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Protocol Implementation Plan for Benthic Macroinvertebrate Monitoring in the Eastern Rivers and Mountains Network

Natural Resource Report NPS/ERMN/NRR—2016/1265

ON THE COVER
Photograph of a Hendrickson may fly (*Ephemerella subvaria*) adult.
Photograph courtesy of C. Tzilkowski

Protocol Implementation Plan for Benthic Macroinvertebrate Monitoring in the Eastern Rivers and Mountains Network

Natural Resource Report NPS/ERMN/NRR—2016/1265

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Abstract

This Protocol Implementation Plan (PIP) outlines the means by which monitoring data are collected, managed, and reported for the benthic macroinvertebrate (BMI) *Vital Sign* in the Eastern Rivers and Mountains Network (ERMN). The ERMN uses peer-reviewed and widely used United States Geological Survey (USGS) protocols with slight modifications due to programmatic and staffing differences. The ERMN uses disturbance sampling to collect BMI samples from 78 sites in high gradient (i.e., riffle-dominated) wadeable streams throughout six of nine ERMN parks. Sites were selected using random or non-random approaches depending on park characteristics and cumulative wadeable stream length within authorized boundaries. In addition to a general description of the USGS methods and necessary modifications, this plan provides information (e.g., monitoring objectives, sampling design) and detailed instructions (e.g., Standard Operating Procedures) for all phases of BMI monitoring in the ERMN.

Introduction

This Protocol Implementation Plan (PIP) outlines the means by which monitoring data are collected, managed, and reported for the *Benthic Macroinvertebrate* (BMI) *Vital Sign* in the Eastern Rivers and Mountains Network (ERMN, Marshall and Piekielek 2007). This PIP applies only to BMI communities in riffle-dominated wadeable streams which are a very common and important feature of ERMN parks. Changes to this PIP should be minimal and infrequent; however, any necessary changes must be made to this narrative and SOPs with enough time for those alterations to be implemented prior to field seasons.

The ERMN uses peer-reviewed and widely used United States Geological Survey (USGS) BMI protocols for field (Moulton et al. 2002), laboratory (Moulton et al. 2000), and analytical (Cuffney 2003) methods – these protocols were developed for the USGS National Water Quality Assessment Program (NAWQA) which began in 1991. These methods have been used extensively by USGS, academia, and other agencies and have contributed to a variety of research, including programs analogous to the NPS Inventory and Monitoring (I&M) Program. For example, these methods are used for the USGS Ecological National Synthesis Project (http://water.usgs.gov/nawqa/ecology/), which is intended to: (1) Assess the status and trends of ecological conditions (invertebrates, fish, algae and habitat) in rivers and wadeable streams; (2) Relate ecological conditions to chemical stressors (e.g., nutrients and pesticides), physical disturbances (e.g., habitat and hydrologic alterations) in the context of different environmental settings and land uses; (3) Enhance understanding of factors that influence the biological integrity of streams and how these stream ecosystems may respond to diverse natural and human factors; and (4) Develop key ecological indicators of aquatic health.

Slight differences between the ERMN approach and the USGS NAWQA sampling protocols (hereafter, *USGS protocols*) are described in this document. These modifications were necessary primarily because of programmatic and staffing differences. Standard Operating Procedures (SOPs) for operations, safety, and equipment are identified to ensure that these well-established protocols are implemented successfully by the ERMN. In addition to the USGS BMI sampling methods, the ERMN also conducts rapid habitat assessments with the widely-used methods developed by the United Stated Environmental Protection Agency (U.S. EPA 2004) because the USGS does not have an analogous rapid assessment method.

Implementation of the USGS protocols (Moulton et al. 2000, Moulton et al. 2002, Cuffney 2003) in ERMN parks occurs with the following modifications:

1. USGS protocol objectives are not explicitly stated in the same manner as in this PIP; however, they were developed so that "The NAWQA provides an understanding of water-quality conditions; whether conditions are getting better or worse over time; and how natural features and human activities affect those conditions." (http://water.usgs.gov/nawqa/, accessed 04/29/16).

2. USGS protocols contain procedures for sampling algal, BMI, and fish communities whereas this PIP applies only to BMI communities.

3. USGS protocols contain two BMI sampling methods (semi-quantitative, richest targeted habitat [RTH] sampling and qualitative sampling). The ERMN conducts RTH sampling but not qualitative sampling to maximize efficiency and thus, maximize spatial coverage of sampling.

4. USGS sampling sites are proportional (40 x) to stream width whereas ERMN sampling sites are 100 m in length.

    a. In addition to BMI sampling methods, USGS protocols contain procedures for sampling fish communities – although not explicitly stated, the intent of sampling a comparatively long reach prescribed by USGS is to obtain a representative fish community sample, which are much more mobile (and have greater home ranges) than BMI.

    b. Evidence is lacking that habitat-specific (e.g., riffles) BMI sampling from reaches longer than 100 m provides better assessment (i.e., representativeness or precision) of wadeable stream biological integrity.

    c. There are significant efficiency and safety advantages to sampling 100 m reaches, particularly in the commonly encountered, rugged (e.g., waterfalls and gorges) and often remote terrain in ERMN parks.

5. USGS protocols contain procedures for identifying habitats to sample (pages 36-37 *in* Moulton et al. 2002). The ERMN used that procedure during pilot testing and refined the sample population to wadeable stream sites that contain the ideal RTH (i.e., riffle, main-channel, coarse-grained substrate habitat); consequently, the ERMN has a simplified procedure for identifying riffle-cobble habitat in which to sample (SOP 3.0).

