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Regional Monitoring Networks to Detect Climate Change Effects in Stream Ecosystems

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) is working with its regional offices, states, tribes, and other organizations to establish regional monitoring networks (RMNs) at which biological, thermal, and hydrologic data will be collected from freshwater wadeable streams to quantify and monitor changes in baseline conditions, including climate change effects. RMNs have been established in the Northeast, Mid-Atlantic, and Southeast, and efforts are expanding into other regions. The need for RMNs stems from the lack of long-term, contemporaneous biological, thermal, and hydrologic data, particularly at minimally disturbed sites. Data collected at RMNs will be used to detect temporal trends; investigate relationships between biological, thermal, and hydrologic data; explore ecosystem responses and recovery from extreme weather events; test hypotheses and predictive models related to climate change; and quantify natural variability. RMN surveys build on existing bioassessment efforts, with the goal of collecting comparable data that can be pooled efficiently at a regional level. This document describes the development of the current RMNs for riffle-dominated, freshwater wadeable streams. It contains information on selection of candidate sites, expectations for data collection, the rationale for collecting these data, and provides examples of how the RMN data will be used and analyzed.

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LIST OF ABBREVIATIONS

AMAAB	Association of Mid-Atlantic Aquatic Biologists Workshop
BaSE	Baseline Streamflow Estimator
BCG	biological condition gradient
BIBI	MD DNR's index of biotic integrity for benthic macroinvertebrates
CT DEEP	Connecticut Department of Energy and Environmental Protection
E	expected
ELOHA	ecological limits of hydrologic alteration
EPT	Ephemeroptera, Plecoptera, and Trichoptera
FIBI	MD DNR's index of biotic integrity for fish
GIS	Geographic Information System
GPS	Global Positioning System
MA DEP	Massachusetts Department of Environmental Protection
MA SYE	Massachusetts Sustainable-Yield Estimator
MD DNR	Maryland Department of Natural Resources
MMI	multimetric index
NARS	EPA National Aquatic Resource Surveys
NC DENR	North Carolina Department of Environmental and Natural Resources
NEAEB	New England Association of Environmental Biologists
NLCD	National Land Cover Database
NMDS	nonmetric multidimensional scaling
NRSA	National Rivers and Streams Assessment
NWQMC	National Water Quality Monitoring Conference
O	observed
OCH	Odonata, Coleoptera, Hemiptera
OTU	operational taxonomic units
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
RBC	river basin commission
RBP	rapid bioassessment protocols
RIFLS	River Instream Flow Stewards Program
RMN	regional monitoring network
RIFLS	River Instream Flow Stewards Program
SDM	species distribution model
SON	September/October/November
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, CONTRIBUTORS, AND REVIEWERS

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) has been working with its regional offices, states, tribes, river basin commissions (RBCs), and other organizations in the Northeast, Mid-Atlantic, and Southeast regions to establish regional monitoring networks (RMNs) at which biological, thermal, hydrologic, physical habitat, and water chemistry data are being collected contemporaneously from freshwater wadeable streams. RMN surveys build on existing bioassessment efforts, with the goal of collecting comparable data that can be pooled efficiently at a regional level. This document describes the development of RMNs in the Northeast, Mid-Atlantic, and Southeast for riffle-dominated, freshwater wadeable streams. It contains information on the selection process for candidate sites, describes expectations and recommendations for data collection and quality assurance/quality control procedures, discusses the rationale for collecting these data, and provides examples of how the RMN data will be used and analyzed. It concludes with a discussion on how these efforts can be expanded to other regions and water body types.

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, fish, and periphyton if resources permit (fish are considered higher priority)
- **Temperature:** continuous water and air temperature (30-minute intervals)
- **Hydrological:** continuous water-level (stage) data (15-minute intervals); converted to streamflow via stage-discharge rating curve development if resources permit
- **Habitat:** qualitative visual habitat measures (e.g., EPA rapid bioassessment protocols); quantitative measures if resources permit (e.g., EPA National Rivers and Streams Assessment methods)
- **Water chemistry:** In situ, instantaneous water chemistry parameters (e.g., specific conductivity, dissolved oxygen, pH); additional or more comprehensive water chemistry measures if resources permit

Top priorities of the RMNs are to collect uninterrupted, long-term biological, thermal, and hydrologic data at primary RMN sites, as well as utilize and build upon data already being collected by states, tribes, RBCs, and other organizations. Data collected can serve many purposes, and will be used to:

- Detect temporal trends in biological, thermal, hydrologic, habitat, and water chemistry data;
- Investigate and resolve relationships between biological, thermal, and hydrologic data;
- Examine how organisms respond and recover from extreme weather events;
- Test hypotheses and predictive models related to climate change; and
  Quantify natural variability.

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). The working groups selected RMN sites using consistent criteria and selected appropriate data-collection protocols and methodologies. As part of this process, working groups considered the site-selection criteria and methods being used in the other regions and tried to use 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. Concurrently, EPA held discussions with RMN members about data collection practices (e.g., continuous temperature and flow monitoring protocols) and infrastructure needs (e.g., data storage and sharing). Working groups have begun implementing the RMNs in the three regions and will continue to collect status updates on sampling activities; discuss potential changes to data-collection and processing recommendations; pursue resources to assist with logistical, training, equipment, and data infrastructure needs; seek additional partners; and ensure that the goals of the RMN are being met.

RMN sampling efforts revolve around a core group of “primary” sites. Primary sites are consistent with the RMN site selection criteria and build upon data already being collected by states, tribes, RBCs, and others. Site selection considerations include: level of anthropogenic disturbance; length of historical sampling record for biological, thermal, or hydrological data; environmental conditions; biological community; accessibility; potential for collaboration or partnerships with other organizations (e.g., colocation with a USGS gage); and level of protection from future anthropogenic disturbance. Results from a broad-scale climate change vulnerability assessment conducted by EPA were also considered, with preference given to sites that rated moderately or most vulnerable to one or more exposure scenarios (increasing temperatures, increased frequency and severity of extreme precipitation events, and increased summer low flow events). The working groups selected 2 to 15 sites per state (depending on the size of the state and availability of resources), with the overall goal of sampling at least 30 sites (either within or across regions) that have comparable environmental conditions and biological communities. Analyses suggest that significant climate-related trends in regional community composition can be detected within 10−20 years if 30 or more comparable sites are monitored regularly.

Most primary RMN sites have minimal or low levels of upstream human-related disturbance. In this document these types of sites are referred to as “reference” sites. Reference sites are targeted because bioassessment programs depend on comparisons to conditions at sites that most closely approximate natural conditions. It is critical to track changes at these sites over time to understand how benchmarks may shift in response to environmental factors, such as climate change. For example, streams that were once perennial could 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. There is a higher likelihood of being able to characterize climate-related impacts when other non-climatic stressors are absent.

Data from additional, “secondary,” sites are also being considered for the RMNs. These are sites where biological data are already being collected annually or biannually as part of other independent monitoring efforts. In some cases, continuous temperature or hydrologic data are being collected as well. Secondary RMN sites generally have higher levels of anthropogenic disturbance, and data from these non-reference sites can be used to evaluate how the effects of climate change interact with other human-related factors like urbanization. Data from secondary sites will also increase the sample size and range of conditions represented in the RMN data set, which will be useful for testing predictive models and hypotheses about the vulnerability of taxa and watersheds to climate change. In addition, secondary sites may provide information about unique or underrepresented geographic areas, such as the New Jersey Pine Barrens or the Coastal Plain ecoregion.

Limited resources are available to implement the RMNs, and efforts are being made to integrate RMN data collection flexibly within existing monitoring programs. To address the challenges of creating regionally consistent data, EPA has developed recommendations on best practices for data collection and has established different levels of rigor for data collected at RMN sites. The RMN framework, therefore, accommodates data collected with different sampling frequencies and methodologies. The goal is to set up a data sharing system that allows users to see what data are being collected at each site and the data quality (i.e., level of rigor used, as categorized in this report) so that users can select the data that meet their needs.

This document should be reevaluated and updated periodically as data are collected and analyzed to ensure that the objectives of the RMNs are being met. The Northeast, Mid-Atlantic, and Southeast RMNs are the pilot studies upon which the RMN framework is based and whose data will be used in initial evaluations and data analyses. Other regions interested in establishing an RMN can build upon and improve these efforts. While the current focus is on states, tribes, and RBCs, collaboration and partnerships with other organizations, such as academia and volunteer monitoring groups, is encouraged as a way to make the networks more robust.

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 (see Figure 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, 2012). During these studies, a lack of long-term, contemporaneous biological, thermal, and hydrologic data became apparent, particularly at minimally disturbed 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), which endorsed the establishment of a collaborative, multipurpose, multiagency national network of reference watersheds and monitoring sites for freshwater streams in the United States for this purpose (NWQMC, 2011).

Given these needs, the top priorities of the RMNs are to collect uninterrupted, long-term biological, thermal, and hydrologic data at primary RMN sites to the extent possible, and to utilize and build upon data already collected. A number of 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 and integrate the RMNs surveys into programs like these. Coordinating and pooling resources at the regional level is especially important as program resources have become increasingly limited.

Data collected from RMN sites can be used to:

- Detect temporal trends in biological, thermal, hydrologic, habitat, and water chemistry data;
- Investigate and resolve relationships between biological, thermal, and hydrologic data;
- Examine how organisms respond and recover from extreme weather events;
- Test hypotheses and predictive models related to climate change; and
- Quantify natural variability.

This document describes the development of RMNs in the Northeast, Mid-Atlantic, and Southeast regions for riffle-dominated, freshwater wadeable streams. It contains information on the selection process for candidate sites, describes expectations and recommendations for data collection and quality assurance/quality control (QA/QC) procedures, discusses the rationale for collecting these data, and provides examples of how the RMN data will be used and analyzed. It concludes with a discussion on how these efforts can be expanded to other regions and water body types in the future. New data collected and analyzed over time will begin to fulfill the purpose of the RMNs.

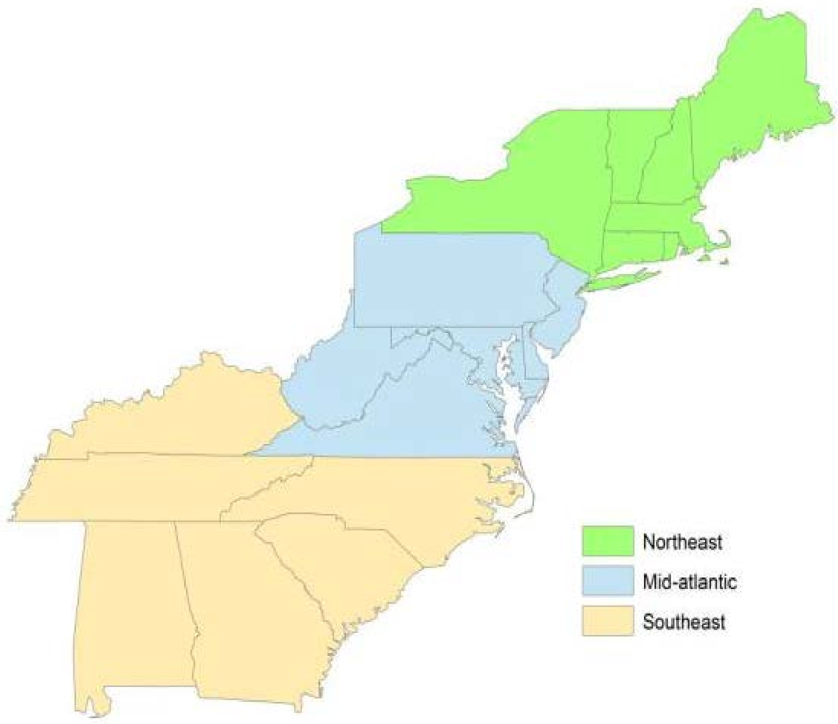

Figure 1. States, tribes, river basin commissions (RBCs), and others in three regions (Northeast, Mid-Atlantic, and Southeast) are working to set up regional monitoring networks (RMNs).

2. METHODOLOGY

Section 2.1 contains a description of RMN development, while Section 2.2 describes site selection. Appendix A contains lists of working group members in the Northeast, Mid-Atlantic, and Southeast regions.

2.1. 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 2.2), and selected appropriate data-collection protocols and methodologies. 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. Concurrently, EPA held discussions with RMN members about data collection practices (e.g., continuous temperature and flow monitoring protocols) and infrastructure needs (e.g., data storage and sharing). Working groups have begun implementing the RMNs in the three regions and will continue to collect status updates on sampling activities; discuss potential changes to data collection and processing recommendations; pursue resources to assist with logistical, training, equipment, and data infrastructure needs; seek additional partners; and ensure the goals of the RMN are being met. Appendix B includes a step-by-step checklist on the process for developing RMNs.

2.2. SITE SELECTION

RMN sampling efforts revolve around a core group of "primary" sites. The working groups selected 2 to 15 primary RMN sites per state (depending on the size of the state and availability of resources), with the overall goal of sampling at least 30 sites (either within or across regions) that have comparable environmental conditions and biological communities. Analyses suggest that significant climate-related trends in regional community composition can be detected within 10−20 years if 30 or more comparable sites are monitored regularly (Bierwagen et al., *in review*). Appendix C lists the candidate primary RMN sites in each region.

Primary sites were selected to utilize and build upon data already being collected by states, tribes, RBCs, and others (see Table 1). For example, 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 (see Table 1). Ways to integrate these survey efforts into national monitoring networks, such as the EPA National Aquatic Resource Surveys (NARS) program and the NWQMC (NWQMC, 2011), have also been considered.

During the site selection process, efforts were made to select primary RMN sites with minimal or low levels of upstream anthropogenic disturbance (see Table 1). In this document these types of sites are referred to as "reference" sites. Members of the regional working groups screened the initial list of sites by evaluating factors like the likelihood of impacts from land use disturbance, dams, mines, and point-source pollution sites. Subsequently, we developed a standardized procedure for characterizing the present-day level of anthropogenic disturbance and applied this across RMNs. Sites from all states and regions were rated on a common scale (see Appendix D), similar to the scale used for the Biological Condition Gradient (BCG) (Davies and Jackson, 2006).

In addition to assessing current levels of disturbance at the candidate RMN sites, EPA and the regional working groups evaluated the potential for future development in the watersheds. This was done by evaluating a spatial data set provided by The Nature Conservancy (TNC)[1] that showed public and private lands and waters secured by a conservation agreement. In addition, some 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. 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.

The regional working groups selected candidate RMN sites that are located in freshwater wadeable streams with rocky substrates and riffle habitat (see Table 1). Existing state and regional classification frameworks for macroinvertebrate assemblages were also considered. For example, the Southeast working group used ecoregions during the initial site selection process because they 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. To inform site selection, we performed a broad-scale classification analysis on macroinvertebrate survey data from the EPA NARS program[2] to reduce natural variability and improve our power to detect long-term trends (Bierwagen et al., *in review*). 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. We 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) colder temperature, faster water; (2) small, low gradient; and (3) warmer temperature, larger lower gradient. Using this analysis, most of the primary RMN sites fell within the colder temperature, faster flow class, which is expected given that sites in this class are generally located in areas with lower levels of human-related disturbance. A goal of the RMNs is to sample at least 30 colder temperature, faster flow sites (either within or across regions; see Table 1).

Because one of the RMN objectives is to detect climate change effects on macroinvertebrate communities, efforts were made to select sites that we hypothesized to be vulnerable to climate change. To assess potential vulnerability we considered three exposure scenarios relevant to aquatic life condition: increasing temperatures, increasing frequency and magnitude of extreme precipitation events, and increasing frequency of summer low flow events. Watersheds were assigned a vulnerability rating (least, moderate, or most vulnerable) for each exposure scenario. Sites that were assigned to the moderate or most vulnerable category for at least one of the scenarios were preferred. As our understanding of climate change impacts evolves, the data collected from these RMN sites will be used to test and refine regional vulnerability hypotheses over time.

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

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. This may improve the quality of data being collected (particularly the hydrologic data). Working groups are also seeking opportunities for partnership or collaboration with outside organizations (e.g., academia, volunteer monitoring groups) to increase the viability and robustness of the network.

Table 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.
Potential for future disturbance	Located in watersheds that are protected from future development.
Sampling record	Lengthy historical sampling record for biological, thermal, or hydrological data.
Equipment	Colocated with existing equipment (e.g., USGS gage, weather station).
Broad-scale classification	Freshwater wadeable streams with rocky substrates and riffle habitat. At least 30 sites (within or across regions) should fall within EPA's broad-scale colder temperature, faster water class.
Sustainability	Accessible (e.g., day trip), opportunities to share the workload with outside agencies or organizations.
Climate change vulnerability	Rated as moderately or most vulnerable to at least one of the exposure scenarios: increasing temperatures, increased frequency and severity of extreme precipitation events, and increased summer low flow events.

Data from additional, "secondary," sites are also being considered for the RMNs. These are sites at which biological data are already being collected annually or biannually as part of other independent monitoring efforts. In some cases, continuous temperature or hydrologic data are being collected as well (if thermal and hydrologic data are not being collected, the priority is to install the equipment at the primary RMN sites first, then at secondary RMN sites). Secondary RMN sites generally have higher levels of anthropogenic disturbance than primary sites, and data from these non-reference sites can be used to investigate how climate change interacts with other human-related factors like urbanization. Data from secondary sites will also increase the sample size and range of conditions represented in the RMN data set, which will be useful for testing predictive models and hypotheses about the vulnerability of taxa and watersheds to climate change. In addition, secondary sites 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.

In summary, the site selection process for the RMNs is a balancing act that takes into account several considerations. The overall goal is to sample at least 30 comparable sites either within or across regions. Reference sites are being targeted because bioassessment programs depend on comparisons to conditions at sites that most closely approximate natural conditions. It is critical to track changes at reference sites over time to understand how reference-condition benchmarks may shift in response to environmental factors, such as climate change. 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. These sites are more likely to characterize climate-related impacts when other non-climatic stressors are absent.

Because of the limited funding for RMN implementation, RMN survey designs must be balanced with practical considerations. For example, some of the primary RMN sites have higher than desired levels of disturbance but have lengthy historical records, are part of existing monitoring networks, or have existing equipment like a USGS gage. As part of making long-term monitoring consistent and sustainable, these types of considerations play necessary and important roles in site selection.

3. DATA COLLECTION

Efforts are being made to collect the following types of data from RMN sites in the Northeast, Mid-Atlantic, and Southeast regions:

- **Biological indicators:** macroinvertebrates, fish, and periphyton if resources permit (fish are considered 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:** qualitative visual habitat measures [e.g., EPA rapid bioassessment protocols (RBP)]; quantitative measures if resources permit [e.g., EPA National Rivers and Streams Assessment (NRSA) methods].
- **Water chemistry:** In situ, instantaneous water chemistry parameters (specific conductivity, dissolved oxygen, pH); additional or more comprehensive water chemistry measures if resources permit
- **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.

To the extent possible, collecting uninterrupted, long-term biological, temperature, and hydrologic data at primary RMN sites is the priority. Analyses by Bierwagen et al. (*in review*) show that well-designed networks of 30 sites monitored consistently can detect underlying changes of 1−2% per year in a variety of biological metrics within 10−20 years. However, trend detection in the thermal and hydrologic data may take longer. Stable estimates of climatic conditions are typically based on 30-year averages (Stager and Thill, 2010), although some researchers argue that alternate time scales may be more appropriate if climate conditions are rapidly changing (e.g., Arguez and Vose, 2011). The long-term data from RMN sites will substantially enhance our ability to characterize temporal trends and attribute them to climate change or distinguish climate trends from other stressors. While trend detection will require longer term data sets, other analyses, such as thermal and hydrologic indicator analyses and the quantification of temperature and flow regimes, can be completed after only a few years of data collection.

Limited resources are available to implement the RMNs, and efforts are being made to integrate RMN data collection flexibly within existing monitoring programs. The RMN framework accommodates data collected at different sampling frequencies and methodologies. For example, for the Mid-Atlantic RMN, species-level identifications for macroinvertebrates for Spring and Fall sampling periods have been combined with genus-level identifications generally performed for these RMN sites on samples collected once a year. In some cases, RMNs can accommodate differences in sampling methodologies (for macroinvertebrate data in particular) within or across regions, while still providing data to generate comparable indicators. Different methodologies, especially gear and subsampling procedures, affect community measures, may introduce biases in analyses, and contribute to variability, which reduces the sensitivity of indicators (Bierwagen et al., *in review*). It is important that these differences be minimized when possible so that comparable data can be generated within and across regions.

To help minimize biases and variability in the data, we developed recommendations in collaboration with the regional working groups on best practices for the collection of biological, thermal, hydrologic, physical habitat, and water chemistry data at RMN sites (see Sections 3.1 through 3.7). Sampling methodologies are broken 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 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 2). Level 3 is the target for primary RMN sites. This framework is consistent with the EPA critical elements process, in which different technical components of biological assessment programs are assigned different levels of rigor (U.S. EPA, 2013a).

These guidelines are general. For example, one recommendation is to use kick nets for macroinvertebrate collection, but there are no specifics on mesh size or frame type. It is up to the regional working groups to work out these details. Appendix F (see Table F-1) describes the specific protocols that were agreed upon by the regional working groups in the Northeast, Mid-Atlantic, and Southeast regions. The goal is to collect comparable data that meets the desired level or rigor (level 3 or 4) from at least 30 colder temperature, higher flow sites within or across regions.

Table 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.

3.1. BIOLOGICAL INDICATORS

At a minimum, macroinvertebrates should be collected at the primary RMN sites. Collections from this assemblage are central to the RMNs because they 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) they are easily and consistently identified, and (3) they have limited mobility, short life cycles, and are highly diverse. Collection of fish and periphyton data is also encouraged, as resources permit. Fish are higher priority than periphyton because they are collected more frequently, their taxonomy is better established, many species are economically and socially important (e.g., trout), and there is widespread interest in predicting and monitoring climate change effects on fish species (e.g., Clark et al., 2001; Flebbe et al., 2006; Trumbo, 2010; Wenger et al., 2011). Guidelines for collecting macroinvertebrates, fish, and periphyton can be found in Sections 3.1.1, 3.1.2, and 3.1.3, respectively.

Biological sampling should be conducted annually (see Table 3). Compared to less frequent sampling, annual sampling can detect changes in climate-sensitive biological indicators sooner (Bierwagen et al., *in review*). Annual data is also important for quantifying natural variability in biological conditions, such as the stability and persistence of taxa, and can be used to document how organisms respond to and recover from extreme weather events like heat waves, droughts, and floods, which are projected to increase in frequency with climate change (Karl et al., 2009). If biological data are only collected once every 5 years, which typically occurs in rotating designs that focus on adequate spatial coverage, taxon- and community-level responses to key events may be missed or confounded with impacts from other years.

Data collection should be done by trained personnel (see Table 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 (see Appendix F, Table F-1). 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. 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)
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)
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***	Work is conducted by a trained biologist who is experienced at collecting aquatic macroinvertebrates
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

3.1.1. 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. An overall goal of the RMNs is to generate data that are comparable both within and across the regions.

At primary RMN sites, macroinvertebrate samples should be collected in reaches with abundant riffle habitat (see Table 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, 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 4. Recommendations on best practices for collecting macroinvertebrate data at 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)
Habitat	No riffle habitat	Multi-habitat composite from a sampling reach with scarce riffle habitat	***Abundant riffle habitat***	Multi-habitat 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
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

Table 4. continued…

Component	1 (lowest)	2	3	4 (highest)
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

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 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.

States and RBCs in the Mid-Atlantic region 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 region, the spring index period is preferred because many of the spring-emerging organisms (e.g., Ephemeroptera and Plecoptera) considered to be good cool/cold water indicators may not be present or easily collected in summer index periods. In the Northeast region, 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 region, macroinvertebrate samples are being collected in April, with some states adding a September sample.

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 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 not ubiquitous and to improve the chances of detecting declines in richness (Bierwagen et al., *in review*). 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-count samples to those lower targets.

Taxa collected at primary RMN sites should be identified to the lowest practical taxonomic level (see Table 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, 2012). Following these recommendations will increase the chances of detecting temperature-related signals 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 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. Although some inconsistencies are likely to occur, large differences in methodologies across organizations can create substantial biases in biological metrics (see Section 4.1, Table 7), which will add variability and reduce the sensitivity of indicators (Bierwagen et al., *in review*). Reduced counts and coarser level identifications, in particular, are likely to affect the richness metrics (Stamp and Gerritsen, 2009), but we currently lack the data needed to quantify exactly how much of an effect these differences would have on biological measures at RMN sites.

If RMN members lack sufficient resources to count 300 organisms and perform species-level identifications, we encourage them to collect a sample using the collection method agreed upon by the regional working group and to retain this sample, in hopes that funds can eventually be obtained to process the samples and perform a 300-organism count. RMN members should periodically refresh these samples with preserving agent so that specimens remain in good enough condition to later be identified. Regional coordinators can also seek funding to cover the costs of macroinvertebrate sample processing and species-level identifications at a common laboratory, at least for 1 year to establish valuable baseline information. For example, EPA Region 3 was able to achieve this during the 2014 sampling season for the Mid-Atlantic RMN members.

If the RMN protocols differ from those that are normally used by RMN members, RMN members could consider conducting a methods comparison study, at least at a subset of sites. There are a number of different possibilities for how to conduct comparison studies. For example, RMN members can collect side-by-side samples with routine and RMN protocols. After paired samples are processed with their respective methods, results can be compared and differences between the methods quantified.

3.1.2. 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. The public and 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.

3.1.3. 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. 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 recently 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 5). In some cases, air temperature data are being recorded by an on-land pressure transducer (versus a stand-alone temperature sensor). Readings from both temperature sensors combined can be used to track responsiveness of stream temperatures to air temperatures and provide insights into the factors that influence the vulnerability or buffering capacity of streams to thermal change. Air temperature readings are also important for quality control (e.g., to determine when water temperature sensors are dewatered) (Bilhimer and Stohr, 2009; Sowder and Steel, 2012).

Table 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
Pre-deployment	No accuracy checks are performed	An accuracy check is performed, but it does not meet all of the recommendations described in Appendix H	***An accuracy check is performed in accordance with the recommendations described in Appendix H***	An accuracy check that is more stringent than the protocols described in Appendix H is performed

Table 5. continued…

Component	1 (lowest)	2	3	4 (highest)
Mid-deployment	No mid-deployment checks are performed	Mid-deployment checks are performed but the protocols do not meet all of the recommendations described in Appendix H	***Mid-deployment checks are performed in accordance with the recommendations described in Appendix H***	Mid-deployment checks that are more stringent than those described in Appendix H are performed
Post-retrieval	No post-retrieval QA/QC procedures are performed	Post-retrieval QA/QC checks are performed but the protocols do not meet all of the recommendations described in Appendix H	***Post-retrieval QA/QC checks are performed in accordance with the recommendations described in Appendix H***	Post-retrieval QA/QC checks that are more stringent than those described in Appendix H are performed

Temperature measurements should be taken year-round at 30-minute intervals (see Table 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 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 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, predeployment, mid-deployment and postretrieval QA/QC checks should be performed in accordance with the guidelines described in Appendix H (see Table 5). These checks are important because sensors may record erroneous readings during deployment for a variety of reasons. For example, sensors may become dewatered or buried in silt in low or high flow conditions or may malfunction because of human interference.

3.3. 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 gauges 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 will be necessary to collect independent hydrologic data at most RMN sites.

A common way to collect hydrologic data at ungaged sites is with pressure transducers, but these devices can pose challenges. For one, pressure transducers are more expensive than the temperature sensors, and some organizations have been unable to find funds to purchase the transducers. Those that have been successful at obtaining transducers may lack the expertise and staff needed to install and operate the equipment. In addition, they may lack the resources needed to conduct mid-deployment and post-retrieval QA/QC checks to ensure that the data meet quality standards.

If states, tribes, RBCs, and other participating organizations cannot deploy transducers during the first several years of data collection, macroinvertebrate and temperature data should still be collected. The transducers should be installed at primary RMN sites as soon as resources permit. In some situations, a phased approach, in which organizations start with one transducer, may work best. Once the entity gains experience with installing and operating the transducer, it can consider installing transducers at additional sites.

At RMN sites where pressure transducer data are being collected, efforts should be made to follow the recommendations in Table 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).

If installed and maintained properly, pressure transducers will provide important information on the magnitude, frequency, duration, timing, and rate of change of flows, and on the relationship between hydrologic and biological variables at RMN sites. Transducer measurements should be taken year-round (see Table 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 2, Table 6). For more detailed guidance on how to install and maintain pressure transducers in wadeable streams, refer to the EPA best practices document (U.S. EPA, 2014).

