization or physical habitat; however, they appear to be affected by acidity. The bluespotted sunfish is one of the many fishes indigenous to the Coastal Plain that prefer naturally acidic streams; high pH was associated with many bluespotted sunfish absences. Liming associated with agriculture practices raises the pH of some naturally acidic streams (Figure 14-73), making them less suitable to acid endemic species (like blue-spotted and other species) and more suitable to other species (like blacknose dace that cannot tolerate low pH). Banded sunfish is another acid endemic species that prefers pH even lower than that for the bluespotted sunfish (Figure 14-74). The banded sunfish is typically associated with blackwater streams with slow water and naturally low acidity and high dissolved organic carbon. Other species including mud sunfish, ironcolor shiner, swamp darter, eastern mudminnow, pirate perch, creek chubsucker, tadpole madtom, redfin pickerel, as well as certain amphibian species including carpenter frogs, are

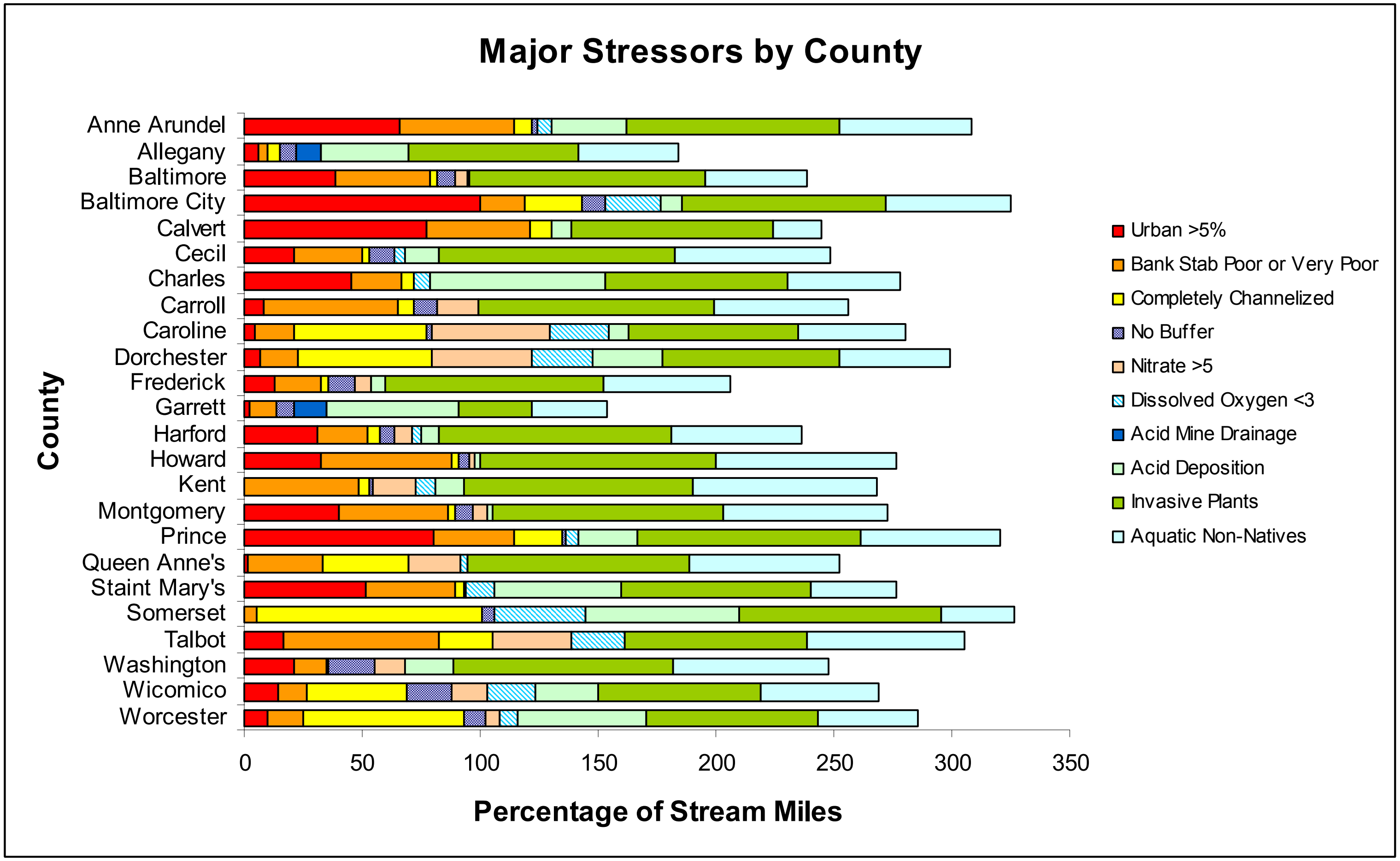


Figure 14-72. Stressors by county, in percent of total stream miles for that county, based on the 2000-2004 MBSS.

Table 14-16. Major stressors resulting in the loss of fish species (by all fish and by three selected species, bluespotted sunfish, blacknose dace, and brook trout) with number of stream miles affected statewide	
Stressors (All species)	**% Stream miles (Std. error)**
Urban/Impervious land cover	5.74 (0.68)
Acidity (low pH or ANC)	8.32 (0.94)
Acid deposition	6.88 (0.84)
Acid mine drainage	0.32 (0.18)
Agriculture	0.50 (0.21)
Unknown	0.64 (0.34)
Physical habitat	16.93 (1.35)
Instream habitat	1.53 (0.45)
Epifaunal substrate	0.02 (0.02)
Velocity/depth diversity	1.03 (0.3)
Insufficient depth	2.24 (0.55)
Loss of canopy shading	1.51 (0.42)
Riffle embeddedness	0.52 (0.27)
Poor pool habitat	1.6 (0.48)
Poor riffle habitat	0.32 (0.23)
Channelization	2.32 (0.53)
Bank erosion	8.96 (0.99)
Agricultural land use	5.01 (0.78)
Nutrients (nitrate-nitrogen)	2.15 (0.49)
Low dissolved oxygen	2.45 (0.6)
Non-native salmonids	0.2 (0.14)
Stressors (Bluespotted sunfish)	**% Stream miles (Std. error)**
Acidity (high pH or ANC)	7.83 (1.67)
Physical habitat	2.25 (1.43)
Bank erosion	2.25 (1.43)
Forest loss	8.38 (1.59)
Agricultural land use	9.42 (1.8)
Sulfate (SO_4)	5.06 (2.13)
Low dissolved oxygen	1.8 (1.29)
Stressors (Blacknose dace)	**% Stream miles (Std. error)**
Urban/Impervious land cover	0.14 (0.1)
Acidity (low pH or ANC)	3.65 (0.72)
Acid deposition	3.22 (0.68)
Acid mine drainage	0.32 (0.21)
Agriculture	none
Unknown	0.11 (0.11)
Physical habitat	1.44 (0.44)
Velocity/depth diversity	0.07 (0.07)
Insufficient depth	0.17 (0.17)
Poor pool habitat	0.22 (0.16)
Channelization	0.39 (0.2)
Bank erosion	0.88 (0.35)
Forest loss	0.25 (0.25)

Table 14-16. (Continued)	
Stressors (Brook trout)	**% Stream miles (Std. error)**
Urban/Impervious land cover	9.44 (1.6)
Acidity (high pH or ANC)	3.79 (1.74)
Acidity (low pH or ANC)	1.79 (0.86)
Acid deposition	0.92 (0.6)
Acid mine drainage	0.98 (0.69)
Agriculture	none
Unknown	0.35 (0.35)
Temperature	3.45 (1.52)
Physical habitat	10.3 (2.35)
Instream habitat	1.97 (1.3)
Velocity/depth diversity	
Insufficient depth	0.37 (0.37)
Lack of canopy shading	2.99 (1.52)
Riffle embeddedness	1.97 (1.3)
Poor pool habitat	0.37 (0.37)
Bank erosion	7.66 (2.03)
Forest loss	5.44 (1.18)
Agricultural land use	1.93 (0.92)
Nutrients (nitrate-nitrogen)	7.09 (1.79)
Low dissolved oxygen	1.97 (1.3)
Non-native salmonids	1.65 (1.23)

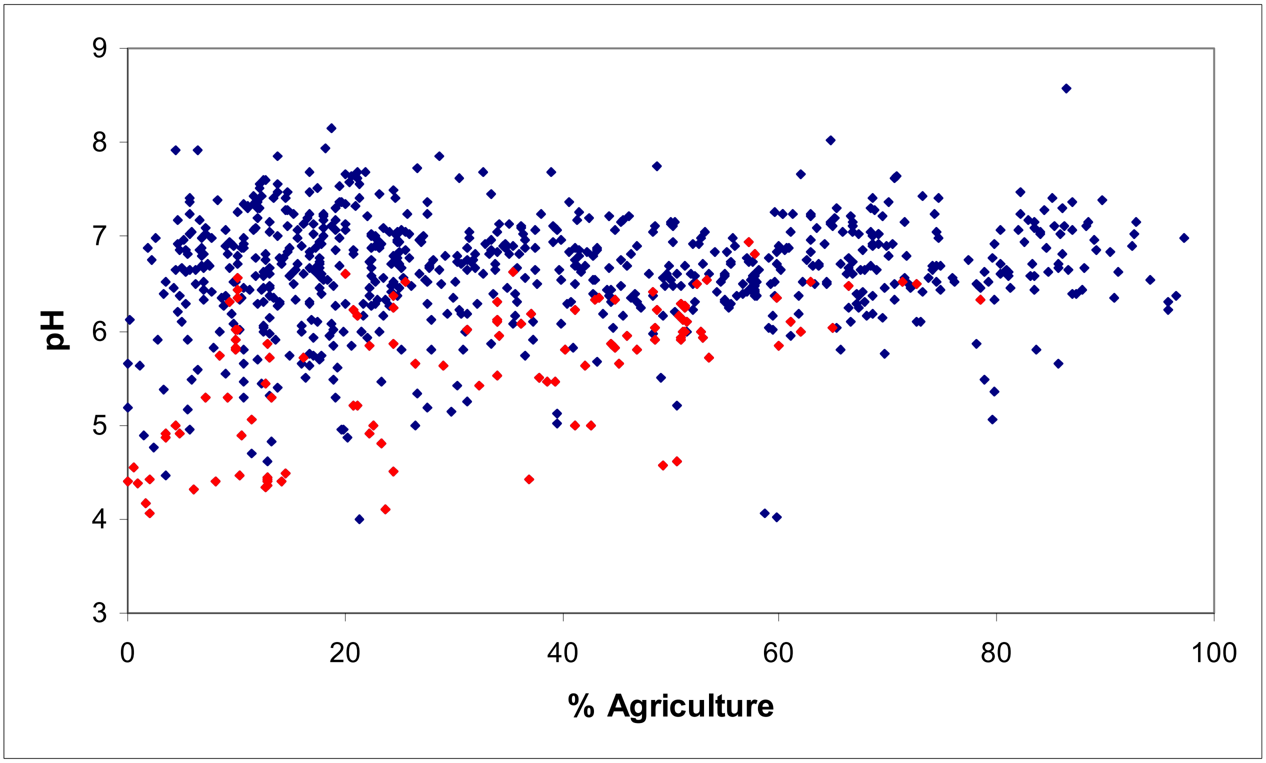


Figure 14-73. Relationship between the pH and the percentage of agricultural land use, statewide for 1995-2004 MBSS. Blackwater streams are indicated by red diamonds.

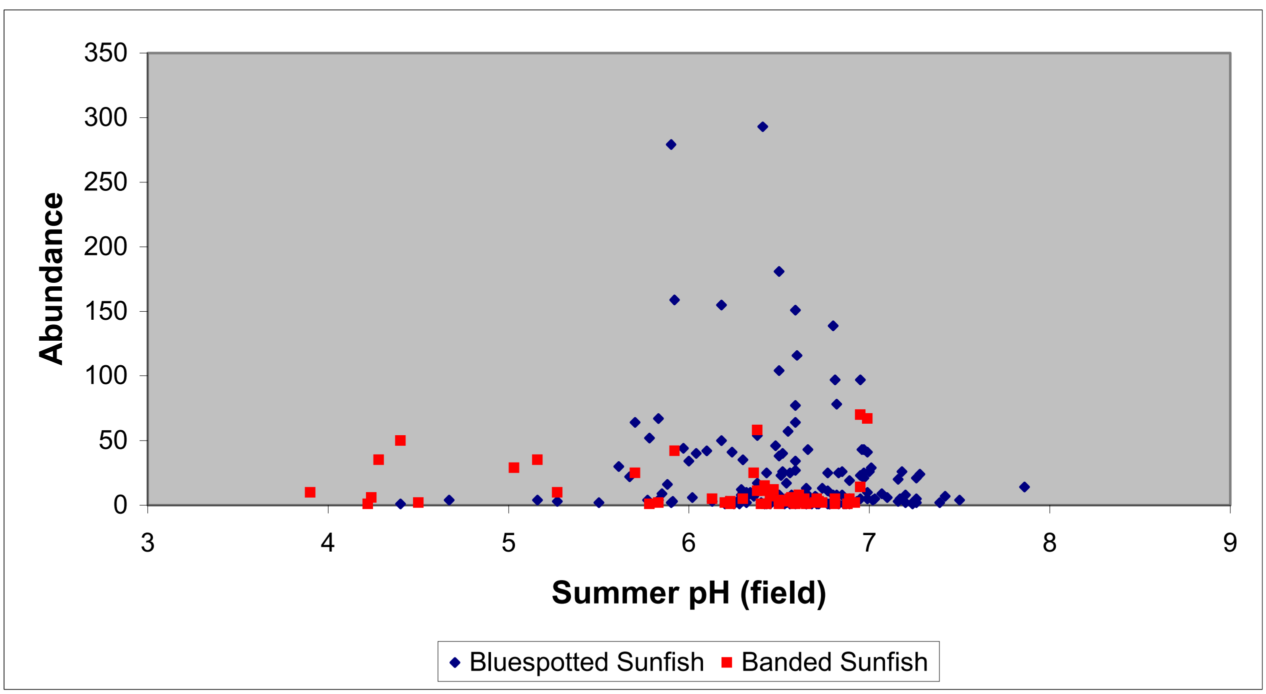


Figure 14-74. Relationship between the bluespotted sunfish and banded sunfish abundance and the summer pH, statewide for 1995-2004 MBSS. Bluespotted sunfish are indicated by black diamonds and the banded sunfish by red squares.

STRESSORS CAUSING FISHLESS STREAMS

The Prediction and Diagnosis Model (PDM) of Stranko et al. (2005a) identifies stressors causing the loss of certain fish species. What are the stressors present in streams with no fish? Based on the MBSS 2000-2004 data, 143 sites had no fish. Of these, 30% had values above the level of concern for one or more of eight stressors. Of these 143 fishless sites, 81 drained catchments of < 300 acres and only 15% were stressed, indicating that smaller streams naturally have fewer fish. In streams draining more than 300 acres, 45% were stressed. The list of stressors (i.e., human-related variables with values above the level associated with adverse effects) found at these fishless sites included the following:

- Channelization = 14 sites
- pH = 13 sites
- DO = 13 sites
- ANC = 11 sites
- Instream Habitat = 10 sites
- % Urban = 8 sites
- Bank Stability = 6 sites
- NO_3 = 0 sites

associated with relatively low pH. This indicates that both high acidity and pH resulting from agricultural liming must be considered in planning the protection of Coastal Plain biodiversity.

14.8 EXAMPLES OF STRESSOR IDENTIFICATION AT THE SITE AND BASIN LEVEL

Stressor identification at state and regional levels is critical to setting priorities and developing government strategies for stream restoration and protection. Specific restorations, however, require that stressors be identified at the scale of the restoration project, i.e., the site or the basin. While definitive stressor identification can require custom monitoring of the site or basin in question, MBSS data are often sufficient to characterize the major stressors of concern.

Volumes 1 through 5 describe that annual sampling of the MBSS and characterize the status of all Maryland 8-digit basins (although the smallest are combined into "super-basins" for assessment). Included in these characterizations are detailed tables listing the land use, water chemistry, and physical habitat values for each MBSS site. Using established thresholds of concern for many of these variables (e.g., ANC < 200 µeq/L or impervious surface > =10%), values exceeding the thresholds are flagged to indicate the likely presence of this stressor. The combined evidence from each of these tables is summarized in the "Interpretation of Basin Condition."

Biological data can also be used for diagnosing stream problems. The use of discernable patterns in the response of aquatic communities to stressors was first described as "biological response signatures" using Ohio EPA data by Yoder (1991) and has since been summarized in Simon (2003). The Ohio EPA approach used graphical techniques to describe fish and macroinvertebrate community responses to nine impact types: complex toxic, conventional municipal/industrial, combined sewer overflows/urban, channelization, agricultural nonpoint, flow alteration, impoundment, combined sewer overflows/urban with toxics, and livestock access (Yoder and Rankin 1995). Specifically, they identified metrics from the fish Index of Biotic Integrity, modified Index of Well-Being, and Invertebrate Community Index (e.g., darter species, percent round-bodied suckers, intolerant species, and percent Deformities, Erosions, Lesions/Ulcers and Tumors (DELT) anomalies) that were characteristic of each impact type. While percent DELT anomalies for fish and percent Cricotopus spp. for macroinvertebrates were indicative of the complex toxic impact types, and number of sunfish species, percent caddisflies, and qualitative EPS indicated the channelization impact type fairly well, there was much broader overlap among the other impact types.

The MBSS has developed a conceptually different, but very effective method for using fish data to identify likely stressors at individual MBSS sites—the Prediction and Diagnostic Model of Stranko et al. (2005a). This approach is based on determining which stream habitat conditions are suitable and preferred for individual fish species in the absence of anthropogenic stress.

Generating predictions of species presence. The first step in developing predictions for the model was to determine the physiographic provinces and basins where each species was collected in the development data set. The next step was to determine the stream conditions that each fish species prefers to inhabit, based on relationships of species abundance compared to nine variables that are not typically affected by anthropogenic influences to streams. These nine variables are referred to as predictor variables. The range of conditions that each species prefers to inhabit was determined for each predictor variable. Any value for a predictor variable that coincided with greater than average species abundance was considered to represent preferred conditions. The range of preferred conditions was considered to be the range of predictor variable values from the minimum to the maximum where each species was collected at greater than average abundance.

Once the ranges of preferred conditions were generated, they were used to generate predictions of the fish species expected to occur in a stream in the absence of major anthropogenic disturbance. Predictions were generated for the sites in the test data set using a hierarchical screening method (Smith and Powell 1971). Using this approach, a fish species was expected to occur at any site in Maryland that was in a physiographic province and basin where the fish species could be found and all of the predictor variables were in the preferred range for the species (in the development data set).

The expected list of species collected at each site in the test data set was then compared to the actual list of species collected. The species that were predicted to occur, but were not collected, were considered to be absent most likely due to the influence of anthropogenic stressors.

<u>Stressor diagnosis</u>. The first step in diagnosing probable stressors to fish species that were expected to occur, but were absent, was to determine the tolerance thresholds of each fish species to 14 stressor variables in the development data set. The tolerance thresholds for each species were considered the minimum and maximum value for each variable where the species was collected in the development data set. If the value for one of these stressor variables exceeded the tolerance thresholds for a species that was absent, but was expected to occur at a site in the test data set, then that variable was considered to be a stressor to the species. For ease of reporting, scores for the five habitat metric variables were combined into a single physical habitat structure stressor and pH and acid neutralizing capacity (ANC) were combined into a single acidity stressor. These combinations resulted in a total of nine stressors being reported.