6. USGS protocols can potentially yield four separately preserved sample components (large-rare, main-body, split, and elutriate) per sampling event; conversely, the ERMN usually retains one sample (rarely two) per sampling event.

    a. The ERMN immediately preserves “large-rare” specimens (e.g., crayfish, hellgrammites), to which the remaining sample composite is added after field-processing; consequently, by immediately preserving large-rare specimens, their potential predatory effect on other organisms in the samples is mitigated.

    b. The ERMN spends as much time as necessary at sampling sites to remove dense organisms (e.g., caddisfly cases, mollusks), thereby eliminating the need for retention and additional processing of additional elutriate components.

    c. It is extremely rare that sample splitting is necessary based on the character of ERMN streams during spring sampling (i.e., instream primary productivity is low); however, split sample components are retained if necessary.

7. USGS protocols call for formalin-based specimen preservation – the ERMN uses ethanol for BMI preservation (95%) and long-term storage (70%) because it is considerably less hazardous to humans and the environment than formalin.

8. Ancillary information and sample tracking procedures differ between the USGS and ERMN due to programmatic differences. USGS laboratories process BMI samples from many different research groups throughout the United States whereas ERMN only processes samples collected by the network.

9. The ERMN identifies BMIs based on the USGS Standard Taxonomic Assessment level with the exception of chironomids (midges) and worms (e.g., Oligochaeta). ERMN identifies these taxa to a coarser (e.g., family or class) taxonomic level than prescribed (e.g., genus) by the USGS Standard Taxonomic Assessment level. These taxa require additional preparation (e.g., head capsule mounts and high magnification) which is prohibitively time-consuming given ERMN staffing (i.e., one taxonomist). The ERMN intends to contract with USGS or other qualified laboratories to perform these identifications on a periodic basis.

10. Due to the small ERMN staff (two people) and expertise compared to USGS, some QA/QC procedures for sample processing and identification must be contracted to other qualified laboratories. See BMI Monitoring Quality Assurance Plan (in development) for details.

Conceptual Framework for Monitoring

The ERMN used broad-scale conceptual models and input from many experts to support the selection of BMI communities as one of 13 vital signs (Marshall and Piekielek 2007). Benthic macroinvertebrates are aquatic invertebrate animals larger than microscopic size that live on or within aquatic substrates. In addition to being instrumental to nutrient and carbon dynamics, BMI are an important link between basal resources (e.g., algae and detritus) and higher trophic levels (e.g., fish and birds) in food webs. The composition and structure of BMI communities are known to respond predictably to improving or degrading ecological condition; consequently, BMI are the most commonly used group for biological monitoring of aquatic systems (Carter and Resh 2001). Given the proven ability to derive ecosystem integrity based on measures of BMI communities, combined with the relatively low cost to sample, BMI are widely regarded as the single best biological group to assess and monitor the ecological integrity of wadeable streams.

Stream-dwelling biological communities (including BMIs) have consistent patterns of structure and function that can be predicted by surrounding landscape and stream characteristics (e.g., chemical, hydrologic, and geologic conditions; Vannote et al. 1980). Furthermore, models such as the Biological Condition Gradient (Davies and Jackson 2006) and multimetric indices based on BMIs are available to make consistent, ecologically relevant interpretations of the response of aquatic biota to stressors. This PIP will enable the ERMN to characterize spatial and temporal variability and trends of BMI communities in Network wadeable streams and will improve understanding of the effects that concurrent stressors may have on them (Table 1) which will aid in park management decision making.

The USGS methods have been used in a variety of ways by many other state and federal agencies. Data collected using USGS methods at hundreds of sites were used as part of the U.S. EPA Wadeable Streams Assessment (U.S. EPA 2004) and National Streams and Rivers Assessment (U.S. EPA 2013); furthermore, “Integrated Assessments” developed by USGS and U.S. EPA “provides a regional context for NAWQA data and allows direct comparisons among the different NAWQA study areas” (USGS 2010). The USGS methods (i.e., targeted riffle sampling) used by ERMN are also preferred by regional, multi-agency efforts (e.g., U.S. EPA Regional Monitoring Network) – riffle habitat is being targeted for this collaboration because sample consistency is strongly associated with the type of habitats sampled (Parson and Norris, 1996; Gerth and Herlihy, 2006). 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., Hewlett, 2000; Ostermiller and Hawkins, 2004; Cao et al., 2005; Gerth and Herlihy, 2006; Rehn et al., 2007; Blocksom et al., 2008).

Table 1. Factors affecting benthic macroinvertebrates (BMI) within Eastern Rivers and Mountains Network Parks and potential measures for Vital Signs monitoring.

Category	Issue	Potential BMI Community Measures
Invasive Species	Exotic and invasive species enter parks across all boundaries and can displace native species and communities. Introductions can also occur from recreational activities (e.g., bait-bucket transfers) and subsequent invasions. All ERMN parks have invasive species threats.	Detection of invasive species in samples, invasive species richness and density, proportion of sites with invasive species
Historic and current land use within authorized park boundaries	Poor or absent wastewater treatment, abandoned mine drainage, atmospheric deposition, impoundments.	Multimetric Indices, Predictive models (observed:expected), occupancy, presence/absence of indicator taxa
Upstream land use	Poor or absent wastewater treatment, urban expansion, residential and commercial land conversion, impoundments, construction, extractive resource development.	Multimetric Indices, Predictive models (observed:expected), occupancy, presence/absence of indicator taxa
Extreme Weather Events	Stream scouring/torrents that redefine thalweg and riparian corridors.	Relative abundance, density, occupancy
Climate Change	Predicted to alter BMI community composition and structure via changing temperature and hydrologic (precipitation) regimes.	Change in taxa richness and community composition

Monitoring Objectives

Preserving the condition of park resources (e.g., wadeable stream ecosystems) unimpaired in perpetuity is the fundamental management objective of the NPS (NPS 2006). This “anti-degradation” or “no decline in condition” management objective captures the essence of the NPS mission and forms the foundation of the NPS Inventory and Monitoring Program (Fancy et al. 2009). To help achieve that goal, the ERMN tracks long-term change in the ecological integrity of wadeable streams throughout the network by monitoring BMI communities. Communicating this knowledge to park staff and cooperators will improve their ability to make informed management decisions, thereby helping to maintain or improve wadeable stream condition in ERMN parks.