Table 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	***Flow/discharge based on stage-discharge rating curves developed from the full range of flow conditions***	Flow/discharge based on stage-discharge rating curves developed from the full range of flow conditions; after establishing a rating curve, discharge is measured at least once annually, and if possible, also after large storms or any other potentially channel-disturbing activities
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***	Continuous measurements taken year-round and discharge measurements taken with flow meter at time of biological sampling event
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 6. continued…

Component	1 (lowest)	2	3	4 (highest)
Mid-deployment	No mid-deployment checks	Mid-deployment checks are performed but the protocols do not meet all of the recommendations described in Appendix I	***Mid-deployment checks are performed in accordance with the recommendations described in Appendix I***	Mid-deployment checks that are more stringent than those described Appendix I are performed
Post-retrieval	No post-retrieval QA/QC procedures are performed	Post-retrieval QA/QC checks are performed but the protocols do not meet all of the recommendations described in Appendix I	***Post-retrieval QA/QC checks are performed in accordance with the recommendations in Appendix I***	Post-retrieval QA/QC checks that are more stringent than those described in Appendix I are performed

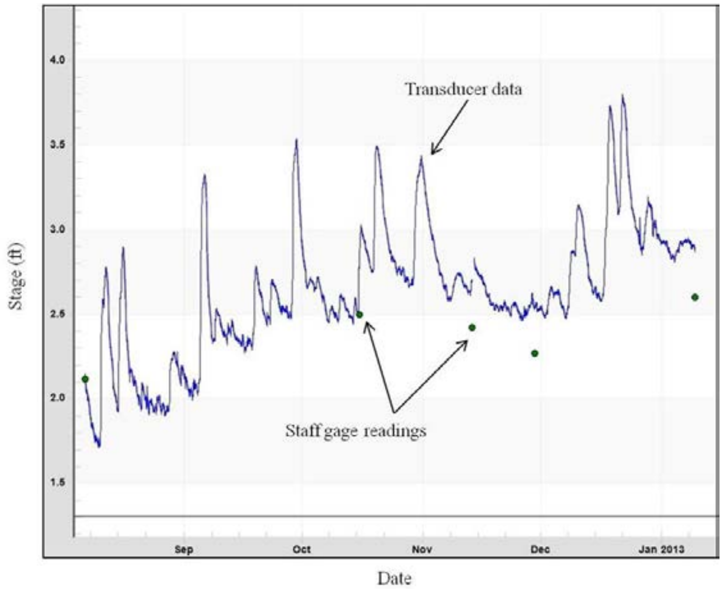

Figure 2. Staff gage readings provide a quality check of transducer data. In this example, staff gage readings stopped matching transducer readings in November, indicating that the transducer or gage may have changed elevation.

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 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 2). 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 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.

To ensure that data meet quality standards, mid-deployment and post-retrieval QA/QC checks should be performed in accordance with the practices described in Appendix I to identify erroneous readings (see Table 6). As with temperature sensors, different types of errors can occur during deployment (e.g., the pressure transducers may become dewatered or buried in sediment during low and high flow conditions). Participating organizations should perform the QA/QC checks when possible, but we recognize that this activity can be resource intensive, as some checks require numerous site visits or are difficult to perform quickly without software aids.

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.

3.4. PHYSICAL HABITAT

Qualitative visual habitat assessments should be performed annually at primary RMN sites in conjunction with biological sampling. Many states, tribes, and RBCs have adopted EPA's RBP (Barbour et al., 1999) (see Appendix J) or have a similar visual rating method (e.g., MD DNR, 2014). 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). Skilled field biologists are capable of performing 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. Such assessments are important because habitat changes associated with climate change will also contribute to shifts in biological assemblage composition and structure over time.

The collection of quantitative habitat data (e.g., bankfull width, slope, substrate composition) is optional but encouraged. If resources permit, we recommend the following basic list of quantitative measurements be collected 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, 2013b; Kaufmann et al., 1999), for making these measurements. All of the methods require expertise and skill, and some can be time intensive. As such, we are not recommending specific quantitative habitat methods at RMN sites. Future discussions about which parameters to measure should focus on reviewing key geomorphological or quantitative measures of physical habitat condition that are known to be ecologically meaningful and are likely to be affected by climate change. As part of a regional classification analysis we developed a predictive model for macroinvertebrate assemblages in the eastern United States. Substrate (percentage sand, percentage fines, embeddedness), flow habitat (percentage pools), and reach-scale slope emerged as important predictor variables in this model. Collecting these data at RMN sites would improve our ability to accurately classify sites and help inform decisions on how data from RMN sites could be pooled together for analyses.

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 to 5 year return periods for bankfull or small flood events, respectively. 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 photodocumenation (see Section 3.6). 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. We believe, however, that more discussion among RMN work group members and outside experts is needed before recommending additional habitat measurements.

3.5. 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. 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. The collection of more complete water quality data (e.g., alkalinity, major cations, major anions, trace metals, nutrients) is optional but encouraged. If additional resources are available, water chemistry samples could be collected multiple times per year at primary RMN sites during different flow conditions.

3.6. 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. 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 determined later.

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). 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 the dominant substrate on point bars 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. Photodocumentation of Big Run, WV, taken from the same location each year. Provided by West Virginia Department of Environmental Protection (WV DEP).

3.7. 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. We recognize that other land use data sets may be available in a given location. For the RMNs, the most current NLCD data set is preferred 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), as well as 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).

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

In this section, we provide recommendations on how to summarize the biological, temperature, hydrologic, habitat, and water quality data that are collected at RMN sites. 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. We attempted to select metrics 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 be conducted to help inform parameter selection, which is an active area of research. 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.

4.1. BIOLOGICAL INDICATORS

To facilitate the sharing of biological data among RMN members, both raw data and summary metrics should be put into the templates shown in Appendix K. Because taxonomic nomenclature can vary across organizations, we recommend that the USGS BioData nomenclature be used to describe taxa from RMN sites. Original identifiers used by each entity will also be retained in the shared file, as shown in Appendix K. The USGS nomenclature can be downloaded from this website (USGS, 2014a):

https://my.usgs.gov/confluence/display/biodata/BioData+Taxonomy+Downloads

Table 7 contains a list of candidate biological indicators that should be summarized from the macroinvertebrate data collected at RMN sites. When developing the list of taxonomically based metrics, consideration was given to which metrics are most commonly used by biomonitoring programs for site assessments. The list includes measures like total taxa richness and Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness and composition (Barbour et al., 1999). Traits-based metrics related to thermal and hydrologic conditions are also included (e.g., functional feeding group, habit, thermal, and flow preference). 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 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. These lists, which can be found in Appendix L, are the basis of the thermal preference metrics listed in Table 7. The thermal indicator lists in Appendix L should be regarded as a first step and should be reevaluated as more stream temperature data become available.

Metrics known or hypothesized to be sensitive to changing hydrologic conditions are also included in Table 7. These metrics were selected based primarily on literature review (e.g., Horrigan and Baird, 2008; Chiu and Kuo, 2012; U.S. EPA, 2012; DePhilip and Moberg, 2013a; Conti et al., 2014). The list of traits-based metrics related to hydrology should be reevaluated periodically and refined as more trait data becomes available and more is learned about how the traits link to hydrology. Given the rapid pace of research in these fields, 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.

Biological condition scores should also be calculated at RMN sites in accordance with each entity's bioassessment methods. 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).

Table 7. Recommendations on candidate biological indicators to summarize from the macroinvertebrate data collected at regional monitoring network (RMN) sites; many of these are indicators that 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, Hemiptera (OCH) taxa	Expected to be more prevalent during summer, low flow (more pool-like) periods	Bonada et al., 2007a
	Percentage OCH individuals		

Table 7. continued…

Type of indicator	Biological indicator	Expected response	Source
Traits-based metric related to temperature	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 7. continued…

Type of indicator	Biological indicator	Expected response	Source
Biological condition	Bioassessment score (e.g., MMI, predictive, BCG)	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 L)	Becker et al., 2010
	Relative abundance		
	Spatial distribution		
Variability	Persistence (variability in presence/absence; see Appendix M)	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 Appendix M)	Expect lower stability in disturbed or climatically harsh environments	Scarsbrook, 2002; Milner et al., 2006

Biological condition scores should also be calculated at RMN sites, 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, the direction of trends can be tracked across RMN sites, and standardized metrics, such as BCG scores, can be used to monitor changes in condition levels over time (Davies and Jackson, 2006). In Section 5.1.3 we describe how BCG models could be used to track changes in biological condition at RMN sites both within and across regions.

In addition to tracking the direction of metrics and condition scores over time, changes in the occurrence (i.e., presence or absence) and the relative abundance of individual taxa can be evaluated at RMN sites, as is being done at MD DNR Sentinel Stream Network sites (Becker et al., 2010). Data tracked across sites then can be used to monitor changes in taxa distributions over time through species distribution models (SDMs) or other means (see Figure 4). These modeling efforts are especially important for taxa that are expected to experience range changes in response to climate change (Hawkins et al., 2013; Domisch et al., 2013; Cao et al., 2013; DeWalt et al., 2013). Section 5.4.2 describes SDM modeling in more detail, and how data collected at RMN sites could be used to fit and validate SDMs.

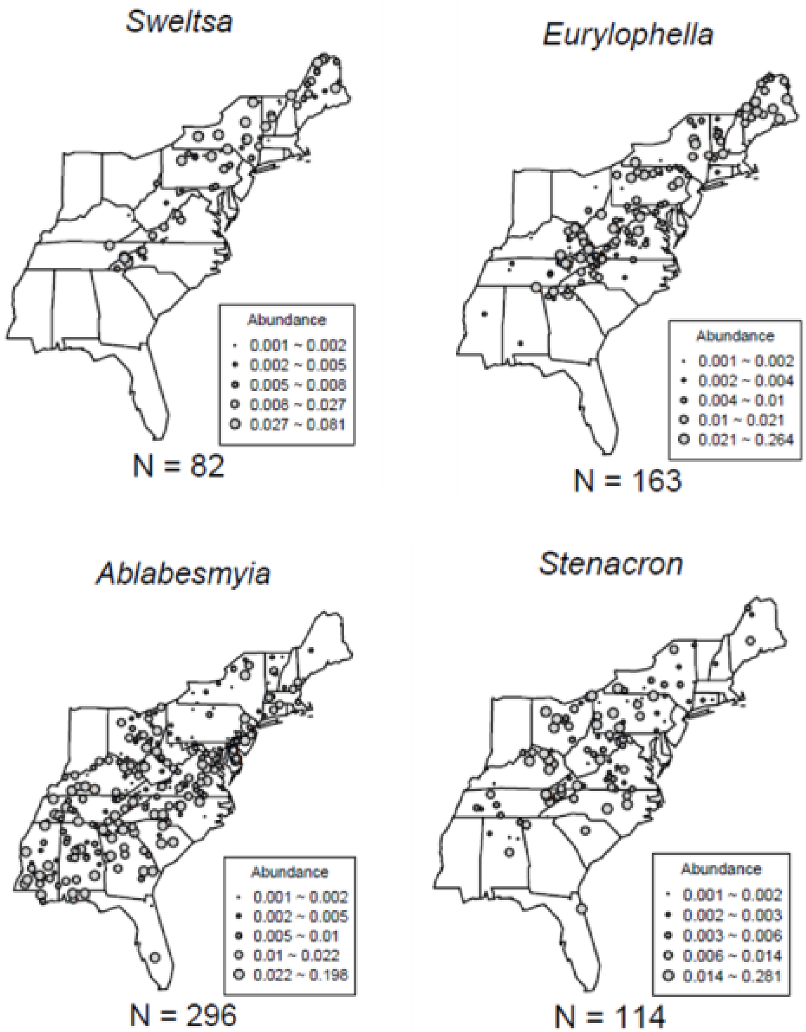

Figure 4. Changes in the spatial distribution of taxa can be tracked over time. At regional monitoring network (RMN) sites, particular attention will be paid to changes in the thermal indicator taxa (in this example, the top two plots show spatial distributions of two of the cold water indicators; the bottom two plots show distributions of warm water indicators).

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. Year-to-year variation in aquatic communities at pristine sites is poorly understood. Metrics of *persistence* and *stability* can be used to quantify year-to-year variation in metrics in long-term data sets (Durance and Ormerod, 2007; Milner et al., 2006), and we recommend that these metrics be calculated for RMN data as well (see formulas are provided in Appendix M). Persistence metrics calculate 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). Both measures can be used to assess community resilience and describe potential vulnerabilities to changing thermal and hydrologic conditions that are projected to occur with climate change (Karl et al., 2009).

4.2. THERMAL STATISTICS

Many metrics can be calculated from year-round air and water temperature measurements taken from RMN sites. These metrics capture various aspects of thermal regimes, such as timing, magnitude, variability, frequency, duration, and rate of change. 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, we have limited information on which temperature metrics are ecologically meaningful in the context of biomonitoring. Thus, providing recommendations on what summary thermal statistics to calculate for air and water temperature data from RMN sites is challenging. Many potential metrics are also correlated, which makes teasing their effects apart in most models difficult. When developing a list of potentially important temperature metrics, we 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). We note that other unlisted metrics have promise, including the use of more complex temperature exceedance metrics and moving average calculations that are related to specific biological thresholds (Schwartz et al.,2008).

Table 8 contains a recommended list of thermal summary statistics to calculate for data from RMN sites. This list of metrics should be regarded as a starting point and should be reevaluated over time. It consists 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). We do not recommend specific temperature thresholds for exceedance values here, as these may vary by location. For example, MD DNR and CT DEEP use different threshold values.

Before the metrics are calculated, the data should be screened using the guidelines described in Appendix H to remove questionable data. Data should be interpreted with caution if no QA/QC procedures are performed during the deployment period. A variety of software packages can be used to calculate thermal statistics, including Microsoft Excel and ThermoStat (Jones and Schmidt, 2012). Once the calculations have been made, the metric values should be entered into the template provided in Appendix K to help facilitate data sharing across RMN members. Raw temperature data collected at RMN sites is properly archived and stored so that additional metrics can be calculated in the future.

Table 8. Recommendations for candidate thermal summary statistics to calculate from 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
	Variance of daily mean	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 8. 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.

4.3. HYDROLOGIC STATISTICS

As with the thermal data, many different metrics can be calculated from daily hydrologic data that capture different aspects of hydrologic regimes (magnitude, frequency, duration, timing, and rate of change) (Olden and Poff, 2003). Again, many metrics are correlated. There has been some research on which hydrologic metrics are most ecologically meaningful in the context of state biomonitoring programs (e.g., Kennen et al., 2008; Chinnayakanahalli et al., 2011).

Table 9 contains a list of recommended hydrologic statistics to calculate for data from RMN sites where water-level or flow data are being collected. This list of metrics should be regarded as a starting point and should be reevaluated over time. It consists of basic statistics that cover daily, monthly, seasonal, and annual time periods. Most metrics have limited redundancy and are relatively easy to calculate. When developing this list, we used a combination of published literature and best professional judgment to inform our recommendations, including 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; DePhilip and Moberg, 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 N) (DePhilip and Moberg, 2013a). We also considered research by Olden and Poff (2003) and Hawkins et al. (2013), which identifies hydrologic metrics that capture critical aspects of hydrologic regimes and are ecologically meaningful in different types of streams (see Appendix N).

The hydrologic statistics listed in Table 9 should be calculated to match periods of calculation used for the annual thermal statistics (e.g., calendar year rather than water year). These include both summary statistics and also measures of variability. While the hydrologic statistics listed in Table 9 can be calculated after the first year of data collection, it takes many years to get stable estimates of hydrologic conditions. 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 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, 2013a).

Before the metrics are calculated, the data should be screened using the guidelines described in Appendix I to remove questionable data. Data should be interpreted with caution if no QA/QC procedures (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 make data sharing easier, the metric values should be entered into the template provided in Appendix K. Raw hydrologic data collected at RMN sites should be properly archived and stored so that additional metrics can be calculated in the future. Additional statistics can easily be calculated from software like Indicators of Hydrologic Alteration (TNC, 2009) and Aquarius (Aquatic Informatics, 2014).

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 (BaSE) 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 Table 10. While these modeled data should not be regarded as a substitute for observational data, we encourage participating organizations to take advantage of whatever resources are available for the RMN sites that they are monitoring.

Table 9. Recommended candidate 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

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
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)

Table 9. continued…

Timeframe	Metric	Calculation
Monthly (continued)	Low flow magnitude (10th percentile)	10th 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 (1st percentile)	1st 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 90th percentile
	Percentage low flows	Percentage of stage or flow measurements in each month that are between the monthly 25th and 1st 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 25th and 90th percentiles [similar to the Q_{75} and Q_{10} measurements used in DePhilip and Moberg (2013)]
Seasonal	Percentage high flows and floods in spring and fall	Percentage of stage or flow measurements in each month that exceed the monthly 90th percentile in spring (March−May) and fall (September−November)

Table 9. continued…

Timeframe	Metric	Calculation
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.

Table 10. 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 (USGS, 2014b)	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.
Massachusetts Sustainable-Yield Estimator (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.

4.4. PHYSICAL HABITAT, WATER QUALITY, AND GEOSPATIAL DATA

Table 11 contains a list of physical habitat and water quality data that should be summarized at RMN sites. Some optional parameters are also included in this table. While most RMN members are using EPA's RBP (Barbour et al., 1999), some have developed a visual rating method customized to their streams (e.g., MD DNR, 2014). Thus, some of the qualitative physical habitat data may not be directly comparable across RMN sites because of differences in methodologies. Despite these potential differences, we believe that the visual habitat assessments will provide sufficiently similar information on the condition of physical habitat to serve the needs of the RMNs.

Table 11. Physical habitat, water quality, and geospatial data that should be collected at regional monitoring network (RMN) sites. Optional parameters are marked with an asterisk

Parameter	Data type	Measurements
Physical habitat	Qualitative visual assessment	Instream, bank, and riparian habitat parameters using visual descriptions that correspond to various degrees of habitat condition (e.g., optimal, suboptimal, marginal, and poor) Dominant riparian vegetation*
	Quantitative*	Bankfull width
		Bankfull depth
		Reach-scale slope
		Substrate composition (percentage fines, percentage sand, etc.)
		Flow habitat types (percentage riffle, percentage pool, percentage glide, percentage run)
		Canopy closure (mid-stream and along bank)
Water quality	In situ	Specific conductivity
		Dissolved oxygen
		pH
	Grab samples[a]	Alkalinity
		Nutrients
		Metals
		Major cations
		Major anions
Geospatial	Land use and impervious cover*	Percentage forest, urban, agriculture, impervious, etc. from the 2006 National Land Cover Database (Fry et al., 2011)

[a]optional

5. DATA USAGE

Data collected from RMN sites can serve many purposes and will be used to:

- Detect temporal trends in biological, thermal, hydrologic, habitat, and water chemistry data;
- Investigate and resolve relationships between biological, thermal, and hydrologic data;
- Examine how organisms respond and recover from extreme weather events;
- Test hypotheses and predictive models related to climate change; and
- Quantify natural variability.

In this section we highlight examples of analytical techniques and applications for the biological, temperature, and hydrologic data that are being collected at RMN sites. These examples were selected because of their relevance to biomonitoring.

5.1. TEMPORAL TRENDS

One of the primary uses of RMN data will be to perform analyses to detect trends in biological, thermal, and hydrologic conditions over time. In this section we provide examples of:

- Basic analytical techniques for conducting temporal trend analyses (see Section 5.1.1),
- Trend detection for taxonomic and traits-based biological indicators (see Section 5.1.2), and
- Tracking changes in biological condition with BCG models (see Section 5.1.3).

5.1.1. Basic Analytical Techniques

Scatterplots, simple correlation and regression analyses, and other basic comparative tools are an important first step in exploring trends or annual differences over time. A major objective of the RMNs is to detect where trends are developing over time in biologic, thermal, and hydrologic regimes or to map changes in biology to changing thermal or hydrologic regimes that are indicative of shifting reference conditions, as well as to document natural variability. The sampling recommendations (see Sections 3.1−3.3) were created to maximize this potential within the context of existing monitoring efforts. Common tools for detecting trends are used in nearly all monitoring programs. For example, U.S. EPA (2012) examined macroinvertebrate data from state biomonitoring programs in Maine, North Carolina, Ohio, and Utah to assess whether bioassessment scores, selected biological metrics, temperature, flow, and precipitation variables have changed over time. Metrics at many sites in U.S. EPA (2012) exhibited considerable year-to-year variability, but some showed clear patterns. For example, at the Sheepscot River in Maine, total taxa richness and warm water taxa richness increased over a 20-year period of continuous biological data collected during a July−September index period (see Figure 5). At a site on the Weber River in Utah, the cold water metrics showed strong negative associations with year, based on September−November kick-method samples collected over a 17-year period (U.S. EPA, 2012).

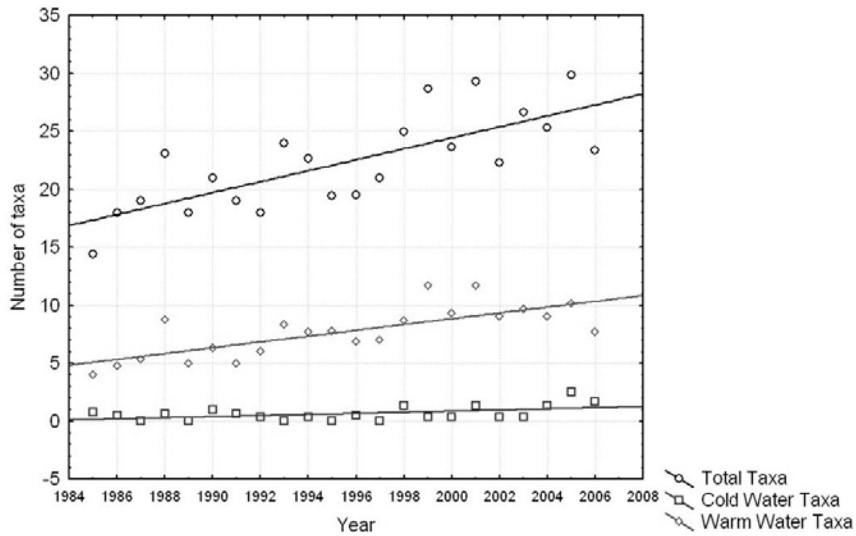

Figure 5. Yearly trends in cold- and warm-water-preference taxa and total taxa richness at a site on the Sheepscot River in Maine (Station 56817) (U.S. EPA, 2012). Samples were collected during July−September using rock baskets (Davies and Tsomides, 2002). Historically, this site has been impacted by nonpoint source pollution.

The Maryland Biological Stream Survey, led by the MD DNR, Monitoring and Non-Tidal Assessment Division, used similar techniques to assess annual variability in stream conditions at high-quality reference streams in their sentinel site network. MD DNR also tracks changes in richness and abundances of cold water macroinvertebrate and fish taxa, which were identified through analyses of continuous temperature data (Becker et al., 2010). Between 2000 and 2009, the percentages of cold-water-preference benthic macroinvertebrate taxa and brook trout abundances at sentinel sites were negatively but not significantly correlated with year (Becker et al., 2010).

In addition, MD DNR uses analysis of variance to determine whether MD DNR’s indices of biotic integrity for benthic macroinvertebrates (BIBI) and fish (FIBI) (Roth et al., 1998; Southerland et al., 2005, 2007) differ between years. MD DNR runs these analyses with sites grouped by geographic region. Between 2000 and 2009, MD DNR found significant differences in index of biological integrity (IBI) scores in the Coastal Plain (western shore) region, but not in the Piedmont, the Coastal Plain—eastern shore region, or the Highlands regions. The differences in IBI scores in the Coastal Plain—western shore region may have been associated with changing hydrologic conditions, because the lowest IBI scores were recorded the year after the lowest flow and rainfall conditions occurred (Becker et al., 2010).

5.1.1.1. *Data Preparation*

Before conducting analyses, data should be screened to minimize the chances of detecting false trends or differences due to changes in field and laboratory protocols. In the U.S. EPA (2012) pilot studies, a screening process was used to identify:

- Changes in taxonomic naming over time (e.g., changes in genus or higher level names, changes in placement within families). This not only reveals changes in systematics over time, but also changes in taxonomists and/or laboratories used to analyze samples.
- Changes in level of resolution over time (e.g., increasing use of species names in recent years where individuals are typically left at the genus or family level in earlier samples).
- Changes in other types of naming conventions (e.g., changes in systematics for taxa such as water mites).
- Changes in sampling methodology (e.g., changes in collection methods or index periods).
- Changes in how early instars, damaged or other unidentifiable taxa, pupae, and semiaquatic taxa are treated.
- Changes in how richness and abundance are calculated and reported (e.g., changes or errors in how subsampling was applied; whether replicates are collected, and whether they are averaged, summed, or reported separately; and whether both qualitative and quantitative samples are collected, and whether those data are mixed together).

The development of operational taxonomic units (OTUs) may be required to address changes in taxonomic naming and systematics that have occurred over time. The intent of OTUs is to include only distinct or unique taxa in the analyses (Cuffney et al., 2007). If possible, expert taxonomists should be involved in this process to determine how to best address the changes in nomenclature. In the U.S. EPA (2012) pilot studies, genus-level OTUs were generally found to be most appropriate, although there were some exceptions (e.g., in the Utah database, a family-level OTU had to be used for Chironomidae due to inconsistencies arising from a change in taxonomy labs).

As part of taxonomic screening or evaluating OTUs, ordinations techniques, such as nonmetric multidimensional scaling (NMDS) or principle component analysis, can be used to show how closely samples cluster based on taxonomic composition. U.S. EPA (2012) used NMDS to evaluate the effectiveness of the OTUs by overlaying grouping variables (e.g., year, month, collection method, taxonomy lab, ecoregion, watershed) on ordinations before and after OTUs were applied. The OTUs were deemed effective if distinct patterns were not evident. NMDS can also be used to evaluate collection and processing protocols that can influence measures of assemblage composition. This technique was used by Bierwagen et al. (*in review*) prior to running power analyses on biomonitoring data from the Northeast. The effects of different methodologies (riffle kicks vs. artificial substrates) on taxonomic composition were evident in the ordination (see Figure 6).

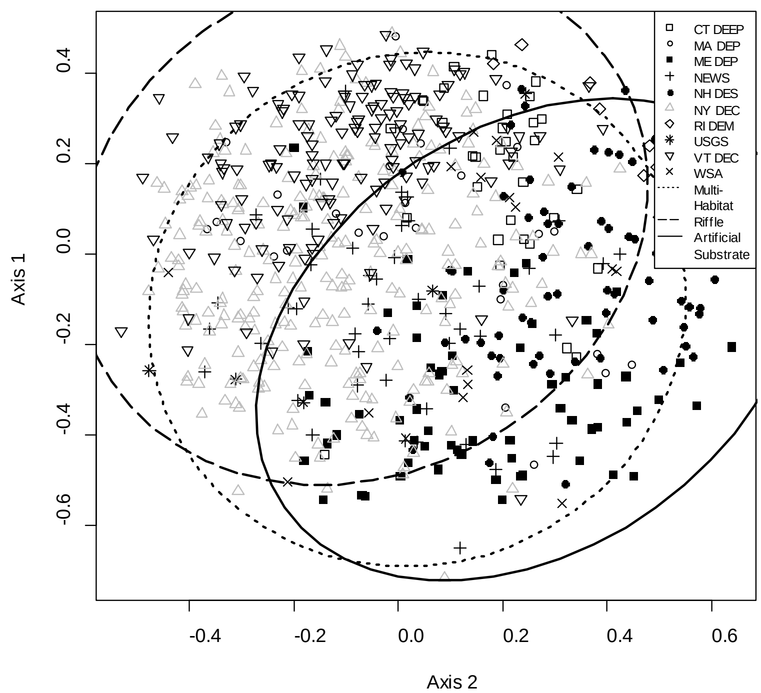

Figure 6. Effects of differences in sampling methodologies on taxonomic composition were evident in this nonmetric multidimensional scaling (NMDS) ordination on the Northeastern data set that was analyzed for an EPA pilot study in 2012. Methods are represented with different symbols and sampling devices are shown with two rings (solid [artificial substrate] and dashed [riffle kicks] 95% confidence ellipsoids). Wadeable Streams Assessment (WSA) and New England Wadeable Streams (NEWS) project samples are also highlighted (dotted 95% confidence ellipsoid). Taken from Bierwagen et al. (*in review*).

5.1.2. Trend Detection for Taxonomic versus Traits-Based Biological Indicators

Data collected from RMN sites can be used to determine which biological metrics are most responsive or sensitive to climate-related changes, and how long it might take for trends to become evident. Bierwagen et al. (*in review*) performed a detailed power analysis on routine biomonitoring macroinvertebrate data in the Northeast to estimate the number of years needed to detect temporal trends in seven biological metrics. Three of the metrics (total taxa richness, EPT richness, and relative abundance) are commonly used in bioassessments, while the other four climate-sensitive metrics (richness and relative abundance of cold- and warm-water taxa) are based on lists of taxa that showed strong thermal preferences (Yuan, 2006; Stamp et al., 2010). Data were grouped into three stream classes that were developed for the Northeast region using stream gradient and drainage area. After accounting for differences in sampling methodology, results suggest that well-designed networks of 25 to 30 sites monitored consistently can detect underlying changes of 1−2% per year in a variety of biological metrics within 10−20 years if such trends are present. Trend detection times were longer for the thermal preference metrics versus traditional metrics, such as total taxa richness and EPT richness. A potential reason for this is that climate-sensitive taxa are less common in samples, so collecting enough individuals to detect their presence is crucial. In support of this, Bierwagen et al. (*in review*) found that cold-water metrics performed better in the high-gradient stream class and warm-water metrics performing better in the low-gradient class, where the richness of these contrasting groups are higher.