14.8.1 Basin Examples Using the Fish Prediction and Diagnosis Model

In 1998, Maryland's basins most in need of restoration and protection were prioritized based on MBSS and other data as part of the state's Unified Basin Assessment (COMAR 1995-26.08.02.03). To assist in distributing limited funds within these priority basins, finer scale stressor information was needed to focus on specific areas where restoration and protection activities could be implemented. Based on MBSS data, sites affected by specific stressors were identified within priority basins.

The range of stress to MBSS sites from urbanization (as measured by percent impervious land cover) in the Gwynns Falls basin is shown in Figure 14-75. The southeastern portion of the basin is located in and near Baltimore City and is strongly affected by urbanization. In contrast, the northwestern portion of the basin is minimally affected.

Nitrate-nitrogen values in the Port Tobacco River basin are shown in Figure 14-76. One unnamed tributary suffers from elevated nitrate-nitrogen values. This stream originates in the town of La Plata and flows westward toward the Port Tobacco River. Other sites in the basin did not have elevated nitrate-nitrogen.

14.8.2 Site-Specific Examples Using the Fish Prediction and Diagnosis Model

Ultimately, site-specific restoration and protection of biota can only be achieved if the specific stressors affecting biota are known. As described above, the Prediction and Diagnosis Model (Stranko et al. 2005a) uses fish species tolerance thresholds to 14 stressor variables and nine non-stressor variables as determined from MBSS data. Non-stressor variable thresholds along with zoogeographic information were used to generate a list of the species expected to occur in a given stream in the absence of severe anthropogenic stress. Stressor variable thresholds were then used to diagnose probable stressors to fish species at sites where they were expected to occur, but were absent. The thresholds for the stressor variables diagnosed by the PDM can also be used to set minimum fish restoration and recovery endpoints. Stressor thresholds for species that are known to occur in a stream can also be used to set limits necessary to protect those species.

Table 14-17 shows results from five sites that illustrate a continuum of stream quality from severely degraded (none of the predicted species present) to minimally-degraded (all of the predicted species present). Probable stressors are listed, by species, for each example site.

Figure 14-77 shows the temperature value measured at the Carroll Branch site (26 ºC), from Table 14-17, and the maximum temperature threshold for brook trout (22 ºC). This illustrates how much one stressor would need to be reduced to result in suitable conditions for one species (brook trout). This is only one of potentially many stressors at this site. In addition, this value is based on a one-time reading of temperature and additional

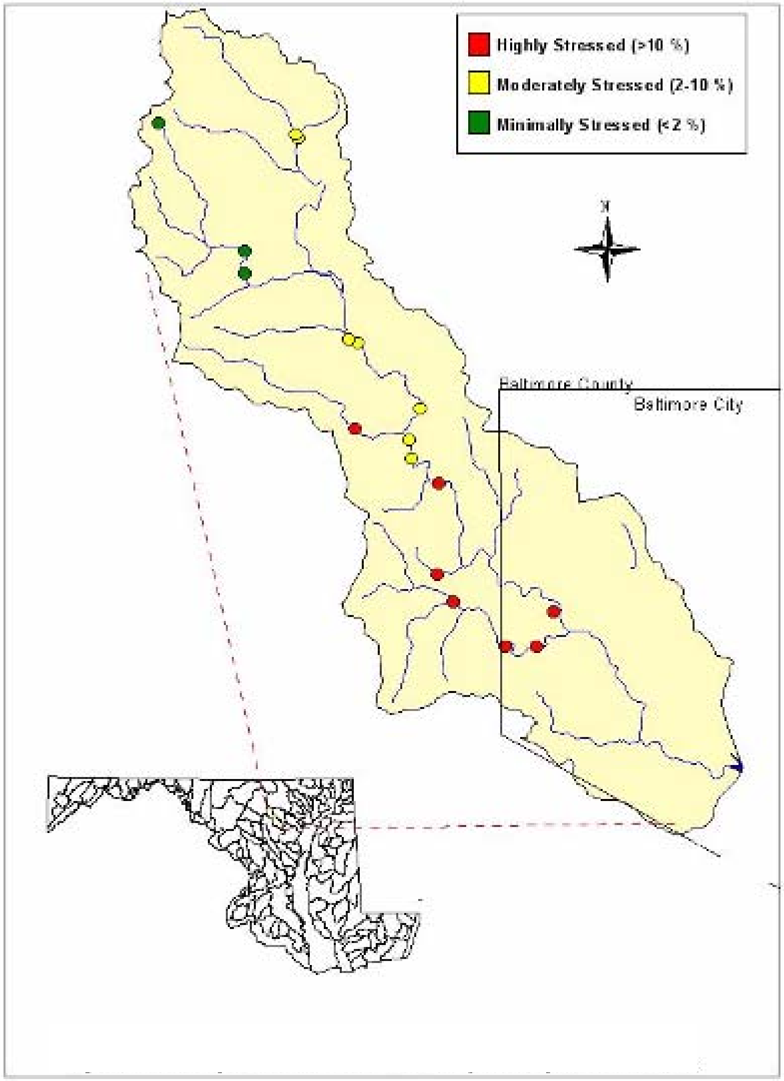


Figure 14-75. Map showing percentage of impervious surface in Gwynns Falls basin.

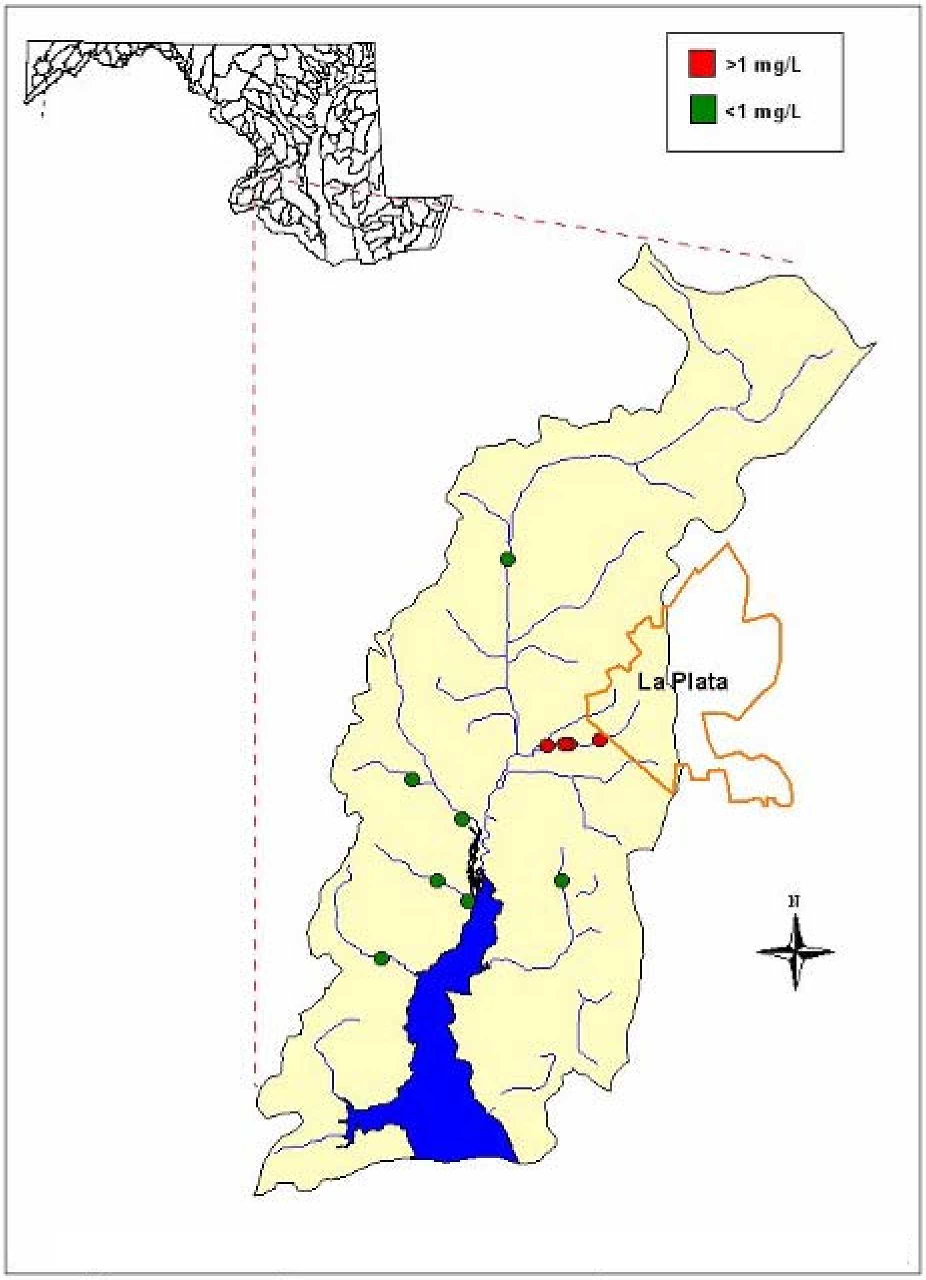


Figure 14-76. Nitrate-nitrogen concentrations at MBSS sites sampled in Port Tobacco River basin.

Table 14-17. Results from the Prediction and Diagnostic Model (Stranko et al. 2005) as applied to five sites to show a gradient of stream quality from severely degraded to minimally degraded. Probable stressors are those variables that exceeded tolerance thresholds for the species that was predicted but absent.

Stony Run, Baltimore City (0% of predicted species present).				
Species Predicted	**Species Present**	**Probable Stressors by species**		
Creek Chub		urban/impervious		
Rosyside Dace		urban/impervious	poor instream habitat	poor velocity/depth/diversity
Tessellated Darter		urban/impervious	poor instream habitat	
Woodland Creek, Kent County (29% of predicted species present)				
Species Predicted	**Species Present**	**Probable Stressors by species**		
Margined Madtom		agriculture land use		
Rosyside Dace		agriculture land use	nitrate/nitrogen	
Sea Lamprey		agriculture land use	nitrate/nitrogen	
White Sucker				
Redbreast Sunfish				
American Eel	American Eel			
Tessellated darter	Tessellated Darter			
Carroll Branch Tributary, Baltimore County (50% of predicted species present)				
Species Predicted	**Species Present**	**Probable Stressors by species**		
Brook Trout		temperature	agriculture land use	
Tessellated Darter			agriculture land use	
Blacknose Dace	Blacknose Dace			
Creek Chub	Creek Chub			
Wild Cat Branch, Montgomery County (90% of predicted species present)				
Species Predicted	**Species Present**	**Probable Stressors by species**		
Central Stoneroller				
Blacknose Dace	Blacknose Dace			
Creek Chub	Creek Chub			
Fantail Darter	Fantail Darter			
Longnose Dace	Longnose Dace			
Blueridge Sculpin	Blueridge Sculpin			
Potomac Sculpin	Potomac Sculpin			
Rosyside Dace	Rosyside Dace			
White Sucker	White Sucker			

Table 14-17. (Continued).

Principio Creek Tributary, Cecil County, Sentinel Site (100% of predicted species present)		
Species Predicted	**Species Present**	**Probable Stressors by species**
American Eel	American Eel	
Blacknose Dace	Blacknose Dace	
Creek Chub	Creek Chub	
Blueridge Sculpin	Blueridge Sculpin	
Rosyside Dace	Rosyside Dace	
Tessellated Darter	Tessellated Darter	
White Sucker	White Sucker	

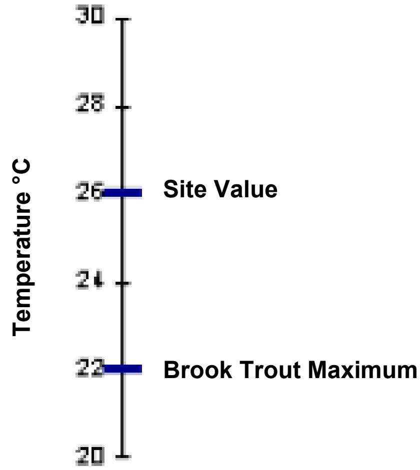


Figure 14-77. Comparison of temperature measured at Carroll Branch site and the maximum temperature threshold for brook trout.

measurements at this site would likely reveal even higher readings.

Figure 14-78 shows the percentage of impervious land cover in the catchment draining to the MBSS Sentinel site on a tributary to Principio Creek. The maximum tolerance thresholds to impervious land cover are shown for each of the species that were present at this site. In this relatively small (726 acre) basin, 400 acres of low-density residential development (0.5 to 5 acre plots) or 130 acres of high density residential (8 dwelling units per acre) or commercial land would likely result in a percentage of impervious land cover that exceeds the maximum threshold for the blueridge sculpin at this site. According to the thresholds for impervious land cover, as documented from MBSS, if the majority of the basin were converted to low-density residential land use, the entire assemblage would likely be lost. A much lower amount of high-density residential or commercial development (300 acres) would eliminate all of the species from this stream.

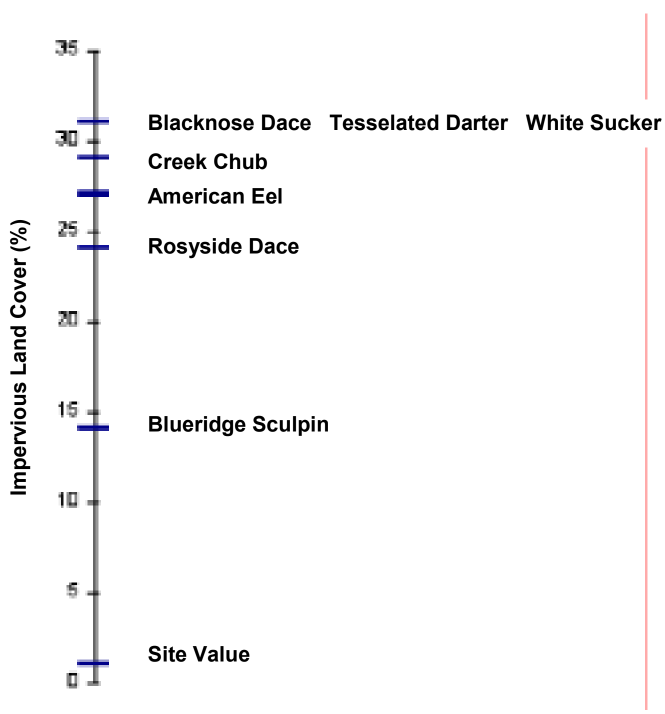


Figure 14-78. Comparison of the percentage of impervious land cover at Sentinel site on a tributary to Principio Creek and maximum tolerance thresholds of species present.

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ATTACHMENT B

K&A Staff Resumes

MARK S. KIESER
SENIOR SCIENTIST

AREAS OF EXPERTISE
Surface Water Quality Assessment and Modeling, Water Quality Trading Policy and Program Development, Non-point Source Pollution Assessment and Modeling, Lake and Watershed Management, Ecological Modeling and Restoration, NPDES Permitting, Waste Load Allocations, TMDL Development, Sediment-Water Interactions

EDUCATION
Master of Science, Biological Sciences (Emphasis: Water Resources)
Michigan Technological University, Houghton, Michigan (1988)

Bachelor of Science, Biological Sciences (Emphasis: Aquatic Ecology)
Wittenberg University, Springfield, Ohio (1982)

SELECTED WATER QUALITY PROJECT EXPERIENCE:
Development of a Water Quality Trading Framework for Ontario's Largest In-land Waterbody, Lake Simcoe: XCG Consultants and Lake Simcoe Conservation Authority, Ontario, Canada, 2012-present.

Development of California's First Water Quality Trading Program for Municipal Wastewater Treatment Facilities, Urban Stormwater and Agriculture: Sotoyome Resource Conservation District, Santa Rosa, CA through a USDA Conservation Innovation Grant, 2012-present.

Identifying Framework Elements and Credit Generating Opportunities for a Nutrient Offset Program Requirement for the City of Santa Rosa's Net-zero Discharge Requirement: City of Santa Rosa, CA, 2010-present.

Development of Watershed Payment Schemes for Cost-effective Funding Mechanisms, Quantification Protocols and Appropriate Environmental Metrics to Restore Water Quality and Quantity in the Rimac River, Lima, Peru: Swiss Development Corp. and Forest Trends, Washington, D.C., 2010-present.

Evaluation of Economic Policy Instruments for Sustainable Water Management in Europe; Case Study on the Great Miami River Water Quality Trading Program: Consortium of EU Policy Institutions under the EU Water Framework Directive, 2011-present.

Assessment of Klamath River Basin (OR, CA) Improvement and Restoration Programs for Effectiveness of Implementation using Water Quality Trading Instruments: Watercourse Engineering and Pacificorp, Davis, CA, 2010-present.

Development of the World's Largest Multi-state Water Quality Trading Program for the Ohio River Basin: Electric Power Research Institute, Palo Alto, CA through a U.S. EPA Targeted Watershed Grant, 2009-present.

Assessment of Market Mechanisms for the 12,100 mi^2 Klamath River Basin (CA/OR) to Address Nutrient, Temperature and Dissolved Oxygen TMDLs: Pacificorp through Watercourse Engineering, Davis, CA, 2011-present.

Assessment of Recent Septic System to Sewer Projects for Water Quality Trading Credits in the Upper Clark Fork River, MT: City of Missoula, MT through Morrison-Maierle, Inc., 2011-present.

Comprehensive Phosphorus and Water Quality Monitoring of Morrow Lake, Kalamazoo River to Assess Phosphorus Re-suspension and Summer-time Sourcing of Nutrients Related to Aquatic Plant and Algal Growths: Forum of Greater Kalamazoo, Kalamazoo, MI with Funding from an MDEQ Innovative Monitoring Research Grant (prepared by K&A), 2010-present.

Assessment of Wetland Nutrient Removal Capabilities in Three Tennessee Watersheds for Water Quality Trading Credit Offset Potential with Applied Ecological Services: The Nature Conservancy, Knoxville, TN with a USEPA Targeted Watershed Grant, 2010-present.

Development of the first Multi-state Water Quality Trading Program for the Ohio River Basin: Electric Power Research Institute, Palo Alto, CA through a $1M EPA Targeted Watershed Grant, 2009-present.

Coupling Market Infrastructure with Ecosystem Service Markets in an Initial Framework Scoping for an Ohio River Credit Trading Program focused on Carbon and Water Quality: Electric Power Research Institute, Palo Alto, CA through a $300K USDA Conservation Innovation Grant, 2009-2011.

Assessment of Storwmater Loading Reductions for Western Michigan University's TMDL Compliance and Offset Needs to become "Stormwater Neutral": WMU through a State of Michigan Clean Michigan Initiative Grant, Kalamazoo, MI, 2009-present.

Water Quality Trading Feasibility Analysis for the 33,000 mi^2 Wabash River Watershed in Ohio, Indiana and Illinois: Conservation Technology Innovation Center, Purdue University, Lafayette, IN through an EPA Targeted Watershed Grant, 2009-present.

Technical Review of Montana Department of Environmental Quality's Draft Water Quality Trading Policy to Meet Nutrient Criteria: MDEQ, Helena, MT, 2009-2010.

Feasibility Study of Water Quality Trading in the Lake Simcoe Watershed, Ontario, Canada with XCG Consultants: Ontario Ministry of the Environment, 2009-2010.

Design and Construction of a 2-stage Urban Stormwater Treatment System for a large Sub-drainage on the 250-acre Western Michigan University Campus Including Intensive Wet Weather Performance Monitoring for Water Quality Trading Credits: WMU, Kalamazoo, MI, 2009-2010.