Monitoring objectives listed below pertain to BMI communities found in high gradient, wadeable streams (< 100 km^2 drainage area) in the ERMN – this stream type is one of the most abundant surface water ecosystem types in the network. A common sampling strategy could not be used for all ERMN parks due to their diversity of sizes, shapes, and relative abundance of wadeable streams; consequently, the monitoring objectives below apply throughout the ERMN but the scale at which they can be applied differs among parks (*see* Sampling Design and Monitoring Schedule).

Monitoring objectives of this protocol are to:

1. Determine the status, variability and trends in BMI density, community composition and structure using commonly used metrics, diversity indices and multimetric indices;

2. Detect and monitor the presence, occupancy, and relative abundance of BMI indicator taxa (e.g., salmonfly, *Pteronarcys spp.*);

3. Detect and monitor the presence, occupancy, and relative abundance of exotic and potentially invasive BMI (e.g., rusty crayfish, *Orconectes rusticus*) and;

4. Quantify BMI response and recovery from extreme weather events and response to climate change.

These objectives are not explicitly stated in the USGS protocols from which ERMN methods were adopted; however, the USGS National Water Quality Assessment (NAWQA) Program that developed these protocols has completed many assessments of “biological stream health” based upon nearly identical objectives. Furthermore, the intent of the NAWQA Program is to establish baseline (1991 – 2001) conditions of the Nation’s freshwater systems and use continued long-term monitoring to determine trends (Moulton 2002). Given the intent, thorough review, efficiency, and wide use of the USGS protocols, they were considered the best available methods to meet the aforementioned objectives.

Methods

As described above, the ERMN uses USGS BMI protocols for field (Moulton et al. 2002), laboratory (Moulton et al. 2000), and analytical (Cuffney 2003) methods. Based upon ERMN pilot testing conducted from 2008-2013 it was decided that the more rigorous USGS sampling approach (i.e., "semi-quantitative" sampling, Moulton et al. 2002) would be used in riffle-cobble habitats because that habitat is considered the faunistically "richest targeted habitat" (Moulton et al. 2002) in the vast majority of ERMN wadeable streams. Permanent sampling sites (100 m stream reaches) were chosen using a random approach where necessary (i.e., two large parks with abundant wadeable streams) and based on professional judgement and consultation with park staff when randomization was not appropriate (i.e., index sites at four comparatively small parks with few wadeable stream km; Appendixes A – E).

An overview of the ERMN BMI sampling approach is:

1. After preparing for the field season (SOP 1.0) and reviewing safety procedures (SOP 2.0), a two person crew navigates to sampling sites to:

    a. Establish or revisit sampling sites (SOP 3.0).

    b. Collect five discrete semi-quantitative BMI samples (each = 0.25 m^2) from riffles with cobble substrate throughout each site. Discrete samples are sequentially composited to obtain one sample per site (SOP 3.0).

    c. Preserve the composited BMI sample after it has been processed to a standard volume (< 750 mL; SOP 3.0).

    d. Take digital photographs from photo-points at upstream and downstream ends of each site (SOP 4.0).

    e. Collect and record core water quality data (water temperature, pH, dissolved oxygen, and specific conductance; SOP 5.0).

    f. Conduct reach-scale, U.S. EPA (2004) Rapid Habitat Assessment (SOP 6.0).

    g. Decontaminate sampling gear prior to sampling at subsequent sites (SOP 7.0)

2. Samples are processed and sub-sampled in the laboratory using the USGS "quantitative processing method" to produce a minimum fixed-count target of 300 organisms (SOP 8.0).

3. BMIs are identified using an approach based upon the USGS Standard Taxonomic Assessment which provides Genus-level taxonomic resolution for most taxa (SOP 8.0).

4. After field data sheets are scanned and saved to the ERMN server, data are entered into the ERMN BMI database and are then checked for accuracy (SOP 9.0).

5. Laboratory data sheets are scanned and saved to the ERMN server. Laboratory data are subsequently entered into the ERMN BMI database and are then checked for accuracy (SOP 9.0).

6. Data are certified, exported from the ERMN BMI database, and then processed and analyzed (Table 2) using the USGS Invertebrate Data Analysis System (IDAS; Cuffney 2003; SOP 10.0).

There are numerous, widely-used metrics and indices to evaluate the condition and trends in BMI community data – IDAS enables calculation of 184 community metrics. The ERMN will routinely calculate several BMI community metrics and indices that have been demonstrated to be most responsive to human stressors with low redundancy (SOP 10.0).

Table 2. Benthic macroinvertebrate (BMI) community data that are collected by the Eastern Rivers and Mountains Network using semi-quantitative, richest-targeted habitat sampling in high gradient wadeable streams. Monitoring objectives are met by calculating BMI densities, community metrics, and multimetric indices from enumerated taxa lists with the U.S. Geological Survey Invertebrate Data Analysis System (Cuffney et al., 2003).

