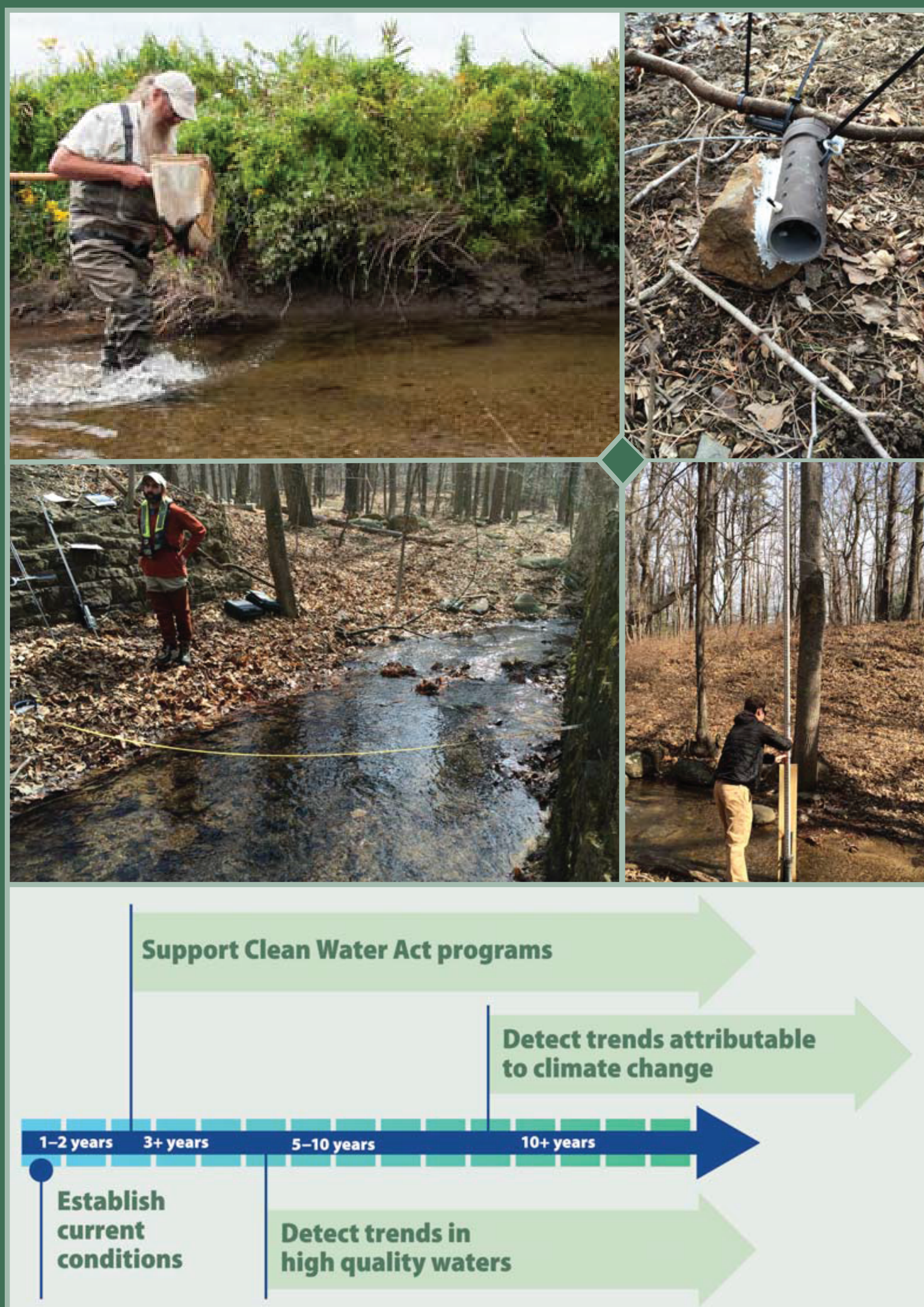
EPA/600/R-15/280 | February 2016 | www.epa.gov/research

EPA
United States
Environmental Protection
Agency

Regional Monitoring Networks (RMNs) to Detect Changing Baselines in Freshwater Wadeable Streams



EPA/600/R-15/280
February 2016
Final Report

Regional Monitoring Networks (RMNs) to Detect Changing Baselines in Freshwater Wadeable Streams

National Center for Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC 20460

DISCLAIMER

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

The United States Environmental Protection Agency (U.S. EPA) is working with its regional offices, states, tribes, river basin commissions and other entities to establish Regional Monitoring Networks (RMNs) for freshwater wadeable streams. RMNs have been established in the Northeast, Mid-Atlantic, and Southeast, and efforts are expanding into other regions. Long-term biological, thermal, hydrologic, physical habitat and water chemistry data are being collected at RMN sites to document current conditions and detect long-term changes. Consistent methods are being used to increase the comparability of data, minimize biases and variability, and ensure that the data meet data quality objectives. RMN surveys build on existing state and tribal bioassessment efforts, with the goal of collecting comparable data at a limited number of sites that can be pooled at a regional level. Pooling data enables more robust regional analyses and improves the ability to detect trends over shorter time periods. This document describes the development and implementation of the RMNs. It includes information on selection of sites, expectations for data collection, the rationale for collecting these data, data infrastructure and provides examples of how the RMN data will be used and analyzed. The report concludes with a discussion on the status of monitoring activities and next steps.

Preferred citation:

U.S. EPA (Environmental Protection Agency). (2016) Regional Monitoring Networks (RMNs) to detect changing baselines in freshwater wadeable stream. (EPA/600/R-15/280). Washington, DC: Office of Research and Development, Washington. Available online at http://www.epa.gov/ncea.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BCG	biological condition gradient
CT DEEP	Connecticut Department of Energy and Environmental Protection
CWA	Clean Water Act
E	expected
ELOHA	ecological limits of hydrologic alteration
EPT	Ephemeroptera, Plecoptera, and Trichoptera
GIS	geographic information system
GPS	global positioning system
MA DEP	Massachusetts Department of Environmental Protection
MD DNR	Maryland Department of Natural Resources
MMI	multimetric index
NARS	EPA National Aquatic Resource Surveys
NLCD	National Land Cover Database
NMDS	nonmetric multidimensional scaling
NRSA	National Rivers and Streams Assessment
NWQMC	National Water Quality Monitoring Conference
O	observed
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RBC	river basin commission
RIFLS	River Instream Flow Stewards Program
RMN	regional monitoring network
SDM	species distribution model
SOP	standard operating procedure
SSN	Sentinel Sites Network
SWPBA	Southeastern Water Pollution Biologists Association
TNC	The Nature Conservancy
U.S. EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VT DEC	Vermont Department of Environmental Conservation
WQX	Water Quality Exchange
WV DEP	West Virginia Department of Environmental Protection

PREFACE

The U.S. Environmental Protection Agency (EPA) is working with states, tribes, river basin commissions, and other organizations in different parts of the country to establish regional monitoring networks (RMNs) to collect data that will further our understanding of biological, thermal, and hydrologic conditions in freshwater wadeable streams and allow for detection of changes and trends. This document describes the framework for the RMNs that have been developed in the Northeast, Mid-Atlantic, and Southeast regions for riffle-dominated, freshwater wadeable streams.

AUTHORS AND REVIEWERS

The National Center for Environmental Assessment, Office of Research and Development is responsible for publishing this report. This document was prepared with the assistance of Tetra Tech, Inc. under Contract No. EP-C-12-060, EPA Work Assignments No.1-01 and 2-01. Dr. Britta Bierwagen served as the Technical Project Officer, providing overall direction and technical assistance.

AUTHORS

Center for Ecological Sciences, Tetra Tech, Inc., Owings Mills, MD
Jen Stamp, Anna Hamilton

U.S. EPA Region 3, Wheeling, WV
Margaret Passmore (retired)

Tennessee Department of Environment and Conservation
Debbie Arnwine

U.S. EPA, Office of Research and Development, Washington DC
Britta G. Bierwagen

Fairfax County Stormwater Planning Division, VA
Jonathan Witt

REVIEWERS

U.S. EPA Reviewers

Jennifer Fulton (R3), Ryan Hill, Ph.D. (ORISE Fellow within ORD), Sarah Lehmann (OW)

External Peer Reviewers

Lucinda B. Johnson, Ph.D. (University of Minnesota), Kent W. Thornton, Ph.D. (FTN), Chris O. Yoder, Ph.D. (Midwest Biodiversity Institute)

ACKNOWLEDGMENTS

The authors would like to thank the many partners who reviewed early versions of this report for clarity and usefulness. Their comments substantially improved this document. Special thanks to K. Herreman and D. Infante (Michigan State University), P. Morefield, C. Mazzarella, and J. Fulton (U.S. EPA), former ORISE participant A. Murdukhayeva, and A. Olivero (The Nature Conservancy) for their contributions to the disturbance screening process described in Appendix D.

EXECUTIVE SUMMARY

The United States Environmental Protection Agency (EPA) is working with its regional offices, states, tribes, river basin commissions and other entities to establish Regional Monitoring Networks (RMNs) for freshwater wadeable streams. RMNs have been established in the Northeast, Mid-Atlantic, and Southeast, and efforts are expanding into other regions. Long-term biological, thermal, hydrologic, physical habitat and water chemistry data are being collected at RMN sites to document current conditions and detect long-term changes. Consistent methods are being used to increase the comparability of data, minimize biases and variability, and ensure that the data meet data quality objectives. RMN surveys build on existing state and tribal bioassessment efforts, with the goal of collecting comparable data at a limited number of sites that can be pooled at a regional level. Pooling data enables more robust regional analyses and improves the ability to detect trends over shorter time periods.

The goal of the RMNs is to provide data that can be used by biomonitoring programs for multiple purposes, spanning short and long-term timeframes. Uses include:

- Monitoring the condition of minimally and least disturbed streams
- Detecting trends attributable to climate change
- Supplementing Clean Water Act (CWA) programs and initiatives under Sections 303 and 305(b)
  - Defining natural conditions/quantifying natural variability
  - Informing criteria refinement or development
  - Developing biological indicators for protection planning
- Gaining a better understanding of relationships between biological, thermal, and hydrologic data
- Gaining a better understanding of ecosystem responses and recovery from extreme weather events
- Gaining insights into effects of regional phenomena such as drought, pollutant/nutrient deposition and riparian forest infestations on aquatic ecosystems and bioassessment programs

The need for RMNs stems from the lack of long-term, contemporaneous biological, thermal, and hydrologic data, particularly at minimally disturbed stream sites. To help fill this gap, efforts are underway to collect the following types of data from the RMN sites:

- Biological indicators: macroinvertebrates
  - Optional: fish and periphyton, if resources permit (fish are higher priority)

- Temperature: continuous water and air temperature (30-minute intervals)
- Hydrological: continuous water-level data (15-minute intervals); converted to discharge if resources permit
- Habitat: parameters agreed upon by regional working group
- Water chemistry: In situ, instantaneous water chemistry parameters (specific conductivity, dissolved oxygen, pH), plus additional or more comprehensive water chemistry measures agreed upon by regional working group
- Photodocumentation
- Geospatial data

The RMNs are designed to detect potentially small trends in biological, thermal, hydrologic, physical habitat and water chemistry data at high quality sites in a decision-relevant timeframe (e.g., within 5 years to inform criteria development; in 10−20 years to inform changing baselines). The RMN design calls for sampling at least 30 sites with similar environmental and biological characteristics in each region on an annual basis for 10 or more years, using comparable methods. To help inform this design, EPA and partners performed power analyses on an aggregated biomonitoring data set from a 2012 Northeast pilot study. The power analyses suggest that significant trends in regional community composition can be detected within 10−20 years if 30 or more comparable sites are monitored regularly. EPA and partners also used literature and standard operating procedures (SOPs) from participating organizations to help inform design decisions.

A generic Quality Assurance Project Plan (QAPP)[1] has been developed for the RMNs that details the core requirements for participation in the network, and outlines best practices for the collection of biological, thermal, hydrologic, physical habitat, and water chemistry data at RMN sites. The QAPP was written in a way that should be transferable across regions, with region-specific protocols included as addendums. The QAPP is intended to increase the comparability of data being collected at RMN sites, improve the ability to detect long-term trends by minimizing biases and variability, and to ensure that the data are of sufficient quality to meet data quality objectives. The ability of some participants to use the regional RMN methods has been limited by resource constraints, so in some situations, there have been differing levels of effort and differing methods across sites and organizations. While this is not ideal, the data can still be used, just in more limited ways. The data management system that EPA and partners are developing will contain metadata that will enable users to select data that meet their needs (e.g., collected using certain methods and at certain levels of rigor).

Sampling efforts at the RMNs are concentrated at a core group of sites called "primary" sites, where efforts are being made to collect the full suite of biological, thermal, hydrologic,

---

[1]The QAPP (U.S. EPA, 2016. Generic Quality Assurance Project Plan for monitoring networks for tracking long-term conditions and changes in high quality wadeable streams) is available online at http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=295758&inclCol=eco#tab-3.

physical habitat and water chemistry data. Efforts were made to select sites that had as many of the following characteristics as possible:

- Part of established, long-term monitoring networks (e.g., U.S. Geological Survey [USGS], sentinel)
- Low level of anthropogenic disturbance
- Exhibit similar environmental and biological characteristics
- Longevity (e.g., accessible [day trip], opportunities to share the workload with outside agencies or organizations)
- Located in watersheds protected from future development
- Lengthy historical sampling record for biological, thermal, or hydrological data

Most primary RMN sites are minimally or least disturbed sites (per Stoddard et al., 2006). High quality waters are being targeted because they are the standard against which other bioassessment sites are compared. It is critical to document current conditions at high quality sites and to track changes at these sites over time to understand how benchmarks may be shifting in response to changing environmental and climatic conditions. Data from additional, "secondary," sites are also being considered for the RMNs. These are sites at which a subset of parameters are already being collected in accordance with RMN protocols as part of other independent monitoring efforts. Data from secondary sites will increase the sample size and range of conditions represented in the RMN data set, and may provide information about unique or underrepresented geographic areas.

Data collection has been underway in the Northeast, Mid-Atlantic, and Southeast RMNs for several years. This report describes the development and implementation of these pilot RMNs. It includes information on selection of sites, expectations for data collection, the rationale for collecting these data, and data infrastructure. The report also provides examples of how the RMN data will be used and analyzed, and concludes with a discussion on the status of monitoring activities. Currently, EPA and partners continue to build capacity and refine protocols, indicator lists, analytical techniques and data management systems for the RMNs, including working with regions to establish RMNs. Long-term data from RMNs can support CWA programs, fill data gaps, and help detect trends attributable to climate change. The RMN framework is flexible and allows for expansion to new regions, as well as to new stream classes and waterbody types. The monitoring data being collected from these regional efforts will provide important inputs for bioassessment programs as they strive to protect water quality and aquatic ecosystems under a changing climate.

1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) has been working with states, tribes, river basin commissions (RBCs), and other organizations in different parts of the United States to establish regional monitoring networks (RMNs) to collect contemporaneous biological, thermal, hydrologic, physical habitat, and water chemistry data from freshwater wadeable streams. RMNs have been established in the Northeast, Mid-Atlantic, and Southeast[2] (see Figure 1-1), and efforts to establish new networks are expanding into other regions. The concept of the RMNs stems from work that began in 2006 with pilot studies that examined long-term climate-related trends in macroinvertebrate data from state biomonitoring programs in Maine, North Carolina, Ohio, and Utah (U.S. EPA, 2012a). During these studies, a lack of long-term, contemporaneous biological, thermal, and hydrologic data became apparent, particularly at minimally disturbed (Stoddard et al., 2006) stream sites. These data gaps have been documented elsewhere (e.g., Mazor et al., 2009; Jackson and Fureder, 2006; Kennen et al., 2011) and have been recognized as important gaps to fill by the National Water Quality Monitoring Council (NWQMC) (NWQMC, 2011).

The goal of the RMNs is to provide data that can be used by biomonitoring programs for multiple purposes, spanning short and long-term timeframes. Uses include:

- Monitoring the condition of minimally and least disturbed streams
- Detecting trends attributable to climate change
- Supplementing Clean Water Act (CWA) programs and initiatives
  - Defining natural conditions/quantifying natural variability to support Section 305(b) programs
  - Informing criteria refinement or development under Section 303
  - Developing biological indicators for protection planning for Section 303(d) programs
- Gaining a better understanding of relationships between biological, thermal, and hydrologic data
- Gaining a better understanding of ecosystem responses and recovery from extreme weather events
- Gaining insights into effects of regional phenomena such as drought, pollutant/nutrient deposition and riparian forest infestations on aquatic ecosystems and bioassessment programs

---

[2]RMN regions are largely (but not exactly) based on EPA regions to help facilitate coordination and sharing of resources. Differences include: New York (EPA Region 2), which joined the EPA Region 1 states in the Northeast RMN; New Jersey (EPA Region 2), which joined the EPA Region 3 states in the Mid-Atlantic RMN; and Mississippi and Florida, which did not join EPA Region 4 states in the Southeast RMN because they lack the targeted habitat (medium to high gradient, cold, riffle-dominated streams).

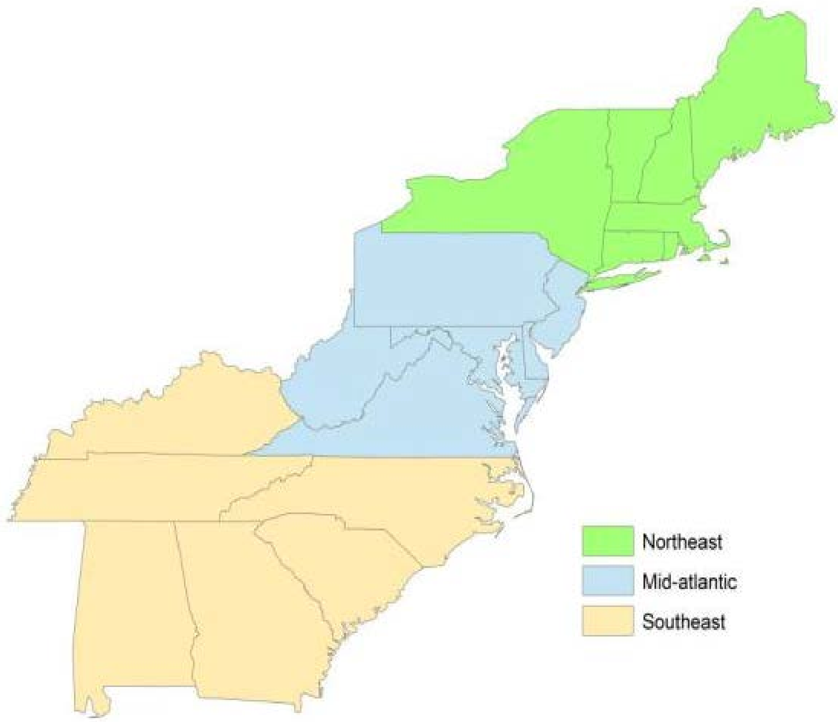


Figure 1-1. States, tribes, river basin commissions (RBCs), and others in three RMN regions (Northeast, Mid-Atlantic, and Southeast) have established regional monitoring networks (RMNs).

The RMNs are designed to detect potentially small trends in biological, thermal, hydrologic, physical habitat and water chemistry data at high quality sites in a decision-relevant timeframe (e.g., 10−20 years to be relevant to climate change). Several states, tribes, RBCs, and others are already collecting annual biological and continuous temperature data at targeted sites, and to a lesser degree, hydrologic data. The goal is to supplement existing efforts like these, and to collect comparable data at a limited number of sites to pool at a regional level. Pooling data enables more robust regional analyses, improves the ability to detect trends over shorter time periods and can inform on changes at a spatial scale similar to climatic changes.

The RMN design calls for sampling at least 30 sites with similar environmental and biological characteristics in each region on an annual basis for 10 or more years, using comparable methods. To help inform this design, EPA and partners performed power analyses on an aggregated biomonitoring data set from the 2012 Northeast pilot study. The power analyses suggest that significant trends in regional community composition can be detected within 10−20 years if 30 or more comparable sites are monitored regularly. A detailed account of these analyses can be found in Appendix A. Design decisions were also informed by literature and standard operating procedures (SOPs) being used by the RMN participants. Efforts are being made to use consistent methods at RMN sites to increase the comparability of data and minimize biases and variability. A Quality Assurance Project Plan (QAPP) has been developed for the RMNs to ensure that participating entities understand the requirements and meet the data quality objectives. Scientific considerations are balanced with practical considerations by participating entities. The RMN framework needs to be flexible enough to tie into existing state and tribal bioassessment efforts and must stay within the resource constraints of its participants.

Data collection in the Northeast, Mid-Atlantic, and Southeast RMNs has been underway for several years, and EPA and partners are starting to use these data in initial evaluations and data analyses. This report describes the development and implementation of these RMNs. It includes information on selection of sites, expectations for data collection, the rationale for collecting these data, and data infrastructure. The report also provides examples of how the RMN data will be used and analyzed. It concludes with a discussion on the status of monitoring activities and next steps.

2. PROCESS FOR SETTING UP THE REGIONAL MONITORING NETWORKS (RMNS)

The Northeast, Mid-Atlantic, and Southeast regions followed similar processes to establish their RMNs. A regional, tribal, or state coordinator formed a working group of interested partners to establish regional goals to determine basic survey bounds, such as selection of a target population (e.g., freshwater wadeable streams with abundant riffle habitat). Working groups selected RMN sites using consistent criteria (see Section 3.1), and selected appropriate data-collection protocols and methodologies (see Section 3.2). As part of this process, working groups considered the site selection criteria and methods being used in the other regions and tried to utilize similar protocols where practical to generate comparable data. The groups then identified logistical, training, and equipment needs and sought resources from agencies such as EPA and the U.S. Geological Survey (USGS) to help address high-priority goals. The regional working groups began implementation several years ago and are starting to use the RMN data in initial evaluations and data analyses. EPA and partners recently developed a generic RMN QAPP that details the core requirements for participation in the network, and outlines best practices for the collection of biological, thermal, hydrologic, physical habitat, and water chemistry data at RMN sites. The regional working groups are in the process of reviewing and approving the QAPP. The EPA and partners are also developing a data management system that will allow participating organizations and outside users to access data and metadata that are being collected at RMN sites (see Section 6). Appendix B includes a step-by-step checklist on the process for developing and implementing RMNs.

3. REGIONAL MONITORING NETWORK (RMN) DESIGN

The RMN design calls for sampling at least 30 sites with similar environmental and biological characteristics in each region on an annual basis for 10 or more years, using comparable methods. In 2011–2012, EPA collaborated with seven states in the northeastern United States on a pilot study that helped lay the groundwork for the RMNs. The goal of the pilot was to design a monitoring network that could detect potentially small trends in biological, thermal, hydrologic, physical habitat and water chemistry data at high quality sites in a decision-relevant timeframe (e.g., 10−20 years to be relevant to climate change). EPA and partners performed power analyses on an aggregated biomonitoring data set from the Northeast to explore questions such as: How long will it take to detect trends in biological metrics? How much of an effect does sampling frequency and classification scheme have on trend detection time? The results suggest that detection times of 10−20 years (at 80% power) are possible for some biological metrics if 30 or more sites with comparable environmental conditions and biological communities are monitored regularly. These results are consistent with a study by Larsen et al. (2004), which found that well-designed networks of 30−50 sites monitored consistently can detect underlying changes of 1−2% per year in a variety of metrics within 10−20 years, or sooner, if such trends are present. The Northeast power analyses are described in detail in Appendix A.

3.1. SITE SELECTION

Sampling efforts at the RMNs are concentrated at a core group of sites called "primary" sites, where efforts are being made to collect the full suite of biological, thermal, hydrologic, physical habitat and water chemistry data (see Section 3.2). The working groups selected 2 to 15 primary sites per state (depending on the size of the state and availability of resources), with the overall goal of sampling at least 30 primary sites in each RMN region. The site selection process takes into account numerous considerations, which are summarized in Table 3-1. Efforts were made to select sites that had as many of the desired characteristics listed in Table 3-1 as possible. Appendix C lists the primary RMN sites in each region as of September 2015.

Table 3-1. Main considerations when selecting primary sites for the regional monitoring networks (RMNs)

Consideration	Desired characteristics at primary sites
Existing monitoring network	Located in established long-term monitoring networks to build upon data already being collected by states, tribes, RBCs, and others.
Disturbance	Low level of anthropogenic disturbance.
Equipment	Colocated with existing hydrologic equipment (e.g., USGS gage, weather station).
Classification	Sites exhibit similar environmental and biological characteristics, which minimizes natural variability across sites, improves power for detecting long-term trends and allows for pooling of data within and across regions.
Longevity	Accessible (e.g., day trip), opportunities to share the workload with outside agencies or organizations.
Sampling record	Lengthy historical sampling record for biological, thermal, or hydrological data.
Potential for future disturbance	Located in watersheds that are protected from future development.

Where feasible, organizations colocated RMN sites with existing stations like USGS gages or in established long-term monitoring networks such as the sentinel networks of the Vermont Department of Environmental Conservation (VT DEC), the Connecticut Department of Energy and Environmental Protection (CT DEEP), Maryland Department of Natural Resources (MD DNR), West Virginia Department of Environmental Protection (WV DEP), and Tennessee Department of Environment and Conservation, continuous monitoring stations of the Susquehanna River Basin Commission, and USGS networks, such as the Northeast Site Network and the Geospatial Attributes of Gages for Evaluating Streamflow (GAGES-II) program. Some of these sites have lengthy historical records, which are preferred for primary RMN sites.

Efforts were made to select minimally disturbed or least disturbed sites (per Stoddard et al. 2006). High quality waters are being targeted because they are the standard against which other bioassessment sites are compared. It is critical to document current conditions at high quality sites and to track changes at these sites over time to understand how benchmarks may be shifting in response to changing environmental and climatic conditions. EPA and partners developed a standardized procedure for characterizing the present-day level of anthropogenic disturbance and applied this across RMNs so that sites from all states and regions are rated on a common scale (see Appendix D). Sites are screened for likelihood of impacts from land use disturbance, dams, mines, point-source pollution and other factors.

The selection criteria also prioritize sites that exhibit similar environmental and biological characteristics, as this helps reduce natural variability across sites (which improves power for detecting long-term trends) and allows for pooling of data within and potentially across regions. The Southeast working group used ecoregions during the initial site selection process because ecoregions dominate the reference-site-stratification approach used by many programs for assessing streams (Carter and Resh, 2013). Most of the RMN sites in the Southeast are located in ecoregions with hilly or mountainous terrain (e.g., Piedmont, Blue Ridge, Central, and North Central Appalachians), where streams generally have higher gradients and more riffle habitat. In the Northeast and Mid-Atlantic regions, size and gradient were key classification variables (see Appendix A).

To further inform stream classification, EPA performed a broad-scale analysis on macroinvertebrate survey data from the EPA National Aquatic Resource Surveys (NARS) program.[3] The data set included minimally disturbed freshwater wadeable stream sites from the Northeast, Mid-Atlantic, and Southeast regions. A cluster analysis was performed, and sites were grouped into three classes based on similarities in taxonomic composition. EPA then developed a model based on environmental variables to predict the probability of occurrence of the three classes in watersheds in the eastern United States. The three classes are referred to as: (1) small to medium size, medium to high gradient, colder temperature; (2) small, low gradient; and (3) warmer temperature, larger size, lower gradient. Most of the primary RMN sites that were selected fall within the small to medium size, medium to high gradient, colder temperature stream class. On average, sites in this stream class have higher numbers of cold water taxa, which improves the likelihood of detecting temperature-related trends in this thermal indicator metric over shorter time periods (see Appendix A).

There were several additional site selection considerations. Where feasible, sites with low potential for future development were selected because future alterations could limit trend detection power as well as the ability to characterize climate-related impacts at RMN sites. Participants utilized what they felt were the best, most current data to assess potential for future development. The Northeast utilized a spatial data set provided by The Nature Conservancy (TNC)[4] that showed public and private lands and waters secured by a conservation agreement. Other RMN members contacted city planners and personnel from transportation and forestry departments to obtain information about the likelihood of future urban and residential development, road construction, and logging or agricultural activities.

Practical considerations were also important during the site screening process. For example, organizations generally selected sites that could be sampled during a day trip and were easy to access, which are factors that will likely increase the frequency at which sites can be visited. More sites visits may improve the quality of data being collected (particularly the

---

[3]Data available at http://water.epa.gov/type/rsl/monitoring/riverssurvey/index.cfm.
[4]Secured lands data set available at https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/secured/Pages/default.aspx.

hydrologic data). Sites were prioritized if they were colocated with existing equipment, such as USGS gages, or if there were opportunities to share the workload with outside agencies or organizations. Efforts have been made to partner with national monitoring programs, such as the EPA NARS, Long Term Ecological Research Network and the National Ecological Observatory Network. For various reasons (e.g., sites are not revisited annually, sites are not located in same stream class), sites that are being sampled for these programs have not been selected as primary RMN sites, but EPA and partners are continuing to seek opportunities for collaboration with these and other potential partners.

Data from additional, “secondary,” sites are also being considered for the RMNs. These are sites at which a subset of parameters are already being collected in accordance with RMN protocols as part of other independent monitoring efforts. Data from secondary sites will increase the sample size and range of conditions represented in the RMN data set, and may provide information about unique or underrepresented geographic areas, such as the New Jersey Pine Barrens or the Coastal Plain ecoregion. Appendix E lists the candidate secondary RMN sites in each region as of September 2015.

3.2. METHODS FOR DATA COLLECTION

Efforts are being made to collect the following types of data (consistent with existing programs and scientific literature) from RMN sites:

- **Biological indicators:** macroinvertebrates
  - Optional: fish and periphyton, if resources permit (fish are higher priority)
- **Temperature:** continuous water and air temperature (30-minute intervals)
- **Hydrological:** continuous water-level data (15-minute intervals); converted to discharge if resources permit
- **Habitat:** parameters agreed upon by regional working group
- **Water chemistry:** in situ, instantaneous water chemistry parameters (specific conductivity, dissolved oxygen, pH), plus additional or more comprehensive water chemistry measures agreed upon by regional working group
- **Photodocumentation:** photographs taken from the same locations during each site visit
- **Geospatial data:** percentage land use and impervious cover, climate, topography, soils, and geology, if resources permit

The goal is to use methods that will maximize the likelihood of detecting subtle changes over as short a time period as possible, while staying within the resource constraints of participating organizations. EPA and partners used results from the Northeast power analyses (see Appendix A), literature and SOPs from participating organizations to help inform methods decisions. Efforts are being made to use as consistent and comparable methods as possible since different methodologies may introduce biases in analyses and contribute to variability, which reduces the sensitivity of indicators and increases trend detection times.

During the initial phases of RMN development, the regional working groups agreed upon methods to use at primary RMN sites. These methods are summarized in Appendix F. EPA and partners recently developed a generic RMN QAPP that details the core requirements for participation in the network, and outlines best practices for the collection of biological, thermal, hydrologic, physical habitat, and water chemistry data at RMN sites. The QAPP is available online at http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=295758&inclCol=eco#tab-3. The regional working groups are in the process of reviewing and approving the QAPP, and are customizing it for their regions via addendums.

The ability of some participants to use the regional RMN methods has been limited by resource constraints, so there have been differing levels of effort and in some situations, differing methods across sites and organizations. While this is not ideal, the data can still be used, just in more limited ways. The data management system that EPA and partners are developing (see Section 6) will contain metadata that will enable users to select data that meet their needs (e.g., collected using certain methods and at certain levels of rigor). To account for the differing levels of effort across sites and organizations, EPA and partners have broken the sampling methodologies down into different elements, and different levels of rigor are established for each element. Examples of elements include type of habitat sampled, gear type, frequency of data collection, level of taxonomic resolution, level of expertise of field and laboratory personnel, and quality assurance/quality control (QA/QC) procedures. There are four levels of rigor in the RMN framework, with Level 1 being the lowest and Level 4 being the best/highest standard (see Table 3-2). Level 3 is the target for primary RMN sites. These elements and levels of rigor are covered in more detail in Sections 3.2.1 through 3.2.7.

Table 3-2. There are four levels of rigor in the regional monitoring network (RMN) framework, with Level 1 being the lowest and Level 4 being the best/highest standard. Level 3 is the target for primary RMN sites.

Level	Usability for RMNs
1	Data are usable under certain or limited circumstances. Data are not collected and processed in accordance with methods agreed upon by the regional working group, which severely limit the data's usefulness.
2	Data are usable under some, but not all circumstances. Only certain aspects of sample collection and processing are done using the protocols that are agreed upon by the regional working group, which limit the data's usefulness.
3	Data meet the desired level of rigor. They are collected in accordance with the methods that are agreed upon by the regional working group. Where methodological differences exist, steps have been taken to minimize biases, and data are sufficiently similar to generate comparable indicators and meet RMN objectives.
4 (optional)	Data exceed expectations. Data include optional high-quality data and meet or exceed the desired level of rigor agreed upon by the regional working group.

3.2.1. BIOLOGICAL INDICATORS

Collection of multiple assemblages (macroinvertebrates, fish, periphyton) at RMN sites is encouraged. At a minimum, macroinvertebrates should be collected at the primary RMN sites. Collections from this assemblage are central to the RMNs because macroinvertebrates are already collected by participating states, tribes, RBCs, and other agencies for a variety of other purposes. For example, macroinvertebrates are crucial for quantifying stream condition because (1) the assemblage responds to a wide range of stressors, (2) many (not all) are easily and consistently identified, and (3) they have limited mobility, short life cycles, and are highly diverse. Guidelines for collecting macroinvertebrates, fish, and periphyton can be found in Sections 3.2.1.1, 3.2.1.2, and 3.2.1.3, respectively.

Data collection should be done by trained personnel (see Table 3-3) because formal training can have a large impact on observer agreement and repeatability and can reduce assessment errors (e.g., Herlihy et al., 2009; Haase et al., 2010). Repeatability is particularly important for RMNs because data are gathered from multiple sources. Ideally, participating organizations should adhere to the sample collection and processing protocols that are agreed upon by the regional working group. Some of these guidelines include QA/QC procedures, which improve data quality (Stribling et al., 2008; Haase et al., 2010). Example QA/QC procedures include collecting replicate samples in the field, conducting audits to ensure that crews are adhering to collection and processing protocols, replicate subsampling (meaning after subsampling occurs, the subsample is recombined with the original sample and subsampled again), and validating taxonomic identifications at an independent laboratory.

Table 3-3. Recommendations on best practices for collecting biological data at regional monitoring network (RMN) sites. The RMN framework has four levels of rigor for biological sampling, with 4 being the best/highest and 1 being the lowest. At primary RMN sites, RMN members should try to adhere to (at a minimum) the Level 3 practices, which are in bold italicized text.

Component	1 (lowest)	2	3	4 (highest)
Expertise	Work is conducted by a novice or apprentice biologist or by untrained personnel	Work is conducted by a novice or apprentice biologist under the direction of a trained professional	***Work is conducted by a trained biologist who has some prior experience collecting the assemblage of interest***	Work is conducted by a trained biologist who has multiple years of experience collecting the assemblage of interest
Collection and processing	Some but not all of the recommended data are collected. Not all aspects of sample collection and processing use protocols agreed upon by the regional working group	All of the recommended data are being collected, but not all aspects of sample collection and processing use protocols agreed upon by the regional working group	***All of the recommended data are being collected. All aspects of sample collection and processing use protocols agreed upon by the regional working group***	In addition to the minimum recommended data, optional data are also being collected. All aspects of sample collection and processing use protocols agreed upon by the regional working group
QA/QC	No QA/QC procedures are performed	Some but not all QA/QC procedures agreed upon by the regional working group are performed	***All of the QA/QC procedures agreed upon by the regional working group are performed***	QA/QC procedures that are more stringent than those being used by the regional working group are performed

3.2.1.1. *Macroinvertebrates*

Developing recommendations on macroinvertebrate sampling protocols is challenging because organizations use different collection and processing protocols when they sample macroinvertebrates, and each entity's biological indices are calibrated to data that are collected and processed using these methods. When developing best practices at RMN sites, efforts were made to accommodate differences in sampling methodologies within regions (see Appendix F) while still providing data that are sufficiently similar that they can be used to generate comparable indicators at the regional level, and to minimize variability where possible.

At primary RMN sites, macroinvertebrate sampling should be conducted at least once annually (see Table 3-4). The Northeast power analyses showed that sampling frequency (1 vs. 2 vs. 5-year intervals) had a significant effect on trend detection time. Sampling macroinvertebrates on an annual basis improves trend detection times, particularly if trends are subtle (see Appendix A). Annual data are also important for quantifying temporal variability. As discussed in Section 5, the data will help us to better understand how natural variability affects the consistency of biological condition scores and metrics from year to year, and how this relates to changing thermal and hydrologic conditions.

In the Northeast, Mid-Atlantic and Southeast RMNs, macroinvertebrate samples are being collected in reaches with abundant riffle habitat (see Table 3-4). Cold water taxa, which are of particular interest due to their potential vulnerability to climate change, typically inhabit riffles. Furthermore, riffle habitat is being targeted because sample consistency is strongly associated with the type of habitats sampled (Parson and Norris, 1996; Gerth and Herlihy, 2006; Roy et al., 2003). Recent methods comparison studies indicate that where abundant riffle habitat is present, single habitat riffle, reach-wide, and multihabitat samples generally produce comparable classifications and assessments, especially when fixed counts and consistent taxonomy are used (e.g., Vinson and Hawkins, 1996; Hewlett, 2000; Ostermiller and Hawkins, 2004; Cao et al., 2005; Gerth and Herlihy, 2006; Rehn et al., 2007; Blocksom et al., 2008). While sampling at RMN sites is focused primarily on riffles, other habitats are also of interest. In the Southeast region, in addition to collecting quantitative samples from riffle habitat, some organizations are also collecting qualitative samples from multiple habitats. They are keeping taxa from the different habitats separate, which provides information on how changing thermal and hydrologic conditions impact taxa in nonriffle habitats. For example, taxa in edge habitats may show a greater response to extended summer low flow events than taxa in riffles because the edge habitats are more likely to go dry.

Table 3-4. Recommendations on best practices for collecting macroinvertebrate data at Northeast, Mid-Atlantic and Southeast regional monitoring network (RMN) sites. The RMN framework has four levels of rigor for macroinvertebrate sampling, with 4 being the best/highest and 1 being the lowest. At primary RMN sites, RMN members should try to adhere to (at a minimum) the Level 3 practices, which are in bold italicized text.

Component	1 (lowest)	2	3	4 (highest)
Sampling frequency	Site is sampled every 5 or more years	Site is sampled every 2−4 years	***Site is sampled annually***	Site is sampled more than once a year (e.g., spring and summer)
Habitat	No riffle habitat	Multihabitat composite from a sampling reach with scarce riffle habitat	***Abundant riffle habitat***	Multihabitat sample with taxa from each habitat kept separate
Time period	Time period varies from year to year, and adjustments are NOT made for temporal variability	Time period varies from year to year, but adjustments are made for temporal variability	***Adherence to a single time period***	Samples are collected during more than one time period (e.g., spring and late summer/early fall)
Fixed count subsample	Presence/absence or field estimated categorical abundance (e.g., rare, common, abundant, dominant)	Fixed count with a target of 100 or 200 organisms	***Fixed count with a target of 300 organisms***	Fixed count with a target of more than 300 organisms
Processing	Organisms are sorted, identified and counted in the field	Samples are processed in the laboratory by trained individuals. Some but not all aspects of sample processing use methods that are agreed upon by the regional working group	***Samples are processed in the laboratory by trained individuals and use methods that are agreed upon by the regional working group***	Samples are processed in the laboratory by trained individuals and use methods that are more stringent than those being used by the regional working group

Table 3-4. continued…

Component	1 (lowest)	2	3	4 (highest)
Sorting efficiency	No checks on sorting efficiency	Sorting efficiency checked internally by a trained individual	***Sorting efficiency checked internally by a taxonomist***	Sorting efficiency checked by an independent laboratory
Qualifications	Identifications are done by a novice or apprentice biologist with no certification	Identifications are done by an experienced taxonomist without certification	***Identifications are done by a trained taxonomist who has the appropriate level of certification***	Identifications are done by a certified taxonomist who is recognized as an expert in species-level taxonomy for one or more groups
Taxonomic resolution	Coarse resolution (e.g., order/family)	Mix of coarse and genus-level resolution (e.g., family-level Chironomidae, genus-level Ephemeroptera, Plecoptera, and Trichoptera [EPT])	***Mix of species and genus level. Identifications are done to the level of resolution specified in Appendix G***	Species level for all taxa, where practical
Validation	No validation	Taxonomic checks are performed internally but not by an independent laboratory. The entire subsample (referred to as a “voucher sample”) is retained for each site.	***Taxonomic checks are performed internally but not by an independent laboratory. The entire subsample (referred to as a “voucher sample”) is retained for each site as well as a reference collection with each unique taxon***	Taxonomic checks are performed by an independent laboratory. The entire subsample (referred to as a “voucher sample”) is retained for each site, as well as a reference collection with each unique taxon verified by an outside expert

At primary RMN sites, macroinvertebrate sampling should occur during a consistent time period to minimize the variability associated with seasonal changes in the composition and abundances of stream biota and to allow for more efficient trend detection (Olsen et al., 1999). At RMN sites, samples should be collected during the same time period (or periods) each year, ideally within 2 weeks of a set collection date (see Table 3-4). If flooding or high water prevents sample collection within the specified time period, samples should be taken as closely to the target period as possible. In addition to taxonomic consistency, samples collected during the same time period can be used to explore whether long-term changes in continuous thermal and hydrologic measurements are occurring during the target period. For example, streams that were once perennial may become intermittent during a late summer or early fall sampling period, or changes in thermal and hydrologic conditions could result in lower abundances or replacement of certain taxa, which could affect biological condition scores.

In the Northeast RMN, sampling is taking place during a summer/early fall (July−September) index period because this range overlaps with existing state index periods and because environmental conditions in the spring are generally not conducive to sampling (e.g., potential ice cover). In the Southeast RMN, macroinvertebrate samples are being collected in April, with some states adding a September sample. States and RBCs in the Mid-Atlantic RMN are currently collecting samples in both spring and summer, as resources permit. The spring index period is being restricted to March−April and the summer index period to July−August because this range overlaps with existing state and RBC index periods and reduces potential temporal variability to a 2-month window. In the future, if only one collection is possible in the Mid-Atlantic RMN, the spring index period is preferred because preliminary data suggest that on average, assemblages are comprised of slightly higher proportions of cold water taxa and individuals in the spring (see Figure 3-1).

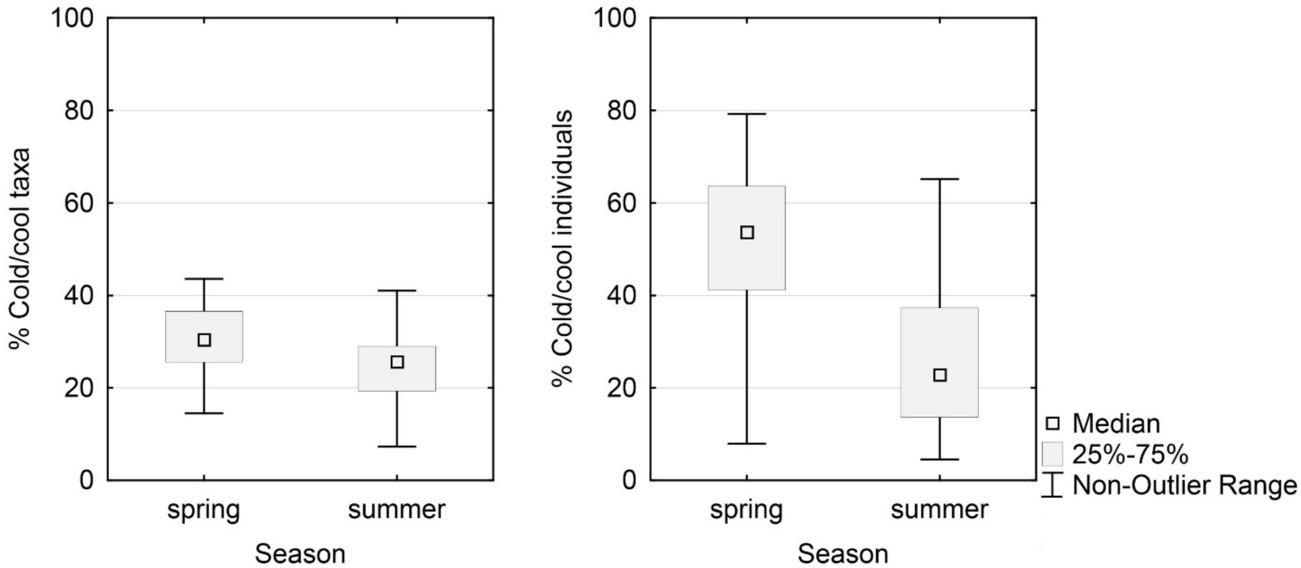


Figure 3-1. Seasonal differences (spring vs. summer) in percentage cold water taxa and individuals in the Mid-Atlantic 2014 data.

When macroinvertebrate samples from primary RMN sites are processed, subsampling should be performed in a laboratory by trained personnel. Participating organizations should perform fixed counts with a target of 300 (or more) organisms to reduce sample variability and ensure sample comparability (see Table 3-4). Consistent subsampling protocols are important because sampling effort and the subsampling method can affect estimates of taxonomic richness (Gotelli and Graves, 1996), taxonomic composition, and relative abundance of taxa (Cao et al., 1997). The 300-organism target is larger than what is specified in some state, tribal, and RBC methods. The purpose of using this larger fixed count is to increase the probability of collecting cold water indicator taxa that are rarer and to improve the chances of detecting trends in richness metrics over shorter time periods, as suggested in the Northeast pilot study (see Appendix A). Having a 300-organism or higher target is further supported by the species accumulation curve shown in Figure 3-2. The curve, which is based on preliminary 2014 data from the Mid-Atlantic RMN, shows that the larger the subsample size, the higher the richness of the thermal indicator taxa. If organizations normally use lower fixed targets (e.g., 100- or 200-count samples) for their assessments, computer software can be used to randomly subsample 300- or higher-count samples to those lower targets.

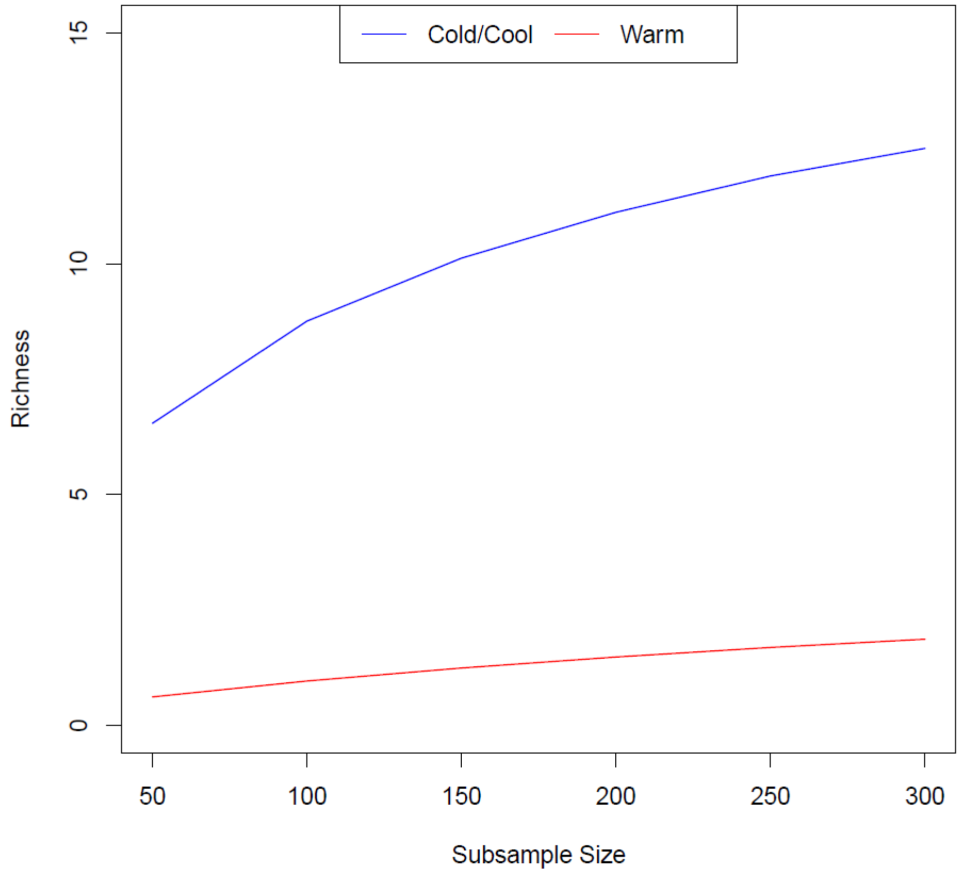


Figure 3-2. Species accumulation curve based on the Mid-Atlantic 2014 data. The larger the subsample size, the higher the richness of thermal indicator taxa.