Assessment of Channel Hydraulics and Erosion using the Soil Water & Assessment Tool (SWAT) for Hoboken Creek Phosphorus TMDL Implementation Planning: Sauk River Watershed District, MN, 2009-2010.

Urban Build-out Analyses Coupled with Non-point Source Modeling for the Black and Galien River Watersheds in Southwest Michigan: Southwest Michigan Planning Commission, Paw Paw, MI, 2009-present.

Analysis of Water Quality Trading Supply & Demand for Agriculture and POTWs in the 200,000 square mile, eight-state Ohio River Basin as the Basis for a Regional Water Quality Trading Program: Electric Power Research Institute, Palo Alto, CA, 2009-2011.

Comprehensive Feasibility Analysis and Preparation of a Coal-fired Power Plant Business Case for Regional Water Quality Trading in the Ohio River Basin: Electric Power Research Institute with Shaw Environmental, 2007-2009.

Comprehensive Workshops for Wastewater Treatment Plants and Agriculture on Water Quality Trading as a Compliance and Water Quality Improvement Tool (Troy, Ohio; Easton, Maryland; Sherrodsville, Ohio; and, Indianapolis, Indiana: Conservation Technology Innovation Center, Purdue University, Lafayette, IN through the Environmental Trading Network via a USDA Conservation Innovation Grant, 2008-2009.

Development of Administrative Infrastructure for Certifying, Aggregating and Marketing Ecosystem Service Credits in the Sauk River Watershed of Minnesota through Point Source/Non-point Source Water Quality Trading, Carbon Markets, Wetlands Banking, and Source Water Protection: Bush Foundation Grant through American Farmland Trust, Columbus, Ohio, 2008-present.

Review and Template Development of Market-based Schemes for a Water Offset Program Framework for the Water Footprint Working Group: World Wildlife Fund, UK, 2008-2009.

Evaluation of Uncertainty using Monte Carlo Statistical Analysis for Point Source and Non-point Source Credit Calculations to Assess Trading Ratios and Discount Factors in Minnesota's Draft Water Quality Trading Rules: Minnesota Pollution Control Agency, 2008-2009.

Technical and Regulatory Support to Legal Counsel for a County WWTP Client in New York regarding Long Island Sound Dissolved Oxygen Compliance with Trading Options: Hunton & Williams Law Firm, Washington, D.C., 2008.

Water Quality Trading Program Development Assistance for the Baltic States: Swedish EPA, 2008.

Agricultural WQT Credit Templates for Pennsylvania's Water Quality Trading Policy for Innovative Nutrient Management BMPs: PA Growing Greener Grant with Agflex, Inc. and American Farmland Trust, 2007-present.

Technical Assessment of the Lower Boise River Phosphorus Implementation Plan and Snake River/Hells Canyon TMDL (Idaho and Oregon) for Clean Water Act Applicability and Water Quality Trading Opportunities for Point Sources: Private Manufacturing Client, Boise, ID, 2007 -2009.

Development of a Water Quality Crediting and Trading Framework for Fine Particle Sediment Loading from Urban Stormwater in the Lake Tahoe Clarity TMDL: U.S. EPA Targeted Watershed Grant through Environmental Incentives, South Lake Tahoe, CA, 2007-2010.

Assessment of Ecosystem Service Market Potential to Address Water Quality in the Maumee River Basin and Sediment Issues in Toledo Harbor: Joyce Foundation funding to the Project Team of the Delta Institute, American Farmland Trust and Kieser & Associates, 2007-2008.

Technical Assistance for the Development of a Kalamazoo River Watershed Management Plan Integrating a Phosphorus TMDL, Sub-basin Plans and Phase II Permits: Kalamazoo River Watershed Council with Section 319 Funding, 2006-2011.

Agricultural Education and Implementation of Innovative Conservation Practice Yield Warranties with Water Quality Trading in MN, PA and Eleven Other States: Agflex, Inc. through USDA Conservation Innovation Grant Funding, 2006-present.

Development of a Water Quality Trading Registry and Administrative Tracking System for the Great Miami River Trading Program: Miami Conservancy District, Dayton, OH, 2005-present.

BMP Applications and Ecological, Streambank and Flow Restoration of Highly Impacted Urban Streams in the Context of a Watershed Management Plan and Phosphorus TMDL: Clean Michigan Initiative and CWA Section 319 Grants through the Forum of Greater Kalamazoo, 2005-present.

Framework Development of Michigan's Electronic Water Quality Trading Registry and Banking Models for Agricultural Participation in the Kalamazoo River Watershed, Michigan for a 5-year U.S.EPA Targeted Watershed Grant: Gun Lake Tribe, MI 2005-2010.

Assessment of Hydrological Conditions Influencing Lake Levels of Cedar Lake, Lake Level Augmentation Design and Development of a Watershed Management Plan: Cedar Lake Association, Inc., Greenbush, MI, 2004-present.

TMDL Implementation Plan Development, Non-point Source Modeling of Watershed Phosphorus Loading, Development of an Innovative, on-line Point Source Discharge Tracking System and Critical Evaluation of Total Phosphorus Data, Flows and Loadings for the Lake Allegan/Kalamazoo River

Watershed TMDL: Kalamazoo Foundation, Michigan Department of Environmental Quality and NPDES-permitted Dischargers, May 1998-present.

Restoring Flow Regimes through Growing Water Transactions and Market-based Approaches: Basin-wide Case Studies in the St. Joseph River (MI, IN, OH), Menomonee River (WI), Upper Cuyahoga River (OH) and the Great Miami River (IN, OH): Great Lake Protection Fund, 2005-2008.

Technical Assistance and Non-point Source (SWAT) Modeling for the Development of a Paw Paw River Watershed Management Plan: Southwest Michigan Commission with Section 319 Funding, 2005-2007.

Innovative Beach Monitoring Applications for *E. coli* in Urban Settings with Predictive Modeling Tool Development: Clean Michigan Initiative Grant through the Kalamazoo County Kalamazoo County Human Services Department, 2005-2006.

Development of an MS4 Watershed Management Plan to meet Phase II Stormwater permitting requirements and EPA Nine Elements for Approval Watershed Management Plans: Kalamazoo County through the Kalamazoo River Stormwater Working Group, 2005-2006.

Water Quality Trading Implementation Training for Region V EPA and Stakeholders in the Ohio River Basin: U.S.EPA Watershed Program Grant, 2005-2006.

Assessment of Phosphorus Impacts from Construction Runoff on Designated Use Impairment of Surface Waters in the U.S.: National Association of Home Builders, Washington, D.C., 2004-2006.

Program Development and Co-sponsorship of an EPA-funded National Conference on Trading for Land-Based Environmental Services, "Overlapping Opportunities and Challenges in Greenhouse Gasses and Water Quality": Texas A&M University, 2004-2005.

Hyperspectral Remote Sensing as an Innovative Monitoring Tool for Invasive Species and Watershed Applications: Clean Michigan Initiative Innovative Monitoring Grant through the Kalamazoo Nature Center, 2004-2005.

Preparation of the first Comprehensive Point Source/Non-point Source Water Quality Trading Feasibility Analysis based on Water Quality Standards Implementation in the Great Miami River of Ohio: Miami Conservancy District, 2004.

Technical Direction for the Development of the First Bi-state, Electronic Watershed Management Plan for Michigan and Indiana in the St. Joseph River Basin: Section 319 CWA Grant through the Friends of the St. Joe River Association, 2002-2005.

Watershed Management Planning in Two Urbanized Subwatersheds Draining to the Kalamazoo River and Development of the First of its kind, Electronically-based Watershed Management Plan: Section 319 CWA Grant through the Forum of Greater Kalamazoo, 2001-2005.

External Review of the Draft Document, "Model Sediment TMDL Protocol" Prepared by Limno-Tech, Inc.: National Association of Home Builders, 2004.

City of Portage Consolidated Drain #1 Drainage Feasibility Study Including Innovative Design and Construction of a $4.4M Regional Stormwater Treatment System Consisting of Wet Detention, Constructed Wetlands, Public Trailways, Long-term Monitoring, Educational Features and Habitat Enhancements to Support Improved Water Quality and Fisheries of Upper Portage Creek: City of Portage, MI, March 1999-2004.

Evaluation, Design and Installation of Innovative Streambank Stabilization Techniques for a Three-County Area of the Kalamazoo River Watershed through a CMI Grant: Kalamazoo County Soil Conservation District, 2001-2006.

Five-year Field and Mechanistic Modeling Evaluation of Thermal Enrichment Impacts by Urban Stormwater on Coldwater Receiving Streams: Research grant sponsored by the Water Environment Research Foundation, Alexandria, VA, 1999-2004.

U.S. Trading Applications for Use in Addressing Water Quality Issues in Japan: Department of Land, Infrastructure & Transportation, Government of Japan, 2003-2004.

Feasibility Analysis of Multiple Environmental Markets to Manage Ecosystems in the Great Lakes: Great Lakes Protection Fund, Chicago, IL, 2001-2004.

Evaluation of Conservation Development Credit Generation through Water Quality Trading to Achieve the Land Use Load Allocation in the Kalamazoo River TMDL: CH2M Hill and Enterprising Environmental Solutions with funding from the Joyce Foundation, Chicago, IL, 2001-2003.

Development of the First Academic Institution Voluntary Phase II Stormwater Permit in Michigan: Western Michigan University, 2000-2002.

Assessment of Muskegon River Watershed Stakeholder Resources for a Multi-million Dollar “River Initiative” to Implement a Model Fishery Enhancement Program: Great Lakes Fishery Trust, 2000.

Development of a Natural Features Inventory Using Thematic Satellite Imagery for Land Use/Land Cover Updates for the Davis Creek Watershed, Kalamazoo County, MI: Kalamazoo Conservation District and Michigan Department of Environmental Quality, 1999-2000.

Experimental Design and Implementation of Streambank Controls and Native Prairie Grass Plantings for Water Quality Trading Credits through Erosion Control at a 100-year old Industrial Site: Great Lakes Commission, 2000-2002.

Design and Development of an In-line Stormwater Treatment Facility for the Largest Commuter Parking Lot in the U.S. Including Native Plantings and Wetland Development: Michigan State University, Lansing, MI with URS Corporation, 2000-2001.

Water Quality Assessment, Modeling, Management and Restoration Plan Development for Numerous Michigan Lakes including: Austin and West Lakes (Portage), Woods Lake, Willow Lake, Asylum Lake and Pikes Pond (Kalamazoo), Baker Lake (Lawrence), Mirror Lake (Jackson County) and Lake Somerset (Hillsdale County) for various Lake Association and Lake Board Clients, 1992-present.

Water Quality Trading Demonstration Project for Phosphorus in the Kalamazoo River Watershed between Point and Non-point Source Dischargers: Great Lakes Protection Fund, Water Environment Research Foundation, Kalamazoo Foundation and Crown Vantage Paper Co., 1995-2001.

Development and Application of Non-point Source and Water Quality Models for a Comprehensive Walloon Lake Management Plan using intensive Lake and Tributary Monitoring Data to Protect a 4,000-acre Oligotrophic Lake: Walloon Lake Association, Petoskey, Michigan, 1986-1991.

Drogue Study in the Hudson River to Evaluate Thermal Mixing for a Waste Incinerator/Cogeneration Plant Discharge: Foster-Wheeler, Inc., Hudson Falls, New York, 1990.

Priority Pollutant Evaluation of Potomac River Basin Sediments in the Vicinity of the District of Columbia: Interstate Commission on the Potomac River Basin, Washington, D.C., 1989-1990.

NPDES Permit Monitoring and Modeling Evaluation of Water Quality Impacts from a Municipal Discharger on a Florida Stream: Florida Cities Water Company, Tampa, Florida, 1988-1990.

Evaluation of Water Quality Impacts from an NPDES Industrial Discharger on an Alabama Stream: Reynolds Metals Company, Muscle Shoals, Alabama, 1989.

Evaluation and Measurement of Atmospheric Reaeration in a Florida Stream for a NPDES Wasteload Allocation Permit Evaluation: Hillsborough Co., Florida, 1988.

Identification of 304(l) Waterbodies in Wyoming and Kentucky: U.S. EPA Monitoring and Data Support Division, Washington, D.C., 1988.

Historical Assessment of Regional Combined Sewer Overflow Control Strategy Effectiveness on Rouge River Water Quality: Wade, Trim and Associates, Inc., Taylor, Michigan, and the Southeast Michigan Council of Governments, Detroit, Michigan, 1987.

Modeling Evaluation of Chlorinated Discharger Impacts on the Aquatic Life of Delaware's Surface Waters, and Development of Chlorine Regulatory Policy Options: Delaware Department of Natural Resources and Environmental Control, Dover, Delaware, 1986-1987.

Technical Assistance in the Preparation of a Detroit River Remedial Action Plan. Southeast Michigan Council of Governments: Detroit, Michigan, 1987.

Review of Water Quality Model Inputs for Evaluation of Arlington and Alexandria WWTP's impacts on Potomac Estuary Water Quality: Metropolitan Washington Council of Governments, Washington, D.C., 1986.

NPDES Wasteload Allocation Modeling and Evaluation of Kalamazoo River Assimilative Capacity and Aquatic Weed Growth for Municipal and Industrial Dischargers: Kalamazoo River Study Group, Kalamazoo, Michigan, 1984-1987.

Mixing Zone Studies and Water Quality, Sediment, and Biotic Monitoring of the Detroit DWSD Discharge Impacts on the Detroit River: Detroit Water and Sewage District through ESE, Inc., 1984-1986.

Summarization and Evaluation of Available Data for the Upper Great Lakes Connecting Channels through Extensive Literature Reviews and Researcher Interviews: Environment Canada, Toronto, Ontario, 1984-1985.

COMMITTEES/APPOINTMENTS:

Chesapeake Fund Voluntary Nitrogen Offsite Program, Advisory Committee Member: Chesapeake Bay Foundation/World Resources Institute/Forest Trends, 2008-present.

Ecosystem Marketplace Advisory Group (http://www.ecosystemmarketplace.com/), 2009-present.

Water Quality Trading Advisory Committee for the World Resources Institute's Project/2009 Publication on "Water Quality Trading Programs: An International Overview," 2007-2008.

Planning Committee Participant & Chair of Trading Mechanics Subcommittee for the USEPA/USDA Second National Water Quality Trading Conference, Pittsburg, PA, 2006.

Invited Panel Moderator, "Interactive Dialogue with Expert Panel: Next Steps in Trading Implementation," Final Panel Discussion at the U.S.EPA, USDA, WEF, ASIWPCA National Forum on Water Quality Trading, Chicago, IL, July 22-23, 2003.
Acting Chair, Environmental Trading Network (formerly the Great Lakes Trading Network; www.envtn.org), a non-profit Clearinghouse for Water Quality Trading and Market-based Environmental Programs, 2000-present.

Member of the Technical/Capacity/Implementation Work Group for the Lake Allegan/Kalamazoo River Watershed Total Maximum Daily Load (TMDL) for Phosphorus, MDEQ Great Lakes Environmental and Assessment Section, September 1998-present.

Member of the MDEQ Surface Water Quality Division Water Quality Trading Workgroup developing a statewide trading framework for rules promulgation, 1997-1999.

Steering Committee Chair, Co-Chair for the Technical Work Group; Water Quality Trading Demonstration Project, In Partnership with the MDEQ/SWQD and The FORUM for Kalamazoo County, Kalamazoo, Michigan, 1997-2001.

SELECTED PUBLICATIONS:

Reviewed Publications:

Water-Quality Trading: A Guide for the Wastewater Community, 2005. (With Cy Jones, Lisa Bacon and David Sheridan). McGraw-Hill, ISBN: 0071464182, 250 pages.

"Revegetation of Urban, Industrial Sites Using Native Grasses and Wildflowers," (with T. Mau-Crimmins). Land & Management, Vol. 45 (6), pp. 18-24, 2002.

"Quantification of Phosphorus Limited Phytoplankton Growth in Green Bay, Lake Michigan." M.S. Thesis, Department of Biological Sciences, Michigan Technological University, Houghton, Michigan, 1988.

"Field Verification Models for Phosphorus and Phytoplankton Growth," (with M.T. Auer and R.P. Canale), Can. J. Fish Aquat. Sci., Vol. 43 (2), pp. 379-388, 1986.

Published Reports:

"Stormwater Thermal Enrichment in Urban Watersheds," (with F. Fang, J. Spoelstra and W. James). Final Report, Water Environment Research Foundation Project 00-WSM-7-UR, 2004.

"Phosphorus Credit Trading in the Kalamazoo River Basin: Forging Nontraditional Partnerships." Final Report, Water Environment Research Foundation, Project 97-IRM-5C, 2000.

"Summary of the Existing Status of the Upper Great Lakes Connecting Channels Data." Prepared for Environment Canada and the U.S. Environmental Protection Agency, March 1985.

Proceedings:

"A Preliminary Analysis of Water Quality Trading Opportunities in the Great Miami River Watershed, Ohio," (with F. Fang, D. Hall and S. Hippensteel). Proceedings of the U.S.EPA Mississippi River Basin Nutrients Science Workshop, October 4-6, 2005, St. Louis, MO.

"Preliminary Economic Analysis of Water Quality Trading Opportunities in the Great Miami River Basin, Ohio." Proceedings of the Water Environment Federation, TMLD 2005 Conference, Philadelphia, PA, June 26-29, 2005.

"Integrating Quality of Life Benefits with Urban Stormwater Management: A Successful Case Study for a Phase II Community," (with F. Feng and J. Spoelstra). Proceedings for the Water Environment Federation 2004 Watershed Conference, Dearborn, MI, July 11-14, 2004.

"Water Quality Trading in the United States-An Overview." Urban Renaissance and Watershed Management Conference, Tokyo, Japan, January 28, 2004.

“Using Conservation Development Credits to Implement the Kalamazoo TMDL Load Allocation.” Proceedings of WEFTEC 2003, with E. Bacon, C. Peluso and J. Rodgers, (CH2Mhill), and A. McElwaine, Enterprising Environmental Solutions.

Role of Urban Stormwater Best Management Practices in Temperature TMDLs,” (with F. Fang and J. Spoelstra). Proceedings of the Water Environment Federation TMDL 2003 Conference, Chicago, IL, November 16-19, 2003.

“Moving Beyond the Bells and Whistles: Implementation Plan Formulation for a Kalamazoo River/Lake Allegan TMDL.” Proceedings of the Water Environment Federation, National TMDL Science and Policy 2002 Specialty Conference, Phoenix, AZ, November 13-16, 2002.

“Water Quality Trading: Another Tool for the Watershed Tool Box,” (with F. Fang). 2002 Illinois Environmental Law Conference, Chicago, IL, August 15-16, 2002.

“Kalamazoo River Water Quality Trading Demonstration Project.” Proceedings of Workshop D: Lessons in Watershed Trading, Water Environment Federation, Watershed 2000 Conference, Vancouver, B.C., July, 2000.

“Defining Phase II Storm Water Regulation's "Maximum Extent Practicable" in Portage, Michigan,” (with V.K. Stromquist and J. Jacobson). Proceedings of the ASCE 2000 Joint Conference on Water Resources Engineering and Water Resources Planning & Management, July 2000.

“Combining Stormwater Quality with Quality of Life in Portage, Michigan,” (with V.K. Stromquist and J. Jacobson). ASCE 2000 Joint Conference on Water Resources Engineering and Water Resources Planning & Management, July 2000.