5.1.3. Tracking Changes in Biological Condition with Biological Condition Gradient (BCG) Models

Trend analyses on RMN data can be used to determine whether changes in biological condition are occurring over time. As discussed in Section 4.1, different organizations often use different techniques for assessing and rating biological condition, so in many cases, quantitative comparisons of biological condition scores from different states are not possible. The BCG model provides a possible solution for this problem. The BCG uses a standardized index with a fixed number of levels that evaluates alteration to biological structure and function relative to baseline of natural conditions (Davies and Jackson, 2006). It can be calibrated and applied to regional and local conditions and puts biological condition on a common, quantifiable scale for all states and regions.

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). If higher levels of refinement are desired, more than six BCG levels can be used. The end assessments are on a single scale that can be applied nationwide. 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.

A number of pilot projects sponsored by the EPA have been conducted for streams and rivers in different regions of the United States to further develop and apply the BCG. Regional BCG models that accommodate methodological differences that have been developed for cold and cool streams in the Northern Forest region of the Midwest and for medium to high gradient streams in parts of New England (Stamp and Gerritsen, 2009; Gerritsen and Stamp, 2012). The New England model is for macroinvertebrates and is cross-calibrated for methods used by biomonitoring programs in Maine, New Hampshire, Vermont, and Connecticut, as well as for EPA NRSA protocols. The Northern Forest models were developed for macroinvertebrate and fish assemblages for Indian Reservations and the states of Michigan, Wisconsin, and Minnesota. Regional models in other parts of the country are being developed (e.g., BCG models are currently being developed for macroinvertebrate and fish assemblages in Alabama and Illinois). These regional BCG models can be applied to data collected from RMN sites and BCG-level scores can be tracked over time across sites. In addition to BCG scores, the component metrics of the BCG models, which are typically related to tolerance of individual taxa, can also be tracked over time.

5.2. RELATIONSHIPS BETWEEN BIOLOGICAL INDICATORS AND ENVIRONMENTAL DATA

Another primary use of RMN data will be to evaluate relationships between the biological and environmental data. The paired biological, thermal, and hydrologic data from RMN sites will allow us to track whether changes in biological indicators are associated with changing thermal and hydrologic conditions. In this section we provide examples of how RMN data can be used to:

- Explore relationships between biological and environmental data (see Section 5.2.1),
- Derive ecologically meaningful variables and thresholds (see Section 5.2.2), and
- Better understand interactive effects of climate change with non-climatic stressors (see Section 5.2.3).

5.2.1. Basic Analytical Techniques

Analytical techniques similar to those described in Section 5.1.1 can be used to explore relationships between biological indicators and environmental data at RMN sites. For example, MD DNR uses scatterplots and correlation analysis to evaluate relationships between biological, thermal, and hydrologic data (temperature, precipitation, flow) from its sentinel sites. Between 2000 and 2009, MD DNR found that BIBI scores at four of six sentinel sites in the Coastal—western shore region were significantly and positively correlated with summer flow percentiles, with the lowest scores following extremely dry years (Becker et al., 2010).

U.S. EPA (2012) conducted similar types of analyses on data sets from state biomonitoring programs in Maine, North Carolina, Ohio, and Utah to examine whether climate-related trends were evident in long-term macroinvertebrate surveys. The analyses found that at some sites, biological metrics showed patterns that were associated with changing thermal and hydrologic conditions, whereas at other sites, patterns were contrary to expectation or not evident. The strongest trends occurred at two Utah sites that had more than 13 years of data. At these sites, richness and relative abundance metrics for cold-water taxa were negatively correlated with air temperature. At one of these sites, the EPT richness metric dropped dramatically from 2000−2005, which corresponded to a period of higher than normal temperatures and lower than normal flows (see Figure 7) (U.S. EPA, 2012).

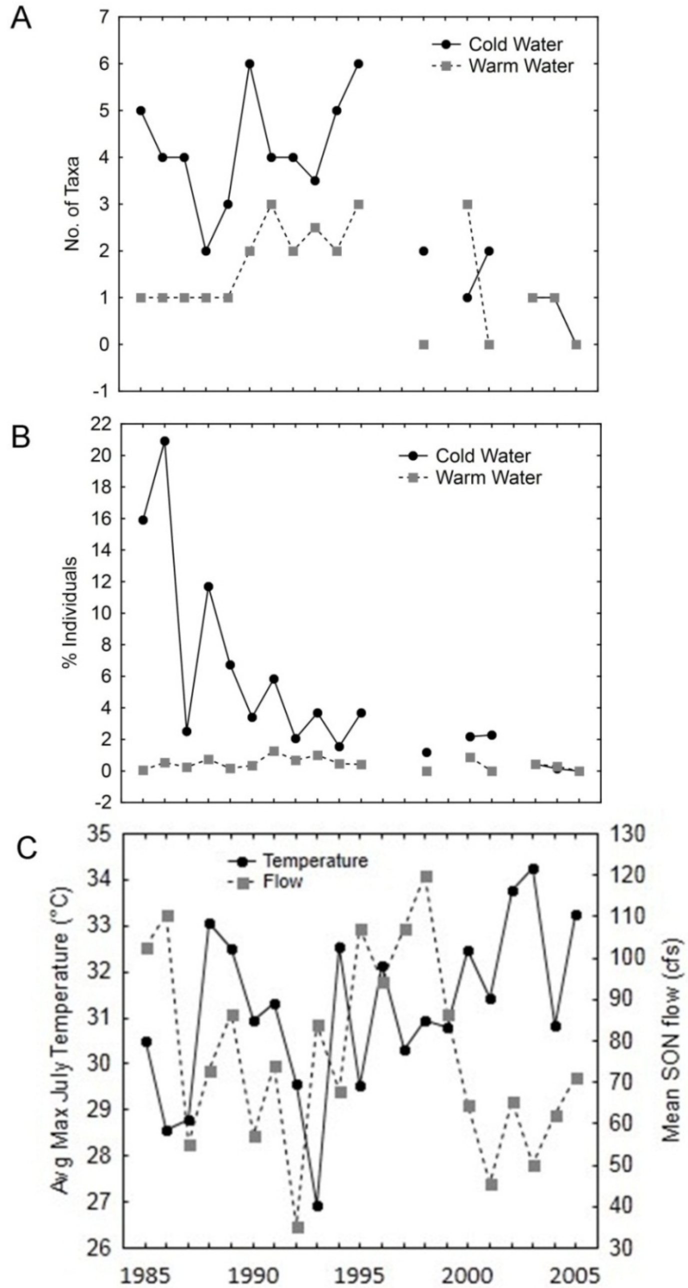

Figure 7. Yearly trends at the Weber River site in Utah (UT 4927250) in (A) number of cold and warm water taxa; (B) percentage cold- and warm-water individuals; and (C) mean maximum July temperature (°C) and mean September/October/November (SON) flow (cfs). Samples were collected from riffle habitats using a Hess sampler during a September/October index period. Trends at this site may have been influenced by nonpoint source pollution.

To explore these differences further, U.S. EPA (2012) partitioned Utah site data into years characterized by hotter and colder temperatures and by higher and lower flows. Results varied across sites and regions. The strongest patterns occurred at the two Utah sites where consecutive years of hot and dry conditions occurred from 2000−2005. At both sites there were fewer total taxa and EPT taxa in hot years than in cold years, and four fewer cold-water taxa in hot years than in cold years. Generally, hotter and drier conditions occurred over consecutive years, and these conditions correspond with declines in biological metrics (taxa richness, EPT richness, or cold-water taxa richness) (U.S. EPA, 2012).

5.2.2. Ecologically Meaningful Variables and Thresholds

Researchers have been wrestling with the concept of ecological thresholds for many years. An ecological threshold is defined as “the point at which there is an abrupt change in an ecosystem quality, property or phenomenon, or where small changes in an environmental driver produce large responses in the ecosystem” (Groffman et al., 2006). Setting thresholds can be challenging due to factors such as nonlinear dynamics and multiple control factors that operate at diverse spatial and temporal scales (Groffman et al., 2006).

Data from RMN sites can be used to gain a better understanding of potential ecological “tipping” points related to thermal and hydrologic conditions. Furthermore, a detailed understanding of temperature and flow relationships can be used to develop meaningful breakpoints in a variety of studies outside of trend detection. Notably, information from the first few years of RMN data collection could be used to inform the creation of break points for vulnerability assessments across the RMNs, which would be used to direct future RMN work or inform management decisions. For example, Beauchene et al. (2014) developed ecologically meaningful stream temperature thresholds for Connecticut streams. They analyzed stream fish survey and continuous water temperature data from 160 sites in perennial, 1st- to 4th-order streams across Connecticut, and developed quantitative thresholds for three major thermal classes at which there are discernible temperature-related changes in fish communities during summer months (see Figure 8):

- Cold <18.29°C
- Cool 18.29−21.70°C
- Warm >21.70°C

Assuming that these thresholds inform on thermal tolerances, they provide easy-to-understand temperature standards that can be used to protect and maintain biological communities.

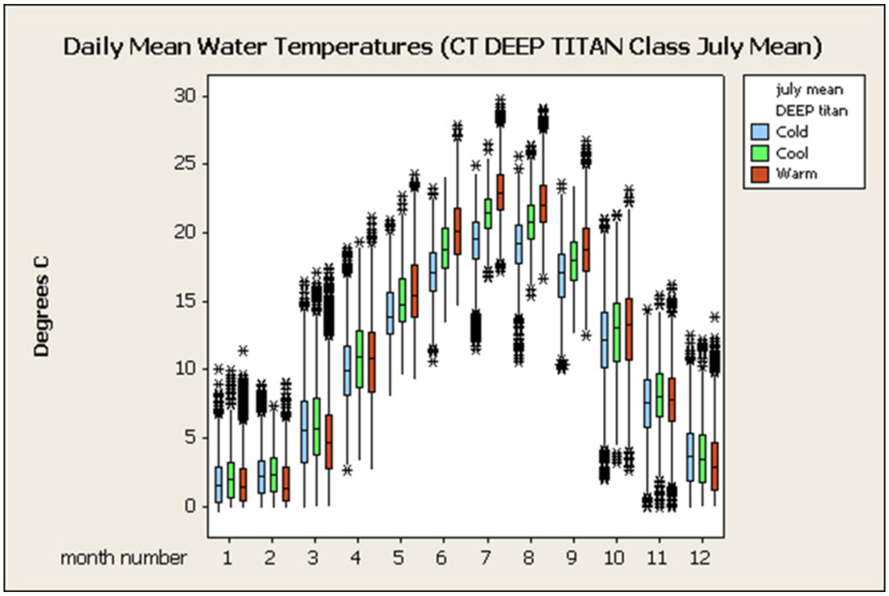

Figure 8. Connecticut Department of Energy and Environmental Protection (CT DEEP) developed ecologically meaningful thresholds for three major thermal classes (cold, cool, warm). Outliers are shown with asterisks. Temperature in these three classes differ most in the summer (figure provided by Mike Beauchene, CT DEEP).

Similarly, Maine is the first state in the United States to adopt statewide environmental flow and lake level standards based on thresholds derived from principles of natural flow variation necessary to protect aquatic life and maintain important hydrological processes (Maine DEP, 2007). Other states are also exploring the development of flow criteria, utilizing the ELOHA framework (Poff et al., 2010). For example, 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). Because some flow recommendations are based on expert elicitation and published literature, data from RMN sites can be used to greatly improve our understanding of these processes to develop regionally informed standards and management decisions.

5.2.3. Interactive Effects of Climate Change with Other Stressors

While many primary RMN sites are minimally disturbed, some primary and many secondary RMN sites span larger stressor gradients. Even sites in minimally disturbed areas may be impacted by more diffuse, non-climate impacts, or will be impacted over the lifetime of the RMN. Here also, RMN data can provide insights into effects of anthropogenic activities on thermal and hydrologic regimes, especially if there are affected and unaffected sites situated in similar environmental conditions (e.g., Dunham et al., 2007; Kaushal et al., 2010). For example, the temperature data from RMN sites may prove useful for addressing temperature-related mandates associated with water quality standards (Birkeland, 2001; Poole et al., 2004; Todd et al., 2008), while hydrologic data could provide information on how altered flows created by extraction practices, such as water withdrawals from hydraulic fracturing, affect ecosystem services (e.g., Carlisle et al., 2010; Appalachian Landscape Conservation Cooperative, 2014).

Similarly, some RMN sites are impacted by urbanization, and data from RMN sites that span an urbanization gradient will allow us to examine how climate change impacts on flow and temperature interact with urban development, as well as to distinguish climate and urban stressors. For example, U.S. EPA (2012) performed a case study using flow data from USGS gages in the Baltimore-Washington D.C. area to examine how the hydrologic response to climatic change in the Mid-Atlantic would compare with land use impacts. Results showed that high flow metrics (e.g., flashiness, high-pulse-count duration, 1-day maximum flow) tend to strongly reflect urbanization and swamp inputs from climate change effects. In comparison, several low-flow metrics, such as 1-, 3- and 7-day minimum flows and low-pulse count, show responses to climate change effects more so than to land use (U.S. EPA, 2012).

5.3. RESPONSE AND RECOVERY OF ORGANISMS TO EXTREME WEATHER EVENTS

Data from RMN sites can be used to gain a better understanding of 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 (Karl et al., 2009). These types of events can either be missed or confounded with events from previous years by routine sampling that is done on a rotational basis (e.g., sites visited once every 5 years) because attribution or detection of key events may require sampling that closely brackets the event. For example, VT DEC (2012) collected macroinvertebrate data from 10 long-term, high-quality monitoring sites after the flooding from Tropical Storm Irene (August 2011) and compared them to historical records collected prior to 2011. They found immediate decreases in invertebrate densities of 69% on average and decreases in total taxa richness of 8% following these high-flow events, but also found that most sites recovered to normal levels the following year (see Figure 9). These dramatic declines and rapid recovery would have been missed if sampling had occurred at longer intervals.

The North Carolina Department of Environment and Natural Resources (NC DENR) Biomonitoring Unit has also conducted research on responses of macroinvertebrates and fish communities to flooding, and assessed impacts from hurricanes (Frances, Ivan, and Jeanne, which struck in September 2004) in the French and Watauga River basins (MacPherson and Tracy, 2005). They found that biological condition scores for both assemblages declined after flooding. In the study areas, declines in mayflies, stoneflies, and beetles likely occurred because woody debris habitats were swept away in the floods. Results for the fish varied by site. NC DENR also documented declines of macroinvertebrate communities in response to drought conditions that occurred from 1999 to 2002 (Herring, 2004). Here, the degree of impact and speed of recovery appeared to be influenced by species traits and habitat preferences. For example, flow-dependent taxa, such as hydropsychids and heptageniids, were slow to recover and edge species did not recover by the end of the study period.

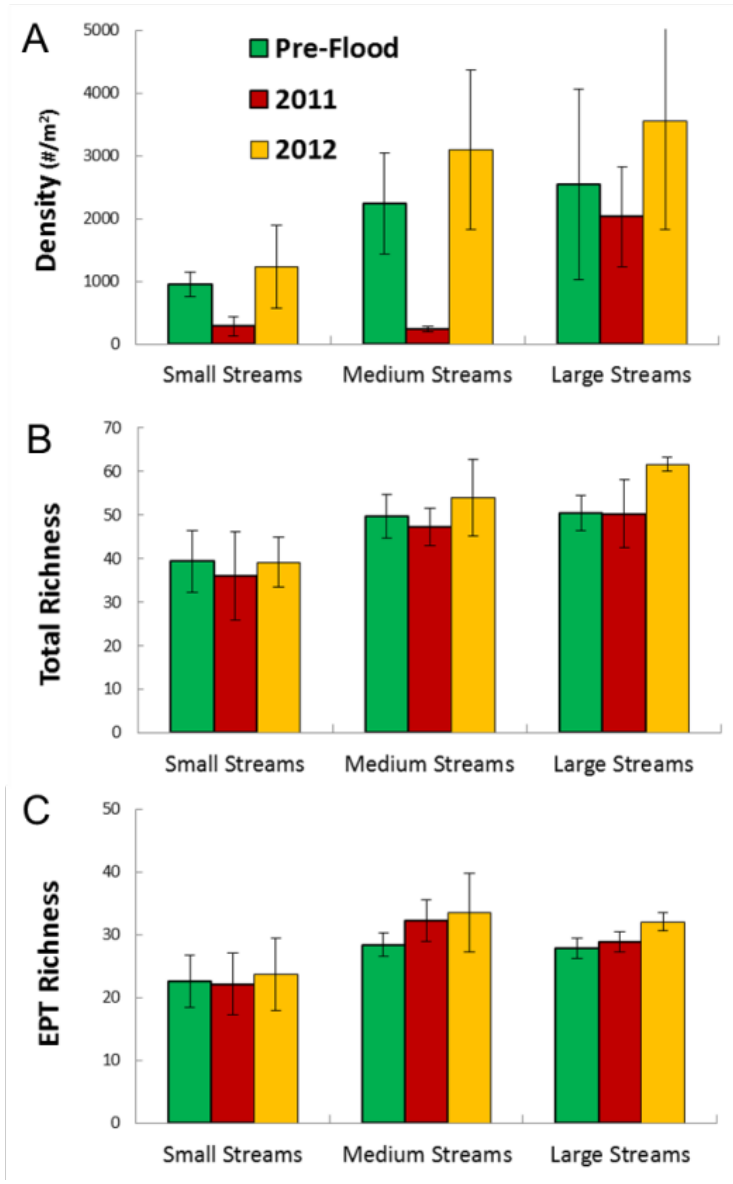

Figure 9. Comparison of (A) macroinvertebrate density values, (B) total taxa richness values, and (C) Ephemeroptera, Plecoptera, and Trichoptera (EPT) richness at 10 stream sites in Vermont before and after Tropical Storm Irene (provided by Moore and Fiske, VT DEC, unpublished data).

5.4. HYPOTHESES AND PREDICTIVE MODELS RELATED TO CLIMATE CHANGE VULNERABILITY

Data being collected at the RMN sites can be used to test predictive models and hypotheses about the vulnerability of taxa and watersheds to climate change. In this section we provide examples of how RMN data can be used to:

- Test hypotheses from the broad-scale climate change vulnerability assessment being conducted by EPA (see Section 5.4.1),
- Test the performance of SDMs (see Section 5.4.2),
- Better understand differing thermal vulnerabilities of streams (see Section 5.4.3), and
- Test the performance of models that predict effects of climate change on streamflow (see Section 5.4.3).

5.4.1. Broad-Scale Vulnerability Assessments

The EPA is conducting broad-scale climate change vulnerability assessments in the Northeast, Mid-Atlantic, and Southeast regions and has developed hypotheses about which watersheds will be most vulnerable to projected changes in temperature and hydrologic conditions, as well as which biological indicators are likely to be most responsive to these changes. Watersheds in these regions are being assigned vulnerability ratings for three different scenarios: increasing temperatures, increasing frequency and magnitude of peak flows, and increasing frequency of summer low-flow events. RMN data can be used generally to validate specific hypotheses in the assessment but more importantly can be used to refine and improve the model, as relationships between biological indicators and environmental conditions are monitored over time.

5.4.2. Species Distribution Models (SDMs)

As discussed in Section 4.1, data tracked across RMN sites can then be used to monitor changes in taxa distributions over time due to changes in thermal and hydrologic conditions, and this data can be used to fit or validate SDMs. For example, using species occurrence data, Hawkins et al. (2013) developed SDMs that predict how the distributions of individual macroinvertebrate taxa and entire assemblages of taxa vary with stream temperature, flow, and other watershed attributes in the conterminous United States. These predictive models were developed with biomonitoring data from reference-quality sites that were sampled during the EPA's 2008−2009 NRSA. To assess potential effects of climate change on biodiversity, Hawkins et al. (2013) compared SDM calculations for 2000−2010 with those for 2090−2100. Their results predicted 287 taxa to increase in frequency of occurrence and 252 taxa to decrease in frequency of occurrence.

SDMs are also being developed for stonefly species in the Midwest (Cao et al., 2013; DeWalt et al., 2013). A data set of 30,355 specimen records and bioclimatic variables derived from downscaled modeled climate data are being used to compare the pre-European settlement and future geographic distributions of 78 stonefly species with the maximum entropy (Maxent) model. Based on the modeled results, approximately 70% of stonefly species and 89% of stonefly families are predicted to experience large range losses, while 6% of species are predicted to increase in range (DeWalt et al., 2013).

Similar SDMs have been developed by Domisch et al. (2013), who used an ensemble of bioclimatic envelope models to model climatic suitability for 191 stream macroinvertebrate species from 12 orders across Europe for two late-century (2080) scenarios. They assessed relative changes in species' climatically suitable areas as well as potential geographic shifts based on thermal preferences. Their models suggest that, under future scenarios, there will still be climatically suitable conditions for most of the modeled stream macroinvertebrates. Suitable habitat for warm-adapted species is projected to increase, while cold-adapted species are projected to lose climatically suitable area. The models showed endemic species losing significantly more suitable habitat than nonendemic species (Domisch et al., 2013).

5.4.3. Differing Thermal Vulnerabilities

Temperature data from RMN sites can be used to investigate why streams have differing vulnerabilities to thermal change. Air temperature, which is projected to increase due to climate change, is known to be an important predictor of water temperature (e.g., Hill et al., 2013). The relationship between air and water temperature, however, varies depending on numerous factors, such as location, stream size, and groundwater contributions and the capacity of the stream to absorb heat (Hill et al., 2014). In Pennsylvania, Kelleher et al. (2012) found that stream size (stream order) and groundwater contribution (baseflow index) were the primary controls of the sensitivity of stream temperature to air temperature. Hawkins et al. (2013) found streams in the Cascades and Appalachian Mountains were most responsive to changes in air temperature, compared to streams in the southeastern United States, which suggests that orography and landscape variables influence rates of temperature change (Loarie et al., 2009; Isaak and Rieman, 2013).

MD DNR and collaborators performed exploratory analyses to gain a better understanding of relationships between air and water temperature along with discharge at their sentinel sites (Hilderbrand et al., 2014). They developed 99 linear regression models based on water and air temperature sensors to evaluate air-water-temperature relationships for the Coastal Plain, Piedmont, and Highlands regions for different site-years (see Table 12). They also investigated the influence of streamflow on water temperatures by including discharge measurements from USGS stream gages. The differences in slopes among the regions suggest that streams in the Highland region may be influenced by a number of factors, such as increased baseflow and increased riparian shading. Improvements in overall model fit also show that streamflow is a small, but important, modifier of water temperature (see Table 12).

Table 12. Results from Hilderbrand et al. (2014) linear regression models based of water and air temperatures from sentinel sites in the Coastal Plain, Piedmont, and Highlands regions. Results show mean slope values for the air-water temperature relationship. Models including discharge measurements (slopes not shown) improve overall fit in each region

Region	Model	*n*	Mean slope	Mean R^2
Coastal plain	Air only	35	0.64	0.72
	Air + discharge	35	0.64	0.76
Piedmont	Air only	18	0.59	0.69
	Air + discharge	18	0.57	0.74
Highlands	Air only	46	0.54	0.61
	Air + discharge	46	0.51	0.73

5.4.4. Testing the Performance of Models that Predict Effects of Climate Change on Streamflow

Hydrologic data from RMN sites can be used to investigate why streams have differing vulnerabilities to hydrologic change. Because of the paucity of long-term flow data at pristine locations, most explorations of climate change on hydrology have been done using models and simulations; data from RMN sites can be used to improve or validate these models. For example, Hawkins et al. (2013) used statistical models to predict flow responses to projected climate change at specific sites in the conterminous United States, where streams were broken into classes based on hydrologic characteristics. Model outputs show both potential changes in stream class assignment, as well as changes in individual flow variables. On the other hand, the Variable Infiltration Capacity model (Liang et al., 1994) has been used to model streamflow projections for the Northeast region by Hayhoe et al. (2007). This process-based model has been applied internationally and to many river basins in the United States. (Beyene et al., 2010; Livneh et al., 2013) and mechanistically includes components of canopy interception, evapotranspiration, runoff generation, infiltration, soil water drainage, and snow pack accumulation and melt. Many other streamflow modeling efforts also exist at more regional scales that can incorporate data from RMN sites (e.g., South Atlantic Landscape Conservation Cooperative).

5.5. QUANTIFYING NATURAL VARIABILITY

Year-to-year variation in the occurrence and relative abundance of individual taxa is not well documented, particularly at pristine sites (Milner et al., 2006). Data from RMN sites can be used to help quantify this, and to assess how natural variation affects the consistency of biological condition scores and metrics. Natural variation can also be linked to environmental variables, and an understanding of these relationships could be important for predicting vulnerability to changing thermal and hydrologic conditions.

As part of this process, it is useful to estimate and bracket historical conditions at RMN sites when possible, as a way to contextualize future changes and screen for unusual conditions. For example, if conditions in a given year are abnormal, organizations may want to interpret their biological condition scores with caution or consider recalibrating their index to encompass a wider range of environmental conditions. Because long-term stream temperature and flow data are not available for many RMN sites, RMN members are encouraged to use air temperature, precipitation, and flow data from nearby weather stations and USGS gages to provide estimates of past conditions. The closest active weather stations can be located, and the daily observed air temperature and precipitation data for those stations can be downloaded from websites like the Utah State University Climate Server:

http://climate.usurf.usu.edu/mapGUI/mapGUI.php

Streamflow data from the nearest USGS gages can be downloaded from the USGS National Water Information System website:

http://waterdata.usgs.gov/usa/nwis/rt

After the first year or two of data collection at RMN sites, regression equations can be developed for localized areas to allow for more accurate extrapolations of historic water temperature and hydrologic data. In addition, broader-scale information on how current conditions compare to past "norms" can be obtained from the National Oceanic and Atmospheric Administration's National Climatic Data Center website (http://www.ncdc.noaa.gov/sotc/) (NOAA, 2014) and the USGS WaterWatch website (USGS, 2014d).

RMN members are also encouraged to research whether predictive stream temperature and flow models are available in their geographic area. As mentioned in Sections 4.3 and 5.4.4, there are many different types of predictive models, each of which have applicability at different spatial scales and vary in their level of accuracy and sophistication. An example of a predictive stream temperature model that could be applied at RMN sites is one developed by Hill et al. (2013). Hill et al. (2013) developed spatially explicit empirical models to predict reference-condition mean summer, mean winter, and mean annual stream temperatures at locations across the conterminous United States that lack observational stream temperature data. The models were calibrated with daily mean stream temperature data from several thousand USGS gages. Both natural factors (e.g., climate, watershed area, topography) and measures of stream and watershed alteration (e.g., reservoirs, urbanization, and agriculture) were considered during model development. The Hill et al. (2013) model can be applied to specific sites if the proper input data are available (e.g., GIS-derived geologic and climate data for the exact watershed). Other models predict stream temperature for entire reaches versus specific sites. For example, Detenbeck et al. (2013) used a flow-weighted spatial autocorrelation model (ver Hoef et al., 2006) to predict thermal metrics for NHDPlus v1 stream flowlines in New England.

6. NEXT STEPS

This document should be reevaluated and updated periodically as data are collected and analyzed to ensure that the objectives of the RMNs are being met and recommendations remain current. In this section we first discuss the most immediate priorities for the RMNs in the Northeast, Mid-Atlantic, and Southeast regions and then discuss future steps, which could potentially include integration of other regions, as well as other water body types.

6.1. MOST IMMEDIATE PRIORITIES

The most immediate priorities for the RMNs in the Northeast, Mid-Atlantic, and Southeast regions are described below.

Formally designate a coordinator in each region to ensure sustainability. The coordinator's role would include:

- Coordinating calls, webinars, and trainings;
- Obtaining and lending equipment;
- Obtaining periodic updates on status of activities;
- Potentially performing tasks related to data infrastructure [e.g., sharing data or coordinating activity on EPA's Water Quality Exchange (WQX)]; and
- Coordinating a work group session at annual meetings [e.g., the New England Association of Environmental Biologists (NEAEB) conference, the Association of Mid-

Atlantic Aquatic Biologists Workshop (AMAAB), and the Southeastern Water Pollution Biologists Association (SWPBA) conference]; and

- Keeping up on other efforts and funding opportunities that the RMNs could potentially tie into.

It may be beneficial for the EPA Regional Monitoring and/or Biocriteria coordinator in each region to fill this role or either share responsibilities or work collaboratively with the designated coordinator.