Taxa collected at primary RMN sites should be identified to the lowest practical taxonomic level (see Table 3-4). Research has shown that finer levels of taxonomic resolution can discriminate ecological signals better than coarse levels (Lenat and Resh, 2001; Waite et al., 2000; Feio et al., 2006; Hawkins, 2006). If this level of resolution is not possible, efforts should be made to conform to the taxonomic resolution recommendations contained in Appendix G. These call for genus-level identifications (where possible) for Ephemeroptera, Plecoptera, Trichoptera, Chironomidae, and Coleoptera and specify certain genera within these taxonomic groups that should be taken to the species level. These genera were selected because they are believed to be good thermal indicators and have shown variability in thermal tolerances at the species level (U.S. EPA, 2012a). Following these recommendations will increase the chances of detecting temperature-related signals over shorter time periods at RMN sites, and will provide important information about which taxa are most sensitive to changing thermal conditions. The recommendations in Appendix G should be regarded as a starting point subject to revision as better data become available in the future.

High-quality taxonomy is a critical component of credible ecological research, and taxonomic identifications for RMN samples should be done by a trained taxonomist who has the appropriate level of certification (see Table 3-4). Analyses have shown that the magnitude of taxonomic error varies among taxa, laboratories and taxonomists, and that the variability can affect interpretations of macroinvertebrate data (Stribling et al., 2008). Sources of these errors include incorrect interpretation of technical literature, recording errors, and vague or coarse terminology, as well as differences in nomenclature, procedures, optical equipment, and handling and preparation techniques (Stribling et al., 2003; Dalcin, 2004; Chapman, 2005). Experience and training can prevent many of these errors (Haase et al., 2006; Stribling et al., 2008). A reference collection of each unique taxon should be housed by each agency and made available for verification or comparison. The entire fixed count subsample (referred to as “voucher samples”) for each primary RMN site should be preserved and archived. When a unique taxon is removed from a voucher sample for the reference collection, it must be clearly documented. Reference collections and voucher samples will be particularly important for RMN samples because identifications often will be made by different taxonomists. If resources permit, a subset of samples should be checked by a taxonomist from an independent laboratory to validate the identifications and ensure consistency across organizations.

The collection of certain types of demographic or life history data could reduce the amount of time needed to detect changes in biological indicators because these traits may respond to climate change earlier than species richness and abundance (Sweeney et al., 1992; Hogg and Williams, 1996; Harper and Peckarsky, 2006). Examples include rates of development, size structure, timing of emergence, and voltinism. More importantly, the frequency and occurrence of the traits themselves can be linked to environmental conditions and used to predict vulnerability of other species (e.g., Townsend and Hildrew, 1994; Statzner et al., 1994; Townsend et al., 1997; Richards et al., 1997; van Kleef et al., 2006; Poff et al., 2006). It is also worth considering qualitative collections of adult insects to verify or assist in species identification. At this time, the collection of these types of ancillary data at RMN sites is optional, and any discussions of additional sampling should consider the costs and benefits of the data for the states, tribes, or RBCs and RMN objectives.

When developing the macroinvertebrate methods for the RMNs, the intent was to balance the need to generate comparable data that meets RMN objectives with generating data that has value for individual RMN member’s routine bioassessment programs. Without additional resources and training, some organizations will not be able to attain these levels of rigor on a consistent, long-term basis. For example, some organizations will not be able to follow the regional protocols for the 300-organism count and species-level identifications. Instead, they will likely follow their normal processing protocols, with counts of 100 or 200 organisms and genus-level identifications. Reduced counts and coarser level identifications, in particular, are likely to affect the richness metrics (Stamp and Gerritsen, 2009; also see Figure 3-2).

RMN members should collect each sample using the method agreed upon by the regional working group and retain this sample, even if the organization lacks sufficient resources to count

300 organisms and perform species-level identifications at this time, since funds may become available at a future date to process samples in accordance with the RMN protocols. RMN members should periodically refresh these samples with preserving agent so that specimens remain in good enough condition to later be identified. In some cases, regional coordinators may be able to obtain funding to cover the costs of macroinvertebrate sample processing and species-level identifications at a common laboratory. For example, EPA Region 3 was able to achieve this during the 2014 sampling season for the Mid-Atlantic RMN members. Even if this can only be done for one year, it serves to establish valuable baseline information.

If the RMN protocols differ from those that are normally used by RMN members, EPA and partners are exploring the possibility of conducting methods comparison studies at a subset of sites. This could involve the collection of side-by-side samples using the different methods. After the paired samples are processed using the respective methods, results would be compared and differences between the methods could be quantified.

3.2.1.2. *Fish*

The collection of fish at RMN sites is optional but encouraged. Fish are considered to be a higher priority assemblage than periphyton at RMN sites because fish are routinely collected by monitoring programs, are easily and consistently identified, and are often species of economic and social importance. Further, the data can be obtained without a significant amount of further sample processing, making this assemblage a cost-effective group to analyze, and the behavioral and physiologic traits can be linked to environmental conditions. Many organizations have strong interests in protecting fisheries, and numerous studies are being done to predict and monitor how fish distributions will change in response to climate change (e.g., Clark et al., 2001; Flebbe et al., 2006; Trumbo, 2010; Wenger et al., 2011). Best practices for fish collection at RMN sites are shown in the following list.

- Participating organizations should follow the protocols that are agreed upon by the regional working group. At this time, only the Southeast region is consistently collecting fish data. Because fish sampling protocols are similar across organizations in this region, the Southeast regional working group agreed to let organizations use their own standard operating procedures. If organizations in other regions start to sample fish on a regular basis, this topic should be revisited and the working groups should take an in-depth look at the comparability of fish sampling protocols within and across regions.

- There should be strict adherence to an index period (or periods).

- Species-level identifications should be done (where practical) by a trained fish taxonomist.

- A reference collection of each unique taxon should be housed by each agency and be made available for verification or comparison.

3.2.1.3. *Periphyton*

The collection of periphyton at RMN sites is optional but encouraged, as periphyton are important indicators of stream condition and stressors (Stevenson, 1998; McCormick and Stevenson, 1998). At this time, the Southeast is the only region that has written guidelines for periphyton collection. Their sampling protocols follow the Southeastern Plains instream nutrient and biological response protocols (U.S. EPA, 2006) or equivalent. They strictly adhere to a spring index period and have a subsampling target of 600 valves (300 cells). Species-level identifications are being done (where practical) by a qualified taxonomist, and reference collections of unique taxa are being retained. The protocols also recommend that the EPA rapid periphyton survey field sheet or equivalent be completed (Barbour et al., 1999).

If organizations from other RMNs start to collect periphyton, they should follow the protocols that are agreed upon by their regional working group. If standardized regional protocols are not used, the methods that each entity uses should be detailed and well documented. With periphyton, some programs have encountered problems with taxonomic agreement among different laboratories and taxonomists, so steps should be taken to ensure consistency in taxonomic identifications (e.g., send all samples to the same laboratory, photodocument taxa in reference collections, conduct taxonomic checks with an independent laboratory).

3.2.2. TEMPERATURE DATA

Some states, tribes, and RBCs have been early adopters of continuous temperature sensor technology and have written their own protocols for deploying these sensors. In an effort to increase comparability of data collection across states and regions, EPA and collaborators published a document on best practices for deploying inexpensive temperature sensors (U.S. EPA, 2014). The best practices for collecting temperature data at RMN sites closely follow these protocols.

At primary RMN sites, both air and water temperature sensors should be deployed (see Table 3-5). Together, the air and water temperature readings can be used to gain a better understanding of the responsiveness of stream temperatures to air temperatures (also referred to as thermal sensitivity), and provide insights into the factors that influence the vulnerability of streams to thermal change (see Section 5). Air temperature readings are also used for quality control (e.g., to determine when water temperature sensors are dewatered; Bilhimer and Stohr, 2009; Sowder and Steel, 2012).

Table 3-5. Recommendations on best practices for collecting temperature data at regional monitoring network (RMN) sites. The RMN framework has four levels of rigor for temperature monitoring, with 4 being the best/highest and 1 being the lowest. At primary RMN sites, RMN members should try to adhere to (at a minimum) the Level 3 practices, which are in bold italicized text.

Component	1 (lowest)	2	3	4 (highest)
Equipment	No temperature sensors	Water temperature sensor only	***Air and water temperature sensors***	Air temperature sensor plus multiple water temperature sensors to measure reach-scale variability
Period of record	Single measurement/s taken at time of biological sampling event	Continuous measurements taken seasonally (e.g., summer only) at intervals of 90 minutes or less	***Continuous measurements taken year-round at 30-minute intervals***	Continuous measurements taken year-round at intervals of less than 30 minutes
Radiation shield	Not installed	Installed; the shield is made using an untested design (its effectiveness has not been documented)	***Installed; the shield is made using a design that has undergone some level of testing to document its effectiveness***	Installed; the shield is made using a design that has been tested year-round, under a range of canopy conditions
QA/QC—sensor accuracy	No accuracy checks are performed	No accuracy checks are performed	***Predeployment accuracy check is performed, along with any other QA/QC checks that are agreed upon by the regional working group***	In addition to the predeployment accuracy check, the following checks are also performed: initial deployment, mid-deployment, biofouling, and postdeployment[a]

[a]For more details, see the QAPP (U.S. EPA, 2016. Generic Quality Assurance Project Plan for monitoring networks for tracking long-term conditions and changes in high quality wadeable streams), which is available online at http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=295758&inclCol=eco#tab-3.

Temperature measurements at RMN sites should be taken year-round at 30-minute intervals (see Table 3-5). Year-round data are necessary to fully understand thermal regimes and how these regimes relate to aquatic ecosystems (U.S. EPA, 2014). Radiation shields should be installed for both water and air temperature sensors (see Table 3-5) to prevent direct solar radiation from hitting the temperature sensors and biasing measurements (Dunham et al., 2005; Isaak and Horan, 2011). The shields also serve as protective housings. Shield effectiveness varies by design (Holden et al., 2013), so it is suggested that organizations use tested designs (see Table 3-5). If a new design is used, organizations should test and document design performance. This can be done using techniques like those described in Isaak and Horan (2011) and Holden et al. (2013).

To ensure that data meet quality standards, at a minimum, predeployment accuracy checks should be performed. In addition, participants are encouraged to perform initial deployment, mid-deployment, biofouling and postdeployment checks. These types of QA/QC checks are important because sensors may record erroneous readings during deployment for a variety of reasons, such as being dewatered or buried in silt. The QA/QC checks improve data quality and allow for data to be corrected (if needed). The QAPP contains more detailed information on these checks.

3.2.3. HYDROLOGIC DATA

Many of the primary RMN sites are located on smaller, minimally disturbed streams with drainage areas less than 100 km^2. Monitoring flow in headwater and mid-order streams is important because flow is considered a master variable that effects the distribution of aquatic species (Poff et al., 1997), and small streams in particular play a critical role in connecting upland and riparian systems with river systems (Vannote et al., 1980). These small upland streams, which are inhabited by temperature sensitive organisms, are also projected to experience substantial climate change impacts (Durance and Ormerod, 2007), though some habitats within these streams will likely serve as refugia from the projected extremes in temperature and flow (Meyer et al., 2007).

The USGS has been measuring flow in streams since 1889, and currently maintains over 7,000 continuous gages. This network provides long-term, high quality information about our nation’s streams and rivers that can be used for planning and trend analysis (e.g., flood forecasting, water allocation, wastewater treatment, and recreation). Efforts have been made to colocate RMN sites with active USGS gages, but many gages are located in large rivers that have multiple human uses, so only a limited number meet the site selection criteria for the primary RMN sites. As such, it is necessary to collect independent hydrologic data at most RMN sites.

A common way to collect hydrologic data at ungaged sites is with pressure transducers. If installed and maintained properly, pressure transducers will provide important information on the magnitude, frequency, duration, timing, and rate of change of flows. These devices can pose challenges. For one, pressure transducers are more expensive than the temperature sensors, which makes it more difficult for RMN participants to purchase the equipment. Then, if participants are successful at obtaining the transducers, they need the expertise to install and operate the equipment, and also need resources to conduct QA/QC checks to ensure that the data meet quality standards. Because of these challenges, some participating organizations have adopted a "phased" approach, in which they start by installing pressure transducers at one or two RMN sites (instead of all sites at once), and add more as they gain experience and as resources permit.

When pressure transducers are installed at RMN sites, efforts should be made to follow the recommendations in Table 3-6. These closely follow the protocols described in the recently published EPA best practices document on the collection of continuous hydrologic data using pressure transducers (U.S. EPA, 2014). Transducer measurements should be taken year-round[5] (see Table 3-6). The transducers should be encased in housings to protect them from currents, debris, ice, and other stressors. Staff gages should also be installed to allow for instantaneous readings in the field, verification of transducer readings, and correction of transducer drift (see Figure 3-3, Table 3-6).

When the pressure transducer is installed, the elevation of the staff gage and pressure transducer should be surveyed to establish a benchmark or reference point for the gage and transducer (see Table 3-6). This benchmark allows for monitoring of changes in the location of the transducer, which is important because if the transducer moves, water-level data will be affected and corrections will need to be applied (see Figure 3-3). While water-level measurements alone yield information about streamflow patterns, including the timing, frequency, and duration of high flows (McMahon et al., 2003), they do not give quantitative information about the magnitude of streamflows or flow volume, which makes it difficult to compare hydrologic data across streams.

If agencies have the resources to convert water-level measurements to streamflow (e.g., volume of flow per second), the most common approach is to develop a stage-discharge rating curve. To develop a rating curve, a series of discharge (streamflow) measurements are made at a variety of stages, covering as wide a range of flows as possible. The EPA best practices document (U.S. EPA, 2014) contains basic instructions on how to take discharge measurements in wadeable streams. More detailed guidance on this topic can be found in documents like Rantz et al. (1982), Shedd (2011), or Chase (2005). After establishing a rating curve, discharge should be measured quarterly. If resources don't permit quarterly measurements, discharge should be measured at least once annually, and if possible, also after large storms and other potentially channel-disturbing activities. In addition, elevation surveys should be performed annually or as needed to check that the sensor has not moved.

[5]In places where streams become completely frozen during the winter, pressure transducers may be removed during winter months if freezing will result in damage to the equipment.

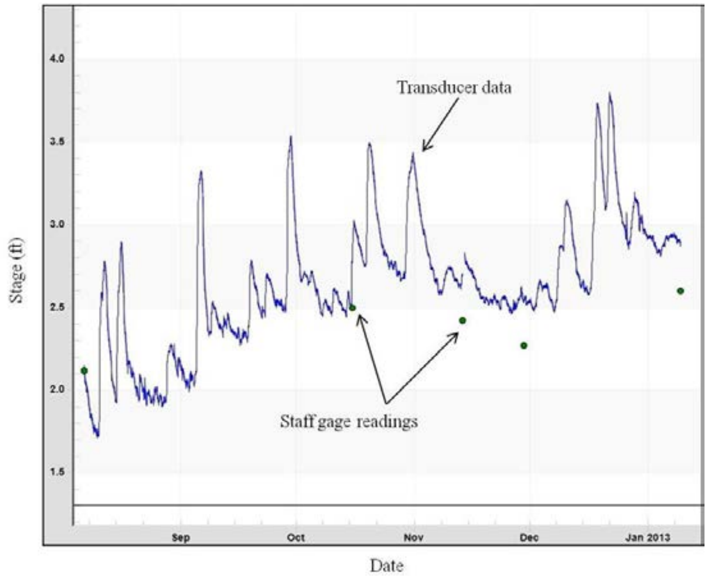


Figure 3-3. Staff gage readings provide a quality check of transducer data. In this example, staff gage readings stopped matching transducer readings in November, indicating that the transducer or gage may have changed elevation.

Table 3-6. Recommendations on best practices for collecting hydrologic data at regional monitoring network (RMN) sites. The RMN framework has four levels of rigor for hydrologic monitoring, with 4 being the best/highest and 1 being the lowest. At primary RMN sites, RMN members should try to adhere to (at a minimum) the Level 3 practices, which are in bold italicized text.

Component	1 (lowest)	2	3	4 (highest)
Equipment	Pressure transducer, water only; no staff gage	Pressure transducer, water and air (encased in housings); no staff gage	***Pressure transducer, water and air (encased in housings); staff gage installed***	Same as Level 3, plus a precipitation gage or USGS gage
Type of data	Stage/water level only; data are not corrected for barometric pressure	Stage/water level only; data are corrected for barometric pressure	***Stage/water level corrected for barometric pressure. In addition, a minimum of 5–10 discharge measurements are taken at a variety of flow conditions to develop a stage-discharge rating curve. The stage-discharge rating curve is used to convert water level to flow/discharge***	Stage/water level corrected for barometric pressure. In addition, 10 or more discharge measurements that capture the full range of flow conditions are taken to develop a stage-discharge rating curve. The stage-discharge rating curve is used to convert water level to flow/discharge.
Period of record	Discharge measurements taken with flow meter at time of biological sampling event	Continuous measurements taken seasonally (e.g., summer only)	***Continuous measurements taken year-round***[a]	Continuous measurements taken year-round[a]
Elevation survey	Not performed	Performed once, at time of installation	***Performed annually***	Performed more than once a year, as needed (e.g., if a storm moves the sensor and it has to be redeployed)

Table 3-6. continued…

Component	1 (lowest)	2	3	4 (highest)
QA/QC—sensor accuracy	No accuracy checks are performed	No accuracy checks are performed	***At least once annually, field crews take a staff gage reading or water depth measurement over the transducer with a stadia rod or other measuring device and compare this to the sensor reading***	***Multiple times per year, field crews take a staff gage reading or water depth measurement over the transducer with a stadia rod or other measuring device and compare this to the sensor reading***
QA/QC—stage-discharge rating curve	After the rating curve is established, no checks are performed to verify the stage-discharge rating curve	After the rating curve is established, no checks are performed to verify the stage-discharge rating curve	***After the rating curve is established, discharge is measured at least once annually to verify the stage-discharge rating curve, and if possible, also after large storms or any other potentially channel-disturbing activities***	***After the rating curve is established, discharge measurements are taken quarterly to verify the stage-discharge rating curve, and if possible, also after large storms or any other potentially channel-disturbing activities***
QA/QC—discharge	No discharge checks are performed	No discharge checks are performed	***Periodically, duplicate discharge measurements are taken, ideally by different people***[b]	***Periodically, duplicate discharge measurements are taken, ideally by different people. Discharge measurements are also periodically compared to a standard, such as a real-time USGS gage, or to measurements obtained by an experienced hydrographer from the USGS or another agency.***

[a]In places where streams become completely frozen during the winter, pressure transducers may be removed during winter months if freezing will result in damage to the equipment.

[b]For more details, see the QAPP (U.S. EPA, 2016. Generic Quality Assurance Project Plan for monitoring networks for tracking long-term conditions and changes in high quality wadeable streams), which is available online at http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=295758&inclCol=eco#tab-3.

As with temperature sensors, different types of errors can occur during deployment (e.g., the pressure transducers may become dewatered, buried in sediment, or fouled by algae). Participants are encouraged to perform QA/QC checks to improve data quality and allow for data to be corrected (if needed). For example, during site visits, field crews should take a staff gage reading or water depth measurement over the transducer with a stadia rod or other measuring device and compare this to the sensor reading. Periodically, the transducer measurements can also be compared to a standard, such as a real-time USGS gage, or to measurements obtained by an experienced hydrographer from the USGS or another agency. Additional information on QA/QC checks for the hydrologic data can be found in the QAPP.

Because the collection of high quality hydrologic data is resource-intensive, states, tribes, RBCs, and other participating organizations are encouraged to explore partnerships with the USGS, universities, and other organizations (e.g., volunteer watershed groups). Some states have been successful at forging such partnerships. For example, the Massachusetts Department of Environmental Protection (MA DEP) has formed a partnership with the Massachusetts River Instream Flow Stewards (RIFLS) program. MA DEP collects macroinvertebrate and temperature data from the primary RMN sites, while the RIFLS program collects the flow data. New Hampshire Department of Environmental Sciences has partnered with Plymouth State University, who provided pressure transducers and helped with installations at New Hampshire's primary RMN sites.

In the future, it would be valuable to start collecting precipitation data as well at the primary RMN sites. Similar to air and water temperature relationships, these data can be used to track responsiveness of stream flow to precipitation. Partnerships through groups, such as the Community Collaborative Rain, Hail, and Snow Network (http://www.cocorahs.org/), can help in this regard. Any discussions of additional sampling should consider the costs and benefits of the data for the states, tribes, or RBCs and RMN objectives.

3.2.4. PHYSICAL HABITAT

During the first several years of data collection, EPA and partners considered the biological, thermal and hydrologic data to be higher priority than the habitat and chemistry data, so not all participants have been collecting habitat data. Of the entities that have been collecting habitat data, most have been using qualitative assessments like EPA's Rapid Bioassessment Protocol (Barbour et al., 1999). These qualitative assessments rate instream, bank, and riparian habitat parameters using visual descriptions that correspond to various degrees of habitat condition (e.g., optimal, suboptimal, marginal, and poor). With the proper training, skilled field biologists can perform comparable and precise visual habitat assessments, and these data, combined with photographs, can be used to qualitatively track habitat changes at RMN sites through time.

The regional working groups are starting to reevaluate the habitat protocols. Many RMN participants feel that quantitative measurements would be better suited for trend detection. Quantitative habitat data would also be helpful for stream classification. EPA performed a broad-scale classification analysis on macroinvertebrate survey data in the eastern United States and found that substrate (percentage sand, percentage fines, embeddedness), flow habitat (percentage pools), and reach-scale slope were important predictor variables (see Appendix A). Collecting these types of quantitative habitat data at RMN sites would improve the ability to accurately classify sites and help inform decisions on how data from RMN sites could be pooled together for analyses.

At this time, EPA and partners are encouraging RMN participants to collect the following types of quantitative habitat data at RMN sites:

- Geomorphological
  - Bankfull width (reach-wide mean or at an established transect)
  - Bankfull depth (reach-wide mean or at an established transect)
  - Reach-scale slope
- Habitat
  - Substrate composition (pebble counts to get percentage fines, percentage sand, etc.)
  - Flow habitat types (percentage riffle, percentage pool, percentage glide, percentage run)
  - Canopy closure (measured with spherical densitometer, mid-stream and along bank)

There are several published methods, such as the EPA National Rivers and Streams Assessment protocols (U.S. EPA, 2013a; Kaufmann et al., 1999), for making these measurements. All of the methods require expertise and skill, and some can be time intensive. As such, the regional working groups will decide which specific quantitative habitat methods to use at RMN sites. The frequency with which quantitative habitat data should be collected from RMN sites also warrants further discussion. It may not be necessary to collect these types of data on an annual basis because channel forming flows that could change baseline geomorphological and instream habitat features generally have 1−2 year return periods for bankfull events or 1−5 year return periods for small flood events. However, specifying an exact timeframe for these measurements is difficult because channel-forming flows are hard to predict and their impacts at a given site can be highly variable. To help inform this discussion, one possibility would be to conduct a pilot study in which RMN members collect quantitative data on an annual basis at a subset of sites and then quantify how much the measurements vary from year to year and from site to site. If this type of comparison is not feasible, another option would be to take quantitative measurements less frequently but then also take measurements when visible geomorphic changes are seen in the photodocumentation (see Section 3.2.6). This topic warrants further discussion among RMN work group members and outside experts.

Also of interest are habitat measurements that are likely to be impacted by climate change. Climate change could contribute to temporally and spatially complex fluvial adjustments (Blum and Törnqvist, 2000). Some of the effects will be direct (e.g., changing precipitation patterns will alter hydrologic regimes, rates of erosion, and sediment yields). Other effects will be indirect, such as increases in sediment yield, which may result from vegetation disturbances that stem from changing thermal and hydrologic conditions (e.g., wildfire, insect/pathogen outbreak, drought-related die off; Goode et al., 2012). Modeling studies from a range of different environments suggest that the increases in rates of erosion could be on the order of 25−50% (Goudie, 2006). Changes in the frequency or magnitude of peak flows could cause significant channel adjustments, especially in higher order streams (Faustini, 2000), but channel adjustments will vary according to many factors. For example, channel adjustments and changes in sediment transport and storage can be greatly influenced by large woody debris dams and boulders that increase roughness (Faustini and Jones, 2003). Climate-related changes in riparian vegetation may also occur (e.g., Iverson et al., 2008; Rustad et al., 2012), which could in turn affect the structure and composition of the benthic macroinvertebrate community (Sweeney, 1993; Whiles and Wallace, 1997; Foucreau et al., 2013).

Monitoring the effects of climate change on physical habitat at RMN sites could be greatly improved by adding carefully selected measurements of geomorphology and quantitative habitat indicators. These measures could include indicators that directly or indirectly reflect changes in hydrology and vertical or lateral channel adjustments (e.g., cross-sectional transects, mean bankfull height throughout a study reach, bank stability, and pebble counts). Indices of relative bed stability (Kaufmann et al., 2008; Kaufmann et al., 2009), measures of embeddedness, or metrics derived from pebble counts (e.g., percentage fines) might be useful measures in characterizing the effects of climate change if hydrological changes result in changes to rates of erosion, channel geometry, slope, bank stability, or sediment supply. However, more discussion among RMN work group members and outside experts is needed before recommending additional habitat measurements.

3.2.5. WATER CHEMISTRY

In situ, instantaneous water chemistry parameters (specific conductivity, dissolved oxygen, and pH) should be collected when RMN sites are visited for biological sampling. Some participating organizations have also been collecting more complete water quality data (e.g., alkalinity, major cations, major anions, trace metals, nutrients). The regional working groups are considering whether to require that a subset of these additional water quality parameters be collected at primary RMN sites. If sufficient resources are available, these water chemistry samples could potentially be collected multiple times per year during different flow conditions. The purpose of collecting these data is to document whether water quality changes are occurring that could potentially contribute to changes in biological assemblage composition and structure over time.

3.2.6. PHOTODOCUMENTATION

Digital photographs should be taken when RMN sites are visited for biological sampling. Photographs are important to document any changes to the monitoring locations, show the near-stream habitat where data are being collected, provide qualitative evidence of changes in geomorphology (e.g., lateral and vertical channel stability), and to locate sensors during subsequent visits (U.S. EPA, 2014). During each visit, the photographs should be taken from the same location(s). Global positioning system (GPS) coordinates (latitude and longitude) should be recorded for the location where the photographs are taken, as well as cardinal direction. The coordinates should be recorded in decimal degrees, using the NAD83 datum for consistency. In areas with good satellite reception, field personnel should wait until there is coverage from four or more satellites before recording the coordinates. The accuracy of the coordinates should later be verified in the office or laboratory by using software (e.g., Google Earth or geographic information system [GIS] software) to plot the location on a map. If GPS coordinates are not available on-site, the location (or locations) should be marked on a map and the coordinates

At least one set of photographs should be taken from a location at mid-reach. The photos should be taken looking upstream and downstream from this location, and should include specific and easily identifiable objects such as large trees, large stable boulders, large woody debris, point bars, established grade control, and so forth (see Figure 3-4). In addition, field personnel are encouraged to take photos of the riffles where macroinvertebrates are collected and, for hydrologic data, the location where instantaneous discharge measurements are taken. Photos of point bars (dominant substrate, extent and type of vegetation) and of banks at established transects are also of interest to document any changes in physical habitat. The photos should be archived yet easily accessible for future use.

Figure 3-4. Photodocumentation of Big Run, WV, taken from the same location each year.

Source: Provided by West Virginia Department of Environmental Protection (WV DEP).

3.2.7. GEOSPATIAL DATA

If resources permit, GIS software can be used to obtain land use and land cover data for RMN sites based on exact watershed delineations for each site. Percentage land use and impervious cover statistics should be generated from the most recent National Land Cover Database (NLCD), and changes in these statistics should be tracked over time. For the RMNs, the most current NLCD data set is preferred over other land use data sets because it is a standardized set of data that covers the conterminous United States and can be used with a standardized disturbance screening process (see Appendix D). Drainage area should also be calculated for each RMN site.

Having exact watershed delineations for RMN sites makes it possible to obtain a wide range of additional geospatial data (e.g., climate, topography, soils, geology), and can also be used to generate flow and temperature statistics (Carlisle et al., 2010; Carlisle et al., 2011; Hill et al., 2013). For purposes of the RMNs, data that are available at a national scale from the NLCD are preferred to landscape-level variables generated from sources that do not provide nationwide coverage, in order to standardize disturbance screening for sites and facilitate other comparisons and analyses. In addition, it would be valuable to examine aerial photographs of the RMN sites for signs of past disturbance, because past land use can have lasting impacts on stream biodiversity (Harding et al., 1998). The use of high resolution Light Detection and Ranging data is also encouraged (if available) to delineate geomorphic features.

4. SUMMARIZING AND SHARING REGIONAL MONITORING NETWORK (RMN) DATA

This section contains recommendations on how to summarize the biological, thermal and hydrologic data that are being collected at RMN sites.[6] At a minimum, certain sets of metrics or statistics should be calculated from the RMN data so that samples can be characterized and compared in a consistent manner. A consistent set of summary metrics also helps in sharing data across organizations. Metrics were selected that are:

- Relevant in the context of biomonitoring and to RMN members
- Straightforward to calculate and interpret
- Known or hypothesized to be most strongly associated with biological indicators
- Known or hypothesized to respond to climate change, and
- Limited in redundancy

These lists of metrics are intended to serve as starting points and should be reevaluated after the first several years of data collection at RMN sites. Periodic literature reviews should also be conducted to help inform parameter selection. Given the rapid pace of research, it is important that the raw data collected at RMN sites be properly archived and stored so that additional metrics can be calculated in the future.

4.1. BIOLOGICAL INDICATORS

Hundreds of different metrics could potentially be calculated from the biological data being collected at RMN sites. When developing the list of recommended summary metrics for the macroinvertebrate data, EPA and partners used a combination of published literature and best professional judgment to narrow down the list. The list, which can be found in Appendix H, contains both taxonomic and traits-based metrics. The list of taxonomic-based metrics includes measures like total taxa richness and Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness and composition (Barbour et al., 1999), which are commonly used by biomonitoring programs for site assessments. Traits-based metrics related to thermal and hydrologic conditions are also included (e.g., functional feeding group, habit, thermal, and flow preference). Trait assignments were obtained from the Freshwater Traits database[7] (U.S. EPA, 2012b).

To derive the thermal preference metrics, methods described in Yuan (2006) were used to estimate the optimal temperature values and ranges of occurrence (tolerances) for taxa that had a sufficient distribution and number of observations to support the analysis. These data, along with

---

[6]The management and sharing of habitat and water chemistry data are discussed in Section 6 (Data Management).
[7]If time and resources permit, regional experts will review and edit the trait assignments and fill in data gaps where possible.

supplemental data provided by states and best professional judgment of regional experts, were used to derive lists of cold and warm water taxa for the eastern states that are participating in the current phase of RMN work (see Appendix I). Metrics known or hypothesized to be sensitive to changing hydrologic conditions are also included in Appendix H. These metrics were selected based primarily on literature review (e.g., Horrigan and Baird, 2008; Chiu and Kuo, 2012; U.S. EPA, 2012a; DePhilip and Moberg, 2013b; Conti et al., 2014). These thermal and hydrologic traits-based metrics should be reevaluated periodically and refined as more data become available and more is learned about relationships between biological, thermal and hydrologic data.

In addition to the taxonomic and traits-based metrics, metrics of *persistence* and *stability* are also being recommended. Persistence is a measure of variation in community richness over time (Holling, 1973), while stability measures the variability in relative abundance of taxa in a community over time (Scarsbrook, 2002; for formulas, see Appendix H). The persistence and stability metrics can be used to quantify year-to-year variation in long-term data sets (Durance and Ormerod, 2007; Milner et al., 2006). Quantifying natural variation in the occurrence and the relative abundance of individual taxa allows biomonitoring programs to assess how this variation affects the consistency of biological condition scores and metrics, and whether variation is linked to specific environmental conditions. In addition, changes in the occurrence (i.e., presence or absence) and the relative abundance of individual taxa should also be evaluated at RMN sites. Spatial distribution maps like the one shown in Figure 4-1 can be created periodically (e.g., every 5 years) to track changes in species distributions over time.

Biological condition scores should also be calculated at RMN sites. Biological indices often take the form of multimetric indices (MMIs) or predictive models like the River Invertebrate Prediction and Classification System (Wright, 2000). MMIs are generally a composite of biological metrics selected to capture ecologically important structural or functional characteristics of communities, where poor MMI scores represent deviations from reference condition (Karr, 1991; Barbour et al., 1995; DeShon, 1995; Yoder and Rankin, 1995; Sandin and Johnson, 2000; Böhmer et al., 2004; Norris and Barbour, 2009). Predictive models compare which reference site taxa are expected (E) to be present at a site, given a set of environmental conditions, to which taxa are actually observed (O) during sampling, where low O:E community ratios represent deviation from reference condition (Wright et al., 1984; Wright, 2000; Hawkins, 2006; Pond and North, 2013).

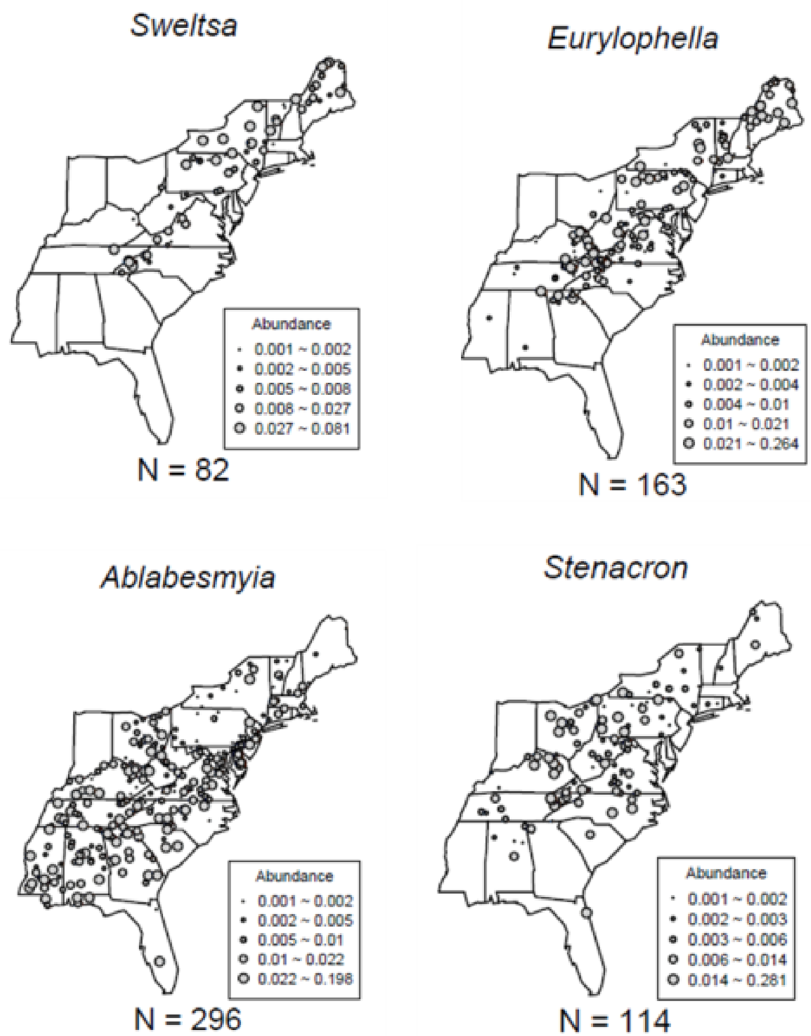


Figure 4-1. Spatial distributions of macroinvertebrate taxa, based on the National Aquatic Resource Survey (NARS) data. These types of maps could be created periodically to track shifts in spatial distributions of taxa over time. At regional monitoring network (RMN) sites, particular attention will be paid to changes in the thermal indicator taxa (in this example, the top two plots show spatial distributions of two of the cold water indicators; the bottom two plots show distributions of warm water indicators).

At this time, there are no plans to develop regional MMIs or O:E predictive models. Rather the biological condition scores should be calculated in accordance with each entity's bioassessment methods. Because different organizations use different techniques for calculating biological condition scores, the index scores themselves may not be comparable across sites sampled by different organizations. However, as discussed in Section 5 (Data Usage) the direction of trends can be tracked over time. In some locations, it may be possible to obtain comparable biological condition scores from regional Biological Condition Gradient (BCG) models. Section 5 (Data Usage) contains more detailed information on how the BCG could potentially be used to summarize RMN data.

The biological data from the RMN sites will need to undergo some level of review, formatting and standardization before it can be summarized and shared. For example, there will be differences in nomenclature across entities that need to be resolved, as well as differences in levels of taxonomic resolution. Users may need to develop operational taxonomic units (OTUs) to address changes in taxonomic naming and systematics that have occurred over time (Cuffney et al., 2007). EPA and partners are currently working on guidance, procedures and R scripts (R Core Team, 2015) that will help facilitate the sharing of the biological data. As discussed in Section 6, the biological data will be eventually be uploaded to a national water data system such as the Water Quality Exchange (WQX). Users will need to be able to access metadata from the data management system so that they can select data that meet their needs (e.g., collected using certain methods and at certain levels of rigor). The raw biological data collected at RMN sites should be properly archived and stored so that additional metrics can be calculated in the future.

4.2. THERMAL STATISTICS

Many metrics can be calculated from year-round air and water temperature measurements. Summer temperature metrics are typically used in analyses with biological data because summer captures a critical time period for most aquatic species' survival, and have been found to predict macroinvertebrate distributions better than winter and summer temperature metrics (Hawkins et al., 2013). Beyond this, there is currently limited information on which temperature metrics are most ecologically meaningful in the context of biomonitoring.

When developing a list of potentially important temperature metrics for the RMN data, EPA and partners sought input from organizations that have been collecting and processing continuous stream temperature data for years, including MD DNR and the U.S. Forest Service Rocky Mountain Research Station (Isaak and Horan, 2011; Isaak et al., 2012; Isaak and Rieman, 2013). They recommended a list of basic statistics that cover daily, monthly, seasonal, and annual time periods, and basic percentage exceedance metrics (e.g., percentage of days that exceed 20°C). The metrics are easy to calculate and capture various aspects of thermal regimes, such as magnitude, frequency, duration, and variability. The list, which can be found in Appendix J, should be regarded as a starting point. Other unlisted metrics also have promise, including the use of more complex temperature exceedance metrics and moving average calculations that are related to specific biological thresholds. Some studies have found that moving average metrics such as 7-day mean and maximum are useful descriptors of thermal regimes and often associate well with stream fish distribution patterns (Wehrly et al., 2003; Nelitz et al., 2007). Other studies (e.g., Butryn et al., 2013) have found that additional metrics are needed to sufficiently capture the variation caused by irregular and extreme events. As such, it is important that the raw data collected at RMN sites is properly archived and stored so that additional metrics can be calculated in the future.

Before the temperature metrics are calculated, the continuous data should be run through a series of quality assurance checks, which are described in the QAPP. EPA and partners are in the process of developing R scripts and procedures to facilitate completion of quality control activities, summarizing and sharing the temperature data (see Section 6). Other options are also available for generating summary statistics, such as the ThermoStat software package (Jones and Schmidt, 2012) and the StreamThermal Version 1.0 R code package that was recently developed by Tsang et al. (in review). In addition to calculating the summary statistics, the metadata for each site should also be reviewed. Data should be interpreted with caution if no accuracy checks were performed during the deployment period. For more information on data management, see Section 6.

4.3. HYDROLOGIC STATISTICS

As with the thermal data, many different metrics can be calculated from daily hydrologic data. Researchers have investigated which hydrologic metrics are most ecologically meaningful in the context of state biomonitoring programs (e.g., Kennen et al., 2008; Chinnayakanahalli et al., 2011) but a detailed understanding of how flow affects ecological conditions remains elusive, in part because observed hydrologic data are unavailable for many biological sampling sites. Also, due to the highly variable nature of hydrologic data, it takes a long period of record to characterize hydrologic regimes. Richter et al. (1997) and Huh et al. (2005) suggest that at least 20 years of data are needed to calculate interannual variability for most hydrologic parameters, and that 30 to 35 years of data may be needed to capture extreme high and low events (e.g., 5- and 20-year floods; Olden and Poff, 2003; DePhilip and Moberg, 2013b).

When developing the list of recommended hydrologic metrics for the RMN data, EPA and partners used a combination of published literature and best professional judgment. The literature included reports from TNC and several partners (states, RBCs, other federal agencies), who developed ecosystem flow needs for some eastern and midwestern rivers and their tributaries (e.g., the Susquehanna, the Upper Ohio, the Delaware, and the Potomac Rivers; Cummins et al., 2010; DePhilip and Moberg, 2013a, 2013b; Buchanan et al., 2013). TNC and its partners utilized components of the Ecological Limits of Hydrologic Alteration (ELOHA) framework (Poff et al., 2010) to make recommendations on flows to protect species, natural communities, and key ecological processes within various stream and river types. For the Upper Ohio River, they recommended a list of flow statistics that capture ecologically meaningful aspects of hydrologic regimes (see Appendix K; DePhilip and Moberg, 2013b). Research by Olden and Poff (2003) and Hawkins et al. (2013; see Appendix K), which identifies hydrologic metrics that capture critical aspects of hydrologic regimes and are ecologically meaningful in different types of streams, also informed the list of metrics.

Appendix K contains the list of recommended hydrologic statistics to calculate for data from RMN sites where water-level or flow data are being collected. The metrics are relatively easy to calculate and include both summary statistics and measures of variability. As with the thermal metrics, this list should be regarded as a starting point and should be reevaluated over time. The raw hydrologic data collected at RMN sites should be properly archived and stored so that additional metrics can be calculated in the future.

Before the hydrologic metrics are calculated, the data should be run through a series of quality assurance checks, which are described in the QAPP. EPA and partners are in the process of developing R scripts and procedures to facilitate completion of quality control activities, summarizing and sharing the hydrologic data (see Section 6). Other options may be available as well, such as software like Indicators of Hydrologic Alteration (TNC, 2009) and Aquarius.[8] In addition to calculating the summary statistics, the metadata for each site should also be reviewed. Data should be interpreted with caution if no accuracy checks (e.g., staff gage readings) were performed during the deployment period, and if the elevations of the staff gage and pressure transducer were not surveyed. The latter are especially important, because they can determine changes in the location of the transducer. If the transducer moves, stage data will be affected and corrections should be applied.

To supplement missing field data or provide estimates of streamflow at ungaged sites, simulation models have been developed in some geographic areas. For example, the Baseline Streamflow Estimator simulates minimally altered streamflow at a daily time scale for ungaged streams in Pennsylvania. This freeware is publicly available, and has a user-friendly point-and-click interface (Stuckey et al., 2012). Other examples of tools used to simulate flows are listed in Appendix K. While these modeled data should not be regarded as a substitute for observational data, participating organizations may want to take advantage of these additional resources to supplement their monitoring efforts.

[8] http://aquaticinformatics.com/

5. DATA USAGE

Biomonitoring programs can use RMN data for multiple purposes, spanning time periods of 1−5, 5−10 and 10+ years (see Figure 5-1). Uses include:

- Monitoring the condition of minimally and least disturbed streams
- Detecting trends attributable to climate change
- Supplementing CWA programs and initiatives
  - Defining natural conditions/quantifying natural variability to support Section 305(b) programs
  - Informing criteria refinement or development under Section 303
  - Developing biological indicators for protection planning for Section 303(d) programs
- Gaining a better understanding of relationships between biological, thermal, and hydrologic data
- Gaining a better understanding of ecosystem responses and recovery from extreme weather events
- Gaining insights into effects of regional phenomena such as drought, pollutant/nutrient deposition and riparian forest infestations on aquatic ecosystems and bioassessment programs

5.1. APPLICATIONS IN A 1−5 YEAR TIMEFRAME

Many of the RMN sites are located on minimally or least disturbed streams (per Stoddard et al. 2006), which are the standard against which other bioassessment sites are compared. It is critical to document current conditions at these sites and to monitor how conditions change over time, as this has implications for CWA programs. Monitoring high quality waters fits in with the long-term vision and goals for a number of CWA programs, such as the Section 303(d) Program. Historically, the 303(d) program has focused on the assessment and identification of waters that are not meeting State water quality standards and on the development of Total Maximum Daily Loads to inform restoration of those waters, but starting in 2016, protection planning priorities that target high quality sites will also be incorporated into the reporting cycle (U.S. EPA, 2013b). Monitoring high quality waters also ties into EPA's Healthy Watershed Initiative, in which State and other partners identify high quality watersheds and develop and implement watershed protection plans to maintain the integrity of those waters (U.S. EPA, 2011).

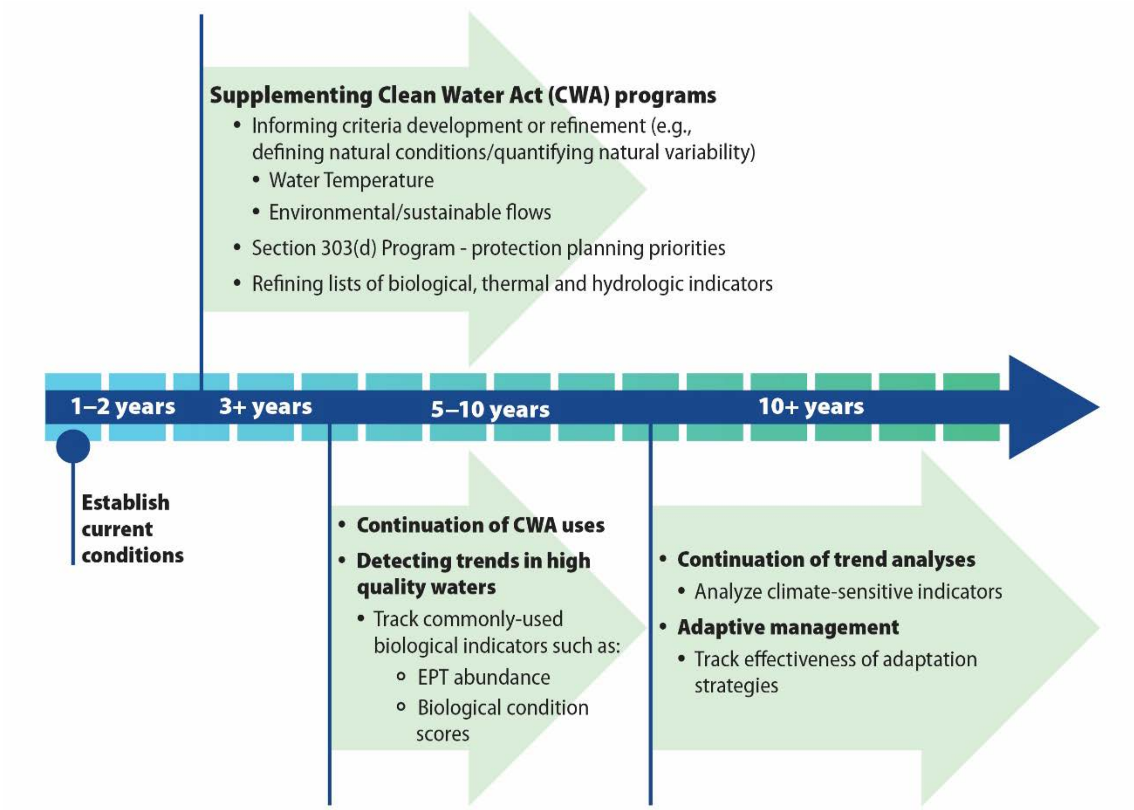


Figure 5-1. RMN data can be used for multiple purposes, over short- and long-term timeframes.