Objective	Derived Data
1. Determine the status and trends in BMI community composition and structure	Taxa richness, tolerance metrics, functional feeding groups, behavioral groups, similarity indices, diversity indices on a biennial basis. Detected change through time in the aforementioned measures.
Quantify natural variability in BMI community composition and structure.	Estimated variability of BMI community metrics in least-perturbed reference sites within ERMN park authorized boundaries. Persistence (variability in presence)
Determine the status, variability and trends in BMI density.	Taxa-specific density estimates on a biennial basis and detected change through time of those estimates.
2. Detect and monitor the presence/occupancy of BMI indicator taxa.	Biennial relative abundance estimates of taxa that have demonstrated tolerance to various stressors (e.g., Abandoned mine drainage, organic pollution).
3. Detect and monitor the presence/occupancy of exotic and potentially invasive BMI.	Biennial presence, occupancy, and relative abundance estimates of non-native BMI taxa.
4. Quantify BMI response and recovery from extreme weather events and response to climate change.	Presence, occupancy, and relative abundance of BMI taxa among thermal tolerances on a biennial basis. Community persistence (variability in presence/absence) and stability (variability in relative abundance).

Sampling Design and Monitoring Schedule

Benthic macroinvertebrate sampling is conducted at six ERMN parks. Continued access to long-term monitoring sites is required; consequently, sites were established only on publicly (e.g., NPS) owned land (Table 3). Three parks in the network are not sampled due to a lack of wadeable streams on public property (Appendix A).

Sampling site inclusion was limited to high gradient wadeable streams with riffle habitat; however, site selection differed among parks and was dictated primarily by cumulative wadeable stream length within each park. At parks where randomization of sampling sites was necessary (due to wadeable stream abundance), site midpoints were selected using a spatially-balanced sampling approach (Generalized Random Tessellation Stratified; Stevens and Olsen 2004; Appendix B). At parks where randomization was illogical (small and/or linear parks), index sites were established near stream mouths or downstream-most park boundaries. By definition, data from non-random (index) sites cannot be combined and analyzed to make a statistical inference to sections of streams that were not sampled. Sites that contained appropriate riffle habitat and were safely accessible were included as permanent sampling sites (Appendix C).

One temporal sampling design (two sampling panels, biennial revisits) applies to all parks and each site (100 m stream reach) is sampled once every two years during the spring index period (March 1 – April 30).

Power Analyses

Power analyses were conducted using ERMN pilot data to evaluate the ability of the sampling design and monitoring schedule to detect change in BMI communities in ERMN wadeable streams (Appendixes D and E). There are many indicators of BMI community condition (e.g., taxonomic- or traits-based metrics, multimetric indices) and analytical approaches (e.g., predictive and occupancy models) that are useful for tracking the ecological integrity of ERMN wadeable streams – we conducted power analyses on one such indicator (i.e., the Multimetric Index of Biotic Integrity [MIBI]; Klemm et al. 2003, Herlihy et al. 2008) that will likely be a core component of future analyses.

Power analyses were conducted separately to evaluate the spatial sampling designs (i.e., random site selection [Appendix D] and non-random site selection [Appendix E]) because each approach yields different scale(s) of inference (Table 3). These analyses will be repeated periodically to validate statistical confidence in observed trends.

Key findings of power analyses were:

1. The ERMN biennial (*paneled*) design is much more sustainable than sampling all sites every year but it sacrifices modest power. For example, after 10 years of sampling, the ERMN *paneled* approach is expected to yield nearly identical power (97%) to a doubled sampling effort (i.e., sampling all sites every year; power = 98%) in regard to detecting a 1% annual change in the MIBI at New River Gorge NR.

2. Sampling randomly chosen sites will yield 80% power to detect a 1% annual change in the MIBI (park-scale) within ten years at Delaware Water Gap NRA and New River Gorge NR.

3. It will typically take more than 20 years to detect a 1% annual change in the MIBI with 80% power at the site-level scale of interest; however, there was sufficient power (80%) to detect a 3% annual decline in 10-18 years at all sites.

4. Very small (i.e., $\leq$ 1%) changes in the MIBI should be detectable at the site and park level with high confidence after baseline conditions are established (i.e., 20 years and beyond).

Table 3. Number of benthic macroinvertebrate monitoring sites throughout Eastern Rivers and Mountains Network wadeable streams. Sites within panels are sampled during the same year and panels are revisited in alternate years; Panel 1 is sampled in even years (e.g., 2016) and Panel 2 is sampled in odd years (e.g., 2017).

Park	Spatial Design	Temporal Design		Total	Scale of Analysis
		Panel 1	Panel 2		
Allegheny Portage Railroad NHS	Index	0	2	2	Site, area of interest
Bluestone NSR	Index	4	0	4	Site, area of interest
Fort Necessity NB	Index	0	2	2	Site, area of interest
Friendship Hill NHS	Index	0	2	2	Site, area of interest
Delaware Water Gap NRA	GRTS[1]	16	16	32	Park, site, area of interest
New River Gorge NR	GRTS	18	18	36	Park, site, area of interest
Gauley River NRA	GRTS	TBD	TBD	TBD	Park, site, area of interest
Johnstown Flood NMem	-	-	-	-	-
Upper Delaware SRR	-	-	-	-	-
Total		**38**	**40**	**78**	

[1] Generalized random tessellation stratified (GRTS) sample selection is a spatially balanced method for randomly selecting sampling locations (Stevens and Olsen 2004)

Data Management, Analysis and Reporting

The types and requisite processing steps for data to be collected as a part of the ERMN BMI monitoring protocol have been documented (Table 4; SOP 9) and will be updated as necessary.

Data Processing and Workflow

1. There are three core data sets that are part of ERMN BMI monitoring: (1) BMI taxa abundance, (2) discrete core water quality, and (3) rapid habitat assessments.

2. All data, including digital copies of supplementary data sheets (e.g., log books), are annually archived locally on the ERMN server. Digital photographs are used for logistical purposes and are archived locally.