Implementation. Efforts should be made to collect as much of the data described in Section 3 as possible at the desired level or rigor. At many RMN sites, collection of macroinvertebrate data and year-round stream and air temperature measurements should be feasible immediately. In some cases, states, tribes, and RBCs are already collecting these data, and these efforts should be expanded to include all participating organizations. As described in Section 3.3, collecting the hydrologic data can pose challenges. We acknowledge these challenges but also recognize the importance of obtaining a better understanding of hydrologic regimes at RMN sites. Thus, we encourage pressure transducer installation at primary RMN sites. Regional coordinators can assist with this by:

- Obtaining and lending equipment;
- Organizing training workshops and materials on how to install and operate the equipment, do elevation surveys, develop flow rating curves, or process the data (Training workshops could coincide with annual regional meetings like AMAAB, NEAEB and SWPBA);
- Finding resources and partners to help with the installations, elevation surveys, and development of flow rating curves; and
- Managing data.

In some situations, a phased approach in which organizations start with one transducer may work best. Once an entity gains experience with installing and operating the transducer, transducers can be installed at additional sites. If high quality data can only be collected at a subset of the primary RMN sites, it is better to collect higher quality hydrologic data at a few sites versus collecting data of questionable quality at numerous sites.

Taxonomic resolution. Species-level identifications for the macroinvertebrate taxa listed in Appendix G is ideal for at least 1 year so that a taxonomic baseline can be established. If funding permits, samples could be sent to a common laboratory. If this is not possible, regional coordinators may consider taxonomic training workshops to ensure consistency in identifying important indicator taxa to species. Training workshops could coincide with annual regional meetings. Regional coordinators can also reach out to natural history museums and other organizations for assistance in identifying important indicator species in each region.

Data infrastructure. Sharing data is critical to the long-term sustainability of the RMNs. Our current goal is to develop one system for sharing RMN data that can be accessed by

RMN members as well as outside users. This system will allow users to see what data are being collected at each site and provide information on data quality so that users can select data that meet their needs and level of rigor. For now, participating organizations should fill out the Excel templates in Appendix K to facilitate data sharing. Using the Excel templates will allow participants to see what is being collected where, at what level of rigor, and by which organizations, but organizations will be responsible for managing the raw data in their existing databases. While the Excel templates provide a temporary solution, an important next step will be to develop or utilize an existing online interface to facilitate the sharing of data and to:

- Develop a program that assists with QA/QC checks on raw data and calculates a standardized set of summary metrics,
- Make the online interface compatible with EPA's WQX, and
- Review commercially available software packages (e.g., Aquarius) and freeware (e.g., Utah State's Observations Data Model services or 52 North's Sensor Observation Service) to help process the continuous data, and discuss their adoption with working groups.

Quality Assurance Project Plan (QAPP). At this time, a QAPP has not been developed specifically for the RMNs, but we are working with regional coordinators to explore this possibility. The QAPPs ensure that data meet quality standards and open up additional funding opportunities. Until an umbrella QAPP for the RMNs is created, efforts will be made to verify that all programs contributing to the effort have a QAPP for their methods.

6.2. FUTURE STEPS

Future steps for the RMNs in the Northeast, Mid-Atlantic, and Southeast regions include the following items.

Reevaluate annually, at least for the first several years. Regional working groups should consider questions like:

- Are we collecting the right data to meet our objectives?
- Is there anything else we should be collecting?
- Is there anything that we should stop collecting?
- Should we make any changes to the collection protocols, such as:
    - Which is more appropriate: a 30- or 60-minute interval for temperature sensors?
    - How big of a difference does 300 versus 200 versus 100 fixed counts make when collecting indicator taxa?
- How large are the data comparability issues that result from differences in collection and processing methodologies?
- Should samples be collected during both spring and summer/early fall index periods?
- Should changes be made to the list of taxa that should be identified to the species-level (see Appendix G)?
- Which biological indicators, thermal, and hydrologic metrics are most sensitive and show the greatest promise for detecting climate change effects?

Conduct a methods comparison study, if different protocols are being used. Although different methodologies can have large effects on community metrics (Bierwagen et al., *in review*), we lack information on how different protocols will affect data being collected at RMN sites in particular. A methods comparison study would provide that information.

Add-ins, as resources permit:

- Collect additional assemblages (fish are higher priority than periphyton).
- Assess the accuracy and precision of temperature sensors and pressure transducers (e.g., perhaps colocate a transducer with a USGS gage and compare results).
- Collect additional replicate biological samples, beyond the existing state, tribal, or RBC QA/QC program requirements (e.g., collect replicate samples within index periods to see whether some important indicator organisms are present in greater numbers during certain dates of the index period). Existing replications sometimes include within-index period replication, but are often focused on defining variability in state/tribal/RBC bioassessment indices rather than variation in presence or relative abundance of specific indicator taxa.
- Collect quantitative measures of physical habitat that are likely to be responsive to climate change effects (e.g., bankfull height and width, measures of incision, measures of bank stability).
- Deploy additional stream temperature sensors at some sites to monitor within-reach variability of thermal regimes and vulnerability to increasing air temperatures.

7. CONCLUSIONS

The Northeast, Mid-Atlantic, and Southeast regions are pilot studies upon which the RMN framework is based and whose data will be used in initial evaluations and data analyses. Other regions that are interested in establishing an RMN can build upon and improve these efforts. The RMN framework is flexible and is not limited to a target population of freshwater wadeable riffle-dominated streams. For example, the processes outlined here can be used to integrate other water body types such as estuaries, lakes, wetlands, and low gradient streams into the RMN framework. While the current focus is on states, tribes, and RBCs, collaborations and partnerships with other organizations, such as academia and volunteer monitoring groups, are encouraged as a way to make the networks more robust. Data collected throughout the various RMNs will further our understanding of biotic and abiotic processes and interactions in streams in order to detect temporal trends; investigate relationships between biological, thermal, and hydrologic data; explore ecosystem responses and recovery from extreme weather events; test hypotheses and predictive models related to climate change; and quantify natural variability. These data will be important inputs for bioassessment programs to continue to protect water quality and aquatic ecosystems under a changing climate.

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APPENDIX A.

REGIONAL WORKING GROUPS

Table A-1. Northeast regional working group

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Table A-2. Mid-Atlantic regional working group

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Table A-3. Southeast regional working group

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APPENDIX B.

CHECKLIST FOR STARTING A REGIONAL MONITORING NETWORK (RMN)

1. Establish the regional working group.

- Coordinator (e.g., from a U.S. EPA Region or a state) volunteers to lead the regional working group.
- The coordinator creates a contact list (see template in Appendix A).
- The coordinator holds a kick-off webinar with EPA to brief the regional working group on the process that will be followed and the timeline (it is ok to include contacts that are interested but not fully committed).

2. The coordinator requests candidate sites from each entity. Considerations include:

- Level of anthropogenic disturbance;
- Length of historical record for biological, thermal, and hydrologic data;
- Level of protection from future anthropogenic disturbance;
- Colocation with existing equipment (e.g., USGS gage);
- Accessibility;
- Environmental conditions and biological potential/classification; and
- Vulnerability to climate change (as available).

3. The regional coordinator compiles information on data collection protocols being used by each regional working group member (see template in Appendix F). The regional working group discusses appropriate data collection protocols for the RMN. During this process, the working group will consider site selection criteria and methods being used in the other regions and will try to use similar protocols where practical. The goal is to generate data that are comparable across the regions. When the regional working group is deciding on protocols, the working group should consider the objectives of the RMN, how different sampling approaches meet or do not meet those objectives, and factors such as:

- What types of habitats are being targeted?
- What collection gear is being used (e.g., artificial substrate vs. kick nets)?
- How big are the differences in sampling protocols across entities?
- What effects will these differences have on the RMN indicators?
- How long have data been collected at candidate RMN sites with different sampling methods?

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 “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 from the regional working group on existing climate change vulnerability assessments and performing broad-scale analyses similar to what was done in the eastern United States to rate vulnerability of the candidate RMN sites to climate change.

5. The regional working group evaluates results of these analyses and designates primary and secondary RMN sites.

6. The regional coordinator works with regional working group members to help find resources for implementation. High priority items 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 REGIONS

Table C-1. Site information for primary RMN sites in the Northeast (4/2/2014). Drainage area, slope, and elevation are estimates based on NHDPlus v1[a] local catchment data. Percent 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)	% 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_Browns	Browns	14.7	0.023	253.5	87.3
−73.03027	42.66697	MA	MA DEP	MADEP_Cold	Cold River	17.7	0.026	592.4	89.3
−72.96731	42.06555	MA	MA DEP	MADEP_B0215	Hubbard	30.0	0.029	359.8	86.5
−72.04780	42.39431	MA	MA DEP	MADEP_Parkers	Parkers Brook	13.8	0.011	244.9	79.5
−72.38454	42.46471	MA	MA DEP	MADEP_WBrSwift	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

Table C-1. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Drainage area (km^2)	Slope (unitless)	Elevation (m)	% Forest
−72.66250	42.76389	VT	VT DEC	VTDEC_670000000166	Green	67.8	0.010	293.3	89.9
−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 (4/2/2014)

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_Browns	Browns	water and air	pressure transducer	stage	
MA	MA DEP	MADEP_Cold	Cold River	water and air	pressure transducer	stage	
MA	MA DEP	MADEP_B0215	Hubbard	water and air	USGS gage (01187300)	discharge	gage is downstream of site but location looks representative of stream conditions
MA	MA DEP	MADEP_Parkers	Parkers Brook	water and air	pressure transducer	stage	
MA	MA DEP	MADEP_WBrSwift	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*	USGS gage (01048220)	discharge	gage located at biological sampling site
NH	NH DES	NHDES_99M-44	Bear	water	pressure transducer	stage	
NH	NH DES	USGS_01064300	Ellis	water	pressure transducer	stage	
NH	NH DES	NHDES_19-ISR	Israel	water	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_98S-44	Paugus	water	pressure transducer	stage	
NH	NH DES	NHDES_WildAmmo	Wild Ammo	water	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*	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	none	none	planning to install a transducer in 2014
VT	VT DEC	VTDEC_495400000161	North Branch Winooski	water	none	none	
VT	VT DEC	VTDEC_033500000081	Winhall	water*	none	none	

*not deployed year-round

Table C-3. Site information for primary RMN sites in the Mid-Atlantic (4/2/2014). Most drainage area, slope, and elevation measurements are estimates based on NHDPlus v1[a] local catchment data. Percent 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)	% 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	USGS_01378780	Primrose	0.01	0.014	123.6	
−77.45100	39.89700	PA	PA DEP	PADEP_Carbaugh	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	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	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
−78.32446	38.74832	VA	Shen NP	1BJER009.67	Jeremys Run (upper)	2.0	0.030	479.1	83.6
−80.57420	37.37265	VA	VDEQ	9-LRY006.90	Little Stony Creek	48.0	0.061	968.1	97.4

Table C-3. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Drainage area (km^2)	Slope (unitless)	Elevation (m)	% Forest
−78.26867	38.70296	VA	Shen NP	3-PIY003.27	Piney River	10.0	0.047	578.8	96.1
−79.34634	38.32267	VA	VDGIF	2-RAM007.29	Ramseys Draft	20.0	0.020	868.7	94.0
−80.30465	36.81065	VA	VDEQ	4ARCC006.89	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	1099.0	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	1078.6	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	1143.6	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 (4/2/2014)

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 2014
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			
MD	MD DNR	PRLN-626-S	Mill Run	water and air			
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				planning to install a water and air temperature sensor in 2014; applied for a grant to get a USGS gage here
NJ	NJ DEP	AN0260	Mossmans Brook				planning to install a water and air temperature sensor in 2014
NJ	NJ DEP		Primrose		USGS staff gage (01378780)	occasional stage	planning to install a water and air temperature sensor in 2014; applied for a grant to get a USGS gage here
PA	PA DEP		Carbaugh Run				planning to install a water and air temperature sensor and possibly a pressure transducer in 2014

Table C-4. continued…

State	Entity	Station ID	Water body name	Temperature	Hydrologic equipment	Hydrologic data type	Notes
PA	SRBC	SRBC_Grays	Grays Run	water	pressure transducer	stage	planning to install an air temperature sensor in 2014
PA	PA DEP	WQN_734	Jones Mill Run				planning to install a water and air temperature sensor in 2014
PA	SRBC	SRBC_Kettle	Kettle	water	pressure transducer	stage	planning to install an air temperature sensor in 2014
PA	PA DEP	WQN_873	West Branch of Caldwell Creek				planning to install a water and air temperature sensor in 2014
VA	VDEQ	2-HUO005.87	Hunting Creek				planning to install a water and air temperature sensor in 2014
VA	Shen NP	1BJER009.67	Jeremys Run (upper)				gage nearby in another drainage, possibly on North Fork Dry Run
VA	VDEQ	9-LRY006.90	Little Stony Creek				planning to install a water and air temperature sensor in 2014
VA	Shen NP	3-PIY003.27	Piney River		Unconfirmed gage		planning to install a water and air temperature sensor in 2014
VA	VDGIF	2-RAM007.29	Ramseys Draft				planning to install a water and air temperature sensor in 2014
VA	VDEQ	4ARCC006.89	Rock Castle Creek				planning to install a water and air temperature sensor in 2014
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			

Table C-4. continued…

State	Entity	Station ID	Water body name	Temperature	Hydrologic equipment	Hydrologic data type	Notes
WV	WV DEP	2571	East Fork/Greenbrier River	water and air			
WV	WV DEP	8756	Seneca Creek	water and air			
WV	WV DEP	2039	South Fork/Cranberry River	water and air			

Table C-5. Site information for primary RMN sites in the Southeast (4/2/2014). 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. Percent 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)	% 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

Table C-5. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Drainage area (km^2)	Slope (unitless)	Elevation (m)	% Forest
−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
−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 (4/2/2014). 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	
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	

Table C-6. continued…

State	Entity	Station ID	Water body name	Temperature	Hydrologic equipment	Hydrologic data type	Notes
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

We performed a screening exercise on the preliminary regional monitoring network (RMN) sites to determine where the sites fall along a standardized disturbance gradient, using data that are available for the entire study area and that are derived using common data sources and methodologies. This allows us to apply this framework within and across regions. We will be using a similar framework for the resiliency component of our climate change vulnerability assessment.

Our screening process has limitations. For one, it is relatively coarse. As an example, we did not do exact watershed delineations when deriving the land use data. Instead, the land cover screenings are estimates based on data associated with the National Hydrography Dataset Plus Version 1 (NHDPlusV1) catchments where the sites are located (U.S. EPA and USGS, 2006). While this approach generally provides a good approximation, sometimes there are discrepancies, which are described in Section D.2.1. Thus, we are soliciting feedback from experts in each state to help provide "ground truth" for our data and identify sites where our results seem inaccurate.

Some sites have higher levels of disturbance than others. This is not necessarily grounds for exclusion from the "core" group of sites that we are considering for the RMNs. In fact, depending on how sites fall out along this gradient, we may be interested in targeting sites with certain types of disturbance. That being said, we do want to make sure we have sufficient representation of minimally disturbed sites in the RMNs. This is because:

- Minimally disturbed sites are the standard against which other sites are compared; thus, it is critical to track changes at these sites over time.
- There is a better chance of distinguishing climate-related impacts at these sites versus those being impacted by other stressors.
- A lack of long-term biological, thermal, and hydrologic data has been documented at these types of sites (e.g., U.S. EPA, 2012; Mazor et al., 2009; Jackson and Fureder, 2006; Kennen et al., 2011).

D.2. METHODOLOGY

We used Geographic Information System software (ArcGIS 10.0) to spatially join the preliminary RMN sites with NHDPlusV1 catchments (U.S. EPA and USGS, 2006). Each NHDPlusV1 catchment has a unique identifier called a COMID. Many data were linked to sites via this COMID.

We performed three different types of disturbance screenings:

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 non-climatic 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).

We selected our data with the following considerations in mind:

- Are they meaningful for assessing biological habitat?
- Do they have sufficient spatial coverage?
- Were they derived using consistent methods and procedures?
- Are they representative of conditions in the past 10 years?
- Are they of sufficient spatial resolution to allow for valid comparisons across catchments?

These considerations are in keeping with the 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

Our 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, we will refer to the total watershed scale 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.

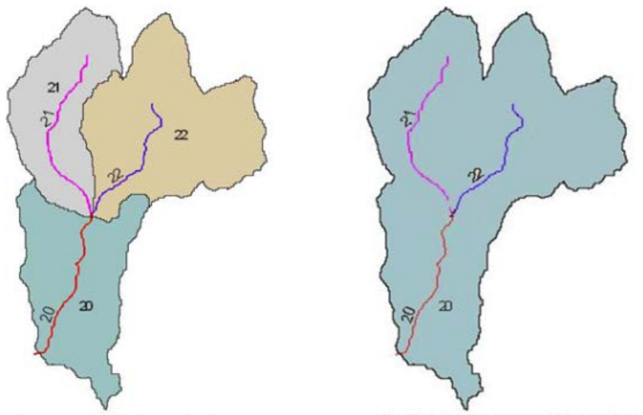

Figure D-1. Land use data were evaluated at both the (A) local catchment and (B) total watershed scales, using NHDPlusV1 delineations (U.S. EPA and USGS, 2006).

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 we lack information on whether landscape disturbance mitigation measures are being applied in a given catchment, and if so, how effective those measures are. Thus, we have to assume that the impacts associated with each land use type are equal.

Another limitation of our preliminary land use screening is that the data are not based on exact watershed delineations. Rather the data are associated with the entire catchment where the site is located, regardless of where the site falls within the catchment. We would have preferred to use data based on exact watershed delineations for our initial screening, but we lacked the resources needed to do exact watershed delineations for all of the candidate sites. The estimates that we 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. Thus, we are checking with each entity to verify that our data match with expectations.

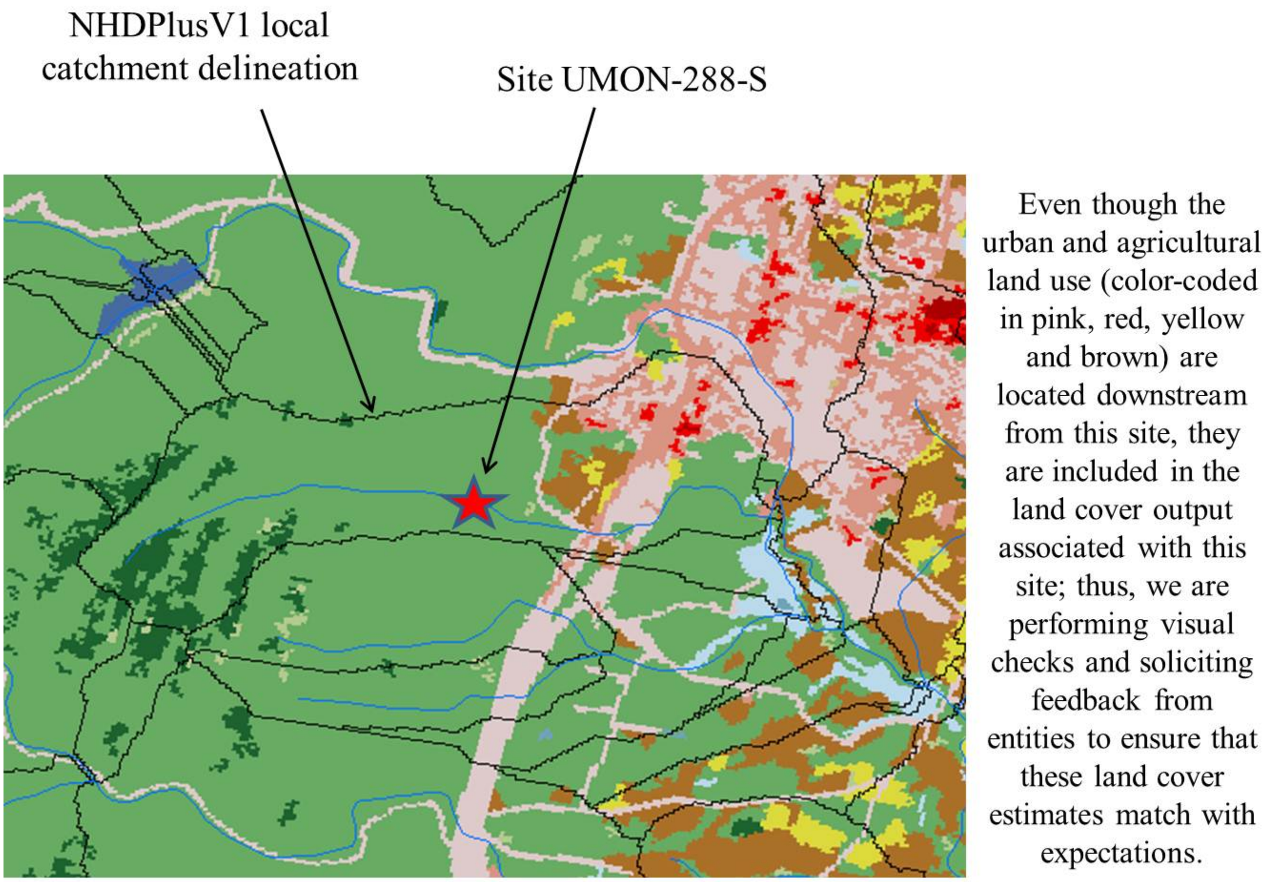

Figure D-2. Example of a situation in which the land use output for a site is inaccurate.

We assessed land use disturbance 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)

We developed a land use disturbance scale with six levels. Thresholds for each parameter are listed in Table D-1. It should be noted that these thresholds are arbitrary, although some research provides guidelines for these levels (e.g., King and Baker, 2010; Carlisle et al., 2008). When rating a site, we first assessed each parameter separately. If the parameter values at the local catchment and network scales differed, we applied the thresholds to the maximum value. For example, if a site has 2% urban land cover at the local catchment scale and 1% urban land cover at the network scale, we applied the threshold 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

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

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, we are checking with each entity to verify that our disturbance level assignments match with expectations.

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	% Impervious	% Urban	% Crops	% 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 our second set of screening, we flagged sites that 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. We considered both the proximity of these stressors to the sites as well as the attribute data associated with each stressor. 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.

We used the following screening procedures:

1. We gathered the data listed in Table D-2.
2. Using GIS software (ArcGIS 10.0), we created a 1-km buffer around the preliminary RMN sites (this included both the upstream and downstream areas).
3. Using GIS software (ArcGIS 10.0), we performed a procedure to identify whether any dams, mines, NPDES major discharges or SNPL sites were located within the 1-km buffer.
4. If so, we flagged those sites and assessed the likelihood of impact based on the following considerations:
    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).

We used best professional judgment 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.

We performed one additional check 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, 2006). If the site was located on a flowline designated as something other than a stream/river, the site was flagged.

As a final step, we checked with each entity to verify that our assessments match with the expectations.

D.2.3. Likelihood of impact from other non-climatic stressors

In our third set of screening, we flagged sites that 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

Stressor	Source
Dams	National Atlas of the United States. 2006. Major Dams of the United States: National Atlas of the United States, Reston, VA. Available online: http://nationalatlas.gov/atlasftp.html#dams00x
Mines	U.S. Geological Survey (USGS). 2005. Active mines and mineral processing plants in the United States in 2003. http://tin.er.usgs.gov/metadata/mineplant.faq.html
	Pennsylvania industrial mine permits—Pennsylvania Spatial Data Access (PASDA). 2013. Data Download—Mine and refuse permits. Available online: http://www.pasda.psu.edu
National Pollutant Discharge Elimination System (NPDES) major discharges from the Permit Compliance System	U.S. Environmental Protection Agency. Geospatial data download service—Geospatial information for all publicly available FRS facilities that have latitude/longitude data [file geodatabase]. Accessed August 27, 2013. Available online: http://www.epa.gov/enviro/geo_data.html
Superfund National Priorities List (SNPL) from the Compensation and Liability Information System	

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.

Because of these factors, we decided to assess the likelihood of impact based on a relative scale instead of by setting firm thresholds. The relative scales were based on values found in NHDPlusV1 catchments across the entire study area. If a site rated on the high end of the risk scale, we flagged it for further evaluation. We then checked with entities to find out their thoughts on the degree of impact and inquired about the availability of more detailed data to help us 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.

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

Stressor	Parameters/description	Source
Roads	Length of roads, local catchment, and network scales	U.S. Census Bureau (2000) from DFW MSU et al. (2011)
	Number of road crossings, local catchment, and network scales	
Atmospheric deposition	NO_3 and SO_4 concentrations, based on 2011 deposition grids	NADP[a] (2013)
	The Nature Conservancy (TNC) geology class	Olivero and Anderson (2008)
Coal mining	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	Coal fields (USGS, Eastern Energy Team, 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)]
	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	Alabama (Alabama Surface Mining Commission, 2013) Pennsylvania (PA SDA, 2013) West Virginia (WV DEP TAGIS, 2013; WV GES, 2014) Virginia (VA DEQ-DMLR, 2013)

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

D.2.3.1. *Roads*

We assessed two aspects of potential road impacts:

- Length of roads and
- Number of road crossings

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

Next, to assess the likelihood of impact from length of roads, we used the following formulas 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 (km2)

Then, we used the following formula 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, we used the maximum score for our assessment. For example, if the local catchment score was 80 and the network score was 50, we used the higher score of 80 for our assessment.

We flagged sites 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 entities for input on the degree of impact at flagged sites. This is important because entities have local knowledge about these sites. Also, our data are not based on exact watershed delineations. Rather, the data are associated with the entire catchment in which the site is located, regardless of where a site falls within the catchment. While this generally provides a good approximation, sometimes inaccuracies occur, as described in Section D.2.1 and Figure D-2.

D.2.3.2. *Atmospheric deposition*

We assessed two aspects of atmospheric deposition:

- Concentrations of NO_3
- Concentrations of SO_4

In addition, we considered TNC geology class (Olivero and Anderson, 2008) as a potential mediating factor. First we gathered the data listed in Table C-3. Using GIS software (ArcGIS 10.0), we linked the NO_3 and SO_4 deposition grid data (1-km resolution) to the sites. Next, we took the average of NO_3 and SO_4. Then, we used the following formula 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):

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

We flagged sites 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, we used GIS software (ArcGIS 10.0) 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.

We flagged sites if they received a score of 100%.

As a final step, we consulted with entities to discuss the degree of impact at flagged sites. This is important because entities have local knowledge about these sites. Also, they may have 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*

We assessed two aspects of coal mining:

- Potential for mining
- Permit activity

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

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

- Whether the site is located in an area that has been designated as a mountaintop removal (MTR) area and/or a coal field (USGS, Eastern Energy Team, 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)].

We performed the following steps when assessing a site for **mining potential**:

1. First we assigned a coal field score, as follows:
   - Using GIS software (ArcGIS 10.0), we linked the coal field and MTR GIS layers to the sites.
   - If the site is located in a catchment that has been designated as a "potentially minable" coal field (USGS, Eastern Energy Team, 2001) and/or a mountaintop removal (MTR) area, we assigned it a score of 1.
   - If the site is located in a catchment that has been designated as a coal field with "other uses" (USGS, Eastern Energy Team, 2001), we assigned it 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 we assigned a coal production score, 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**, we multiplied the coal field score by the coal production score. Scores ranged from 0 (no mining potential) to 100 (highest potential for mining).

We flagged sites 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, we assessed permit activity on a state-by-state basis. If sites were located in states where permit data were available, we performed the following steps to assess the intensity of **permit activity**:

1. We gathered the permit data listed in Table D-3.
2. Using GIS software (ArcGIS 10.0), we created a 1-km buffer around the preliminary RMN sites (this included both the upstream and downstream areas).
3. Using GIS software (ArcGIS 10.0), we performed 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):

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

We flagged sites for further evaluation if they received a score of >0.

As a final step, we checked with entities to find out their thoughts on the degree of impact at flagged sites. This is important because entities have local knowledge about these sites and may have access to more detailed data. 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*

We assessed two aspects of shall gas drilling:

- Potential for drilling
- Permit activity

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

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

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

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

1. We gathered the permit data listed in Table D-3.
2. Using GIS software (ArcGIS 10.0), we created a 1-km buffer around the preliminary RMN sites (this included both the upstream and downstream areas).
3. Using GIS software (ArcGIS 10.0), we performed 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):

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

We flagged sites for further evaluation if they received a score of >0%.

As a final step, we checked with entities to find out their thoughts on the degree of impact at flagged sites. This is important because entities have local knowledge about these sites and may have access to more detailed data. 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*

We used EPA's ICLUS tools and data sets (Version 1.3 and 1.3.1) (U.S. EPA, 2011) to assess the potential that a site will experience future urban development. We used the ICLUS Tools 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).

First we used GIS software (ArcGIS 10.0) 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 entities to find out their thoughts on the potential for future development at flagged sites. This is important because entities have local knowledge about these sites and may have access to more detailed information on the potential for future development in areas near the sites.