To characterize current conditions at the RMN sites, the data, metrics, and summary statistics described in Section 4 and Appendices H, J, and K will be compiled for each site and sent to regional coordinators and EPA. Before this happens, the interim data infrastructure systems described in Section 6 will be put into place. The procedures and R scripts (R Core Team, 2015) that EPA and partners are currently working on will help facilitate these outputs. For the macroinvertebrate data, the output will include metrics that are commonly used by biomonitoring programs for site assessments (e.g., EPT metrics), as well as traits-based metrics related to thermal and hydrologic conditions. At this time, there are no plans to develop regional MMIs or O:E predictive models. Rather, assessments of overall biological condition will be based on biological condition scores that are calculated in accordance with each entity's bioassessment methods. In many cases, the index scores will not be comparable across sites sampled by different organizations, but valuable information can be gleaned by monitoring the direction of trends in biocondition scores across RMN sites, in addition to changes in the biological metrics. Moreover, some programs may be able to use the biological data from RMN sites to help calibrate or refine biological indices specific to their programs.

In some places, it may be possible to obtain comparable biological condition scores from regional BCG models. The BCG is a conceptual, narrative model that describes how biological structure and function of aquatic ecosystems change along a gradient of increasing anthropogenic stress (Davies and Jackson, 2006). The BCG model can be calibrated and applied to regional and local conditions and puts biological condition on a common, quantifiable scale that can be applied nationwide. BCG models are typically calibrated to six levels that reflect a continuum of quality from pristine (BCG Level 1) to severely degraded (BCG Level 6; Davies and Jackson, 2006). Thus, a BCG Level 2 sample in one region is comparable to a BCG Level 2 sample in another region because both assessments are dependent on comparisons to natural conditions. At this time regional BCG models for macroinvertebrate or fish assemblages have been developed for cold and cool streams in the Northern Forest region of the Midwest (Stamp and Gerritsen, 2009) and medium to high gradient streams in parts of New England (Stamp and Gerritsen, 2009). In addition, BCG models for fish and macroinvertebrate assemblages have been calibrated for northern Piedmont streams of Maryland (Stamp et al., 2014), and are currently being calibrated in Alabama, Illinois, and Indiana. These models can be applied to data collected from RMN sites and BCG-level scores, as well as the component metrics of the BCG models (which are typically related to tolerance of individual taxa), can be used to characterize biological condition and track changes at sites over time.

Once the first several years of biological data become available, taxonomic composition at the RMN sites will also be evaluated, along with the broad-scale macroinvertebrate classification model developed by EPA and partners (see Section 2.2). Based on the broad-scale model, which was developed using National Rivers and Streams Assessment (NRSA) data, most of the primary RMN sites fall within the small to medium-size, colder temperature, faster water stream class. EPA and partners will use nonmetric multidimensional scaling (NMDS) to evaluate similarities and differences in taxonomic composition across RMN sites and to test the performance of the classification model. Results will help inform if and how macroinvertebrate data can be pooled for regional analyses. The ability to pool data could be particularly valuable for biomonitoring programs that are trying to calibrate biocondition indices and develop numeric biocriteria but only have limited numbers of high quality sites.

EPA and partners will also assess the number of cold/cool thermal indicator taxa at RMN sites. Having higher numbers of cold/cool taxa at RMN sites will improve trend detection ability (see Appendix A). Based on preliminary analyses, RMN sites have relatively high proportions of cold/cool taxa (see Figure 5-2). The biological and continuous stream temperature data from RMN sites can be used to refine the regional list of cold/cool and warm water macroinvertebrate taxa, which were developed based on instantaneous stream temperature measurements (see Appendix I). Biological indicator lists can also be used for protection planning. For example, regulatory agencies in Maryland are currently assessing the accuracy of their current use designations for cold water streams as part of their protection planning process. As part of these efforts, MD DNR used continuous temperature data from its Sentinel Sites Network (SSN)[9] to develop a thermal indicator organism list for macroinvertebrates. Two stoneflies, *Sweltsa* and

---

[9]MD DNR has been collecting biological data and continuous temperature data from 27 high quality sites since 2000 as part of it SSN. Five of the SSN sites are primary RMN sites. For more information, see Becker et al. (2010).

Tallaperla, meet obligate cold taxa requirements for Maryland streams and are being used in combination with trout to help identify and protect cold water streams (see Figure 5-3).

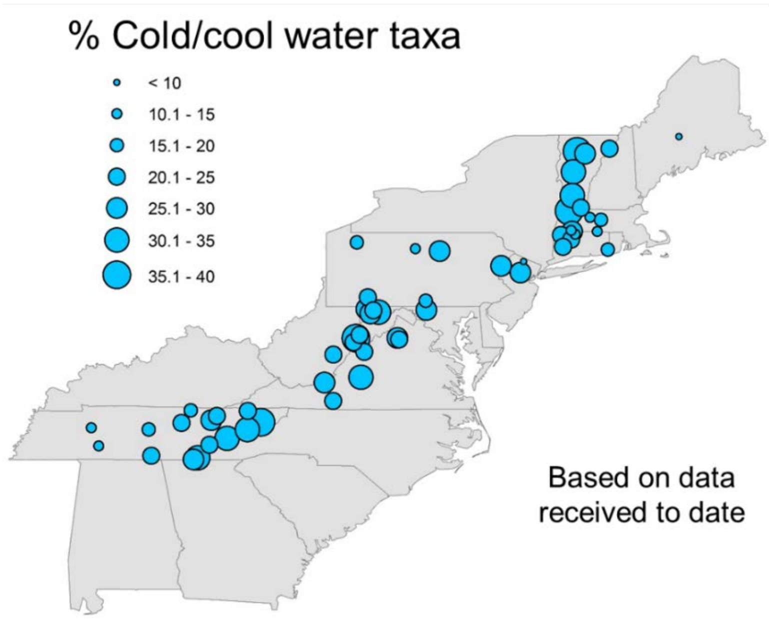


Figure 5-2. Proportion of cold/cool indicator taxa at RMN sites, based on preliminary data from a subset of sites. More details on the cold/cool taxa list can be found in Appendix I.

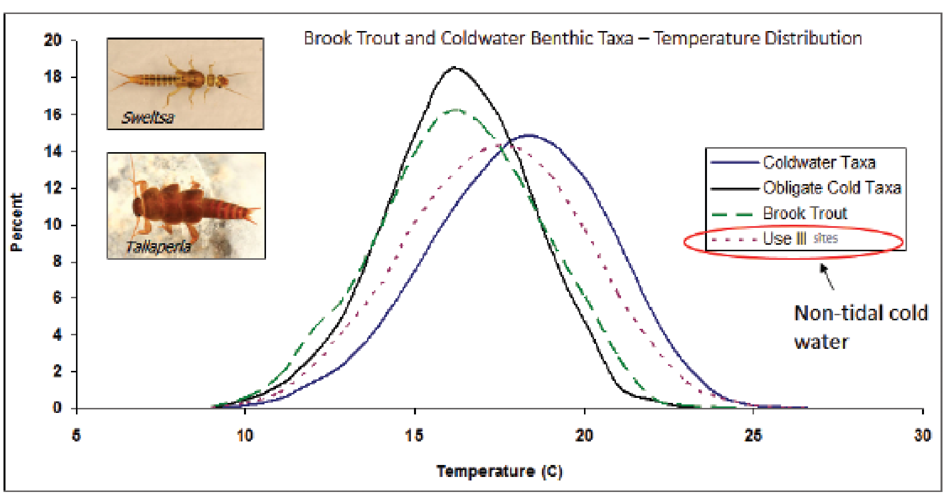


Figure 5-3. The thermal tolerances of *Sweltsa* and *Tallaperla* match very closely with brook trout. These two macroinvertebrate taxa are being used in combination with trout to help identify and protect cold water streams in Maryland. This figure was provided by the Maryland Department of Natural Resources.

The biological and stream temperature data from RMN sites can also be used to inform criteria refinement or development and to help identify ecologically meaningful thresholds. For example, some regulatory agencies are in the process of assessing whether their current temperature criteria are adequately protecting designated uses related to cold water fisheries. In Connecticut, Beauchene et al. (2014) used year-round temperature data and fish data to develop quantitative thresholds for three major thermal classes at which there are discernible temperature-related changes in stream fish communities (see Figure 5-4). This type of information is very useful for fisheries management and can be used to help make criteria more biologically meaningful and defensible.

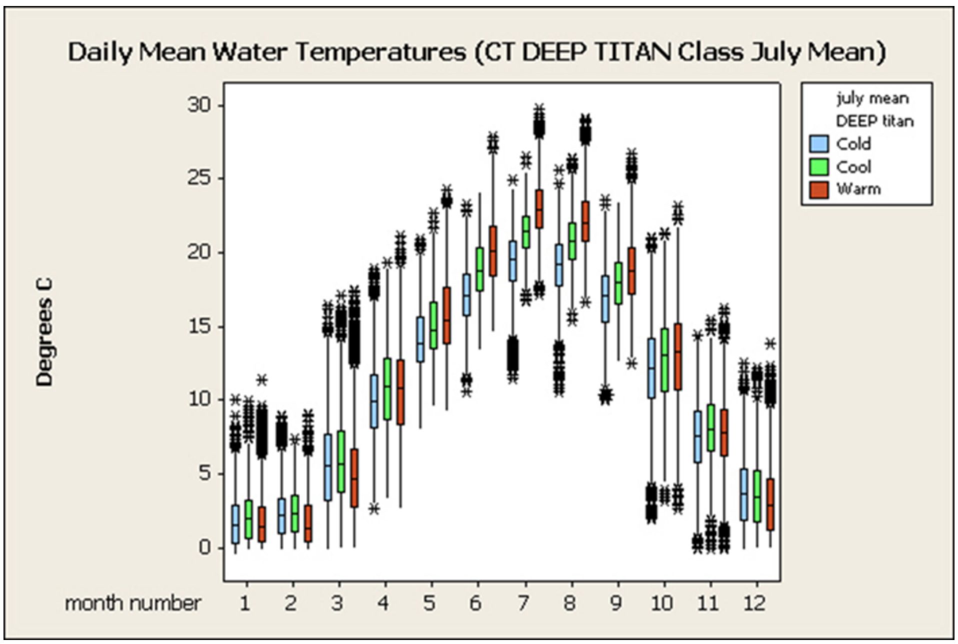


Figure 5-4. Connecticut Department of Energy and Environmental Protection (CT DEEP) developed ecologically meaningful thresholds for three major thermal classes (cold, cool, warm). Outliers are shown with asterisks. Temperature in these three classes differ most in the summer (figure provided by Mike Beauchene, CT DEEP).

The hydrologic data being collected at RMN sites can be used for similar types of analyses and applications. For example, Maine used biological and hydrologic data to develop statewide environmental flow and lake level standards. The standards are based on thresholds derived from principles of natural flow variation necessary to protect aquatic life and maintain important hydrological processes (MDEP, 2007; see Figure 5-5; Ricupero, 2009). Other states are also exploring the development of flow criteria, utilizing the ELOHA framework (Poff et al., 2010). TNC and several partners (states, RBCs, other federal agencies) have used components of the ELOHA framework that consider flow needs for sensitive species and key ecosystem processes to develop flow recommendations for some eastern and midwestern rivers (e.g., the Susquehanna, the Upper Ohio, the Delaware, and the Potomac Rivers; DePhilip and Moberg, 2010; Cummins et al., 2010; DePhilip and Moberg, 2013a, 2013b; Buchanan et al., 2013). Data from RMN sites can be used in similar ways to improve our understanding of these processes and to help develop regionally informed standards and management strategies.

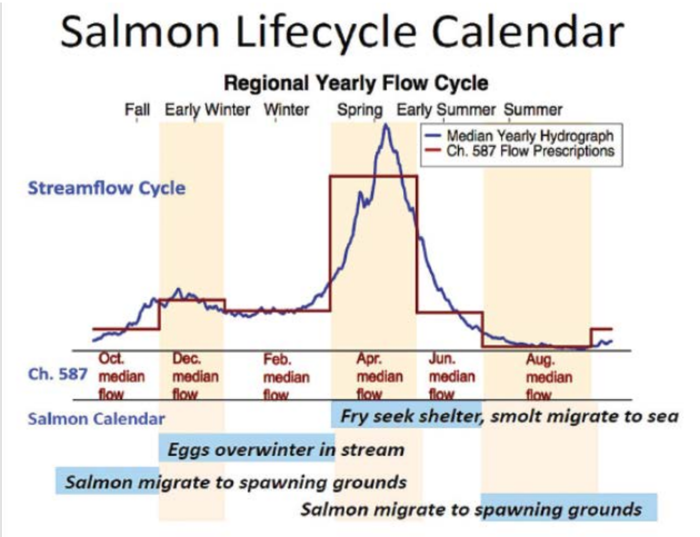


Figure 4. Salmon life cycle plotted in relation to yearly flow cycle (Ricupero 2009).

Figure 5-5. Salmon life cycle plotted in relation to yearly flow cycle (Ricupero, 2009).

At many RMN sites, the year-round thermal and hydrologic regimes are poorly documented, so the first several years of continuous thermal and hydrologic data will be used to start characterizing these regimes. The continuous data will provide robust data sets that capture natural temporal patterns, episodic events and spatial variability, which may be missed by limited numbers of discrete measurements (see Figure 5-6). The collection of these types of data will also build capacity of biomonitoring programs that have limited experience with continuous sensors and management of continuous data.

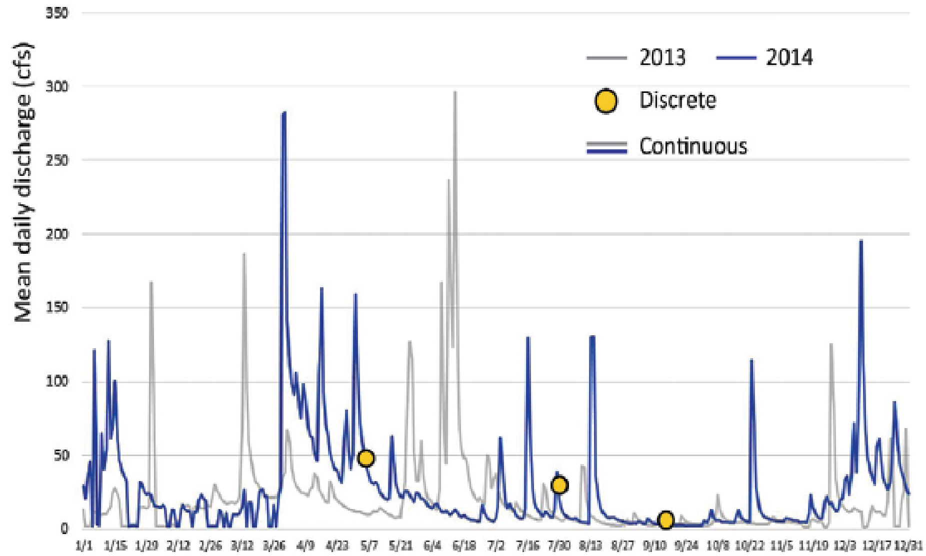


Figure 5-6. RMN data will help us gain a better understanding of natural variability in hydrologic conditions in small least disturbed streams, and will allow us to investigate relationships between biological, thermal, and hydrologic conditions.

The continuous RMN data could also be used to help further the development of ecologically relevant classifications of thermal and hydrologic regimes. For example, Maheu et al. (2015) recently developed a thermal classification scheme for streams in the conterminous United States based on magnitude and variability (amplitude and timing), with six classes: highly variable cool, variable cold, variable cool, variable warm, stable cool, and stable cold. In another study, Dhungel (2014) developed an empirical model and hydrologic classification scheme for streams in the conterminous United States based on magnitude, timing, predictability, and intermittency of flows, with eight classes: small steady perennial, large steady perennial, steady intermittent, early intermittent, late intermittent, early flashy perennial, small flashy perennial, and large flashy perennial. Efforts are also underway to develop a hierarchical classification for natural flowing stream and river systems in the Appalachians (Olivero et al. 2015). These existing models could be used to classify RMN sites based on thermal and hydrologic data.

Once the RMN sites have been classified, the continuous thermal and hydrologic data can be used to help characterize baseline or reference conditions for the different stream classes. Characterization (and quantification) of these regimes is important because some water quality standards are based on comparisons with natural conditions. Thermal and hydrologic data from stream segments altered by anthropogenic activities such as dams and land use changes could potentially be compared to data from high quality RMN sites. Another potential application of the RMN data is to improve or validate models and simulations that predict stream temperature and flow. Several stream temperature models now exist for the conterminous United States, including empirical models developed by Hill et al. (2013) and Segura et al. (2015).

Advancements in flow models, such as the Variable Infiltration Capacity model (Liang et al., 1994), continue to be made as well. These models could potentially be applied to RMN sites, and the simulated stream temperatures and flows could then be compared to the observed values. If the models provide good approximations, the models could potentially be used to predict climate change effects on thermal and hydrologic regimes at RMN sites.

Another way in which RMN data can be used is to assess the "thermal sensitivity" of each site. The "thermal sensitivity" of a stream is often quantified as the slope of the regression line between air and stream temperature (Kelleher et al. 2012). Air temperature, which is projected to increase due to climate change (Melillo et al. 2014), is known to be an important predictor of water temperature (Kelleher et al., 2012; Hill et al., 2013). The relationship between air and water temperature, however, varies depending on numerous modifying factors, such as geographic location, stream size, and groundwater contributions (Kelleher et al., 2012; Hill et al., 2013). Hildebrand et al. (2014) used the paired continuous air-water temperature data from MD DNR's sentinel sites to explore thermal sensitivities in different regions of Maryland. They found baseflow and riparian shading to be important modifying factors, along with discharge. In Pennsylvania, Kelleher et al. (2012) found that stream size and groundwater contribution were the primary controls of the sensitivity of stream temperature to air temperature. Relationships between the air and stream temperature data can also be used to characterize groundwater influence at local scales (Kanno et al., 2014; Snyder et al., 2015). The first several years of paired air-stream temperature data can be used to assess the sensitivity of each RMN site to rising air temperatures, and to gain a better understanding of factors that make some sites more vulnerable to climate change than others. This information could be very useful for management and conservation planning.

5.2. APPLICATIONS IN A 5−10 YEAR TIMEFRAME

Over the 5−10 year time period, RMN data will continue to be used to characterize current conditions against which future climate influences can be assessed, to support CWA programs in ways similar to those described in Section 5.1 and to evaluate and refine the lists of recommended metrics and indicators provided in Section 4 and Appendices H, J, and K. In addition, a variety of analyses can be performed to look for trends and patterns in the biological, thermal, hydrologic, habitat, and water chemistry data. Scatterplots, simple correlation and regression analyses, analysis of variance, NMDS ordinations, and other analytical tools will be used to explore differences or trends over time, as well as relationships between the different types of data. The analyses will be similar to those described in MD DNR's SSN report (Becker et al., 2010) and the 2012 EPA pilot study in which long-term state biomonitoring data in Maine, North Carolina, Ohio, and Utah were evaluated for climate-related trends (U.S. EPA, 2012a). In both studies, there were examples of shifts in biological indicators occurring in association with changing thermal or hydrologic conditions. In the Maryland study, the lowest Index of Biological Integrity scores in the Coastal Plain—western shore region were recorded the year after the lowest flow and rainfall conditions occurred (Becker et al., 2010), and in the EPA pilot study, a strong decline in EPT richness corresponded with a period of higher than normal temperatures and lower than normal flows at one of the Utah sites (U.S. EPA, 2012a). RMN data for the 5–10 year time period can also be used to assess temporal (year to year) variability, which is not well documented at high quality sites (Milner et al., 2006). The RMN data facilitates a better understanding of how natural variability affects the consistency of biological condition scores and metrics from year to year, and how this relates to changing thermal and hydrologic conditions.[10]

5.3. APPLICATIONS IN A 10+ YEAR TIMEFRAME

For the 10+ year timeframe, the data will continue to be used to characterize conditions and temporal variability, support CWA programs, evaluate and refine the lists of recommended metrics and indicators and perform trend analyses. In addition, climate change effects may start to become evident. A number of climate projections are relevant to aquatic life condition, including increasing temperatures, increasing frequency and magnitude of extreme precipitation events, and increasing frequency of summer low flow events (Melillo et al. 2014). The long-term data from high quality RMN sites will substantially enhance the ability to detect and characterize trends attributable to climate change.

Many organizations are performing vulnerability assessments and developing hypotheses about which organisms, community types, watersheds or stream classes are likely to be most vulnerable to climate change. For example, the EPA and partners are conducting a broad-scale climate change vulnerability assessment on streams in the eastern United States. They are assigning vulnerability ratings to each watershed[11] based on a scenario in which stream temperatures warm and the frequency and duration of summer low flow events increases (see Figure 5-7). The RMN data can be used to help test these types of hypotheses and to track whether certain types of streams are showing greater resiliency to climate change effects than others. This type of information can inform adaptation strategies and conservation planning.

[10]In order to be able to attribute variability in the biological data to ‘natural’ vs. other factors, anthropogenic factors (such as changes in land use) also need to be tracked at each site over time.
[11]Watershed delineations are based on the NHDPlus v2 local catchment layer: http://www.horizon-systems.com/NHDPlus/NHDPlusV2_data.php.

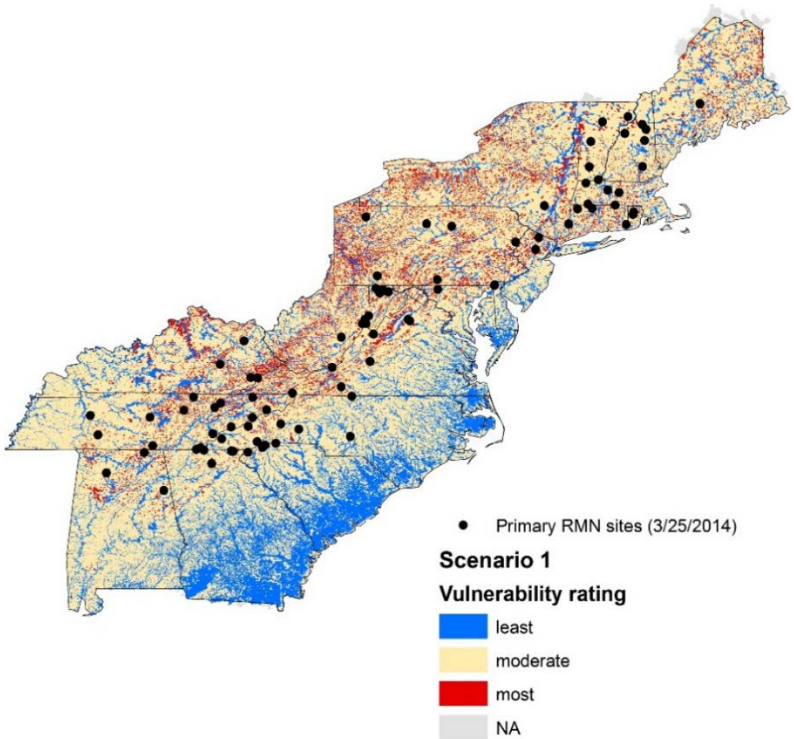


Figure 5-7. EPA and partners are conducting a broad-scale climate change vulnerability assessment on streams in the eastern United States, based on a scenario in which stream temperatures warm and the frequency and duration of summer low flow events increases. Vulnerability ratings (least, moderate or most) are being assigned to each watershed.

The RMN data can also be used to track whether shifts in the distributions of biological indicators (such as cold water taxa) are occurring as the climate changes, which would have implications for bioassessment programs. In some locations, species distribution models (SDMs) have been developed. For example, Zheng et al.[12] (2014) generated models to predict how species occurrence will change by mid-century in the Northeast under conditions of rising air temperatures and changing precipitation patterns.[13] Results suggest an overall decline in species richness across much of the region (see Figure 5-8). SDM models have been generated for other regions as well. For example, Hawkins et al. (2013) used biomonitoring data from the EPA's 2008−2009 NRSA to develop SDMs that predict how the distributions of individual macroinvertebrate taxa and entire assemblages of taxa vary with stream temperature, flow, and

[12]Zheng, L., Stamp, J., Hamilton, A., Bierwagen, B. and J. Witt. 2014. Species Distribution Modeling in the Northeast US - Impact of Climate Change and Taxa Vulnerability. Poster. Joint Aquatic Sciences Meeting. Portland, OR.

[13]Mid-century (2040−2069) projections for air temperature, precipitation and moisture surplus were based on average values from an ensemble of 15 GCMs, using the a2 (high) emissions scenario. Data were obtained from the Climate Wizard website and are based on the WCRP CMIP3 multimodel data set.

other watershed attributes in the conterminous United States, for baseline (2000−2010) versus late century (2090−2100) time periods. SDMs are also being developed for stonefly species in the Midwest (Cao et al., 2013; DeWalt et al., 2013). If applied to RMN sites, SDMs could serve as valuable tools for conservation planning.

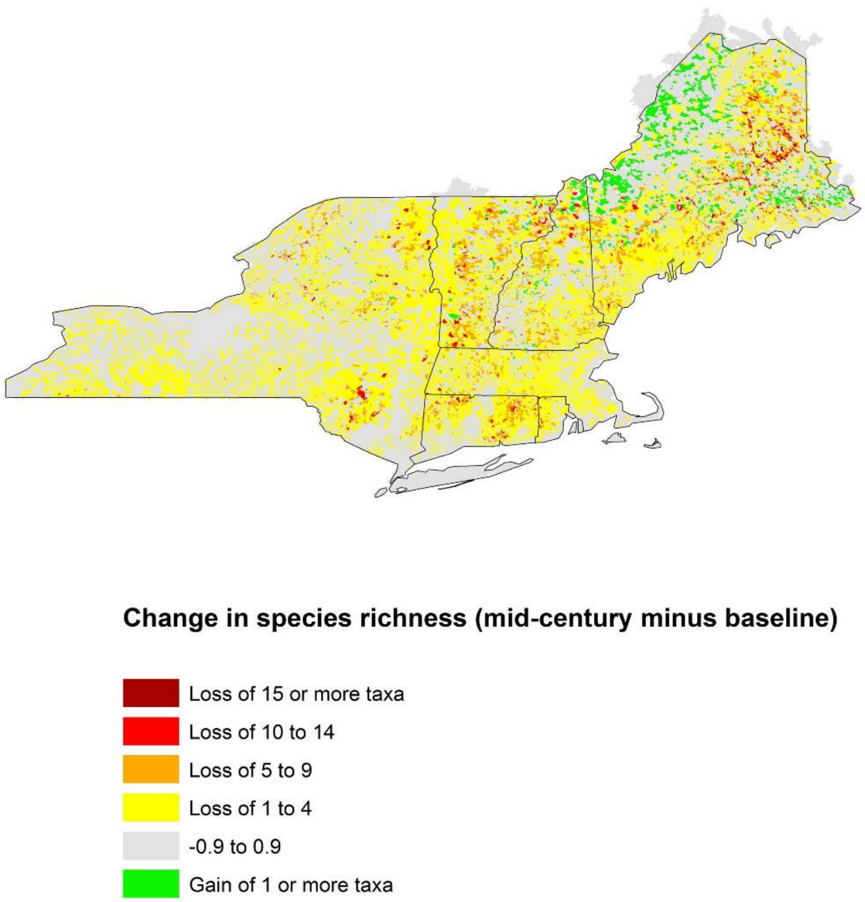


Figure 5-8. Modeling results predict declines in species richness across much of the Northeast by mid-century (2040−2069).[14]

Models have also been developed to predict climate change effects on stream temperature and flow. For example, at the national scale, Hill et al. (2013) developed a stream temperature model for the conterminous United States based on air temperature and watershed feature data (e.g., watershed area and slope) from reference-condition USGS sampling sites, and applied the model to simulate the effects of climate change on mean summer stream temperature (Hill et al. 2014). The model predicts a mean warming of 2.2°C for stream temperatures in the

---

[14]Zheng, L., Stamp, J., Hamilton, A., Bierwagen, B. and J. Witt. 2014. Species Distribution Modeling in the Northeast US—Impact of Climate Change and Taxa Vulnerability. Poster. Joint Aquatic Sciences Meeting. Portland, OR.

conterminous United States by late century (2090−2099) relative to a 2001−2010 baseline period, with values at individual sites ranging from 0°C to +6.2°C. In another study, Dunghel (2014) developed statistical models to predict flow responses to projected changes in precipitation and temperature. Results suggest that changes in flow attributes will be most evident in rain-fed small perennial streams and intermittent streams in the central and eastern United States. These models could potentially be applied to RMN sites, and the performance of the models could be tracked over time.

RMN data may also provide insights on how organisms respond to and recover from extreme weather events such as droughts and floods, which are projected to occur with greater frequency in the future (Melillo et al., 2014). Impacts can be evaluated through comparative analyses on the pre- and postevent data. For example, VT DEC performed these types of analyses on macroinvertebrate data collected before and after flooding from Tropical Storm Irene. Using data from 10 high-quality sites, VT DEC documented immediate decreases in invertebrate densities of 69% on average, but also found that most sites recovered to normal levels the following year (see Figure 5-9).[15] The substantial decline in density and the rapid recovery would have been missed if sampling had occurred at longer intervals, such as on a 5-year rotational sampling schedule. Moreover, the collection of continuous thermal and hydrologic data will allow the magnitude, frequency and duration of the event to be documented. Whether or not the RMN data can fully capture biological responses to extreme weather events will depend on the timing of the event in relation to the RMN sampling period.

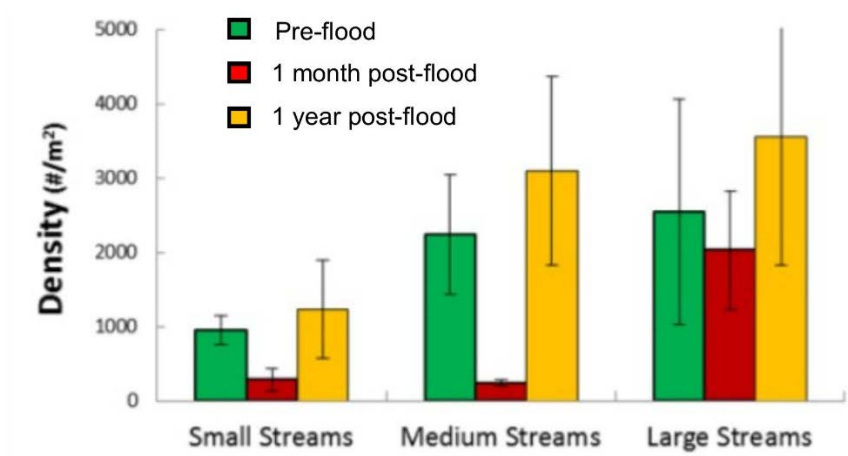


Figure 5-9. Comparison of macroinvertebrate density values at 10 stream sites in Vermont before and after Tropical Storm Irene.[16]

[15]Moore, A. and S. Fiske. (2012) What's Left in Vermont's Streams after Tropical Storm Irene—Monitoring Results From Long Term Reference Sites. Presentation. New England Association of Environmental Biologists Annual Conference. Falmouth, MA.
[16]Ibid.

6. DATA MANAGEMENT

The EPA and partners are developing a data management system that will allow participating organizations and outside users to access data and metadata that are being collected at RMN sites. The biological, habitat, and water chemistry data will be uploaded to a national water data system such as the WQX. At this time not all RMN partners have the capacity to upload these data into WQX, so the EPA and partners are working on an interim solution. Until the interim system is in place, the individual organizations will be custodians and owners of these data, and all data files will be backed up and stored in a centralized, secure location. Because WQX cannot accommodate continuous data, the thermal and hydrologic data being collected by RMN partners will be uploaded into a separate data management system. A multiagency effort is underway to develop a data management system for the continuous data. In the interim, EPA and partners are developing guidance for storing and managing the continuous RMN data files. This includes the development of R scripts (R Core Team, 2015) and procedures for performing QC on the data and for deriving standardized sets of summary outputs for desired time periods. Until the permanent data management system is in place, the individual organizations will be the custodians and owners of the continuous thermal and hydrologic monitoring data. The EPA and partners are also developing procedures for joining the different sets of data and facilitating the types of data analyses described in Section 5.

7. IMPLEMENTATION AND NEXT STEPS

Implementation of the RMNs is underway in the Northeast, Mid-Atlantic, and Southeast regions. Sampling efforts began in the Northeast in 2012, followed by the Southeast in 2013 and the Mid-Atlantic in 2014. Currently there are 25 primary RMN sites in the Northeast, 27 in the Mid-Atlantic and 38 in the Southeast (see Appendix C). More sites will be added in all regions as resources permit. Efforts are also underway to develop RMNs in the Midwest, where sampling is expected to start in 2016 (see Figure 7-1). A number of organizations in the western United States have also expressed interest in setting up RMNs.

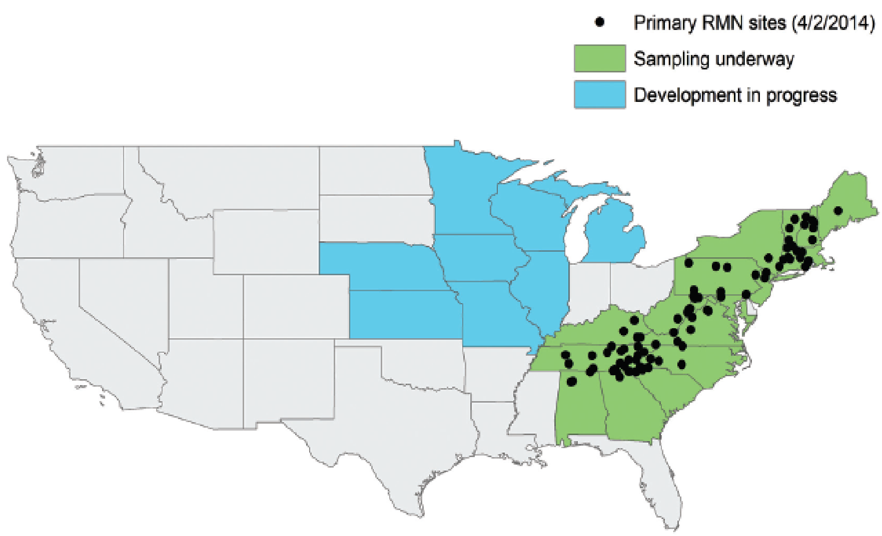


Figure 7-1. Sampling has been underway at the Northeast, Mid-Atlantic and Southeast RMNs for several years. RMNs are currently being developed in the Midwest.

Efforts are being made to integrate RMN data collection flexibly within existing monitoring programs to maximize available resources. Some RMN partners have taken a phased approach to implementation, particularly with collecting hydrologic data at ungaged sites. For example, some participating organizations have installed pressure transducers at one or two sites, and are planning to add more as they gain experience and as resources permit. In many states, the collection of macroinvertebrate data and year-round temperature measurements have been feasible during the first year of implementation. However, it has been difficult for some participating organizations to find resources to process the macroinvertebrates samples in accordance with the regional methods. When this occurs, the preserved samples are being retained so that they can be processed at a later time, when resources become available.

To help build capacity and improve data quality, EPA and partners have held several training workshops on field protocols for continuous temperature sensors and pressure transducers, and wrote the EPA best practices document (U.S. EPA, 2014). In addition, the regional coordinator in the Mid-Atlantic is planning to hold a training workshop on species-level identifications for high priority taxa (see Appendix G). There are also plans to hold hands-on, interactive workshops on data management at annual meetings (e.g., the New England Association of Environmental Biologists conference, the Association of Mid-Atlantic Aquatic Biologists Workshop, the Southeastern Water Pollution Biologists Association conference).

As discussed in Section 3, EPA has also developed a QAPP for the RMNs to address the challenges of creating regionally consistent data sets. It is a generic QAPP that details the core requirements for participation in the network, and outlines best practices for the collection of biological, thermal, hydrologic, physical habitat, and water chemistry data at RMN sites. The QAPP was written in a way that should be transferable to other regions, with region-specific protocols included as addendums. The QAPP is intended to increase the comparability of data being collected at RMN sites, improve the ability to detect long-term trends by minimizing biases and variability, and to ensure that the data are of sufficient quality to meet data quality objectives. Efforts will be made to finalize the QAPPs for the Northeast, Mid-Atlantic, Southeast and Midwestern regions by 2016. The protocols in the QAPP will be reevaluated periodically and updated as needed. EPA and partners are also exploring the possibility of conducting methods comparison studies in regions where macroinvertebrate collection and processing protocols differ across participating organizations. This could involve the collection of side-by-side samples using the different methods. After the paired samples are processed using the respective methods, results would be compared and differences between the methods could be quantified.

In coming years, EPA and partners will continue to build capacity and refine protocols, indicator lists, analytical techniques and data management systems for the Northeast, Mid-Atlantic, and Southeast RMNs. Other regions have expressed interest in establishing RMNs as well. They recognize how these types of long-term data can support CWA programs, fill data gaps, and help detect trends attributable to climate change. The RMN framework is flexible and allows for expansion to new regions, as well as to new stream classes and waterbody types. For example, some parts of the Midwest lack the higher gradient, riffle-dominated cold water streams that are being targeted in the Northeast, Mid-Atlantic, and Southeast RMN pilot studies. Instead, these regions may focus their sampling efforts on low gradient, sandy-bottom, warm water streams. A Midwestern working group has also been formed to explore the possibility of setting up a RMN for inland lakes. The monitoring data being collected from these regional efforts will provide important inputs for bioassessment programs as they strive to protect water quality and aquatic ecosystems under a changing climate.

8. LITERATURE CITED

Barbour, MT; Stribling, JB; Karr, JR. (1995) The multimetric approach for establishing biocriteria and measuring biological condition. [p. 63−76]. In Davis, WS; Simon, TP (eds). Biological assessment and criteria: tools for water resource planning and decision making. Boca Raton, FL: CRC Press.

Barbour, MT; Gerritsen, J; Snyder, BD; Stribling, JB. (1999) Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish, Second Edition. [EPA 841-B-99-002]. Washington, D.C: U.S. Environmental Protection Agency, Office of Water. Available online: http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm.

Beauchene, M; Becker, M; Bellucci, C; Hagstrom, N; Kanno, Y. (2014) Summer thermal thresholds of fish community transitions in Connecticut streams. J N Am Fish Manage 34(1):119–131.

Becker, AJ; Stranko, SA; Klauda, RJ; Prochaska, AP; Schuster, JD; Kashiwagi, MR; Graves, PH. (2010) Maryland biological stream survey's sentinel site network: A multi-purpose monitoring program. Annapolis, MD: Maryland Department of Natural Resources.

Bilhimer, D; Stohr, A. (2009) Standard Operating Procedures for continuous temperature monitoring of fresh water rivers and streams conducted in a Total Maximum Daily Load (TMDL) project for stream temperature, Version 2.3. Olympia, WA: Washington State Department of Ecology, Environmental Assessment Program. Available online: http://www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_Cont_Temp_Monit_TMDL_v3_0EAP044.pdf.

Blocksom, KA; Autrey, BC; Passmore, M; Reynolds, L. (2008) A comparison of single and multiple habitat protocols for collecting macroinvertebrates in wadeable streams. JAWRA 44(3):577−593.

Blum, MD; Törnqvist, TE. (2000) Fluvial responses to climate and sea-level change: a review and look forward. Sedimentology 47:2−48.

Böhmer, J; Rawer-Jost, C; Zenker, A. (2004) Multimetric assessment of data provided by water managers from Germany: assessment of several different types of stressors with macrozoobenthos communities. Hydrobiologia 516(1-2):215−228.

Buchanan, C; Moltz, HLN; Haywood, HC; Palmer, JB; Griggs, AN. (2013) A test of The Ecological Limits of Hydrologic Alteration (ELOHA) method for determining environmental flows in the Potomac River basin, U.S.A. Freshw Biol 58(12):2632−2647.

Butryn, RS; Parrish, DL; Rizzo, DM. (2013) Summer stream temperature metrics for predicting brook trout (***Salvelinus fontinalis***) distribution in streams. Hydrobiologia 703:47–57.

Cao, Y; Williams, WP; Bark, AW. (1997) Effects of sample size (number of replicates) on similarity measures in river benthic Aufwuchs community analysis. Water Environ Res 69(1):107−114.

Cao, Y; Hawkins, CP; Storey, AW. (2005) A method for measuring the comparability of different sampling methods used in biological surveys: Implications for data integration and synthesis. Freshw Biol 50(6):1105−1115.

Cao, Y; DeWalt, RE; Robinson, JL; Tweddale, T; Hinz, L; Pessino, M. (2013) Using Maxent to model the historic distributions of stonefly species in Illinois streams: The effects of regularization and threshold selections. Ecol Model 259:30−39.

Carlisle, DM; Falcone, J; Wolock, DM; Meador, MR; Norris, HR. (2010) Predicting the natural flow regime: models for assessing hydrological alteration in streams. River Res Appl 26(2):118−36.

Carlisle, DM; Wolock, DM; Meador, MR. (2011) Alteration of streamflow magnitudes and potential ecological consequences: a multiregional assessment. Front Ecol Environ 9:264−270.

Carter, JL; Resh, VH. (2013) Analytical approaches used in stream benthic macroinvertebrate biomonitoring programs of state agencies in the United States. [USGS Open-File Report 2013-1129]. Reston, VA: U.S. Geological Survey. http://pubs.usgs.gov/of/2013/1129/.

Chapman, AD. (2005) Principles of data quality. Version 1.0. Report for the Global Biodiversity Information Facility (GBIF). Global Biodiversity Information Facility, Copenhagen, Denmark: Global Biodiversity Information Facility. Available online at http://www2.gbif. org/DataQuality.pdf.

Chase, R. (2005). Standard Operating Procedure: Streamflow measurement. [CN 68.0]. Massachusetts Department of Environmental Protection, Division of Watershed Management.

Chinnayakanahalli, KJ; Hawkins, CP; Tarboton, DG; Hill, RA. (2011) Natural flow regime, temperature and the composition and richness of invertebrate assemblages in streams of the western United States. Freshw Biol 56:1248−1265. doi: 10.1111/j.1365-2427.2010.02560.x.

Chiu, MC; Kuo, MH. (2012) Application of r/K selection to macroinvertebrate responses to extreme floods. Ecol Entomol 37(2):145−154.

Clark, ME; Rose, KA; Levine, DA; Hargrove, WW. (2001) Predicting climate change effects on Appalachian trout: combining GIS and individual-based modeling. Ecol Appl 11(1):161−178.

Conti, L; Schmidt-Kloiber, A; Grenouillet, G; Graf, W. (2014) A trait-based approach to assess the vulnerability of European aquatic insects to climate change. Hydrobiologia 721(1): 297−315.

Cuffney, TF; Bilger, MD; Haigler, AM. (2007) Ambiguous taxa: effects on the characterization and interpretation of invertebrate assemblages. J N Am Benthol Soc 26(2):286−307.

Cummins, J; Buchanan, C; Haywood, HC; Moltz, H; Griggs, A; Jones, C; Kraus, R; Hitt, NP; Bumgardner, R. (2010) Potomac large river ecologically sustainable water management report. [ICPRB Report 10-3]. Interstate Commission on the Potomac River Basin for The Nature Conservancy. Available online at www.potomacriver.org/pubs.

Davies, SP; Jackson, SK. (2006) The Biological Condition Gradient: A descriptive model for interpreting change in aquatic ecosystems. Ecol Appl 16(4):1251−1266.

DePhilip, M; Moberg, T. (2010) Ecosystem flow recommendations for the Susquehanna River Basin. Harrisburg, PA: The Nature Conservancy. Available online at http://www.srbc.net/policies/docs/TNCFinalSusquehannaRiverEcosystemFlowsStudyReport_Nov10_20120327_fs135148v1.PDF.

DePhilip, M; Moberg, T. (2013a) Ecosystem flow recommendations for the Delaware River basin. Harrisburg, PA: The Nature Conservancy.

DePhilip, M; Moberg, T. (2013b) Ecosystem flow recommendations for the Upper Ohio River basin in western Pennsylvania. Harrisburg, PA: The Nature Conservancy.

DeShon, J. (1995) Development and application of the Invertebrate Community Index (ICI). [p. 217−243]. In Davis, WS; Simon, TP (eds). Biological assessment and criteria: tools for water resource planning and decision making. Boca Raton:CRC Press.

DeWalt, RE; Cao, Y; Robinson, JL; Tweddale, T; Hinz, L. (2013) Predicting climate change effects on riverine stonefly (Insecta: Plecoptera) species in the Upper Midwest. INHS Technical Report 2013 (22). Prepared for U.S. Fish and Wildlife Service.

Dhungel, S. (2014) Prediction of climate change effects on streamflow regime important to stream ecology. All Graduate Theses and Dissertations: Paper 3083. http://digitalcommons.usu.edu/etd/3083.

Dunham, J; Chandler, G; Rieman, B; Martin, D. (2005) Measuring stream temperature with digital data sensors: a user's guide. [Gen. Tech. Rep. RMRSGTR-150WWW]. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p. Available online at http://fresc.usgs.gov/products/papers/1431_Dunham.pdf.

Durance, I; Ormerod, SJ. (2007) Climate change effects on upland stream macroinvertebrates over a 25-year period. Glob Change Biol 13:942−957.

Faustini, JM. (2000) Stream channel response to peak flows in a fifth-order mountain watershed. Corvallis, OR: Oregon State University, Corvallis, OR.

Faustini, JM; Jones, JA. (2003) Influence of large woody debris on channel morphology and dynamics in steep, boulder-rich mountain streams, western Cascades, Oregon. Geomorphology 51(1−3):187−205.

Feio, MJ; Reynoldson, TB; Graça, MAS. (2006) The influence of taxonomic level on the performance of a predictive model for water quality assessment. Can J Fish Aquat Sci 63(2):367−376.

Flebbe, PA; Roghair, LD; Bruggink, JL. (2006) Spatial modeling to project southern Appalachian trout distribution in a warmer climate. Trans Am Fish Soc 135(5):1371−1382.

Foucreau, N; Piscart, C; Puijalon, S; Hervant, F. (2013) Effect of climate-related change in vegetation on leaf litter consumption and energy storage by Gammarus pulex from Continental or Mediterranean populations. PLoS ONE 8(10): e77242.

Gerth, WJ; Herlihy, AT. (2006) The effect of sampling different habitat types in regional macroinvertebrate bioassessment surveys. J N Am Benthol Soc 25:501−512.

Goode, JR; Luce, CH; Buffington, JM. (2012) Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern Rocky Mountains. Geomorphology 139–140:1−15.

Gotelli, NJ; Graves, GR. (1996) Null models in ecology. Washington, DC: Smithsonian Institution Press.

Goudie, AS. (2006) Global warming and fluvial geomorphology. Geomorphology 79(3−4):384−394.

Haase, P; Murray-Bligh, J; Lohse, S; Pauls, S; Sundermann, A; Gunn, R; Clarke, R. (2006) Assessing the impact of errors in sorting and identifying macroinvertebrate samples. Hydrobiologia, 566:505−521.

Haase, P; Pauls, SU; Schindehütte, K; Sundermann, A. (2010) First audit of macroinvertebrate samples from an EU Water Framework Directive monitoring program: human error greatly lowers precision of assessment results. J N Am Benthol Soc 29(4):1279−1291. 10.1899/09-183.1 http://www.jnabs.org/doi/abs/10.1899/09-183.1.

Harding, JS; Benfield, EF; Bolstad, PV; Helfman, GS; Jones III, EBD. (1998) Stream biodiversity: The ghost of land use past. Proc Nat Acad Sci 95:14843−14847.

Harper, MP; Peckarsky, BL. (2006) Emergence cues of a mayfly in a high-altitude stream ecosystem: Potential response to climate change. Ecol Appl 16:612−621.

Hawkins, CP. (2006) Quantifying biological integrity by taxonomic completeness: Its utility in regional and global assessment. Ecol Appl 16(4):1277−1294.

Hawkins, CP; Tarboton, DG; Jin, J. (2013) Consequences of global climate change for stream biodiversity and implications for the application and interpretation of biological indicators of aquatic ecosystem condition. Final Report. [EPA Agreement Number: RD834186]. Logan Utah: Utah State University. http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/9063.

Herlihy, AT; Sifneos, J; Bason, C; Jacobs, A; Kentula, ME; Fennessy, MS. (2009) An approach for evaluating the repeatability of rapid wetland assessment methods: The effects of training and experience. Environ Manage 44:369−377.

Hewlett, R. (2000) Implications of taxonomic resolution and sample habitat for stream classification at a broad geographic scale. J N Am Benthol Soc 19:352−361.

Hildebrand, RH; Kashiwagi, MT; Prochaska, AP. (2014) Regional and local scale modeling of stream temperatures and spatio-temporal variation in thermal sensitivities. Environ Manage 54:14−22.