“Point/Non-point Source Water Quality Trading for Phosphorus in the Kalamazoo River Watershed: A Demonstration Project” (with D.J. Batchelor). Proceedings of Conference Workshop #115, Watershed-based Effluent Trading Demonstration Projects: Results Achieved and Lessons Learned, Water Environment Federation, 71st Annual Conference & Exposition, Orlando, FL., November 1998.

SELECTED PRESENTATIONS, SYMPOSIA AND INVITED PAPERS:

“Getting it Right: Baselines for Agricultural Non-Point Sources,” Invited Panelist; Ecosystem Markets – Making Them Work, Madison, WI, June 29-July 1, 2011.

“Case Study in the Ohio River Basin: Domestic Regulatory Watershed Market at Scale,” Invited Workshop Speaker for a Pre-Conference Academy Session on Ecosystem Services, Part III: Policy to Practice, Annual Meeting of the Consultative Group on Biological Diversity, “Creating a Recipe for Relevance in a Changed World,” Whitefish, MT, June 6-9, 2011.

“Water Quality Credit Trading in the U.S.,” Invited Workshop Presenter for Conference, “Numeric Nutrient Criteria Implementation: Toward Understanding the Options in WI, FL and other States,” National Council for Air & Stream Improvement May 17, 2011.

“National Regulatory Agency Trends for Nutrient Trading” and “Considerations for Estimating N and P Loading from Septic Systems for Water Quality Trading Credits,” Invited Speaker for the Nutrient Trading Training Workshop, MT Department of Environmental Quality, Helena, MT, April 13-14, 2011.

“Innovation, Technology & Research…Emerging Water Markets for Agriculture,” Invited Speaker, National Agricultural Landscapes Forum, Washington, D.C., April 7-8, 2011.

“Innovative Experiences with River Contamination in the United States,” Invited Speaker to the Symposium on Natural Environmental & Water Management in Latin American Cities, Sponsored by the Public Water Supply and Sanitation Company of Quito, November 25-27, 2010, Quito, Ecuador.

“Water Quality Trading in the Ohio River Basin as a Future Compliance Tool,” Ohio Water Environment Association Annual Meeting, Blue Ash, KY, November 18, 2010.

“Water Quality Trading Applications in the U.S.,” Illinois Association of Wastewater Agencies, Starved Rock State Park, Utica, IL, November 12, 2010.

“Emerging Markets and Market-like approaches for Water,” CARBON TradeEx AMERICA, Chicago, IL, September 28, 2010.

“Ohio River Water Quality Trading Project: Engaging Agriculture,” Ohio Agricultural Stakeholders Meeting, July 6, 2010.

“Emerging Markets and Market-like Approaches to Watershed Quality,” Invited Speaker for Katoomba XVII – Hanoi, Taking the Lead: Payments for Ecosystem Services in Southeast Asia, Hanoi, Vietnam, June 23-24, 2010.

“Ohio River Water Quality Trading Project Overview,” Presentation to the ORB Sub-basin Steering Committee to the Gulf Hypoxia Task Force. Cincinnati, OH, June 3, 2010.

“Water Quality Trading in the U.S. & New Opportunities in the Ohio River Basin,” Wastewater Industrial Technical Training Education Conference (WITEC), Greenwood, IN, April 14, 2010.

“Water Quality Trading 101: Improving Conservation & Agricultural Economics with Water Quality Trading,” American Farmland Trust Listening Session, March 8-9, 2010.

“Water Quality Trading: An Opportunity for Overcoming Trans-boundary Issues.” Invited Speaker for the Canadian Water Resources Association – Ontario Winter Workshop, Burlington, Ontario, February 5, 2010.

“Nutrient Trading as a Means of Lowering Costs: Experiences from the U.S.,” USEPA’s POTW Nutrient Reduction and Efficiency Conference, Evansville, Indiana, January 14, 2010.

“Review of Water Quality Trading Experiences from the US: What have we learned?” Invited Speaker for Economic Instruments to support water policy in Europe – Paving the way for Research and Future Development, European Workshop Organized by Office National de l'Eau et des Milieux Aquatiques / French National Agency for Water and Aquatic Ecosystems, Paris, France, December 9-10, 2009.

“Water Quality Trading Past & Present: Is there a Future?”, Invited Workshop Speaker, 17th National Nonpoint Source Monitoring Workshop; Reducing Nutrients and Documenting Results, New Orleans, LA, September 16, 2009.

“The Ohio River Basin Project – Trading at a Regional Scale” and “Where Can I Trade Today?” Invited Workshop Speaker, National Council for Air and Stream Improvement, Inc., IN: *Water Quality Credit Trading: What is it? Why should I be interested?* Stevens Point, Wisconsin, May 19, 2009.

“Regional Water Quality Trading Program for Nutrients in the Ohio River Basin.” 2009 Ohio Stormwater Conference, Mason, Ohio, May 14, 2009.

“No More Waiting: the First Multi-state Water Quality Trading Program for the Ohio River Basin.” New & Emerging Markets, 2009 National Mitigation & Ecosystem Banking Conference, Salt Lake City, UT, May 7, 2009.

“Water Quality Trading in the U.S.: Program Examples and Considerations.” Invited Speaker at Conference on Trading in the Baltic States, Stockholm, Sweden, September 23, 2008.

"Global Overview of Payments for Watershed Services" and "Key Challenges to Efficient & Equitable PWS Schemes: How Should the Market Deal be Structured?" Invited speaker and panelist at the Global Katoomba Meetings – East Africa, Dar es Salom and Morogoro, Tanzania, September, 2008.

Invited panelist on the "Water Panel" at the Global Katoomba Meeting, Water Markets Session, Washington, DC, June 9-10, 2008.

Invited panelist at the Environmental Law Institute Annual 2007 Policy Forum for "Ecosystem Services: Is there a business case for environmental protection?" Washington D.C., November, 2007.

"Market-based Trading Applications for Environmental Restoration and Preservation." Invited Speaker at the Symposium, "Smart Ecosystem Restoration for Tomorrow's Delaware Estuary: Natural Capital Values, Cost-Benefit Tradeoffs, and Regional Coordination to Maximize Environmental Outcomes along Ecological Trajectories," Academy of Natural Sciences, Philadelphia PA, September 25, 2007.

"Regional Water Quality Trading Opportunities in the Mississippi River Basin." Philanthropy Roundtable's "Markets to Improve Water Quality," Jackson Lake Lodge, Moran, WY, July 10-11, 2007.

"Market-based Incentives to Improve Water Quality: Trading Program Examples." Invited Speaker at the State of MN Water Quality Trading Rule Development Advisory Committee, April 17, 2007.

"Ecosystem Service Markets: Strategies for Sustaining Clean & Abundant Water." Invited Speaker and Panelist at Duke University's conference on "The Future of Water in North Carolina," March 1, 2007.

"Market-based Incentives to Improve Water Quality; Water Quality Credit Trading for Michigan Agriculture." Invited Speaker at the "Agriculture's Conference on the Environment: Managing Today for Tomorrow," Lansing, MI, February, 2007.

"Water Quality Trading Infrastructure and Banking Instruments for the Kalamazoo River Watershed, State of Michigan and U.S. EPA." Presented at the AWRA Annual Water Resources Conference in Baltimore, Maryland, November 6-9, 2006.

"Water Quality Trading as a Tool for Water Resources Management: Hype, Hysteria or Helpful? Invited Keynote Speaker at the Annual Water Resources Joint Conference, Earle Brown Heritage Center, Brooklyn Center, Minnesota, October 24, 2006.

"Water Quality Trading: A National Perspective…Where have we been & where are we going?" Invited Speaker at the West Virginia Water Conference Sponsored by West Virginia University, Roanoke, WV, October 10, 2006.

"Opportunities in Water Quality Trading: New Technologies & Credit Quantification Tools." Invited Speaker at the Environmental Trading Congress - Strategies for Succeeding in the Environmental Financial Markets. Financial Research Associates, LLC, The New York Helmsley Hotel, Midtown Manhattan, NY, July 25, 2006.

"Developing Watershed Payments." Invited Speaker at the Portand Katoomba Event, "Making the Priceless Valuable: Jumpstarting Environmental Markets," World Forestry Center, Portland, OR, June 8, 2006.

Water Quality Trading: Moving from Disharmony to Harmony...are we really there yet? Invited Speaker and Panelist, Portland Katoomba Workshop on "Water Quality Markets & Practice: The Willamette Basin," Jean Vollum Natural Capital Center, Portland, OR, June 9, 2006.

"Preliminary Analysis of Water Quality Trading Opportunities in the Great Miami River Watershed, OH." USEPA/USDA Second National Water Quality Trading Conference, Pittsburg, PA, May 23, 2006.

“Water Quality Trading and Conservation Markets in the U.S.” Invited Speaker and Panelist at the Defenders of Wildlife Conservation Markets Roundtable on “The Ins and Outs of Conservation Markets: Beginning to Answer the Tough Questions,” Willamette University, Salem, OR, May 5, 2006.

“Designing Effluent Trading Programs and U.S. Case Studies.” Invited Speaker and Panelist for “A Symposium on Servicing Development within the Lake Simcoe Watershed,” Sponsored by the York Region, Kingbridge Center, King City, ON, April 3, 2006.

Moderator and Presenter on, “The State of Water Quality Trading.” Workshop on “Environmental Credits Generated through Land-Use Changes: Challenges and Approaches,” with the Environmental Trading Network and Texas A&M University, Baltimore, MD, March 8-9, 2006.

“How Water Quality Trading Works for Agriculture.” Invited Speaker at the “Trading Water Quality Credits in the Upper Midwest Workshop,” Sponsored by the MN Cooperative Development Services, Roseville, Roseville, MN, December 8, 2005.

“Economic Analysis of Water Quality Trading Opportunities in the Great Miami River Basin, Ohio.” U.S.EPA Mississippi River Basin Nutrients Science Workshop, St. Louis, MO, October 6, 2005.

“Water Quality Trading in the U.S. - An Overview**.”** Invited Presentation at the Workshop on Water Quality Trading in Canada, La Grange de la Gatineau, Cantley, Québec, September 19-20, 2005.

Invited Participant IN: “Biophysical and Geochemical Considerations in the Development of Water Quality Trading to Address Agricultural Sources of Pollution in Canada: An expert “think tank.” Hosted by Agriculture and Agri-food Canada (AAFC), and the Policy Research Initiative (PRI), Les Suites Hotel, Ottawa, May 27, 2005.

“Restoring Flow Regimes and Ecosystems in the Great Lakes Through Environmental Markets,” (with S. Apfelbaum and G. Kelly). Presented at the 8th National Mitigation & Conservation Banking Conference, Charlotte, NC, April 21, 2005.

“Conservation Practices as Commodities: A New Era for Financing Agricultural Operations through Voluntary Water Quality Trading Programs.” Invited Presentation at the 2004 West Virginia Conservation Partnership Conference, Charleston, WV, October 26-28, 2004.

“Market-based Environmental Approaches for Agriculture.” Invited Presentation by the Friends of the Potomac for the Potomac Highlands Environmental Markets Workshop, Moorefield WV, March 29, 2004.

“Water Quality Trading: Restoration Methods at Banks to Enhance Water Quality Benefits.” Presented at the 7th National Mitigation & Conservation Banking Conference, New Orleans, LA March 3-5, 2004.

“Economic and Environmental Benefits of Water Quality Trading.” Invited Speaker and Panelist for the Urban Renaissance and Watershed Management Conference, Tokyo and Otsu, Japan, January 28 & February 3, 2004.

“Role of Urban Stormwater Best Management Practices in Temperature TMDLs.” WEF TMDL 2003 Conference, Chicago, IL, November 19, 2003.

“Market Approaches for Environmental Improvements: ***Opportunities*** in the Great Lakes Region and Beyond.” Friends of the Potomac, Environmental Markets in the Potomac Basin Working Forum, September 16-17, 2003, Rockwood Manor Park, Potomac, Maryland.

“Looking Ahead: Trading Opportunities and Next Steps.” Panel Moderation for Interactive Dialogue with Expert Panel: Next Steps in Trading Implementation, First Annual U.S.EPA Sponsored Forum on Water Quality Trading. July 22-23, 2003.

“Market Opportunities to Achieve Water Quality Goals through Watershed Commodities.” Presented to the Colonial Soil & Water Conservation District Stakeholder Workshop, Williamsburg, VA, April 30, 2003.

“Ecosystem Multiple Markets: The Next Generation of Ecological Restoration and Management.” 6th National Mitigation & Conservation Banking Conference, San Diego, CA, April 23-25, 2003.

“Water Quality Trading…from the local level to the broader ecosystem: A tool to achieve environmental improvements.” Presented at the World Resources Institute Press Conference for Release of “Awakening the ‘Dead Zone’: An investment for agriculture, water quality, and climate change.” Minneapolis, MN, March 6, 2003.

“Markets to Achieve Environmental Improvements: Successful Applications and Opportunities for Agriculture.” Invited Presentation to USDA-NRCS and U.S.EPA Office of Water, Washington, D.C., December 20, 2002.

“Markets to Achieve Environmental Improvements: Controversy or Common Sense.” Invited presentation at the World Watershed Summit, America’s Clean Water Foundation, Washington, D.C., October 30 - November 1, 2002.

“Watershed-based trading in the Midwest.” Invited presentation to the Department of Agricultural and Resource Economics, and the Regional Research Institute, West Virginia University, Morgantown, WV, October 18, 2002.

“Stormwater Thermal Enrichment in Urban Watersheds - Turn Down the Heat!” Invited presentation at Workshop #W111, Tools for Weathering the Storm: Stormwater Management, Water Environment Federation, WEFTEC 2002, Chicago, IL, September 28, 2002.

“Water Quality Trading: Another Tool for the Watershed Tool Box.” Invited presentation for the 2002 Illinois Environmental Law Conference, Chicago, IL, August 15-16, 2002.

“Developing Markets to Manage Ecosystems.” Invited presentation at the 5th National Wetlands Mitigation Banking Conference, Washington, D.C., February 27 - March 1, 2002.

“Transitioning to Statewide Trading Rules and a Phosphorus TMDL: The Kalamazoo River Trading Experience.” Presented in the Workshop on Incentives for Watershed Action: Environmental Credit Trading Before, During and After TMDLs, Water Environmental Federation, Watershed 2002 Conference, Fort Lauderdale, FL, February 24-27, 2002.

“Water Quality as a Commodity? The Shift to Market-based Incentives for Environmental Improvements.” Presented at the Conference on Working Landscapes in the Midwest: Creating Sustainable Futures for Agriculture, Forestry and Communities, Institute for Agriculture and Trade Policies, Delevan, WI, November 8-9, 2001.

“New Approaches for the Future: Water Quality Trading…The Kalamazoo River Demonstration as a Voluntary, Community-based Project.” Invited Presentation at the Great Lakes Trading Network Conference on ‘Markets for the New Millennium – How Can Water Quality Trading Work for You,? May 18-19, 2000, Chicago, IL.

“Watershed Changes & Implementation Issues - A Perspective from the Muskegon River Initiative Assessment.” Invited presentation at the Muskegon River Specialty Conference sponsored by the Great Lakes Fishery Trust and the Wege Foundation, Muskegon, MI, August 24, 2000.

“Thermal Enrichment: A Critical Design Criterion for Protecting and Restoring Cold Water Habitats in North Temperate Climates,” (with M. Crimmins and J. Jacobson). Presented at the 1999 North American Lake Management Society Meetings, December 1-4, 1999.

“Water Quality Trading...Uncommon Partnerships to Achieve Common Water Quality Objectives: The Kalamazoo River Demonstration.” Invited speaker for the 1999 Central-Lake States Regional Meeting of NCASI, Kalamazoo, MI, May 19-20, 1999.

“Point/Non-point Source Water Quality Trading for Phosphorus in the Kalamazoo River Watershed: A Demonstration Project.” Invited speaker for Conference Workshop #115, Watershed-based Effluent Trading Demonstration Projects: Results Achieved and Lessons Learned,” Water Environment Federation, 71st Annual Conference & Exposition, Orlando, FL., November 1998.

“The Kalamazoo River Water Quality Trading Demonstration Project - Forging Non-traditional Partnerships to Achieve Economic and Environmental Benefits.” Invited speaker at the conference on ‘Keeping It on the Land...and Out of the Water, Soil Erosion and Sediment Control Opportunities for the Great Lakes Basin,’ Sponsored by the Great Lakes Commission, Toledo, Ohio, September 16-18, 1998.

“Water Quality Trading in Michigan - Kalamazoo River.” Invited speaker for the Agricultural Water Quality Conference Sponsored by MI Farm Bureau, MI Department of Agriculture, MI Agri-Business Association, MI Association of Timberman, Lansing, Michigan, February 3, 1998.

“When to Cut Your Losses: the Saga of a High Quality Lake Turned Sour with Sweet Corn Silage,” (with M.L. Storey). Presented at the NALMS 16th International Symposium, North American Lake Management Society, Minneapolis, MN, November, 1996.

“Restoration Feasibility for a Stormwater-impacted Urban Lake.” (with M.L. Storey). Presented at the NALMS 16th International Symposium, North American Lake Management Society, Minneapolis, Minnesota, November, 1996.

“An Interactive Nonpoint Source Loading Model for Lake Management.” (with D.W. Dilks, P.W. Rodgers, G. Sommerville, and D. Heidtke). Presented at the 9th International Symposium on Lake and Reservoir Management, North American Lake Management Society, Austin, Texas, November 7-11, 1989.

“Development and Application of a Lake Management Model for Assessing Nonpoint Source Impacts.” (with D.W. Dilks, T.A. Slawecki, and P.W. Rodgers). Presented at the 9th International Symposium on Lake and Reservoir Management, North American Lake Management Society, Austin, Texas, November 7-11, 1989.

“Walloon Lake Management Initiatives.” Invited Speaker, North American Lake Management Society, Michigan Chapter, 1st Annual Conference, Central Michigan University, Mt. Pleasant, Michigan, May 5, 1989.

“Sampling in Support of Toxic Waste Load Allocation Models.” Invited Speaker, Toxics Modeling Workshop, U.S. EPA Region III, Philadelphia, Pennsylvania, September 26-28, 1988.

“Walloon Lake Water Quality Studies: Proactive Lake Management,” (with P.W. Rodgers, D.W. Dilks, D. Heidtke). Presented at the 7th International Symposium, North American Lake Management Society, Orlando, Florida, November 3-7, 1987.

“Kalamazoo River Studies: A Comprehensive Modeling Evaluation of Environmental vs. Wastewater Loading Impacts on Water Quality,” (with P.W. Rodgers, P.L. Freedman, J.K. Marr, B. Minsley). Presented at the 60th Annual Conference, Water Pollution Control Federation, Philadelphia, Pennsylvania, October 4-7, 1987.

“Water Quality Problems in the Kalamazoo River: Causes and Cures,” (with P.W. Rodgers, P.L. Freedman, J.K. Marr) Presented at the 1986 NCASI Central-Lake States Regional Meeting, Rosemont, Illinois, September 15-17, 1986.

"The Role of Sediment Phosphorus Release in the Phosphorus Budget of Green Bay, Lake Michigan," (with M.T. Auer and R.P. Canale). Presented at the Forty-eighth Annual Meeting of the American Society of Limnology and Oceanography, Minneapolis, Minnesota, June, 1985.

"Sediment Phosphorus Release in Green Bay, Lake Michigan," (with M.T. Auer). Presented at the 28th Conference on Great Lakes Research, University of Wisconsin-Milwaukee, June 3-5, 1985.