D.2.3.6. *Water withdrawals*

We assessed three aspects of water use:

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

First we gathered the data listed in Table D-3. These data are based on 2005 water use and are only available at the county-level (USGS, 2010). Then we used GIS software (ArcGIS 10.0) to associate the county-level data with NHDPlusV1 local catchments. Next we linked sites with NHDPlusV1 local catchments. For each parameter, we used the following formula 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):

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

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

As a final step, we consulted with entities to discuss the potential for impacts from water withdrawals at the flagged sites. This is important because entities have local knowledge about these sites and may have access to more detailed information on water use in areas near the sites.

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APPENDIX E.

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

At this time there are no secondary sites in the Southeast region

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

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−72.7439	43.7667	VT	VT DEC	130000000319	White River	VT DEC sentinel site
−72.7464	43.7708	VT	VT DEC	130000000324	White River	VT DEC sentinel site
−72.8952	43.8714	VT	VT DEC	135404000018	Bingo Brook	VT DEC sentinel site
−72.9458	43.8556	VT	VT DEC	135411000013	Smith Brook	VT DEC sentinel site
−72.1542	43.9917	VT	VT DEC	170000000026	Waits River	VT DEC sentinel site
−72.1614	44.4911	VT	VT DEC	211109100032	Pope Brook	VT DEC sentinel site; USGS gage (01135150)
−71.6356	44.7522	VT	VT DEC	280000000002	Nulhegan River	VT DEC sentinel site
−71.6356	44.7550	VT	VT DEC	280000000003	Nulhegan River	VT DEC sentinel site
−72.7819	44.5036	VT	VT DEC	493238200015	Ranch Brook	VT DEC sentinel site; USGS gage (04288230)
−73.2336	44.2486	VT	VT DEC	530000000035	Lewis Creek	VT DEC sentinel site
−73.2292	44.2483	VT	VT DEC	530000000037	Lewis Creek	VT DEC sentinel site
−72.7472	42.7469	VT	VT DEC	660600000117	East Branch North River	VT DEC sentinel site
−72.9384	42.0356	CT	CT DEEP	1156	Hubbard Brook	CT DEEP sentinel site; colocated with USGS gage (01187300)
−72.3289	41.4100	CT	CT DEEP	1236	Beaver Brook	CT DEEP sentinel site
−72.3343	41.4603	CT	CT DEEP	1239	Burnhams Brook	CT DEEP sentinel site

Table E-1. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−72.82146	41.93717	CT	CT DEEP	359	West Branch Salmon	CT DEEP sentinel site
−73.2155	41.5575	CT	CT DEEP	1468	Weekepeemee River	CT DEEP sentinel site; colocated with USGS gage (01203805)
−72.5365	41.6615	CT	CT DEEP	2295	Mott Hill Brook	CT DEEP sentinel site
−72.4226	41.4283	CT	CT DEEP	2297	Hemlock Valley Brook	CT DEEP sentinel site
−73.1214	41.9328	CT	CT DEEP	2299	Rugg Brook	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	CT DEEP sentinel site
−73.1679	41.8646	CT	CT DEEP	2312	Jakes Brook	CT DEEP sentinel site
−72.1509	41.7812	CT	CT DEEP	2331	Stonehouse Brook	CT DEEP sentinel site
−73.3678	41.2931	CT	CT DEEP	2346	Little River	CT DEEP sentinel site
−73.1745	41.5783	CT	CT DEEP	2676	Nonewaug River	CT DEEP sentinel site; USGS gage (01203600)
−72.9630	41.7807	CT	CT DEEP	2711	Bunnell Brook	CT DEEP sentinel site; USGS gage (01188000)
−72.4640	41.8272	CT	CT DEEP	345	Tankerhoosen River	CT DEEP sentinel site
−72.1256	41.9199	CT	CT DEEP	2532	Branch	initially selected as a primary RMN site but not being sampled annually for benthic macroinvertebrates
−72.3372	41.4671	CT	CT DEEP	1092	Eightmile	initially selected as a primary RMN site but not being sampled annually for benthic

Table E-1. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
						macroinvertebrates
−69.0440	44.3143	ME	ME DEP	MEDEP_57368	Ducktrap River—Station 626	initially selected as a primary RMN site but not being sampled annually for benthic macroinvertebrates; USGS gage (01037380)—air and water temperature, discharge
−70.3620	44.8553	ME	ME DEP	MEDEP_56760	Sandy River—Station 17	initially selected as a primary RMN site but not being sampled annually for benthic macroinvertebrates; USGS gage (01047200)—discharge, but too far away to be representative?
−70.6035	44.6826	ME	ME DEP	MEDEP_57089	Swift River—Station 346	initially selected as a primary RMN site but not being sampled annually for benthic macroinvertebrates; USGS gage (01055000)—discharge, air temperature
−69.5933	44.2232	ME	ME DEP	MEDEP_56817	Sheepscot River—Station 74	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	ME DEP long-term biological monitoring site
−68.2346	44.3934	ME	ME DEP	MEDEP_57065	Duck Brook—Station 322	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

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−79.21349	39.54119	MD	MD DNR	SAVA-276-S	Double Lick Run	MD DNR sentinel site—Highlands
−78.45571	39.68672	MD	MD DNR	FIMI-207-S	Fifteen Mile Creek	MD DNR sentinel site—Highlands
−77.54528	39.65833	MD	MD DNR	ANTI-101-S	Unnamed tributary to Edgemont Reservoir	MD DNR sentinel site—Highlands
−77.48935	39.58739	MD	MD DNR	UMON-119-S	Buzzard Branch	MD DNR sentinel site—Highlands
−76.97198	39.16949	MD	MD DNR	RKGR-119-S	Unnamed tributary to Patuxent River	MD DNR sentinel site—Highlands
−76.86417	39.44055	MD	MD DNR	LIBE-102-S	Timber Run	MD DNR sentinel site—Highlands
−76.71875	39.42925	MD	MD DNR	JONE-315-S	North Branch of Jones Falls	MD DNR sentinel site—Highlands
−76.69843	39.43951	MD	MD DNR	JONE-109-S	Unnamed tributary to Dipping Pond Run	MD DNR sentinel site—Highlands
−76.69829	39.48052	MD	MD DNR	LOCH-120-S	Baisman Run	MD DNR sentinel site—Highlands
−76.04611	39.61055	MD	MD DNR	FURN-101-S	Unnamed tributary to Principio Creek	MD DNR sentinel site—Highlands
−75.46182	38.26359	MD	MD DNR	NASS-302-S-2012	Nassawango Creek	MD DNR sentinel site—Coastal Plain

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−75.49247	38.24950	MD	MD DNR	NASS-108-S-2012	Millville Creek	MD DNR sentinel site—Coastal Plain
−75.59259	38.41408	MD	MD DNR	WIRH-220-S-2012	Leonard Pond Run	MD DNR sentinel site—Coastal Plain
−75.78362	39.28768	MD	MD DNR	UPCR-208-S-2012	Cypress Branch	MD DNR sentinel site—Coastal Plain
−75.96062	38.72408	MD	MD DNR	UPCK-113-S-2012	Unnamed tributary to Skeleton Creek	MD DNR sentinel site—Coastal Plain
−76.09499	39.08754	MD	MD DNR	CORS-102-S-2012	Unnamed tributary to Emory Creek	MD DNR sentinel site—Coastal Plain
−76.21896	39.19352	MD	MD DNR	LOCR-102-S-2012	Swan Creek	MD DNR sentinel site—Coastal Plain
−76.73717	38.36662	MD	MD DNR	STCL-051-S-2012	Unnamed tributary to St. Clements Creek	MD DNR sentinel site—Coastal Plain
−76.76012	38.56392	MD	MD DNR	PAXL-294-S-2012	Swanson Creek	MD DNR sentinel site—Coastal Plain
−76.90348	38.49936	MD	MD DNR	ZEKI-012-S-2012	Unnamed tributary to Zekiah Swamp Run	MD DNR sentinel site—Coastal Plain
−77.02912	38.51108	MD	MD DNR	PTOB-002-S-2012	Hoghole Run	MD DNR sentinel site—Coastal Plain
−77.08594	38.48386	MD	MD DNR	NANJ-331-S-2012	Mill Run	MD DNR sentinel site—Coastal Plain
−77.09766	38.58225	MD	MD DNR	MATT-033-S-2012	Mattawoman Creek	MD DNR sentinel site—Coastal Plain

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−74.88980	40.77471	NJ	EPA R2	1	Unnamed tributary to Musconetcong River	long-term monitoring site—Jim Kurtenbach (U.S. EPA R2)
−74.84479	40.75211	NJ	EPA R2	2	Teetertown Brook	long-term monitoring site—Jim Kurtenbach (U.S. EPA R2)
−74.50486	40.95164	NJ	EPA R2	17	Hibernia Brook	long-term monitoring site—Jim Kurtenbach (U.S. EPA R2)
−75.12652	40.97400	NJ	NPS—ERMN	DEWA.3005	Dunnfield Creek 03	
−75.10517	40.98337	NJ	NPS—ERMN	DEWA.3033	Dunnfield Creek 26	
−74.94059	41.08567	NJ	NPS—ERMN	DEWA.3026	Unnamed tributary Vancampens Brook 05	
−74.98445	41.06470	NJ	NPS—ERMN	DEWA.3025	Vancampens Brook 22	NPS—ERMN high priority
−74.96505	41.07109	NJ	NPS—ERMN	DEWA.3014	Vancampens Brook 43	
−74.94123	41.09062	NJ	NPS—ERMN	DEWA.3038	Vancampens Brook 76	
−74.92372	41.09674	NJ	NPS—ERMN	DEWA.3010	Vancampens Brook 95	
−74.79550	41.29461	NJ	NPS—ERMN	DEWA.3028	White Brook 15	
−75.00528	41.03179	NJ	NPS—ERMN	DEWA.3030	Yards Creek 07	
−74.50528	39.88500	NJ	USGS	USGS 01466500	McDonalds Branch	USGS gage in Byrne State Forest (Pine Barrens)
−77.73670	42.31903	NY	SRBC	CANA	Canacadea Creek	precip gage
−77.37918	42.07520	NY	SRBC	Tuscarora	Tuscarora Creek	pressure transducer (real-time)
−76.92222	42.10278	NY	SRBC	SING 0.9	Sing Sing Creek	

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−76.72019	42.04209	NY	SRBC	Baldwin	Baldwin Creek	precip gage
−76.47508	42.20472	NY	SRBC	Catatonk	Catatonk Creek	pressure transducer (stand-alone)
−76.15029	42.06312	NY	SRBC	Apal	Apalachin Creek	precip gage
−76.10589	42.59277	NY	SRBC	Trout Brook	Trout Brook	precip gage
−76.05357	42.20426	NY	SRBC	Nanticoke	Nanticoke Creek	
−76.00931	42.01582	NY	SRBC	CHOC	Choconut Creek	pressure transducer (stand-alone)
−75.50220	42.77596	NY	SRBC	Sangerfield	Sangerfield River	
−74.79921	42.70639	NY	SRBC	Cherry	Cherry Valley Creek	
−75.323216	41.73465	PA	DRBC	MB_Dyberry	Middle Branch Dyberry Creek	
−74.86975	41.24147	PA	NPS—ERMN	DEWA.3027	Adams Creek 03	NPS—ERMN high priority
−74.87711	41.24882	PA	NPS—ERMN	DEWA.3011	Adams Creek 14	
−74.88168	41.25185	PA	NPS—ERMN	DEWA.3039	Adams Creek 21	
−74.89043	41.25780	PA	NPS—ERMN	DEWA.3012	Adams Creek 33	
−78.45247	40.41597	PA	NPS—ERMN		Blair Gap Run—Foot of Ten	
−78.51846	40.43269	PA	NPS—ERMN		Blair Gap Run—Muleshoe	
−75.14398	40.97139	PA	NPS—ERMN	DEWA.3001	Caledonia Creek 13	NPS—ERMN high priority
−74.90309	41.19744	PA	NPS—ERMN	DEWA.3003	Deckers Creek 03	
−74.87464	41.22245	PA	NPS—ERMN	DEWA.3004	Dingmans Creek 05	
−74.89481	41.23067	PA	NPS—ERMN	DEWA.3031	Dingmans Creek 30	

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−74.90343	41.23052	PA	NPS—ERMN	DEWA.3015	Dingmans Creek 39	
−74.91831	41.23772	PA	NPS—ERMN	DEWA.3008	Dingmans Creek 57	
−79.92348	39.78393	PA	NPS—ERMN		Dublin Run	
−79.58149	39.81449	PA	NPS—ERMN		Great Meadows Run	
−74.89987	41.19356	PA	NPS—ERMN	DEWA.3035	Hornbecks Creek 15	
−79.93024	39.78248	PA	NPS—ERMN		Ice Pond Run	
−80.97161	37.58466	PA	NPS—ERMN		Little Bluestone River	
−75.00533	41.09383	PA	NPS—ERMN	DEWA.3013	Little Bushkill Creek 01	
−74.92431	41.15917	PA	NPS—ERMN	DEWA.3036	Mill Creek 12	
−74.92673	41.16889	PA	NPS—ERMN	DEWA.3020	Mill Creek 25	
−78.48373	40.41876	PA	NPS—ERMN		Milllstone Run	
−81.02055	37.53483	PA	NPS—ERMN		Mountain Creek	
−74.84545	41.29520	PA	NPS—ERMN	DEWA.3032	Raymondskill Creek 13	
−75.01434	41.08235	PA	NPS—ERMN	DEWA.3029	Sand Hill Creek 08	
−74.90598	41.17560	PA	NPS—ERMN	DEWA.3007	Spackmans Creek 08	
−74.95645	41.12711	PA	NPS—ERMN	DEWA.3034	Toms Creek 03	
−74.95916	41.12946	PA	NPS—ERMN	DEWA.3018	Toms Creek 07	
−74.96252	41.13729	PA	NPS—ERMN	DEWA.3006	Toms Creek 20	
−74.96279	41.14150	PA	NPS—ERMN	DEWA.3022	Toms Creek 25	

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−74.88573	41.23542	PA	NPS—ERMN	DEWA.3023	Unnamed tributary Dingmans Creek 07	
−79.59970	39.81014	PA	NPS—ERMN		Unnamed tributary (Scotts Run)	
−74.98444	41.11381	PA	NPS—ERMN	DEWA.3002	Van Campen Creek 12	
−76.91134	41.32519	PA	PA DEP	WQN_408	Loyalsock Creek	long-term data, EV (protected)
−78.80331	40.69289	PA	SRBC	WB SUS	West Branch Susquehanna River	pressure transducer (stand-alone)
−78.64757	40.63052	PA	SRBC	CHEST	Chest Creek	
−78.59258	40.26388	PA	SRBC	BOBS	Bobs Creek	pressure transducer (real-time) and precip gage
−78.46158	41.04564	PA	SRBC	PA_Moose	Moose Creek	
−78.40722	40.97000	PA	SRBC	LCLF0.1	Little Clearfield Creek	
−78.36118	41.07359	PA	SRBC	TROT	Trout Run	pressure transducer (real-time) and precip gage
−78.27484	41.49444	PA	SRBC	West	West Creek	
−78.27008	41.52649	PA	SRBC	Driftwood	Driftwood Branch Sinnemahoning Creek	pressure transducer (real-time)
−78.25348	41.36235	PA	SRBC	Hicks	Hicks Run	
−78.22029	41.51169	PA	SRBC	Portage	Portage Creek	
−78.17458	41.45256	PA	SRBC	Hunts	Hunts Run	precip gage

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−77.91244	41.57467	PA	SRBC	East Fork	East Fork First Fork Sinnemahoning Creek	
−77.76387	41.79146	PA	SRBC	Ninemile	Ninemile Run	precip gage
−77.76123	41.79011	PA	SRBC	Upper Pine	Pine Creek	pressure transducer (real-time)
−77.68520	41.40016	PA	SRBC	Young	Young Woman's Creek	
−77.66985	41.72483	PA	SRBC	WPIN	West Branch Pine Creek	
−77.60997	41.06022	PA	SRBC	MARS	Marsh Creek	
−77.60667	41.24694	PA	SRBC	BAKR0.1	Baker Run	pressure transducer (real-time) and precip gage
−77.58154	41.73642	PA	SRBC	ELKR	Elk Run	
−77.55928	41.76142	PA	SRBC	Long	Long Run	
−77.45056	41.64694	PA	SRBC	Pine Blackwell	Pine Creek	
−77.41333	41.76306	PA	SRBC	Marsh Tioga	Marsh Creek	
−77.36278	41.31000	PA	SRBC	LPIN0.2	Little Pine Creek	
−77.29313	41.85752	PA	SRBC	CROK	Crooked Creek	
−77.23044	41.47393	PA	SRBC	BLOC	Blockhouse Creek	precip gage
−77.18943	41.32739	PA	SRBC	LARR	Larrys Creek	
−76.92300	41.49143	PA	SRBC	Ples	Pleasant Stream	
−76.91416	41.70931	PA	SRBC	TIOG	Tioga River	
−76.91233	41.99164	PA	SRBC	HAMM	Hammond Creek	

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−76.76835	41.78974	PA	SRBC	SUGR	Sugar Creek	
−76.76011	41.65262	PA	SRBC	TOWA	Towanda Creek	
−76.64148	41.19353	PA	SRBC	LMUN	Little Muncy Creek	
−76.60723	41.78132	PA	SRBC	TOMJ	Tomjack Creek	
−76.34434	41.32261	PA	SRBC	EBFC	East Branch Fishing Creek	
−76.33104	41.45880	PA	SRBC	LYSK5.0	Loyalsock Creek	pressure transducer (real-time) and precip gage
−76.28083	41.96661	PA	SRBC	WAPP	Wappasening Creek	
−76.27436	41.62644	PA	SRBC	Sugar Run	Sugar Run	
−76.24282	41.23366	PA	SRBC	Kitchen	Kitchen Creek	
−76.07111	41.78832	PA	SRBC	EBWC	East Branch Wyalusing Creek	
−76.06980	41.58154	PA	SRBC	LMEHOOP	Little Mehoopany Creek	pressure transducer (real-time)
−76.02756	41.42725	PA	SRBC	BOWN	Bowman Creek	
−75.98474	41.61164	PA	SRBC	MESH	Meshoppen Creek	pressure transducer (stand-alone)
−75.84137	41.92994	PA	SRBC	SNAK	Snake Creek	pressure transducer (stand-alone)
−75.77788	41.55783	PA	SRBC	SBTK	South Branch Tunkhannock Creek	pressure transducer (real-time)
−75.52351	41.95946	PA	SRBC	STAR	Starrucca Creek	
−75.47324	41.68331	PA	SRBC	LACK	Lackawanna River	
−81.08737	37.96331	WV	NPS—ERMN	NERI.3038	Arbuckle Creek 2	

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−81.09031	37.96421	WV	NPS—ERMN	NERI.3054	Arbuckle Creek 5	
−81.10399	37.84261	WV	NPS—ERMN	NERI.3064	Batoff Creek 7	
−80.90375	37.71400	WV	NPS—ERMN	NERI.3024	Big Branch 10	
−80.90266	37.71391	WV	NPS—ERMN	NERI.3072	Big Branch 9	
−80.95156	37.87324	WV	NPS—ERMN	NERI.3042	Bucklick Branch 3	
−81.01278	37.91956	WV	NPS—ERMN	NERI.3005	Buffalo Creek 16	
−81.02195	37.91346	WV	NPS—ERMN	NERI.3069	Buffalo Creek 4	NPS—ERMN high priority; WV DEP reference site
−81.04551	37.87994	WV	NPS—ERMN	NERI.3013	Dowdy Creek 16	
−81.05947	37.88203	WV	NPS—ERMN	NERI.3077	Dowdy Creek 2	
−81.03647	37.87402	WV	NPS—ERMN	NERI.3025	Dowdy Creek 30	
−81.01287	37.96168	WV	NPS—ERMN	NERI.3050	Ephraim Creek 8	NPS—ERMN high priority; WV DEP reference site
−80.93452	37.74875	WV	NPS—ERMN	NERI.3100	Fall Branch 10	
−80.93170	37.74969	WV	NPS—ERMN	NERI.3052	Fall Branch 7	NPS—ERMN high priority; WV DEP reference site
−81.06012	38.06032	WV	NPS—ERMN	NERI.3035	Fern Creek 11	
−81.05947	38.06101	WV	NPS—ERMN	NERI.3099	Fern Creek 12	
−81.02453	37.94417	WV	NPS—ERMN	NERI.3021	Fire Creek 17	
−81.02102	38.03256	WV	NPS—ERMN	NERI.3018	Keeney Creek 10	
−81.01693	38.03013	WV	NPS—ERMN	NERI.3082	Keeney Creek 15	

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−81.00490	37.85802	WV	NPS—ERMN	NERI.3037	Laurel Creek 47	
−80.98218	37.86476	WV	NPS—ERMN	NERI.3085	Laurel Creek 61	
−81.03925	37.85120	WV	NPS—ERMN	NERI.3044	Laurel Creek 8	
−80.97903	37.85864	WV	NPS—ERMN	NERI.3026	Little Laurel Creek 6	
−80.91077	37.81927	WV	NPS—ERMN	NERI.3011	Meadow Creek 17	
−80.89788	37.83271	WV	NPS—ERMN	NERI.3043	Meadow Creek 39	
−80.88025	37.83799	WV	NPS—ERMN	NERI.3059	Meadow Creek 58	
−81.09167	37.94410	WV	NPS—ERMN	NERI.3001	Meadow Fork 1	
−81.09510	37.94727	WV	NPS—ERMN	NERI.3065	Meadow Fork 6	
−81.01654	37.78795	WV	NPS—ERMN	NERI.3040	Polls Branch 14	
−80.95197	37.86122	WV	NPS—ERMN	NERI.3058	Richlick Branch 17	
−81.04918	37.82895	WV	NPS—ERMN	NERI.3016	River Branch 4	
−81.04749	37.82782	WV	NPS—ERMN	NERI.3032	River Branch 6	WV DEP reference site
−80.92717	37.80196	WV	NPS—ERMN	NERI.3047	Sewell Branch 2	
−81.05316	37.83172	WV	NPS—ERMN	NERI.3080	Slate Fork—Mill Creek 1	
−81.05710	37.82369	WV	NPS—ERMN	NERI.3048	Slate Fork—Mill Creek 12	
−81.02849	37.89156	WV	NPS—ERMN	NERI.3053	Slater Creek 13	
−81.02305	37.88808	WV	NPS—ERMN	NERI.3009	Slater Creek 20	
−81.02506	37.98267	WV	NPS—ERMN	NERI.3034	Unnamed tributary 21 New River 1	

Table E-2. continued…

Longitude	Latitude	State	Entity	Station ID	Water body name	Notes
−81.01080	37.91417	WV	NPS—ERMN	NERI.3049	Unnamed tributary Buffalo Creek 6	
−80.94296	37.74477	WV	NPS—ERMN	NERI.3036	Unnamed tributary Fall Branch 2	
−81.01984	37.85830	WV	NPS—ERMN	NERI.3041	Unnamed tributary Laurel Creek 3	
−81.08293	38.04904	WV	NPS—ERMN	NERI.3029	Wolf Creek 30	
−81.08257	38.04763	WV	NPS—ERMN	NERI.3093	Wolf Creek 32	
−79.61147	39.04225	WV	WV DEP	8357	Otter Creek	long-term monitoring site impacted by acid rain
−79.69583	38.73825	WV	WV DEP	12455	Laurel Fork/Dry Fork	
−79.39594	38.97394	WV	WV DEP	8255	Red Creek	long-term monitoring site impacted by acid rain
−80.37117	38.33544	WV	WV DEP	9315	Middle Fork/Williams River	long-term monitoring site impacted by acid rain
−80.32127	38.25981	WV	WV DEP	2046	North Fork/Cranberry River	long-term monitoring site impacted by acid rain
−81.14683	37.50275	WV	WV DEP	2359	Mash Fork	long-term monitoring site impacted by acid rain
−81.93119	38.38489	WV	WV DEP	8482	Sams Fork	
−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
−82.12353	38.48514	WV	WV DEP	11897	Unnamed tributary/Left Fork river mile 1.69/Mill Creek	
−82.28014	38.06845	WV	WV DEP	4513	Little Laurel Creek	

APPENDIX F.

MACROINVERTEBRATE COLLECTION METHODS

Table F-1. Macroinvertebrate collection methods for medium-high gradient freshwater wadeable streams with abundant riffle habitat and rocky substrate, as agreed upon by the Northeast, Mid-Atlantic, and Southeast regional working groups

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 collection methods used by Northeastern states when sampling 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 800−900-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 collection methods used by Mid-Atlantic states and RBCs when sampling 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	Multi-habitat (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
WV DEP	Wadeable streams (WVSCI)	4 kicks composited	Rectangular kick net (50 cm wide	riffle-run	1 m^2	April 15–October 15	200 ± 20%	Family (all insects)

Table F-3. continued…

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
	Wadeable streams (GLIMPSS)—Mountain and Plateau		× 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		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 multi-habitat) are composited	D-frame net (50 cm wide × 30 cm high × 50 cm deep) with 500 µm net mesh	Riffle, unless absent, then multi-habitat	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)
	Sub-basin 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 collection methods used by Southeast states when sampling 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	Multi-habitat—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 (multi-habitat) 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]	Multi-habitat (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 (U.S. 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 collection methods used in national surveys conducted by U.S. EPA and USGS

Entity	Project or stream type	Effort	Gear	Habitat	Sampling area	Index period	Target # organisms	Taxonomic resolution
U.S. 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	Multi-habitat 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

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 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. http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=239585

APPENDIX H.

GUIDELINES FOR TEMPERATURE MONITORING QA/QC

These recommendations are intended to make data processing and screening easier and more efficient.

H.1. PREDEPLOYMENT

- Set the sensors up so that they start recording at the **top of the hour (xx:00)** or on the **half hour (xx:30)**.
- Set the air and water temperature sensors up so that they **record at the same time**.
- Consider using **military time** (if this is an option) to avoid potential confusion with AM/PM.
- Consider using **standard time** (e.g., UTC-5 for sites in the Eastern Time zone) instead of daylight savings time. Regardless of which one you choose, make sure that any discrete measurements that are taken for accuracy checks are consistent with this setting.
- Conduct a **predeployment accuracy check.**

    - Use either an **ice bath** technique, like the one described in MD DNR's quality assurance document (http://www.dnr.state.md.us/streams/pdfs/QA_TemperatureMonitoring.pdf) or a **multipoint** technique, like the one described in U.S. EPA (2014).
    - The measurement from the sensor **should not exceed the accuracy quoted by the manufacturer**. Sensors that have anomalous readings should be returned to the manufacturer for replacement.

H.2. FIELD CHECKS

- It is essential to **take good field notes**! Sample field forms can be found in the appendices of U.S. EPA (2014). If you have existing field forms already [and they are comparable or more detailed than the ones in U.S. EPA (2014)], it is fine to use those instead.
- Be sure to **record the exact times of deployment (in proper position) and recovery**. This information is needed for trimming data after retrieval.
- During your field checks, **note things that could affect the quality of your data**, such as:

    - Signs of **physical damage**, **vandalism**, or **disturbance**;
    - Signs of the sensor being buried in **sediment**;
    - Signs of the sensor being **out of the water**; and
    - Potential **fouling** from debris, aquatic vegetation, algae.

- Conduct **middeployment accuracy checks**, as described in U.S. EPA (2014) (**optional but encouraged**). To minimize the chance of a faulty measurement:

    - Take the instantaneous measurement with a National Institute of Standards and Technology **(NIST)—certified field thermometer**,
    - Take the measurement **as close as possible to the sensor**,

- Take the measurement **as close as possible to the time that the sensor is recording** a measurement. Note whether the time is **standard or daylight savings time**, and
- Make sure that sufficient time has passed to allow the temperature reading to **stabilize**.

- Conduct a **biofouling check (optional)**. To do this, remove the sensor and gently clean it (per manufacturer's instructions) to remove any biofilm or sediment, then replace it. Note on your field form the time at which the "precleaning" measurement was made as well as the time of the first "postcleaning" measurement. Compare the readings.

H.3. POSTRETRIEVAL

H.3.1. Record keeping and data storage

Make sure you **set up a good record keeping and data storage system**. Large amounts of data will accumulate quickly, so a central temperature database should be developed and maintained from the initial stages of monitoring. Also, all field and accuracy check forms should be organized, easily accessible, and archived in a way that allows for safe, long-term storage.

Original raw data files should be retained for all sites, and should be kept separate from files in which data have been manipulated. The data should be accessible because someone may want to go back and calculate different metrics in the future.

H.3.2. Postdeployment accuracy check

Conduct a **postdeployment accuracy check** using the same technique that was used for the predeployment accuracy check.

H.3.3. Data evaluation

Conduct QA/QC checks. **Carefully document these steps** as well as any changes that you make to the data. The checks can be conducted using a number of different software packages (e.g., Microsoft Excel, Hoboware, Aquarius). Recommended steps for evaluating data include:

1. Save the file that you are manipulating with a **different file name** so that you do not confuse it with the original raw data file.