3. The BMI Monitoring database is the interim repository for field and laboratory data, including BMI taxa abundance data, core water quality data, and rapid habitat assessment scores. The database includes QA/QC measures for data verification and validation which are detailed in the ERMN BMI Monitoring Quality Assurance Plan (in prep.).

4. Certification and publication of data sets will occur biennially after a full sampling cycle (i.e., sites in both panels are sampled). In general, provisional data sets should *not* be released or used as interim products.

5. The ERMN Aquatic Ecologist biennially certifies data from the ERMN BMI database.

    a. Certified discrete water quality data are uploaded to EQuIS based on forthcoming NPS Water Resources Division guidance (Dean Tucker, WRD, pers. Comm.).

    b. Certified BMI and rapid habitat assessment data are published as *.csv* files to the NPS DataStore and are archived locally.

6. When certified data are processed and/or analyzed for reporting or distribution, those data sets will be archived locally as *.csv* files in the appropriate annual archive.

7. Summary reports will be routinely (biennially) produced based upon forthcoming NPS Inventory and Monitoring Division guidance whereas in-depth synthesis and/or trend reporting (e.g., primary literature) will occur less frequently and will be dictated by monitoring results.

Table 4. Data processing and certification matrix for the Eastern Rivers and Mountains Network Benthic Macroinvertebrate monitoring protocol. Procedures for processing and certifying datasets are outlined in SOP 9.

Data Quality Level	Data Processing Level				
	Level 0 (Unprocessed)	**Level 1 (Entered/Validated)**	**Level 2 (Value Added)**	**Level 3 (Rescaled)**	**Level 4 (Synthesized)**
Raw	GPS Point Features (Sampling site midpoints) Data Sheets Digital Photos.	Corrected GPS data (shapefiles) Field and laboratory data entered into MS Access database. Metadata embedded in digital photos. Metadata embedded into scanned data sheets	--	--	--
Provisional	--	Corrected GPS data (shapefiles) w/ errors/outliers trimmed. BMI and water quality data with QA/QC applied, stored in MS Access database.	BMI data processed/standardized (taxonomic ambiguity resolved) with IDAS.	BMI metrics (IDAS derived) and core water quality data summarized at scales of interest (park, site, area of interest).	TBD
Certified	Data sheets and uncorrected GPS data archived locally.	Shapefiles published as L1 data product to DataStore with associated georeferenced field notes. BMI taxa abundance data exported from MS Access database as .csv files; archived locally and exported as L1 data product to DataStore biennially. Core water quality data exported from MS Access database as .csv files; archived locally and exported to EQuIS biennially.	--	--	TBD

Budget

The estimated annual cost ($132,588, based on FY2015 dollars) of implementing the ERMN BMI Protocol is based on estimated staff, travel, and equipment costs. All tasks are performed by ERMN staff – parks may provide monitoring support, primarily in terms of providing housing. This budget does not include park support because it is beyond ERMN control and has differed from year to year during pilot testing; consequently, this estimate is a conservative one and costs could be lower.

The ERMN Aquatic Ecologist provides project oversight, assists with field work, identifies and enumerates BMI, and conducts most analysis and reporting. The Hydrologic Technician assists with field work, processes samples in the laboratory, assists with BMI identification, and is responsible for most data entry. The Program Manager and Data Manager assist with project oversight and data management, respectively.

Table 5. Estimated annual cost (based on FY2015) to implement the Eastern Rivers and Mountains Network benthic macroinvertebrate monitoring protocol.

Category	Item	Cost
Personnel	ERMN Aquatic Ecologist (0.60 FTE GS-12)	64,796
	ERMN Hydrologic Technician (0.70 FTE GS-07)	47,887
	ERMN Program Manager (0.05 FTE GS-13)	6,181
	ERMN Data Manager (0.05 FTE GS-12)	5,014
	Total Personnel Cost	**$123,878**
Equipment & Supplies	Vehicle fuel costs ($40.00/day)	800
	Ethanol	750
	Laboratory Supplies	1,000
	Field Supplies	1,000
	Total Equipment and Supplies Cost	**$3,550**
Travel	Lodging	3,320
	MI&E	1,840
	Total Travel Cost	**$5,160**
All	**Total Annual Cost**	**$132,588**

Safety

Implementation of this protocol has multiple complex risks. The ERMN continuously evaluates risks at the programmatic, personnel, and site level. Programmatic-level safety information is presented here and procedures to mitigate risks associated with specific activities related to protocol implementation (e.g., safe vehicle use and operation, injury reporting and accident reporting) are addressed in SOP 2.

Job Hazard Analyses (JHAs) were completed for personnel who implement portions of the protocol in which risks and risk abatement strategies (including training needs) were identified. Risks and abatement strategies were synthesized to develop a protocol-level JHA. The protocol JHA was then used to perform a programmatic-level Green-Amber-Red (GAR) risk analysis to assess whether implementation of this protocol could be accomplished within an acceptable level of risk.

Injury or loss of life while in transit to and from field sites and during sampling activities within sites are the most significant risks encountered while BMI sampling. Based on reconnaissance performed during 2013 to evaluate sampling site access, several randomly selected sites (primarily at New River Gorge NR) were removed from the sampling design because the risk inherent with accessing them was deemed too great for inclusion (Appendix C).

Specific safety concerns include:

- Crew members will spend many hours (and miles) driving to, between, and from sampling sites.
- Crew members may be working in park areas outside of communication range (either by park radio or by cell phone).
- Crew members will frequently be exposed to cold air and water temperatures and will be working for extended periods of time in remote areas with the potential for rapidly changing and severe weather conditions.
- Crew members will be exposed to treacherous terrain, toxic and thorny plants, stinging and biting insects, venomous and other hazardous animals, and potentially hazardous materials and debris (e.g., illegal garbage dumping), fencing and piping, contaminated soils, and other waste materials.