"The Role of Internal Phosphorus Pool Size in Regulating Primary Production in Green Bay (Lake Michigan)," (with M. T. Auer, and A. K. Barth). Presented at the Forty-seventh Annual Meeting of the American Society of Limnology and Oceanography, Vancouver, British Columbia, June 11-14, 1984.

"Field Verification Models for Phosphorus and Phytoplankton Growth," (with M.T. Auer, and R. P. Canale). Presented at the Annual Meeting of the International Association for Great Lakes Research, Twenty-seventh Conference on Great Lakes Research, St. Catherine's, Ontario, April 29-May 3, 1984.

"Estimation of Primary Production and Internal Carbon Loading for Green Bay (Lake Michigan)," (with M. T. Auer, and A. K. Barth). Presented at the Annual Meeting of the International Association for Great Lakes Research, Twenty-seventh Conference on Great Lakes Research, St. Catherine's, Ontario, April 29-May 3, 1984.

"ANDREW" FENG FANG, PH.D., P.E.
PROJECT ENGINEER

AREAS OF EXPERTISE

Surface Water Quality Modeling, Nonpoint Source Watershed Modeling, Environmental Chemistry, Environmental Economics, Market-based Environmental Resources Management

EDUCATION

Doctor of Philosophy, Water Resources Science
University of Minnesota, Minneapolis-St. Paul, Minnesota (2002)

Master of Science, Applied Economics
University of Minnesota, Minneapolis-St. Paul, Minnesota (2002)

Master of Science, Ecology and Environmental Science
University of Maine, Orono, Maine (1997)

Bachelor of Science, Environmental Engineering
Shanghai University, Shanghai, China (1994)

PROFESSIONAL CERTIFICATION

Licensed Professional Engineer, State of Oklahoma

SELECTED EXPERIENCE

Kieser & Associates, LLC:

Preliminary Analysis of Watershed Modeling Needs for a Payment for Watershed Services Scheme in Beijing, China: Forest Trends, Washington, D.C., 2012-present.

Analysis of Agriculture Field Nutrient Loss Data for Assessing Water Quality Trading Credit Options from Precision Agriculture: American Farmland Trust, Washington, D.C. through a USDA Conservation Innovation Grant, 2012-present.

Assessment of Urban Stormwater Loads and Offset Needs for a Nutrient TMDL in the Laguna de Santa Rosa for Water Quality Trading Program Development: Sotoyome Resource Conservation District, Santa Rosa, CA through a USDA Conservation Innovation Grant, 2012-present.

Development of Statistical Models to Predict Inland Lake Swimming Beach *E. Coli* Concentrations Based on Readily Available Environmental and Metrological Observations: Kalamazoo County Health & Human Services, Kalamazoo, MI, 2005-2006.

Investigation of Groundwater-fed Lake Hydrology to Maintain Target Water Levels, Including Piezometer Installation and Data Analysis: Cedar Lake Association, Greenbush, MI, 2005-2006.

Development and Application of Infrastructure for a Model Trading Registry and Agricultural Participation in the Kalamazoo River Watershed, Michigan: Gun Lake Tribe, Door, MI through a U.S. EPA Targeted Watershed Grant, 2005-2006.

Assessment of Programmatic Options for Restoring Flow Regimes through Growing Water Transactions in Basin-wide Case Studies: Great Lake Protection Fund, Chicago, IL, 2003-2006.

Management and Statistical Analysis of Landfill Groundwater Monitoring Data, Including Field Sampling and Establishing New Pollutant Tolerance Limits for Environmental Compliance: Graphic Packaging, Kalamazoo, MI, 2002-2006.

Generation and Analysis of GIS Data Layers for Watershed Management Applications for the St. Joe River Watershed Management Plan: Friends of the St. Joe River Association, Inc., South Bend, IN, 2002-2006.

Assessment of Phosphorus Impacts from Construction Runoff on Designated Use Impairment of Surface Waters: U.S. National Association of Home Builders, Washington, D.C., 2004-2005

Preliminary Economic Analysis for Development of a Point Source/Nonpoint Source Water Quality Trading Program and Assessment of BMP Efficiency and Program Implementation in the Great Miami River, Ohio: Miami Conservancy District, Dayton, OH, 2004-2005.

Soil and Water Assessment Tool (SWAT) Modeling of the St. Joseph River Basin for Sediment, Phosphorus, and Atrazine: Friends of the St. Joe River Association, Inc., South Bend, IN through the St. Joseph River 319 Watershed Management Plan Project, 2003-2005.

Evaluation of Thermal Enrichment Impacts by Urban Stormwater on a Coldwater Receiving Stream in Portage, MI: Water Environmental Research Foundation, Alexandria, VA, Kalamazoo Community Foundation, Kalamazoo, MI, and the City of Portage, MI, 2002-2004.

Critical Evaluation of Total Phosphorus Data, Flows and Loadings for the Lake Allegan/Kalamazoo River Watershed TMDL: Menasha Corporation, Paperboard Division, Ostego, MI, 2002-2004.

Concept Development of Environmental Multiple Markets for Ecosystem Management: Funded by the Great Lakes Protection Fund, 2002-2003.

Conservation Development Credit Generation through Water Quality Trading to Achieve the Land Use Load Allocation in the Kalamazoo River TMDL: CH2M Hill, Milwaukee, WI and Enterprising Environmental Solutions, Harrisburg, PA through Funding from the Joyce Foundation, Chicago IL, 2001-2003.

Oklahoma DEQ:

Conducted Watershed Stakeholder Meetings for Input to TMDL Projects, 2011-2012.

Led Oklahoma's Inter-Agency TMDL Workgroup, Hosting Quarterly Meetings and Coordinating TMDL Related Monitoring and Water Quality Assessment Work among Five State Agencies and Two Regional Inter-Governmental Organizations, 2009-2012.

Development of U.S. EPA Funded Watershed Modeling and Monitoring Projects, 2007-2012.

Management of TMDL Development Projects for the State of Oklahoma, Including Contract Negotiation, Technical Work Plan Development and Technical Quality Control, 2006-2012.

Development of U.S. EPA Approved Nutrients, Bacteria, and Turbidity TMDLs for Oklahoma State, 2006-2012.

Development of Watershed Hydrology and Water Quality Models (e.g., HSPF and SWAT) for Water Quality Protection Evaluation and TMDL Development, 2006-2012.

Application of Stream Water Quality Models to Determine Wastewater Discharge Limits, 2006-2012.

Conducted Regulatory Review of Wastewater and Stormwater Treatment Designs, 2006-2012.

Participation in the Development and Revision of Oklahoma State Water Quality Standards and Regulations, 2006-2012.

The Metropolitan Council, MN:

Analysis of GIS Data Layers for the Natural Resources Inventory of the Twin Cities, MN, 2001.

Review of the Report on the Potential Impact of Infiltrated Stormwater on Groundwater Quality in Urban Areas, MN, 2001.

Research:

Conducted Cost-effectiveness Analysis for the Phosphorus Water Quality Trading Program in the Minnesota River Basin: MS Thesis Research, University of Minnesota, Minneapolis-St. Paul, MN, 2001-2002.

Lab and Field Research on Watershed Nonpoint Source Pollution Control with a Focus on the Fate and Transport of Phosphorus in the Minnesota River Basin; Links between Soil Characteristics and the Release of Phosphorus from Farmland Soil to Runoff: PhD Dissertation Research, University of Minnesota, Minneapolis-St. Paul, MN, 1997-2001.

Critically Examined the Economic and Environmental Consequences of World Bank-supported On-site Sanitation Projects by Interviewing Task Managers and Reviewing Various Bank Internal Reports: The World Bank, Washington D.C., Summer 1998.

Research on the Transport and Fate of Organic Pollutants such as PAHs and Pesticides, and their Interaction with Natural Organic Matter by the Fluorescence Spectroscopy Technique: MS Thesis Research, University of Maine, Orono, ME, 1995-1996.

PREVIOUS EMPLOYMENT

Professional Engineer III (2006-2012)
Oklahoma Department of Environmental Quality, Oklahoma City, Oklahoma

Project Scientist (2002-2006)
Kieser & Associates, Kalamazoo, Michigan

Intern (2001-2002)
Metropolitan Council, St. Paul, Minnesota

Intern (1998)
The World Bank, Washington D.C.

Research Assistant (1997-2001)
Water Resources Center, University of Minnesota, Minneapolis-St. Paul, Minnesota

Teaching Assistant (1997-2001)
Depts. of Civil and Environmental Engineering and Applied Economics, University of Minnesota, Minneapolis-St. Paul, Minnesota

SELECTED PUBLICATIONS AND PROCEEDINGS

"Point-nonpoint source water quality trading in the Minnesota River Basin: A cost-effectiveness analysis," (with K.W. Easter and P.L Brezonik), Journal of American Water Resources Association, Vol. 41, pp. 645-658, 2005.

"Characterization of soil algal bioavailable phosphorus in the Minnesota River Basin," (with P.L. Brezonik, K.J. Mulla, and L.K. Hatch), Soil Science Society of America Journal, Vol. 69, No. 4, pp. 1016-1025, 2005.

"A Preliminary Analysis of Water Quality Trading Opportunities in the Great Miami River Watershed, Ohio," (with M. Kieser, N. Ott, D. Hall, and S. Hippensteel), Proceedings of the Third Conference on Watershed Management to Meet Water Quality Standards and Emerging TMDL, Atlanta, GA, March 5-9, 2005.

Stormwater Thermal Enrichment in Urban Watersheds, (with M. Kieser and J. Spoelstra), Final Report, Water Environment Research Foundation, Project 00-WSM-7-UR, Water Environmental Research Foundation, Alexandria, Virginia, IWA Publishing, London, U.K., 2004.

"Integrating Quality of Life Benefits with Urban Stormwater Management: A Successful Case Study for a Phase II Community," (with M. Kieser and J. Spoelstra), Proceedings of the Water Environment Federation 2004 Watershed Conference, Dearborn, MI, July 11-14, 2004.

"Role of Urban Stormwater Best Management Practices in Temperature TMDLs," (with M.S. Kieser and J.A. Spoelstra), Proceedings of the Water Environment Foundation National TMDL Science and Policy Conference, Chicago, IL, November 19, 2003.

"Pollution Trading to Offset New Pollutant Loadings – A Case Study in the Minnesota River Basin" (with K.W. Easter), Proceedings of American Agricultural Economics Association Annual Meeting, Montreal, Canada, July 29, 2003.

"Estimating runoff phosphorus losses from calcareous soils in the Minnesota River Basin," (with P.L. Brezonik, D.J. Mulla, and L.K. Hatch), Journal of Environmental Quality, Vol. 31, pp. 1918-1929, 2002.

On-site Sanitation: An International Review of World Bank Experience, UNDP – World Bank Regional Water and Sanitation Group-South Asia, New Delhi, India, July 1999.

"A spectrofluorimetric study of the binding of carbofuran, carbaryl, and aldicarb with dissolved organic matter" (with S. Kanan, H.H. Patterson, C.S. Cronan), Analytica Chimica Acta, Vol. 373, Issues 2-3, pp. 139-151, November 11, 1998.

"Enhancement of the Water Solubility of Organic Pollutants such as Pyrene by Dissolved Organic Matter," (with H.H. Patterson, B. MacDonald, and C. Cronan), *Humic and Fulvic Acids: Isolation, Structure, and Environmental Role*, Eds. J.S. Gaffney, N.A. Marley, and S.B. Clark, Washington, D.C.: American Chemical Society, Vol. 651, pp. 288-298, Print, November 14, 1996.

"Use of fluorescence polarization to probe the structure and aluminum complexation of three molecular weight fractions of a soil fulvic acid," (with S. Lakshman, R. Mills, H. Patterson, and C. Cronan), Analytica Chimica Acta, Vol. 321, Issue 1, pp. 113-119, March 8, 1996.

SELECTED PRESENTATIONS, SYMPOSIA AND INVITED PAPERS

"Biophysical Aspects of Water Insecurity in the Miyun Watershed," Panel Moderator, Katoomba XVIII: Forests, Water, and People, Beijing, China, May 17, 2013.

"The Total Maximum Daily Load Program in the U.S.," Invited Speaker, Institute for Resources, Environment and Sustainability, University of British Columbia, Vancouver, Canada, March 28, 2013.

"TMDL and the Stormwater Permit Program in the U.S.," Invited Foreign Expert seminar, Shanghai Academy of Environmental Sciences, Shanghai, China, May 30, 2011.

"Nutrient TMDLs for Reservoirs with Limited Data," (with M. Derichsweiler, J. Patek and M. Suarez), Speaker, Annual Symposium of the North America Lake Management Society, Oklahoma City, OK, November 2010.

"Water Quality Modeling in the U.S.," Invited Foreign Expert seminar, Shanghai Academy of Environmental Sciences, Shanghai, China, August, 2009.

"Water Quality Trading in the United States – An Overview," (with M. Kieser), Invited Speaker, Urban Renaissance and Watershed Management Conference, Tokyo, Japan, January 28, 2004.

"Role of Urban Stormwater Best Management Practices in Temperature TMDLs," (with M. Kieser and J. Spoelstra), Speaker, Water Environment Federation TMDL 2003 Conference, Chicago, IL, November 19, 2003.

"Pollution Trading to Offset New Pollutant Loadings – A Case Study in the Minnesota River Basin," (with K.W. Easter), Speaker, American Agricultural Economics Association Annual Meeting, Montreal, Canada, July 29-31, 2003.

"Water Quality Trading: Another Tool for the Watershed Tool Box," (with M. Kieser), Invited Speaker, 2002 Illinois Environmental Conference, Chicago, IL, August 2002.

"Role of River Suspended Sediment in Phosphorus Transport," Speaker, The Eighth Biennial Minnesota Water Conference, St. Cloud, MN, April 2002.

"Algal Bioavailability of Phosphorus and Soil Phosphorus Sorption Capacity in the Minnesota River Basin," Speaker, Annual Meeting of Soil Science Society of America, Minneapolis, MN, November 2000.

"Runoff Phosphorus Losses in the Minnesota River Basin," Speaker, Annual Meeting of the American Chemical Society, Washington DC, August 2000.

JAMES A. KLANG, P.E.
SENIOR PROJECT ENGINEER

AREAS OF EXPERTISE
Watershed Planning, Total Maximum Daily Load (TMDL) Studies, Best Management Practices, Nonpoint Source and Surface Water Quality Assessment, Water Quality Trading, Wastewater Treatment Facility Planning and Design, NPDES Permitting, Urban Stormwater Planning

EDUCATION
Bachelor of Science, Civil Engineering
Colorado State University, Fort Collins, Colorado (1981)

CERTIFICATIONS
Licensed Professional Engineer, State of Minnesota

SELECTED K&A EXPERIENCE
Water Quality Trading Feasibility Assessment and Program Framework Development for Non-point Source Trading of Bacteria and Sediments between Urban Stormwater and Animal Agriculture: Moody County Conservation District, Flandreau, SD with a USDA Conservation Innovation Grant, 2012-present.

Development of Protocol for Using Terrain Analysis and other Spatial Analysis Tools to Identify Priority Agricultural Sites for BMP Implementation: Barr Engineering and the University of Minnesota, Minneapolis, MN through a MN Department of Agriculture Grant, 2012-present.

Evaluation of the Feasibility for a National Row Crop Certification Program Regarding Corn and Soybean Supply Chains for Food Manufactures: Gold’n Plump Chicken and Environmental Initiatives, Minneapolis, MN, 2012-present.

Development of Technical Briefs to Assess the Potential Cost-Effectiveness of Agricultural Drainage Water Management for Nitrate Loss Reductions with Water Quality Trading Applications: Agri Drain Corporation, Adair, IA, 2012-present.

Development of a Water Quality Trading Framework for Ontario’s Largest Inland Waterbody, Lake Simcoe: XCG Consultants and Lake Simcoe Conservation Authority, Ontario, Canada, 2012-present.

Evaluation and Development of a Water Quality Trading Nutrient Reduction Credit Methodology for Precision Agriculture Variable Rate Technology in the Midwest: American Farmland Trust, Washington, D.C. through a USDA Conservation Innovation Grant, 2012-present.

Evaluation of Sediment Reduction Efficiencies for Best Management Practices (BMPs) on Flood-irrigated Lands in Idaho for Water Quality Offsets: Confidential Client, 2012-present.

Identification of Priority Management Zones (PMZs) for Upland BMP Implementation in Impaired Watersheds of MN: Barr Engineering and the University of Minnesota, Minneapolis, MN through a MN Department of Agriculture Grant, 2011-present.

Identification of and Regulatory Approval for Credit Generating Opportunities for a Nutrient Offset Program Requirement for the City of Santa Rosa’s Net-zero Discharge Requirement: City of Santa Rosa, CA, 2010-present.

Development of the World’s Largest Multi-state Water Quality Trading Program for the Ohio River Basin: Electric Power Research Institute, Palo Alto, CA through a U.S. EPA Targeted Watershed Grant, 2009-2012.

Assessment of NPDES Permitting Requirements for a Surface Water Discharge from a Food Processing Facility in Southwest Michigan: Honee Bear Canning Corporation, Lawton, MI, 2007-present.

Development of a Water Quality Trading Registry and Administrative Tracking System for the Great Miami River Trading Program: Miami Conservancy District, Dayton, OH, 2006-present.

Assessment of Wetland Nutrient Removal Capabilities in Three Tennessee Watersheds for Water Quality Trading Credit Potential with Applied Ecological Services: The Nature Conservancy, Knoxville, TN through a U.S. EPA Targeted Watershed Grant, 2010-2012.

Development of Administrative Infrastructure for Certifying, Aggregating and Marketing Ecosystem Service Credits in Three Large Minnesota Watersheds through Point Source/Nonpoint Source Water Quality Trading, Carbon Markets, Wetlands Banking, and Source Water Protection: American Farmland Trust, Columbus, OH, through a Bush Foundation Grant and MN River Basin Joint Powers Board USDA, Mankato, MN through a Conservation Innovation Grants, 2008-2012.

Water Quality Trading Feasibility Analysis for the 33,000 mi^2 Wabash River Watershed in Indiana and Illinois: Conservation Technology Innovation Center, Purdue University, West Lafayette, IN through a U.S. EPA Targeted Watershed Grant, 2009-2011.

Assessment of Field-scale and Watershed Models to Reduce Uncertainty and Improve Ecological Effectiveness of Water Quality Trading Programs: Evaluation of the Nutrient Trading Tool and the Watershed Analysis Risk Management Framework. Electric Power Research Institute, Palo Alto, CA, 2009-2011.

Assessment of Channel Hydraulics and Erosion Using the Soil Water & Assessment Tool (SWAT) for Hoboken Creek Phosphorus TMDL Implementation Planning and Water Quality Trading Options: Sauk River Watershed District, MN, 2009-2011.

Agricultural Credit Templates for Pennsylvania’s Water Quality Trading Policy for Innovative Nutrient Management BMPs: Agflex, Inc., Madison, WI and American Farmland Trust, Washington, D.C. through a PA Growing Greener Grant, 2008-2011.

Review and Assessment of the MPCA Nutrient and Total Suspended Solids Water Quality Standard Development: Scott County Watershed Management Organization, Scott County, MN, 2011.

Feasibility Study of Water Quality Trading in the Lake Simcoe Watershed, Ontario, Canada with XCG Consultants: Ontario Ministry of the Environment, Toronto, Ontario, Canada, 2009-2010.

Point Source Participation Presentations in Comprehensive Workshops for Wastewater Treatment Plants and Agriculture on Water Quality Trading as a Compliance and Water Quality Improvement Tool (Troy, Ohio; Easton, MD; Sherrodsville, OH; and Indianapolis, IN): Conservation Technology Innovation Center, Purdue University, West Lafayette, IN through the Environmental Trading Network via a USDA Conservation Innovation Grant, 2008-2010.