2. **Format the data** so that it is easy to analyze. An example of how the data could potentially be formatted in Excel is shown in Table H-1. Tips on formatting data in Excel are available upon request (email: Jen.Stamp@tetratech.com).

3. **Trim data** (as necessary) to remove measurements taken before and after the sensor is correctly positioned.

4. **Plot all of the measurements** and **visually check** the data. Look for **missing data** and **abnormalities.** Consider doing the following, as data permits:

Table H-1. Potential format for water and air temperature data if MS Excel software is used. Information on formatting data in Excel is available upon request (email: Jen.Stamp@tetratech.com).

Water serial number	Air serial number	Station ID	Year	Month	Season	Day	Julian date	Date	Time	AM / PM	Date time, GMT—04:00	#	Water temp-erature, °C	Water temp-erature grade	Water temp-erature QC notes	Air temp-erature, °C	Air temp-erature grade	Air temp-erature QC notes
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	10:30:00	AM	07/25/13 10:30:00 AM	1	20.14	good		21.76	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	11:00:00	AM	07/25/13 11:00:00 AM	2	20.04	good		22.24	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	11:30:00	AM	07/25/13 11:30:00 AM	3	20.33	good		22.43	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	12:00:00	PM	07/25/13 12:00:00 PM	4	20.71	good		23.00	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	12:30:00	PM	07/25/13 12:30:00 PM	5	21.09	good		23.68	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	1:00:00	PM	07/25/13 01:00:00 PM	6	21.28	good		24.35	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	1:30:00	PM	07/25/13 01:30:00 PM	7	21.47	good		24.74	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	2:00:00	PM	07/25/13 02:00:00 PM	8	21.76	good		25.22	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	2:30:00	PM	07/25/13 02:30:00 PM	9	21.95	good		25.51	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	3:00:00	PM	07/25/13 03:00:00 PM	10	22.24	good		25.81	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	3:30:00	PM	07/25/13 03:30:00 PM	11	22.33	good		25.90	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	4:00:00	PM	07/25/13 04:00:00 PM	12	22.43	good		25.61	good	
10229557	10229571	ECO66G12	2013	7	summer	25	206	7/25/2013	4:30:00	PM	07/25/13 04:30:00 PM	13	22.53	good		25.51	good	

- Plot **air** and **stream temperature** data on the same graph, as shown in Figure H-1.
- Plot **stream temperature** data **with stage** data.

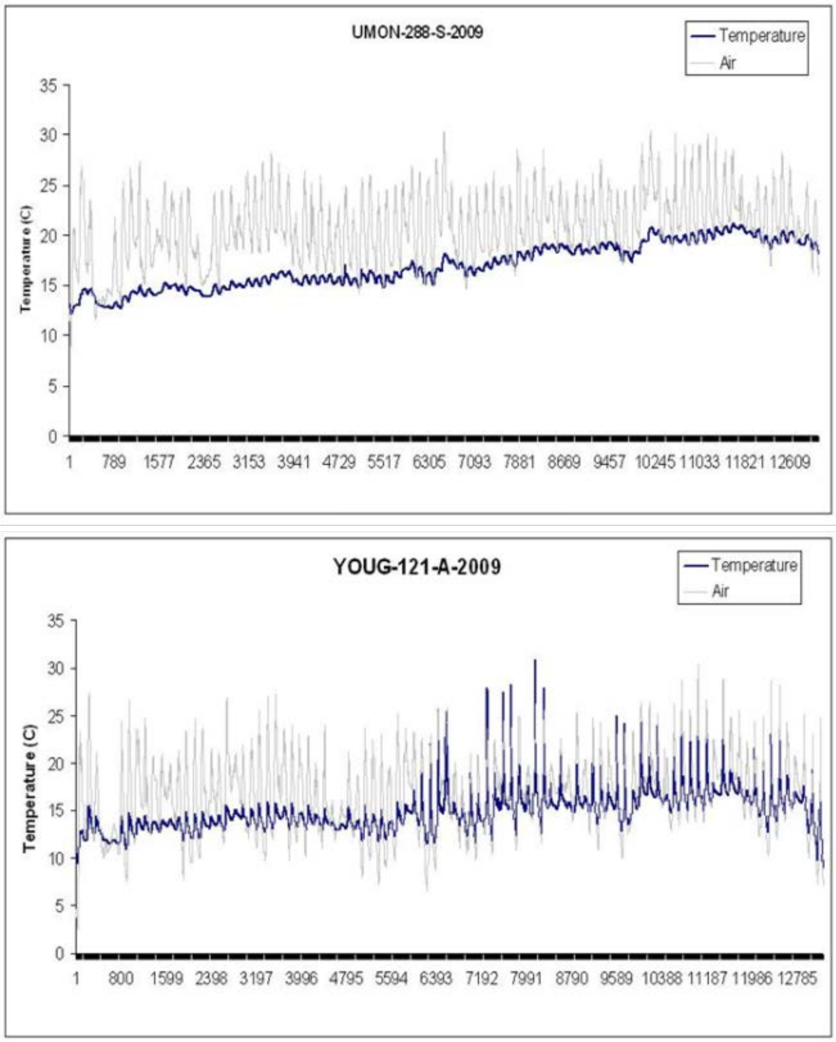

Figure H-1. Examples of how air and stream temperature data can be plotted together to visually screen continuous temperature data. At the site shown in the bottom graph, dewatering occurred, evidenced by the close correspondence between water and air temperature. These graphs were provided by Michael Kashiwagi, MD DNR.

Specific things to watch for:

- **Missing data**
- **A close correspondence between water and air temperature—**this indicates that the stream sensor may have been out of the water.
- **Diel fluxes with flat tops—**this indicates that the sensor may have been buried in sediment.

Optional:

- Graphically **compare data across sites**.
- Graphically **compare data across years**; when data from one year are dramatically different, there may be errors.
- Graphically **compare with data from the nearest active weather station**, if appropriate. The closest active weather stations can be located and the daily observed air temperature data for those stations can be downloaded from websites like the Utah State University Climate server: http://climate.usurf.usu.edu/mapGUI/mapGUI.php.

Additional checks (optional):

- If using MS Excel, **use pivot tables to check for missing data**, as shown in Figure H-2. If a 30-minute interval is used, there should be 48 measurements per day. If there are fewer (or more) than 48, check the original data and your field notes and try to determine what might have caused this to occur.
- Flag data points for potential errors if they:

    - Exceed a thermal maximum of 25°C*
    - Exceed a thermal minimum of −1°C*
    - Exceed a daily change of 10°C*
    - Exceed the upper 5th percentile of the overall distribution
    - Fall below the lower 5th percentile of the overall distribution

**These values should be adjusted to thermal limits appropriate for each location.*

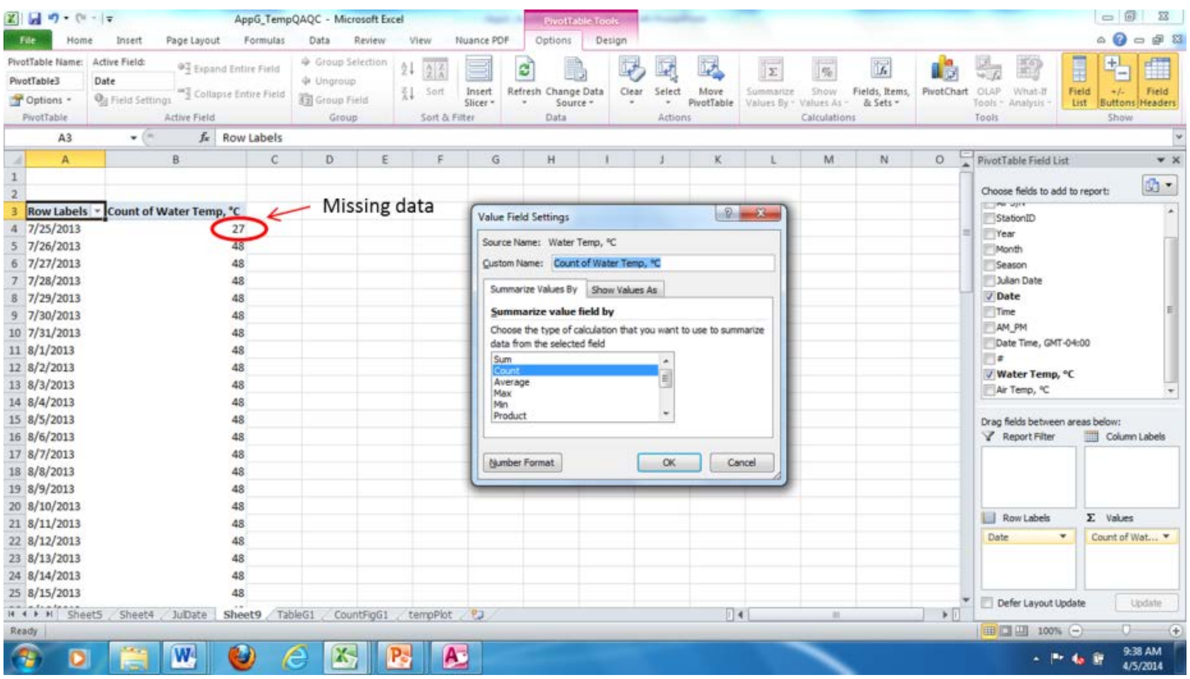

Figure H-2. Example of how pivot tables in MS Excel can be used to identify missing data.

H.3.4. Application of data corrections

Errors should be addressed on a case-by case-basis. In general, there are three possible actions:

1) Leave data as is,
2) Apply correction factor, or
3) Remove data.

If you are inexperienced at addressing errors with continuous temperature data, consider seeking guidance from someone with more experience and consult references like Wagner et al. (2006) (see Section H.5). Table H-2 provides a general summary of different types of problems that can occur (e.g., missing data, failed accuracy check) and recommended actions for addressing them. Corrections should not be made unless the cause(s) of error(s) can be validated or explained in the field notes or by comparison with information from nearby stations. Accurate field notes and accuracy check logs are essential in the data correction process. Any discrepancies should be documented in your data file and any actions you take should be carefully documented.

Table H-2. General summary of different types of problems that can occur with continuous temperature data and recommended actions for addressing them

Problem	Recommended action
Missing data	Leave blank
Water temperature sensor was dewatered or buried in sediment for part of the deployment period.	Use the plot to determine the period during which the problem occurred. Exclude these data when calculating the summary statistics.
Recorded values are off by a constant, known amount (e.g., due to a calibration error).	Adjust each recorded value by a single, constant value within the correction period.
There is a large amount of drift and there is no way to tell when and how much the sensor was "off" by. (When drift occurs, the difference between discrete measurements and sensor readings increases over time.)	The data should be removed.
Discrepancy between sensor reading and discrete measurement taken during an accuracy or fouling check	General rules: • If the errors are smaller than the sensor accuracy quoted by the manufacturer and cannot be easily corrected (e.g., they are not off by a constant amount), leave the data as is, and include the data in the summary statistics calculations. • If the sensor fails a mid-deployment accuracy check, review field notes to see if any signs of disturbance or fouling were noted, and also look for notes about the quality of the QC measurement (e.g., was the thermometer NIST-certified? Did environmental conditions prevent the measurement from being taken next to the sensor?). Also check whether the same time setting was used for both the sensor and discrete measurements (daylight savings time vs. standard time). Based on this information, use your best judgment to decide which action (leave as is, apply correction, or remove) is most appropriate. • If a sensor fails a postretrieval accuracy check, repeat the procedure. If it fails a second time, use your best judgment to decide which action (leave as is, apply correction, or remove) is most appropriate.

H.4. SUMMARIZING THE DATA

Recommendations on thermal summary statistics to calculate from continuous temperature data at RMN sites can be found in Section 4.2 of the RMN report. Annual statistics should be calculated based on calendar year (January 1 through December 31). For years with incomplete data (e.g., in the example in Table H-1, the sensor installation was done on July 25, 2013), calculate daily, monthly, and seasonal statistics as data permit. Instructions on how the summary statistics should be formatted to facilitate data sharing can be found in Appendix K. Tips on how to calculate summary statistics with pivot tables in MS Excel are available upon request (email: Jen.Stamp@tetratech.com). Free software programs like ThermoStat can also be used to calculate some of the summary statistics (Jones and Schmidt, 2013).

H.5. REFERENCES

Jones, NE; Schmidt, B. (2013). ThermoStat 3.1: Tools for analyzing thermal regimes. Ontario, Canada: Ontario Ministry of Natural Resources, Aquatic Research and Development. http://people.trentu.ca/nicholasjones/ThermoStat31_Manual.pdf

U.S. EPA (U.S. Environmental Protection Agency). (2014) Best practices for continuous monitoring of temperature and flow in wadeable streams (External review draft). (EPA/6--/R-13/170). Washington, DC; National Center for Environmental Assessment. http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=261911

Wagner, RJ; Boulger, RW, Jr; Oblinger, CJ; Smith, BA. (2006) Guidelines and standard procedures for continuous water-quality monitors—Station operation, record computation, and data reporting. (USGS Techniques and Methods 1–D3, 51p). Washington, DC: U.S. Department of the Interior, U.S. Geological Survey. http://pubs.usgs.gov/tm/2006/tm1D3/

APPENDIX I.

GUIDELINES FOR HYDROLOGIC MONITORING QA/QC

If the site is colocated with a USGS gage, the stage or discharge data can be downloaded from the USGS National Water Information System (NWIS) website available at http://waterdata.usgs.gov/usa/nwis/rt. The USGS data are put through a rigorous QA/QC process before they are posted, so the summary statistics can be calculated directly from those data.

If you are working with pressure transducer data, these recommendations are intended to make data processing and screening easier and more efficient.

I.1. PREDEPLOYMENT

- Set the sensors up so that they start recording at the **top of the hour (xx:00), half hour (xx:30), or quarter after/of the hour (xx:15 or xx:45).**
- If you are using unvented pressure transducers, set both transducers up so that they **record at the same time**.
- Consider using **military time** (if this is an option) to avoid potential confusion with AM/PM.
- Consider using **standard time** (e.g., UTC-5 for sites in the Eastern Time zone) instead of daylight savings time. Regardless of which one you choose, make sure that any discrete measurements that are taken for accuracy checks are consistent with this setting.

I.2. FIELD CHECKS

- It is essential to **take good field notes**! Sample field forms can be found in the appendices of U.S. EPA (2014). If you have existing field forms already [and they are comparable or more detailed than the ones in U.S. EPA (2014)], it is fine to use those instead.
- Be sure to **record the exact times of deployment (in proper position) and recovery**. This information is needed for trimming data after retrieval.
- During your field checks, **note things that could affect the quality of your data**, such as:

    - Signs of **physical damage**, **vandalism**, or **disturbance**;
    - Signs of the stream pressure transducer being buried in **sediment**;
    - Signs of the stream pressure transducer being **out of the water**; and
    - Potential **fouling** from debris, aquatic vegetation, algae.

- Take **staff gage readings** or **measure the depth of water** over the transducer with a stadia rod or other measuring device (as frequently as resources permit) **to check the accuracy** of the transducer data (U.S. EPA, 2014). Data should be compared over a variety of water depths to ensure the transducer is accurate over the full range of depths. To minimize the chance of a faulty measurement:

    - Take the measurement **as close as possible to the time that the pressure transducer is recording** a measurement, and

- Get as stable a reading as possible. If flows are fluctuating rapidly at the time of the measurement, note this on your field form and do the best you can to record the depth accurately.

- 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. This allows for **monitoring of changes in the location of the transducer**, which is important because if the transducer moves, stage data will be affected and corrections will need to be applied (see Figure I-1).
- Conduct a **biofouling check (optional)**. To do this, remove the transducer and gently clean it (per manufacturer's instructions) to remove any biofilm or sediment, then replace it. Note on your field form the time at which the "precleaning" measurement was made as well as the time of the first "postcleaning" measurement. Compare the readings.

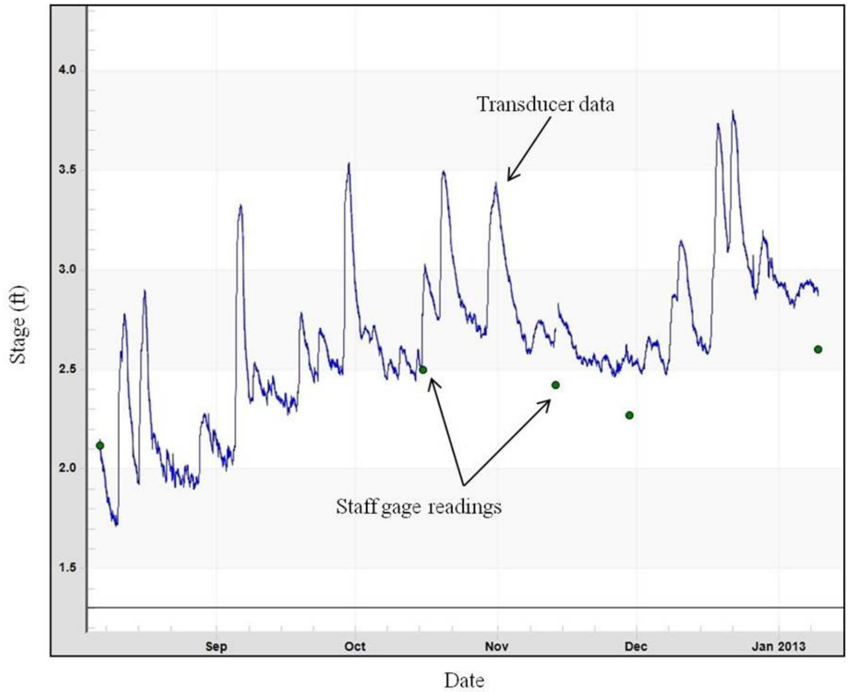

Figure I-1. Staff gage readings provide a quality check of transducer data. In this example, staff gage readings stopped matching transducer readings in November, indicating that the transducer or gage may have changed elevation.

I.3. POSTRETRIEVAL

I.3.1. Record keeping and data storage

Make sure you **set up a good record keeping and data storage system**. Large amounts of data will accumulate quickly, so a central hydrologic database should be developed and maintained from the initial stages of monitoring. Also, all field and accuracy check forms should be organized, easily accessible, and archived in a way that allows for safe, long-term storage.

Original raw data files should be retained for all sites, and should be kept separate from files in which data have been manipulated. The data should be accessible because someone may want to go back and calculate different metrics in the future.

I.3.2. Data evaluation

Conduct QA/QC checks. **Carefully document these steps** as well as any changes that you make to the data. The checks can be conducted using a number of different software packages (e.g., Microsoft Excel, Hoboware, Aquarius). Recommended steps for evaluating data include:

1. Save the file that you are manipulating with a **different file name** so that you do not confuse it with the original raw data file.
2. **Format the data** so that it is easy to analyze. An example of how the data could potentially be formatted in Excel is shown in Table I-1. Tips on formatting data in Excel are available upon request (email: Jen.Stamp@tetratech.com).
3. **Trim data** (as necessary) to remove measurements taken before and after the sensor is correctly positioned.
4. **Plot all of the stage measurements** and **visually check** the data (see Figure I-2). Look for **missing data** and **abnormalities**.

Specific things to watch for:

- **Missing data**
- **Values of 0—**this could mean that the pressure transducer was dewatered. Another possibility (with vented transducers) is that moisture got into the cable and caused readings of zero water depth.
- **Values flat-lining at 0°C/32°F—**the stream pressure transducer is likely encased in ice.
- **Negative values—**if unvented transducers are being used, this may indicate that the barometric pressure correction is off. This could occur for a number of reasons, such as:

    - The land-based transducer is not close enough to the stream pressure transducer to accurately capture barometric pressure.
    - If the land-based transducer is housed in PVC pipe that has a solid bottom, condensation and laterally blown rain and snow can penetrate through the drilled holes and collect in the bottom, filling the pipe to a depth sufficient to inundate the ports through which the barometric pressure is compensated. Thereafter, "barometric pressure" is actual barometric pressure plus a small amount of pressure due to this accumulated water. (A hole should be drilled in the bottom of the PVC pipe to prevent this from happening.)

- **Outliers or rapidly fluctuating values—**the stream pressure transducer may have moved (e.g., due to a high flow event or vandalism).

Table I-1. Potential format for stage water temperature data if MS Excel software is used. Information on formatting data in Excel is available upon request (email: Jen.Stamp@tetratech.com).

Water sensor serial number	Station ID	Year	Month	Season	Day	Julian date	Date	Time	AM/ PM	Date time, GMT—04:00	#	Sensor depth, feet	Stage grade	Stage QC notes	Water temp-erature, °C	Water temp-erature grade	Water temp-erature QC notes
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	10:30:00	AM	07/25/13 10:30:00 AM	1	0.574	good		20.14	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	11:00:00	AM	07/25/13 11:00:00 AM	2	0.577	good		20.04	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	11:30:00	AM	07/25/13 11:30:00 AM	3	0.578	good		20.33	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	12:00:00	PM	07/25/13 12:00:00 PM	4	0.579	good		20.71	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	12:30:00	PM	07/25/13 12:30:00 PM	5	0.579	good		21.09	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	1:00:00	PM	07/25/13 01:00:00 PM	6	0.572	good		21.28	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	1:30:00	PM	07/25/13 01:30:00 PM	7	0.579	good		21.47	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	2:00:00	PM	07/25/13 02:00:00 PM	8	0.581	good		21.76	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	2:30:00	PM	07/25/13 02:30:00 PM	9	0.579	good		21.95	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	3:00:00	PM	07/25/13 03:00:00 PM	10	0.578	good		22.24	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	3:30:00	PM	07/25/13 03:30:00 PM	11	0.577	good		22.33	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	4:00:00	PM	07/25/13 04:00:00 PM	12	0.572	good		22.43	good	
10229557	ECO66G12	2013	7	summer	25	206	7/25/2013	4:30:00	PM	07/25/13 04:30:00 PM	13	0.569	good		22.53	good	

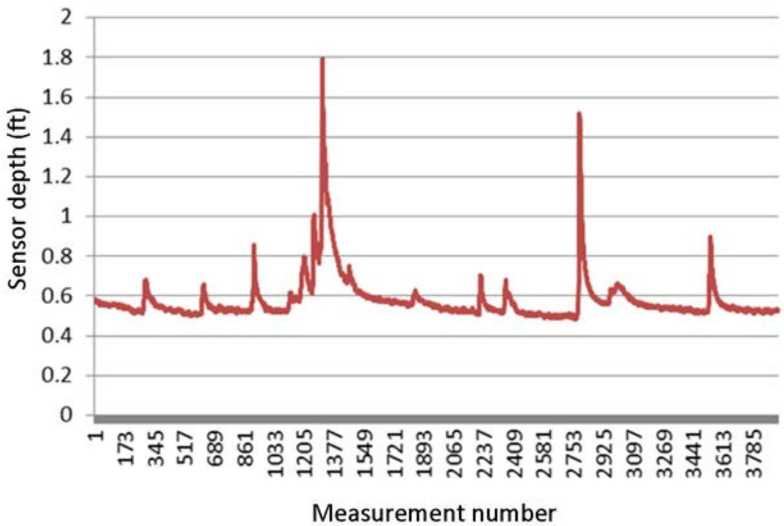

Figure I-2. Examples of how stage data can be plotted to visually screen the data.

In addition, consider doing the following, as data permits:

- Plot **stage** and **temperature** data on the **same graph**. Watch for the following signals in the temperature data:
    - **Diel fluxes with flat tops—**this indicates that the pressure transducer may have been buried in sediment.
    - A **close correspondence between water and air temperature** (if air temperature data are available)**—**this indicates that the pressure transducer may have been out of the water.

Optional:

- Graphically **compare data across years**; when data from one year are dramatically different, there may be errors.
- Graphically **compare with precipitation data from the nearest active weather station**, if appropriate. The closest active weather stations can be located and the daily observed precipitation data for those stations can be downloaded from websites like the Utah State University Climate server: http://climate.usurf.usu.edu/mapGUI/mapGUI.php.
- Graphically **compare with data from the nearest USGS stream gage**, if appropriate. The closest active USGS gage can be located and the daily flow data for those gages can be downloaded from the USGS National Water Information System (NWIS) website: http://waterdata.usgs.gov/usa/nwis/rt.

Additional checks (optional):

- If using MS Excel, **use pivot tables to check for missing data**, as shown in Figure I-3. In this example, a 30-minute interval is used. If a 15-minute interval is used [as recommended in U.S. EPA (2014)], there should be 96 measurements per day. If there are fewer (or more) than 96, check the original data and your field notes and try to determine what might have caused this to occur.

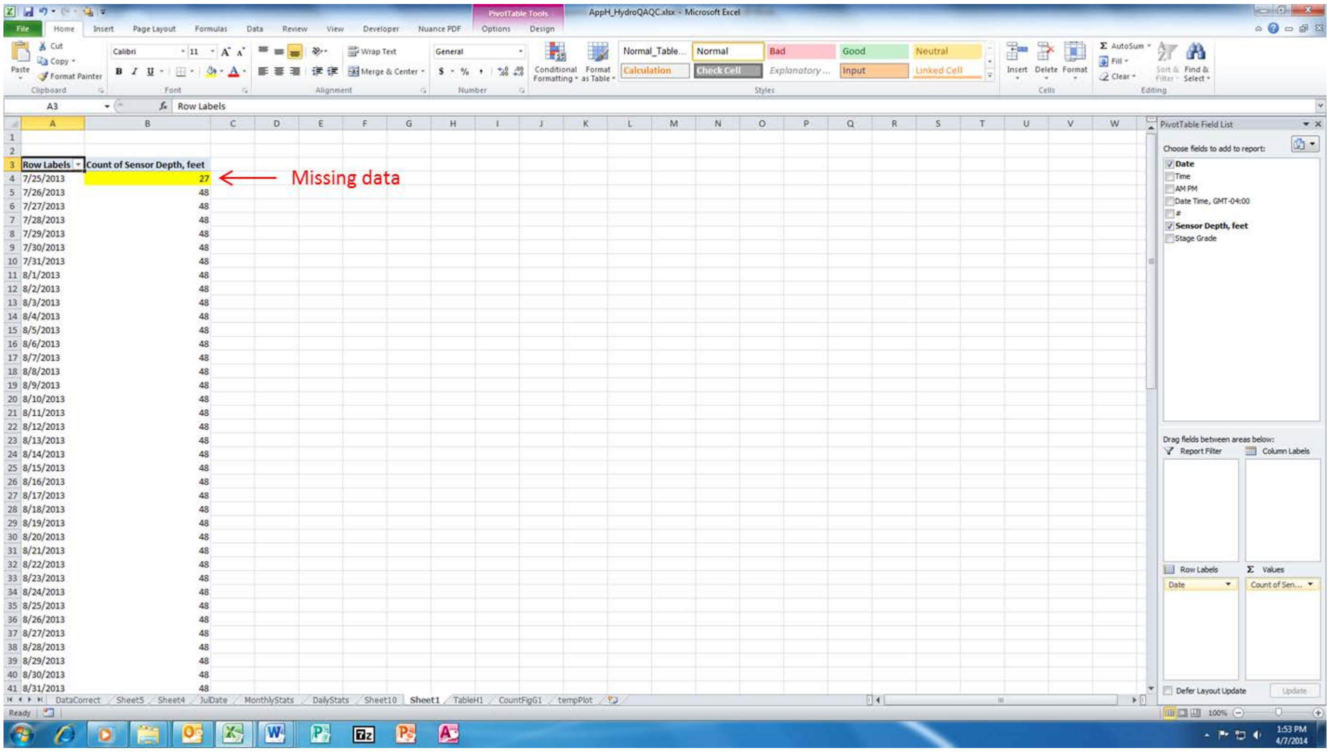

Figure I-3. Example of how pivot tables in MS Excel can be used to identify missing data.

I.3.3. Application of data corrections

Erratic readings with pressure transducers can occur for a number of reasons, such as:

- They may become dewatered during low flow conditions.
- High flow events may bury them in sediment.
- High flow events may move them.
- They may become fouled from debris, aquatic vegetation, or algae.
- Humans may cause interference.
- They may become encased in ice.
- If moisture gets into the cable of a vented transducer, it may result in erratic readings or readings of zero water depth.
- If the cable of a vented transducer gets kinked or plugged, it can result in the data not being corrected for barometric pressure.

Errors should be addressed on a case-by-case basis. In general, there are three possible actions:

1) Leave data as is,
2) Apply correction factor, or

3) Remove data.

If you are inexperienced at addressing errors with continuous stage data, consider seeking guidance from someone with more experience and consult references like Wagner et al. (2006) and Shedd and Springer (2012) (see Section I.5). Corrections should not be made unless the cause(s) of error(s) can be validated or explained in the field notes or by comparison with information from nearby stations. Accurate field notes and accuracy check logs are essential in the data correction process. Any discrepancies should be documented in your data file and any actions you take should be carefully documented.