Hill, RA; Hawkins, CP; Carlisle, DM. (2013) Predicting thermal reference conditions for USA streams and rivers. Freshw Sci 32(1):39−55.

Hill, RA; Hawkins, CP; Jin, J. (2014) Predicting thermal vulnerability of stream and river ecosystems to climate change. Clim Change 125:399–412. doi:10.1007/s10584-014-1174−4.

Hogg, ID; Williams, DD. (1996) Response of stream invertebrates to a global warming thermal regime: an ecosystem-level manipulation. Ecology 77:395−407.

Holden, ZA; Klene, A; Keefe, R; Moisen, G. (2013) Design and evaluation of an inexpensive solar radiation shield for monitoring surface air temperatures. Agric For Meteorol 180:281−286.

Holling, CS. (1973) Resilience and stability of ecological systems. Ann Rev Ecol Systems 4:1−23.

Horrigan, N; Baird, DJ. (2008) Trait patterns of aquatic insects across gradients of flow-related factors: a multivariate analysis of Canadian national data. Can J Fish Aquat Sci 65: 670−680.

Huh, S; Dickey, DA; Meador, MR; Rull, KE. (2005) Temporal Analysis of the frequency and duration of low and high streamflow: years of record needed to characterize streamflow variability. J Hydrol 310:78−94.

Isaak, DJ; Horan, DL. (2011) An assessment of underwater epoxies for permanently installing temperature in mountain streams. N Am J Fish Manage 31:134−137. Available online: http://www.treesearch.fs.fed.us/pubs/37476.

Isaak, DJ; Wollrab, S; Horan, D; Chandler, G. (2012) Climate change effects on stream and river temperatures across the Northwest U.S. from 1980−2009 and implications for salmonid fishes. Clim Change 113:499−524.

Isaak, DJ; Rieman, BE. (2013) Stream isotherm shifts from climate change and implications for distributions of ectothermic organisms. Glob Change Biol 19:742−751.

Iverson, L; Prasad, A; Matthews, S. (2008) Potential changes in suitable habitat for 134 tree species in the Northeastern United States. Mitig Adapt Strat Glob Change 13:517−540. http://treesearch.fs.fed.us/pubs/15295.

Jackson, JK; Fureder, L. (2006) Long-term studies of freshwater macroinvertebrates—A review of the frequency, duration, and ecological significance. Freshw Biol 51:591−603.

Jones, NE; Schmidt, B. (2012) ThermoStat version 3.0: Tools for analyzing thermal regimes. Ontario Ministry of Natural Resources, Aquatic Research and Development Section. http://people.trentu.ca/nicholasjones/thermostat.htm.

Kanno, Y; Vokoun, JC; Letcher, BH. (2014) Paired stream-air temperature measurements reveal fine-scale thermal heterogeneity within headwater brook trout stream networks. River Res Applic 30:745-755.

Karr, JR. (1991) Biological integrity: A long-neglected aspect of water resource management. Ecol Appl 1:66−84.

Kaufmann, PR; Levine, P; Robinson, EG; Seeliger, C; Peck, DV. (1999) Quantifying physical habitat in wadeable streams. [EPA/620/R-99/003]. Washington, DC: U.S. Environmental Protection Agency. http://www.epa.gov/emap/html/pubs/docs/groupdocs/surfwatr/field/phyhab.html.

Kaufmann, PR; Faustini, JM; Larsen, DP; Shirazi, MA. (2008) A roughness-corrected index of relative bed stability for regional stream surveys. Geomorphology 99(1−4):150−170.

Kaufmann, PR; Larsen, DP; Faustini, JM. (2009) Bed stability and sedimentation associated with human disturbances in Pacific Northwest streams. J Am Water Resour Assoc 45:434−459.

Kelleher, C; Wagener, T; Gooseff, M; McGlynn, B; McGuire, K; Marshall, L. (2012) Investigating controls on the thermal sensitivity of Pennsylvania streams. Hydrological Processes 26(5):771−785.

Kennen, JG; Kauffman, LJ; Ayers, MA; Wolock, DM; Colarull, SJ. (2008) Use of an integrated flow model to estimate ecologically relevant hydrologic characteristics at stream biomonitoring sites. Ecol Modell 211:57−76.

Kennen, JG; Sullivan, DJ; May, JT; Bell, AH; Beaulieu, KM; Rice, DE. (2011) Temporal changes in aquatic-invertebrate and fish assemblages in streams of the north-central and northeastern U.S. Ecol Indic 18:312−329.

Larsen, D; Kaufmann, P; Kincaid, T; Urquhart, N. (2004) Detecting persistent change in the habitat of salmon-bearing streams in the Pacific Northwest. Can J Fish Aqua Sci 61:283−291.

Lenat, DR; Resh, VH. (2001) Taxonomy and stream ecology—The benefits of genus- and species-level identifications. J N Am Benthol Soc 20:287−298.

Liang, X; Lettenmaier, DP; Wood, EF; Burges, SJ. (1994) A simple hydrologically based model of land surface water and energy fluxes for GSMs. J Geophys Res 99(D7):14,415−14,428.

Maheu, A; Poff, NL; St-Hilaire, A. (2015) A classification of stream water temperature regimes in the conterminous USA. River Research and Applications: doi: 10.1002/rra.2906.

MDEP (Maine Department of Environmental Protection). (2007) Chapter 587: In-stream flows and lake and pond water levels. In Sustainable water use program. Augusta, ME: Maine DEP. http://www.maine.gov/sos/cec/rules/06/096/096c587.doc.

Mazor, RD; Purcell, AH; Resh, VH. (2009) Long-term variability in benthic macroinvertebrate bioassessments: A 20-year study from two northern Californian streams. Environ Manage 43:1269−1286.

McCormick, PV; Stevenson, RJ. (1998) Periphyton as a tool for ecological assessment and management in the Florida Everglades. J Phycol 34(5):726−733.

McMahon, G; Bales, JD; Coles, JF; Giddings, EMP; Zappia, H. (2003) Use of stage data to characterize hydrologic conditions in an urbanizing environment. J Am Water Resources Assoc 39:1529−1536.

Melillo, JM; Richmond, TC; Yohe, GW. (2014) Climate change impacts in the United States: the third National Climate Assessment. US Global Change Research Program 841.

Meyer, JL; Strayer, DL; Wallace, JB; Eggert, SL; Helfman, GS; Leonard, NE. (2007) The contribution of headwater streams to biodiversity in river networks. J Am Water Resour Assoc 43:86−103.

Milner, AM; Conn, SC; Brown, LE. (2006) Persistence and stability of macroinvertebrate communities in streams of Denali National Park, Alaska: implications for biological monitoring. Freshw Biol 51:373−387.

Nelitz, MA; MacIsaac, EA; Peterman, RM. (2007) A science-based approach for identifying temperature-sensitive streams for rainbow trout. N Am J Fish Manage 27:405–424.

Norris, RH; Barbour, MT. (2009) Bioassessment of aquatic ecosystems. In: Likens, GE (Ed) Encyclopedia of inland waters, volume 3. Oxford: Elsevier. pp. 21−28.

NWQMC (National Water Quality Monitoring Council). (2011) Establishing a collaborative and multipurpose national network of reference watersheds and monitoring sites for freshwater streams in the United States. U.S. Department of the Interior, U.S. Geological Survey. http://acwi.gov/monitoring/workgroups/wis/National_Reference_Network_for_Streams.pdf.

Olden, JD; Poff, NL. (2003) Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. River Res Appl 19:101−121.

Olivero SA; Barnett, A; Anderson, MG. (2015) A Stream Classification for the Appalachian Region. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA.

Olsen, AR; Sedransk, J; Edwards, D; Gotway, CA; Liggett, W; Rathbun, S; Reckhow. KH; Young, LJ. (1999) Statistical issues for monitoring ecological and natural resources in the United States. Environ Monitor Assess 54:1−54.

Ostermiller, JD; Hawkins, CP. (2004) Effects of sampling error on bioassessments of stream ecosystems: application to RIVPACS-type models. J N Am Benthol Soc 23:363−382.

Parson, M; Norris, RH. (1996) The effect of habitat specific sampling on biological assessment of water quality using a predictive model. Freshw Biol 36:419−434.

Poff, NL; Allan, JD; Bain, MB; Karr, JR; Prestegaard, KL; Richter, BD; Sparks, RE; Stromberg, JC. (1997) The natural flow regime: a paradigm for river conservation and restoration. BioScience 47(11):769−784.

Poff, NL; Olden, JD; Vieira, NKM; Finn, DS; Simmons, MP; Kondratieff, BC. (2006) Functional trait niches of North American lotic insects: traits-based ecological applications in light of phylogenetic relationships. J N Am Benthol Soc 25(4):730−755.

Poff, NL; Pyne, MI; Bledsoe, BP; Cuhaciyan, CC; Carlisle, DM. (2010) Developing linkages between species traits and multiscaled environmental variation to explore vulnerability of stream benthic communities to climate change. J N Am Benthol Soc 29(4):1441−1458.

Pond, GJ; North, SH. (2013) Application of a benthic observed/expected-type model for assessing Central Appalachian streams influenced by regional stressors in West Virginia and Kentucky. Environ Monit Assess 185(11):9299−9320.

Rantz, SE; et al. (1982) Measurement and computation of streamflow, Volume I: Measurement of stage and discharge and Volume II: Computation of discharge. [USGS Water Supply Paper 2175]. U.S. Department of the Interior, U.S. Geological Survey. Available online at http://water.usgs.gov/pubs/wsp/wsp2175/.

R Core Team (2015) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available online at http://www.R-project.org/.

Rehn, AC; Ode, PR; Hawkins, CP. (2007) Comparisons of targeted-riffle and reach-wide benthic macroinvertebrate samples: implications for data sharing in stream-condition assessments. J N Am Benthol Soc 26(2):332−348.

Richards, C; Haro, RJ; Johnson, LB; Host, GE. (1997) Catchment and reach-scale properties as indicators of macroinvertebrate species traits. Freshw Biol 37:219−230.

Richter, BD; Baumgartner, J; Wigington, R; Braun, D. (1997) How much water does a river need? Freshw Biol 37:231–249.

Ricupero, K. (2009) Changing streamflow patterns in the New England region: Implications for ecosystem services, water users and sustainable resources management. Master of Science thesis. Department of Civil and Environmental Engineering, University of Maine, Orono, 212 pages.

Roy, AH; Rosemond, AD; Leigh, DS; Paul, MJ; Wallace, JB. (2003) Habitat-specific responses of macroinvertebrates to land cover disturbance: biological consequences and monitoring implications. J N Am Benthol Soc 22:292−307.

Rustad, L; Campbell, J; Dukes, JS; Huntington, T; Lambert, KF; Mohan, J; Rodenhouse, N. (2012) Changing climate, changing forests: The impacts of climate change on forests of the Northeastern United States and Eastern Canada. [General Technical Report NRS-99]. Newtown Square, PA: United States Department of Agriculture, US Forest Service, Northern Research Station. Available online at http://nrs.fs.fed.us/pubs/41165.

Sandin, L; Johnson, RK. (2000) The statistical power of selected indicator metrics using macroinvertebrates for assessing acidification and eutrophication of running waters. Hydrobiologia 422/423:233−243.

Scarsbrook, MR. (2002) Persistence and stability of lotic invertebrate communities in New Zealand. Freshw Biol 47:417−431.

Segura, C; Caldwell, P; Sun, G; McNulty, S; Zhang, Y. (2015) A model to predict stream water temperature across the conterminous USA. Hydrol Process 29(9):2178−2195.

Shedd, JR. (2011) Standard operating procedure for measuring and calculating stream discharge. Washington State Department of Ecology, Environmental Assessment Program. Available online: http://www.ecy.wa.gov/programs/eap/quality.html.

Snyder, CD; Hitt, NP; Young, JA. (2015) Accounting for groundwater in stream fish thermal habitat responses to climate change. Ecological Applications 25(5):139−-1419.

Sowder, C; Steel, EA. (2012) A note on the collection and cleaning of water temperature data. Water 4:597−606.

Stamp, J; Gerritsen, J. (2009) Methods and assessment comparability among state and federal biological monitoring protocols. Lowell, MA: New England Interstate Water Pollution Control Commission.

Stamp, J; Gerritsen, J; Pong, G; Jackson, SK; Van Ness, K. (2014) Calibration of the Biological Condition Gradient (BCG) for Fish and Benthic Macroinvertebrate Assemblages in the Northern Piedmont region of Maryland. Prepared for U.S. EPA Office of Science and Technology and Montgomery County Department of Environmental Protection.

Statzner, B; Resh, VH; Dolédec, S. (1994) Ecology of the upper Rhône river: a test of habitat templet theories. Freshw Biol 31:253−554.

Stevenson, RJ. (1998) Diatom indicators of stream and wetland stressors in a risk management framework. Environ Monit Assess 51(1−2):107−118.

Stoddard, JL; Larsen, DP; Hawkins, CP; Johnson, RK; Norris, RH. (2006) Setting expectations for the ecological condition of streams: the concept of reference condition. Ecol Appl 16(4):1267−1276.

Stribling, JB; Moulton, SR; Lester, GL. (2003) Determining the quality of taxonomic data. J N Am Benthol Soc 22:621−631.

Stribling, JB; Pavlik, KL; Holdsworth, SM; Leppo, EW. (2008) Data quality, performance, and uncertainty in taxonomic identification for biological assessments. J N Am Benthol Soc 27(4):906−919. Available online at http://www.jnabs.org/doi/abs/10.1899/07-175.1.

Stuckey, MH; Koerkle, EH; Ulrich, J. (2012) Estimation of baseline daily mean streamflows for ungagged location on Pennsylvania streams, water years 1960-2008. [USGS Scientific Investigations Report 2012-5142]. New Cumberland, PA: U.S. Geological Survey. Available online at http://pubs.usgs.gov/sir/2012/5142/.

Sweeney, BW; Jackson, JK; Newbold, JD; Funk, DH. (1992) Climate change and the life histories and biogeography of aquatic insects in eastern North America. [Pages 143−176]. In Firth, P; Fisher, SG (eds). Global climate change and freshwater ecosystems. New York: Springer-Verlag.

Sweeney, BW. (1993) Effects of streamside vegetation on macroinvertebrate communities of White Clay Creek in eastern North America. Proc Acad Nat Sci Phil 144: 291−340.

TNC (The Nature Conservancy). (2009) Indicators of hydrologic alteration version 7.1 user's manual. Available online at http://www.conservationgateway.org/ConservationPlanning/ToolsData/Tools/CommonlyUsedTools/Pages/commonly-used-tools.aspx#IHA.

Townsend, CR; Hildrew, AG. (1994) Species traits in relation to a habitat templet for river systems. Freshw Biol 31:265−275.

Townsend, CR; Dolédec, S; Scarsbrook, MR. (1997) Species traits in relation to temporal and spatial heterogeneity in streams: a test of habitat templet theory. Freshw Biol 37:367−387.

Trumbo, BA. (2010) Sensitivity and exposure of brook trout (Salvelinus fontinalis) habitat to climate change. [Masters Thesis]. Harrisonburg, VA: Department of Biology, James Madison University.

Tsang, Y; Infante, DM; Stewart, J; Wang, L; Tingly III, RW; Thornbrugh, D; Cooper, AR; Daniel, WM. (submitted). StreamThermal: A software package for calculating thermal metrics from stream temperature data (submitted to Fisheries Magazine).

U.S. EPA (Environmental Protection Agency). (2006) Southeastern plains in-stream nutrient & biological response (SPINBR) study quality assurance project plan for state agency activities. [Project Number: 06-0267]. Region 4.

U.S. EPA (Environmental Protection Agency). (2011) Healthy Watersheds Initiative: National Framework and Action Plan. Publication Number: EPA 841-R-11-005.

U.S. EPA (Environmental Protection Agency). (2012a) Implications of climate change for state bioassessment programs and approaches to account for effects. [EPA/600/R-11/036F]. Washington, DC: Global Change Research Program, National Center for Environmental Assessment. http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=239585.

U.S. EPA (Environmental Protection Agency). (2012b) Freshwater biological traits database (final report). [EPA/600/R-11/038F]. Washington, DC: National Center for Environmental Assessment. Available online at http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=241813

U.S. EPA (Environmental Protection Agency). (2013a) National rivers and streams assessment 2013−2014: Field operations manual—wadeable. [EPA/841/B-12/007]. Washington, DC: U.S. Environmental Protection Agency, Office of Water.

U.S. EPA (Environmental Protection Agency). (2013b) A Long-Term Vision for Assessment, Restoration, and Protection under the Clean Water Act Section 303(d) Program. http://www2.epa.gov/sites/production/files/2015-07/documents/vision_303d_program_dec_2013.pdf.

U.S. EPA (Environmental Protection Agency). (2014) Best practices for continuous monitoring of temperature and flow in wadeable streams. Final report. [EPA/600/R-13/170F]. Washington, DC: Global Change Research Program, National Center for Environmental Assessment. Available online at http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=280013.

van Kleef, HH; Verberk, WCEP; Leuven, RSEW; Esselink, H; Van der Velde, G; Van Duinen, GA. (2006) Biological traits successfully predict the effects of restoration management on macroinvertebrates in shallow softwater lakes. Hydrobiologia 565:201−216.

Vannote, RL; Minshall, GW; Cummins, KW; Sedell, JR; Cushing, CE. (1980) The river continuum concept. Can J Fish Aquat Sci 37(1):130−137.

Vinson, MR; Hawkins, CP. (1996) Effects of sampling area and subsampling procedure on comparisons of taxa richness among streams. J N Am Benthol Soc 15(3):392−399.

Waite, IR; Herlihy, AT; Larsen, DP; Klemm, DJ. (2000) Comparing strengths of geographic and nongeographic classifications of stream benthic macroinvertebrates in the Mid-Atlantic Highlands, USA. J N Am Benthol Soc 19(3):429−441.

Wehrly, KE; Wiley MJ; Seelbach, PW. (2003) Classifying regional variation in thermal regime based on stream fish community patterns. Trans Am Fish Soc 132:18–38.

Wenger, SJ; Isaak, DJ; Luce, CH; Neville, HM; Fausch, KD; Dunham, JB; Dauwalter, DC; Young, MK; Elsner, MM; Rieman, BE; Hamlet, AF; Williams, JE. (2011) Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. Proc Nat Acad Sci USA 108(34):14175−14180.

Whiles, MR; Wallace, JB. (1997) Leaf litter decomposition and macroinvertebrate communities in headwater streams draining pine and hardwood catchments. Hydrobiologia 353:107−119.

Wright, JF; Moss, D; Armitage, PD; Furse, MT. (1984) A preliminary classification of running-water sites in Great Britain based on macroinvertebrate species and the prediction of community type using environmental data. Freshw Biol 14:221−256.

Wright, JF. (2000) An introduction to RIVPACS. [pgs 1−24]. In Wright, JF; Sutcliffe, DW; Furse, MT (eds). Assessing the biological quality of freshwaters: RIVPACS and other techniques. Ambleside, Cumbria, UK: Freshwater Biological Association.

Yoder, CO; Rankin, ET. (1995) Biological criteria program development and implementation in Ohio. [pp. 109−144, Chapter 9]. In Davis, WS; Simon, T (eds.). Biological assessment and criteria: Tools for water resource planning and decision making. Boca Raton FL: Lewis Publishers.

Yuan, L. (2006) Estimation and application of macroinvertebrate tolerance values. National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC; EPA/600/P-04/116F. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=154869.

APPENDIX A.

POWER ANALYSIS

A.1. BACKGROUND

In 2011−2012, EPA collaborated with seven states in the northeastern United States on a pilot study that laid the groundwork for the Northeast Regional Monitoring Network (RMN). The intent was to design a monitoring network that could detect potentially small trends in biological, thermal, hydrologic, physical habitat, and water chemistry data at high quality sites in a decision-relevant timeframe (e.g., 10−20 years to be relevant to climate change). The design had to achieve a balance between scientific and practical considerations. It had to build on existing state and tribal bioassessment efforts and not exceed resource limitations of the biomonitoring programs.

To help inform the network design, EPA and partners performed a series of analyses on an aggregated data set to explore the following questions:

1) How long will it take to detect trends in biological metrics?
2) How much of an effect do different design decisions, such as sampling frequency and classification scheme, have on trend detection times?

A.2. METHODS

A.2.1. Data Preparation

EPA performed a series of analyses on a regional data set comprised of benthic macroinvertebrate, habitat, and water quality data from participating state biomonitoring programs in New York, Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont. In addition, macroinvertebrate data sets covering the same northeastern study area were obtained from the U.S. EPA Wadeable Streams Study (WSA; U.S. EPA, 2006), the New England Wadeable Streams project (NEWS; Snook et al., 2007), and the U.S. Geological Survey (USGS) National Water Quality Assessment (NAWQA). For purposes of the analyses, the data set was limited to reference sites only, which were defined as locations with the least amount of anthropogenic disturbance (Hughes et al., 1986). Table A-1 lists the reference criteria and Figure A-1 shows the locations of the reference sites. The data set was further limited to include samples collected from June−September[1] and samples with 80 or more total individuals[2]. Samples that had only family-level or coarser identifications were also removed from the data set.

The final data set was comprised of 1,398 samples from 953 reference sites, with sample years ranging from 1981 to 2010. Ten different methods were represented (see Table A-2). The

[1]This encompasses the general timeframe during which participating organizations collected samples for routine assessments.
[2]We selected this threshold because it is 20% smaller than the smallest subsample target size among sampling entities, and a target of ±20% is in keeping with data quality objectives for most subsampling routines (Barbour et al., 1999). While some samples could have low densities due to natural conditions, others reasons, such as quality assurance issues, may account for the low count.

methods differ to varying degrees in sampling effort, sampling gear, habitats sampled, index periods, subsampling/sample processing, and/or level of taxonomic resolution (see Table A-3). Approximately 70% of the samples were collected using kick nets. The other sampling gear consisted of artificial substrates or Surber samplers. Most samples were collected from riffle habitats. Approximately 7% were collected from multiple habitats.

Table A-1. Reference site criteria

Variable	Reference criterion
Percentage Natural land cover[a] (NLCD 2001 upstream)	>85%
Landscape Disturbance Index (LDI)[b]	<1.5 index units
Percentage Imperviousness (2001 upstream)	<1%
Percentage Imperviousness (2006 1-km radius)[c]	<1%
NPDES major discharges	>500 m from the site
Dams	>500 m from the site
Dissolved oxygen	>6 mg/L
Conductivity	<200 µS/cm

[a]Land cover screenings were estimates based on data associated with the National Hydrography Dataset Plus Version 1 (NHDPlusV1) catchments in which the sites are located (http://www.horizon-systems.com/NHDPlus). Land use data were based on the 2001 National Land Cover Database (NLCD; Homer et al., 2007) (http://www.mrlc.gov/nlcd01_data.php). For this exercise, natural land cover included open water, forest, wetlands, barren, and grassland/herbaceous. Data were accumulated for the entire upstream catchment.
[b]The LDI (Brown and Vivas, 2005) was calculated by associating land uses with a scale of disturbance intensity and weighting the index score by percentage coverage of the 2001 land uses in the upstream catchment of each site.
[c]Percentage impervious data for the 1-km radius were based on the 2006 National Land Cover Database (NLCD; Fry et al., 2011) (http://www.mrlc.gov/nlcd06_data.php).

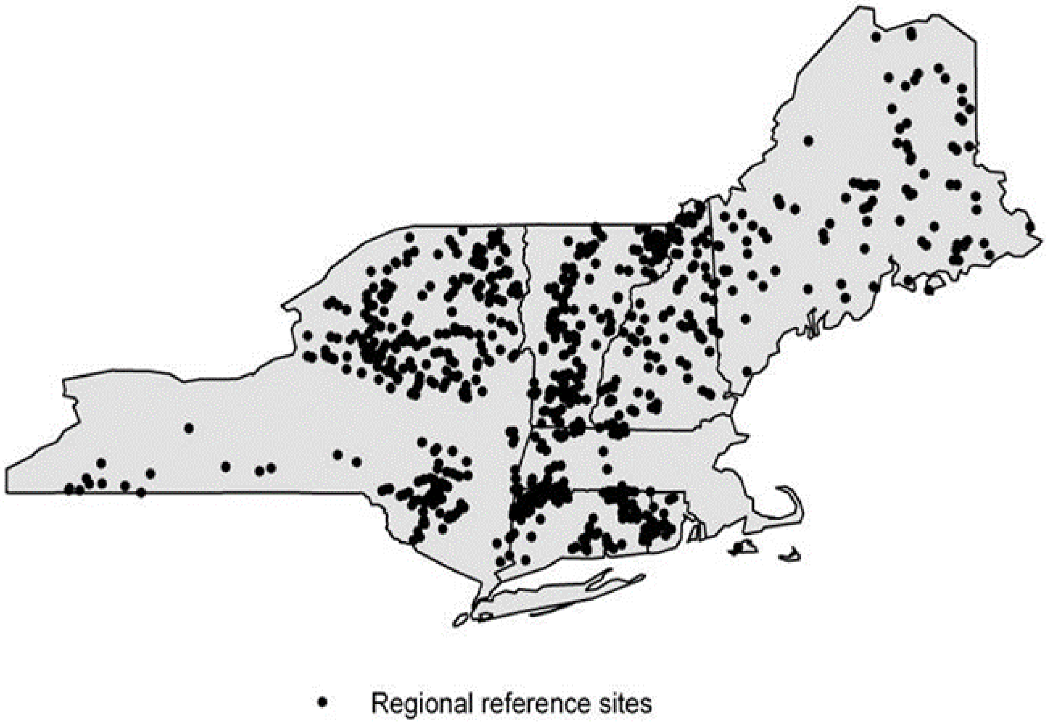


Figure A-1. Reference site locations throughout New England and New York.

Table A-2. Distribution of samples across states, sampling agencies and methods

State	Method	# Samples
CT	CT DEEP Kick Riffle	53
	NEWS Kick Multihabitat	6
MA	CT DEEP Kick Riffle	1
	MA DEP Kick Riffle	49
	NEWS Kick Multihabitat	1
	USGS Surber Riffle	14
	WSA Kick Multihabitat	1
ME	ME DEP Rock Basket	129
	NEWS Kick Multihabitat	30
	WSA Kick Multihabitat	7
NH	NEWS Kick Multihabitat	25
	NH DES Rock Basket	85
	USGS Surber Riffle	1
	WSA Kick Multihabitat	5
NY	NY DEC Kick Riffle	497
	USGS Surber Riffle	12
	WSA Kick Multihabitat	13
RI	NEWS Kick Multihabitat	4
	RIDEM Kick Riffle	21
VT	NEWS Kick Multihabitat	12
	USGS Surber Riffle	1
	VT DEC Kick Riffle	430
	WSA Kick Multihabitat	1
	Total	**1,398**

Table A-3. Description of collection and processing methods included in the analytical data set

Entity	Collection method	Gear	Habitat	Sample area	Subsampling	Index period
CT DEEP	12 kick samples are taken throughout riffle habitats within the sampling reach	Rectangular net (18" wide × 9 " high), 500 µm mesh	Riffle	~2 m^2	200-organism minimum count, randomly selected from a 56 grid (5 cm × 5 cm grids) subsampling tray	Sep 15−Nov 30
VT DEC	Kick samples taken from riffle habitat in 4 different locations in the sampling reach. Substrate disturbed at each for ~ 30 seconds, total active sampling effort 2 minutes.	D-frame net (18" wide × 12" high) with 500 µm mesh	Riffle	~1 m^2	1/4 of the sample, with a minimum of 300 organisms (if less than 300 organisms are found, 1 grid at a time is picked until the target is reached or the whole sample is picked)	Sep− mid Oct
ME DEP	3 cylindrical rock-filled wire baskets, placed in locations with similar habitat characteristics for 28 ± 4 days.	Contents washed into sieve bucket with 600 µm mesh	Riffle/run preferred.	~0.3 m^2 per basket	Subsampling rules are difficult to briefly summarize (see Davies and Tsomides, 2002). For this project, the entire samples were processed and identified.	Jul−Sep 30
NH DES	3 cylindrical rock-filled wire baskets in riffle habitat or at base of riffles at depths that cover the baskets by at least 5 inches, for 6 to 8 weeks.	Contents washed into sieve bucket with 600 µm mesh	Riffle/run preferred.	~0.3 m^2 per basket	Quarter of the sample with a minimum of 100 organisms (if less than 100 organisms are found, then the entire sample is processed)	late Jul−Sep
NEWS	A 0.2-m^2 quadrat randomly tossed in a particular mesohabitat of stream reach; sampled for 1 minute. 20 total quadrats collected per site in proportion to existing habitat in reach.	1/5 meter square quadrat. D-frame net with 500 µm mesh.	Multihabitat Composite	~4 m^2	200-organism minimum count, randomly selected from a Caton grid	Jul−Sep

Table A-3. continued…

Entity	Collection method	Gear	Habitat	Sample area	Subsampling	Index period
WSA	A 1 square foot area was sampled for 30 seconds at a randomly selected location at each of the 11 transects. The samples were composited into one sample per site.	Modified D-frame net (12" wide) with 500 µm mesh	Multihabitat Composite	~1 m^2	500-organism minimum count, randomly selected from a Caton grid	Jun− mid Oct[a]
MA DEP	10 kick-samples are taken in riffle habitats within the sampling reach and composited	kick-net, 46 cm wide opening, 500 µm mesh	Riffle/run preferred	~2 m^2	Count-based, 100-organism randomized pick	Jul 1−Sep 30
RI DEM	Kick samples are taken from riffle habitats along 100 meter reach representative of the stream sampled timed for a total active sampling effort of 3 minutes.	D-frame net (0.3 m width) with 500 µm mesh	Riffle	100 liner meters	100 organism minimum count, grids randomly selected from a 16-grid tray until minimum is picked	Aug−Sep
NY DEC	Substrate is dislodged by foot, upstream of the net for 5 minutes and a distance of 5 meters. The preferred line of sampling is a diagonal transect of the stream	Rectangular net (9” × 18”) with 800−900 µm mesh	Riffle	2.5 m	100	Jul−Sep
USGS	Semiquantitative sample, composite of 5 discrete collections from the richest targeted habitat (typically riffle, main-channel, coarse-grained substrate habitat type).	Slack sampler, 500-µm nets and sieves	Riffle	1.25 m^2	300-organism target	Late Jun−mid Oct

[a]The WSA index period was supposed to end in September but some samples were collected in October

The analysis consisted of 7 different biological metrics. Three of the metrics (total taxa richness and EPT richness and percentage composition) are commonly used in bioassessments, and the other 4 (richness and percentage composition of cold and warm water taxa) are believed to be climate-sensitive. The list of cold and warm water taxa, which can be found in Appendix I, were derived from: (1) generalized additive modeling analyses (GAM; Yuan, 2006) on the Northeast data set; (2) supplemental data provided by participating organizations in the Northeast, Mid-Atlantic and Southeast regions; and (3) best professional judgment of regional experts. Samples with larger numbers of individuals are likely to have greater numbers of taxa, necessitating adjustments to account for differences in subsampling procedures before calculating richness metrics (Gotelli and Colwell, 2001). Samples were randomly subsampled to 120 organisms, which is the upper end of the 20% target used for most subsampling routines (Barbour et al., 1999). The subsampling routine was repeated 1,000 times, and metric values were averaged across these 1,000 runs.

A.2.2. Classification

This study explored three different classification frameworks for the Northeast. The first one is based on an analysis of the regional macroinvertebrate data set (for details, see the supplemental data at the end of this appendix). The classification scheme is comprised of four broad stream classes based on slope (NHDPlus flowline slope; unitless) and size (NHDPlus cumulative drainage area; km^2). The classes are broad enough to be represented in most states (see Figure A-2) and similar enough biologically to justify combining the macroinvertebrate data across the region. These analyses assessed the following 3 classes: high gradient, less than 100 km^2 (HGL); moderate gradient, less than 100 km^2 (MGL); and low gradient and/or greater than 100 km^2 (LGG). The fourth class ('other,' which are streams that are low gradient [<0.005] with drainage areas <10 km^2 or high gradient [>0.02] with drainage areas >100 km^2) was excluded from the analysis because it occurs infrequently in the data set.

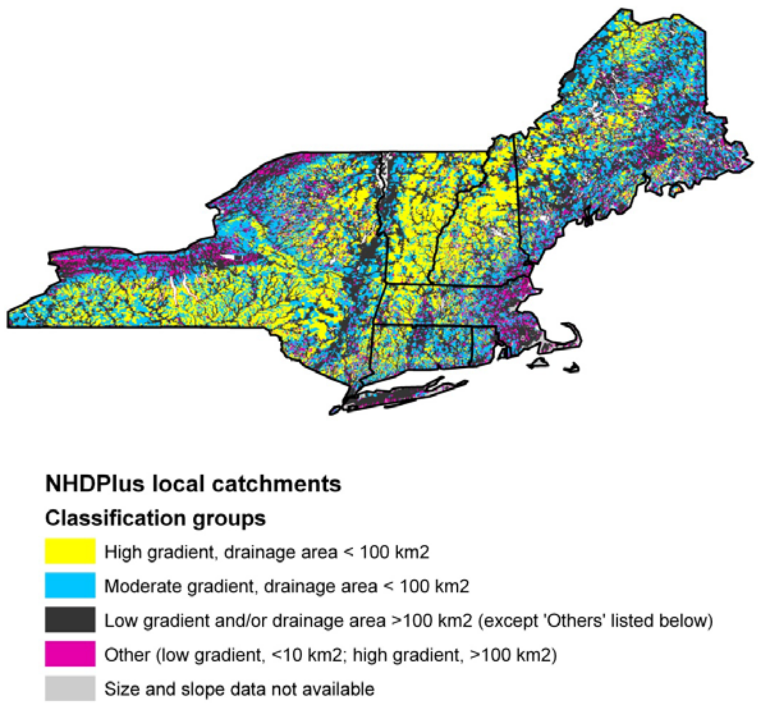


Figure A-2. Spatial distribution of NHDPlus local catchments grouped by size/slope class.

The other two stream classifications were: EPA Level 2 ecoregions (Omernik, 1995) and the Northeast Aquatic Habitat Classification (NAHC) developed by The Nature Conservancy (TNC; Olivero and Anderson, 2008). Ecoregions are delineated based on similarities in characteristics such as geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology, while the NAHC represents natural flowing-water aquatic habitat types using stream size (seven classes; headwaters to great rivers), NHDPlus flowline slope (six classes; very low to very high gradient), temperature (four classes: cold to warm water) and geology (three classes: buffered to acidic). These analyses evaluated two of the EPA Level 2 ecoregions (the Atlantic Highlands and Mixed Wood Plains, which encompass the majority of the study area) and two groupings of the NAHC classes (Creek—Moderate to High Gradient—Moderately Buffered—Cold [TNC 1]; and Creek—Moderate to High Gradient—Acidic—Cold [TNC 2]). Table A-4 summarizes the number of samples in each classification group.

Table A-4. Summary of the data sets on which the power analyses are based

Data set	Class	Description	Number of Samples	Years covered
Slope/size	HGL	High gradient (>0.02), drainage area <100 km^2	515	1986–2010
	MGL	Moderate gradient (0.005 to 0.02), drainage area <100 km^2	362	1987–2010
	LGG	Low gradient (<0.005) and/or drainage area >100 km^2 EXCEPT low gradient (<0.005), drainage area <10 km^2 and high gradient (>0.02), drainage area >100 km^2	500	1981–2010
EPA Level 2 Ecoregion	ER 5.3	Atlantic Highlands (5.3)	1,108	1983–2010
	ER 8.1	Mixed Wood Plains (8.1)	278	1981–2009
Northeast Aquatic Habitat Classification (Olivero and Anderson 2008)	TNC 1	Creek (10–100 km^2), moderate or high gradient (≥0.005 and <0.05), cold, moderately buffered or neutral	325	1986–2010
	TNC 2	Creek (10–100 km^2), moderate or high gradient (≥0.005 and <0.05), cold, low buffered or acidic	159	1988–2010

A.2.3. Analytical techniques

Estimations of variance components and power analyses simulations can help assess differences in trend detection ability between:

- climate-sensitive and traditional metrics
- sampling frequency (1 vs. 2 vs. 5-year)
- effect size[3] (0.5, 1, and 2%)
- classification schemes (size/slope; Level 2 ecoregion; NAHC)

[3]Effect size refers to the annual rate of change (e.g., the 0.5% effect size represents the smallest rate of change while the 2% effect size represents the largest rate of change).

Power analyses are well-suited for experimental design because one can experiment with different settings, such as power[4] (e.g., 80% or higher), sample size (e.g., 25 vs. 50), and effect size (0.5, 1, or 2%), to get a sense of how long it will take to detect a change of a given size at a certain level of confidence. Results can also be used to provide information on design decisions that minimize variability and increase the power to detect trends over shorter time periods.

The variance components analysis focused on three major components of variation: among methods, among subbasins (using eight digit hydrologic units, or HUC8s), and residual variation. Data were aggregated at the subbasin level instead of the site level because very few sites had a significant number of revisits. Variance among methods was included because methods strongly influence community structure (see Figure A-S1 in the supplemental material at end of this appendix). Variance components were estimated for each metric and stream class using mixed effects models of the form $y_{ijk} = \beta_0 + \beta_1 * x_{ijk} + \epsilon_{ijk}$, where x_{ijk} is the year (k) the sample was collected with a specific method (i) and within a specific subbasin (j), and where the error term is partitioned into three components, $\epsilon_{ijk} = b_{0,i} + b_{0,j} + \eta_{ijk}$. The models produce linear equations of change in each metric over time, and estimate the variability among collection methods, $b_{0,i} \sim N(0, \sigma_{CollMeth})$, among subbasins, $b_{0,j} \sim N(0, \sigma_{HUC8})$, and unaccounted for interannual variation, $\eta_{ijk} \sim N(0, \sigma_{residual})$. In each simulation run, samples were assigned to an artificial subbasin and one of ten methods (3 samples per method). Each simulation was run 1,000 times, for a fixed number of years, ranging from 2 to 131 years, where power is the percentage of runs with a significant slope effect (β_1, $p < 0.05$). Variance components for each model were estimated with REML using the LME4 package in R (Bates et al., 2011).

Power analyses were conducted for each combination of stream class (using the 7 classes listed in Table A-4), invertebrate metric (7 metrics), effect size (0.5, 1.0, or 2.0%), and sampling frequency (1 vs. 2 vs. 5-year) as categorical main effects. For each metric and stream class combination, the power analyses calculated the number of years needed to reach 80% power by creating simulated data sets using the above estimated error components at different effect sizes (2.0, 1.0, or 0.5% annual rate of change) and sampling intervals (annual, biannual, or every five years). It was assumed that 30 sites were sampled at each sampling frequency[5]. To summarize these results, the number of years needed to exceed 80% power was analyzed using a linear model that included the stream class, invertebrate metric, effect size, and sampling frequency as categorical factors. Since it was expected that specific metrics would perform well in specific stream classes (e.g., that cold-water taxa would have higher detection probabilities in classes that included higher gradient, upland streams), a metric-class interaction was added into the model. Similarly, because it was expected that higher sampling frequency would be more important for low effect sizes, an effect size-sampling frequency interaction was also included in the model. To

---

[4]Power is the likelihood or probability of correctly detecting an outcome of a given size; for example, 80% power means that there is an 80% probability that an outcome of a given size is correctly detected.
[5]EPA and partners performed an exploratory analysis to evaluate how much of a difference it would make if 30 vs. 50 sites were sampled. They found that trend detection times were very similar (detection times differed by 1−2 years, depending on the effect size; the smaller the effect size, the greater the difference; unpublished data).

meet model assumptions, exceedances were log transformed before analysis. When applicable, follow-up multiple comparisons were conducted using a Bonferroni correction for multiple testing.

A.3. RESULTS

Trend detection time was significantly (*P* < 0.0001) influenced by frequency of sampling, type of metric, and stream classification (see Table A-5). The interactions included in the model were significant as well, indicating that detection times associated with each metric depended on the stream class, and that the relationship between sampling frequency and detection time depended on the effect size (*P* < 0.001; see Table A-5).

Table A-5. Power analysis model output table, assuming 80% power and a 30-site sample size

Factor	DF	SS	MS	F	*P*
Biological metric	6	92.32	15.39	7,120.07	<0.0001
Stream class	6	0.92	0.15	70.63	<0.0001
Biological metric × stream class	36	3.95	0.11	50.75	<0.0001
Effect size	2	62.8	31.4	14,529.82	<0.0001
Sampling frequency	2	15.87	7.94	3,672.31	<0.0001
Effect size × sampling frequency	4	0.04	0.01	4.12	0.0003
Residual	384	0.83	0.002		

Results suggest that trends in biological indicators can be detected within 10−20 years (at 80% power) if 30 or more sites that have comparable environmental conditions and biological communities are monitored regularly (see Figure A-3). As shown in Figure A-3, the 'traditional' metrics (total taxa richness and EPT richness and percentage composition) had shorter trend detection times than the climate-sensitive metrics, and the climate-sensitive richness metrics had shorter trend detection times than the climate-sensitive percentage composition metrics (see Figure A-3). Table A-6 contains a complete list of the number of years needed to exceed 80% power for each metric and stream class combination with different effect sizes (0.5, 1, and 2%) and sampling frequencies (1, 2 and 5-year). Overall, the total taxa richness metric had the shortest trend detection time (13−15 years, depending on classification scheme), while the warm-water percentage individual metric had the longest trend detection time (30+ years; see Table A-6). As expected, the total taxa and EPT richness metrics had higher mean values than the climate-sensitive richness metrics. As shown in Figure A-4, mean richness metric values are inversely related to the number of years needed to detect a trend with 80% power. Put more simply, richness metrics that have higher mean values have shorter trend detection times.

There were differences in performance across the different stream classes (see Figure A-3, Table A-6). The differences were most evident in the climate-sensitive metrics. Overall, the Mixed Wood Plains (8.1) EPA Level 2 ecoregion generally had the longest trend detection times, particularly with the traditional metrics (see Figure A-3, Table A-6). The NAHC classes and 2 of the size/slope classes (high gradient/less than 100 km^2 [HGL] and moderate gradient/less than 100 km^2 [MGL]) generally had the shortest trend detection times for the traditional metrics and the cold water metrics, while the low gradient and/or greater than 100 km^2 (LGG) class had the shortest trend detection times for the warm water metrics (see Figure A-3, Table A-6). Generally speaking, the classifications that were built to separate out small to medium-sized, moderate to high gradient, cold water streams versus large, low gradient warm water streams tended to detect trends in the climate-sensitive metrics in the shortest time periods.

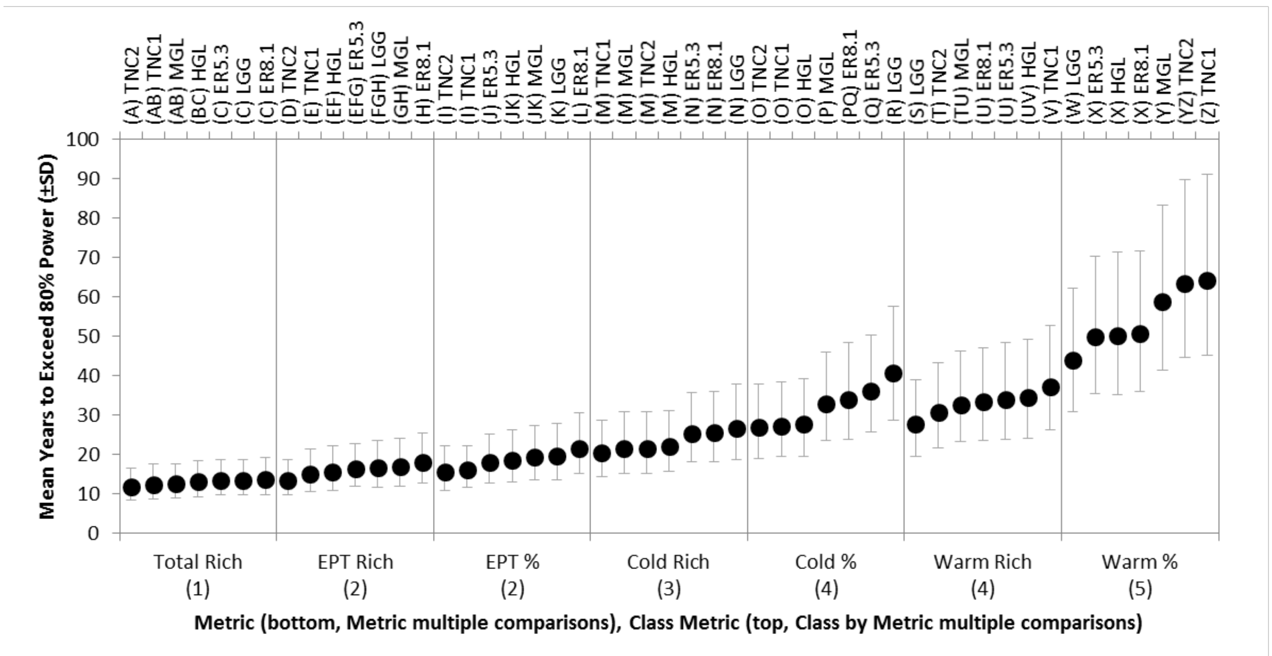


Figure A-3. Mean (±SD) years to detect trends with 80% power for metric and stream class combinations. Results were averaged across the 3 effect sizes (0.5, 1, and 2%) and 3 sampling frequencies (1, 2 and 5-year; 9 estimates per data point). This analysis assumes a 30-site sample size. If the classes (top) share the same letter, this means that the mean number of years to detect trends with 80% power across those classes (for a given metric) are not significantly different (*p* < 0.001). If the biological metrics (bottom) share the same number, this means that the mean number of years to detect trends with 80% power across those metrics (for a given class) are not significantly different (*p* < 0.001).

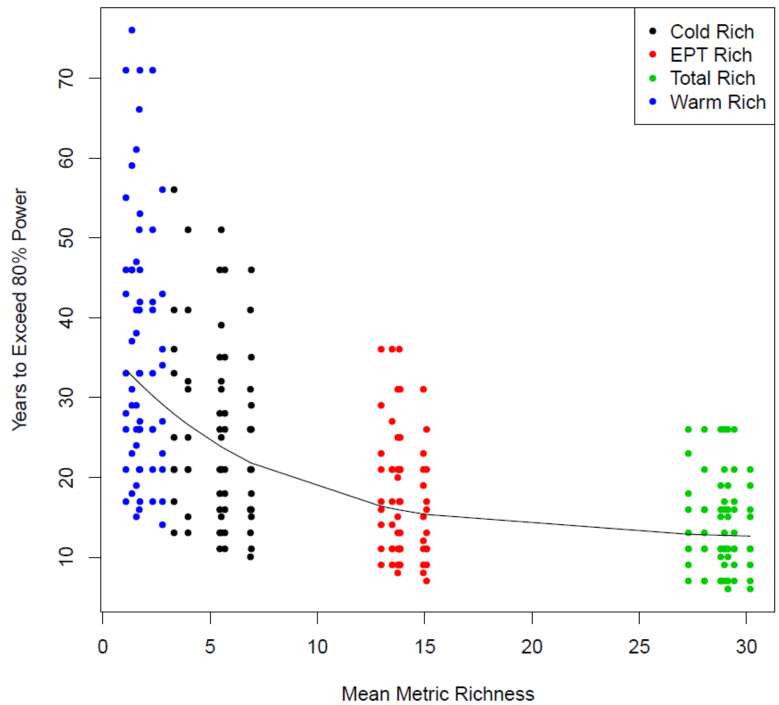


Figure A-4. Relationship between mean metric richness values and number of years to detect trends. Each dot represents the number of years needed to exceed 80% power based on various combinations of the 4 richness metrics, 7 stream classes, 3 effect sizes, and 3 sampling frequencies. Richness metrics are color-coded (cold water richness = black; EPT richness = red; total richness = green; warm water richness = blue). This analysis assumes a 30-site sample size.

Sampling frequency (1 vs. 2 vs. 5-year) also had a significant effect on trend detection times. The weaker the trend (and lower the effect size), the more of a difference the sampling frequency made (see Figure A-5). Annual sampling had the shortest trend detection time across all effect sizes. Annual sampling at 1.0 and 0.5% effect sizes was equivalent to sampling every five years at 2.0 and 1.0% effect sizes, respectively (see Figure A-5).