Based on the JHA and associated risk abatement measures, it was determined that this protocol can be safely implemented provided that ERMN staff do so in accordance with the referenced SOPs and recommended risk abatement strategies. In addition to SOPs that have been developed to safely implement this protocol, specific training needs for all staff have been identified including certification in Wilderness First Responder First Aid. To increase the overall level of safety and awareness, obtaining additional levels of training beyond these certifications are encouraged.

Safety procedures will be routinely reviewed by Network staff before field operations as prescribed in SOPs. Personnel-level JHAs will be reviewed annually and revised if necessary. Safety SOPs are

reviewed at least annually and updated as necessary to ensure that they adequately mitigate risks to personnel.

In addition to protocol-specific safety procedures and guidelines, ERMN staff will follow the general guidelines set forth in the NPS Occupational Safety and Health Program (Directors Order #50B, September 2008).

Standard Operating Procedures

To ensure consistent implementation of this protocol, the following Standard Operating Procedures (SOPs) were adopted from the USGS (Moulton et al. 2000, Moulton et al. 2002, Cuffney 2003) or developed as needed by the ERMN (Table 6). All approved SOPs are published in the NPS Natural Resource Report series and the latest approved versions of operational SOPs are always available for download at the NPS Integrated Resource Management Applications portal at http://irma.nps.gov.

Table 6. Standard Operating Procedures (SOPs) required for the Eastern Rivers and Mountains Network Benthic Macroinvertebrate Monitoring Protocol. SOPs are listed by task category and can found by searching for their Integrated Resource Management Applications (IRMA) holding number at https://irma.nps.gov.

Topic	Citation	Notes	IRMA Holding
1. Pre-sampling Preparation	Eastern Rivers and Mountains Network. 2016. Annual workflow and field season preparation. Eastern Rivers and Mountains Network Standard Operating Procedure NPS/ERMN/SOP-1.0. National Park Service, University Park, Pennsylvania.	Adopted from USGS	2229326
2. Personal Safety	Eastern Rivers and Mountains Network. 2016. Personal Safety. Eastern Rivers and Mountains Network Standard Operating Procedure NPS/ERMN/SOP-2.0. National Park Service, University Park, Pennsylvania.	Developed by ERMN	2229328
3. Sampling Site Establishment and Benthic Macroinvertebrate Sample Collection	Eastern Rivers and Mountains Network. 2016. Sampling Site Establishment and Benthic Macroinvertebrate Sample Collection. Eastern Rivers and Mountains Network Standard Operating Procedure NPS/ERMN/SOP-3.0. National Park Service, University Park, Pennsylvania.	Adopted from USGS	2229329
4. Digital Photography and Photo Points	Eastern Rivers and Mountains Network. 2016. Digital Photography and Photo Points. Eastern Rivers and Mountains Network Standard Operating Procedure NPS/ERMN/SOP-4.0. National Park Service, University Park, Pennsylvania.	Based on Klamath Network	2229330

Table 6 (continued). Standard Operating Procedures (SOPs) required for the Eastern Rivers and Mountains Network Benthic Macroinvertebrate Monitoring Protocol. SOPs are listed by task category and can found by searching for their Integrated Resource Management Applications (IRMA) holding number at https://irma.nps.gov.

Topic	Citation	Notes	IRMA Holding
5. Core Water Quality – Equipment Maintenance and Data Collection	Eastern Rivers and Mountains Network. 2016. Core Water Quality – Equipment Maintenance and Data Collection. Eastern Rivers and Mountains Network Standard Operating Procedure NPS/ERMN/SOP-5.0. National Park Service, University Park, Pennsylvania.	Based on Klamath Network	2229331
6. Rapid Habitat Assessment	Eastern Rivers and Mountains Network. 2016. Rapid Habitat Assessments. Eastern Rivers and Mountains Network Standard Operating Procedure NPS/ERMN/SOP-6.0. National Park Service, University Park, Pennsylvania.	Adopted from USEPA	2229332
7. Equipment Decontamination	Eastern Rivers and Mountains Network. 2016. Sampling Equipment Decontamination. Eastern Rivers and Mountains Network Standard Operating Procedure NPS/ERMN/SOP-7.0. National Park Service, University Park, Pennsylvania.	Based on Great Lakes Network	2229333
8. Sample Processing, Identification, and Enumeration	Eastern Rivers and Mountains Network. 2016. Benthic Macroinvertebrate Sample Processing and Identification. Eastern Rivers and Mountains Network Standard Operating Procedure NPS/ERMN/SOP-8.0. National Park Service, University Park, Pennsylvania.	Adopted from USGS	2229334
9. Data Management	Eastern Rivers and Mountains Network. 2016. Data Management. Eastern Rivers and Mountains Network Standard Operating Procedure NPS/ERMN/SOP-9.0. National Park Service, University Park, Pennsylvania.	Based on Northeast Temperate Network	2229335

Table 6 (continued). Standard Operating Procedures (SOPs) required for the Eastern Rivers and Mountains Network Benthic Macroinvertebrate Monitoring Protocol. SOPs are listed by task category and can found by searching for their Integrated Resource Management Applications (IRMA) holding number at https://irma.nps.gov.

Topic	Citation	Notes	IRMA Holding
10. Data Analysis and Reporting	Eastern Rivers and Mountains Network. 2016. Data Analysis and Reporting. Eastern Rivers and Mountains Network Standard Operating Procedure NPS/ERMN/SOP-10.0. National Park Service, University Park, Pennsylvania.	Based on Klamath Network	2229336

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Appendix A. Defining the Sampling Frame

Overview

This appendix describes the data layers and procedures used to define the sampling frame for this implementation plan and two other monitoring protocols (rivers and streamside birds) related to flowing surface waters in the ERMN. It was our intent to develop a sampling frame that could be used for multiple ERMN monitoring protocols and would allow sampling co-location among protocols.