The types of errors that can occur and how they manifest themselves will vary, which makes it difficult to develop specific guidelines for applying data corrections. Moreover, the discrepancies with the stage data can be more difficult to understand and interpret than problems that arise with temperature data, which tend to show more consistent signals (e.g., close correspondence with air temperature if the sensor becomes dewatered). Your ability to apply corrections to stage data may also be limited by the software you are using. If you do not have access to software like Aquarius, which has built-in functions that facilitate data correction, you may have to remove more data unless simple corrections can be made. You may also be limited by the number of gage readings you were able to make. Frequent gage readings facilitate error screening and early detection and correction of transducer problems that help minimize data loss, but can be resource intensive.

Table I-2 provides a general summary of different types of problems that can occur (e.g., missing data, failed accuracy check) and recommended actions for addressing them. Any discrepancies should be documented in your data file and any actions you take should be carefully documented.

I.4. SUMMARIZING THE DATA

Recommendations on hydrologic summary statistics to calculate from continuous stage or discharge data at RMN sites can be found in Section 4.3 of the RMN report. Annual statistics should be calculated based on calendar year (January 1 through December 31) (this is consistent with how the annual temperature statistics are calculated). For years with incomplete data (e.g., the transducer installation was done mid-year), calculate daily, monthly, and seasonal statistics as data permit. Instructions on how the summary statistics should be formatted to facilitate data sharing can be found in Appendix K. Tips on how to calculate the summary statistics in MS Excel are available upon request (email: Jen.Stamp@tetratech.com). Free software programs like Indicators of Hydrologic Analysis (IHA) (TNC, 2009) can also be used to calculate some of the summary statistics.

Table I-2. General summary of different types of problems that can occur with pressure transducer data and recommended actions for addressing them.

Problem	Recommended action
Missing data	Leave blank
Stream pressure transducer was dewatered or buried in sediment for part of the deployment period.	Use the plot (and temperature data, if available) to determine the period during which the problem occurred. Exclude these data when calculating the summary statistics.
Recorded values are off by a constant, known amount (e.g., due to a calibration error).	Adjust each recorded value by a single, constant value within the correction period.
There is a large amount of drift and there is no way to tell when and how much the sensor was "off" by. (When drift occurs, the difference between staff gage or depth readings and transducer readings increases over time.)	The data should be removed.
Discrepancy between pressure transducer reading and discrete measurement taken during a staff gage or depth check.	General rules: • If the errors are smaller than the accuracy quoted by the manufacturer and cannot be easily corrected (e.g., they are not off by a constant amount), leave the data as is, and include the data in the summary statistics calculations. • If the transducer fails a staff gage or depth accuracy check, review field notes to see if any signs of disturbance or fouling were noted, and also look for notes about the quality of the gage measurement (e.g., if flows were fluctuating rapidly at the time of the measurement). Also check whether the same time setting was used for both the transducer and gage or depth measurements (daylight savings time vs. standard time). Based on this information, use your best judgment to decide which action (leave as is, apply correction, or remove) is most appropriate.

Table I-2. General summary of different types of problems that can occur with pressure transducer data and recommended actions for addressing them. (continued)

Problem	Recommended action
A shift is detected and an elevation survey reveals that the stream pressure transducer has moved.	Stage readings can be adjusted by adding or subtracting the difference in elevation. If the exact date of the elevation change is unknown, compare gage data to transducer data to observe any shifts. If there are no gage data for the time period, transducer data should be examined for any sudden shifts in stage. Changes in the elevation typically occur during high flows, so closely examine all data during these time periods.
The sensitivity of the transducer changes with stage (e.g., the transducer is less sensitive or accurate at high stages).	Sensitivity drift may be detected by graphing the difference between transducer and staff gage readings against the gage height and plotting a linear trend line through it. A strong correlation between the data sets and a positive or negative trend line as stage increases or decreases may indicate a sensitivity shift. Based on this information, use your best judgment to decide which action (leave as is, apply correction, or remove) is most appropriate.

I.5. REFERENCES

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APPENDIX J.

RAPID QUALITATIVE HABITAT ASSESSMENT SURVEY FORM FOR HIGH-GRADIENT STREAMS (BARBOUR ET AL., 1999)

HABITAT ASSESSMENT FIELD DATA SHEET—HIGH-GRADIENT STREAMS (FRONT)

STREAM NAME	LOCATION
STATION # RIVERMILE	STREAM
LAT LONG	RIVER BASIN
STORET #	AGENCY
INVESTIGATORS	
FORM COMPLETED BY	DATE ________ TIME ________ AM PM | REASON FOR SURVEY

Parameters to be evaluated in sampling reach

Habitat parameter	Condition category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
1. Epifaunal Substrate/ Available Cover	Greater than 70% of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient.	40-70% mix of stable habitat; well suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale).	20-40% mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed.	Less than 20% stable habitat; lack of habitat is obvious; substrate unstable or lacking.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2. Embeddedness	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment. Layering of cobble provides diversity of niche space.	Gravel, cobble, and boulder particles are 25−50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50−75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3. Velocity/Depth Regime	All four velocity/depth regimes present (slow-deep, slow-shallow, fast-deep, fast-shallow). (Slow is <0.3 m/s, deep is >0.5 m.)	Only 3 of the 4 regimes present (if fast-shallow is missing, score lower than if missing other regimes).	Only 2 of the 4 habitat regimes present (if fast-shallow or slow-shallow are missing, score low).	Dominated by 1 velocity/ depth regime (usually slow-deep).
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
4. Sediment Deposition	Little or no enlargement of islands or point bars and less than 5% of the bottom affected by sediment deposition.	Some new increase in bar formation, mostly from gravel, sand or fine sediment; 5−30% of the bottom affected; slight deposition in pools.	Moderate deposition of new gravel, sand or fine sediment on old and new bars; 30−50% of the bottom affected; sediment deposits at obstructions, constrictions, and bends; moderate deposition of pools prevalent.	Heavy deposits of fine material, increased bar development; more than 50% of the bottom changing frequently; pools almost absent due to substantial sediment deposition.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
5. Channel Flow Status	Water reaches base of both lower banks, and minimal amount of channel substrate is exposed.	Water fills >75% of the available channel; or <25% of channel substrate is exposed.	Water fills 25−75% of the available channel, and/or riffle substrates are mostly exposed.	Very little water in channel and mostly present as standing pools.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

HABITAT ASSESSMENT FIELD DATA SHEET—HIGH GRADIENT STREAMS (BACK)

Parameters to be evaluated broader than sampling reach

Habitat parameter	Condition category			
	Optimal	**Suboptimal**	**Marginal**	**Poor**
6. Channel Alteration	Channelization or dredging absent or minimal; stream with normal pattern.	Some channelization present, usually in areas of bridge abutments; evidence of past channelization, i.e., dredging, (greater than past 20 yr) may be present, but recent channelization is not present.	Channelization may be extensive; embankments or shoring structures present on both banks; and 40 to 80% of stream reach channelized and disrupted.	Banks shored with gabion or cement; over 80% of the stream reach channelized and disrupted. Instream habitat greatly altered or removed entirely.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
7. Frequency of Riffles (or bends)	Occurrence of riffles relatively frequent; ratio of distance between riffles divided by width of the stream <7:1 (generally 5 to 7); variety of habitat is key. In streams where riffles are continuous, placement of boulders or other large, natural obstruction is important.	Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 and 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 and 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is a ratio of >25.
SCORE	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. Bank Stability (score each bank) Note: determine left or right side by facing downstream.	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.	Moderately stable; infrequent, small areas of erosion mostly healed over. 5−30% of bank in reach has areas of erosion.	Moderately unstable; 30−60% of bank in reach has areas of erosion; high erosion potential during floods.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60−100% of bank has erosional scars.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
9. Vegetative Protection (score each bank)	More than 90% of the streambank surfaces and immediate riparian zone covered by native vegetation, including trees, understory shrubs, or non-woody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.	70−90% of the streambank surfaces covered by native vegetation, but one class of plants is not well- represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	50−70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining.	Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0
10. Riparian Vegetative Zone Width (score each bank riparian zone)	Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.	Width of riparian zone 12−18 meters; human activities have impacted zone only minimally.	Width of riparian zone 6−12 meters; human activities have impacted zone a great deal.	Width of riparian zone <6 meters: little or no riparian vegetation due to human activities.
SCORE ___ (LB)	Left Bank 10 9	8 7 6	5 4 3	2 1 0
SCORE ___ (RB)	Right Bank 10 9	8 7 6	5 4 3	2 1 0

Total Score

J.1. REFERENCES

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APPENDIX K.

DATA SHARING TEMPLATES

The templates in the Excel worksheets that accompany this Appendix (see Excel file titled "Appendix_K_Excel") are intended to facilitate the sharing of data across entities. Data are organized into different worksheets as follows:

Worksheet name	Description
Bugs_MasterTaxa	Taxa attributes used in the bug metric calculations (e.g., thermal preference, FFG, habit)
Bugs_Raw	Raw macroinvertebrate data for each sampling event (list of taxa and number of individuals)
Bugs_Metrics	Macroinvertebrate metrics (taxonomic-based, traits-based related to temperature and hydrology, persistence and stability)
WT_Daily	Daily water temperature summary statistics
WT_Month	Monthly water temperature summary statistics
WT_Seasonal	Seasonal water temperature summary statistics
WT_Annual	Annual water temperature summary statistics
AT_Daily	Daily air temperature summary statistics
AT_Month	Monthly air temperature summary statistics
AT_Seasonal	Seasonal air temperature summary statistics
AT_Annual	Annual air temperature summary statistics
Stage_Daily	Daily stage summary statistics
Stage_Monthly	Monthly stage summary statistics
Stage_Season	Seasonal stage summary statistics
Stage_Annual	Annual stage summary statistics
Flow_Daily	Daily discharge summary statistics
Flow_Monthly	Monthly discharge summary statistics
Flow_Season	Seasonal discharge summary statistics
Flow_Annual	Annual discharge summary statistics
Habitat	Qualitative [per RBP high gradient field form; Barbour et al. (1999)] plus some optional quantitative measures
WaterQual	in situ measurements (pH, DO[a], specific conductance)
SiteInfo	Site information (e.g., latitude, longitude, drainage area), ecoregion, NLCD land use
DisturbScreen	Land use rating, likelihood of impacts from dams, mines, point-source pollution sites
CCVuln	Climate change vulnerability ratings and classification (eastern United States)

[a]Dissolved oxygen

The tables below show the list of parameters that are included in each worksheet, along with descriptions of these parameters. Not all parameters will be collected at every RMN site (e.g., some sites may only have water temperature and macroinvertebrate data, while others may have macroinvertebrate, water and air temperature, and stage data).

Each regional working group should decide on a process for compiling the data across entities (e.g., perhaps the data from each entity will be sent to the regional coordinator, and the coordinator will then compile the data and distribute it to the regional working group).

There are a number of different techniques that can be used to combine data from different worksheets, so that will be left to the discretion of the user (e.g., one technique would be to upload the worksheets into MS Access, link the tables via Station ID and collection date (or month, season, or year), and write and run queries to get the desired outputs).

These Excel worksheets are intended to serve as a temporary solution for sharing data. Ideally, an online interface will be developed that will make it easier to share and use data from RMN sites.

The tables below show the list of parameters that are included in each worksheet, along with descriptions of these parameters.

Worksheet name	Type of data	Variable	Description
Bugs_MasterTaxa	Taxa attributes used for bug metric calculations	ITIS_TSN	TSN number (unique identifier) in www.itis.gov
		BiodataTaxonName	Taxon name based on the USGS BioData nomenclature (version 4.7)
		orig_FinalID	Taxon name based on the nomenclature of the entity that collected the sample
		Phylum	Taxonomy
		Class	Taxonomy
		Order	Taxonomy
		Family	Taxonomy
		Tribe	Taxonomy
		Genus	Taxonomy
		Species	Taxonomy
		FFG	Primary functional feeding group
		Habit	Primary habit
		Thermal	Thermal preference (cold, warm)
		Rheo	Rheophily (depositional, erosional, both)

Worksheet name	Type of data	Variable	Description
Bugs_Raw	Raw macroinvertebrate data	StationID	Unique station identifier
		Waterbody Name	Name of water body
		CollMeth	Collection method
		SampID	Unique identifier for the sample (unique station-date-method combination)
		Year	Year of the sampling event
		Month	Month of the sampling event
		CollDate	Date of the sampling event
		ITIS_TSN	TSN number (unique identifier) in www.itis.gov
		BiodataTaxonName	Taxon name based on the USGS BioData nomenclature (version 4.7)
		orig_FinalID	Taxon name based on the nomenclature of the entity that collected the sample
		NumInd	Number of individuals
		TotalInd	Total number of individuals in the sample
		RA	Relative abundance; number of individuals of each taxon/total number of individuals in the sample

Worksheet name	Type of data	Variable	Description
Bugs_Metrics	Taxonomic-based metric	nt_total	Total number of taxa (richness)
		nt_EPT	Number of EPT taxa (Ephemeroptera [mayflies], Plecoptera [stoneflies], and Trichoptera [caddisflies])
		nt_Ephem	Number of Ephemeroptera (mayfly) taxa
		nt_Plecop	Number of Plecoptera(stonefly) taxa
		nt_Trichop	Number of Trichoptera (caddisfly) taxa
		pi_EPT	Percentage EPT individuals
		pi_Ephem	Percentage Ephemeroptera individuals
		pi_Plecop	Percentage Plecoptera individuals
		pi_Trichop	Percentage Trichoptera individuals
		nt_OCH	Number of Odonata/Coleoptera/Hemiptera (OCH) taxa
		pi_OCH	Percentage Odonata/Coleoptera/Hemiptera (OCH) individuals
	Traits-based metric related to temperature	nt_cold	Number of cold water taxa
		pt_cold	Percentage cold water taxa
		pi_cold	Percentage cold water individuals
		nt_warm	Number of warm water taxa
		pt_warm	Percentage warm water taxa
		pi_warm	Percentage warm water individuals
	Traits-based metric related to hydrology	nt_CollFilt	Number of collector filterer taxa
		nt_CollGath	Number of collector gatherer taxa
		nt_Scraper	Number of scraper/herbivore taxa
		nt_Shred	Number of shredder taxa
		nt_Pred	Number of predator taxa
		nt_Swim	Number of swimmer taxa
		nt_RheoDepo	Number of rheophily—depositional taxa
		nt_RheoEros	Number of rheophily—erosional taxa
		pi_CollFilt	Percentage collector filterer individuals
		pi_CollGath	Percentage collector gatherer individuals
		pi_Scraper	Percentage scraper/herbivore individuals
		pi_Shred	Percentage shredder individuals

Worksheet name	Type of data	Variable	Description
		pi_Pred	Percentage predator individuals
		pi_Swim	Percentage swimmer individuals
		pi_RheoDepo	Percentage Rheophily—depositional individuals
		pi_RheoEros	Percentage Rheophily—erosional individuals
	Year-to-year variability	Persist	Persistence (variability in presence/absence from year to year; see Appendix L)
		Stab	Stability (variability in relative abundance from year to year; see Appendix L)

Worksheet name	Type of statistics	Variable	Description
WT_Daily	Daily water temperature	WT_DMean	Daily mean (°C)
		WT_DMax	Daily maximum (°C)
		WT_DMin	Daily minimum (°C)
		WT_DDif	Daily difference (maximum−minimum) (°C)
		WT_DVar	Standard deviation for each day (°C)
WT_Month	Monthly water temperature	WT_MMean	Monthly mean (°C)
		WT_MMax	Monthly maximum (°C)
		WT_MMin	Monthly minimum (°C)
		WT_MDif	Monthly difference (maximum−minimum) (°C)
		WT_MVar	Standard deviation for each month (°C)
WT_Seasonal	Seasonal water temperature	WT_SMean	Seasonal mean (°C)
		WT_SMax	Seasonal maximum (°C)
		WT_SMin	Seasonal minimum (°C)
		WT_SDif	Seasonal difference (maximum−minimum) (°C)
		WT_SVar	Standard deviation for each season (°C)
WT_Annual	Annual water temperature (January 1−December 31)	WT_AMean	Annual mean (°C)
		WT_AMax	Annual maximum (°C)
		WT_AMin	Annual minimum (°C)
		WT_ADifMean	Mean annual difference (°C)
		WT_ADifMax	Maximum annual difference (°C)
		WT_ADifMin	Minimum annual difference (°C)
		WT_AVar	Standard deviation of the annual mean difference (°C)

Worksheet name	Type of statistics	Variable	Description
AT_Daily	Daily air temperature	AT_DMean	Daily mean (˚C)
		AT_DMax	Daily maximum (˚C)
		AT_DMin	Daily minimum (˚C)
		AT_DDif	Daily difference (maximum−minimum)(˚C)
		AT_DVar	Standard deviation for each day (˚C)
AT_Month	Monthly air temperature	AT_MMean	Monthly mean (˚C)
		AT_MMax	Monthly maximum (˚C)
		AT_MMin	Monthly minimum (˚C)
		AT_MDif	Monthly difference (maximum−minimum) (˚C)
		AT_MVar	Standard deviation for each month (˚C)
AT_Seasonal	Seasonal air temperature	AT_SMean	Seasonal mean (˚C)
		AT_SMax	Seasonal maximum (˚C)
		AT_SMin	Seasonal minimum (˚C)
		AT_SDif	Seasonal difference (maximum−minimum) (˚C)
		AT_SVar	Standard deviation for each season (˚C)
AT_Annual	Annual air temperature (January 1−December 31)	AT_AMean	Annual mean (˚C)
		AT_AMax	Annual maximum (˚C)
		AT_AMin	Annual minimum (˚C)
		AT_ADifMean	Mean annual difference (˚C)
		AT_ADifMax	Maximum annual difference (˚C)
		AT_ADifMin	Minimum annual difference (˚C)
		AT_AVar	Standard deviation of the annual mean difference (˚C)

Worksheet name	Type of statistics	Variable	Description
Stage_Daily	Daily stage	Stage_DMean	Mean stage for each day (ft)
		Stage_DMed	Median stage for each day (ft)
		Stage_DMax	Maximum stage for each day (ft)
		Stage_DMin	Minimum stage for each day (ft)
		Stage_DDif	Difference between the maximum and minimum stage for each day (ft)
		Stage_DVar	Standard deviation for stage for each day (ft)
Stage_Monthly	Monthly stage	Stage_MMean	Mean stage for each month (ft)
		Stage_MMax	Maximum stage for each month (ft)
		Stage_MMin	Minimum stage for each month (ft)
		Stage_MDif	Difference between the maximum and minimum stage values for each month (ft)
		Stage_MMag90	High flow magnitude (90^{th} percentile of monthly stage values) (ft)
		Stage_MMag50	Median magnitude (50^{th} percentile of monthly stage values) (ft)
		Stage_MMag25	Low flow magnitude (ft) (25^{th} percentile of monthly stage values); this represents low flows in smaller streams [drainage areas <50 mi^2, per DePhilip and Moberg (2013)]
		Stage_MMag10	Low flow magnitude (ft) (10^{th} percentile of monthly stage values); this represents low flows in medium to larger-sized streams [drainage areas >50 mi^2 per DePhilip and Moberg (2013)]
		Stage_MMag1	Extreme low flow magnitude (ft) (1^{st} percentile of monthly stage values); this represents extreme low flows
		Stage_Mp90	Percentage high flow and floods (%) (percentage of stage values in each month that exceed the monthly 90^{th} percentile)
		Stage_Mp1_25	Percentage low flows (%); percentage of stage values in each month that are between the monthly 25^{th} and 1^{st} percentiles
		Stage_Mp25_90	Percentage typical (%); percentage of stage values in each month that are between the

Worksheet name	Type of statistics	Variable	Description
			monthly 25th and 90st percentiles
Stage_Season or Flow_Season	Seasonal stage	Stage_Sp90	Percentage high flows and floods in spring and fall (%); percentage of stage values in each month that exceed the monthly 90th percentile in spring (March−May) and fall (September−November)
Stage_Annual	Annual stage	Stage_AMean	Annual mean stage (ft)
		Stage_AMax	Annual maximum stage (ft)
		Stage_ADateMax	Julian date of annual maximum stage (number)
		Stage_AMin	Annual minimum stage (ft)
		Stage_ADateMin	Julian date of annual minimum stage (number)
		Stage_ADifMean	Mean annual difference in stage (ft)
		Stage_ADifMax	Maximum of the daily difference in stage (ft)
		Stage_ADifMin	Minimum of the daily difference in stage (ft)
		Stage_AVar	Standard deviation of the daily difference in stage (ft)
		Stage_AZero	Number of days having stage values of 0 (number)

Worksheet name	Type of statistics	Variable	Description
Flow_Daily	Daily discharge	Flow_DMean	Mean flow for each day (ft^3/sec)
		Flow_DMed	Median flow for each day (ft^3/sec)
		Flow_DMax	Maximum flow for each day (ft^3/sec)
		Flow_DMin	Minimum flow for each day (ft^3/sec)
		Flow_DDif	Difference between the maximum and minimum flow for each day (ft^3/sec)
		Flow_DVar	Standard deviation for flow for each day (ft^3/sec)
Flow_Monthly	Monthly discharge	Flow_MMean	Mean flow for each month (ft^3/sec)
		Flow_MMax	Maximum flow for each month (ft^3/sec)
		Flow_MMin	Minimum flow for each month (ft^3/sec)
		Flow_MDif	Difference between the maximum and minimum flow values for each month (ft^3/sec)
		Flow_MMag90	High flow magnitude (90^{th} percentile of monthly flow values) (ft^3/sec)
		Flow_MMag50	Median flow magnitude (50^{th} percentile of monthly flow values) (ft^3/sec)
		Flow_MMag25	Low flow magnitude (ft^3/sec) (25^{th} percentile of monthly flow values); this represents low flows in smaller streams [drainage areas <50 mi^2, per DePhilip and Moberg (2013)]
		Flow_MMag10	Low flow magnitude (ft^3/sec) (10^{th} percentile of monthly flow values); this represents low flows in medium to larger-sized streams [drainage areas >50 mi^2 per DePhilip and Moberg (2013)]
		Flow_MMag1	Extreme low flow magnitude (ft^3/sec) (1^{st} percentile of monthly flow values); this represents extreme low flows
		Flow_Mp90	Percentage high flow and floods (%) (percentage of flow values in each month that exceed the monthly 90^{th} percentile)

Worksheet name	Type of statistics	Variable	Description
		Flow_Mp1_25	Percentage low flows (%); percentage of flow values in each month that are between the monthly 25th and 1st percentiles
		Flow_Mp25_90	Percentage typical (%); percentage of flow values in each month that are between the monthly 25th and 90st percentiles
Flow_Season	Seasonal discharge	Flow_Sp90	Percentage high flows and floods in spring and fall (%); percentage of flow values in each month that exceed the monthly 90th percentile in spring (March−May) and fall (September−November)
Flow_Annual	Annual discharge	Flow_AMean	Annual mean flow (ft^3/sec)
		Flow_AMax	Annual maximum flow (ft^3/sec)
		Flow_ADateMax	Julian date of annual maximum flow (number)
		Flow_AMin	Annual minimum flow (ft^3/sec)
		Flow_ADateMin	Julian date of annual minimum flow (number)
		Flow_ADifMean	Mean annual difference in flow (ft^3/sec)
		Flow_ADifMax	Maximum of the daily difference in flow (ft^3/sec)
		Flow_ADifMin	Minimum of the daily difference in flow (ft^3/sec)
		Flow_AVar	Standard deviation of the daily difference in flow (ft^3/sec)
		Flow_AZero	Number of days having flow values of 0 (number)

Worksheet name	Type of statistics	Variable	Description
Habitat	Qualitative (per RBP high gradient field form)	Epif_Cover	Rating of epifaunal substrate/available cover, from 0 (worst) to 20 (best)
		Embed	Rating of embeddedness, from 0 (worst) to 20 (best)
		VeloDepth	Rating of velocity/depth regime, from 0 (worst) to 20 (best)
		SedDepo	Rating of sediment deposition, from 0 (worst) to 20 (best)
		ChanFlow	Rating of channel flow status, from 0 (worst) to 20 (best)
		ChanAlt	Rating of channel alteration, from 0 (worst) to 20 (best)
		FreqRiff	Rating of frequency of riffles, from 0 (worst) to 20 (best)
		BankStab_LB	Rating of bank stability on left bank, from 0 (worst) to 10 (best)
		BankStab_RB	Rating of bank stability on right bank, from 0 (worst) to 10 (best)
		VegProt_LB	Rating of vegetative protection on left bank, from 0 (worst) to 10 (best)
		VegProt_RB	Rating of vegetative protection on right bank, from 0 (worst) to 10 (best)
		RipWidth_LB	Rating of riparian vegetative zone width on left bank, from 0 (worst) to 10 (best)
		RipWidth_RB	Rating of riparian vegetative zone width on right bank, from 0 (worst) to 10 (best)
	Quantitative (optional)	BFwidth	Bankfull width (m)
		BFdepth	Bankful depth (m)
		Slope	Reach-scale slope (unitless)
		Canopy_mid	Canopy closure (mid-stream)
		Canopy_bank	Canopy closure (along bank)
		pRiffle	Percentage riffle habitat in biological sampling reach
		pRun	Percentage run habitat in biological sampling reach

Worksheet name	Type of statistics	Variable	Description
		pPool	Percentage pool habitat in biological sampling reach
		pGlide	Percentage glide habitat in biological sampling reach
		pFine	Percentage fine substrate in biological sampling reach
		pSand	Percentage sand substrate in biological sampling reach
		pGravel	Percentage gravel substrate in biological sampling reach
		pCobble	Percentage cobble substrate in biological sampling reach
		pBoulder	Percentage boulder substrate in biological sampling reach
		pBedrock	Percentage bedrock substrate in biological sampling reach

Worksheet name	Type of statistics	Variable	Description
WaterQual	in situ	SpCond	Specific conductivity (µS/cm)
		DO	Dissolved oxygen (%)
		pH	pH

Worksheet name	Type of statistics	Variable	Description
SiteInfo	Site information	StationID	Unique station identifier
		Waterbody Name	Name of water body
		Long	Longitude, decimal degrees, NAD83
		Lat	Latitude, decimal degrees, NAD83
		State	State that the site is located in
		DrArea_km2	Drainage area (km^2)
		SLOPE	Slope of flowline (unitless) (source: NHDPlus)
		Elev_m	Elevation of site (m)
		BFI	Baseflow index (Wolock, 2003)
	Ecoregion	US_L4CODE	U.S. EPA level 4 ecoregion (code) that the site is located in
		US_L4NAME	U.S. EPA level 4 ecoregion (name) that the site is located in
		US_L3CODE	U.S. EPA level 3 ecoregion (code) that the site is located in
		US_L3NAME	U.S. EPA level 3 ecoregion (name) that the site is located in
	NLCD total watershed	IMPERV	Percentage of total watershed defined as impervious (source: most recent NLCD)
		LU_11	Percentage of total watershed defined as open water (source: most recent NLCD)
		LU_12	Percentage of total watershed defined as perennial ice/snow (source: most recent NLCD)
		LU_21	Percentage of total watershed defined as developed, open space (source: most recent NLCD)
		LU_22	Percentage of total watershed defined as developed, low intensity (source: most recent NLCD)
		LU_23	Percentage of total watershed defined as developed, medium intensity (source: most recent NLCD)

Worksheet name	Type of statistics	Variable	Description
		LU_24	Percentage of total watershed defined as developed, high intensity (source: most recent NLCD)
		LU_31	Percentage of total watershed defined as barren land (Rock/Sand/Clay) (source: most recent NLCD)
		LU_41	Percentage of total watershed defined as deciduous forest (source: most recent NLCD)
		LU_42	Percentage of total watershed defined as evergreen forest (source: most recent NLCD)
		LU_43	Percentage of total watershed defined as mixed forest (source: most recent NLCD)
		LU_52	Percentage of total watershed defined as shrub/scrub (source: most recent NLCD)
		LU_71	Percentage of total watershed defined as grassland/herbaceous (source: most recent NLCD)
		LU_81	Percentage of total watershed defined as pasture/hay (source: most recent NLCD)
		LU_82	Percentage of total watershed defined as cultivated crops (source: most recent NLCD)
		LU_90	Percentage of total watershed defined as woody wetlands (source: most recent NLCD)
		LU_95	Percentage of total watershed defined as emergent herbaceous wetlands (source: most recent NLCD)

Worksheet name	Type of statistics	Variable	Description
Disturbance screening	Land use	Overall	Overall land use disturbance level; see Appendix C—Table C-1
		Imperv	Impervious disturbance level; see Appendix C—Table C-1
		Urban	Urban disturbance level; see Appendix C—Table C-1
		Crops	Crops disturbance level; see Appendix C—Table C-1
		Hay	Hay disturbance level; see Appendix C—Table C-1
	Impacts from dams, mines and point-source pollution sites	Flag_FTYPE	1 = flagged; 0 = not flagged. NHDPlus v1[1] flowline (FTYPE) the site is located on (e.g., stream/river, artificial pathway, canal/ditch, pipeline, connector). If the site was located on a flowline designated as something other than a stream/river, the site was flagged.
		Flag_Dams	1 = flagged; 0 = not flagged. Sites are flagged if dams are present within 1 km of the site.
		Dam_Assess	Likelihood of impact (unlikely, likely, unsure) from dams at the flagged sites; for more information see Appendix C—Section C2.2
		Flag_Mines	1 = flagged; 0 = not flagged. Sites are flagged if mines are present within 1 km of the site.
		Mines_Assess	Likelihood of impact (unlikely, likely, unsure) from mines at the flagged sites; for more information see Appendix C—Section C.2.2
		Flag_NPDES	1 = flagged; 0 = not flagged. Sites are flagged if NPDES major discharge permits have been issued within 1 km of the site.