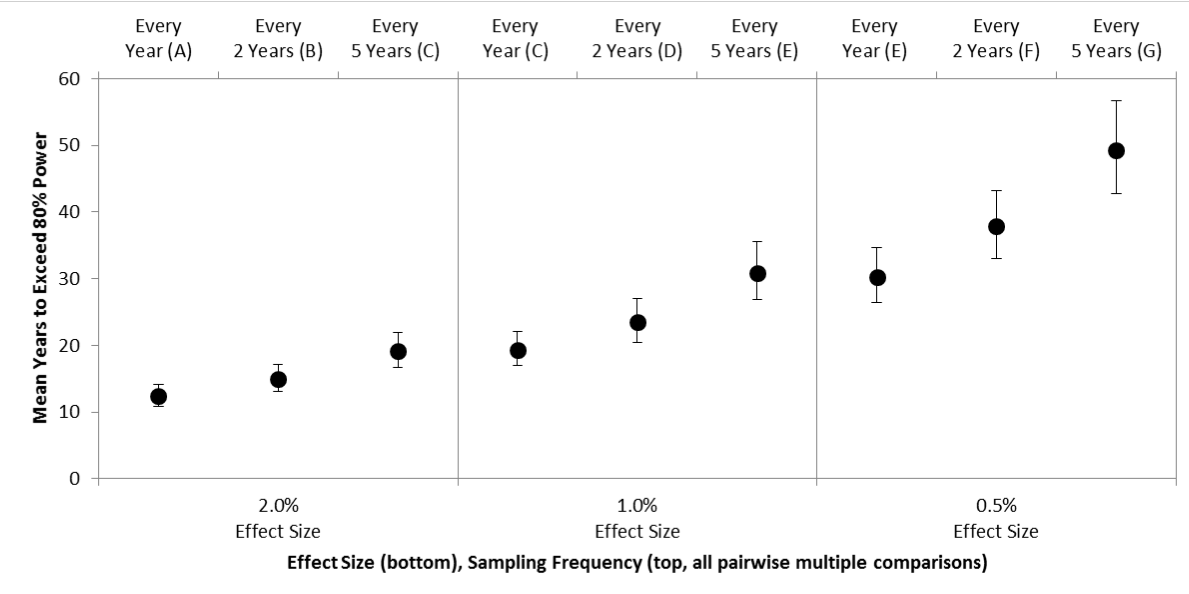


Figure A-5. Mean (±SD) years to detect trends with 80% power for effect size and sampling frequency combinations. Results were averaged across the 7 stream classes and 7 biological metrics (49 estimates per data point). If results share the same letter, this means that the mean number of years to detect trends with 80% power across those effect sizes (for a given sampling frequency) are not significantly different ($p < 0.001$). This analysis assumes a 30-site sample size.

Table A-6. Number of years to detect trends with 80% power for metric and stream class combinations with different effect sizes (0.5, 1, and 2%) and sampling frequencies (1, 2 and 5-year). This assumes a 30-site sample size. Asterisks ([a]) indicate that trend detection times exceed 40 years

Metric	Class	2.0%			1.0%			0.5%		
		1 yr	2 yr	5 yr	1 yr	2 yr	5 yr	1 yr	2 yr	5 yr
Number of Total taxa	Atlantic Highlands (ER 5.3)	7	9	11	11	13	16	17	21	26
	Mixed Wood Plains (ER 8.1)	7	9	11	11	13	16	18	23	26
	High gradient, <100 km^2 (HGL)	7	7	11	11	13	16	16	21	26
	Low gradient and/or >100 km^{2a} (LGG)	7	9	11	11	13	16	17	21	26
	Moderate gradient, <100 km^2 (MGL)	7	7	11	10	11	16	15	19	26
	Creek, mod/high gradient, cold, mod buffer/neutral (TNC 1)	6	7	11	10	11	16	15	19	26
	Creek, mod/high gradient, cold, low buffer/acidic (TNC 2)	6	7	11	9	11	16	15	19	21
Number of EPT taxa	Atlantic Highlands (ER 5.3)	9	11	11	13	17	21	21	25	31
	Mixed Wood Plains (ER 8.1)	9	11	16	14	17	21	23	29	36
	High gradient, <100 km^2 (HGL)	8	9	11	13	15	21	20	25	31
	Low gradient and/or >100 km^{2a} (LGG)	9	11	11	13	17	21	21	25	36
	Moderate gradient, <100 km^2 (MGL)	9	11	11	14	17	21	21	27	36
	Creek, mod/high gradient, cold, mod buffer/neutral (TNC 1)	8	9	11	12	15	21	19	23	31
	Creek, mod/high gradient, cold, low buffer/acidic (TNC 2)	7	9	11	11	13	16	17	21	26

Table A-6. continued…

Metric	Class	2.0%			1.0%			0.5%		
		1 yr	2 yr	5 yr	1 yr	2 yr	5 yr	1 yr	2 yr	5 yr
Percentage EPT individuals	Atlantic Highlands (ER 5.3)	9	11	16	14	17	21	22	29	36
	Mixed Wood Plains (ER 8.1)	11	13	16	18	21	26	28	33	[a]
	High gradient, <100 km^2 (HGL)	9	11	16	15	17	26	23	29	36
	Low gradient and/or >100 km^2[a] (LGG)	10	11	16	15	19	26	24	31	[a]
	Moderate gradient, <100 km^2 (MGL)	10	11	16	15	19	26	23	29	[a]
	Creek, mod/high gradient, cold, mod buffer/neutral (TNC 1)	9	11	11	13	15	21	20	25	31
	Creek, mod/high gradient, cold, low buffer/acidic (TNC 2)	8	9	11	13	15	21	20	25	31
Number of Cold water taxa	Atlantic Highlands (ER 5.3)	13	15	21	21	25	31	32	39	[a]
	Mixed Wood Plains (ER 8.1)	13	15	21	21	25	31	32	[a]	[a]
	High gradient, <100 km^2 (HGL)	11	15	16	18	21	26	29	35	[a]
	Low gradient and/or >100 km^2[a] (LGG)	13	17	21	21	25	36	33	[a]	[a]
	Moderate gradient, <100 km^2 (MGL)	11	13	16	18	21	26	28	35	[a]
	Creek, mod/high gradient, cold, mod buffer/neutral (TNC 1)	10	13	16	16	21	26	26	31	[a]
	Creek, mod/high gradient, cold, low buffer/acidic (TNC 2)	11	13	16	18	21	26	28	35	[a]

Table A-6. continued…

Metric	Class	2.0%			1.0%			0.5%		
		1 yr	2 yr	5 yr	1 yr	2 yr	5 yr	1 yr	2 yr	5 yr
Percentage Cold water individuals	Atlantic Highlands (ER 5.3)	18	23	31	28	35	[a]	[a]	[a]	[a]
	Mixed Wood Plains (ER 8.1)	17	21	26	26	33	[a]	[a]	[a]	[a]
	High gradient, <100 km^2 (HGL)	14	17	21	22	29	36	35	[a]	[a]
	Low gradient and/or >100 km^2[a] (LGG)	21	25	31	32	[a]	[a]	[a]	[a]	[a]
	Moderate gradient, <100 km^2 (MGL)	17	21	26	26	33	[a]	40	[a]	[a]
	Creek, mod/high gradient, cold, mod buffer/neutral (TNC 1)	14	17	21	22	27	36	34	[a]	[a]
	Creek, mod/high gradient, cold, low buffer/acidic (TNC 2)	14	17	21	21	25	36	33	[a]	[a]
Number of Warm water taxa	Atlantic Highlands (ER 5.3)	17	21	26	27	33	[a]	[a]	[a]	[a]
	Mixed Wood Plains (ER 8.1)	17	21	26	26	33	[a]	[a]	[a]	[a]
	High gradient, <100 km^2 (HGL)	17	21	26	28	33	[a]	[a]	[a]	[a]
	Low gradient and/or >100 km^2[a] (LGG)	14	17	21	23	27	36	34	[a]	[a]
	Moderate gradient, <100 km^2 (MGL)	16	21	26	26	33	[a]	[a]	[a]	[a]
	Creek, mod/high gradient, cold, mod buffer/neutral (TNC 1)	18	23	31	29	37	[a]	[a]	[a]	[a]
	Creek, mod/high gradient, cold, low buffer/acidic (TNC 2)	15	19	26	24	29	[a]	38	[a]	[a]

Table A-6. continued…

Metric	Class	2.0%			1.0%			0.5%		
		1 yr	2 yr	5 yr	1 yr	2 yr	5 yr	1 yr	2 yr	5 yr
Percentage Warm water individuals	Atlantic Highlands (ER 5.3)	25	31	[a]	39	[a]	[a]	[a]	[a]	[a]
	Mixed Wood Plains (ER 8.1)	26	31	[a]	40	[a]	[a]	[a]	[a]	[a]
	High gradient, <100 km^2 (HGL)	25	31	[a]	39	[a]	[a]	[a]	[a]	[a]
	Low gradient and/or >100 km^{2}[a] (LGG)	22	27	36	34	[a]	[a]	[a]	[a]	[a]
	Moderate gradient, <100 km^2 (MGL)	29	37	[a]	[a]	[a]	[a]	[a]	[a]	[a]
	Creek, mod/high gradient, cold, mod buffer/neutral (TNC 1)	31	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
	Creek, mod/high gradient, cold, low buffer/acidic (TNC 2)	32	39	[a]	[a]	[a]	[a]	[a]	[a]	[a]

[a]Except low gradient (<0.005), drainage area <10 km^2 and high gradient (>0.02), drainage area >100 km^2

Table A-7 contains 3 sets of results from the variance components analysis: (1) overall variability (estimates are averaged across all metric and stream class combinations); (2) mean variability for each biological metric (estimates are averaged across the stream classes); and (3) mean variability for each stream class (estimates are averaged across the biological metrics). Overall, the residual variation (which represents variability that cannot be attributed to the trend over time, the collection method, and HUC8) was largest (7.02), followed by collection method (4.9) and HUC8 subbasin (3.3; see Table A-7). Percentage individual metrics had higher mean variability than the richness metrics, particularly the percentage EPT and percentage cold water individuals metric (see Table A-7). The mean variability estimates were fairly similar across stream classes.

Table A-7. Results from the variance components analysis. For the overall average, estimates are averaged across all metric and stream class combinations. For the biological metrics, estimates are averaged across the stream classes and for the stream classes, estimates are averaged across the biological metrics.

Set of results	Mean CollMeth	Mean HUC8	Mean Residual
Overall average	4.9	3.3	7.0
Biological metrics			
Total taxa richness	5.7	2.6	5.1
EPT richness	2.0	1.8	3.5
Cold water taxa richness	1.8	1.1	2.3
Warm water taxa richness	0.8	0.7	1.3
Percentage EPT individuals	14.1	6.8	16.5
Percentage Cold water individuals	7.0	6.7	13.0
Percentage Warm water individuals	3.0	3.3	7.4
Stream classes			
Atlantic Highlands (5.3)	5.0	3.0	7.5
Mixed Wood Plains (8.1)	5.3	3.2	7.7
High gradient, <100 km^2 (HGL)	5.1	2.7	7.0
Moderate gradient, <100 km^2 (MGL)	4.8	3.0	7.1
Low gradient and/or >100 km^2* (LGG)	4.9	3.8	7.0
Creek, mod/high gradient, cold, mod buffer/neutral (TNC 1)	4.0	3.6	6.5
Creek, mod/high gradient, cold, low buffer/acidic (TNC 2)	5.5	4.0	6.3

A.4. CONCLUSIONS

The analyses suggest that detection times of 10−20 years (at 80% power) are possible for several of the biological metrics if 30 or more sites with comparable environmental conditions and biological communities are monitored regularly. These results are consistent with other research. For example, Larsen et al. (2004) found that well-designed networks of 30−50 sites monitored consistently can detect underlying changes of 1−2% per year in a variety of metrics within 10−20 years, or sooner, if such trends are present. Larsen et al. (2004) also emphasized the importance of the duration of the survey, citing that trend detection capability increases substantially with time.

The analyses also show that richness metrics have lower variability than percentage individual metrics, which means that there is a greater likelihood of detecting trends in the richness metrics over shorter time periods. Because richness values increase with subsampling effort, it is important to identify an adequate number of organisms, particularly for metrics with low representation (e.g., cold-water taxa). Identifying a larger subsample of organisms at RMN sites (e.g., 300 or more organisms) will improve the power to detect trends. While this may increase costs in the short-term, the resulting increase in power lowers detection times, thereby reducing overall costs of the long-term monitoring effort. Moreover, the earlier detection may lead to management actions that could alleviate additional, costlier impacts.

The classification scheme also influences trend detection times. Thus, the Northeast should be partitioned to minimize environmental variability and gradients. Size and gradient are key variables to capture. Schemes that consider additional variables like thermal class and geology (like TNC's NAHC) may further improve performance, but those variables are generally not as readily available (or dependable), and in this study, did not make a large difference in trend detection times. Classification is also an important consideration during site selection. Since one of the objectives of the RMNs is to detect trends attributable to climate change, tracking changes in the thermal indicator taxa (particularly cold water taxa) is of interest. As discussed above, the more cold water taxa present at the RMN sites, the greater the chance of detecting trends in the cold water richness metric over shorter time periods. Based on unpublished analyses on the Northeast data set, sites in small to medium-sized, medium to high gradient stream classes (MGL and HGL) have higher numbers of cold-water taxa, so selecting sites in these stream classes will improve the chances of detecting climate-related trends over shorter time periods.

Sampling frequency is another important consideration. The analyses show that sampling macroinvertebrates on an annual basis improves trend detection times, particularly if trends are subtle. If sites in the Northeast RMN are sampled annually over a long time period (e.g., 10+ years), this will improve the chances of detecting trends. Other design recommendations, which are described in Section 3.1.1, are based on literature and Standard Operating Procedures (SOPs) commonly used by RMN partners. These include recommendations on time periods for sample collection (also referred to as 'index periods'), collection protocols, type(s) of habitats sampled, and level of taxonomic identification. The use of consistent methods will increase the comparability of data, minimize biases and variability, and ensure that the data meet data quality objectives of the Northeast RMN. These recommendations also can be applied to other regions interested in climate change detection in streams.

A.5. SUPPLEMENTAL MATERIAL

A.5.1. Derivation of the Size/Slope Classification Scheme

Prior to running the classification analysis on the aggregated Northeast data set, the data set was reduced by randomly selecting one sample per site so that sites with multiple years of data would not receive unequal weight (sample size = 689). The 689 sites were distributed across the whole study region. For site classification, nonmetric multidimensional scaling (NMDS) ordination was used to explore predominant types of reference samples based on taxa presence and absence. The ecodist package in R was used to calculate Bray-Curtis similarity measures (Goslee and Urban, 2007; R Core Development Team, 2012) to perform NMDS. Prior to running the analysis, guidelines recommended in Cuffney et al. (2007) were used to develop Operational Taxonomic Units (OTUs) as necessary to achieve an acceptable level of taxonomic consistency across the data set. For interpretability, the NMDS was limited to four axes (Stress = 0.20, r^2 = 0.4).

Initial NMDS ordination using all data showed that sites group by method (see Figure A-S1), indicating that method is an important determinant of taxonomic structure. These differences appeared along all four axes, but were most pronounced in the first three. For example, samples from Maine and New Hampshire (artificial substrate ellipsoid, see Figure A-S1) overlapped and were largely distinct from New York and Vermont samples (riffle D-net ellipsoid, see Figure A-S1). The strongest correlations ($|r| > 0.3$) between taxa and environmental variables included some combination of slope and drainage size in all four axes, but also included longitude on axis 2, and elevation and maximum temperature on axis four (see Table A-S1, left). Axis 1 can be interpreted as shifts in the macroinvertebrate community that occurred as measures of slope increased and drainage area decreased (particularly slope and $\log_{10}$ drainage area), while axes two and three separated the two. Axis two was most strongly related to mean slope (and longitude) and axis three to $\log_{10}$ drainage area. Axis four is less easily interpreted.

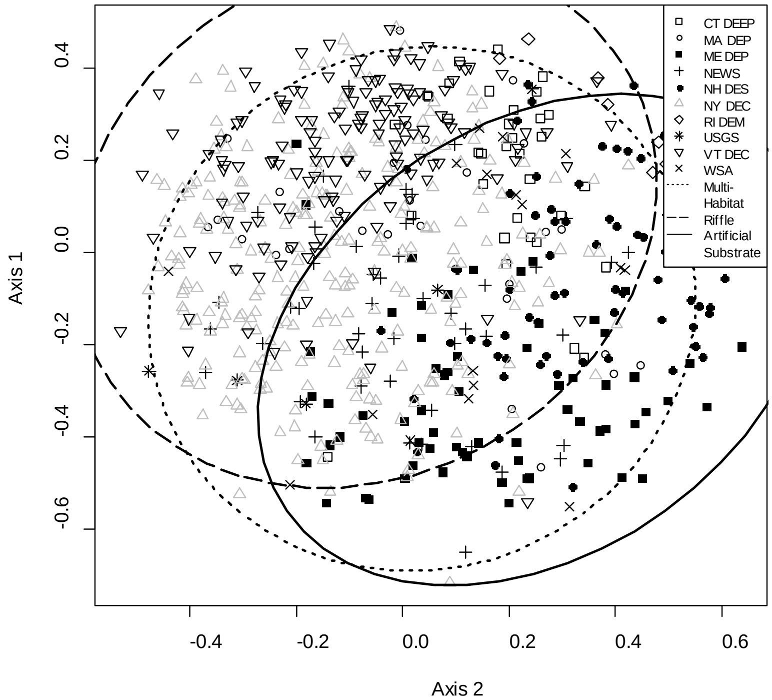


Figure A-S1. Axes 1 and 2 from first NMDS ordination, using data from all methods. All four axis correlations are confounded by method. Methods are represented with different symbols and sampling devices are shown with two rings (solid and dashed 95% confidence ellipsoids). WSA and NEWS samples are also highlighted (dotted 95% confidence ellipsoid).

Table A-S1. Correlations between environmental variables and NMDS axes for all sites (left) and NEWS and WSA sites (right). Both analyses show consistent ties between taxonomic axes and aspects of slope and drainage area. $|r^2| > 0.3$ are bolded.

Environmental	All Sites				NEWS and WSA sites			
Variable	**X1**	**X2**	**X3**	**X4**	**X1**	**X2**	**X3**	**X4**
Latitude	−0.157	0.033	0.056	−0.178	0.062	−0.123	−0.241	0.121
Longitude	−0.173	**0.405**	0.024	−0.244	0.270	−0.130	0.037	−0.001
Sinuosity	−0.039	0.080	−0.002	0.068	0.128	−0.041	0.112	−0.223
Slope	**0.405**	−0.112	−0.093	**−0.462**	−0.205	0.174	**−0.506**	**−0.320**
Mean Slope	0.259	**−0.327**	0.219	**−0.313**	−0.064	0.028	**−0.602**	−0.237
Drainage Area	−0.245	0.086	0.016	0.150	**0.317**	−0.257	0.154	0.136
Log_{10}(Dr Area)	**−0.403**	−0.117	**0.369**	**0.366**	**0.403**	**−0.339**	0.023	0.116
Elevation	0.215	−0.247	−0.073	**−0.308**	−0.203	0.278	**−0.351**	−0.095
Stream Aspect	−0.070	0.015	−0.003	0.053	−0.256	0.112	0.060	0.094
Max Temp	0.041	0.165	−0.049	**0.305**	0.031	−0.004	**0.416**	−0.004
Min Temp	0.027	0.057	0.013	0.263	−0.086	−0.064	−0.013	0.253
Length	0.082	−0.118	0.143	−0.115	0.102	−0.002	**−0.309**	**−0.324**

To eliminate the confounding effects of method, a second NMDS ordination used data only from agencies that used similar methods and sampled across the region. This included 64 sites from the NEWS and WSA studies (multihabitat ellipsoid, see Figure A-S1). The resulting ordination also was limited to four axes for interpretability (Stress = 0.18, $r^2 = 0.53$). This ordination showed high overlap between the two studies on all four axes. Likewise, the strongest correlations ($|r| > 0.3$) between taxa axes and environmental variables included some combination of slope or mean slope and drainage area or $\log_{10}$(drainage area) in all four axes, but also included elevation and maximum temperature on axis 3, and NHDPlus flowline length on axes 3 and 4 (see Table A-S1, right). Axes 1 and 2 reflected shifts in the macroinvertebrate community that occur as measures of drainage area change, while axes 3 and 4 showed shifts related to measures of slope.

Given the consistent appearance of slope and drainage area variables in both NMDS results, these two variables were chosen as a simple way to identify stream classes. Thresholds for both slope and drainage were selected to be consistent with the TNC's Northeast Aquatic Habitat Classification (NAHC; Olivero and Anderson, 2008). The distributions of the biological metrics used in this study were compared in multiple categories of slope and catchment area. In streams with catchments <100 km^2, slope was a dominant effect. Streams with similar slopes but differing catchment size (<10 or >10 km^2) had similar metric distributions. In small rivers with catchments >100 km^2, slope was less of a factor and metric distributions resembled those in lower gradient smaller streams.

The end result was the following four broad stream classes based on slope (NHDPlus flowline slope; unitless) and size (NHDPlus cumulative drainage area; km^2):

- High gradient, less than 100 km^2 (HGL)
- Moderate gradient, less than 100 km^2 (MGL)
- Low gradient and/or greater than 100 km^2 (LGG)
- ‘Other’—low gradient (<0.005), drainage area <10 km^2 and high gradient (>0.02), drainage area >100 km^2

A.6. LITERATURE CITED

Barbour, MT; Gerritsen, J; Snyder, BD; Stribling, JB. (1999) Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish, Second Edition. [EPA 841-B-99-002]. Washington, D.C: U.S. Environmental Protection Agency, Office of Water. Available online: http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm

Bates, D; Maechler, M; Bolker, B. (2011) lme4: Linear mixed-effects models using S4 classes. R package version 0.999375-42. Available online at http://CRAN.R-project.org/package=lme4.

Brown, MT; Vivas, MB. (2005) Landscape development intensity index. Environmental Monitoring and Assessment 101(289-309).

Cuffney, TF; Bilger, MD; Haigler, AM. (2007) Ambiguous taxa: effects on the characterization and interpretation of invertebrate assemblages. J N Am Benthol Soc 26(2):286−307.

Davies, SP; Tsomides, L. (2002). Methods for biological sampling and analysis of Maine's rivers and streams. (DEP LW0387-B2002). August, Maine: Maine Department of Environmental Protection. http://www.maine.gov/dep/water/monitoring/biomonitoring/materials/finlmeth1.pdf

Fry, J; Xian, G; Jin, S; J.Dewitz, C.Homer, L.Yang, C.Barnes, N.Herold, and J. Wickham. (2011) Completion of the 2006 national land cover database for the conterminous United States. PE&RS 77(9): 859−864. Available online at www.mrlc.gov/downloadfile2.php?file=September2011PERS.pdf

Goslee, S; Urban, D. (2007) The ecodist package for dissimilarity-based analysis of ecological data. J Stat Soft 22:1−19.

Gotelli, NJ; Colwell, RK. (2001) Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecol Lett 4:379−391.

Homer, C; Dewitz, J; Fry, J; Coan, M; Hossain, N; Larson, C; Herold, N; McKerrow, A; VanDriel, JN; Wickham, J. (2007) Completion of the 2001 National Land Cover Database for the Conterminous United States. PE&RS 73(4):337−341. Available online at http://www.asprs.org/a/publications/pers/2007journal/april/highlight.pdf

Hughes, RM; Larsen, DP; Omernik, JM. (1986) Regional reference sites: a method for assessing stream potentials. Environmental Management 10(5):629-635.

Larsen, D; Kaufmann, P; Kincaid, T; Urquhart, N. (2004) Detecting persistent change in the habitat of salmon-bearing streams in the Pacific Northwest. Can J Fish Aqua Sci 61:283−291.

Olivero, AP; Anderson, MG. (2008) Northeast aquatic habitat classification. Denver, CO: The Nature Conservancy. Available online at http://rcngrants.org/content/northeastern-aquatic-habitat-classification-project

Omernik, JM. (1995) Ecoregions: a spatial framework for environmental management. In: Davis, W; Simon, T; Eds Biological assessment and criteria: tools for water resource planning and decision making. [pp 49−62]. Boca Raton, FL: Lewis Publishers.

R Core Development Team. (2012) R: A language and environment for statistical computing. Vienna, Austria.

Snook, H; Davies, S; Gerritsen, J; Jessup, B; Langdon, R; Neils, D;Pizutto, E. (2007) The New England Wadeable Stream Survey (NEWS): development of common assessments in the framework of the biological condition gradient. Prepared for USEPA Office of Science and Technology and Office of Wetlands, Oceans and Watersheds, Washington, DC.

U.S. EPA (Environmental Protection Agency). (2006) Wadeable Streams Assessment: a collaborative survey of the Nation's streams. Office of Water, Washington, DC; EPA 841/B-06/002.

Yuan, LL. (2006) Estimation and application of macroinvertebrate tolerance values. [EPA/60/P-04/116F]. Washington, DC National Center for Environmental Assessment. U.S. Environmental Protection Agency, Washington, DC.

APPENDIX B.

CHECKLIST FOR STARTING A REGIONAL MONITORING NETWORK (RMN)

1. Establish the regional working group.

- Coordinator (e.g., from an U.S. EPA Region or a state) volunteers to lead the regional working group.
- The coordinator works with EPA and partners to create a contact list.
- EPA and the coordinator hold a kick-off webinar to brief potential partners on current RMN efforts, describe the RMN framework and development process, and discuss a potential timeline for implementation.

2. The coordinator requests candidate sites from each entity. During the site selection process, the working group considers site selection criteria being used in other RMN regions and tries to use similar criteria where practical. Desired site characteristics include:

- Part of established, long-term monitoring networks
- Low level of anthropogenic disturbance
- Colocated with existing equipment (e.g., USGS gage, weather station)
- Exhibit similar environmental and biological characteristics
- Longevity (e.g., accessible [day trip], opportunities to share the workload with outside agencies or organizations)
- In watersheds that are protected from future development
- Lengthy historical sampling record for biological, thermal or hydrological data

3. The regional coordinator compiles information on data collection and processing protocols being used by each regional working group member, and EPA distributes the generic RMN QAPP[1]. The regional working group reviews the generic QAPP and discusses appropriate protocols for their region. The group attempts to use similar protocols to other RMNs. The draft (region-specific) protocols are written up in an addendum to the QAPP.

4. EPA has been conducting research on screening, classification, and vulnerability analyses for several pilot RMNs (additional documentation to conduct these steps are available from EPA). Pending availability and funding, EPA may be able to assist with the following steps:

- Screening the candidate sites by running them through a disturbance screening process similar to what is described in Appendix D. This may include developing criteria for

[1]U.S. EPA. 2015. Draft generic Quality Assurance Project Plan for monitoring networks for tracking long-term conditions and changes in high quality wadeable streams. This document is available from EPA upon request. Contact Britta Bierwagen (bierwagen.britta@epa.gov).

"reference" sites in urban and agricultural areas. Disturbance ratings will be assigned to the candidate sites.

- Gathering information from the regional working group on existing classification schemes in the region and performing analyses to explore regional classification. Sites will be assigned to classification groups.
- Gathering information on existing climate change vulnerability assessments and performing broad-scale analyses to assess the vulnerability of the candidate RMN sites to climate change.

5. The regional coordinator works with EPA and regional working group members to finalize site selection and protocols. These are included as addendums to the QAPP.

6. The group identifies and seeks resources for implementation. High priority start-up items typically include obtaining equipment and finding funds to process macroinvertebrate samples.

APPENDIX C.

PRIMARY REGIONAL MONITORING NETWORK (RMN) SITES IN THE NORTHEAST, MID-ATLANTIC, AND SOUTHEAST RMN REGIONS

Table C-1. Site information for primary RMN sites in the Northeast (3/2015). Drainage area, slope, and elevation are estimates based on NHDPlus v1[a] local catchment data. Percentage forest is derived from the NLCD 2001[b] data layer and is based on the total watershed

Longitude	Latitude	State	Entity	Station ID	Water body name	Drainage area (km^2)	Slope (unitless)	Elevation (m)	Percentage Forest (%)
−73.27990	41.92670	CT	CT DEEP	CTDEP_2342	Brown Brook	14.7	0.026	286.4	90.2
−71.83424	41.47482	CT	CT DEEP	CTDEP_1748	Pendleton Hill	10.4	0.006	55.2	71.7
−72.83917	41.94639	CT	CT DEEP	CTDEP_1433	West Branch Salmon	34.5	0.021	169.35	81.6
−72.16196	42.03448	MA	MA DEP	MADEP_BB01	Browns	14.7	0.023	253.5	87.3
−73.03027	42.66697	MA	MA DEP	MADEP_CR01AA	Cold River	16.8	0.026	592.4	89.3
−72.96731	42.06555	MA	MA DEP	MADEP_HRCC	Hubbard	30.0	0.029	359.8	86.5
−72.04780	42.39431	MA	MA DEP	MADEP_PBCC	Parkers Brook	13.8	0.011	244.9	79.5
−72.38454	42.46471	MA	MA DEP	MADEP_WSR01	West Branch Swift	9.8	0.011	209.9	91.5
−69.64424	44.95675	ME	ME DEP	MEDEP_57229	East Branch Wesserunsett Stream—Station 486	126.0	0.008	207.2	83.4
−71.35110	43.14410	NH	NH DES	NHDES_99M-44	Bear	25.7	0.005	138.9	81.5
−71.24924	44.21896	NH	NH DES	USGS_01064300	Ellis	28.2	0.031	686.7	88.6
−71.36166	44.35426	NH	NH DES	NHDES_19-ISR	Israel	16.6	0.023	544.7	92.5
−71.29306	43.89639	NH	NH DES	NHDES_98S-44	Paugus	31.5	0.008	264.2	97.8
−71.87633	44.10563	NH	NH DES	NHDES_WildAmmo	Wild Ammo	96.2	0.010	481.0	96.7
−73.54621	41.49457	NY	NY DEC	NYDEC_HAVI_01	Haviland Hollow	24.9	0.011	202.9	85.7
−74.26626	42.01954	NY	NY DEC	NYDEC_LBEA_01	Little Beaver Kill	42.7	0.008	393.3	90.3
−71.61201	41.83760	RI	RI DEM	RIDEM_RMR03a	Rush	12.2	0.017	118.2	72.6
−71.63562	41.76482	RI	RI DEM	RIDEM_SCI01	Wilbur Hollow	11.2	0.008	124.3	74.5
−72.88583	43.87167	VT	VT DEC	VTDEC_135404000013	Bingo	29.2	0.017	458.5	97.3
−72.66250	42.76389	VT	VT DEC	VTDEC_670000000166	Green	67.8	0.010	293.3	89.9

Table C-1. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Drainage area (km^2)	Slope (unitless)	Elevation (m)	Percentage Forest (%)
−71.78528	44.58417	VT	VT DEC	VTDEC_211200000268	Moose	59.0	0.015	532.7	97.5
−72.53705	44.43400	VT	VT DEC	VTDEC_495400000161	North Branch Winooski	29.1	0.014	327.1	95.3
−72.93194	43.13833	VT	VT DEC	VTDEC_033500000081	Winhall	43.8	0.017	587.7	95.0

[a]http://www.horizon-systems.com/nhdplus/nhdplusv1_home.php
[b]http://www.mrlc.gov/nlcd01_data.php

Table C-2. Equipment installed at primary RMN sites in the Northeast (3/2015)

State	Entity	Station ID	Water body name	Temperature	Hydrologic equipment	Hydrologic data type	Notes
CT	CT DEEP	CTDEP_2342	Brown Brook	water	none	none	
CT	CT DEEP	CTDEP_1748	Pendleton Hill	water and air	USGS gage (01118300)	discharge	gage located at biological sampling site
CT	CT DEEP	CTDEP_1433	West Branch Salmon	water	none	none	
MA	MA DEP	MADEP_BB01	Browns	water and air	pressure transducer	stage and discharge	flow rating curve developed by MA RIFLS
MA	MA DEP	MADEP_CR01AA	Cold River	water and air	pressure transducer/USGS gage	stage and discharge	flow rating curve developed by MA RIFLS; USGS gage is now being installed at this site
MA	MA DEP	MADEP_ HRCC	Hubbard	water and air	USGS gage (01187300)	discharge	gage is downstream of site but location looks representative of stream conditions
MA	MA DEP	MADEP_PBCC	Parkers Brook	water and air	pressure transducer	stage and discharge	flow rating curve developed by MA RIFLS
MA	MA DEP	MADEP_WSR01	West Branch Swift	water and air	USGS gage (01174565)	discharge	gage is downstream of site but location looks representative of stream conditions
ME	ME DEP	MEDEP_57229	East Branch Wesserunsett Stream—Station 486	water[a]	USGS gage (01048220)	discharge	gage located at biological sampling site
NH	NH DES	NHDES_99M-44	Bear	water and air	pressure transducer	stage	
NH	NH DES	USGS_01064300	Ellis	water and air	pressure transducer	stage	

Table C-2. continued…

State	Entity	Station ID	Water body name	Temperature	Hydrologic equipment	Hydrologic data type	Notes
NH	NH DES	NHDES_19-ISR	Israel	water and air	pressure transducer	stage	
NH	NH DES	NHDES_98S-44	Paugus	water and air	pressure transducer	stage	
NH	NH DES	NHDES_WildAmmo	Wild Ammo	water and air	pressure transducer	stage	
NY	NY DEC	NYDEC_HAVI_01	Haviland Hollow	water and air	none	none	
NY	NY DEC	NYDEC_LBEA_01	Little Beaver Kill	water and air	USGS gage (01362497)	discharge	gage located at biological sampling site
RI	RI DEM	RIDEM_RMR03a	Rush	Water	USGS gage (01115114)	discharge	gage located at biological sampling site
RI	RI DEM	RIDEM_SCI01	Wilbur Hollow	Water	USGS gage (01115297)	discharge	gage located at biological sampling site
VT	VT DEC	VTDEC_135404000013	Bingo	water[a]	none	none	
VT	VT DEC	VTDEC_670000000166	Green	Water	USGS gage (01170100)	discharge	gage is downstream of site but location looks representative of stream conditions
VT	VT DEC	VTDEC_211200000268	Moose	water and air (Wx station)	pressure transducer	stage	working on flow rating curve
VT	VT DEC	VTDEC_495400000161	North Branch Winooski	water	none	none	
VT	VT DEC	VTDEC_033500000081	Winhall	water[a]	none	none	

[a]not deployed year-round

Table C-3. Site information for primary RMN sites in the Mid-Atlantic (3/2015). Most drainage area, slope, and elevation measurements are estimates based on NHDPlus v1[a] local catchment data. Percentage forest is based on total watershed and is mostly derived from the NLCD 2001[b] data layer. Better data were used, where available (e.g., MD DNR was able to provide information based on exact watershed delineations and the NLCD 2006[c] data layer)

Longitude	Latitude	State	Entity	Station ID	Water body name	Drainage area (km^2)	Slope (unitless)	Elevation (m)	Percentage Forest (%)
−75.74869	39.74567	DE	DNREC	105212	Tributary of White Clay	2	0.023	84.4	57.9
−75.75587	39.72995	DE	DNREC	105213	Tributary of White Clay	2.2	0.018	69.5	61.8
−79.27980	39.64252	MD	MD DNR	YOUG-432-S	Bear Creek	22.7	0.011	805.9	65.9
−79.15566	39.50363	MD	MD DNR	SAVA-204-S	Crabtree Creek	43.9	0.041	620.0	84.3
−77.43406	39.60929	MD	MD DNR	UMON-288-S	High Run	3.3	0.075	310.7	100.0
−78.90556	39.54581	MD	MD DNR	PRLN-626-S	Mill Run	2.0	0.108	522.0	100.0
−79.06689	39.59930	MD	MD DNR	SAVA-225-S	Savage River	138.3	0.018	682.7	83.6
−75.12664	40.97143	NJ	NJ DEP/EPA R2	AN0012	Dunnfield Creek	9.5	0.048	358.4	96.8
−74.43437	41.10693	NJ	NJ DEP	AN0260	Mossmans Brook	10.0	0.009	343.9	80.9
−74.52972	40.76500	NJ	NJ DEP	AN0215A	Primrose	0.01	0.014	123.6	
−77.45100	39.89700	PA	PA DEP	CR	Carbaugh Run	15.5	0.022	435.3	91.0
−77.01929	41.42653	PA	SRBC	SRBC_Grays	Grays Run	51.2	0.014	429.8	93.2
−79.23750	40.00333	PA	PA DEP	JMR/WQN_734	Jones Mill Run	12.8	0.019	710.1	93.1
−77.77068	41.49970	PA	SRBC	SRBC_Kettle	Kettle	210.3	0.000	418.8	84.8
−79.57152	41.69451	PA	PA DEP	WBC/WQN_873	West Branch of Caldwell Creek	50.7	0.005	453.7	82.0
−79.44821	37.53920	VA	VDEQ	2-HUO005.87	Hunting Creek	10	0.047	581.1	90.6
−78.40670074	38.48708676	VA	Shen NP	3-RAP088.21	Rapidan River (upper)	12.7	0.030	928	96
−80.57352	37.37393	VA	VDEQ	9-LRY007.02	Little Stony Creek	48.0	0.061	968.1	97.4
−78.26867	38.70296	VA	Shen NP	3-PIY003.27	Piney River	10.0	0.047	578.8	96.1

Table C-3. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Drainage area (km^2)	Slope (unitless)	Elevation (m)	Percentage Fores (%)t
−79.34634	38.32267	VA	VDGIF	2-RAM007.29	Ramseys Draft	20.0	0.020	868.7	94.0
−80.33483	36.80553	VA	VDEQ	4ARCC008.86	Rock Castle Creek	20.6	0.020	562.5	90.0
−81.75611	36.62583	VA	TVA	TVA_Whitetop	Whitetop Laurel Creek	145.3	0.012	790.0	91.1
−79.60111	38.74322	WV	WV DEP	3593	Big Run	10.4	0.031	1,099.0	98.3
−79.56808	38.62673	WV	WV DEP	6112	Big Run	36.0	0.027	930.9	96.3
−79.67617	38.61844	WV	WV DEP	2571	East Fork/Greenbrier River	28.0	0.011	1,078.6	93.5
−79.48686	38.84942	WV	WV DEP	8756	Seneca Creek	42.5	0.024	873.8	98.3
−80.30063	38.23512	WV	WV DEP	2039	South Fork/Cranberry River	36.3	0.004	1,143.6	97.5

[a]http://www.horizon-systems.com/nhdplus/nhdplusv1_home.php
[b]http://www.mrlc.gov/nlcd01_data.php
[c]http://www.mrlc.gov/nlcd2006.php

Table C-4. Equipment installed at primary RMN sites in the Mid-Atlantic (3/2015)

State	Entity	Station ID	Water body name	Temperature	Hydrologic equipment	Hydrologic data type	Notes
DE	DNREC	105212	Trib White Clay				planning to install water and air temperature sensors and pressure transducers in 2015
DE	DNREC	105213	Trib White Clay				
MD	MD DNR	YOUG-432-S	Bear Creek	water and air			USGS gage (03076600) downstream of site; about nine tributaries (including a major one) enter between gage and site
MD	MD DNR	SAVA-204-S	Crabtree Creek	water and air	USGS gage (01597000)	discharge	
MD	MD DNR	UMON-288-S	High Run	water and air		stage	
MD	MD DNR	PRLN-626-S	Mill Run	water and air		stage	
MD	MD DNR	SAVA-225-S	Savage River	water and air	USGS gage (01596500)	discharge	gage is downstream of site but location looks representative of stream conditions
NJ	NJ DEP/ EPA R2	AN0012	Dunnfield Creek	water and air			applied for a grant to get a USGS gage installed here
NJ	NJ DEP	AN0260	Mossmans Brook	water and air			
NJ	NJ DEP	AN0215A	Primrose	water and air	USGS staff gage (01378780)	occasional stage	applied for a grant to get a USGS gage installed here
PA	PA DEP	CR	Carbaugh Run	water and air			Will try to install pressure transducer in 2015
PA	SRBC	SRBC_Grays	Grays Run	water and air	pressure transducer	stage	Working on flow rating curve
PA	PA DEP	JMR/WQN_734	Jones Mill Run	water and air			
PA	SRBC	SRBC_Kettle	Kettle	water and air	pressure transducer	stage	Working on flow rating curve
PA	PA DEP	WBC/WQN_873	West Branch of Caldwell Creek	water and air			
VA	VDEQ	2-HUO005.87	Hunting Creek	water and air			

Table C-4. continued…

State	Entity	Station ID	Water body name	Temperature	Hydrologic equipment	Hydrologic data type	Notes
VA	Shen NP	3-RAP088.21	Rapidan River (upper)	water and air			Flow nearby though in another drainage (gage in Staunton R)
VA	VDEQ	9-LRY007.02	Little Stony Creek	water and air			
VA	Shen NP	3-PIY003.27	Piney River	water and air	gage		
VA	VDGIF	2-RAM007.29	Ramseys Draft	water and air			
VA	VDEQ	4ARCC008.86	Rock Castle Creek	water and air			
VA	TVA	TVA_Whitetop	Whitetop Laurel Creek	water and air	pressure transducer	stage	
WV	WV DEP	3593	Big Run	water and air	pressure transducer	stage	
WV	WV DEP	6112	Big Run	water and air	pressure transducer	stage	
WV	WV DEP	2571	East Fork/Greenbrier River	water and air			planning to install pressure transducer in 2015
WV	WV DEP	8756	Seneca Creek	water and air			planning to install pressure transducer in 2015
WV	WV DEP	2039	South Fork/Cranberry River	water and air			planning to install pressure transducer in 2015

Table C-5. Site information for primary RMN sites in the Southeast (3/2015). Most drainage areas are estimates based on NHDPlus v1[a] local catchment data. Where available, data from exact watershed delineations were used. Slope and elevation are estimated based on NHDPlus v1 local catchment data. Percentage forest is derived from the NLCD 2001[b] data layer and is based on the total watershed

Longitude	Latitude	State	Entity	Station ID	Water body name	Drainage area (km^2)	Slope (unitless)	Elevation (m)	Percentage Forest (%)
−87.2862	34.3307	AL	AL DEM	BRSL-3	Brushy Creek	23.6	0.002	240.8	96.9
−86.1330	34.9180	AL	AL DEM	HURR-2	Hurricane Creek	102.6	0.000	297.07	93.5
−87.3991	34.2856	AL	AL DEM	SF-1	Sipsey Fork	231.8	0.000	204.6	95.5
−83.5716	34.9590	GA	GA DNR	66d-WRD768	Charlies Creek	7.2	0.040	927.0	99.0
−83.5166	34.9520	GA	GA DNR	66d-44-2	Coleman River	13.6	0.033	866.9	96.8
−84.3851	34.9851	GA	TVA	3890-1	Fightingtown Creek	182.9	0.003	468.8	86.8
−84.1512	34.6020	GA	GA DNR	66g-WRD773	Jones Creek	9.1	0.011	586.0	98.4
−83.9039	37.4550	KY	KY DEP	DOW04036022	Hughes Fork	3.5	0.019	359.1	86.6
−83.1924	38.1311	KY	KY DEP	DOW06013017	Laurel Creek	37.8	0.002	294.3	72.9
−82.9940	37.0774	KY	KY DEP	DOW04055002	Line Fork UT	0.6	NA	335.6	100.0
−82.7916	37.0666	KY	KY DEP	DOW02046004	Presley House Branch	3.0	0.093	736.6	97.0
−82.1014	35.7347	NC	NC DENR	CB6	Buck Creek	37.5	0.011	529.7	96.6
−83.0728	35.6672	NC	NC DENR/TVA	EB320	Cataloochee Creek	127.0	0.010	939.2	99.0
−82.8089	35.2281	NC	NC/DENR/TVA	EB372	Cedar Rock Creek	3.1	0.042	985.9	98.6
−80.0303	35.3792	NC	NC DENR	QB283	Dutchmans Creek	9.1	0.014	177.5	92.2
−81.5672	35.5906	NC	NC DENR	CB192	Jacob Fork	66.5	0.001	380.1	89.4
−79.9906	36.5355	NC	NC DENR	NB28	Mayo River	626.8	0.010	254.9	73.4
−83.8552	35.3094	NC	TVA	10605-2	Snowbird Creek	108.8	0.007	677.8	97.1
−83.0793	34.9235	SC	SC DHEC	SV-684	Crane Creek	4.0	0.078	623.6	97.0
−82.6477	35.0642	SC	SC DHEC	S-086	Matthews Creek	25.8	0.003	360.2	96.3

Table C-5. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Drainage area (km^2)	Slope (unitless)	Elevation (m)	Percentage Forest (%)
−82.5739	35.1254	SC	SC DHEC	S-076	Middle Saluda River	16.0	0.042	582.3	96.6
−82.2515	35.1831	SC	SC DHEC	B-099-7	Vaughn Creek	12.0	0.008	368.4	95.6
−87.5355	35.4217	TN	TN DEC	ECO71F19	Brush Creek	33.3	0.004	245.1	75.8
−84.1182	35.4548	TN	TVA	CITIC011.0MO	Citico Creek	118.1	0.010	399.0	97.2
−82.5291	36.1508	TN	TN DEC	ECO66E09	Clark Creek	23.8	0.017	596.6	95.1
−84.0597	36.2136	TN	TN DEC	ECO67F06	Clear Creek	7.2	0.014	337.1	87.9
−85.9921	35.9286	TN	TN DEC	ECO71H17	Clear Fork Creek	38.1	0.005	262.9	88.8
−85.9111	35.1155	TN	TN DEC	ECO68C20	Crow Creek	47.7	0.006	311.5	84.5
−82.9381	36.5001	TN	TN DEC/TVA	ECO6702	Fisher Creek	30.0	0.003	429.7	82.0
−87.7614	35.9806	TN	TN DEC	ECO71F29	Hurricane Creek	177.6	0.003	156.3	81.0
−84.6981	36.5161	TN	TN DEC	ECO68A03	Laurel Fork Station Camp Creek	15.3	0.014	392.9	97.2
−83.5773	35.6533	TN	TN DEC	ECO66G05	Little River	81.2	0.029	879.5	99.8
−84.9827	36.1299	TN	TN DEC/TVA	MYATT005.1CU	Myatt Creek	12.4	0.016	525.1	78.8
−84.4803	35.0539	TN	TN DEC	ECO66G20	Rough Creek	15.5	0.020	520.6	98.9
−84.6122	35.0031	TN	TN DEC	ECO66G12	Sheeds Creek	14.8	0.031	436.6	98.8
−83.8917	36.3436	TN	TN DEC	ECO67F13	White Creek	8.0	0.009	379.8	90.9
−82.9456	35.9224	TN	TVA	12358-1	Wolf Creek	28.5	0.014	429.9	96.0

[a]http://www.horizon-systems.com/nhdplus/nhdplusv1_home.php
[b]http://www.mrlc.gov/nlcd01_data.php

Table C-6. Equipment installed at primary RMN sites in the Southeast (3/2015). EPA R4 is planning to install equipment at the sites in North and South Carolina as resources permit

State	Entity	Station ID	Water body name	Temperature	Hydrologic equipment	Hydrologic data type	Notes
AL	AL DEM	BRSL-3	Brushy Creek	water and air	pressure transducer	stage	
AL	AL DEM	HURR-2	Hurricane Creek	water and air	pressure transducer	stage	
AL	AL DEM	SF-1	Sipsey Fork	water	USGS gage (02450250)	discharge	water temperature is being measured at the USGS gage
GA	GA DNR	66d-WRD768	Charlies Creek	water and air	pressure transducer	stage	
GA	GA DNR	66d-44-2	Coleman River	water and air	pressure transducer	stage	
GA	TVA	3890-1	Fightingtown Creek	water and air	pressure transducer	stage	Inactive USGS gage (03560000)
GA	GA DNR	66g-WRD773	Jones Creek	water and air	pressure transducer	stage	
KY	KY DEP	DOW04036022	Hughes Fork	water and air	pressure transducer	stage	
KY	KY DEP	DOW06013017	Laurel Creek	water and air	pressure transducer	stage	
KY	KY DEP	DOW04055002	Line Fork UT	water and air	pressure transducer	stage	
KY	KY DEP	DOW02046004	Presley House Branch	water and air	pressure transducer	stage	
NC	NC DENR	CB6	Buck Creek	none	none	none	
NC	TVA	EB320	Cataloochee Creek	water	USGS gage (03460000)	discharge	water temperature is being measured at the USGS gage
NC	NC DENR	EB372	Cedar Rock Creek	none	none	none	USGS gage downstream on Catheys Creek (03440000)
NC	NC DENR	QB283	Dutchmans Creek	none	none	none	inactive USGS gage (02123567)
NC	NC DENR	CB192	Jacob Fork	none	USGS gage (02143040)	discharge	precip is being measured at the USGS gage
NC	NC DENR	NB28	Mayo River	none	USGS gage (02070500)	discharge	

Table C-6. continued…

State	Entity	Station ID	Water body name	Temperature	Hydrologic equipment	Hydrologic data type	Notes
NC	TVA	10605-2	Snowbird Creek	water and air	pressure transducer	stage	inactive USGS gage (03516000)
SC	SC DHEC	SV-684	Crane Creek	none	none	none	
SC	SC DHEC	S-086	Matthews Creek	none	none	none	
SC	SC DHEC	S-076	Middle Saluda River	none	none	none	USGS gage (02162350) downstream of site but unsure whether it is representative (some major tributaries enter between site and gage); EPA R4 will install equipment as resources permit
SC	SC DHEC	B-099-7	Vaughn Creek	none	none	none	
TN	TN DEC	ECO71F19	Brush Creek	water and air	pressure transducer	stage	
TN	TVA	CITIC011.0MO	Citico Creek	water and air	pressure transducer	stage	
TN	TN DEC	ECO66E09	Clark Creek	water and air	pressure transducer	stage	
TN	TN DEC	ECO67F06	Clear Creek	water and air	pressure transducer	stage	
TN	TN DEC	ECO71H17	Clear Fork Creek	water and air	pressure transducer	stage	
TN	TN DEC	ECO68C20	Crow Creek	water and air	pressure transducer	stage	
TN	TN DEC/TVA	ECO6702	Fisher Creek	water and air	pressure transducer	stage	
TN	TN DEC	ECO71F29	Hurricane Creek	water and air	pressure transducer	stage	
TN	TN DEC	ECO68A03	Laurel Fork Station Camp Creek	water and air	pressure transducer	stage	

Table C-6. continued…

State	Entity	Station ID	Water body name	Temperature	Hydrologic equipment	Hydrologic data type	Notes
TN	TN DEC	ECO66G05	Little River	water and air	pressure transducer	stage	
TN	TN DEC/TVA	MYATT005.1CU	Myatt Creek	water and air	pressure transducer	stage	
TN	TN DEC	ECO66G20	Rough Creek	water and air	pressure transducer	stage	
TN	TN DEC	ECO66G12	Sheeds Creek	water and air	pressure transducer	stage	
TN	TN DEC	ECO67F13	White Creek	water and air	pressure transducer	stage	
TN	TVA	12358-1	Wolf Creek	water and air	pressure transducer	stage	

APPENDIX D.