All flowing surface waters were delineated and then placed into size categories according to upstream contributing area (i.e., watershed area) using ArcGIS. All streams and rivers with a contributing area ≥ 100.0 km^2 at their mouth (i.e., outpour point) or at the park boundary (if a stream/river flows out of the park) were categorized as *rivers* and are monitored as described in the River Monitoring Protocol Implementation Plan (in prep.). All streams with a contributing area ≤ 2.0 km^2 at most parks were defined as *ephemeral* or *intermittent* and not included in the sampling frame of any ERMN protocol. This criterion was relaxed to ≤ 1.0 km^2 at Fort Necessity NB and Friendship Hill NHS so that the limited amount of surface water at those small parks was included and sampled.

Wadeable streams defined as *perennial* using the aforementioned criteria were included in the common sampling frame for this implementation plan and the Streamside Bird Monitoring Protocol (Marshall et al. 2016). Wadeable streams at the two largest parks in the ERMN (Delaware Water Gap NRA and New River Gorge NR) were partitioned into a population of discrete 100 m stream segments from which sampling sites could be randomly drawn (e.g., Appendix B). Sample sites at other ERMN parks were chosen non-randomly, based on resource value, practicality, and consultation with park staff (Appendix B).

All associated input files and products described in this appendix are archived and available upon request.

Step 1. Drainage Line Modeling and Delineation

We used the Terrain Preprocessing functions in Arc Hydro (version 2.0, October 2011) for ArcGIS 10.0 to generate a flow accumulation model and delineate drainage lines representing the network of perennially flowing surface waters (i.e., streams and rivers) for each park (Table A.1).

Flow Accumulation Models

Generating a flow accumulation model required two input files: a digital elevation model (DEM) and a hydrology layer to precondition DEMs for processing. The best available DEM data that covered the area of interest for all parks was the 10 m grid from the USGS National Elevation Dataset. We evaluated both LiDAR and 3 m DEMs but complete coverages were not available for all parks and areas of interest; consequently, we used the best available hydrology dataset with complete coverage (i.e., USGS National Hydrography Dataset (NHD), high resolution (1:24,000) flowline feature class).

Drainage Line Delineation

We considered perennial streams as having at least a 2.0 km^2 drainage area and streams with contributing area as intermittent (Paybins 2003; pers. obs.); therefore, we set a threshold (2.0 km^2) in

the flow accumulation model to initiate a stream (and downstream flow) as having a drainage area of 2.0 km^2. Each grid cell that had a drainage area of at least 2.0 km^2 was given a value of 1 in the resulting stream grid layer. This stream grid layer was then used to generate drainage lines that represented streams with at least 2.0 km^2 drainage areas. The 2.0 km^2 criterion resulted in very few delineated *streams* at Fort Necessity NB and Friendship Hill NHS; consequently, the criterion was relaxed to 1.0 km^2 at those parks to delineate (and sample) the limited amount of flowing surface water at these small parks (Table A.2).

Step 2. Drainage Line Refinement

Because all ERMN sampling is constrained to within the authorized boundary of each park, we first clipped the drainage lines (generated in Step 1) at park boundaries using the most recent park boundary shapefiles. Next, we split drainage lines at their outpour points (i.e., confluence with another stream) which resulted in line sections (streams), separated by nodes (confluences; Table A.3). This *splitting* process determined the number of stream sections that were classified among watershed size classes (Step 3).

Drainage lines, which were *line features*, did not accurately represent the areal nature of larger streams and rivers; therefore, we overlaid the USGS NHD high resolution (1:24,000) area feature class and split drainage lines based on the *edge* of rivers (e.g., Delaware River) as defined by the NHD and then removed overlapping sections. Similarly, the NHD did not accurately represent stream area (particularly large streams and rivers) when compared to available aerial photography in some cases. In these cases, we used aerial photography (ESRI's Basemap services) to more accurately determine where to split drainage lines – this was a subjective procedure based on the best available data that, in our judgment, more accurately represented reality than relying solely on the NHD. Using this method, we defined 689.7 km of perennially flowing surface waters within the nine ERMN park unit boundaries (Table A.4).

Step 3. Drainage Line Categorization – Watershed Size

We defined a batch point at the downstream end of each drainage line section to generate watershed polygons and calculate the watershed area for each section using the Watershed Processing functions in Arc Hydro. We then categorized line sections into four size classes based upon watershed size (Table A.5). This process resulted in three large river sections, eight medium rivers, 14 small rivers, and more than 220 km of wadeable streams throughout the ERMN (Table A.6; Figures A.1 – A.9).

Step 4. Defining the Wadeable Stream Sampling Frame

A random site selection approach was necessary at the three largest ERMN parks (Delaware Water Gap NRA, Gauley River NRA, and New River Gorge NR; Appendix B); therefore, we created a *wadeable stream* sampling frame comprised of discrete (100 m) sampling units from which co-located BMI and Streamside Bird sampling sites could be randomly drawn.