[1]http://www.horizon-systems.com/nhdplus/nhdplusv1_home.php

Worksheet name	Type of statistics	Variable	Description
		NPDES_Assess	Likelihood of impact (unlikely, likely, unsure) from NPDES major discharges at the flagged sites; for more information see Appendix C—Section C.2.2
		Flag_SNPL	1 = flagged; 0 = not flagged. Sites are flagged if Superfund National Priorities List (SNPL) sites are present within 1 km of the site.
		SNPL_Assess	Likelihood of impact (unlikely, likely, unsure) from SNPL sites at the flagged sites; for more information see Appendix C—Section C.2.2
	Impact from other nonclimatic stressors	Flag_Roads	1 = flagged; 0 = not flagged. Sites are flagged if road score is ≥75%; for more information see Appendix C—Section C.2.3
		Roads_Assess	Likelihood of impact (unlikely, likely, unsure) from roads at the flagged sites; for more information see Appendix C—Section C.2.3
		Flag_AtmosDep	1 = flagged; 0 = not flagged. Sites are flagged if atmospheric deposition score is ≥75%; for more information see Appendix C—Section C.2.3
		AtmosDep_Assess	Likelihood of impact (unlikely, likely, unsure) from atmospheric deposition at the flagged sites
		Flag_Coal	1 = flagged; 0 = not flagged. Sites are flagged if the coal mining potential score is ≥75% and/or the permit activity score (if available) is >0; for more information see Appendix C—Section C.2.3
		Coal_Assess	Likelihood of impact (unlikely, likely, unsure) from coal mining at the flagged sites

Worksheet name	Type of statistics	Variable	Description
		Flag_ShaleGas	1 = flagged; 0 = not flagged. Sites are flagged if the shale gas drilling potential score is 100% and/or the permit activity score (if available) is >0; for more information see Appendix C—Section C.2.3
		ShaleGas_Assess	Likelihood of impact (unlikely, likely, unsure) from shale gas drilling at the flagged sites
		Flag_FutureUrb	1 = flagged; 0 = not flagged. Sites are flagged if they currently have a local catchment-scale percentage impervious value ≤10% and the average projected future change (by 2050) is ≥0.5%; for more information see Appendix C—Section C.2.3
		FutureUrb_Assess	Likelihood of impact (unlikely, likely, unsure) from future urban development at the flagged sites
		Flag_WaterUse	1 = flagged; 0 = not flagged. Sites are flagged if they received a score of ≥50% for any of the 3 water use parameters listed below; for more information see Appendix C—Section C.2.3
		WaterUse_Assess	Likelihood of impact (unlikely, likely, unsure) from water withdrawals at the flagged sites

Worksheet name	Type of statistics	Variable	Description
Climate change vulnerability	Classification	Class_Bug	Bug classification group—eastern United States, based on the maximum probability value (e.g., if a site received a Group 1 membership value of 0.7 and a Group 4 membership value of 0.3, it was assigned to Group 1).
		Prob_G1	Probability of membership in classification Group 1; scores range from 0 to 1; higher values indicate higher probability of membership
		Prob_G3	Probability of membership in classification Group 3; scores range from 0 to 1; higher values indicate higher probability of membership
		Prob_G4	Probability of membership in classification Group 4; scores range from 0 to 1; higher values indicate higher probability of membership
	Vulnerability rating	Vuln_Sc1	Vulnerability rating (least, moderate, most) for scenario 1 (increasing temperatures)
		Vuln_Sc2	Vulnerability rating (least, moderate, most) for scenario 2 (increase in frequency and severity of peak flows)
		Vuln_Sc3	Vulnerability rating (least, moderate, most) for scenario 3 (increased frequency of summer low flow events)
		Vuln_Overall	Overall vulnerability rating (least, moderate, most) (lowest rating across scenarios)

K.1. REFERENCES

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APPENDIX L.

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 (MD DNR, PA DEP, VT DEC). Best professional judgment from regional taxonomists was also considered.

Table L-1 contains the list of taxa that were the basis of the thermal preference metrics used in the regional classification analyses (unpublished data). There are 51 cold/cool water taxa and 39 warm water taxa on this regional list. The taxonomic resolution is genus level or higher to match with the taxonomic resolution of the NRSA/WSA data. Please note:

- ***The list in Table L-1 only includes taxa that occur in the NRSA/WSA data set analyzed for the regional classification analysis***.
- Initially we tried to distinguish between cold and cool water taxa but later decided that additional data and further analyses are necessary to better refine those designations (if such designations can be made).

Table L-2 contains a list of thermal indicator taxa identified based on thermal tolerance analyses (per Yuan, 2006) conducted on data from New England and New York (unpublished U.S. EPA Northeast pilot study), and Table L-3 contains lists of taxa that have been identified as thermal indicators by VT DEC (Steve Fiske and Aaron Moore, unpublished).

Table L-4 contains the list of taxa that have been identified as cold water taxa by Maryland DNR (Becker et al., 2010) and also contains information that was provided by Pennsylvania DEP (Amy Williams and Dustin Shull, unpublished data).

Table L-5 contains a list of thermal 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 Tennessee DEC.

All of these lists are intended to be starting points. They should be revised as better data become available and may need to be further customized by region. It may be appropriate to have a list that spans the three regions, plus customized lists for each region. If so, Table L-1 could potentially serve as the “three-region” list, Tables L-2 and L-3 could potentially serve as the starter list for the Northeast region, Table L-4 could potentially serve as the starter list for the Mid-Atlantic region, and Table L-5 could potentially serve as the starter list for the Southeast region.

Table L-1. Taxa that were the basis of the thermal preference metrics used in the regional classification analyses (unpublished data, U.S. EPA, 2012). This list only includes taxa that occur in the NRSA/WSA data set analyzed. We primarily received reviewer feedback from biologists in the Mid-Atlantic region. Final identifications at the genus level are italicized in the Final ID column

Order	Final ID	Type	Reviewer feedback
Trichoptera	*Agapetus*	Cold/cool	Agree
Plecoptera	*Alloperla*	Cold/cool	Agree
Ephemeroptera	*Ameletus*	Cold/cool	Agree
Plecoptera	*Amphinemura*	Cold/cool	Mixed
Trichoptera	*Apatania*	Cold/cool	Mixed
Trichoptera	*Arctopsyche*	Cold/cool	Agree
Diptera	*Brillia*	Cold/cool	Mixed
Plecoptera	Capniidae	Cold/cool	Agree
Plecoptera	*Allocapnia*	Cold/cool	Agree
Plecoptera	*Paracapnia*	Cold/cool	Agree
Plecoptera	*Sweltsa*	Cold/cool	Agree
Ephemeroptera	*Cinygmula*	Cold/cool	Agree
Ephemeroptera	*Diphetor*	Cold/cool	Agree
Plecoptera	*Diploperla*	Cold/cool	Unsure
Trichoptera	*Dolophilodes*	Cold/cool	Agree
Ephemeroptera	*Drunella*	Cold/cool	Agree
Ephemeroptera	*Ephemerella*	Cold/cool	Agree
Ephemeroptera	*Eurylophella*	Cold/cool	Mixed
Trichoptera	*Glossosoma*	Cold/cool	Mixed
Plecoptera	*Isoperla*	Cold/cool	Mixed
Trichoptera	*Lepidostoma*	Cold/cool	Mixed
Plecoptera	*Malirekus*	Cold/cool	Agree
Plecoptera	Nemouridae	Cold/cool	Mixed
Coleoptera	*Oulimnius*	Cold/cool	Mixed
Trichoptera	*Parapsyche*	Cold/cool	Agree

Table L-1. continued…

Order	Final ID	Type	Reviewer Feedback
Plecoptera	*Peltoperla*	Cold/cool	Agree
Plecoptera	*Pteronarcys*	Cold/cool	Mixed
Trichoptera	*Rhyacophila*	Cold/cool	Agree
Plecoptera	*Taenionema*	Cold/cool	Agree
Plecoptera	*Taeniopteryx*	Cold/cool	Mixed
Plecoptera	*Tallaperla*	Cold/cool	Agree
Trichoptera	*Wormaldia*	Cold/cool	Agree
Plecoptera	*Zapada*	Cold/cool	Agree
Diptera	*Antocha*	Cold/cool	Disagree
Diptera	*Atherix*	Cold/cool	Mixed
Trichoptera	*Diplectrona*	Cold/cool	Agree
Ephemeroptera	*Epeorus*	Cold/cool	Agree
Ephemeroptera	*Habrophlebia*	Cold/cool	Agree
Odonata	*Lanthus*	Cold/cool	Agree
Diptera	*Pagastia*	Cold/cool	Mixed
Coleoptera	*Promoresia*	Cold/cool	Agree
Ephemeroptera	*Rhithrogena*	Cold/cool	Agree
Diptera	*Diamesa*	Cold/cool	Unsure
Lumbriculida	Lumbriculidae	Cold/cool	Disagree
Diptera	*Micropsectra*	Cold/cool	Disagree
Megaloptera	*Nigronia*	Cold/cool	Disagree
Diptera	*Orthocladius*	Cold/cool	Disagree
Diptera	*Parametriocnemus*	Cold/cool	Disagree
Trichoptera	*Polycentropus*	Cold/cool	Disagree
Trichoptera	*Psilotreta*	Cold/cool	Agree
Diptera	*Ablabesmyia*	Warm	Agree
Odonata	*Argia*	Warm	Agree
Hemiptera	*Belostoma*	Warm	Unsure

Table L-1. continued…

Order	Final ID	Type	Reviewer Feedback
Coleoptera	*Berosus*	Warm	Agree
Isopoda	*Caecidotea*	Warm	Unsure
Ephemeroptera	*Caenis*	Warm	Agree
Diptera	*Cardiocladius*	Warm	Agree
Trichoptera	*Chimarra*	Warm	Agree
Diptera	*Dicrotendipes*	Warm	Agree
Unionoida	*Elliptio*	Warm	Unsure
Ephemeroptera	*Ephoron*	Warm	Agree
Arhynchobdellida	*Erpobdella*	Warm	Agree
Arhynchobdellida	*Mooreobdella*	Warm	Agree
Amphipoda	*Gammarus*	Warm	Unsure
Diptera	*Glyptotendipes*	Warm	Agree
Rhynchobdellida	*Helobdella*	Warm	Agree
Odonata	*Helocordulia*	Warm	Agree
Odonata	*Hetaerina*	Warm	Agree
Neotaenioglossa	Hydrobiidae	Warm	Agree
Trichoptera	*Hydroptila*	Warm	Agree
Odonata	*Ischnura*	Warm	Agree
Ephemeroptera	*Leucrocuta*	Warm	Unsure
Coleoptera	*Lioporeus*	Warm	Agree
Odonata	*Macromia*	Warm	Agree
Trichoptera	*Macrostemum*	Warm	Agree
Trichoptera	*Neureclipsis*	Warm	Agree
Odonata	*Neurocordulia*	Warm	Agree
Diptera	*Nilotanypus*	Warm	Agree
Diptera	*Nilothauma*	Warm	Agree
Trichoptera	*Oecetis*	Warm	Agree
Diptera	*Pentaneura*	Warm	Agree

Table L-1. continued…

Order	Final ID	Type	Reviewer Feedback
Basommatophora	*Physella*	Warm	Agree
Veneroida	*Sphaerium*	Warm	Agree
Ephemeroptera	*Stenacron*	Warm	Mixed
Coleoptera	*Stenelmis*	Warm	Agree
Diptera	*Stenochironomus*	Warm	Agree
Diptera	*Tanytarsus*	Warm	Agree
Ephemeroptera	*Tricorythodes*	Warm	Agree
	Turbellaria[a]	Warm	Agree

[a]Final ID is a Class

Table L-2. Thermal indicator taxa in New England and New York, based on thermal tolerance analyses (per Yuan, 2006) conducted on state biomonitoring data from New England and New York (unpublished U.S. EPA Northeast pilot study). Results are based on relative ranks from: (1) the generalized additive model (GAM) only and (2) multiple models. Final identifications at the genus level are italicized in the Final ID column

Order	Family	Regional final ID	Thermal preference	GAM only	Multiple models
		Nematomorpha[a]	cold	yes	
Basommatophora	Ancylidae	*Laevapex*	cold	yes	
Coleoptera	Dryopidae	*Helichus*	cold	yes	yes
Coleoptera	Elmidae	*Oulimnius*	cold		yes
Coleoptera	Hydrophilidae	*Tropisternus*	cold	yes	
Coleoptera	Psephenidae	*Ectopria*	cold		yes
Diptera	Ceratopogonidae	Ceratopogonidae	cold		yes
Diptera	Chironomidae	*Brillia*	cold	yes	yes
Diptera	Chironomidae	*Brundiniella*	cold	yes	
Diptera	Chironomidae	*Diplocladius*	cold	yes	
Diptera	Chironomidae	*Heleniella*	cold	yes	
Diptera	Chironomidae	*Parachaetocladius*	cold	yes	yes
Diptera	Chironomidae	*Paraphaenocladius*	cold	yes	
Diptera	Chironomidae	*Stilocladius*	cold	yes	
Diptera	Dixidae	*Dixa*	cold	yes	
Diptera	Psychodidae	*Pericoma*	cold	yes	
Diptera	Simuliidae	*Prosimulium*	cold	yes	yes
Diptera	Tipulidae	*Dicranota*	cold		yes
Diptera	Tipulidae	*Hexatoma*	cold		yes
Diptera	Tipulidae	*Limnophila*	cold	yes	yes
Diptera	Tipulidae	*Molophilus*	cold	yes	
Diptera	Tipulidae	*Pseudolimnophila*	cold	yes	yes
Diptera	Tipulidae	*Tipula*	cold		yes
Ephemeroptera	Ameletidae	*Ameletus*	cold	yes	yes

Table L-2. continued…

Order	Family	Regional final ID	Thermal preference	GAM only	Multiple models
Ephemeroptera	Ephemerellidae	*Ephemerella*	cold	yes	yes
Ephemeroptera	Ephemerellidae	*Eurylophella*	cold	yes	yes
Ephemeroptera	Heptageniidae	*Rhithrogena*	cold	yes	yes
Ephemeroptera	Leptophlebiidae	Leptophlebiidae	cold		yes
Odonata	Gomphidae	*Lanthus*	cold	yes	
Plecoptera	Capniidae	Capniidae	cold	yes	yes
Plecoptera	Chloroperlidae	Chloroperlidae	cold	yes	yes
Plecoptera	Leuctridae	Leuctridae	cold		yes
Plecoptera	Nemouridae	Nemouridae	cold	yes	yes
Plecoptera	Peltoperlidae	*Peltoperla*	cold	yes	yes
Plecoptera	Perlodidae	*Isogenoides*	cold	yes	yes
Plecoptera	Perlodidae	*Isoperla*	cold	yes	yes
Plecoptera	Perlodidae	*Malirekus*	cold	yes	yes
Plecoptera	Pteronarcyidae	*Pteronarcys*	cold	yes	yes
Plecoptera	Taeniopterygidae	*Taenionema*	cold	yes	yes
Plecoptera	Taeniopterygidae	*Taeniopteryx*	cold	yes	yes
Trichoptera	Apataniidae	*Apatania*	cold	yes	yes
Trichoptera	Glossosomatidae	*Glossosoma*	cold		yes
Trichoptera	Hydropsychidae	*Arctopsyche*	cold	yes	
Trichoptera	Hydropsychidae	*Diplectrona*	cold	yes	yes
Trichoptera	Hydropsychidae	*Parapsyche*	cold	yes	yes
Trichoptera	Hydroptilidae	*Palaeagapetus*	cold	yes	yes
Trichoptera	Lepidostomatidae	*Lepidostoma*	cold		yes
Trichoptera	Limnephilidae	*Hydatophylax*	cold	yes	yes
Trichoptera	Philopotamidae	*Dolophilodes*	cold		yes
Trichoptera	Philopotamidae	*Wormaldia*	cold	yes	

Table L-2. continued…

Order	Family	Regional final ID	Thermal preference	GAM only	Multiple models
Trichoptera	Rhyacophilidae	*Rhyacophila*	cold	yes	yes
Tricladida	Dugesiidae	*Cura*	cold		yes
Trombidiformes	Hydrachnidae	Hydrachnidae	cold		yes
Trombidiformes	Hydryphantidae	Hydryphantidae	cold	yes	
Trombidiformes	Hygrobatidae	*Hygrobates*	cold	yes	
Trombidiformes	Sperchonidae	*Sperchon*	cold	yes	
Trombidiformes	Torrenticolidae	Torrenticolidae	cold	yes	
Basommatophora	Ancylidae	*Ferrissia*	cold/cool		yes
Coleoptera	Elmidae	*Optioservus*	cold/cool		yes
Coleoptera	Elmidae	*Promoresia*	cold/cool		yes
Diptera	Athericidae	*Atherix*	cold/cool		yes
Diptera	Chironomidae	*Diamesa*	cold/cool		yes
Diptera	Chironomidae	*Micropsectra*	cold/cool		yes
Diptera	Chironomidae	*Orthocladius*	cold/cool		yes
Diptera	Chironomidae	*Pagastia*	cold/cool		yes
Diptera	Chironomidae	*Parametriocnemus*	cold/cool		yes
Diptera	Chironomidae	*Rheocricotopus*	cold/cool		yes
Diptera	Chironomidae	*Sublettea*	cold/cool		yes
Haplotaxida	Enchytraeidae	Enchytraeidae	cold/cool		yes
Lumbriculida	Lumbriculidae	Lumbriculidae	cold/cool		yes
Megaloptera	Corydalidae	*Nigronia*	cold/cool		yes
Odonata	Aeshnidae	*Boyeria*	cold/cool		yes
Trichoptera	Odontoceridae	*Psilotreta*	cold/cool		yes
Trichoptera	Polycentropodidae	*Polycentropus*	cold/cool		yes
		Turbellaria[b]	warm	yes	yes
Aeolosomatida	Aeolosomatidae	Aeolosomatidae	warm	yes	

Table L-2. continued…

Order	Family	Regional final ID	Thermal preference	GAM only	Multiple models
Amphipoda	Crangonyctidae	*Synurella*	warm	yes	
Amphipoda	Gammaridae	*Gammarus*	warm	yes	yes
Amphipoda	Hyalellidae	*Hyalella*	warm	yes	
Basommatophora	Physidae	*Physella*	warm	yes	yes
Basommatophora	Planorbidae	*Planorbella*	warm	yes	
Coleoptera	Elmidae	*Stenelmis*	warm	yes	yes
Coleoptera	Gyrinidae	*Dineutus*	warm	yes	
Coleoptera	Gyrinidae	*Gyrinus*	warm	yes	
Coleoptera	Haliplidae	*Haliplus*	warm	yes	
Coleoptera	Hydrophilidae	*Berosus*	warm	yes	
Diptera	Chironomidae	*Ablabesmyia*	warm	yes	yes
Diptera	Chironomidae	*Cardiocladius*	warm	yes	yes
Diptera	Chironomidae	*Chironomus*	warm	yes	
Diptera	Chironomidae	*Cryptotendipes*	warm	yes	
Diptera	Chironomidae	*Dicrotendipes*	warm	yes	yes
Diptera	Chironomidae	*Endochironomus*	warm	yes	
Diptera	Chironomidae	*Glyptotendipes*	warm	yes	yes
Diptera	Chironomidae	*Helopelopia*	warm	yes	
Diptera	Chironomidae	*Labrundinia*	warm	yes	
Diptera	Chironomidae	*Nilotanypus*	warm	yes	yes
Diptera	Chironomidae	*Parachironomus*	warm	yes	
Diptera	Chironomidae	*Paratanytarsus*	warm	yes	
Diptera	Chironomidae	*Paratendipes*	warm	yes	
Diptera	Chironomidae	*Pentaneura*	warm	yes	yes
Diptera	Chironomidae	*Phaenopsectra*	warm	yes	
Diptera	Chironomidae	*Pseudochironomus*	warm	yes	

Table L-2. continued…

Order	Family	Regional final ID	Thermal preference	GAM only	Multiple models
Diptera	Chironomidae	*Rheopelopia*	warm	yes	
Diptera	Chironomidae	*Tanytarsus*	warm	yes	yes
Diptera	Chironomidae	*Tribelos*	warm	yes	
Diptera	Chironomidae	*Xenochironomus*	warm	yes	
Ephemeroptera	Baetidae	*Centroptilum*	warm	yes	
Ephemeroptera	Baetidae	*Procloeon*	warm	yes	
Ephemeroptera	Baetidae	*Pseudocloeon*	warm	yes	
Ephemeroptera	Caenidae	*Caenis*	warm	yes	yes
Ephemeroptera	Ephemerellidae	*Attenella*	warm	yes	
Ephemeroptera	Heptageniidae	*Leucrocuta*	warm	yes	yes
Ephemeroptera	Heptageniidae	*Stenacron*	warm	yes	yes
Ephemeroptera	Leptohyphidae	*Tricorythodes*	warm	yes	yes
Ephemeroptera	Polymitarcyidae	*Ephoron*	warm	yes	yes
Ephemeroptera	Potamanthidae	*Anthopotamus*	warm	yes	
Isopoda	Asellidae	*Caecidotea*	warm	yes	
Lepidoptera	Pyralidae	Pyralidae	warm	yes	
Neotaenioglossa	Hydrobiidae	Hydrobiidae	warm	yes	yes
Neotaenioglossa	Pleuroceridae	Pleuroceridae	warm	yes	yes
Neotaenioglossa	Bithyniidae	Bithyniidae	warm	yes	
Odonata	Coenagrionidae	*Argia*	warm	yes	yes
Odonata	Coenagrionidae	*Enallagma*	warm	yes	
Odonata	Coenagrionidae	*Ischnura*	warm	yes	
Odonata	Corduliidae	Corduliidae	warm	yes	
Odonata	Gomphidae	*Hagenius*	warm	yes	
Plecoptera	Perlidae	*Attaneuria*	warm	yes	
Plecoptera	Perlidae	*Perlesta*	warm	yes	

Table L-2. continued…

Order	Family	Regional final ID	Thermal preference	GAM only	Multiple models
Rhynchobdellida	Glossiphoniidae	*Placobdella*	warm	yes	
Trichoptera	Hydropsychidae	*Macrostemum*	warm	yes	yes
Trichoptera	Hydroptilidae	*Hydroptila*	warm	yes	yes
Trichoptera	Leptoceridae	*Ceraclea*	warm	yes	
Trichoptera	Leptoceridae	*Nectopsyche*	warm	yes	
Trichoptera	Leptoceridae	*Oecetis*	warm	yes	yes
Trichoptera	Polycentropodidae	*Cernotina*	warm	yes	
Trichoptera	Polycentropodidae	*Neureclipsis*	warm	yes	yes
Tricladida	Planariidae	Planariidae	warm	yes	
Tubificida	Naididae	*Chaetogaster*	warm	yes	
Tubificida	Naididae	*Dero*	warm	yes	
Veneroida	Pisidiidae	*Musculium*	warm	yes	
Veneroida	Pisidiidae	*Sphaerium*	warm	yes	yes

[a]Final identification is a Phylum.
[b]Final identification is a Class

Table L-3. 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 L-3. 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 L-4. 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 L-4. 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 L-5. 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 L-5. continued…

Type	Order	Taxon	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	
cool	Plecoptera	*Sweltsa*		yes	warm and

Table L-5. continued…

Type	Order	Taxon	NC (U.S. EPA, 2012)	TN	Notes—TN
					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	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		
warm	Odonata	*Macromia*	yes		
warm	Odonata	*Neurocordulia*	yes		
warm	Odonata	*Tetragoneuria*	yes		

Table L-5. continued…

Type	Order	Taxon	NC (U.S. EPA, 2012)	TN	Notes—TN
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		
warm		*Erpobdella/Mooreobdella*	yes		

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APPENDIX M.

FORMULAS FOR CALCULATING PERSISTENCE AND STABILITY

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

$$J(AB) = \frac{j}{a + b - j}$$

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):

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

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 M-1:

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

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

$$= 1 - \frac{9 + 35 + 0 + 5 + 1}{23 + 73} = 1 - \frac{50}{96} = 0.48$$

Table M-1. 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 their 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 there can exist substantial year-to-year shifts in relative abundances.

M.1. REFERENCE:

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APPENDIX N.

HYDROLOGIC SUMMARY STATISTICS AND TOOLS FOR CALCULATING ESTIMATED STREAMFLOW STATISTICS

The Nature Conservancy (TNC) and several partners (states, RBCs, 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 N-1 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 N-1 can be generated for data from RMN sites.

Table N-1. 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}

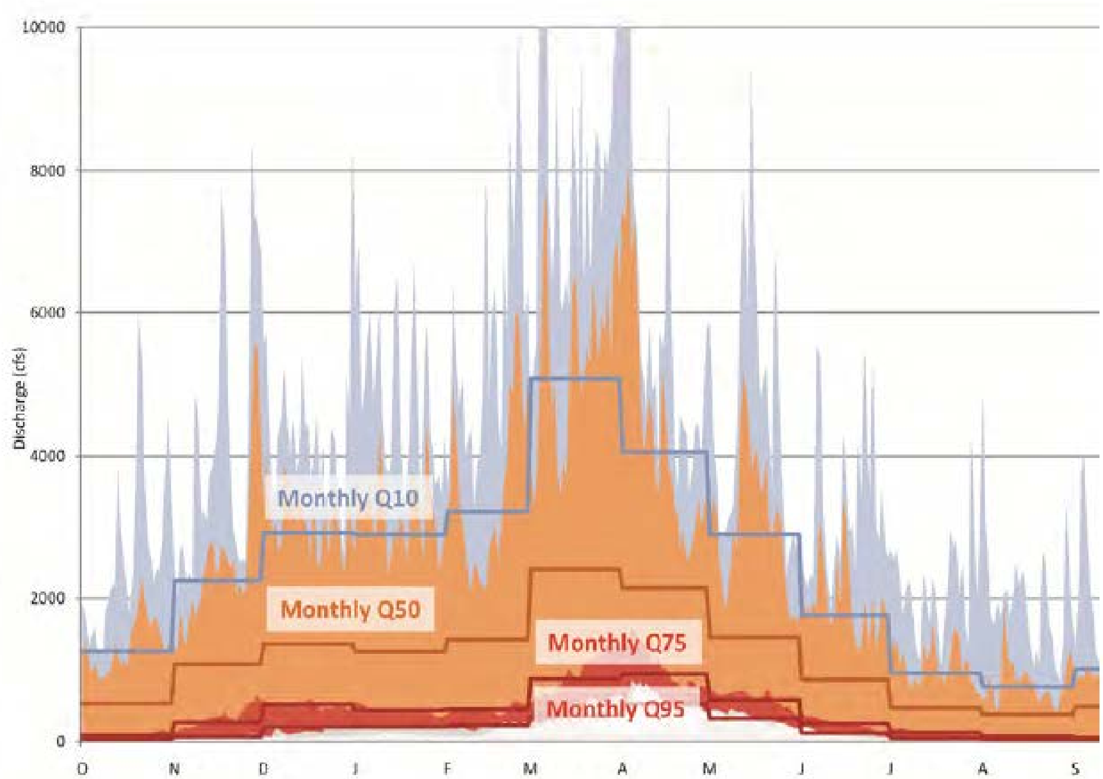

Figure N-1. In the Upper Ohio River basin, monthly flow exceedance values (Q_{ex}) were plotted against daily discharges to highlight specific portions of the hydrograph and facilitate discussions about the ecological importance of each portion (from DePhilip and Moberg, 2013).

Olden and Poff (2003) did a comprehensive review of 171 hydrologic metrics, including Indicators of Hydrologic Alteration (IHA). 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 N-2 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 N-2. 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
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

Table N-2. continued…

Category	Metric	Description	Abbreviated metric
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 25th percentile (low pulse) of all daily values for the time period.	Fl1
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 3 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 3 times median flow over all years	Fh6
	Flood frequency	Mean number of high flow events per year using an upper threshold of 7 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

Table N-2. continued…

Category	Metric	Description	Abbreviated metric
Duration	Number of zero flow days	Mean annual number of days having 0 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
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

Table N-2. continued…

Category	Metric	Description	Abbreviated metric
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

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 N-3.

Table N-3. 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)

N.1. REFERENCES

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