DISTURBANCE SCREENING PROCEDURE FOR RMN SITES

D.1. BACKGROUND

This project developed a screening procedure for candidate regional monitoring network (RMN) sites to determine where the sites fall along a standardized disturbance gradient, using data that are available nationwide and that are derived using common data sources and methodologies. The first iteration of the screening process was developed during the Northeast RMN pilot study in 2012, when over 900 sites were screened. Additional screening considerations related to coal mining, shale gas drilling, atmospheric deposition and other stressors were added during the Mid-Atlantic RMN site selection process.

The screening processes that were performed during the development of the pilot RMNs have limitations. For one, there were insufficient resources to do exact watershed delineations for all of the candidate sites. Instead, the land use data for many of the candidate sites were based on data associated with the National Hydrography Dataset Plus Version 1 (NHDPlusV1) catchments in which the sites are located (U.S. EPA, 2005. While this approach generally provides a good approximation, sometimes there are discrepancies, which are described in Section D.2.1. To address this issue, additional checks were performed to verify the accuracy of the results before finalizing site selection (e.g., local experts who were familiar with the sites verified that results were in keeping with their expectations). In the future, as resources permit, the RMN site screening process will be further refined, and exact watershed delineations will be done for all of the RMN sites.

D.2. METHODOLOGY

Candidate RMN sites were spatially joined with NHDPlusV1 catchments (U.S. EPA and USGS, 2005) using Geographic Information System software (ArcGIS 10.0). Each NHDPlusV1 catchment has a unique identifier called a COMID. Many data were linked to sites via this COMID.

Three different types of disturbance screenings were performed:

1. Land use (see Section D.2.1);
2. Likelihood of impact from dams, mines, and point-source pollution sites (see Section D.2.2); and
3. Likelihood of impact by the following other nonclimatic stressors:
    - Roads (see Section D.2.3.1),
    - Atmospheric deposition (see Section D.2.3.2),
    - Coal (see Section D.2.3.3),
    - Shale gas (see Section D.2.3.4),
    - Future urban development (see Section D.2.3.5), and/or
    - Water withdrawals (see Section D.2.3.6).

These considerations are consistent with recent work performed by Michigan State University (MSU) on the National Fish Habitat Action Plan (NFHAP; DFW MSU et al., 2011; Esselman et al., 2011a). That work included the development of the cumulative disturbance index (DFW MSU et al., 2011; Esselman et al., 2011b).

D.2.1. Land Use Disturbance

The first set of screening was done on land use and impervious cover data from the 2001 National Land Cover Database (NLCD) version 1 data set (Homer et al., 2007). The land use disturbance screening was conducted at both the local catchment and total watershed scales [*important note: for purposes of this exercise, the total watershed scale will be referred to as the "network" scale, in keeping with the work done by DFW MSU et al. (2011)*]. Local catchments are defined as the land area draining directly to a reach, and network catchments are defined by all upstream contributing catchments to the reach's outlet, including the reach's own local catchment (see Figure D-1). GIS shapefiles with delineations of the local catchments were downloaded from the Horizon-Systems website: http://www.horizon-systems.com/NHDPlus/NHDPlusV1_data.php. The network-scale data were generated (and graciously shared) by MSU.

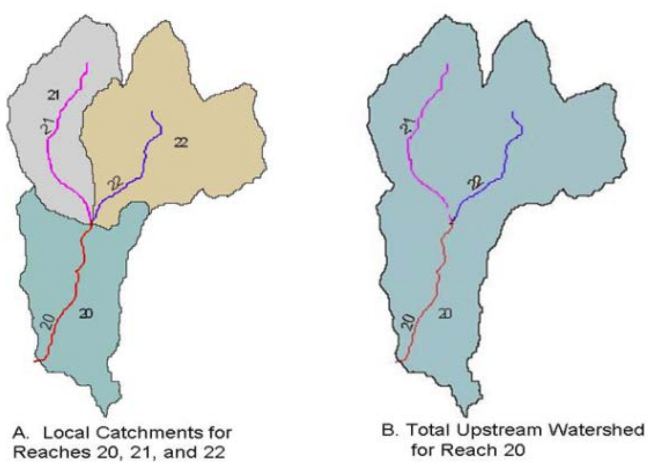


Figure D-1. Land use data were evaluated at both the (A) local catchment and (B) total watershed scales, using NHDPlusV1 delineations (U.S. EPA and USGS, 2005).

While these data generally provide good approximations of land use, they have limitations. For one, there are biases and accuracy issues associated with the NLCD data set (e.g., Novak and Greenfield, 2010; Wickham et al., 2013). Another limitation is that there is no information on whether landscape disturbance mitigation measures are being applied in a given catchment, and if so, how effective those measures are. Thus, we had to assume that the impacts associated with each land use type are equal.

As mentioned earlier, the preliminary land use screening was not based on exact watershed delineations. Rather the data were associated with the entire catchment in which the site is located, regardless of where the site falls within the catchment (it would have been preferable to use data based on exact watershed delineations, but we lacked the resources needed to do exact watershed delineations for all of the candidate sites). The estimates that were used were readily available for all of the sites and generally provide a good approximation (especially when sites are located at the downstream end of the catchment). However, sometimes inaccuracies occur. An example is illustrated in Figure D-2. Maryland site UMON-288-S is located about halfway up the catchment flowline. Urban and agricultural land uses are located within this catchment, but are all downstream of the site. Because these land uses are in the catchment, they are included in the land cover output for this site. An accurate output for that site would only include forested land cover. To catch errors like these, an additional series of checks were performed on the top candidate sites (e.g., we asked local experts to verify that results were in keeping with their expectations and also performed additional desktop screening using aerial photos from Google Earth).

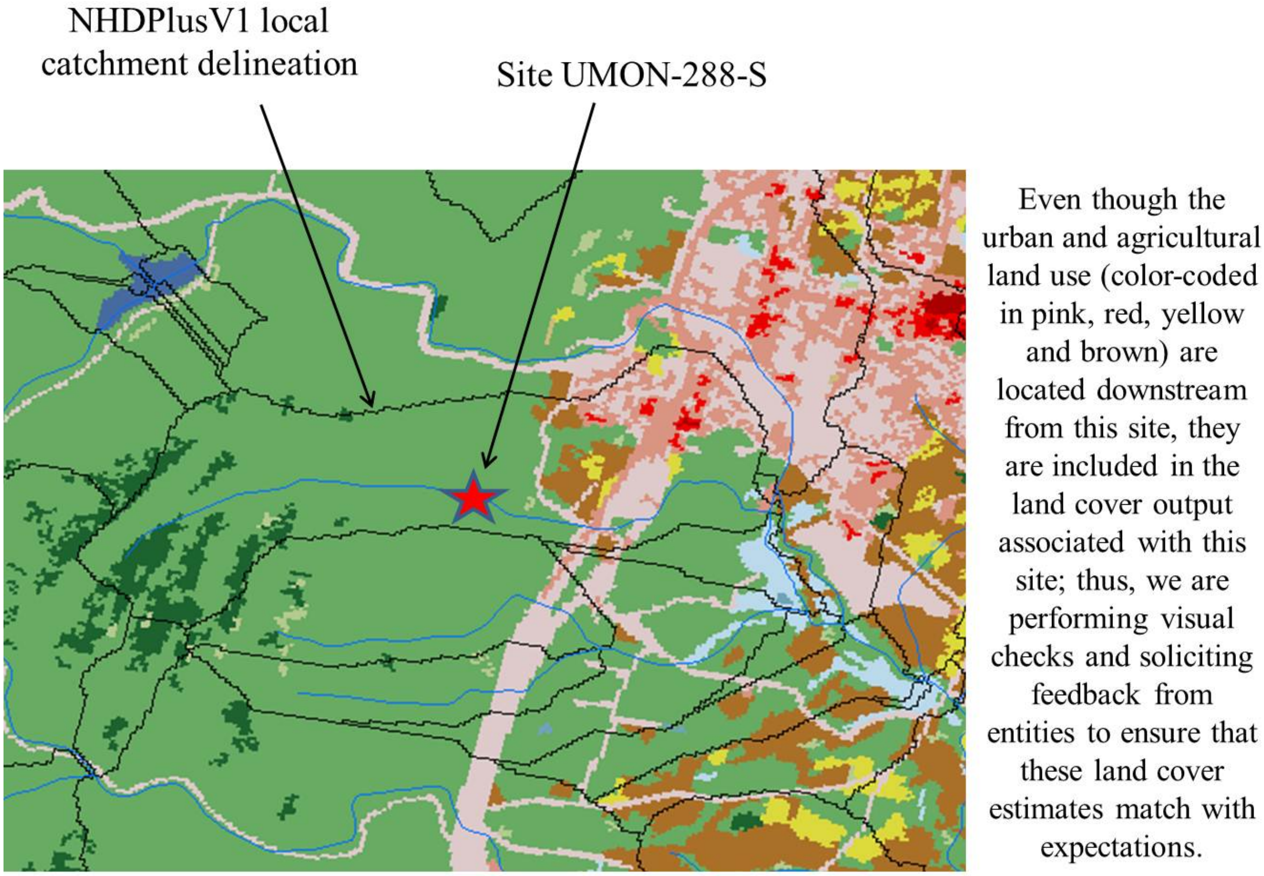


Figure D-2. Example of a situation in which the land use output for a site is inaccurate.

Land use disturbance was assessed at both the local catchment and network scales. This was done for the following four parameters (source: NLCD 2001 version 1 data set[1]):

1. Percentage impervious cover
2. Percentage urban (this includes low, medium, and high intensity developed—NLCD codes 22 + 23 + 24)
3. Percentage cultivated crops (NLCD code 82)
4. Percentage pasture/hay (NLCD code 81)

The project developed a land use disturbance scale with six levels. Thresholds for each parameter, which are guided by literature where available (e.g., King and Baker, 2010; Carlisle et al., 2008), are listed in Table D-1. When rating a site, each parameter was first assessed

[1] http://www.mrlc.gov/nlcd01_data.php

separately. If the parameter values at the local catchment and network scales differed, the thresholds were applied to the maximum value. For example, if a site had 2% urban land cover at the local catchment scale and 1% urban land cover at the network scale, the threshold was applied to the maximum value (in this case, 2% or level 3 for urban land use). This was done for each parameter. Then, sites were assigned an overall disturbance level. This was based on the highest disturbance level assigned across parameters. For example, if a site was level 3 for impervious, level 2 for urban, level 1 for crops, and level 2 for pasture/hay, it was assigned to disturbance level 3. As a final step, local biologists familiar with the sites were consulted to find out their thoughts on the degree of land use impact and also to inquire about the availability of more detailed land use data to help better assess the potential degree of impact.

Table D-1. The thresholds used when assigning sites to the six levels of land use disturbance. Each of the four parameters (impervious, urban, crops, pasture/hay) were assessed separately. Then, sites were assigned an overall disturbance level based on the highest level of disturbance across parameters

Level of land use disturbance	Percentage Impervious (%)	Percentage Urban (%)	Percentage Crops (%)	Percentage Pasture/hay (%)
1	<0.1	0	0	0
2	≤1	≤1	≤1	≤5
3	≤2	≤3	≤5	≤15
4	≤5	≤5	≤15	≤25
5	≤10	≤10	≤25	≤35
6	>10	>10	>25	>35

D.2.2. Likelihood of Impacts from Dams, Mines, and Point-source Pollution Sites

In the second set of screening, sites were flagged if they had a high likelihood of being impacted by dams, mines, National Pollutant Discharge Elimination System (NPDES) major discharges and/or Superfund National Priorities List (SNPL) sites. Both the proximity of these stressors to the sites as well as the attribute data associated with each stressor were considered. The attribute data are important because there are many site-specific factors, such as dam size and storage capacity, that can greatly affect the degree of impact. Table D-2 contains a list of data that were assessed, along with the sources of those data.

The following screening procedures were performed:

1. The data listed in Table D-2 were gathered.

2. Using GIS software (ArcGIS 10.0), a 1-km buffer was created around the preliminary RMN sites (this included both the upstream and downstream areas).

3. Using GIS software (ArcGIS 10.0), a procedure was performed to identify whether any dams, mines, NPDES major discharges or SNPL sites were located within the 1-km buffer.

4. If so, those sites were flagged and the likelihood of impact based on the following considerations was assessed:

    a. Location in relation to the site, assessed via a desktop screening with GIS software (ArcGIS 10.0) and Google Earth.

    b. Attributes of the stressors (e.g., dam size, storage capacity, size of NPDES major discharge).

Best professional judgment was used to assign the flagged sites to one of three impact categories:

- Unlikely impacted
- Likely impacted
- Unsure

Some examples of situations in which sites were assigned to the "unlikely impacted" category are:

- The site was flagged for an NPDES major discharge, but the discharge was relatively small and was located hundreds of meters downstream from the site.

- The site was flagged for a dam, but the dam was located on a different stream.

Some examples of situations in which sites were assigned to the "likely impacted" category are:

- The site was flagged for a NPDES major discharge. It was a large discharge occurring about 100 m upstream from the site.

- The site was flagged for a dam. It was a large dam located on the same stream, just upstream from the site.

Some examples of situations in which sites were assigned to the “unsure” category are:

- The site was flagged for a NPDES major discharge, but the site was located near a confluence and it was difficult to determine which stream contained the discharge.
- The stressor was small- or medium-sized and was located 500 m or more from the site.

One additional check was performed to assess the potential for flow alteration at the sites. We examined the type of NHDPlusV1 flowline (FTYPE) located on the site (e.g., stream/river, artificial pathway, canal/ditch, pipeline, connector; U.S. EPA and USGS, 2005). If the site was located on a flowline designated as something other than a stream/river, the site was flagged.

As a final step, local biologists familiar with the sites were consulted to find out their thoughts on the degree of impact and also to inquire about the availability of more detailed data to help better assess the potential degree of impact.

D.2.3. Likelihood of impact from other nonclimatic stressors

In the third set of screening, sites were flagged if they had a high likelihood of being impacted by:

- Roads,
- Atmospheric deposition,
- Coal mining,
- Shale gas drilling,
- Future urban development, and/or
- Water withdrawals.

Table D-2. These data were assessed when screening for the likelihood of impacts from flow alteration, mines, National Pollutant Discharge Elimination System (NPDES) major discharges, and/or Superfund National Priorities List (SNPL) sites

<table>
<tr><th>Stressor</th><th>Source</th></tr>
<tr><td>Dams</td><td>USGS (U.S. Geological Survey). (2014) Major dams of the United States: National Atlas of the United States. Reston, VA: United States Geological Survey. Available online at : http://nationalatlas.gov/atlasftp.html#dams00x</td></tr>
<tr><td rowspan="2">Mines</td><td>USGS (U.S. Geological Survey). (2005) Active mines and mineral processing plants in the United States in 2003. Reston, VA: USGS. Available online at http://tin.er.usgs.gov/metadata/mineplant.faq.html</td></tr>
<tr><td>PASDA (Pennsylvania Spatial Data Access). (2013) Data download –mine and refuse permits. Available online at www.pasda.psu.edu.</td></tr>
<tr><td>National Pollutant Discharge Elimination System (NPDES) major discharges from the Permit Compliance System</td><td rowspan="2">U.S. EPA (U.S. Environmental Protection Agency). (2013) Geospatial data download service - Geospatial information for all publicly available FRS facilities that have latitude/longitude data [file geodatabase]. Available online at http://www.epa.gov/enviro/geo_data.html</td></tr>
<tr><td>Superfund National Priorities List (SNPL) from the Compensation and Liability Information System</td></tr>
</table>

Table D-3 contains a list of data that were gathered and assessed, along with the sources of those data. There are a lot of site-specific factors that can greatly affect the degree of impact from these stressors, which makes it difficult to set thresholds. For example, a site could be exposed to high concentrations of atmospheric deposition but may not be impacted by acidity because of site-specific mediating factors like calcareous geology. Another example is permit activity associated with coal mining. Just because mining permits have been issued in an area does not mean that mining activities are actually taking place. And even if mining activities are taking place, impacts can vary greatly depending on site-specific factors such as the size and type of mine.

Table D-3. These data were assessed when screening for the likelihood of impacts from roads, atmospheric deposition, coal mining, shale gas drilling, future urban development, and water withdrawals. These data were converted to relative measures, as described in the text.

<table>
<tr><th>Stressor</th><th>Parameters/description</th><th>Source</th></tr>
<tr><td rowspan="2">Roads</td><td>Length of roads, local catchment, and network scales/catchment area</td><td rowspan="2">U.S. Census Bureau (2000) from DFW MSU et al. (2011)</td></tr>
<tr><td>Number of road crossings, local catchment, and network scales/catchment area</td></tr>
<tr><td rowspan="2">Atmospheric deposition</td><td>NO_3 and SO_4 concentrations, based on 2011 deposition grids</td><td>NADP[a]</td></tr>
<tr><td>The Nature Conservancy (TNC) geology class</td><td>Olivero and Anderson (2008)</td></tr>
<tr><td rowspan="2">Coal mining</td><td>Potential for development, based on:
• whether the site is located in a coal field and/or the mountaintop removal (MTR) region
• coal production by state</td><td>Coal fields (USGS, 2001)
MTR region [unknown source; GIS layer was provided by Christine Mazzarella (U.S. EPA)]
Coal production by State [see Table 6 in U.S. EIA (2012)]</td></tr>
<tr><td>Permit activity, based on number of permits issued within 1 km of the site. Data type and availability varied by state.

Alabama:
• Number of active coal mine permits
Pennsylvania:
• Anthracite permits
• Anthracite refuse
• Bituminous permits
• Bituminous refuse
West Virginia:
• WV_permitboundary
• WV_refuse
• WV_valleyfill
• WV_all_mining
Virginia:
• Surface mine permit boundaries</td><td>Alabama (Alabama Surface Mining Commission, 2013)

Pennsylvania (PASDA, 2013)

West Virginia (WVDEP, 2013; WVGES, 2014)

Virginia (VDEQ, 2013)</td></tr>
</table>

Table D-3. continued…

Stressor	Parameters/description	Source
Shale gas drilling	Potential for development, based on whether the site is located in the shale play region	U.S. EIA (2013)
	Permit activity, based on the number of unconventional permits issued within 1 km of the site. These data were available for Pennsylvania (file name: PA_UncPermits_05092013) and West Virginia (file name: WV_Perm_05132013).	Frac Tracker (2013)
Future urban development	Potential for future urban development based on projected change in percentage imperviousness by 2050	U.S. EPA (2011); work performed by Angie Murdukhayeva (U.S. EPA)
Water withdrawals (county-level)	Irrigation, total withdrawals, fresh (Mgal/day)	USGS (2010)
	Total withdrawals, fresh (Mgal/day)	
	Total withdrawals, total (fresh + saline; Mgal/day)	

[a]http://nadp.sws.uiuc.edu/NTN/annualmapsbyyear.aspx

Because of these factors, a relative scale (vs. firm thresholds) was used to assess the likelihood of impact. The relative scales were based on values found in NHDPlusV1 catchments across the entire study area. If a site had an elevated risk score (e.g., >75th percentile), it was flagged for further evaluation (the thresholds [e.g., 50%, 75%] vary depending on the distribution of data in each data set and best professional judgment). These thresholds should be regarded as a starting point, and should be further refined in future iterations of the screening procedure. Local biologists familiar with the sites were then consulted to find out their thoughts on the degree of impact and also to inquire about the availability of more detailed data to help better assess the potential degree of impact [e.g., is mining actually taking place? What are the pH and acid neutralizing capacity (ANC) values at sites flagged for atmospheric deposition?]. The specific screening procedures that were followed for each stressor are described below.

D.2.3.1. *Roads*

Two aspects of potential road impacts were assessed:

- Length of roads and
- Number of road crossings

First the roads data listed in Table D-3 were gathered for both the local catchment and network scales.

Next, to assess the likelihood of impact from length of roads, the following formulas were used to normalize the data:

Local catchment scale = Length of roads in the local catchment (m) ÷ Area of the local catchment (km^2)

Network scale = Length of roads in the network (m) ÷ Area of the network (km^2)

Then, the following formula was used to convert these values to a scoring scale ranging from 0 (no roads) to 100 (highest length of roads per area; note: the minimum and maximum values used in this formula are based on the range of values found across the entire study area):

$$100 \times (\text{Value} - \text{Minimum}) \div (\text{Maximum} - \text{Minimum})$$

If the parameter values at the local catchment and network scales differed, the maximum score was used for the assessment. For example, if the local catchment score was 80 and the network score was 50, the higher score of 80 was used for the assessment.

Sites were flagged for further evaluation if they received a score of ≥75%.

The same procedure was followed when assessing the likelihood of impact from road crossings.

As a final step, we consulted with local biologists who were familiar with the sites to get input on the degree of impact at flagged sites.

D.2.3.2. *Atmospheric Deposition*

Two aspects of atmospheric deposition were assessed:

- Concentrations of NO_3
- Concentrations of SO_4

In addition, TNC geology class (Olivero and Anderson, 2008) was considered as a potential mediating factor. First the data listed in Table C-3 were gathered. Using GIS software (ArcGIS 10.0), the NO_3 and SO_4 deposition grid data (1-km resolution) were linked to the sites. Next, the NO_3 and SO_4 values were averaged. Then, the following formula was used to convert these values to a scoring scale ranging from 0 (no nitrogen and sulfate deposition) to 100 (highest average concentration of NO_3 and SO_4; note: the minimum and maximum values used in this formula are based on the range of values found across the entire study area):

$$100 \times (\text{Value} - \text{Minimum}) \div (\text{Maximum} - \text{Minimum})$$

Sites were flagged for further evaluation if they received a score of ≥75%.

Geology can potentially mediate some of the effects of atmospheric deposition. To assess this potential, GIS software (ArcGIS 10.0) was used to link the TNC geology class (Olivero and Anderson, 2008) to the sites (note: at this time the TNC geology class data are only available for Northeast and Mid-Atlantic regions).

Sites were scored as follows:

- Sites located in areas designated as “low buffered, acidic” received a score of 100.
- Sites located in areas designated as “moderately buffered, neutral” or “assume moderately buffered (Size 3+ rivers)” received a score of 50.
- Sites located in areas designated as “highly buffered, calcareous” received a score of 0.
- Sites located in areas that lacked data or were designated as “unknown buffering/missing geology” were not assessed.

Sites were flagged if they received a score of 100%.

As a final step, we consulted with local biologists who were familiar with the sites to get input on the degree of impact at flagged sites, and to see if they had access to more detailed data, such as pH and ANC measurements, to help us better assess the potential degree of impact.

D.2.3.3. *Coal Mining*

Two aspects of coal mining were assessed:

- Potential for mining
- Permit activity

First the data listed in Table D-3 were gathered.

To assess the potential for coal mining, the following were considered:

- Whether the site is located in an area that has been designated as a mountaintop removal (MTR) area and/or a coal field (USGS, 2001).
    - If the site is located in a coal field, is it designated as “potentially minable” or is it tagged for “other uses”?
- What the total coal production is for the state where the site is located [source: Table 6 in the 2011 Annual Coal Report (U.S. EIA, 2012)].

The following steps were performed when assessing a site for **mining potential**:

1. First a coal field score was assigned, as follows:
    - Using GIS software (ArcGIS 10.0), the coal field and MTR GIS layers were linked to the sites.
    - If the site is located in a catchment that has been designated as a “potentially minable” coal field (USGS, 2001) and/or a mountaintop removal (MTR) area, it was assigned a score of 1.
    - If the site is located in a catchment that has been designated as a coal field with “other uses” (USGS, 2001), it was assigned a score of 0.5.
    - If the site is located in a catchment that is not part of a coal field or MTR area, it received a score of 0.
2. Then a coal production score was assigned, as follows:
    - Total coal production values for each state were taken from Table 6 in the 2011 Annual Coal Report (U.S. EIA, 2012).
    - Those values were converted to a scale of 0 to 100 using this formula (note: the minimum and maximum values used in this formula are based on the range of values found in the states in our study area):

$$100 \times (\text{Value} - \text{Minimum}) \div (\text{Maximum} - \text{Minimum})$$

    - Sites were assigned scores based on what state they were located in. For example, West Virginia had the highest total coal production of all of the states in the study area, so any sites located in West Virginia received a coal production score of 100.

3. To get the final score for **mining potential**, the coal field score was multiplied by the coal production score. Scores ranged from 0 (no mining potential) to 100 (highest potential for mining).

Sites were flagged for further evaluation if they received a score of ≥75%.

Permit data were not available for all the states, and where those data were available, data type and quality varied, as did the attribute data. Therefore, permit activity was assessed on a state-by-state basis. If sites were located in states where permit data were available, the following steps were performed to assess the intensity of **permit activity**:

1. Gather the permit data listed in Table D-3.

2. Using GIS software (ArcGIS 10.0), create a 1-km buffer around the candidate RMN sites (this included both the upstream and downstream areas).

3. Using GIS software (ArcGIS 10.0), perform a procedure to determine how many mining permits had been issued within the 1-km buffer.

4. The following formula was used to convert those values to a scale of 0 to 100 (note: since the type of data available for each state varied, the minimum and maximum values used in this formula were based on the range of data found in each state):

$$100 \times (\text{Value} - \text{Minimum}) \div (\text{Maximum} - \text{Minimum})$$

Sites were flagged for further evaluation if they received a score of >0.

As a final step, we consulted with local biologists who were familiar with the sites to get input on the degree of impact at flagged sites, and to see if they had access to more detailed data to help us better assess the potential degree of impact. Just because mining permits have been issued in an area does not mean that mining activities are actually taking place. And even if mining activities are taking place, impacts can vary greatly depending on site-specific factors such as the size and type of mine.

D.2.3.4. *Shale Gas Drilling*

Two aspects of shall gas drilling were assessed:

- Potential for drilling
- Permit activity

First the data listed in Table D-3 were gathered.

To assess the **potential for shale gas drilling**, the following screening procedure was performed:

- Using GIS software (ArcGIS 10.0), the shale play GIS layer (see Table D-3) was linked to the sites.
- If the site is located in a shale play region, it was assigned a score of 100 and flagged it for further evaluation.

Permit data were only available for the states of West Virginia and Pennsylvania. The following steps were performed to assess the intensity of **permit activity** at sites in those sites:

1. Gather the permit data listed in Table D-3.
2. Using GIS software (ArcGIS 10.0), create a 1-km buffer around the candidate RMN sites (this included both the upstream and downstream areas).
3. Using GIS software (ArcGIS 10.0), perform a procedure to determine how many unconventional permits had been issued within the 1-km buffer.
4. The following formula was used to convert those values to a scale of 0 to 100 (note: since the type of data available for each state varied, the minimum and maximum values used in this formula were based on the range of data found in each state):

$$100 \times (\text{Value} - \text{Minimum}) \div (\text{Maximum} - \text{Minimum})$$

Sites were flagged for further evaluation if they received a score of >0%.

As a final step, we consulted with local biologists who were familiar with the sites to get input on the degree of impact at flagged sites, and to see if they had access to more detailed data to help us better assess the potential degree of impact. Just because drilling permits have been issued in an area does not mean that drilling activities are actually taking place. And even if drilling activities are taking place, impacts can vary greatly depending on site-specific factors.

D.2.3.5. *Potential for Future Urban Development*

EPA's ICLUS tools and data sets (Version 1.3 and 1.3.1; U.S. EPA, 2011) were used to assess the potential that a site will experience future urban development. The ICLUS Tools were used to project the percentage change in imperviousness in each NHDPlusV1 local catchment by

2050 based on high (A2) and low (B1) emissions scenarios (note: the ICLUS data have a resolution of 1-km).

GIS software (ArcGIS 10.0) was used to link sites with NHDPlusV1 local catchments. Sites were flagged for further evaluation if the following conditions occurred:

- The percentage impervious value in the NHDPlusV1 local catchment where the site is located is currently ≤10% (based on values derived from the 2001 NLCD version 1 data set), and
- The future projection is for a positive value ≥0.5% (this is based on an average of the high [A2] and low [B1] emissions scenarios).

As a final step, we checked with local biologists who were familiar with the sites to find out their thoughts on the potential for future development at flagged sites, and to see if they had access to more detailed data to help us better assess the potential degree of impact.

D.2.3.6. *Water Withdrawals*

Three aspects of water use were assessed:

- Irrigation, total withdrawals, fresh;
- Total withdrawals, fresh only; and
- Total withdrawals, total.

First the data listed in Table D-3 were gathered. These data are based on 2005 water use and are only available at the county-level (USGS, 2010). Then GIS software (ArcGIS 10.0) were used to associate the county-level data with NHDPlusV1 local catchments. Next sites were linked with NHDPlusV1 local catchments. For each parameter, the following formula was used to convert the values to a scoring scale ranging from 0 (no withdrawals) to 100 (highest withdrawals; note: the minimum and maximum values used in this formula are based on the range of values found across the entire study area):

$$100 \times (\text{Value} - \text{Minimum}) \div (\text{Maximum} - \text{Minimum})$$

Sites were flagged for further evaluation if they received a score of ≥50% for any of the three parameters.

As a final step, we checked with local biologists who were familiar with the sites to find out their thoughts on the potential for future development at flagged sites, and to see if they had access to more detailed data to help us better assess the potential degree of impact.

D.3. REFERENCES

Alabama Surface Mining Commission. (2013) Alabama coal mine geospatial data – permit boundaries (1983-present). Jasper, AL: State of Alabama http://surface-mining.alabama.gov/.

Carlisle, DM; Hawkins, CP; Meador, MR; Potapova, M; Falcone, J. (2008) Biological assessments of Appalachian streams based on predictive models for fish, macroinvertebrate, and diatom assemblages. J N Am Benthol Soc 27(1): 6–37.

DFW MSU (Department of Fisheries and Wildlife, Michigan State University), Esselman, PC; Infante, DM; Wang, L; Taylor, WW; Daniel, WM; Tingley, R; Fenner, J; Cooper, A; Wieferich, D; Thornbrugh, D; Ross, J. (2011) National Fish Habitat Action Plan (NFHAP) 2010 HCI scores and human disturbance data for conterminous United States linked to NHDPLUSV1. Denver, CO: National Fish Habitat Action Plan (NFHAP). Available online at https://www.sciencebase.gov/catalog/item/514afb90e4b0040b38150dbc

Esselman, PC; Infante, DM; Wang, L; Taylor, WW; Daniel, WM; Tingley, R; Fenner, J; Cooper, C; Wieferich, D; Thornbrugh, D; Ross, R, (2011a) A landscape assessment of fish habitat conditions in United States rivers and their watersheds. Denver, Co: National Fish Habitat Action Plan (NFHAP). Available online at http://fishhabitat.org/.

Esselman, PC; Infante, DM; Wang, L; Wu, D; Cooper, AR; Taylor, WW. (2011b) An index of cumulative disturbance to river fish habitats of the conterminous United States from landscape anthropogenic activities. Ecol Restor 29:133–151.

Frac Tracker. (2013) Frac Tracker – data [web page]. http://www.fractracker.org/downloads/

Homer, C; Dewitz, J; Fry, J; Coan, M; Hossain, N; Larson, C; Herold, N; McKerrow, A; VanDriel, JN; Wickham, J. (2007) Completion of the 2001 National Land Cover Database for the Conterminous United States. PE&RS 73(4):337−341. Available online at http://www.asprs.org/a/publications/pers/2007journal/april/highlight.pdf

King, RS; Baker, ME. (2010) Considerations for identifying and interpreting ecological community thresholds. J N Am Benthol Assoc 29(3):998-1008

Nowak, DJ; Greenfield, EJ. (2010) Evaluating the National Land Cover Database tree canopy and impervious cover estimates across the conterminous United States: a comparison with photo-interpreted estimates. Environ Manage 46:378–390.

Olivero, AP; Anderson, MG. (2008) Northeast aquatic habitat classification. Denver, CO: The Nature Conservancy. Available online at http://rcngrants.org/content/northeastern-aquatic-habitat-classification-project

PASDA (Pennsylvania Spatial Data Access). (2013) Data download –mine and refuse permits. Available online at www.pasda.psu.edu.

U.S. Bureau of the Census. (2000) Census 2000 TIGER/Line data. Available online at http://www.icpsr.umich.edu/icpsrweb/ICPSR/themes/tiger/2000/

U.S. EIA (Energy Information Administration). (2013) Maps: exploration, resources, reserves, and production - United States shale gas maps - Lower 48 states shale plays. Available online at http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm

U.S. EIA (Energy Information Administration). (2012) Annual coal report 2011. http://www.eia.gov/coal/annual/

U.S. EPA/USGS (Environmental Protection Agency/U.S. Geological Survey). (2005). National hydrography dataset plus, NHDPlus Version 1.0. (NHDPlusV1). Available online at http://www.fws.gov/r5gomp/gom/nhd-gom/metadata.pdf

U.S. EPA (Environmental Protection Agency). (2011) ICLUS tools and datasets (Version 1.3 & 1.3.1). [EPA/600/R-09/143F]. Washington, DC: U.S. Environmental Protection Agency. Available on line at http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=205305

U.S. EPA (U.S. Environmental Protection Agency). (2013) Geospatial data download service - Geospatial information for all publicly available FRS facilities that have latitude/longitude data [file geodatabase]. Available online at http://www.epa.gov/enviro/geo_data.html

USGS (U.S. Geological Survey). (2001) Coal fields of the United States: National Atlas of the United States. Reston, VA: USGS. Available online at http://nationalatlas.gov/atlasftp.html#coalfdp

USGS (U.S. Geological Survey). (2005) Active mines and mineral processing plants in the United States in 2003. Reston, VA: USGS. Available online at http://tin.er.usgs.gov/metadata/mineplant.faq.html

USGS (U.S. Geological Survey) (2010). Water use in the United States: Estimated use of water in the United States, 2005. Reston, VA: USGS. Available online at http://water.usgs.gov/watuse/

USGS (U.S. Geological Survey). (2014) Major dams of the United States: National Atlas of the United States. Reston, VA: United States Geological Survey. Available online at : http://nationalatlas.gov/atlasftp.html#dams00x

VDEQ (Virginia Department of Environmental Quality. (2013) Surface mine permit boundaries. Richmond, VA: Division of Mined Land Reclamation. Available online at ftp://ftp.dmme.virginia.gov/DMLR/downloads/permits/shape_files/nad83/

Wickham, JD; Stehman, SV; Gass, L; Dewitz, J; Fry, JA; Wade, TG. (2013) Accuracy assessment of NLCD 2006 land cover and impervious surface. Rem Sens Environ 130: 294–304.

WVDEP (West Virginia Department of Environmental Protection). (2013) Data download – mining permit shapefiles. Charleston, WV: Technical Applications and GIS Unit (TAGIS). Available online at http://tagis.dep.wv.gov/home/Downloads

WVGES (West Virginia Geological Ecomic Survey). (2014). West Virginia coal bed mapping [online mapper]. Available online at http://www.wvgs.wvnet.edu/www/coal/cbmp/coalims.html

APPENDIX E.

SECONDARY REGIONAL MONITORING NETWORK (RMN) SITES IN THE NORTHEAST AND MID-ATLANTIC REGIONS

Table E-1. Secondary RMN sites in the Northeast (4/2/2014). At all of the VT DEC and CT DEEP sentinel sites, macroinvertebrates are collected annually and water temperature sensors are deployed year-round. For this exercise, natural land cover included open water, forest, wetlands, barren, and grassland/herbaceous. Data were accumulated for the entire upstream catchment. Land cover screenings were estimates based on data associated with the National Hydrography Dataset Plus Version 1 (NHDPlusV1) catchments in which the sites are located (http://www.horizon-systems.com/NHDPlus). Land use data were based on the 2001 National Land Cover Database (NLCD; Homer et al., 2007) (http://www.mrlc.gov/nlcd01_data.php).

Longitude	Latitude	State	Entity	Station ID	Water body name	Percentage natural (%)	Notes
−72.7464	43.7708	VT	VT DEC	130000000324	White River	92.4	VT DEC sentinel site
−72.9458	43.8556	VT	VT DEC	135411000013	Smith Brook	99	VT DEC sentinel site
−71.6356	44.7550	VT	VT DEC	280000000003	Nulhegan River	90	VT DEC sentinel site
−72.7819	44.5036	VT	VT DEC	493238200015	Ranch Brook	96	VT DEC sentinel site; USGS gage (04288230)
−73.2292	44.2483	VT	VT DEC	530000000037	Lewis Creek	64	VT DEC sentinel site
−72.9384	42.0356	CT	CT DEEP	1156	Hubbard Brook	96	CT DEEP sentinel site; colocated with USGS gage (01187300)
−72.3289	41.4100	CT	CT DEEP	1236	Beaver Brook	89	CT DEEP sentinel site
−72.3343	41.4603	CT	CT DEEP	1239	Burnhams Brook	85	CT DEEP sentinel site
−72.82146	41.93717	CT	CT DEEP	359	West Branch Salmon	86	CT DEEP sentinel site
−73.2155	41.5575	CT	CT DEEP	1468	Weekepeemee River	72	CT DEEP sentinel site; colocated with USGS gage (01203805)
−72.5365	41.6615	CT	CT DEEP	2295	Mott Hill Brook	92	CT DEEP sentinel site

Table E-1. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Percentage Natural (%)	Notes
−72.4226	41.4283	CT	CT DEEP	2297	Hemlock Valley Brook	81	CT DEEP sentinel site
−73.1214	41.9328	CT	CT DEEP	2299	Rugg Brook	91	CT DEEP sentinel site
−72.4338	41.5623	CT	CT DEEP	2304	Day Pond Brook	--	CT DEEP sentinel site
−73.3200	41.9459	CT	CT DEEP	2309	Flat Brook	90	CT DEEP sentinel site
−73.1679	41.8646	CT	CT DEEP	2312	Jakes Brook	91	CT DEEP sentinel site
−72.1509	41.7812	CT	CT DEEP	2331	Stonehouse Brook	89	CT DEEP sentinel site
−73.3678	41.2931	CT	CT DEEP	2346	Little River	81	CT DEEP sentinel site
−73.1745	41.5783	CT	CT DEEP	2676	Nonewaug River	53	CT DEEP sentinel site; USGS gage (01203600)
−72.9630	41.7807	CT	CT DEEP	2711	Bunnell Brook	71	CT DEEP sentinel site; USGS gage (01188000)
−72.4640	41.8272	CT	CT DEEP	345	Tankerhoosen River	66	CT DEEP sentinel site
−69.5933	44.2232	ME	ME DEP	MEDEP_56817	Sheepscot River—Station 74	87	ME DEP long-term monitoring site; USGS gage (01038000)—water and air temperature, discharge
−69.5313	44.3679	ME	ME DEP	MEDEP_57011	West Branch Sheepscot River—Station 268	85	ME DEP long-term biological monitoring site

Table E-1. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Percentage Natural (%)	Notes
−68.2346	44.3934	ME	ME DEP	MEDEP_57065	Duck Brook—Station 322	83	ME DEP long-term biological monitoring site

Table E-2. Secondary RMN sites in the Mid-Atlantic (4/2/2014). At all of the MD DNR sentinel sites, macroinvertebrates are collected annually and water and air temperature sensors are deployed year-round. At the WV DEP sites, macroinvertebrates are collected annually and water temperature sensors may be deployed. At the SRBC continuous monitoring sites, macroinvertebrates are collected annually and water temperature sensors are deployed year-round; stage and precipitation data are also being collected at some sites (see Notes field). At the NPS—ERMN sites (National Park Service sites that are in the Eastern Rivers and Mountains Network), macroinvertebrates are collected every other year and efforts will be made to install temperature sensors at high priority sites. Land use data, which were accumulated for the entire upstream catchment, were estimates based on data associated with the National Hydrography Dataset Plus Version 1 (NHDPlusV1) catchments in which the sites are located (http://www.horizon-systems.com/NHDPlus). Land use data were based on the 2001 National Land Cover Database (NLCD; Homer et al., 2007) (http://www.mrlc.gov/nlcd01_data.php).