Identifying and Quantifying Critical Factors for a Scientifically Defensible Process for the Exchange of Pollutant Credits under Minnesota’s Proposed Water Quality Trading Rules in Support of MPCA Water Quality Trading Rule Development: Minnesota Pollution Control Agency, St. Paul, MN, 2008-2009.

Technical Support for Statement of Needs and Reasonableness (SONAR) Documentation Supporting the State of Minnesota Water Quality Trading Credit Definitions and Estimation Protocols: Minnesota Pollution Control Agency, St. Paul, MN 2008-2009.

Development of a Water Quality Crediting and Trading Framework for Fine Particle Sediment Loading from Urban Stormwater in the Lake Tahoe Clarity TMDL: U.S. EPA Targeted Watershed Grant through Environmental Incentives, South Lake Tahoe, CA, 2007-2010.

Nonpoint Source Modeling of the Kalamazoo River Watershed for the Development of a Watershed Management Plan through a CWA Section 319 Planning Grant: Kalamazoo River Watershed Council, Kalamazoo, MI, 2007-2010.

Engineering Design for Streambank Restoration and Stormwater Infiltration BMPs for Urban Runoff in a Highly Impaired Coolwater Stream in Southwest Michigan: FORUM of Greater Kalamazoo, Kalamazoo, MI through a Clean Michigan Initiative Grant, 2007-2010.

Facilitating Watershed Management with Agricultural Nonpoint Source BMP Implementation through Market-based Incentives and Watershed Permits using Water Quality Trading and the "BMP Challenge": with Agflex, Inc., Madison, WI and American Farmland Trust, Washington, D.C. through a USDA-NRCS Conservation Innovation Grant, 2006-2010.

Development of Credit Estimation and Tracking Tools for Water Quality Trading in the Kalamazoo River Phosphorus TMDL and for Michigan's Trading Rules: Gun Lake Tribe, Dorr, MI through a U.S. EPA Targeted Watershed Grant, 2006-2010.

Comprehensive Feasibility Analysis and Preparation of a Coal-fired Power Plant Business Case for Regional Water Quality Trading in the Ohio River Basin: Electric Power Research Institute, Palo Alto, CA with Shaw Environmental, Bothell, WA, 2007-2009.

Technical Assessment of the Lower Boise River Phosphorus Implementation Plan and Snake River/Hells Canyon TMDL (Idaho and Oregon) for Clean Water Act Applicability and Water Quality Trading Opportunities for Point Sources: Private Manufacturing Client, Boise, ID, 2007-2009.

Technical and Regulatory Support to Legal Counsel for a County WWTP Client in New York Regarding Connecticut Long Island Sound Dissolved Oxygen Compliance with Trading Options: Hunton & Williams, Washington, D.C., 2008.

Nonpoint Source Loading Estimates for a Future Build-out Analysis based on Township Zoning in the Paw Paw River Watershed of Michigan: Southwest Michigan Planning Commission, Benton Harbor, MI through a CWA Section 319 Planning Grant, 2007-2008.

SELECTED PREVIOUS EMPLOYMENT

Minnesota Pollution Control Agency: Twenty-one years of experience working with watershed issues covering all aspects of pollutant source identification, source control, watershed modeling and assessment, watershed and TMDL program and protocol development, technical and regulatory implementation of Clean Water Act authorized programs such as the National Pollution Discharge Elimination System (NPDES) permit program, Section 319 (nonpoint source grant program), Section 208 nonpoint source planning requirements, and Section 303(d) (required listing of impaired water activities). Key programs, projects and assignments included the following.

TMDL Principal Engineer (2005-2006). Led the State of Minnesota TMDL protocol development for turbidity, dissolved oxygen, lake eutrophication and bacteria impairments. Developed TMDL activity guidance regarding development, internal review and state approval administration. Served as MPCA's technical representative and/or lead on over twenty TMDLs. Notable project involvement included:

- Editor and lead engineer for the development of the Low Flow Dissolved Oxygen TMDL Protocol. Provided guidance for practitioners in the State of Minnesota regarding tools and evaluation techniques available to conduct an adequate stressor identification process and water quality sampling program to define sources, parameters of concern, goals and physical extent of impaired reaches.

- Co-author of the Minnesota River Summer Low Flow Dissolved Oxygen TMDL. Coordinated technical requirements for wasteload and load allocations across the 12,000 square mile watershed with approximately 150 NPDES-permitted wastewater facilities.

- Technical lead for the Minnesota River Basin General Phosphorus Permit – Phase I. This permit accelerated the implementation of the Summer Low Flow Dissolved Oxygen TMDL by providing financial and scheduling flexibility via a watershed permit that allowed for point source-point source water quality trading.

- Participated on the Lake Pepin Nutrient TMDL and supported the Mississippi River and Minnesota River Turbidity TMDLs. Involvement included technical committees and public meetings addressing turbidity issues in the mainstem of the two rivers and the related Lake Pepin eutrophication impairment from a watershed covering over 50 percent of the State and portions of Wisconsin, Iowa, and North and South Dakota.

- Technical support on the Turbidity TMDL protocol team developing guidance for proper goal-setting techniques based on magnitude, duration and frequency of events. Was tasked with providing guidance to address the significant variability between turbidity meters and historic monitoring plans.

Best Management Practice Senior Engineer (1991-2004). This position assisted in the facilitation of watershed-based approaches for protection and restoration of Minnesota's vast water resources. Work responsibilities included landuse and water quality assessments to support project managers developing implementation plans for Minnesota's Clean Water Partnership grant program, Basin Planning efforts and early TMDL study activities. The process included providing technical guidance on over fifty watershed assessment efforts for voluntary programs, basin-planning efforts in four major basins, and initiation of the TMDL activities in late 2004. In addition, this position responded to inter and intra-agency supporting guidance development to coordinate and integrate the many watershed programs operating in the state. Notable projects included:

- Minnesota River Assessment Project. This six-year study conducted an extensive evaluation of the physical, chemical and biological conditions existing in the Minnesota River Basin. The MPCA report included an assessment of the source types, loading and restoration options, as well as the inherent physical and non-anthropogenic pollutant loadings.

- Development of the sediment and nutrient reduction estimate tracking system for the Minnesota Board of Water and Soil Resources program Landuse Annual Reporting System (LARS). This later evolved into eLINK, a web-based tracking system that provided additional spatial information via a GIS-based platform for facilitating reporting and tracking requirements for all state-run conservation BMP grant programs.

- Detailed assessment of phosphorus sources to Minnesota watersheds. Provided agricultural and rural non-agricultural review and input on evaluation and assessment quantification of phosphorus sources and loading for the nine major watersheds in Minnesota.

- Represented the Minnesota Pollution Control Agency on the University of Minnesota-led Minnesota Phosphorus Index (MN P-Index) development. The MN P-Index provides a repeatable and scientifically-based agricultural and water quality evaluation of the sensitivity and BMP potential for whole farm planning efforts. This tool uses commonly gathered farm planning information and agronomic inputs to assist farmers and planners in targeting the higher priority fields and evaluating BMP selection options. The tool is used in targeting, education and selection reporting efforts increasing the understanding of field-to-field variability while expanding the BMP menu based on treatment reduction efficiencies.

- Water quality trading permit engineer for nonpoint source crediting and NPDES permit compliance requirements for the Rahr Malting and Southern Minnesota Beet Sugar Cooperative point to nonpoint source offset trading. Authored the Rahr Malting water quality-trading permit; the first of its kind in the nation that is still successfully in compliance today. Wrote the Southern Minnesota Beet Sugar Cooperative permit that similarly allows the co-op to remain in compliance in an allocation-limited watershed.

Solid Waste Landfill Permit Senior Engineer (1990-1991). Work tasks included implementation of regulatory rules and guidance for permitted solid waste landfills and superfund sites across the State of Minnesota. Specific tasks included site investigations, plan and specification review, financial assurance requirements for over sixty operating and closed landfills including three of the largest permitted landfills in the State (Pine Bend, McLeod County, and Anoka County).

Special Projects Senior Engineer (1989-1990). Supported technical review engineers permitting WWTPs by developing the Minnesota Water Balance Test for waste stabilization ponds. Provided technical support for emerging de-chlorination requirements, and difficult projects that were experiencing regulatory and approval compliance issues during the construction process.

Staff Engineer (1985-1989). Worked within the Construction Grants Program conducting review and approval of municipal wastewater treatment plant facility planning, plan and specification development, operation and maintenance planning and construction inspections. Work tasks included review of over 60 projects including waste stabilization ponds, community infiltration mound systems, infiltration basins, oxidation ditches, and conventional activated sludge facilities ranging in size from 50,000 gallons per day up to 10 million gallons per day in municipal and industrial influent.

Additional duties from 1986-1990 included development, coordination, review and approval of Landfill Leachate additions to NPDES permitted WWTPs. Provided protocol development and administration of over 30 requests to dispose of solid waste facility leachate by discharging into municipal or industrial wastewater treatment plants. Assessed risk of plant upset, acute and chronic toxicity standards compliance, and safety issues for NPDES permitted facilities.

COMMITTEES AND APPOINTMENTS

"Nation Network for Consistency and Integrity in Water Quality Trading," Leadership Team Member: World Resources Institute, Washington, D.C. and the Willamette Partnership, Portland, OR, 2012-present.

"Conservation Marketplace Midwest," Board Member: Minnesota River Board, Mankato, MN, 2012-present.

SELECTED PUBLICATIONS

"Evaluation of a GIS-based watershed modeling approach for sediment transport," (with V. Nangia and P. Wymar), International Journal of Agricultural and Biological Engineering, Vol. 3, No. 3, 2010.

SELECTED PRESENTATIONS AND INVITED PAPERS

"Conservation Marketplace: Surviving Beyond Pilots with Voluntary and Visionary Market Demand," Invited Speaker, ACES and Environmental Markets 2012: Where Buyers are Coming to the Market, Fort Lauderdale, FL, December 14, 2012.

"Restored Wetlands and Water Quality Trading in Western Tennessee," Speaker, U.S. EPA Region IV Webcast, November 16, 2012.

"Wabash River Watershed Water Quality Trading Feasibility Study," Invited Speaker, IN WEA Watershed Conference, Lafayette, IN, September 20, 2012.

"Regulatory/Legal Update, Mississippi River Basin," Invited Speaker, US Poultry and Egg Association Environmental Management Seminar, Nashville, TN, March 7, 2012.

"Wabash River Watershed Water Quality Trading Feasibility Study," Speaker, U.S. EPA Webcast, January 31, 2012.

"Water Quality Trading as a Compliance Tool," Speaker, KY/TN WEA Watershed Conference, Louisville KY, January 25, 2012.

"Strategies for Attainable Water Quality Standards," Invited Speaker, MN Association of Soil and Water Conservation Districts Annual Conference, Minneapolis, MN, December 5, 2011.

“Water Quality Trading,” Invited Speaker, National Council for Air and Stream Improvements Workshop, Stevens Point, WI, May 17, 2011.

“Conservation Marketplace of Minnesota Credit Valuation and Stacking,” Speaker, Community of Ecosystem Services (ACES) Conference, Phoenix, AZ, December 6-9, 2010.

“Water Quality Trading,” Invited Speaker, Agren Sponsored Information Session for the Raccoon River, IA Community, August 12, 2010.

“Conservation Marketplace of Minnesota, a Regional Approach to Ecosystem Service Markets,” Panelist, SWCS Annual Conference, St. Louis, MO, July 18-21, 2010.

“Conservation Marketplace of Minnesota,” Invited Speaker, Ecosystem Markets: Making Them Work Conference, Raleigh-Durham, NC, June 2010.

“Conservation Marketplace of Minnesota,” Invited Speaker, National Mitigation and Ecosystem Banking Conference, Austin, TX, May 2010.

“Water Quality Trading, a Minnesota Perspective,” Invited Keynote Speaker, Fox Wolf Watershed Alliance Stormwater Conference, March 2009.

“Water Quality Trading – Watershed Based Examples in Minnesota,” Invited Speaker, MPCA Lake Pepin TMDL 2008 Policy Forum, Red Wing, MN, April 2008.

“Market-based Examples for Agricultural Conservation,” Invited Speaker, Rural Advantage’s Producer Educational Seminars, Faribault, MN, March 24, 2008.

“Water Quality Trading 101,” Agflex Training Seminar for the BMP Challenge and WQT, New Ulm, Alexandria, Redwood Falls, and Owatana, MN, January-December 2007.

“Water Quality Trading,” Invited Expert Panelist, Minnesota Association of Watershed Districts Annual Conference, Alexandria, MN, November 30, 2007.

“Watershed Implementation Strategies: Emerging Policies and Programs in Use Across the Country,” Invited Speaker, Fourth Annual Watershed Planning Conference, Milwaukee, WI, April 24, 2007.

Training Workshop on Water Quality Trading, Invited Speaker, Region V Training Conference, Environmental Trading Network, Cincinnati, OH, August 22-24, 2006.

“The State of Trading-Water Quality,” Invited Speaker, U.S. EPA-funded National Conference on Trading for Land-Based Environmental Services: Overlapping Opportunities and Challenges in Greenhouse Gasses and Water Quality, Baltimore, MD, March 8-9, 2006.

“How Water Quality Trading Works for Agriculture,” Invited Speaker, Trading Water Quality Credits in the Upper Midwest Conference, Minnesota Cooperative Development Services, Roseville, MN, December 8, 2005.

“Minnesota River Watershed Model and TMDL,” (with J. B. Butcher and H. Munir), Presented Paper, WEFTEC, 2004.

“Point-Nonpoint Trading in Minnesota,” Invited Speaker, U.S. EPA Innovations Symposium, Kansas City, MO, December 7, 2000.

Rahr Malting Pollutant Trading, Invited Speaker, Watershed Heroes Field Training Symposium, American Farm Bureau Sponsored, Amana, IA, June 5-7, 2000.

PATTY HOCH-MELLUISH
PROJECT SCIENTIST

AREAS OF EXPERTISE
Watershed Management, Comprehensive Lake Studies, Surface Water Quality Modeling, Wetland Evaluations, Streambank/Lakeshore/Wetland Restoration with Native Plantings, Watershed-scale Pollutant Loading Analysis

EDUCATION
Master of Science, Water Resources Science
University of Minnesota, St. Paul, Minnesota (1997)

Bachelor of Science, Biology
Western Michigan University, Kalamazoo, Michigan (1989)

CONTINUING EDUCATION
- 3rd Annual Shoreline and Shallows Conference, "Natural Shorelines and Habitat Connection, Michigan State University, East Lansing, MI, March 6, 2013.
- Natural Shoreline Maintenance and Native Plant ID Trainings, Michigan Natural Shoreline Professional, Kensington Metropark, Brighton, MI, July 18, 2012.
- 2nd Annual Shoreline and Shallows Conference: "Climate Change and Lakeshore Landscaping," Michigan State University, East Lansing, MI, March 7, 2012.
Annual Conference, Michigan Chapter of the North American Lake Management Society, Tustin, MI, September 23, 2011.
- Encapsulated Soil Lift Training, Michigan Natural Shoreline Professional, Kellogg Biological Station, Gull Lake, MI, July 14, 2011.
- Annual Conference, Midwest Aquatic Plant Management Society, Grand Rapids, MI, February 28-March 1, 2011. Michigan Natural Shoreline Professional Training, Michigan State University Extension, Brighton, MI, February 22-24, 2011.
- "Developing and Communicating Experimental Tools for Restoration of Midwestern Prairie-Savanna Landscapes," W.K. Biological Station, Hickory Corners, MI, May 8-9, 2002.
- The Practice of Restoring Native Ecosystems National Conference, Arbor Day Farm, Nebraska City, NE, November 6-7, 2001.
- "Creating and Using Wetlands for Wastewater and Stormwater Treatment and Water Quality Improvement," University of Wisconsin, Madison, WI, April 26-28, 1999.
- "Constructed Wetlands for Wastewater Treatment," Michigan State University, East Lansing, MI, March 9, 1999.

SELECTED EXPERIENCE
- Native Lakeshore Design: Walton Property, Indian Lake, Vicksburg, MI, September 2012.
- Stormwater Treatment Cell Native Plant Design: Kalamazoo Valley Community College, Kalamazoo, MI, August 2012.
- Stormwater Treatment Cell Native Plant Design Howard Street and Stadium Drive: Western Michigan University and the City of Kalamazoo, Kalamazoo, MI, 2011
- Water Quality Study: Lake Somerset Property Owner's Association, Somerset Center, MI, May-September 2011.
- Annual Aquatic Plant Management Study: Lake Somerset Property Owner's Association, Somerset Center, MI, 2007-2011.
- Watershed Determination and Vegetation Survey for Treating Stormwater to Arcadia Creek, Kalamazoo, MI: Western Michigan University, Kalamazoo, MI and Michigan Department of Environmental Quality, Lansing, MI, through a Clean Michigan Initiative Grant, 2010.
- Design of Treatment Pond Native Plants, Lot 23: Western Michigan University, Kalamazoo, MI, May 2009.
- Streambank and Stormwater Treatment Cell Native Plant Design: Milham Park and Loy Norrix High School, Kalamazoo, MI and Michigan Department of Environmental Quality, Lansing, MI through a Clean Michigan Initiative Grant:, 2008.
- Aquatic Vegetation Study at Asylum Lake: Western Michigan University, Kalamazoo, MI, April 2008.
- Streambank Native Plant Design for Stormwater Project: Kalamazoo Christian High School, Kalamazoo, MI

through a Clean Michigan Initiative Grant, 2007.
- Comprehensive Lake Management Study: Lake Somerset Property Owner's Association, Somerset Center, MI, September 2004-2006.
- Comprehensive Lake Management Study: Mirror Lake Association, Jackson, MI, June 2003-June 2004.
- Assessment and Seasonal Surveys of Streambank Controls and Native Prairie Grass Plantings for Erosion Control at the Graphic Packaging Corporation Site, Kalamazoo, MI: Great Lakes Commission, Kalamazoo Conservation District, MI, 2002-2004.
- Streambank and Prairie Native Plant Design for Kalamazoo Water Reclamation Plant Streambank Stabilization Project: Kalamazoo Conservation District, Kalamazoo, MI through a Clean Michigan Initiative Grant, June 2002-2004.
- Evaluation of Water Quality and Biota on the Rocky River at Three Rivers, MI: St. Joseph County Conservation District, Centerville, MI and Michigan Department of Environmental Quality, Lansing, MI through 319 Watershed Funding, December 2002-June 2004.
- Riparian Zone Native Planting Project: Woods Lake Association, Kalamazoo, MI, August 2002-September 2003.
- Rain Garden Design: Maple Street School and the City of Kalamazoo, Kalamazoo, MI, August 2003.
- Evaluation of Thermal Enrichment Impacts by Urban Stormwater on Biota in Coldwater Receiving Streams: Water Environment Research Foundation Sponsored Research, Washington, D.C., 1999-2003.
- Design of Native Wetland Plantings in an Innovative Stormwater Treatment System on Woods Lake, MI: Woods Lake Association, Kalamazoo, MI, 1998-2003.
- Comprehensive Study of Pike's Pond for Determination of Future Management Options Including Stormwater, Aquatic Vegetation and Riparian Zone Options: Pike's Pond Association, Kalamazoo, MI, February-December 2002.
- Vegetation and Erosion Survey of Riparian Areas along Portage, Arcadia and Axtell Creek Watersheds: Michigan Department of Environmental Quality, Lansing, MI through a 319 Funded Grant, 2001-2002.
- Conceptual Design and Development of an In-line Stormwater Treatment Facility for the Largest Commuter Parking Lot in the U.S. including Native Plantings and Wetland Development, Michigan State University, Lansing, MI: URS Corporation, San Francisco, CA, 2000- 2001.
- Assessment of Stormwater Impacts on Willow Lake Water Quality Using GIS-based Pollutant Loading Models, Remotely Sensed Data and Field Studies: Parkview Hills Association, Kalamazoo, MI, 1999-2001.
- City of Portage Consolidated Drain #1 Drainage Feasibility Study Including Innovative Design and Construction of a Regional Stormwater Treatment System Consisting of Wet Detention, Constructed Wetlands, Public Trailways, Educational Features and Habitat Enhancements to Support Improved Water Quality and Fisheries of Upper Portage Creek: City of Portage, MI, March 1999-2000.
- Wetland Delineation and Design of Treatment Wetland for Regional Stormwater Treatment Facility: City of Portage, MI, September 1999-2000.
- Evaluation of Feasibility of Created Wetlands for Treating Stormwater Runoff in Woods Lake: City of Kalamazoo and Woods Lake Association, Kalamazoo, MI, November 1998-2000.
- Evaluation of Feasibility of Regional Stormwater Treatment Facility Using Wetpond/Wetland Complex: City of Portage, MI, February-September 1999.
- Preparation and Review of Annual Watershed Management Plans Considering Future Land-use Changes in the Watershed: Rice Creek and Shingle Creek Watershed Districts, Minneapolis/St. Paul, MN, 1997.
- Determination of Annual Pollutant Loads Using Modeling Software: Rice Creek and Shingle Creek Watershed Districts: Minneapolis/St. Paul, MN, 1997.
- Evaluation of Options for Phosphorus Inactivation for Centerville Lake: St. Paul, MN, 1997.
- Implementation of Sediment Toxicity Program, Including Methods Development and Organism Culture: Battelle Great Lakes Environmental Center, Traverse City, MI, 1990-1992.
- Fish Entrainment Studies for FERC Relicensing of Hydroelectric Facilities: Howard Energy, Alpena, MI, 1990-1992.