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−75.323216	41.73465	PA	DRBC	MB_Dyberry	Middle Branch Dyberry Creek		79.9	0.0	14.0	0.6
−74.88980	40.77471	NJ	EPA R2	1	Unnamed tributary to Musconetcong River	long-term monitoring site—Jim Kurtenbach (U.S. EPA R2)	67.9	0.0	4.2	23.9
−74.50486	40.95164	NJ	EPA R2	17	Hibernia Brook	long-term monitoring site—Jim Kurtenbach (U.S. EPA R2)	82.1	2.1	0.0	0.8
−74.84479	40.75211	NJ	EPA R2	2	Teetertown Brook	long-term monitoring site—Jim Kurtenbach (U.S. EPA R2)	53.9	1.3	14.6	17.7

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−77.54528	39.65833	MD	MD DNR	ANTI-101-S	Unnamed tributary to Edgemont Reservoir	MD DNR sentinel site—Highlands	90.6	0.4	4.4	0.5
−76.09499	39.08754	MD	MD DNR	CORS-102-S	Unnamed tributary to Emory Creek	MD DNR sentinel site—Coastal Plain	71.6	0.2	4.6	7.2
−78.45571	39.68672	MD	MD DNR	FIMI-207-S	Fifteen Mile Creek	MD DNR sentinel site—Highlands	88.3	0.1	5.6	0.9
−76.04611	39.61055	MD	MD DNR	FURN-101-S	Unnamed tributary to Principio Creek	MD DNR sentinel site—Highlands	80.5	0.5	9.3	8.1
−76.69843	39.43951	MD	MD DNR	JONE-109-S	Unnamed tributary to Dipping Pond Run	MD DNR sentinel site—Highlands	45.3	2.5	32.4	6.7
−76.71875	39.42925	MD	MD DNR	JONE-315-S	North Branch of Jones Falls	MD DNR sentinel site—Highlands	52.8	1.1	23.8	16.3
−76.86417	39.44055	MD	MD DNR	LIBE-102-S	Timber Run	MD DNR sentinel site—Highlands	70.1	0.3	12.7	15.5
−76.69829	39.48052	MD	MD DNR	LOCH-120-S	Baisman Run	MD DNR sentinel site—Highlands	71.2	0.3	24.4	2.4

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−76.21896	39.19352	MD	MD DNR	LOCR-102-S	Swan Creek	MD DNR sentinel site—Coastal Plain	20.8	0.0	0.0	17.7
−77.09766	38.58225	MD	MD DNR	MATT-033-S	Mattawoman Creek	MD DNR sentinel site—Coastal Plain	48.3	12.8	1.8	7.5
−77.08594	38.48386	MD	MD DNR	NANJ-331-S	Mill Run	MD DNR sentinel site—Coastal Plain	72.5	0.2	1.8	9.9
−75.49247	38.2495	MD	MD DNR	NASS-108-S	Millville Creek	MD DNR sentinel site—Coastal Plain	8.9	0.8	0.6	8.0
−75.46182	38.26359	MD	MD DNR	NASS-302-S	Nassawango Creek	MD DNR sentinel site—Coastal Plain	18.8	0.4	4.4	17.0
−76.76012	38.56392	MD	MD DNR	PAXL-294-S	Swanson Creek	MD DNR sentinel site—Coastal Plain	67.3	0.2	2.4	15.3
−77.02912	38.51108	MD	MD DNR	PTOB-002-S	Hoghole Run	MD DNR sentinel site—Coastal Plain	74.2	1.0	0.7	12.1

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−76.97198	39.16949	MD	MD DNR	RKGR-119-S	Unnamed tributary to Patuxent River	MD DNR sentinel site—Highlands	31.8	0.5	44.0	14.2
−79.21349	39.54119	MD	MD DNR	SAVA-276-S	Double Lick Run	MD DNR sentinel site—Highlands	92.1	0.0	6.6	0.0
−76.73717	38.36662	MD	MD DNR	STCL-051-S	Unnamed tributary to St. Clements Creek	MD DNR sentinel site—Coastal Plain	69.8	0.0	2.2	15.8
−77.48935	39.58739	MD	MD DNR	UMON-119-S	Buzzard Branch	MD DNR sentinel site—Highlands	97.5	0.0	0.2	0.0
−75.96062	38.72408	MD	MD DNR	UPCK-113-S	Unnamed tributary to Skeleton Creek	MD DNR sentinel site—Coastal Plain	23.9	0.3	10.7	29.4
−75.78362	39.28768	MD	MD DNR	UPCR-208-S	Cypress Branch	MD DNR sentinel site—Coastal Plain	40.3	0.2	4.0	26.7
−75.59259	38.41408	MD	MD DNR	WIRH-220-S	Leonard Pond Run	MD DNR sentinel site—Coastal Plain	26.7	8.0	6.3	30.3

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−76.90348	38.49936	MD	MD DNR	ZEKI-012-S	Unnamed tributary to Zekiah Swamp Run	MD DNR sentinel site—Coastal Plain	89.8	0.0	0.6	5.3
−78.45247	40.41597	PA	NPS—ERMN		Blair Gap Run—Foot of Ten		92.9	1.4	1.8	0.2
−78.51846	40.43269	PA	NPS—ERMN		Blair Gap Run—Muleshoe		96.1	0.4	0.5	0.1
−79.92348	39.78393	PA	NPS—ERMN		Dublin Run		--	--	--	--
−79.58149	39.81449	PA	NPS—ERMN		Great Meadows Run		75.2	2.4	9.4	3.5
−79.93024	39.78248	PA	NPS—ERMN		Ice Pond Run		--	--	--	--
−80.97161	37.58466	PA	NPS—ERMN		Little Bluestone River		75.7	1.5	15.3	0.9
−78.48373	40.41876	PA	NPS—ERMN		Milllstone Run		97.0	0.3	0.8	0.0
−81.02055	37.53483	PA	NPS—ERMN		Mountain Creek		75.9	1.6	14.9	0.6
−79.59970	39.81014	PA	NPS—ERMN		Unnamed tributary (Scotts Run)		95.9	0.0	0.0	0.0
−75.14398	40.97139	PA	NPS—ERMN	DEWA.3001	Caledonia Creek 13	NPS—ERMN high priority	78.0	1.0	8.0	1.5
−74.98444	41.11381	PA	NPS—ERMN	DEWA.3002	Van Campen Creek 12		74.2	2.4	0.1	0.1

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−74.90309	41.19744	PA	NPS—ERMN	DEWA.3003	Deckers Creek 03		82.0	0.0	0.3	2.4
−74.87464	41.22245	PA	NPS—ERMN	DEWA.3004	Dingmans Creek 05		71.3	2.0	0.1	0.0
−75.12652	40.974	NJ	NPS—ERMN	DEWA.3005	Dunnfield Creek 03		96.8	0.0	0.3	0.0
−74.96252	41.13729	PA	NPS—ERMN	DEWA.3006	Toms Creek 20		80.2	0.6	0.0	0.0
−74.90598	41.1756	PA	NPS—ERMN	DEWA.3007	Spackmans Creek 08		91.1	0.5	0.7	0.4
−74.91831	41.23772	PA	NPS—ERMN	DEWA.3008	Dingmans Creek 57		69.8	2.0	0.1	0.0
−74.92372	41.09674	NJ	NPS—ERMN	DEWA.3010	Vancampens Brook 95		93.8	0.0	0.0	0.0
−74.87711	41.24882	PA	NPS—ERMN	DEWA.3011	Adams Creek 14		86.9	0.9	0.1	0.1
−74.89043	41.2578	PA	NPS—ERMN	DEWA.3012	Adams Creek 33		82.8	1.2	0.1	0.1
−75.00533	41.09383	PA	NPS—ERMN	DEWA.3013	Little Bushkill Creek 01		76.9	0.5	0.0	0.0
−74.96505	41.07109	NJ	NPS—ERMN	DEWA.3014	Vancampens Brook 43		95.3	0.0	0.0	0.0
−74.90343	41.23052	PA	NPS—ERMN	DEWA.3015	Dingmans Creek 39		69.8	2.0	0.1	0.0
−74.95916	41.12946	PA	NPS—ERMN	DEWA.3018	Toms Creek 07		80.2	0.6	0.0	0.0
−74.92673	41.16889	PA	NPS—ERMN	DEWA.3020	Mill Creek 25		83.5	0.3	0.4	0.4

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−74.96279	41.1415	PA	NPS—ERMN	DEWA.3022	Toms Creek 25		80.2	0.6	0.0	0.0
−74.88573	41.23542	PA	NPS—ERMN	DEWA.3023	Unnamed tributary Dingmans Creek 07		71.3	2.0	0.1	0.0
−74.98445	41.0647	NJ	NPS—ERMN	DEWA.3025	Vancampens Brook 22	NPS—ERMN high priority	95.3	0.0	0.0	0.0
−74.94059	41.08567	NJ	NPS—ERMN	DEWA.3026	Unnamed tributary Vancampens Brook 05		97.8	0.0	0.0	0.0
−74.86975	41.24147	PA	NPS—ERMN	DEWA.3027	Adams Creek 03	NPS—ERMN high priority	86.9	0.9	0.1	0.1
−74.79550	41.29461	NJ	NPS—ERMN	DEWA.3028	White Brook 15		53.2	1.6	13.6	7.6
−75.01434	41.08235	PA	NPS—ERMN	DEWA.3029	Sand Hill Creek 08		63.5	6.1	0.8	0.0
−75.00528	41.03179	NJ	NPS—ERMN	DEWA.3030	Yards Creek 07		86.0	0.0	0.0	0.0
−74.89481	41.23067	PA	NPS—ERMN	DEWA.3031	Dingmans Creek 30		69.8	2.0	0.1	0.0
−74.84545	41.2952	PA	NPS—ERMN	DEWA.3032	Raymondskill Creek 13		73.7	1.0	0.9	0.1
−75.10517	40.98337	NJ	NPS—ERMN	DEWA.3033	Dunnfield Creek 26		96.8	0.0	0.3	0.0
−74.95645	41.12711	PA	NPS—ERMN	DEWA.3034	Toms Creek 03		81.2	0.5	0.0	0.2

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−74.89987	41.19356	PA	NPS—ERMN	DEWA.3035	Hornbecks Creek 15		82.0	0.8	0.7	1.0
−74.92431	41.15917	PA	NPS—ERMN	DEWA.3036	Mill Creek 12		83.5	0.3	0.4	0.4
−74.94123	41.09062	NJ	NPS—ERMN	DEWA.3038	Vancampens Brook 76		93.8	0.0	0.0	0.0
−74.88168	41.25185	PA	NPS—ERMN	DEWA.3039	Adams Creek 21		85.0	1.0	0.1	0.1
−81.09167	37.9441	WV	NPS—ERMN	NERI.3001	Meadow Fork 1		74.1	6.1	6.1	0.1
−81.01278	37.91956	WV	NPS—ERMN	NERI.3005	Buffalo Creek 16		98.5	0.0	0.0	0.2
−81.02305	37.88808	WV	NPS—ERMN	NERI.3009	Slater Creek 20		97.7	0.0	0.0	0.0
−80.91077	37.81927	WV	NPS—ERMN	NERI.3011	Meadow Creek 17		84.9	2.5	4.6	1.1
−81.04551	37.87994	WV	NPS—ERMN	NERI.3013	Dowdy Creek 16		99.1	0.0	0.0	0.0
−81.04918	37.82895	WV	NPS—ERMN	NERI.3016	River Branch 4		95.9	0.0	3.8	0.3
−81.02102	38.03256	WV	NPS—ERMN	NERI.3018	Keeney Creek 10		89.7	2.3	1.5	0.8
−81.02453	37.94417	WV	NPS—ERMN	NERI.3021	Fire Creek 17		99.2	0.0	0.0	0.2
−80.90375	37.714	WV	NPS—ERMN	NERI.3024	Big Branch 10		95.3	0.2	2.9	0.0
−81.03647	37.87402	WV	NPS—ERMN	NERI.3025	Dowdy Creek 30		99.1	0.0	0.0	0.0
−80.97903	37.85864	WV	NPS—ERMN	NERI.3026	Little Laurel Creek 6		91.3	0.0	3.8	1.5

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−81.08293	38.04904	WV	NPS—ERMN	NERI.3029	Wolf Creek 30		56.6	6.5	25.5	0.1
−81.04749	37.82782	WV	NPS—ERMN	NERI.3032	River Branch 6	WV DEP reference site	95.9	0.0	3.8	0.3
−81.02506	37.98267	WV	NPS—ERMN	NERI.3034	Unnamed tributary 21 New River 1		69.3	2.2	20.8	0.7
−81.06012	38.06032	WV	NPS—ERMN	NERI.3035	Fern Creek 11		88.1	2.9	3.1	0.4
−80.94296	37.74477	WV	NPS—ERMN	NERI.3036	Unnamed tributary Fall Branch 2		97.8	0.0	1.4	0.1
−81.00490	37.85802	WV	NPS—ERMN	NERI.3037	Laurel Creek 47		93.0	0.6	1.5	0.6
−81.08737	37.96331	WV	NPS—ERMN	NERI.3038	Arbuckle Creek 2		47.7	24.9	12.2	0.3
−81.01654	37.78795	WV	NPS—ERMN	NERI.3040	Polls Branch 14		70.0	1.2	20.5	0.1
−81.01984	37.8583	WV	NPS—ERMN	NERI.3041	Unnamed tributary Laurel Creek 3		93.0	0.6	1.5	0.6
−80.95156	37.87324	WV	NPS—ERMN	NERI.3042	Bucklick Branch 3		98.8	0.0	0.2	0.0
−80.89788	37.83271	WV	NPS—ERMN	NERI.3043	Meadow Creek 39		84.3	2.6	4.8	1.1
−81.03925	37.8512	WV	NPS—ERMN	NERI.3044	Laurel Creek 8		93.0	0.6	1.5	0.6
−80.92717	37.80196	WV	NPS—ERMN	NERI.3047	Sewell Branch 2		71.0	0.4	22.0	0.1

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−81.05710	37.82369	WV	NPS—ERMN	NERI.3048	Slate Fork—Mill Creek 12		81.9	2.9	9.9	0.1
−81.01080	37.91417	WV	NPS—ERMN	NERI.3049	Unnamed tributary Buffalo Creek 6		98.5	0.0	0.0	0.2
−81.01287	37.96168	WV	NPS—ERMN	NERI.3050	Ephraim Creek 8	NPS—ERMN high priority; WV DEP reference site	99.3	0.0	0.0	0.0
−80.93170	37.74969	WV	NPS—ERMN	NERI.3052	Fall Branch 7	NPS—ERMN high priority; WV DEP reference site	95.3	0.5	2.7	0.2
−81.02849	37.89156	WV	NPS—ERMN	NERI.3053	Slater Creek 13		97.7	0.0	0.0	0.0
−81.09031	37.96421	WV	NPS—ERMN	NERI.3054	Arbuckle Creek 5		47.7	24.9	12.2	0.3
−80.95197	37.86122	WV	NPS—ERMN	NERI.3058	Richlick Branch 17		97.1	0.0	0.3	0.5
−80.88025	37.83799	WV	NPS—ERMN	NERI.3059	Meadow Creek 58		81.4	3.5	5.8	1.2
−81.10399	37.84261	WV	NPS—ERMN	NERI.3064	Batoff Creek 7		75.6	6.6	5.9	0.0
−81.09510	37.94727	WV	NPS—ERMN	NERI.3065	Meadow Fork 6		74.0	5.1	6.5	0.1

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−81.02195	37.91346	WV	NPS—ERMN	NERI.3069	Buffalo Creek 4	NPS—ERMN high priority; WV DEP reference site	98.5	0.0	0.0	0.2
−80.90266	37.71391	WV	NPS—ERMN	NERI.3072	Big Branch 9		95.3	0.2	2.9	0.0
−81.05947	37.88203	WV	NPS—ERMN	NERI.3077	Dowdy Creek 2		99.1	0.0	0.0	0.0
−81.05316	37.83172	WV	NPS—ERMN	NERI.3080	Slate Fork—Mill Creek 1		86.3	2.0	7.9	0.1
−81.01693	38.03013	WV	NPS—ERMN	NERI.3082	Keeney Creek 15		89.7	2.3	1.5	0.8
−80.98218	37.86476	WV	NPS—ERMN	NERI.3085	Laurel Creek 61		91.9	0.8	1.7	0.7
−81.08257	38.04763	WV	NPS—ERMN	NERI.3093	Wolf Creek 32		56.6	6.5	25.5	0.1
−81.05947	38.06101	WV	NPS—ERMN	NERI.3099	Fern Creek 12		88.1	2.9	3.1	0.4
−80.93452	37.74875	WV	NPS—ERMN	NERI.3100	Fall Branch 10		95.3	0.5	2.7	0.2
−76.91134	41.32519	PA	PA DEP	WQN_408	Loyalsock Creek	long-term data, EV (protected)	81.6	0.2	6.3	4.4
−76.15029	42.06312	NY	SRBC	Apal	Apalachin Creek	precip gage	69.5	0.6	23.1	1.5
−77.60667	41.24694	PA	SRBC	BAKR0.1	Baker Run	pressure transducer (real-time) and precip gage	97.0	0.0	0.0	0.0
−76.72019	42.04209	NY	SRBC	Baldwin	Baldwin Creek	precip gage	73.0	0.1	15.4	5.0

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−77.23044	41.47393	PA	SRBC	BLOC	Blockhouse Creek	precip gage	74.1	0.8	13.6	5.4
−78.59258	40.26388	PA	SRBC	BOBS	Bobs Creek	pressure transducer (real-time) and precip gage	88.5	0.2	4.7	2.1
−76.02756	41.42725	PA	SRBC	BOWN	Bowman Creek		89.1	0.2	1.8	5.0
−77.73670	42.31903	NY	SRBC	CANA	Canacadea Creek	precip gage	69.5	1.1	19.8	1.3
−76.47508	42.20472	NY	SRBC	Catatonk	Catatonk Creek	pressure transducer (stand-alone)	71.4	0.5	11.2	4.5
−74.79921	42.70639	NY	SRBC	Cherry	Cherry Valley Creek		66.1	0.3	15.1	5.1
−78.64757	40.63052	PA	SRBC	CHEST	Chest Creek		58.1	0.8	21.5	13.2
−76.00931	42.01582	NY	SRBC	CHOC	Choconut Creek	pressure transducer (stand-alone)	72.7	0.2	19.9	2.3
−77.29313	41.85752	PA	SRBC	CROK	Crooked Creek		45.9	0.1	27.1	21.6
−78.27008	41.52649	PA	SRBC	Driftwood	Driftwood Branch Sinnemahoning Creek	pressure transducer (real-time)	92.0	0.0	1.0	0.1

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−77.91244	41.57467	PA	SRBC	East Fork	East Fork First Fork Sinnemahoning Creek		89.1	0.0	0.2	0.0
−76.34434	41.32261	PA	SRBC	EBFC	East Branch Fishing Creek		92.4	0.0	0.1	0.0
−76.07111	41.78832	PA	SRBC	EBWC	East Branch Wyalusing Creek		50.0	0.4	32.3	10.4
−77.58154	41.73642	PA	SRBC	ELKR	Elk Run		81.8	0.0	10.4	0.4
−76.91233	41.99164	PA	SRBC	HAMM	Hammond Creek		46.6	0.2	33.6	14.0
−78.25348	41.36235	PA	SRBC	Hicks	Hicks Run		91.6	0.0	1.6	0.0
−78.17458	41.45256	PA	SRBC	Hunts	Hunts Run	precip gage	90.7	0.0	0.0	0.0
−76.24282	41.23366	PA	SRBC	Kitchen	Kitchen Creek		85.9	0.2	3.5	0.5
−75.47324	41.68331	PA	SRBC	LACK	Lackawanna River		68.2	0.4	11.3	9.0
−77.18943	41.32739	PA	SRBC	LARR	Larrys Creek		75.7	0.1	19.1	1.0
−78.40722	40.97	PA	SRBC	LCLF0.1	Little Clearfield Creek		68.5	0.2	19.1	2.4
−76.06980	41.58154	PA	SRBC	LMEHOOP	Little Mehoopany Creek	pressure transducer (real-time)	66.8	0.1	8.1	16.7
−76.64148	41.19353	PA	SRBC	LMUN	Little Muncy Creek		56.1	0.2	23.1	13.9

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−77.55928	41.76142	PA	SRBC	Long	Long Run		82.0	0.0	10.4	1.9
−77.36278	41.31	PA	SRBC	LPIN0.2	Little Pine Creek		82.7	0.4	8.4	3.5
−76.33104	41.4588	PA	SRBC	LYSK5.0	Loyalsock Creek	pressure transducer (real-time) and precip gage	85.5	0.1	0.6	0.7
−77.60997	41.06022	PA	SRBC	MARS	Marsh Creek		83.7	0.7	7.9	3.4
−77.41333	41.76306	PA	SRBC	Marsh Tioga	Marsh Creek		72.0	1.3	15.5	5.0
−75.98474	41.61164	PA	SRBC	MESH	Meshoppen Creek	pressure transducer (stand-alone)	47.1	0.2	18.5	27.3
−76.05357	42.20426	NY	SRBC	Nanticoke	Nanticoke Creek		62.2	0.4	24.9	7.8
−77.76387	41.79146	PA	SRBC	Ninemile	Ninemile Run	precip gage	84.4	0.4	3.8	2.8
−78.46158	41.04564	PA	SRBC	PA_Moose	Moose Creek		90.3	--	--	--
−77.45056	41.64694	PA	SRBC	Pine Blackwell	Pine Creek		80.5	0.4	7.7	2.0
−76.92300	41.49143	PA	SRBC	Ples	Pleasant Stream		87.6	0.0	1.4	1.0
−78.22029	41.51169	PA	SRBC	Portage	Portage Creek		91.9	0.3	2.5	0.1
−75.50220	42.77596	NY	SRBC	Sangerfield	Sangerfield River		35.8	0.4	17.0	14.0
−75.77788	41.55783	PA	SRBC	SBTK	South Branch Tunkhannock Creek	pressure transducer (real-time)	53.4	3.4	5.9	24.1

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−76.92222	42.10278	NY	SRBC	SING 0.9	Sing Sing Creek		61.5	3.1	9.9	10.9
−75.84137	41.92994	PA	SRBC	SNAK	Snake Creek	pressure transducer (stand-alone)	67.1	0.2	23.0	2.8
−75.52351	41.95946	PA	SRBC	STAR	Starrucca Creek		73.1	0.2	15.9	1.1
−76.27436	41.62644	PA	SRBC	Sugar Run	Sugar Run		64.4	0.1	9.9	18.6
−76.76835	41.78974	PA	SRBC	SUGR	Sugar Creek		44.9	1.0	34.3	13.2
−76.91416	41.70931	PA	SRBC	TIOG	Tioga River		83.0	0.0	1.7	2.9
−76.60723	41.78132	PA	SRBC	TOMJ	Tomjack Creek		42.7	0.3	35.9	15.6
−76.76011	41.65262	PA	SRBC	TOWA	Towanda Creek		54.9	0.8	25.5	13.1
−78.36118	41.07359	PA	SRBC	TROT	Trout Run	pressure transducer (real-time) and precip gage	90.4	0.0	0.4	0.0
−76.10589	42.59277	NY	SRBC	Trout Brook	Trout Brook	precip gage	62.7	0.5	24.8	5.3
−77.37918	42.0752	NY	SRBC	Tuscarora	Tuscarora Creek	pressure transducer (real-time)	42.9	0.3	35.1	13.6
−77.76123	41.79011	PA	SRBC	Upper Pine	Pine Creek	pressure transducer (real-time)	75.1	0.0	11.4	4.0
−76.28083	41.96661	PA	SRBC	WAPP	Wappasening Creek		63.4	0.0	30.2	1.8

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−78.80331	40.69289	PA	SRBC	WB SUS	West Branch Susquehanna River	pressure transducer (stand-alone)	68.7	3.5	15.8	3.0
−78.27484	41.49444	PA	SRBC	West	West Creek		83.8	0.5	6.5	0.4
−77.66985	41.72483	PA	SRBC	WPIN	West Branch Pine Creek		87.0	0.0	0.5	0.0
−77.68520	41.40016	PA	SRBC	Young	Young Woman's Creek		96.8	0.0	0.1	0.0
−74.50528	39.885	NJ	USGS	USGS 01466500	McDonalds Branch	USGS gage in Byrne State Forest (Pine Barrens)	--	--	--	--
−82.12353	38.48514	WV	WV DEP	11897	Unnamed tributary/Left Fork river mile 1.69/Mill Creek		--	--	--	--
−79.69583	38.73825	WV	WV DEP	12455	Laurel Fork/Dry Fork		89.5	0.0	0.1	0.1
−80.86781	38.88133	WV	WV DEP	12689	Long Lick Run		--	--	--	--
−81.09958	39.22211	WV	WV DEP	12690	Unnamed tributary/North Fork river mile 22.26/Hughes River		--	--	--	--

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes	Percentage Forest (%)	Percentage Urban (%)	Percentage Hay (%)	Percentage Crop (%)
−80.32127	38.25981	WV	WV DEP	2046	North Fork/Cranberry River	long-term monitoring site impacted by acid rain	98.9	0.0	0.0	0.0
−81.14683	37.50275	WV	WV DEP	2359	Mash Fork	long-term monitoring site impacted by acid rain	93.1	0.0	5.2	0.0
−82.28014	38.06845	WV	WV DEP	4513	Little Laurel Creek		--	--	--	--
−79.39594	38.97394	WV	WV DEP	8255	Red Creek	long-term monitoring site impacted by acid rain	97.7	0.0	0.1	0.0
−79.61147	39.04225	WV	WV DEP	8357	Otter Creek	long-term monitoring site impacted by acid rain	99.5	0.0	0.0	0.0
−81.93119	38.38489	WV	WV DEP	8482	Sams Fork		--	--	--	--
−80.37117	38.33544	WV	WV DEP	9315	Middle Fork/Williams River	long-term monitoring site impacted by acid rain	99.5	0.0	0.0	0.0

E.1. REFERENCES

Homer, C; Dewitz, J; Fry, J; Coan, M; Hossain, N; Larson, C; Herold, N; McKerrow, A; VanDriel, JN; Wickham, J. (2007) Completion of the 2001 National Land Cover Database for the Conterminous United States. PE&RS 73(4):337−341. Available online at http://www.asprs.org/a/publications/pers/2007journal/april/highlight.pdf

APPENDIX F.

MACROINVERTEBRATE COLLECTION METHODS

Table F-1. Macroinvertebrate methods for medium-high gradient freshwater wadeable streams with abundant riffle habitat and rocky substrate. These are the methods that were agreed upon by the Northeast, Mid-Atlantic, and Southeast regional working groups during the pilot phase of the RMNs (before the QAPP was developed). At this time (fall 2015), the regional working groups are working on the region-specific QAPP addendums. It is possible that some updates will be made during this process.

Regional network	Effort	Reach length	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
Northeast	Kick samples are taken from riffle habitats in 4 different locations in the sampling reach. At each location the substrate is disturbed for approximately 30 seconds, for a total active sampling effort of 2 minutes.	150 m	D-frame net (46 cm wide × 30 cm high) with 500-µm mesh	Riffles	Approximately 1 m^2	September−mid-October	300	Lowest practical (species whenever possible)
Mid-Atlantic	Data should be collected with existing state or RBC methods, or in such a way that the data can be rendered comparable to historical state methods. A minimum of 1 m^2 is collected using a minimum of 4 separate kicks in riffle habitats throughout the 100-m reach.	100 m	Varies by entity (either square frame kick nets or D-frame nets, with mesh size ranging from 450−600 µm)	Abundant riffles	Minimum of 1 m^2	Spring (March−April) and summer (July−August)	300	Lowest practical (species whenever possible)

Table F-1. continued…

Regional network	Effort	Reach length	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
Southeast	Semiquantitative: riffle kick samples are taken from 2 riffles or upper or lower end of a large riffle and composited; in smaller streams, multiple riffles may need to be collected to achieve the desired area	100 m	Kick-net with 500-µm mesh	Riffles	Approximately 2 m^2	April 2013. Subsequent samples will be collected annually within 2 weeks of the original collection	300 ± 10%	Lowest practical (species whenever possible)
	Qualitative: 3 "jabs" will be collected from all available habitats; taxa from each habitat will be kept in separate containers (separate species lists will be generated for each habitat)	100 m	Dip-net with 500-µm mesh	Multihabitat	NA (qualitative)		NA (qualitative)	

Table F-2. Macroinvertebrate methods used by Northeastern states for routine sampling events in medium-high gradient freshwater wadeable streams with riffle habitat and rocky substrate

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
CT DEEP	Streams with riffle habitat	12 kick samples are taken throughout riffle habitats within the sampling reach	Rectangular net (46 cm × 46 cm × 25 cm) with 500-µm mesh	Riffles	Approximately 2 m^2	October 1−November 30	200	Lowest practical (species whenever possible)
VT DEC	Moderate to high gradient streams with riffle habitat	Kick samples are taken from riffle habitats in 4 different locations in the sampling reach. At each location the substrate is disturbed for approximately 30 seconds, for a total active sampling effort of 2 minutes.	D-frame net (46 cm wide × 30 cm high) with 500-µm mesh	Riffles	Approximately 1 m^2	September−mid-October	300	Lowest practical (species whenever possible)
ME DEP	Streams with riffle and run habitat	3 cylindrical rock-filled wire baskets are placed in locations with similar habitat characteristics for 28 ± 4 days.	Contents are washed into a sieve bucket with 600-µm mesh	Riffle/run is the preferred habitat.	Approximately 0.3 m^2 per basket	July 1−September 30	Entire samples are processed and identified, with exceptions	Lowest practical (species whenever possible)

Table F-2. continued…

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
NH DES	Streams with riffle and run habitat	3 cylindrical rock-filled wire baskets are placed in riffle habitats or at the base of riffles at depths that cover the artificial substrate by at least 5 inches for 6 to 8 weeks.	Contents are washed into a sieve bucket with 600-µm mesh	Riffle/run is the preferred habitat.	Approximately 0.3 m^2 per basket	late July−September	100	Genus, except Chironomidae (family-level)
RI DEM	Routine monitoring in streams with riffle habitat	Kick samples are taken from riffle habitats along 100-m reach representative of the stream sampled timed for a total active sampling effort of 3 minutes.	D-frame net (30-cm width) with 500-µm mesh	Riffle	Within reach (100 linear meters)	August−September	100	Mostly genus-level. Chironomidae are identified to the subfamily or tribe-level
NY DEC	Routine monitoring in streams with riffle habitat	Substrate is dislodged by foot, upstream of the net for 5 minutes and a distance of 5 m. The preferred line of sampling is a diagonal transect of the stream	Rectangular net (23 cm × 46 cm) with 800−900-µm mesh	Riffle	2.5 m^2	July−September	100	Lowest practical (mostly genus- or species-level, some family-level [e.g., Gastropoda and Pelecypoda])

Table F-2. continued…

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
MA DEP	Routine monitoring in streams with riffle habitat	10 kick-samples are taken in riffle habitats within the sampling reach and composited	Kick-net, 46-cm wide opening, 500-µm mesh	Riffle/run is the preferred habitat	Approximately 2 m^2	July 1− September 30	100	Lowest practical level

Table F-3. Macroinvertebrate methods used by Mid-Atlantic states and RBCs for routine sampling events in medium-high gradient freshwater wadeable streams with riffle habitat and rocky substrate

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
NJ DEP	Riffle/run	10−20 kicks are taken from riffle/run areas and composited	D-frame net (30 cm) with 800 × 900-µm mesh	Riffle/run	10−20 net dimensions	April−November	100 ± 10%	Genus
DE DNREC	Piedmont	2 kicks composited	Kick-net (1-m^2 area) with 600 µm mesh	Riffle	2 m^2	October−November	200 ± 20%	Genus or lowest practical
PA DEP	Smaller freestone riffle-run streams (<25−50 mi^2)	6 kicks are taken from riffle areas and composited	D-frame net (30 cm wide × 20 cm high) with 500-µm mesh	Riffle	6 m^2	Year-round	200 ± 20%	Genus, except Chironomidae, snails, clams, mussels (family); Nematoda, Nemertea, Bryozoa (phylum); Turbellaria, Hirudenia, Oligochaeta (class); water mites (artificial)
	Limestone spring streams	2 kicks are taken from riffle-run areas (1 fast, 1 slow) and composited	D-frame net (30 cm wide 20 cm high) with 500-µm mesh	Riffle-run (1 fast, 1 slow)	2 m^2	January−May	300 ± 20%	

Table F-3. continued…

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
MD DNR	Maryland Biological Stream Survey (MBSS)	Approximately 20 kicks/jabs/sweeps /rubs from multiple habitats (sampled in proportion to availability in reach) are composited	D-frame net (about 30 cm wide) with 450-µm mesh	Multihabitat (in order of preference) riffles, root wads, root mats/woody debris/snag, leaf packs, SAV/associated habitat, undercut banks; less preferred = gravel, broken peat, clay lumps, detrital/sand areas in runs; moving water preferred to still water; sampled in proportion to availability in reach, ensuring all potentially productive habitats are represented in sample	About 2 m^2	March−April	100 ± 20%	Genus (or lowest practical); crayfish and mussels identified to species (sometime subspecies?) in the field along with fish, reptiles, amphibians, and some invasive plants

Table F-3. continued…

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
WV DEP	Wadeable streams (WVSCI)	4 kicks composited	Rectangular kick net (50 cm wide × 30 cm high × 50 cm deep) with 600-µm net mesh (595-µm sieve); D-frame net (30 cm wide) can be used for smaller streams	riffle-run	1 m^2	April 15–October 15	200 ± 20%	Family (all insects)
	Wadeable streams (GLIMPSS) —Mountain and Plateau				1 m^2	Winter (December–mid-February), spring (March–May) —Plateau only, summer (June–mid-October)	200 ± 20%	Genus (all insects minus Collembola)
VA DEQ	Noncoastal Plain (VSCI)	6 kicks from riffle habitat (unless absent, then multihabitat) are composited	D-frame net (50 cm wide × 30 cm high × 50 cm deep) with 500 µm net mesh	Riffle, unless absent, then multihabitat	2 m^2	Spring (March–May) and fall (September–November)	110 ± 10%	Family (working toward developing a genus-level index)

Table F-3. continued…

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
SRBC	Aquatic Resource Surveys	6 kicks composited or 5 minutes for a distance of 5 m (PA or NY)	D-frame net/aquatic net (30 cm × 20 to 23 cm × 46 cm [PA or NY]); 500-µm; 800 µm × 900 µm (depending on PA or NY)	Riffle-run	6 m^2 or distance of 5 m (PA or NY)	Typically late April into May, late June into July, and October	PADEP or NYSDEC protocol	Genus, except Chironomidae, snails, clams mussels (family); Nematoda, Nemertea, Bryozoa (phylum); Turbellaria, Hirudenia, Oligochaeta (class); water mites (artificial)
	Subbasin Survey, Year 1/Interstate Streams	2 kicks composited	Kick-net (1 m^2) with 600-µm mesh		2 m^2	Year 1—historically spring−fall, now spring−May 30. Interstate—May (Group 3) or August (Group 1 and 2); varies depending on site classification	200 ± 20%	
	Remote Water Quality Monitoring Network	6 kicks composited	D-Frame Net (46 cm × 20 cm) with 500-µm mesh		6 m^2	October	200 ± 20%	

Table F-3. continued…

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
NPS	Eastern Rivers and Mountains Network	A semiquantitative sample consisting of 5 discrete collections from the richest targeted habitat (typically riffle, main-channel, coarse-grained substrate habitat type) are processed and combined into a single composited sample.	Slack sampler, 500-µm nets and sieves	Riffle	Each discrete sample = 0.25 m^2 area; total area sampled = 1.25 m^2	April−early June	300	Genus, except Chironomidae, snails, clams mussels (family); Nematoda, Nemertea, Bryozoa (phylum); Turbellaria, Hirudenia, Oligochaeta (class); water mites (artificial)

Table F-4. Macroinvertebrate methods used by Southeast states for routine sampling events in medium-high gradient freshwater wadeable streams with riffle habitat and rocky substrate

Entity	Stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
AL DEM	WMB-I protocols	Several samples are collected at a site by stream habitat type; each sample is processed separately; the taxa lists are recombined after standardizing individual counts to density units	Kick net, 2 A-frame nets, 2 #30 sieve buckets, 2 #30 sieves, plastic elutriation treys, 100% denatured ethanol, and plastic sample containers	Riffle, rock-log, Rootbank, CPOM, sand, and macrophytes (macrophytes not always available and excluded from index)	Approximately 4 m^2	Late April−early July	100 organisms per habitat	Genus or lowest possible level
GA DNR	High (riffle/run) gradient	20 jabs from multiple habitats are composited	D-frame net (30-cm width) with 500-µm net mesh	Multihabitat**—**riffles, woody debris/snags, undercut banks/rootwads, leafpacks, soft sediment/sandy substrate, and submerged macrophytes (when present)	20 jabs, each for a linear distance of 1 m	Mid-September−February	200 ± 20%	Lowest practical level (generally genus or species)

Table F-4. continued…

Entity	Stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
KY DEP	Wadeable, moderate/high gradient streams	Combination of quantitative (composite of 4 riffle kicks) and qualitative (multihabitat) samples	Quantitative—kick net (600-µm mesh); qualitative—dip net, mesh bucket, forceps 600-µm mesh	Quantitative samples are taken from riffles; qualitative are taken from multiple habitats (undercut banks/roots, wood, vegetation, leaf packs, soft and rocky substrates)	1 m^2 (quantitative)	Summer (June−September)	300	Lowest practical level (generally genus or species)
	Headwater, moderate/ high gradient streams					Spring index period (February−May)		
NC DENR	Standard qualitative method for wadeable flowing streams and rivers	Composite of 2 kicks, 3 sweeps, 1 leaf pack sample, 2 fine mesh rock and/or log wash samples, 1 sand sample and visual collections from habitats and substrate types missed or under-sampled by the other collection techniques	Multiple gear types (kick net with 600-µm mesh; triangular sweep net; fine-mesh samplers [300-µm mesh]; sieve bucket)	Multihabitat (riffles, bank areas, macrophyte beds, woody debris, leaf packs, sand, etc.)	NA (qualitative only)	Year-round	Organisms are field picked roughly in proportion to their abundance. Abundance data are recorded as rare (1−2 specimens), common (3−9 specimens) or abundant (≥10 specimens)	All of the field-picked organisms are identified in the laboratory to the lowest practical level (generally genus or species)

Table F-4. continued…

Entity	Stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
SC DHEC	Ambient monitoring	Same as NC DENR				Feb 1 to March 15: Middle Atlantic Coastal Plain Ecoregion (EPA Level III 63); June 15 to Sept 1: Statewide, minus EPA Level III Ecoregion 63	Same as NC DENR	
TN DEC	Streams with riffles	Single habitat, semiquantitative; composite of 2 riffle kicks	Kick net (1-m^2, 500-µm mesh)	Riffle	2 m^2	Year-round	200 ± 20%	Genus level

Table F-5. Macroinvertebrate methods used in national surveys conducted by EPA and USGS

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
EPA National Aquatic Resource Surveys	WSA and NRSA	A 0.1-m^2 area was sampled for 30 seconds at a randomly selected location at each of the 11 transects. The samples were composited into one sample per site.	Modified D-frame net (30 cm wide) with 500-µm mesh	Multihabitat Composite	Approximately 1 m^2	June−September	500	Genus level
USGS	NAWQA	A semiquantitative sample consisting of 5 discrete collections from the richest targeted habitat (typically riffle, main-channel, coarse-grained substrate habitat type) are processed and combined into a single composited sample.	Slack sampler, 500-µm nets and sieves	Riffle	Each discrete sample = 0.25-m^2 area; total area sampled = 1.25 m^2	Late June−mid-October	300	Lowest practical level

APPENDIX G.

LEVEL OF TAXONOMIC RESOLUTION

When possible, all taxa should be taken to the lowest practical taxonomic level (ideally species level). If this is not possible, efforts should be made to identify the taxa listed in Table G-1 to the level of resolution described in the table. Ephemeroptera, Plecoptera, Trichoptera, and Chironomidae that are not listed in Table G-1 should be identified to at least the genus level, where possible.

The taxa in Table G-1 were selected based on differences in thermal tolerances that were evident in analyses (U.S. EPA, 2012; unpublished Northeast pilot study) and from best professional judgment. The list in Table G-1 should be regarded as a starting point and should be updated as better data become available in the future. Table G-2 contains a list of taxa that were considered for inclusion in Table G-1 but for various reasons, were not selected.

Table G-1. At RMN sites, we recommend that the taxa listed below be taken to the specified level of resolution, where practical. The Chironomidae require a slide mount and a compound microscope to identify to the species-level.

Order	Family	Genus	Level of resolution	Notes
Coleoptera	Elmidae	*Promoresia*	adults to species	Potential variability in thermal preferences of *P. tardella* (cold) and *P. elegans* (warm).
Diptera	Chironomidae	*Eukiefferiella*	species	Potential variability in thermal preferences of *E. brevicalar*, *E. brehmi*, and *E. tirolensis* (cold); and *E. claripennis* and *E. devonica* (warm).
Diptera	Chironomidae	*Polypedilum*	species	*P. aviceps* is generally regarded as a cold water taxon.
Diptera	Chironomidae	*Tvetenia*	species group	*T. vitracies* is warm water oriented in the Northeast.
Diptera	Simuliidae		genus	General agreement that *Prosimilium* is a cold water indicator but there is potential for variability within this genus (e.g., *P. mixtum* vs. *P. vernale*), and species-level systematics are not well developed at this time.
Ephemeroptera	Baetidae	*Baetis*	species	Potential variability in thermal preferences (e.g., *B. tricaudatus*—cold; *B. intercalaris* and *B. flavistriga*—warm).
Ephemeroptera	Ephemerellidae	*Ephemerella*	species (as maturity allows)	Potential variability in thermal preferences (e.g., *E. subvaria*—colder); need mature individuals (early instars are difficult to speciate).
Plecoptera	Perlidae	*Acroneuria*	species	Potential variability in thermal preferences of *A. abnormis* (warmer) and *A. carolinensis* (cooler).

Table G-1. continued…

Order	Family	Genus	Level of resolution	Notes
Plecoptera	Perlidae	*Paragnetina*	species	Potential variability in thermal preferences of *P. immarginata* (cold) and *P. media* and *P. kansanensis*.
Plecoptera	Pteronarcyidae	*Pteronarcys*	species	*P. dorsata* may be warmer water oriented.
Trichoptera	Brachycentridae	*Brachycentrus*	species	Potential variability in thermal preferences in the Northeast.
Trichoptera	Hydropsychidae	*Ceratopsyche*	species	Potential variability in thermal preferences.
Trichoptera	Rhyacophilidae	*Rhyacophila*	species	Most species are cold water, but some variability has been documented in the Northeast (U.S. EPA, 2012, unpublished data).
Trichoptera	Uenoidae	*Neophylax*	species	Some variability was noted in a pilot study in North Carolina (U.S. EPA, 2012).

Table G-2. Taxa that were considered for inclusion in Table G-1

Order	Family	Genus	Level of resolution	Notes
Coleoptera	Elmidae	*Oulimnius*	species	*O. latiusculus* is regarded as a cold-water taxon in Vermont, but species-level IDs may not be necessary for the larger region because most of the taxa are *O. latiusculus*.
Diptera	Chironomidae	*Micropsectra*	species	General agreement that there is variability in thermal preferences, but the taxonomy for this genus needs to be further developed.
Diptera	Ceratopogonidae		species	General agreement that there is variability in thermal preferences, but the taxonomy for this family needs to be further developed.
Ephemeroptera	Ephemerellidae	*Drunella*	species	Variability in thermal tolerances within this genus was noted in the Utah pilot study, but in the Eastern states, species are believed to be all cold/cool water.
Ephemeroptera	Ephemerellidae	*Eurylophella*	species	Some variability was noted in a pilot study in North Carolina (U.S. EPA, 2012); could be seasonal phenology vs. thermal preference.
Ephemeroptera	Heptageniidae	*Epeorus*	species	Some variability was noted in a pilot study in Utah (U.S. EPA, 2012); can be difficult to speciate.
Ephemeroptera	Heptageniidae	*Stenacron*	species	In the Mid-Atlantic region, some regard *S. interpunctatum* as a warm-water taxon and the others as cooler/some cold. Taxonomy may be tricky.

Table G-2. continued…

Order	Family	Genus	Level of resolution	Notes
Trichoptera	Goeridae	*Goera*	species	Some variability was noted in a pilot study in North Carolina (U.S. EPA, 2012). The two species found in Kentucky are associated with cold water. In New Jersey, this genus is found as often in the coastal plain as in northern high gradient streams and is currently not taken to the species level.
Trichoptera	Hydropsychidae	*Hydropsyche*	species	Some variability was noted in a pilot study in New England (U.S. EPA, 2012, unpublished data) but is generally considered to be eurythermal (not sure which species would be regarded as cold water taxa).
Trichoptera	Leptoceridae	*Oecetis*	species	Some variability was noted in a pilot study in North Carolina (U.S. EPA, 2012). The species found in Kentucky are associated with warm water. In New Jersey, this genus is typically found in low gradient coastal plain streams.
Trichoptera	Philopotamidae	*Chimarra*	species	Some variability was noted in a pilot study in New England (U.S. EPA, 2012, unpublished data) but most species were warm-water oriented. *C. obscura* and *C. atterima* predominate, but tend to co-occur.
Oligochaeta			family	Enchytraeidae is regarded as a cold-water family in Vermont. In the Mid-Atlantic region, it is found mostly in small streams. In New Jersey, it is found throughout the state.

Table G-2. continued…

Order	Family	Genus	Level of resolution	Notes
Amphipoda	Gammaridae	*Gammarus*	species	*G. pseudolimnaeus* is regarded as a cold- or cool-water taxon in Vermont (and is tolerant of nutrients). *Gammarus* (assumed to be *pseudolimnaeus*) is also regarded as a cold-water indicator in Minnesota (Gerritsen and Stamp, 2012).
Amphipoda	Hyalellidae	*Hyallela*	species	*H. azteca* is regarded as a cold/cool water taxon in Vermont. In Kentucky, *Hyallela* it is believed to be a completely warm-water genus.
Isopoda	Asellidae	*Caecidotea*	species	*C. brevicauda* has been noted as a potential cold-water indicator in the Midwest (Gerritsen and Stamp, 2012).
Neoophora	Planariidae	*Dugesia*	species	*D. tigrina* is regarded as a warm-water taxon in Vermont, as well as in New Jersey. Can be difficult to speciate in speciose regions.
Neoophora	Dugesiidae	*Cura*	species	*C. formanii* is regarded as a cold-water taxon in Vermont. Can be difficult to speciate in speciose regions.

G.1. LITERATURE CITED:

Gerritsen, J; Stamp, J. (2012) Calibration of the biological condition gradient (BCG) in cold and cool waters of the upper Midwest for fish and benthic macroinvertebrate assemblages [Final Report]. Prepared by Tetra Tech, Inc. for the USEPA Office of Water and USEPA Region 5. Owings Mills, MD: Tetra Tech. Available online at http://www.uwsp.edu/cnr-ap/biomonitoring/Documents/pdf/USEPA-BCG-Report-Final-2012.pdf

U.S. EPA (Environmental Protection Agency). (2012) Implications of climate change for bioassessment programs and approaches to account for effects. [EPA/600/R-11/036F]. Washington, DC: Global Change Research Program, National Center for Environmental Assessment. Available online at http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=239585

APPENDIX H.

SUMMARIZING MACROINVERTEBRATE DATA

H.1. LIST OF CANDIDATE BIOLOGICAL INDICATORS

Table H-1. Recommendations on candidate biological indicators to summarize from the macroinvertebrate data collected at regional monitoring network (RMN) sites; many of these indicators are commonly used by biomonitoring programs for site assessments.

Type of indicator	Biological indicator	Expected response	Source
Taxonomic-based metric	Total number of taxa (richness)	Predicted to decrease in response to increasing anthropogenic stress	Barbour et al., 1999 (compiled from DeShon, 1995; Barbour et al., 1996; Fore et al., 1996; Smith and Voshell, 1997); these metrics are commonly used in bioassessments
	Number of EPT taxa (Ephemeroptera [mayflies], Plecoptera [stoneflies], and Trichoptera [caddisflies])		
	Number of Ephemeroptera (mayfly) taxa		
	Number of Plecoptera (stonefly) taxa		
	Number of Trichoptera (caddisfly) taxa		
	Percentage EPT individuals		
	Percentage Ephemeroptera individuals		
	Percentage Plecoptera individuals		
	Percentage Trichoptera individuals		
	Number of Odonata, Coleoptera, and Hemiptera (OCH) taxa	Expected to be more prevalent during summer, low flow (more pool-like) periods	Bonada et al., 2007a
	Percentage OCH individuals		

Table H-1. continued…

Type of indicator	Biological indicator	Expected response	Source
Traits-based metric related to temperature (for list of thermal indicator taxa, see Appendix I)	Number of cold water taxa	Predicted to decrease in response to warming temperatures	Lake, 2003; Hamilton et al., 2010; Stamp et al., 2010; U.S. EPA, 2012
	Percentage cold water individuals		
	Number of warm water taxa	Predicted to increase in response to warming temperatures	
	Percentage warm water individuals		
Traits-based metric related to hydrology	Collector filterer	Predicted to decrease during low flow conditions	Wills et al., 2006; Bogan and Lytle, 2007; Walters and Post, 2011
	Collector gatherer	Predicted to increase during slow velocity conditions	Heino, 2009
	Scraper/herbivore	Predicted to increase during conditions of stable flow and habitat availability; decrease during drought conditions	Richards et al., 1997; McKay and King, 2006; Wills et al., 2006; Fenoglio et al., 2007; Griswold et al., 2008; Diaz et al., 2008
	Shredder	Expected to respond to changing thermal and hydrologic conditions	Richards et al., 1997; Buzby and Perry, 2000; McKay and King, 2006; Foucreau et al., 2013
	Predator	Predicted to increase during low flow conditions	Bogan and Lytle, 2007; Miller et al., 2007; Walters and Post, 2011
	Swimmer	Predicted to comprise higher proportion of assemblage during drier, harsher, climatic conditions	Béche et al., 2006; Bonada et al., 2007b; Diaz et al., 2008
	Rheophily—depositional	Favor low flow/slow velocity conditions	Richards et al., 1997; Lake, 2003; Wills et al., 2006; Poff et al., 2010; Brooks et al., 2011
	Rheophily—erosional	Favor high flow/fast velocity conditions	

Table H-1. continued…

Type of indicator	Biological indicator	Expected response	Source
Biological condition	Bioassessment score (e.g., multimetric index, predictive, biological condition gradient)	Expected to worsen in response to increasing anthropogenic stress	Barbour et al., 1995; DeShon, 1995; Hawkins et al., 2000; Davies and Jackson, 2006
Individual taxa	Presence—absence	Hypotheses have been developed for some individual taxa (e.g., the cold and warm water taxa listed in Appendix I)	Becker et al., 2010
	Relative abundance		
	Spatial distribution		
Variability	Persistence (variability in presence/absence; see Section H.2 of this appendix)	Expect lower persistence in disturbed or climatically harsh environments	Holling, 1973; Bradley and Ormerod, 2001; Milner et al., 2006; Durance and Ormerod, 2007
	Stability (variability in relative abundance; see Section H.2 of this appendix)	Expect lower stability in disturbed or climatically harsh environments	Scarsbrook, 2002; Milner et al., 2006

H.2. FORMULAS FOR CALCULATING PERSISTENCE AND STABILITY

Persistence between samples can be calculated using Jaccard's similarity coefficient (*J*):

$$J(AB) = \frac{j}{a + b - j} \qquad \text{(H-1)}$$

Here *j* is the number of taxa common to both years (or sites) *A* and *B*, while *a* and *b* are the number of taxa in year (or site) *A* and *B*, respectively. It is interpreted as the proportion of taxa common to both samples, such that values close to zero and one have low and high persistence, respectively.

Stability, on the other hand, can be calculated using Bray-Curtis similarity (BC [Bray and Curtis, 1957]):

$$BC(AB) = 1 - \frac{\sum_i |n_{Ai} - n_{Bi}|}{N_A + N_B} \quad \text{(H-2)}$$

Here n_{Ai} and n_{Bi} are the number of individuals of taxa i in year (or site) A and B, and N_A and N_B are the total number of individuals in year (or site) A and B, respectively. It is interpreted as the proportion of individuals (rather than taxa) common to both samples, such that values close to zero and one have low and high stability, respectively.

As an example, we calculate persistence and stability using Jaccard and Bray-Curtis similarities with the data in Table H-2:

$$J(AB) = \frac{3}{3 + 5 - 3} = \frac{3}{5} = 0.60 \quad \text{(H-3)}$$

$$BC(AB) = 1 - \frac{|10 - 19| + |0 - 35| + |5 - 5| + |8 - 13| + |0 - 1|}{23 + 73} \quad \text{(H-4)}$$

$$= 1 - \frac{9 + 35 + 0 + 5 + 1}{23 + 73} = 1 - \frac{50}{96} = 0.48 \quad \text{(H-5)}$$

Table H-2. Sample data for calculating persistence and stability

Samples	Taxa V	Taxa W	Taxa X	Taxa Y	Taxa Z	Sum
Sample year (or site) A	10	0	5	8	0	23
Sample year (or site) B	19	35	5	13	1	73

High persistence and stability are thought to occur where environmental conditions are similar or relatively constant, or where change occurs incrementally. For additional background and an example of these techniques applied to long-running surveys in Alaskan streams, see Milner et al. (2006). At these sites, mean persistence and stability between study years ranged from 0.49 to 0.70 and from 0.29 to 0.44, respectively, which suggests that even among the most persistent sites, substantial year-to-year shifts in relative abundances can occur.

H.1. REFERENCE:

Barbour, MT; Stribling, JB; Karr, J. (1995) Multimetric approach for establishing biocriteria and measuring biological condition. In Davis, W.S. & T.P. Simon (eds). Biological Assessment and Criteria; Tools for Water Resource Planning and Decision Making. Lewis Publishers. Boca Raton, FL: 63-77.