SELECTED PUBLICATIONS, PROCEEDINGS, AND PUBLISHED REPORTS

- "More than just pretty flowers—The scientific argument for naturalizing lake shorelines," (with J. McCarthy and J. Allerhand), The Michigan Riparian, Vol. 47, No. 4, pp. 22-23, Fall 2012.
- "The Cedar Lake Watershed Study-An In-Depth (and Underground) Look at Complex Lake Management Issues," (with B. Boyer, J. McCarthy and M. Kieser), The Michigan Riparian, Vol. 47, No. 1, pp. 24-28, 2012.
- "A Framework for Assessing the Effects of Urbanization on the Twin Cities Metropolitan Area Rivers and Streams," M.S. Project, Water Resources Science Department, University of Minnesota, St. Paul, MN, 1997.

ATTACHMENT C

Versar Staff Resumes

Name & Title: **Mark T. Southerland, PhD, Director**
Project Assignment: **Contract Manager and Technical Leader for Watershed Assessments and Restoration Plans**
Year Experience: With this Firm: **20** *With Others:* **12**

Education (degree(s)/year/specialization) and Registrations:
Smithsonian Fellow, Smithsonian Environmental Research Center, 1986
Ph.D., Biology (Ecology), University of North Carolina at Chapel Hill, 1985
B.A., Zoology, Pomona College, CA, 1977
Project Management Professional (#331205)
Certified Senior Ecologist, ESA

Relevant Experience and Qualifications:
Dr. Southerland has 32 years of research and management experience directed at the characterization of natural systems, both terrestrial and aquatic, and their response to environmental stress and perturbations. Specific areas of expertise include NPDES stormwater compliance, watershed analysis and natural resources planning, freshwater and terrestrial monitoring programs, environmental impact assessment, ecosystem and habitat restoration, ecological policy development, water quality standards and criteria, and biodiversity conservation. Since joining Versar, Dr. Southerland has provided expert scientific and policy support to the Council on Environmental Quality (CEQ), U.S. Environmental Protection Agency (EPA), Department of Defense (DOD), Department of Interior (DOI), Federal Energy Regulatory Commission (FERC), Maryland Departments of Natural Resources (DNR) and Environment (MDE), New York State Department of Environmental Conservation (NYSDEC), and many local governments. He is currently Director of Ecological Sciences and Applications for Versar. He was the primary author of U.S. EPA programmatic guidance for biological criteria in surface waters and is the lead consultant to the Maryland Biological Stream Survey (MBSS). Dr. Southerland is also a national expert on NEPA analysis, representing CEQ across the country. In 1994, Ray Clark, Acting Chairman of CEQ, called Dr. Southerland "a true national asset." He is currently the Chair of the Maryland Water Monitoring Council, past co-chair of the Howard County Commission on Environmental Sustainability, member of Maryland Academy of Sciences' Scientific and Educational Advisory Board, and an Adjunct Professor at Frostburg State University.

Dr. Southerland is the past project manager for Versar's Frederick County NPDES Stormwater contract, a position he also held on similar contracts with Anne Arundel, Arlington, Harford, and Howard Counties. His national reputation in water resources management and his intimate familiarity with Frederick County and Maryland State programs make him the ideal choice to serve as a Technical Leader on this contract.

Watershed Planning and Stormwater Management - Since 1993, Dr. Southerland has been involved in U.S. Army Corps of Engineers reconnaissance and feasibility studies for environmental restoration of the Susquehanna River, Delaware River, Anacostia River, and Barnegat Bay watersheds. For these studies, Dr. Southerland developed innovative watershed analysis and planning methods for the Philadelphia, Baltimore, Norfolk, and Pittsburgh Districts. Dr. Southerland received commendations from both the Baltimore and Philadelphia Districts for his innovative watershed restoration planning work. Dr. Southerland has also developed watershed plans to address stream degradation and stormwater issues at federal installations such as Fort Lee, VA.

Dr. Southerland has been applying his innovative watershed planning approaches to NPDES stormwater compliance contracts with Anne Arundel, Baltimore, Frederick, Howard, and Montgomery Counties in Maryland, and Fairfax and Loudoun Counties in Virginia. He has successfully completed all phases of these studies, from problem identification to restoration site selection, prioritization of opportunities, concept designs, cost-benefit analyses, and project construction. The $1M Fairfax County comprehensive watershed management plan for Cameron Run included extensive public involvement, intensive SWMM and HEC-RAS stormwater modeling, as well as identification and design of innovative stormwater management (e.g., Low Impact Development) and restoration projects. Subsequent watershed plans have refined the art and science or restoration planning through 3 plans each for Anne Arundel and Baltimore Counties. Most recently, Dr. Southerland prepared Countywide Implementation Strategies for Montgomery and Howard Counties that detail optimal scenarios for meeting all NPDES permit and

TMDL requirements, including the Chesapeake Bay WIP. Other innovative support for Howard County has included countywide surveys of LID opportunities on government property and evaluation of all public and private detention ponds for enhancement, design and monitoring of Trust Fund restoration, and development of a precise stormwater fee.

Monitoring and Assessment - Dr. Southerland's work at Versar also involves directing major programs in the monitoring, assessment, and restoration of freshwater and terrestrial ecosystems. He is the lead consultant to the ongoing MBSS which characterizes the physical, chemical, and biological condition of nontidal streams through the probabilistic sampling of sites every years beginning in 1995. To date 3,500 sites have been sampled. Dr. Southerland has prepared the new Round 4 sampling design and developed the current fish, benthic macroinvertebrate, and salamander IBI. Most importantly, MBSS data are being used by MDE to implement biological criteria as part of state water quality standards and to designate waters for inclusion on the Maryland 303d list. Dr. Southerland has helped MDE develop the Biological Stressor Identification methodology, revise their biological listing methodology, and identify an approach to urban TMDL targets that uses flow duration curves and impervious cover.

1) Name: **Nancy Roth**

2) Title: Project Manager

3) Affiliation, Years Employed: Versar, Inc., Columbia, MD – 16 years

4) Degrees: M.S., Resource Ecology and Management, University of Michigan, 1994

B.A., Biology, Carleton College, Minnesota, 1987

5) Related Project Experience:

Maryland Department of Natural Resources — *Senior Scientist, 1996-Present:* A national expert in stream ecology and watershed assessment, Ms. Roth brings more than 20 years of experience including watershed restoration plans, stream habitat and biological assessment, water monitoring, geomorphology, NPDES stormwater compliance, and GIS. Ms. Roth uses innovative, multi-disciplinary approaches to develop effective watershed protection and restoration strategies for USEPA, USACE, and state and local governments, particularly in Maryland and Virginia. She is a senior technical expert for the Maryland Biological Stream Survey, a nationally recognized program to assess the state's freshwater streams. For MBSS, Ms. Roth has served as Task Manager and primary author of stream assessments, providing statewide and watershed evaluations based on sampling at 200-300 sites per year. Ms. Roth led the development and validation of the fish Index of Biotic Integrity (IBI) and has utilized fish and benthic macroinvertebrate indicators extensively. She has directed Quality Assurance analysis and annual QA reports.

Community Development Division, Frederick County, MD — *Task Manager 1999-2000, Project Manager, 2000-Present:* Ms. Roth directs design and implementation of the Frederick County Stream Survey, which has evaluated benthos, water quality, and habitat at 200 sites countywide. She also directs annual biological assessments to fulfill long-term NPDES monitoring goals and to evaluate restoration projects. She directed field studies and identification of restoration and stormwater retrofit opportunities (including geodatabase development) in the County's top three priority watersheds. Ms. Roth co-authored Quality Assurance Project Plans for stormwater and stream monitoring.

Department of Public Works, Anne Arundel County, MD — *Project Manager, 2009:* Ms. Roth supervised biological monitoring and habitat assessments at 50 stream sites in Patapsco Tidal and Bodkin Creek watersheds. These targeted sites were sampled using MBSS and USEPA methods for benthic macroinvertebrate sampling and identification, habitat assessment, and in-situ water quality monitoring. Versar developed a database and results report, including maps, analyses of Index of Biotic Integrity and physical habitat indicators, and characterization of individual site conditions. Data were incorporated by Anne Arundel County into its Watershed Management Tool as part of a comprehensive watershed assessment to support restoration planning.

Department of Environmental Protection and Resource Management, Baltimore County, MD — *Project Manager 2003-2004, Project Advisor, 2004-2007:* Ms. Roth directed annual stream benthic and habitat monitoring in Baltimore County watersheds, supervising field staff in conducting stream assessments using USEPA Rapid Bioassessment Protocols at 100 sites yearly. She also coordinated with County personnel, oversaw laboratory benthic identification, and conducted field QA audits.

Department of Environmental Protection and Sustainability, Baltimore County — *Project Manager, 2010-Present:* Ms. Roth leads Versar in developing Small Watershed Action Plans (SWAPs) in Lower Patapsco Watershed (completed spring 2012) and Bird River (to begin late 2012). Work includes field investigations, GIS analysis, modeling of pollutant loads and reductions to meet TMDL goals, and development of watershed restoration recommendations. Ms. Roth coordinates with a watershed Steering Committee involving local residents, County staff, and other agencies.

National Park Service, Center for Urban Ecology — *Project Manager, 2008-Present:* Ms. Roth directs stream biological monitoring (MBSS methods) supporting the Inventory & Monitoring Program, National Capital Region Network. Ms. Roth oversees assessments of water quality, physical habitat, benthic macroinvertebrates, and fishes.

Department of Building and Development, Loudoun County, VA — *Project Manager, 2009:* Ms. Roth designed and directed the Loudoun County Stream Assessment, which provided the first-ever countywide evaluation of stream conditions. Tasks included review and synthesis of existing stream assessment data from past studies; development of a strategic plan and protocols, including a Quality Assurance Project Plan; and field studies. Versar conducted field investigations at 200 benthic monitoring sites and 500 stream habitat assessment sites. Benthic monitoring employed USEPA's Rapid Bioassessment Protocols, laboratory identification of samples, and indicator analysis.

U.S. Environmental Protection Agency, National Watershed Protection Program — *Project Manager, 2006-2008:* Ms. Roth directed the identification of stressors contributing to impairment in five water bodies on the Iowa and Missouri Clean Water Act Section 303(d) lists. Initial work involved compiling previous data and developing custom sampling plans for new field investigations, in consultation with EPA Region 7 and State agency partners. Data collection included benthic macroinvertebrate, physical habitat assessment, water chemistry, and watershed reconnaissance. Analyses employed USEPA's Stressor Identification protocol and will support further state TMDL efforts.

U.S. Environmental Protection Agency, National Watershed Protection Program — *Project Advisor, 2011-Present:* Ms. Roth directed an assessment of conditions and identification of stressors in headwater streams in the Central Great Plains ecoregion in Kansas and Nebraska in support of the Central Great Palins Headwater Stream Assessment. Data collection included benthic macroinvertebrate, physical habitat assessment, water chemistry, and watershed reconnaissance. Analyses employed USEPA's Stressor Identification protocol and Bayesian statistical analysis.

Department of Public Works and Environmental Services, Stormwater Planning Division, Fairfax County, VA — *Project Environmental Scientist 2006-2007, Project Manager 2007-Present:* As Project Manager of the Municipal Stormwater Permit Monitoring Program, Ms. Roth directed stream assessments, including fish, habitat, and benthic macroinvertebrate monitoring, and developed a QA/QC protocol for benthic monitoring. She has supervised dry- and wet-weather monitoring. Ms. Roth conducted a literature review and drafted a white paper on bacteria monitoring approaches to refine the county's current program. She directed tasks on innovative BMP monitoring to evaluate the effectiveness at the county's green roof and bioretention pilot projects.

Stream Assessment and Watershed Restoration Plan, City of Gaithersburg, MD — *Project Manager, 2001-2003:* Ms. Roth supervised staff in designing and conducting a stream assessment program, including biological monitoring (fish and benthic assessments), physical habitat assessments, database management, and analysis. She also directed tasks to identify stream restoration and BMP retrofit sites and map stormwater outfalls. Ms. Roth presented findings in a briefing for the Mayor and City Council.

U.S. Army Corps of Engineers, Norfolk District — *Task Manager, 2002:* Ms. Roth developed a macroinvertebrate and habitat survey to assess stream conditions at the Naval Support Activity Norfolk (NSAN), Northwest, Virginia. Ms. Roth also developed educational materials and helped train NSAN staff on benthic field collection methods.

6) Previous Employment and Years of Experience:

Environmental Protection Specialist, USEPA Wetlands Division (2 years)
Research Assistant, University of Michigan (2 years)
Environmental Education Program Manager, Chesapeake Bay Foundation (3 years)

7) Specialized Training:

Project Management Professional (PMP No. 416397), Project Management Institute, 2006
Rosgen Level I, Applied Fluvial Geomorphology, 1994
Rosgen Level II, River Morphology and Applications, 2003

8) Professional Affiliations:

Project Management Institute
Society for Freshwater Science

1) *Name*: **Brenda Morgan**

2) *Title*: Field Manager

3) *Affiliation, Years Employed*: Versar, Inc., Columbia, MD – 8 years

4) *Degrees*: B.A., Biology, Ithaca College, Ithaca, NY, 2001

5) *Related Project Experience:*

Department of Environmental Protection and Resource Management, Baltimore County, MD — *Environmental Scientist, 2004-2007:* Ms. Morgan was the Field Crew Leader for a multi-year field and laboratory support contract to collect benthic macroinvertebrate samples, water quality data, and information on physical habitat conditions at 100 stream monitoring sites in various basins over each of the last four years of the surveys. This stream survey program utilizes MBSS field and laboratory methods. M. Morgan coordinated sample collection and logistics, trained field staff, was a Field Crew Leader, and helped prepare project reports. Ms. Morgan also served as Lead Instructor to train Versar and County staff in MBSS protocols and methods.

U.S. Environmental Protection Agency, Region 7 — *Environmental Scientist, 2006-2008, 2011-present:* Ms. Morgan helped develop and implement sampling plans to identify stressors in 303d listed streams in Iowa, Missouri, Nebraska and Kansas. She gathered background information, communicated with clients, and assessed GIS data. She also carried out fieldwork that included: continuous DO monitoring, water quality sampling, photodocumentation, physical habitat assessments, and macroinvertebrate sampling. Ms. Morgan provided data analysis, site mapping, and prepared reports of results and potential stressor identification for each state.

National Park Service, Center for Urban Ecology — *Environmental Scientist, 2007-Present:* Ms. Morgan serves as Field Manager for the stream biological monitoring supporting the Inventory & Monitoring Program, National Capital Region Network. The program collects data on a number of vital signs including stream biological integrity and physical habitat. Ms. Morgan led field crews in assessments of water quality, physical habitat, benthic macroinvertebrates, and fishes throughout various national parks over the past five years following MBSS sampling protocols. In addition, she oversaw data entry and prepared annual field reports.

Department of Public Works, Anne Arundel County — *Environmental Scientist, 2010-Present:* Under this on-going project, Ms. Morgan served as Field Manager for a survey of 50 stream monitoring locations in the Bodkin Creek watershed and the Patapsco Tidal watershed. She oversaw and reviewed the results of all fieldwork. She also served as GIS and data manager for the project, overseeing the development of a project geodatabase, data entry, and data QA/QC. She helped prepare several reports and created various deliverables for the client. Ms. Morgan has also participated in a watershed field assessment of these watersheds, which involved using ArcPad on field computers to record habitat and Rosgen assessments and various stream features in the Bodkin Creek, Patapsco Tidal, and Little Patuxent River subwatersheds.

Office of Sustainability and Environmental Resources, Frederick County, MD — *Environmental Scientist, GIS Analyst, Database Manager, 2003-Present:* Ms. Morgan has provided field support and completed data analysis tasks in support of the Office of Sustainability and Environmental Resources NPDES Municipal Storm Sewer System Permit requirements. Ms. Morgan developed a geodatabase within ArcGIS to identify, organize, assess, and rank potential restoration and retrofit opportunities within Linganore Creek and Ballenger Creek watersheds. This database included field observations, a costing calculator, cost/benefit analysis worksheets, and a project factsheet design. She also developed another set of geodatabases to organize County-wide and restoration site stream monitoring data. Ms. Morgan developed a quality control/quality assurance plan (QAPP) for the County's stream monitoring projects. Ms. Morgan conducted stream assessments, including benthic macroinvertebrate and fish sampling, habitat assessment, and geomorphic surveying throughout the County. Ms. Morgan participated in a task to assess the effectiveness of the 2000 Maryland Stormwater Design Manual standards for stream channel protection. As part of this task, she performed detailed geomorphic field surveys. Ms. Morgan managed production of the County's 2012 and 2013 annual NPDES reports for submittal to the Maryland Department of the Environment.

Department of Public Works and Environmental Services, Fairfax County, VA — *Environmental Scientist, GIS Analyst, 2004-2007:* Versar conducted a two-year project to prepare a watershed management plan that included extensive data analysis, modeling, and the involvement of watershed stakeholders to help identify, prioritize, and develop approaches to improve stormwater management controls in Cameron Run, a highly urbanized, older residential area within the Capital Beltway. Ms. Morgan was responsible for analysis of biological and physical habitat data collected. She has conducted GIS analyses and mapping to aid in selecting and ranking specific, potential restoration, retrofit, and Low Impact Development (LID) projects within the watershed. In addition, she has used GIS to develop targeting strategies for wet and dry weather monitoring programs currently being designed for the County.

Department of Building And Development, Loudoun County, VA — *Field Manager, 2009:* Ms. Morgan served as field manager for a county-wide survey of Loudoun County streams, including 200 benthic macroinvertebrate monitoring stations and 500 habitat assessments. She also served as GIS and data manager for the project, overseeing the development of a project geodatabase, data entry, and data QA/QC. She helped prepare several reports and created various deliverables for the client. Ms. Morgan also helped lead demonstrations of field techniques for the client and various stakeholders.

6) *Previous Employment and Years of Experience:*

Maryland Department of Natural Resources, Monitoring and Non-Tidal Assessment, 2003, 2001, 2000, 1999; Natural Resources Biologist I.

Carroll County, Maryland Government, Water Resources Planning Division, 2002-2003; Watershed Restoration Action Strategy (WRAS) Coordinator.

Ithaca College, Biology Department, 1999-2001; Plant Physiology Research Assistant.

7*) Specialized Training:*

Maryland Biological Stream Survey – Field Sampling Training, 1998-2001, 2003-2004, 2006, 2007, 2010.

NOAA Office of Response and Restoration, Emergency Response Division – Shoreline Cleanup Assessment Technique (SCAT) Team Member Training, August 2012.

40-hour Hazardous Waste Site Worker Certification, October 2012.

Versar ESM Technical Writing Seminar, Winter 2005-2006.

Maryland Department of Natural Resources – Stream Corridor Assessment Field Training, September 2002.

8) Professional Affiliations: Not Applicable

Name: **Lisa Methratta**

Title: **Senior Environmental Scientist**

Company Affiliation, Office Location, and Years Employed: Versar, Inc., Columbia, MD – 5 yrs.

Education:
Postdoctoral Research Fellow, University of Pennsylvania, 2005-2007
Postdoctoral Research Fellow, Woods Hole, MA, NOAA/NMFS/NEFSC, 2003-2005
Ph.D., Biology, University of Pennsylvania, 2003
B.S. Biology, Pennsylvania State University, 1996

Relevant Experience and Qualifications:

Dr. Methratta has 10 years of postgraduate experience in ecological research focusing on marine and freshwater ecology, quantitative statistics, ecological modeling, spatial analysis, and experimental design. She has conducted critical reviews of the design, statistical analyses, and results for CWA §316(b) studies aimed at evaluating the impingement and entrainment of aquatic organisms at the cooling water intake facilities of power generating sites in the State of Maryland. Comprehensive written reports which synthesized existing information, identified gaps, and suggested additional information to be collected were key deliverables for these projects. Dr. Methratta has served as the task and/or technical lead for projects supporting multiple state agencies (e.g.,, Maryland, Virginia, Kansas, Nebraska), federal agencies, (e.g., NOAA, U.S. Army Corps of Engineers, U.S. EPA), many of which have been done in collaboration with other privately owned companies (e.g., RTI, Kleinschmidt Associates). Dr. Methratta regularly interacts with clients via email, phone conference, or in-person meetings. Dr. Methratta has authored numerous client reports, agency reports, and peer-reviewed manuscripts, and has presented work at regional and national conferences.

Related Projects:

CWA §316(b) Study Review for the C.P. Crane and H.A. Wagner Generating Stations, Power Plant Research Program, Maryland Department of Natural Resources — Statistical Lead, 2009-Present: Dr. Methratta provided critical analysis of the design, statistical analyses, and results for studies conducted to evaluate impingement and entrainment of aquatic organisms at C. P. Crane and H.A. Wagner Generating Stations of Maryland in accordance with the U.S. Environmental Protection Agency Phase II Rule for the implementation of Section 316(b) of the Clean Water Act. Dr. Methratta produced detailed written reports which gave a comprehensive critical review of the design and analyses of the studies conducted by the power company. Her written reports also provided suggestions for additional analyses with existing data and further studies that the power company could conduct to address relevant ecological questions.

Headwaters Assessment for the Central Great Plains, U.S. Environmental Protection Agency — Technical Lead, 2013-Present: Versar was chosen as a subcontractor by RTI International to design and conduct a survey of Central Great Plains headwater streams to identify stressors in this ecosystem and to use these data to evaluate the usefulness of existing biotic indices of integrity in assessing the biological status of these streams. Dr. Methratta designed and presented an analysis plan to collaborators at RTI, EPA, and representatives from the States of Kansas and Nebraska. She conducted all analyses and authored a technical report describing the findings of the survey and subsequent biological assessments.

Ecosystem Modeling, National Oceanic and Atmospheric Administration — Technical Lead, 2009-Present: Dr. Methratta developed a spatially explicit food web and energetic model for the Rhode River Estuary, a tributary to the Chesapeake Bay. Dr. Methratta compiled and integrated numerous data sources to determine diet relationships, vital population rates, and spatially explicit habitat characteristics of the system. Using the Ecopath with Ecosim and Ecospace suite of modeling software, Dr. Methratta developed a balanced model and generated model runs to evaluate fishery and habitat degradation scenarios. Dr. Methratta is planning to use the output of an EPA watershed planning model to determine how nutrients from the Rhode River watershed influence fisheries and other ecosystem dynamics downstream in the estuary.

Maryland Biological Stream Survey, Maryland Department of Natural Resources — Technical Lead, 2007-Present: The Maryland Biological Stream Survey (MBSS) has been conducted by the State of Maryland since the late 1990s. This statewide stratified-random survey collects data on stream invertebrates, fish, and salamanders in all of the watersheds of Maryland. Dr. Methratta leads the design and analysis for projects that utilize this vast dataset for the determination of biological status of streams. Dr. Methratta has used these data to evaluate the health of headwater streams which are biodiversity hotspots and particularly vulnerable to development. She has applied MBSS data to explore the impacts of water withdrawals on fish community composition and function which has implications for power plant cooling and potential fracking activities. Dr. Methratta has been the technical leader of a project aimed at developing the biological condition gradient for Maryland fish in order to ascertain the level of degradation of streams based on the fish communities that are present.

Development of Five American Eel White Papers Project, New York Power Authority — Technical Lead, 2008-2010: Versar was chosen as a subcontractor by Kleinschmidt Associates to develop white papers to support American eel passage around hydroelectric projects on the St. Lawrence River in Quebec, Canada. Dr. Methratta was a lead author for the white papers evaluating methods for capturing, holding, and transporting eels and the application of attractants/repellants for guiding eels. Dr. Methratta complied and synthesized an exhaustive set of literature pertaining to these topics. She authored the white papers which provided a synthesis and critical review of relevant studies and identified gaps in knowledge on each topic. She provided recommendations for further studies and potential approaches for guiding and transporting eels around hydroelectric projects on the St. Lawrence.

Native Oyster Restoration Master Plan, U.S. Army Corps of Engineers— Technical Lead, 2009-2010: Dr. Methratta was the task manager and technical lead for the U.S. Army Corps Baltimore District project designed to enhance geographic site selection for native oyster restoration in the Chesapeake Bay. She coordinated efforts aimed at identifying and compiling relevant, spatially-resolved data on the native oyster's biological attributes and environmental preferences. At meetings of the project team, which included U.S. Army Corps staff from the states of Maryland, Virginia, and Massachusetts as well as academic biologists, Dr. Methratta presented detailed project status updates and lead brain-storming sessions on spatially-explicit habitat delineation. Using spatial mapping and analytical tools, Dr. Methratta developed the protocol for data interpolation, creating multiple GIS data layers of environmental variables for the entire extent of Chesapeake Bay. These data layers are providing managers with locations within the Bay and its tributaries where oyster restoration has the highest probability of success.

Publications (Select List):

Methratta, E.T., C.A. Menzie, W.T. Wickwire, and W.A. Richkus. 2013. Evaluating the risk of establishing a self-sustaining population of nonnative oysters through large scale aquaculture in Chesapeake Bay. In press at *Human and Ecological Risk Assessment: An International Journal*.

Methratta, E.T. and J.S. Link. 2012. Feeding hotspots for four northwest Atlantic groundfish species. *International Council for the Exploration of the Seas (ICES) Journal of Marine Science* 69: 1710-1721.

Southerland, M., S. Schreiner, E. Methratta, B. Franks, R. Morgan, L. Currey, A. Kasko. 2012. Conceptual framework for incorporating urban watershed functions into Maryland's TMDL Program. Chesapeake Bay Modeling Symposium. Annapolis, MD.

Methratta, E.T. and P.S. Petraitis. 2008. Propagation of scale-dependent effects from recruits to adults in barnacles and seaweeds. *Ecology* 89: 3128-3137.

1) ***Name***: **Roberto Llanso**

2) *Title*: Project Manager

3) *Affiliation, Years Employed*: Versar, Inc., Columbia MD – 13 years

4) *Degrees*: Ph.D., Marine Science, School of Marine Science, The College of William and Mary, 1990

M.A., Marine Science, School of Marine Science, The College of William and Mary, 1985

B.S., Zoology, Universidad Complutense, Madrid, Spain, 1979

5) *Related Project Experience:*

Maryland Department of Natural Resources — *Project Manager, 1999-Present:* Dr. Llansó is Principal Investigator of the Long-Term Benthic Monitoring and Assessment component (LTB) of the Chesapeake Bay Program, conducted for the MD DNR. He is responsible for program management, survey design, data collection, analysis and interpretation, and report preparation. Dr. Llansó contributes to the synthesis and analysis of monitoring data, interpretation of status and trends, and development and application of biocriteria. He has participated in the development and application of the Chesapeake Bay B-IBI. He is author or co-author of 21 peer-reviewed scientific publications.

U.S. Department of Transportation, Maritime Administration — *Project Manager, 2006-2012:* Dr. Llansó served as Principal Investigator and marine biologist expert for the U.S. Maritime Administration conducting nonindigenous species studies on National Defense Reserve Fleet vessels in Virginia, Texas, and California to assess (1) risk of invasive species transfers and (2) the effectiveness of various hull cleaning and alternative hull management options. Seventeen vessels were surveyed at three Reserve Fleet locations (James River, Beaumont, TX, and San Francisco Bay). The biofouling communities were sampled before hull cleaning, after hull cleaning, and after transit of the vessels from their fleets to ship-breaking facilities in Brownsville, TX. Dr. Llansó participated in all the aspects of the project, including sampling, taxonomic identification of difficult phyla groups, data analysis, and report preparation.

Maryland Department of Natural Resources and USEPA — *Project Manager, 2000-2010:* Dr. Llansó was Project Manager in the sampling and assessment of benthic communities in the coastal bays of Maryland and the Chesapeake Bay for the Coastal Bays Program and USEPA's National Coastal Condition Assessment (NCCA). He was responsible for all the tasks under this contract, including sampling, laboratory analysis, data analysis, and report preparation. He participated directly in the sampling, which included Young grab benthic samples, sediments for grain size, organic carbon, benthic chlorophyll, contaminants, and toxicity testing, and a variety of water quality parameters.

Virginia Department of Environmental Quality — *Project Manager, 2003-2005:* Dr. Llansó developed biocriteria for impaired waters assessments (Clean Water Act) in Chesapeake Bay for the states of Maryland and Virginia. With support from benthic monitoring program staff at Old Dominion University and statisticians at Versar, Dr. Llansó worked together with the states of MD and VA and the USEPA to develop a method that could be reasonably used to define impaired waters in Chesapeake Bay using benthic data. The impaired waters decision method combined benthic program data, the B-IBI, and a statistical test of impairment. Dr. Llansó subsequently applied the method to identify impaired waters in Chesapeake Bay for the 2006 and 2008 reporting cycles as required by Section 305(b) of the Clean Water Act, and provided support to the Bay Program and the states in their implementation of the method for subsequent years.

New York State Department of Environmental Conservation — *Project Manager, 2000-2005:* Dr. Llansó provided support to NYSDEC in the development of biocriteria for the Hudson River Estuary. This effort required indicators to characterize conditions in a large river across estuarine and freshwater boundaries. Dr. Llansó participated in all the aspects of the project, including collection of benthic samples with a Young grab; concurrent measures of sediment contaminants, water quality, and nutrients, from Battery to Troy; data analysis; report preparation; and management and scientific presentations.

USEPA National center for Environmental Assessment, Cincinnati, OH — *Project Manager, 2003-2004-:* Dr. Llansó provided extensive analysis of EMAP data to quantify relationships between sediment contaminant concentrations, direct toxicity, and fish and invertebrate response measures. The objective of the project was to test assumptions associated with the level of protection afforded by chemical criteria and other sediment quality guidelines that have measurement endpoints at the individual (toxicity), population, and community levels. Dr. Llansó was tasked with compiling data sets, which required extensive taxonomic standardization work, document sampling designs and methods, review the scientific literature to determine estuarine and benthic invertebrate and fish community metrics applicable to the EMAP regions, review the literature for chemical-specific criteria relevant to the stressors measured by EMAP, select and calculate metrics of benthic and fish community condition, and produce statistical analyses to compare agreement between classifications of samples based on chemical criteria, toxicity data, and the estuarine and fish community metrics.

USEPA Mid-Atlantic Integrated Assessment — *Project Manager, 1999-2000-:* Dr. Llansó conducted the development of a benthic index of biotic integrity for the Mid-Atlantic Integrated Assessment (MAIA) program. The index included data for mid-Atlantic estuaries collected over various years and under various state and federal programs, from Delaware Bay to Pamlico Sound. This project required the standardization of species-level taxonomic data from many surveys, which requires profound taxonomic knowledge and skill. Dr. Llansó has acquired wide benthic taxonomic knowledge of tidal fresh, estuarine, and marine environments through sampling and monitoring projects he has conducted in Chesapeake Bay, Tampa Bay, San Francisco Bay, and Puget Sound. He was founding member of NAMIT (Northern Association of Marine Invertebrate Taxonomists), and arranged for various taxonomy workshops for which he invited experts nationwide.

6) *Previous Employment and Years of Experience:*

Washington State Department of Ecology, Olympia, WA, 1994-1999. P.I. of the Puget Sound Sediment Monitoring Program. Dr. Llansó was responsible for overall organization and implementation of the program, including sampling design; development of field, laboratory, and analytical methods; data collection (chemistry, toxicity, benthos); data analysis and interpretation; management of program contracts; report preparation; and presentations at management and scientific meetings.

Florida Department of Environmental Protection, Tallahassee, FL, 1992-1993. Dr. Llansó was responsible for the development of a water quality and biological data base integrating data and providing taxonomic screening from state-wide biological surveys of streams, lakes, and estuaries of Florida over 30 years.

7*) Specialized Training:* None applicable

8) Professional Affiliations:

Association for the Sciences of Limnology and Oceanography (since 1993)
Atlantic Estuarine Research Society (since 1985)
Coastal and Estuarine Research Federation (since 1989)
Society of Environmental Toxicology & Chemistry (since 2004)

Name & Title: **Thomas Jones, Project Manager**
Project Assignment: **IDDE / Stormwater Monitoring**
Year Experience: With this Firm: **16** *With Others:* **8**

Education (degree(s)/year/specialization) and Registrations:
B.A., Chemistry, University of Maryland Baltimore County, MD, 1988
Certificate, Health Physics & Radiation Protection Course, 1993

Relevant Experience and Qualifications: Mr. Jones has over 15 years of experience in conducting and managing NPDES compliance tasks for a clientele that currently consists of seven Phase I communities in two states. He has implemented Illicit Discharge Detection and Elimination (IDDE) programs, conducted hot-spot investigations (HSI), and conducted retrofit reconnaissance inventories (RRI) in target watersheds. His experience includes managing and conducting field surveys of stormwater conduit and stream infrastructure using state of the art Trimble GPS units for watershed planning. Additionally, he has more than 15 years' experience coordinating meteorological, field, laboratory, and technical support of storm monitoring tasks. He has extensive experience in hands-on storm monitoring fieldwork and currently provides management oversight and quality control guidance for nine storm monitoring and BMP assessment tasks.

NPDES Municipal Stormwater Permit and Watershed Planning Support,
Frederick County, MD – Task Manager and Scientist, 1999-present. As scientist, Mr. Jones coordinated and conducted baseflow and storm discharge water chemistry monitoring on Peter Pan Run and at a land use-specific BMP beginning with project inception and site installation in 1999. He is intimately familiar with all facets of storm monitoring work through his 15 years of experience ranging from hands-on field work to task management. He designed and conducted pre-and post- LID retrofit storm runoff monitoring at Urbana High School. Mr. Jones has been the lead author of the water chemistry portion of the last thirteen NPDES Annual Reports. He has participated in geomorphic assessments and fish surveys of selected stream reaches. He led a field team to investigate and evaluate LID retrofit opportunities in Lower Linganore Creek watershed. He developed field screening and internal communication procedures for the County's IDDE program as well as currently manages Versar teams for site visits on an as-needed basis. He provided field demonstration and programmatic support during a recent EPA audit of the County's IDDE program.

NPDES Storm Monitoring Support, Department of Environmental Protection, Montgomery County, MD –
Project Manager and Scientist, 1998-present. Mr. Jones manages Versar's Montgomery County support contract. In this capacity he directs all water chemistry monitoring activities, including storm event and baseflow sampling, laboratory coordination, and instream water quality monitoring station and instrumentation maintenance. He manages the compilation of project data for the water chemistry portion (text and MDE-required database) of the County's NPDES Annual Report. Mr. Jones has also monitored trash, nutrient, and metals runoff for a source control BMP study. He has worked with the County to design and implement LID monitoring projects at several County and proposed community facilities, including continuous flow, water chemistry, and groundwater.

NPDES MS4 Services, Department of Public Works, Howard County, MD –
Task Manager, 2011-present. Mr. Jones supports the County's IDDE program by managing field investigations of outfalls and trackdowns of pollutant sources using differential GPS in the field. He also summarizes chemistry data from several stream monitoring tasks for inclusion in the County's annual report. He is the technical coordinator for storm runoff monitoring using automated samplers in stream restoration and stormwater retrofit sites. He also conducted sediment bedload sampling using passive samplers and suspended sediment sampling using siphon samplers in these same stream restoration reaches.

NPDES MS4 Services, Department of Public Works, Harford County, MD –
Task Manager, 2010-present. Mr. Jones manages the County's IDDE and HIS efforts by selecting sites, managing field activities, compiling data, and preparing annual reports. Fieldwork consists of using customized Arcpad field data sheets to record dry weather screening data. He has previously conducted and currently provides management and QA oversight for storm runoff monitoring in Wheel Creek watershed in support of the County's NPDES permit and Chesapeake Bay Trust Fund monitoring requirements.

NPDES MS4 Services, Department of Public Works and Environmental

Services, Fairfax County, VA – Task Manager and Scientist, 2003-present. During previous contract cycles, Mr. Jones managed and conducted BMP performance water chemistry monitoring on a variety of innovative stormwater control measures. He led field teams to perform dry weather screening of County maintained stormwater outfalls in priority subwatersheds using differential GPS, geodatabase-linked electronic field data sheets, field water chemistry kits, water quality measurements, and physical assessments. Mr. Jones presented results of the screenings, including illicit connections found, in annual reports and geodatabases. Currently he coordinates the selection of optimal industrial parcels and MS4 service area catchments for targeted, automated wet weather screening.

NPDES MS4 Services, Anne Arundel County, MD – Task Manager, 2012-present. Mr. Jones serves as project manager for the illicit discharge and hotspot investigation field efforts. Field activities include selecting candidate outfalls, screening the outfalls for chemical and non-chemical indicators, and performing a trackdown of pollution problems and documenting the source. He prepares site-specific reports on illicit discharge, infrastructure, and hotspot problems.