Barbour, MT; Gerritsen, J; Griffith, GE; Frydenborg, R; McCarron, E; White, JS; Bastian, ML. (1996) A framework for biological criteria for Florida streams using benthic macroinvertebrates. J N Am Benthol Soc 15(2):185−211.

Barbour, MT; Gerritsen, J; Snyder, BD; Stribling, JB. (1999) Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish, Second Edition. [EPA 841-B-99-002]. Washington, D.C: U.S. Environmental Protection Agency, Office of Water. Available online: http://water.epa.gov/scitech/monitoring/rsl/bioassessment/index.cfm.

Bêche, LA; McElracy, EP; Resh, VH. (2006) Long-term seasonal variation in the biological traits of benthic-macroinvertebrates in two Mediterranean-climate streams in California U.S.A. Freshw Biol 51:56−75.

Becker, AJ; Stranko, SA; Klauda, RJ; Prochaska, AP; Schuster, JD; Kashiwagi, MR; Graves, PH. (2010) Maryland biological stream survey’s sentinel site network: A multi-purpose monitoring program. Annapolis, MD: Maryland Department of Natural Resources.

Bonada, N; Rieradevall, M; Prat, N. (2007a). Macroinvertebrate community structure and biological traits related to flow permanence in a Mediterranean river network. Hydrobiologia 589:91−106.

Bonada, N; Dolédec, S; Statzner, B. (2007b). Taxonomic and biological trait differences of stream macroinvertebrate communities between Mediterranean and temperate regions: implications for future climatic scenarios. Global Change Biol 13:1658−1671.

Bogan, MT; Lytle, DA. (2007) Seasonal flow variation allows ‘time-sharing’ by disparate aquatic insect communities in montane desert streams. Freshw Biol 52(2):290−304. doi:10.1111/j.1365-2427.2006.01691.x

Bradley, DC; Ormerod, SJ. (2001) Community persistence among upland stream invertebrates tracks the North Atlantic Oscillation. J Animal Ecol 70(6):987−996.

Brooks, A; Chessman, B; Haeusler, T. (2011) Macroinvertebrate traits distinguish unregulated rivers subject to water abstraction. J N Am Benthol Soc 30(2):419−435.

Buzby, KM; Perry, SA. (2000). Modeling the potential effects of climate change on leaf pack processing in central Appalachian streams. Can J Fish Aquatic Sci 57(9):1773−1783.

Davies, SP; Jackson, SK. (2006) The Biological Condition Gradient: A descriptive model for interpreting change in aquatic ecosystems. Ecol Appl 16(4):1251−1266.

DeShon, J. (1995) Development and application of the Invertebrate Community Index (ICI). [p. 217−243]. In Davis, WS; Simon, TP (eds). Biological assessment and criteria: tools for water resource planning and decision making. Boca Raton:CRC Press.

Diaz, AM; Suarez Alonso, ML; Vidal-Abarca Gutierrez, MR. (2008) Biological traits of stream macroinvertebrates from a semi-arid catchment: patterns along complex environmental gradients. Freshw Biol 53:1−21.

Durance, I; Ormerod, SJ. (2007) Climate change effects on upland stream macroinvertebrates over a 25-year period. Glob Change Biol 13:942−957.

Fenoglio, S; Bo, T; Cucco, M; Malacarne, G. (2007) Response of benthic invertebrate assemblages to varying drought conditions in the Po river (NW Italy). Ital J Zool 74(2):191−201.

Fore, LS; Karr, JR; Wisseman, RW. (1996) Assessing invertebrate responses to human activities: Evaluating alternative approaches. J N Am Benthol Soc 15(2):212−231.

Foucreau, N; Piscart, C; Puijalon, S; Hervant, F. (2013) Effect of climate-related change in vegetation on leaf litter consumption and energy storage by Gammarus pulex from Continental or Mediterranean populations. PLoS ONE 8(10): e77242.

Griswold, MW; Berzinis, RW; Crisman, TL; Golladay, SW. (2008) Impacts of climatic stability on the structural and functional aspects of macroinvertebrate communities after severe drought. Freshw Biol 53(12):2465-2483. doi:10.1111/j.1365-2427.2008.02067.x.

Hamilton, AT; Stamp, J; Bierwagen, BG. (2010) Vulnerability of biological metrics and multimetric indices to effects of climate change. J N Am Benthol Soc 29(4):1379−1396.

Hawkins, CP; Norris, RH; Hogue, JN; Feminella, JW. (2000) Development and evaluation of predictive models for measuring the biological integrity of streams. Ecol Appl 10:1456−1477.

Heino, J. (2009) Species co-occurrence, nestedness and guild− environment relationships in stream macroinvertebrates. Freshw Biol 54(9):1947−1959.

Holling, CS. (1973) Resilience and stability of ecological systems. Ann Rev Ecol Systems 4:1−23.

Lake, PS. (2003) Ecological effects of perturbation by drought in flowing waters. Freshw Biol 48:1161−1172.

McKay, SF; King, AJ. (2006) Potential ecological effects of water extraction in small, unregulated streams. River Res Appl 22:1023−1037.

Miller, S; Wooster, D; Li, J. (2007) Resistance and resilience of macroinvertebrates to irrigation water withdrawals. Freshw Biol 52:2494−2510.

Milner, AM; Conn, SC; Brown, LE. (2006) Persistence and stability of macroinvertebrate communities in streams of Denali National Park, Alaska: implications for biological monitoring. Freshw Biol 51:373−387.

Poff, NL; Allan, JD; Bain, MB; Karr, JR; Prestegaard, KL; Richter, BD; Sparks, RE; Stromberg, JC. (1997) The natural flow regime: a paradigm for river conservation and restoration. BioScience 47(11):769−784.

Richards, C; Haro, RJ; Johnson, LB; Host, GE. (1997) Catchment and reach-scale properties as indicators of macroinvertebrate species traits. Freshw Biol 37:219−230.

Scarsbrook MR. (2002) Persistence and stability of lotic invertebrate communities in New Zealand. Freshw Biol 47:417−431.

Smith, EP; Voshell, Jr, JR. (1997) Studies of benthic macroinvertebrates and fish in streams within EPA Region 3 for development of biological indicators of ecological condition. Blacksburg, VA: Virginia Polytechnic Institute and State University.

Stamp, J; Hamilton, A; Zheng, L; Bierwagen, B. (2010) Use of thermal preference metrics to examine state biomonitoring data for climate change effects. J N Am Benthol Soc 29(4):1410−1423.

U.S. EPA (Environmental Protection Agency). (2012) Implications of climate change for state bioassessment programs and approaches to account for effects. [EPA/600/R-11/036F]. Washington, DC: Global Change Research Program, National Center for Environmental Assessment. http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=239585.

Walters, AW; Post, D. (2011) How low can you go? Impacts of a low-flow disturbance on aquatic insect communities. Ecol Appl 21:163−174.

Wills, TC; Baker, EA; Nuhfer, AJ; Zorn, TG. (2006) Response of the benthic macroinvertebrate community in a northern Michigan stream to reduced summer streamflows. River Res Appl 22:819−836.

H.2. REFERENCE:

Bray, JR; Curtis, JT. (1957) An ordination of the upland forest communities of southern Wisconsin. Ecol Monogr 27:325–349.

Milner, AM; Conn, SC; Brown, LE. (2006) Persistence and stability of macroinvertebrate communities in streams of Denali National Park, Alaska: implications for biological monitoring. Freshw Biol 51:373−387.

APPENDIX I.

MACROINVERTEBRATE THERMAL INDICATOR TAXA

This appendix contains lists of macroinvertebrate taxa that are believed to have strong thermal preferences based on analyses conducted by EPA (U.S. EPA, 2012; unpublished Northeast pilot study) and state biomonitoring programs (Maryland Department of Natural Resources [MD DNR], Pennsylvania Department of Environmental Protection [PA DEP], Tennessee Department of Environment and Conservation [TN DEC], Vermont Department of Environmental Conservation [VT DEC]). Best professional judgment from regional taxonomists was also considered.

Table I-1 contains a list of cold- and warm-water preference taxa (benthic macroinvertebrates) for the eastern United States, based on Generalized Additive Models (GAM)—full temperature range model rank results from the Northeast pilot study (U.S. EPA, 2012) and the best professional judgment of regional experts.

Table I-2 contains lists of taxa that have been identified as thermal indicators by VT DEC (Steve Fiske, Aaron Moore, and Jim Kellogg, unpublished).

Table I-3 contains the list of taxa that have been identified as cold water taxa by MD DNR (Becker et al., 2010) and also contains information that was provided by PA DEP (Amy Williams and Dustin Shull, unpublished data).

Table I-4 contains a list of indicator taxa identified based on thermal tolerance analyses (per Yuan, 2006) conducted on data from North Carolina (U.S. EPA, 2012), and also contains information that was provided by Debbie Arnwine from TN DEC.

All of these lists are intended to be starting points, which can be revised as more data become available.

Table I-1. List of cold- and warm-water preference taxa (benthic macroinvertebrates) for the eastern United States, based on GAM—full temperature range model rank results from the Northeast pilot study (EPA, 2012) and the best professional judgment of regional experts

Order	Family	Genus	Final identification	Indicator
Coleoptera	Elmidae	*Oulimnius*	*Oulimnius*	Cold
Coleoptera	Elmidae	*Promoresia*	*Promoresia tardella*	Cold
Diptera	Chironomidae	*Brillia*	*Brillia*	Cold
Diptera	Chironomidae	*Eukiefferiella*	*Eukiefferiella brevicalcar*	Cold
Diptera	Chironomidae	*Eukiefferiella*	*Eukiefferiella claripennis*	Cold
Diptera	Chironomidae	*Heleniella*	*Heleniella*	Cold
Diptera	Chironomidae	*Parachaetocladius*	*Parachaetocladius*	Cold
Diptera	Chironomidae	*Polypedilum*	*Polypedilum tritum*	Cold
Diptera	Dixidae	*Dixa*	*Dixa*	Cold
Diptera	Psychodidae	*Pericoma*	*Pericoma*	Cold
Diptera	Simuliidae	*Prosimulium*	*Prosimulium*	Cold
Ephemeroptera	Ameletidae	*Ameletus*	*Ameletus*	Cold
Ephemeroptera	Baetidae	*Baetis*	*Baetis tricaudatus*	Cold
Ephemeroptera	Baetidae	*Diphetor*	*Diphetor*	Cold
Ephemeroptera	Ephemerellidae	*Drunella*	*Drunella*	Cold
Ephemeroptera	Ephemerellidae	*Ephemerella*	*Ephemerella*	Cold
Ephemeroptera	Ephemerellidae	*Eurylophella*	*Eurylophella*	Cold
Ephemeroptera	Heptageniidae	*Cinygmula*	*Cinygmula*	Cold
Ephemeroptera	Heptageniidae	*Epeorus*	*Epeorus*	Cold
Ephemeroptera	Heptageniidae	*Rhithrogena*	*Rhithrogena*	Cold
Ephemeroptera	Leptophlebiidae	*Habrophlebia*	*Habrophlebia*	Cold
Odonata	Gomphidae	*Lanthus*	*Lanthus*	Cold
Plecoptera	Capniidae		Capniidae	Cold
Plecoptera	Chloroperlidae		Chloroperlidae	Cold
Plecoptera	Nemouridae		Nemouridae	Cold
Plecoptera	Peltoperlidae	*Peltoperla*	*Peltoperla*	Cold

Table I-1. continued…

Order	Family	Genus	Final identification	Indicator
Plecoptera	Peltoperlidae	*Tallaperla*	*Tallaperla*	Cold
Plecoptera	Perlodidae	*Isoperla*	*Isoperla*	Cold
Plecoptera	Perlodidae	*Malirekus*	*Malirekus*	Cold
Plecoptera	Pteronarcyidae	*Pteronarcys*	*Pteronarcys*	Cold
Plecoptera	Taeniopterygidae	*Taenionema*	*Taenionema*	Cold
Plecoptera	Taeniopterygidae	*Taeniopteryx*	*Taeniopteryx*	Cold
Trichoptera	Apataniidae	*Apatania*	*Apatania*	Cold
Trichoptera	Brachycentridae	*Brachycentrus*	*Brachycentrus americanus*	Cold
Trichoptera	Glossosomatidae	*Agapetus*	*Agapetus*	Cold
Trichoptera	Glossosomatidae	*Glossosoma*	*Glossosoma*	Cold
Trichoptera	Hydropsychidae	*Arctopsyche*	*Arctopsyche*	Cold
Trichoptera	Hydropsychidae	*Ceratopsyche*	*Ceratopsyche alhedra*	Cold
Trichoptera	Hydropsychidae	*Ceratopsyche*	*Ceratopsyche macleodi*	Cold
Trichoptera	Hydropsychidae	*Ceratopsyche*	*Ceratopsyche ventura*	Cold
Trichoptera	Hydropsychidae	*Diplectrona*	*Diplectrona*	Cold
Trichoptera	Hydropsychidae	*Parapsyche*	*Parapsyche*	Cold
Trichoptera	Hydroptilidae	*Palaeagapetus*	*Palaeagapetus*	Cold
Trichoptera	Odontoceridae	*Psilotreta*	*Psilotreta*	Cold
Trichoptera	Philopotamidae	*Dolophilodes*	*Dolophilodes*	Cold
Trichoptera	Philopotamidae	*Wormaldia*	*Wormaldia*	Cold
Trichoptera	Rhyacophilidae	*Rhyacophila*	*Rhyacophila*	Cold
-	-	-	*Turbellaria*[a]	Warm
Basommatophora	Physidae	*Physella*	*Physella*	Warm
Coleoptera	Elmidae	*Stenelmis*	*Stenelmis*	Warm
Coleoptera	Hydrophilidae	*Berosus*	*Berosus*	Warm
Diptera	Chironomidae	*Ablabesmyia*	*Ablabesmyia*	Warm
Diptera	Chironomidae	*Cardiocladius*	*Cardiocladius*	Warm

Table I-1. continued…

Order	Family	Genus	Final identification	Indicator
Diptera	Chironomidae	*Dicrotendipes*	*Dicrotendipes*	Warm
Diptera	Chironomidae	*Glyptotendipes*	*Glyptotendipes*	Warm
Diptera	Chironomidae	*Nilotanypus*	*Nilotanypus*	Warm
Diptera	Chironomidae	*Nilothauma*	*Nilothauma*	Warm
Diptera	Chironomidae	*Pentaneura*	*Pentaneura*	Warm
Diptera	Chironomidae	*Polypedilum*	*Polypedilum convictum*	Warm
Diptera	Chironomidae	*Polypedilum*	*Polypedilum flavum*	Warm
Diptera	Chironomidae	*Stenochironomus*	*Stenochironomus*	Warm
Diptera	Chironomidae	*Tanytarsus*	*Tanytarsus*	Warm
Diptera	Chironomidae	*Tvetenia*	*Tvetenia vitracies*	Warm
Ephemeroptera	Baetidae	*Baetis*	*Baetis intercalaris*	Warm
Ephemeroptera	Caenidae	*Caenis*	*Caenis*	Warm
Ephemeroptera	Heptageniidae	*Stenacron*	*Stenacron*	Warm
Ephemeroptera	Leptohyphidae	*Tricorythodes*	*Tricorythodes*	Warm
Neotaenioglossa	Hydrobiidae		Hydrobiidae	Warm
Odonata	Coenagrionidae	*Argia*	*Argia*	Warm
Odonata	Coenagrionidae	*Ischnura*	*Ischnura*	Warm
Odonata	Corduliidae	*Helocordulia*	*Helocordulia*	Warm
Odonata	Corduliidae	*Macromia*	*Macromia*	Warm
Trichoptera	Hydropsychidae	*Macrostemum*	*Macrostemum*	Warm
Trichoptera	Hydroptilidae	*Hydroptila*	*Hydroptila*	Warm
Trichoptera	Leptoceridae	*Oecetis*	*Oecetis*	Warm
Trichoptera	Philopotamidae	*Chimarra*	*Chimarra obscura*	Warm
Trichoptera	Polycentropodidae	*Neureclipsis*	*Neureclipsis*	Warm
Veneroida	Pisidiidae	*Sphaerium*	*Sphaerium*	Warm

[a]Class *Turbellaria*

Table I-2. Thermal indicator taxa that have been identified by VT DEC (Steve Fiske, Aaron Moore and Jim Kellogg, unpublished data)

Order	Genus	Species	Indicator
Diptera	*Polypedilum*	*aviceps*	Cold
Diptera	*Neostempellina*	*reissi*	Cold
Diptera	*Tvetenia*	*bavarica grp*	Cold
Ephemeroptera	*Rhithrogena*	sp	Cold
Ephemeroptera	*Ameletus*	sp	Cold
Trichoptera	*Arctopsyche*	sp	Cold
Trichoptera	*Arctopsyche*	*ladogensis*	Cold
Trichoptera	*Rhyacophila*	*carolina*	Cold
Trichoptera	*Rhyacophila*	*torva*	Cold
Trichoptera	*Rhyacophila*	*nigrita*	Cold
Trichoptera	*Rhyacophila*	*invaria*	Cold
Trichoptera	*Rhyacophila*	*acutiloba*	Cold
Plecoptera	*Peltoperla*	sp	Cold
Plecoptera	*Tallaperla*	sp	Cold
Plecoptera	*Taenionema*	sp	Cold
Decapoda	*Cambarus*	*bartoni*	Cold
Trichoptera	*Palaeagapetus*	sp	Cold
Diptera	*Eukiefferella*	*brevicalar*, *brehmi*, and *tirolensis*	Cold
Coleoptera	*Oulimnius*	*latiusculus*	Cold
Coleoptera	*Promoresia*	*tardella*	Cold
Amphipoda	*Gammarus*	*pseudolimnaeus*	Cold/cool
Amphipoda	*Hyallela*	*azteca*	Cold/cool
Neoophora	*Cura*	*formanii*	Cold
Diptera	*Eukiefferella*	*claripennis*	Warm
Diptera	*Polypedilum*	*flavum*	Warm
Diptera	*Tvetenia*	*discoloripes*, *vitracies*	Warm

Table I-2. continued…

Order	Genus	Species	Indicator
Trichoptera	*Leucotrichia*	sp	Warm
Trichoptera	*Rhyacophila*	*mainensis*	Warm
Trichoptera	*Rhyacophila*	*manistee*	Warm
Trichoptera	*Rhyacophila*	*minora*	Warm
Plecoptera	*Neoperla*	sp	Warm
Plecoptera	*Taeniopteryx*	sp	Warm
Coleoptera	*Promoresia*	*elegans*	Warm
Neoophora	*Dugesia*	*tigrina*	Warm

Table I-3. Taxa that have been identified as cold or cool water indicators by MD DNR (Becker et al., 2010) and/or PA DEP (Amy Williams and Dustin Shull, unpublished data)

Type	Order	Genus	MD	PA	Occurrence in PA DEP data set
Cold	Diptera	*Bittacomorpha*	Yes		
Cold	Diptera	*Dixa*	Yes		
Cold	Diptera	*Heleniella*	Yes		
Cold	Diptera	*Prodiamesa*	Yes		
Cold	Ephemeroptera	*Ameletus*		Yes	Common
Cold	Ephemeroptera	*Cinygmula*	Yes	Yes	Common
Cold	Ephemeroptera	*Diphetor*	Yes	Yes	Common
Cold	Ephemeroptera	*Drunella*		Yes	Common
Cold (MD)/cool (PA)	Ephemeroptera	*Epeorus*	Yes	Yes	Common
Cold	Ephemeroptera	*Ephemera*	Yes		
Cold	Ephemeroptera	*Ephemerella*		Yes	Common
Cold	Ephemeroptera	*Eurylophella*		Yes	Common
Cold (MD)/cool (PA)	Ephemeroptera	*Habrophlebia*	Yes	Yes	Rare
Cold	Ephemeroptera	*Paraleptophlebia*	Yes		
Cold	Plecoptera	*Alloperla*	Yes	Yes	Common
Cold	Plecoptera	*Amphinemura*		Yes	Common
Cold	Plecoptera	*Diploperla*		Yes	Rare
Cold	Plecoptera	*Haploperla*		Yes	Rare
Cold	Plecoptera	*Isoperla*		Yes	Common
Cold	Plecoptera	*Leuctra*	Yes		
Cold	Plecoptera	*Malirekus*		Yes	Rare
Cold	Plecoptera	*Peltoperla*		Yes	Rare
Cold	Plecoptera	*Pteronarcys*		Yes	Rare
Cold	Plecoptera	*Remenus*		Yes	Rare
Cold	Plecoptera	*Sweltsa*	Yes	Yes	Common

Table I-3. continued…

Type	Order	Genus	MD	PA	Occurrence in PA DEP data set
Cold	Plecoptera	*Tallaperla*	Yes	Yes	Common
Cold	Plecoptera	*Yugus*		Yes	Rare
Cold	Trichoptera	*Diplectrona*	Yes		
Cold	Trichoptera	*Wormaldia*	Yes	Yes	Common

Table I-4. Taxa that have been identified as cold, cool, or warm water indicators based on thermal tolerance analyses (per Yuan, 2006) conducted on data from North Carolina (U.S. EPA, 2012) and/or based on unpublished data provided by Debbie Arnwine from TN DEC

Type	Order	Genus	NC (U.S. EPA, 2012)	TN	Notes—TN
Cold (NC)/ cool (TN)	Coleoptera	*Promoresia*	Yes	Yes	
Cold (NC)/ cool (TN)	Diptera	*Antocha*	Yes	Yes	
Cold (NC)/ cool (TN)	Diptera	*Atherix*	Yes	Yes	
Cold	Diptera	*Cardiocladius*	Yes		
Cold	Diptera	*Diamesa*	Yes		
Cold	Diptera	*Dicranota*	Yes		
Cold	Diptera	*Eukiefferiella*	Yes		
Cold	Diptera	*Heleniella*	Yes		
Cold (NC)/ cool (TN)	Diptera	*Pagastia*	Yes	Yes	
Cold	Diptera	*Potthastia*	Yes		
Cold	Diptera	*Rheopelopia*	Yes		
Cold	Ephemeroptera	*Acentrella*	Yes		
Cold	Ephemeroptera	*Cinygmula*	Yes		
Cold (NC)/ cool (TN)	Ephemeroptera	*Drunella*	Yes	Yes	
Cold (NC)/ cool (TN)	Ephemeroptera	*Epeorus*	Yes	Yes	
Cold	Ephemeroptera	*Nixe*	Yes		
Cold (NC)/ cool (TN)	Ephemeroptera	*Rhithrogena*	Yes	Yes	
Cold (NC)/ cool (TN)	Odonata	*Lanthus*	Yes	Yes	
Cold	Plecoptera	*Amphinemura*	Yes		

Table I-4. continued…

Type	Order	Genus	NC (U.S. EPA, 2012)	TN	Notes—TN
Cold	Plecoptera	*Clioperla*	Yes		
Cold	Plecoptera	*Cultus*	Yes		
Cold	Plecoptera	*Diploperla*	Yes	Yes	Uncommon in TN data set
Cold	Plecoptera	*Isoperla*	Yes		
Cold	Plecoptera	*Malirekus*	Yes	Yes	Uncommon in TN data set
Cold	Plecoptera	*Peltoperla*		Yes	Uncommon in TN data set
Cold	Plecoptera	*Pteronarcys*		Yes	
Cold	Plecoptera	*Tallaperla*	Yes	Yes	
Cold	Plecoptera	*Zapada*	Yes		
Cold (NC)/ cool (TN)	Trichoptera	*Agapetus*	Yes	Yes	
Cold	Trichoptera	*Apatania*	Yes	Yes	Uncommon in TN data set
Cold	Trichoptera	*Arctopsyche*	Yes	Yes	Uncommon in TN data set
Cold	Trichoptera	*Dolophilodes*	Yes	Yes	Mostly cool or cold
Cold	Trichoptera	*Glossosoma*	Yes	Yes	Mostly cool or cold
Cold	Trichoptera	*Parapsyche*	Yes	Yes	Uncommon in TN data set
Cold/cool	Ephemeroptera	*Ameletus*		Yes	
Cold/cool	Trichoptera	*Lepidostoma*		Yes	
Cool	Ephemeroptera	*Habrophlebia*		Yes	Uncommon in TN data set
Cool	Plecoptera	*Alloperla*		Yes	

Table I-4. continued…

Type	Order	Genus	NC (U.S. EPA, 2012)	TN	Notes—TN
Cool	Plecoptera	*Sweltsa*		Yes	Warm and cold but mostly cool
Cool	Plecoptera	*Taenionema*		Yes	uncommon in TN data set
Cool	Trichoptera	*Diplectrona*		Yes	Warm and cold—more common in cool or cold
Cool	Trichoptera	*Wormaldia*		Yes	
Warm	Arhynchobdellida	*Erpobdella*	Yes		
Warm	Arhynchobdellida	*Mooreobdella*	Yes		
Warm	Basommatophora	*Physella*	Yes		
Warm	Coleoptera	*Berosus*	Yes		
Warm	Coleoptera	*Lioporeus*	Yes		
Warm	Decapoda	*Palaemonetes*	Yes		
Warm	Diptera	*Nilothauma*	Yes		
Warm	Diptera	*Parachironomus*	Yes		
Warm	Diptera	*Pentaneura*	Yes		
Warm	Diptera	*Procladius*	Yes		
Warm	Diptera	*Stenochironomus*	Yes		
Warm	Ephemeroptera	*Diphetor*		Yes	
Warm	Ephemeroptera	*Tricorythodes*	Yes		
Warm	Hemiptera	*Belostoma*	Yes		
Warm	Isopoda	*Caecidotea*	Yes		
Warm	Odonata	*Epicordulia*	Yes		
Warm	Odonata	*Helocordulia*	Yes		
Warm	Odonata	*Hetaerina*	Yes		
Warm	Odonata	*Ischnura*	Yes		

Table I-4. continued…

Type	Order	Genus	NC (U.S. EPA, 2012)	TN	Notes—TN
Warm	Odonata	*Macromia*	Yes		
Warm	Odonata	*Neurocordulia*	Yes		
Warm	Odonata	*Tetragoneuria*	Yes		
Warm	Rhynchobdellida	*Helobdella*	Yes		
Warm	Rhynchobdellida	*Placobdella*	Yes		
Warm	Trichoptera	*Chimarra*	Yes		
Warm	Trichoptera	*Macrostemum*	Yes		
Warm	Trichoptera	*Neureclipsis*	Yes		
Warm	Trichoptera	*Phylocentropus*	Yes		
Warm	Unionoida	*Elliptio*	Yes		

I.1. REFERENCES

Becker, AJ; Stranko, SA; Klauda, RJ; Prochaska, AP; Schuster, JD; Kashiwagi, MR; Graves, PH. (2010) Maryland biological stream survey's sentinel site network: A multi-purpose monitoring program. Annapolis, MD: Maryland Department of Natural Resources.

U.S. EPA (Environmental Protection Agency). (2012) Implications of climate change for bioassessment programs and approaches to account for effects. [EPA/600/R-11/036F]. Washington, DC: Global Change Research Program, National Center for Environmental Assessment. http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=239585.

Yuan, L. (2006) Estimation and application of macroinvertebrate tolerance values. National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC; EPA/600/P-04/116F. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=154869.

APPENDIX J.

THERMAL SUMMARY STATISTICS

Table J-1. Recommended thermal statistics to calculate for each year of continuous temperature data at regional monitoring network (RMN) sites.

Timeframe	Thermal statistic	Calculation
Daily	Daily mean	Mean temperature for each day
	Daily maximum	Maximum temperature for each day
	Daily minimum	Minimum temperature for each day
	Daily difference (maximum−minimum)	Difference between the maximum and minimum temperatures for each day
	Daily variance	Standard deviation for each day
Monthly	Monthly mean	Mean of the daily means for each month
	Monthly maximum	Maximum value for each month
	Monthly minimum	Minimum value for each month
	Monthly difference (maximum−minimum)	Difference between the maximum and minimum temperatures for each month
	Monthly variance	Standard deviation for each month
Seasonal[a]	Seasonal mean	Mean of the daily means for each season
	Seasonal maximum	Maximum value for each season
	Seasonal minimum	Minimum value for each season
	Seasonal difference (maximum−minimum)	Difference between the maximum and minimum temperatures for each season
	Seasonal variance	Standard deviation for each season

Table J.1. continued…

Timeframe	Thermal statistic	Calculation
Annual	Annual mean	Mean of the daily means for the year (January 1−December 31)
	Annual maximum	Maximum value for the year (January 1−December 31)
	Annual minimum	Minimum value for the year (January 1−December 31)
	Mean annual difference	Mean of the daily difference (January 1−December 31)
	Maximum annual difference	Maximum of the daily difference (January 1−December 31)
	Minimum annual difference	Minimum of the daily difference (January 1−December 31)
	Variance of the annual mean difference	Standard deviation of the daily difference (January 1−December 31)
	Percentage exceedance	([Number of measurements that exceed a threshold[b]] ÷ [total number of measurements in a year]) × 100

[a]Seasons are defined as follows. Winter: December, January, February; Spring: March, April, May; Summer: June, July, August; Fall: September, October, November.
[b]Thresholds may vary by entity and location.

APPENDIX K.

HYDROLOGIC SUMMARY STATISTICS AND TOOLS FOR CALCULATING ESTIMATED STREAMFLOW STATISTICS

K.1. LIST OF RECOMMENDED HYDROLOGIC SUMMARY STATISTICS FOR REGIONAL MONITORING NETWORK (RMN) SITES

Table K-1. Recommended hydrologic statistics to calculate on each year of water-level or flow data from regional monitoring network (RMN) sites. These provide information on high, seasonal, and low flow components to maintain ecosystem flows. These candidate metrics were derived from DePhilip and Moberg (2013) for the Upper Ohio River Basin and Olden and Poff (2003). Work that was done by Hawkins et al. (2013) was also considered. For more details on these studies, see Sections K.2−K.4.

Timeframe	Metric	Calculation
Daily	Daily mean	Mean stage or flow for each day
	Daily median	Median stage or flow for each day
	Daily maximum	Maximum stage or flow for each day
	Daily minimum	Minimum stage or flow for each day
	Daily difference (maximum−minimum)	Difference between the maximum and minimum stage or flows for each day
	Coefficient of variation	Standard deviation for stage or flow for each day/mean daily stage or flow

Table K-1. continued…

Timeframe	Metric	Calculation
Monthly	Monthly mean	Mean stage or flow for each month
	Monthly maximum[a]	Maximum stage or flow for each month
	Monthly minimum[b]	Minimum stage or flow for each month
	Monthly difference (maximum−minimum)	Difference between the maximum and minimum stage or flow values for each month
	High flow magnitude (90^{th} percentile)	90^{th} percentile of monthly stage or flow values; this represents high flows and is similar to the Q_{10} measurement used in DePhilip and Moberg (2013)
	Median magnitude (50^{th} percentile)	50^{th} percentile of monthly stage or flow values; this represents the monthly median
	Low flow magnitude (25^{th} percentile)	25^{th} percentile of monthly stage or flow values; this represents low flows in smaller streams (drainage areas <50 mi^2, per DePhilip and Moberg [2013]) and is similar to the Q_{75} measurement used in DePhilip and Moberg (2013)
	Low flow magnitude (10^{th} percentile)	10^{th} percentile of monthly stage or flow values; this represents low flows in medium to larger-sized streams (drainage areas >50 mi^2 per DePhilip and Moberg [2013]) and is similar to the Q_{90} measurement used in DePhilip and Moberg (2013)
	Extreme low flow magnitude (1^{st} percentile)	1^{st} percentile of monthly stage or flow values; this represents extreme low flows and is similar to the Q_{99} measurement used in DePhilip and Moberg (2013)
	Percentage high flow and floods	Percentage of stage or flow measurements in each month that exceed the monthly 90^{th} percentile
	Percentage low flows	Percentage of stage or flow measurements in each month that are between the monthly 25^{th} and 1^{st} percentiles (similar to the Q_{75} and Q_{99} measurements used in DePhilip and Moberg [2013])
	Percentage typical	Percentage of stage or flow measurements in each month that are between the monthly 25^{th} and 90^{th} percentiles (similar to the Q_{75} and Q_{10} measurements used in DePhilip and Moberg [2013])

Table K-1. continued…

Timeframe	Metric	Calculation
Seasonal	Percentage high flows and floods in spring and fall	Percentage of stage or flow measurements in each month that exceed the monthly 90^{th} percentile in spring (March−May) and fall (September−November)
Annual (January 1−December 31)	Annual mean	Mean of the daily mean stage or flow
	Annual maximum	Maximum stage or flow
	Julian date of annual maximum	Julian date of annual maximum stage or flow
	Annual minimum	Minimum stage or flow
	Julian date of annual minimum	Julian date of annual minimum stage or flow
	Mean annual difference	Mean of the daily difference
	Maximum annual difference	Maximum of the daily difference
	Minimum annual difference	Minimum of the daily difference
	Variance of the annual mean difference	Standard deviation of the daily difference
	Number of zero flow days	Number of days having stage or flow measurements of 0

[a]In Olden and Poff (2003), mean maximum August flow and mean maximum October flow captured important aspects of high flow conditions.

[b]In Olden and Poff (2003), mean minimum April flow captured important aspects of low flow conditions.

K.2. HYDROLOGIC METRICS DERIVED FROM DEPHILIP AND MOBERG (2013) FOR THE UPPER OHIO RIVER BASIN

The Nature Conservancy and several partners (states, river basin commissions, other federal agencies) have developed ecosystem flow needs for some Eastern and Midwestern rivers and their tributaries (e.g., the Susquehanna, the Upper Ohio, and the Potomac Rivers) (DePhilip and Moberg, 2010; Cummins et al., 2010; DePhilip and Moberg, 2013; Buchanan et al., 2013). Table K-2 contains the lists of 10 flow statistics that were chosen to represent the high, seasonal, and low flow components in the Upper Ohio River basin (DePhilip and Moberg, 2013). These statistics were selected because they are easy to calculate, commonly used, and integrate several aspects of the flow regime, including frequency, duration, and magnitude (DePhilip and Moberg, 2013). Diagrams like the one shown in Figure K-1 can be generated for data from RMN sites.

Table K-2. Flow statistics that were selected to track changes to high, seasonal, and low flow components in the Upper Ohio River basin. These are flow exceedance values. For example, Q_{10} equals the 10% exceedance probability (Q_{10}), which represents a high flow that has been exceeded only 10% of all days in the flow period. This is a reproduction of Table 3.2 in DePhilip and Moberg (2013)

Flow component	Flow statistic
High flows	
***Annual/interannual (≥bankfull*)**	
Large flood	Magnitude and frequency of 20-year flood
Small flood	Magnitude and frequency of 5-year flood
Bankfull	Magnitude and frequency of 1- to 2-year high flow event
***High flow pulses (<bankfull*)**	
Frequency of high flow pulses	Number of events > monthly Q_{10} in spring and fall
High pulse magnitude	Monthly Q_{10}
Seasonal flows	
Monthly magnitude	Monthly median
Typical monthly range	Area under monthly flow duration curve between Q_{75} and Q_{10} (or some part of this range)
Low flows	
Monthly low flow range	Area under monthly flow duration curve between Q_{75} and Q_{99}
Monthly low flow magnitude	Monthly Q_{75}
	Monthly Q_{90}

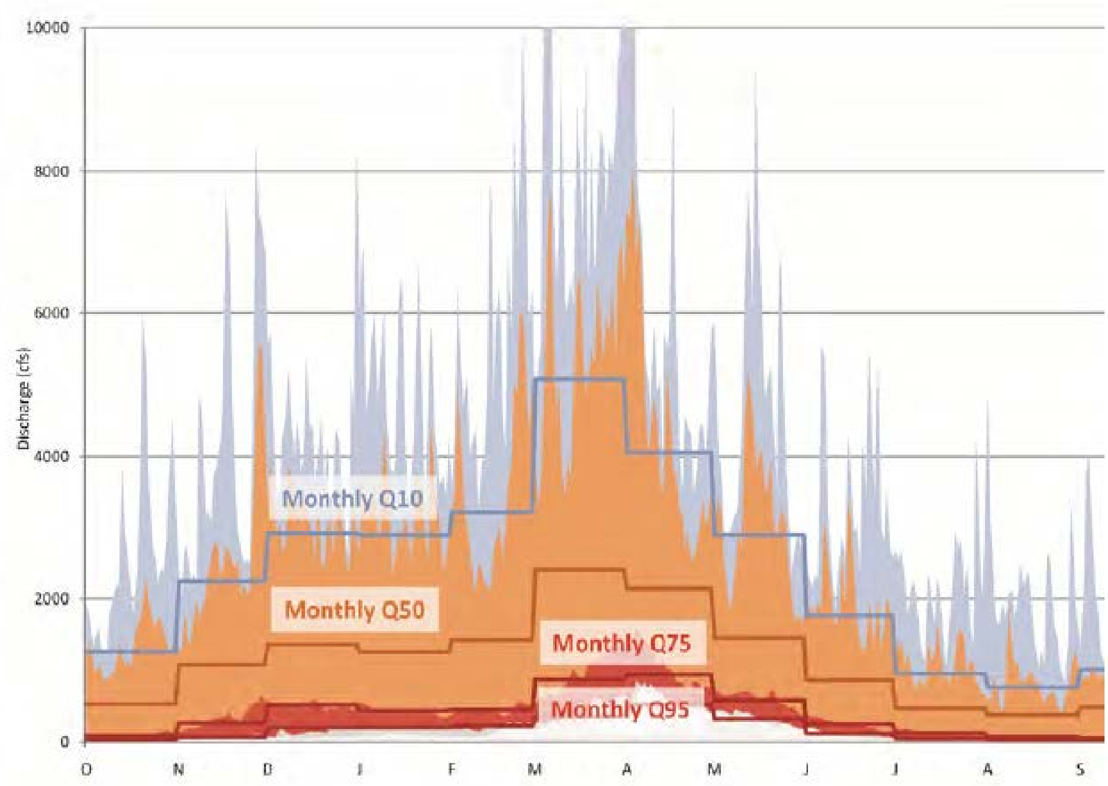


Figure K-1. In the Upper Ohio River basin, monthly flow exceedance values (Q_{ex}) were plotted against daily discharges to highlight specific portions of the hydrograph and facilitate discussions about the ecological importance of each portion (from DePhilip and Moberg, 2013).

K.3. HYDROLOGIC METRICS DERIVED FROM OLDEN AND POFF (2003)

Olden and Poff (2003) did a comprehensive review of 171 hydrologic metrics, including Indicators of Hydrologic Alteration. They provided recommendations on a reduced set of metrics that capture critical aspects of the hydrologic regime, are not overly redundant, and are ecologically meaningful in different types of streams. Table K-3 contains a list of 34 metrics that, based on their analyses, effectively capture different aspects of flow regimes in all stream types and have limited redundancy.

Table K-3. Based on analyses done by Olden and Poff (2003), these 34 hydrologic flow statistics effectively capture different aspects of the flow regime in all stream types and have limited redundancy. This is a reproduction of Table 3 (all streams) in Olden and Poff (2003)

Category	Metric	Description	Abbreviated metric
Magnitude—average flow conditions	Skewness in daily flows	Mean daily flows divided by median daily flows	Ma5
	Mean annual runoff	Mean annual flow divided by catchment area	Ma41
	Variability in daily flows 1	Coefficient of variation in daily flows	Ma3
	Spreads in daily flows	Ranges in daily flows ($25^{th}/75^{th}$ percentiles) divided by median daily flows	Ma11
Magnitude—low flow conditions	Baseflow index 1	7-day minimum flow divided by mean annual daily flows averaged across all years	Ml17
	Mean minimum April flow	Mean minimum monthly flow in April	Ml4
	Variability across annual minimum flows	Coefficient of variation in annual minimum flows averaged across all years	Ml21
	Variability in baseflow index 1	Coefficient of variation in baseflow index (Ml17)	Ml18

Table K-3. continued…

Category	Metric	Description	Abbreviated metric
Magnitude—high flow conditions	High flow discharge	Mean of the 10^{th} percentile from the flow duration curve divided by median daily flow across all years	Mh16
	Mean maximum August flow	Mean maximum monthly flow in August	Mh8
	Mean maximum October flow	Mean maximum monthly flow in October	Mh10
	Median of annual maximum flows	Median of the highest annual daily flow divided by the median annual daily flow averaged across all years	Mh14
Frequency of flow events—low flow conditions	Frequency of low flow spells	Total number of low flow spells (threshold equal to 5% of mean daily flow) divided by record length in years	Fl3
	Variability in low flow pulse count	Coefficient of variation in Fl1	Fl2
	Low flow pulse count	Number of annual occurrences during which the magnitude of flow remains below a lower threshold. Hydrologic pulses are defined as those periods within a year in which the flow drops below the 25^{th} percentile (low pulse) of all daily values for the time period.	Fl1

Table K-3. continued…

Category	Metric	Description	Abbreviated metric
Frequency of flow events—high flow conditions	High flood pulse count 2	Number of annual occurrences during which the magnitude of flow remains above an upper threshold. Hydrologic pulses are defined as those periods within a year in which the flow goes above three times the median daily flow and the value is an average instead of a tabulated count.	Fh3
	Flood frequency	Mean number of high flow events per year using an upper threshold of three times median flow over all years	Fh6
	Flood frequency	Mean number of high flow events per year using an upper threshold of seven times median flow over all years	Fh7
	Variability in high flood pulse count	Coefficient of variation in high pulse count (defined as 75th percentile)	Fh2
Duration	Number of zero flow days	Mean annual number of days having zero daily flow	Dl18
	Variability in low flow pulse duration	Coefficient of variation in low flow pulse duration	Dl17
	Low flow pulse duration	Mean duration of Fl1	Dl16
	Means of 30-day minimum daily discharge	Mean annual 30-day minimum divided by median flow	Dl13
	Means of 30-day maximum daily discharge	Mean annual 30-day maximum divided by median flow	Dh13
	Variability in high flow pulse duration	Coefficient of variation in Fh1	Dh16
	High flow duration	Upper threshold is defined as the 75th percentile of median flows	Dh20
	High flow pulse duration	Mean duration of Fh1	Dh15

Table K-3. continued…

Category	Metric	Description	Abbreviated metric
Timing of flow events	Constancy	See Colwell (1974)	Ta1
	Seasonal predictability of nonflooding	Maximum proportion of the year (number of days/365) during which no floods have ever occurred over the period of record	Th3
	Variability in Julian date of annual minimum	Coefficient of variation in Tl1	Tl2
Rate of change	Variability in reversals	Coefficient of variation in Ra8	Ra9
	Reversals	Number of negative and positive changes in water conditions from 1 day to the next	Ra8
	Change of flow	Median of difference between natural logarithm of flows between 2 consecutive days with increasing/decreasing flow	Ra6
	No day rises	Ratio of days where flow is higher than the previous day	Ra5

K.4. HYDROLOGIC METRICS USED BY HAWKINS ET AL. (2013)

Hawkins et al. (2013) used an iterative process to identify 16 streamflow variables that, in their judgment, could characterize those general aspects of streamflow regimes relevant to stream ecosystem structure and function. These variables are listed in Table K-4.

Table K-4. These 16 streamflow variables were selected by Hawkins et al. (2013) to quantify aspects of hydrologic regimes believed to be important to stream biota

Metrics
Extended low flow index (ELFI); this equals BFI—ZDF, where BFI is the baseflow index (ratio of the minimum daily flow in any year to the mean annual flow) and ZDF is the zero day fraction
CV of daily flows (DAYCV)
Contingency (M)
Number of low flow events (LFE)
Number of zero flow events (ZFE)
Mean 7-day minimum flow ($Q_{min}7$)
Mean daily discharge (QMEAN)
Mean bankfull flow (Q167)
Mean 7-day maximum flow ($Q_{max}7$)
Flow reversals (R)
Flood duration (FLDDUR)
Number of high flow events (HFE)
Day of year of 50% of flow (T50)
Day of year of peak flow (Tp)
Predictability (P)
Constancy (C)

K.5. TOOLS FOR ESTIMATING STREAMFLOW AT UNGAGED SITES

Table K-5. Examples of tools for estimating streamflow and/or streamflow statistics at ungaged sites. A similar tool is currently being developed for New York

Tool	Geographic area	Website	Description
USGS StreamStats[1]	Varies by state	http://water.usgs.gov/osw/streamstats/	Available for most but not all states in the eastern United States. The types of output statistics that are available vary by state. These statistics represent long-term averages and do not capture year-to-year variability.
BaSE (Stuckey et al., 2012)	Pennsylvania	http://pubs.usgs.gov/sir/2012/5142/	This tool simulates minimally altered streamflow at a daily time scale for ungaged streams in Pennsylvania using data collected during water years 1960−2008. It is free, publicly available, and uses a point-and-click interface.
MA SYE (Archfield et al., 2010)	Massachusetts	http://pubs.usgs.gov/sir/2009/5227/	The MA SYE can estimate a daily time series of unregulated, daily mean streamflow for a 44-year period of record spanning 1960 to 2004.
West Virginia DEP 7Q10 Report Tool (Shank, 2011)	West Virginia	http://tagis.dep.wv.gov/streamflow/	This free, publicly available tool utilizes a point-and-click interface. Seven Q_{10}, annual and monthly flow estimates are generated when you click on a location.

[1]http://water.usgs.gov/osw/streamstats/

USGS = U.S. Geological Survey; BaSE = Baseline Streamflow Estimator; MA SYE = Massachusetts Sustainable Yield Estimator; DEP = Department of Environmental Protection

K.6. REFERENCES

Archfield, SA; Vogel, RM; Steeves, PA; Brandt, SL: Weiskel, PK; Garabedian, SP. (2010) The Massachusetts sustainable-yield estimator: A decision-support tool to assess water availability at ungaged stream locations in Massachusetts. [USGS Scientific Investigations Report 2009−5227]. Northborough, MA: Massachusetts-Rhode Island Water Science Center, U.S. Geological Survey. 41 pp. Available online: http://pubs.usgs.gov/sir/2009/5227/.

Buchanan, C; Moltz, HLN; Haywood, HC; Palmer, JB; Griggs, AN. (2013) A test of The Ecological Limits of Hydrologic Alteration (ELOHA) method for determining environmental flows in the Potomac River basin, U.S.A. Freshw Biol 58(12):2632−2647.

Colwell RK. (1974) Predictability, constancy, and contingency of periodic phenomena. Ecol. 55:1148–1153.

Cummins, J; Buchanan, C; Haywood, HC; Moltz, H; Griggs, A; Jones, C; Kraus, R; Hitt, NP; R. Bumgardner, R. (2010). Potomac large river ecologically sustainable water management report. [ICPRB Report 10-3]. Interstate Commission on the Potomac River Basin for The Nature Conservancy. Available online at www.potomacriver.org/pubs.

DePhilip, M; Moberg, T. (2010) Ecosystem flow recommendations for the Susquehanna River Basin. Harrisburg, PA: The Nature Conservancy. Available online at http://www.srbc.net/policies/docs/TNCFinalSusquehannaRiverEcosystemFlowsStudyReport_Nov10_20120327_fs135148v1.PDF

DePhilip, M; Moberg, T. (2013). Ecosystem flow recommendations for the Upper Ohio River basin in western Pennsylvania. Harrisburg, PA: The Nature Conservancy.

Hawkins, CP; Tarboton, DG; Jin, J. (2013) Consequences of global climate change for stream biodiversity and implications for the application and interpretation of biological indicators of aquatic ecosystem condition. Final Report. [EPA Agreement Number: RD834186]. Logan Utah: Utah State University. http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/9063

Olden, JD; Poff, NL. (2003) Redundancy and the choice of hydrologic indices for characterizing streamflow regimes. River Res Appl 19:101−121.

Stuckey, MH; Koerkle, EH; Ulrich, J. (2012) Estimation of baseline daily mean streamflows for ungagged location on Pennsylvania streams, water years 1960-2008. [USGS Scientific Investigations Report 2012-5142]. New Cumberland, PA: U.S. Geological Survey. Available online at http://pubs.usgs.gov/sir/2012/5142/.

Shank, M. (2011) West Virginia DEP 7Q10 report tool [web page]. Accessed 1 August 2014. Available online at http://tagis.dep.wv.gov/7q10/.

SCIENCE

EPA
United States
Environmental Protection
Agency

National Center for Environmental Assessment
Office of Research and Development
Washington, DC 20460

Official Business
Penalty for Private Use
$300

Printed on 100% recycled/recyclable paper
with a minimum 50% post-consumer
fiber using vegetable-based ink.