For several reasons, we had to first eliminate several wadeable stream sections prior to developing the sampling frame. All sections ≤ 400 m were eliminated because ERMN Streamside Bird sampling requires three point count stations, spaced 200 m apart and parallel to the stream (totaling 400 m; the largest sampling unit of the wadeable stream-based protocols). This ensured that all wadeable

stream-based protocols could be implemented at selected sites. Second, we removed wadeable stream sections that were within large stream/river floodplains (Table A.7) to minimize variance associated with these hydrologically and biologically distinct transition zones. Third, we eliminated several sections of wadeable stream that meandered across park boundaries. Due to the uncertainty of determining if these sections fell on NPS property, we elected to eliminate them *a priori*. Finally, after partitioning the remaining sections of wadeable stream into 100 m segments, any remaining segment < 100 m was eliminated. The total length of wadeable stream eliminated (and therefore not included in the sampling frame and area of statistical inference) for each of these criteria is summarized in Table A.8.

After finalizing the wadeable stream population to be included in the sampling frame, we used several Arc GIS 10.0 tools to create the 100 m segments that constitute the sampling frame (Figure A.10). The segments were discrete but continuous, such that Delaware Water Gap NRA had 607 uniquely identified 100 m stream segments that corresponded to 60.7 km of wadeable stream in the park. Similarly, New River Gorge NR and Gauley River NRA had 1,008 and 109 uniquely identified 100 m stream segments, respectively. Each 100 m segment was defined by the UTM coordinates of the center point of the segment.

Table A.1. Input files used, and final products generated while delineating drainage lines that represent Eastern Rivers and Mountains Network intermittent and perennial streams.

Category	File Names
Input Files	USGS NHD high resolution (1:24,000) line feature class
	USGS NHD high resolution (1:24,000) area feature class
	ERMN_Park_Boundaries.shp
	USGS National Elevation Dataset 10 m Digital Elevation Model (DEM)
Final Products	UPDE_DrainageLines_2sqkm.shp
	DEWA_DrainageLines_2sqkm.shp
	ALPO_DrainageLines_2sqkm.shp
	GARI_DrainageLines_2sqkm.shp
	NERI_DrainageLines_2sqkm.shp
	BLUE_DrainageLines_2sqkm.shp
	FONE_DrainageLines_1sqkm.shp
	FRHI_DrainageLines_1sqkm.shp

Table A.2. Eastern Rivers and Mountains Network perennial stream shapefiles.

Park	Shapefile
Allegheny Portage Railroad NHS	ALPO_ FlowingWaters _2sqkm.shp
Bluestone NSR	BLUE_ FlowingWaters _2sqkm.shp
Delaware Water Gap NRA	DEWA_ FlowingWaters _2sqkm.shp
Fort Necessity NB	FONE_ FlowingWaters _1sqkm.shp
Friendship Hill NHS	FRHI_ FlowingWaters _1sqkm.shp
Gauley River NRA	GARI_ FlowingWaters _2sqkm.shp
Johnstown Flood NMem	JOFL_FlowingWaters_2sqkm.shp
New River Gorge NR	NERI_ FlowingWaters _2sqkm.shp
Upper Delaware SRR	UPDE_FlowingWaters_2sqkm.shp

Table A.3. Number and cumulative length of perennial stream and river sections in Eastern Rivers and Mountains Network parks. Stream sections were defined as having ≥2.0 km^2 contributing area and were delimited by confluences or park boundaries.

Park	Sections	Length (km)
Upper Delaware SRR	68	182.9
Delaware Water Gap NRA	45	174.9
Allegheny Portage Railroad NHS	3	3.7
Johnstown Flood NMem	2	1.0
Fort Necessity NB[1]	3	2.3
Friendship Hill NHS[1]	2	1.2
Gauley River NRA	22	68.2
New River Gorge NR	86	230.7
Bluestone NSR	7	24.7
Total	**238**	**689.7**

[1] Stream segments (drainage lines) were defined at these parks by contributing areas ≥1.0 km^2 so that the limited number and length of streams present were included (and sampled).

Table A.4. Park, size category, name, length in park (Length), and contributing area (Area) for flowing surface waters in the Eastern Rivers and Mountains Network. UNT = Unnamed tributary.

Park	Category	Name	Length (km)	Area (km^2)
New River Gorge NR	Large River	New River	90.41	17815.13
New River Gorge NR	Small River	Dunloup Creek	6.45	125.36
New River Gorge NR	Small River	Glade Creek	9.94	163.64
New River Gorge NR	Small River	Lick Creek	1.25	101.25
New River Gorge NR	Small River	Manns-Glade Creek	9.11	151.01
New River Gorge NR	Small River	Piney Creek	1.28	351.65
New River Gorge NR	Wadeable Stream	Arbuckle Creek	2.79	23.82
New River Gorge NR	Wadeable Stream	Batoff Creek	2.14	9.40
New River Gorge NR	Wadeable Stream	Big Branch	1.25	2.86
New River Gorge NR	Wadeable Stream	Bills Branch	1.49	3.66
New River Gorge NR	Wadeable Stream	Bucklick Branch	0.57	2.71
New River Gorge NR	Wadeable Stream	Buffalo Creek	2.69	14.11
New River Gorge NR	Wadeable Stream	Butcher Branch	1.20	3.16
New River Gorge NR	Wadeable Stream	Camp Branch	1.74	4.20
New River Gorge NR	Wadeable Stream	Camp Creek	1.50	5.23
New River Gorge NR	Wadeable Stream	Coal Run	1.70	9.68
New River Gorge NR	Wadeable Stream	Craig Branch	2.06	3.13
New River Gorge NR	Wadeable Stream	Davis Branch	1.22	3.00
New River Gorge NR	Wadeable Stream	Dowdy Creek	3.23	6.52

Park	Category	Name	Length (km)	Area (km^2)
New River Gorge NR	Wadeable Stream	Ephraim Creek	2.89	14.06
New River Gorge NR	Wadeable Stream	Fall Branch	2.38	20.28
New River Gorge NR	Wadeable Stream	Farleys Creek	3.53	16.85
New River Gorge NR	Wadeable Stream	Fern Creek	1.73	9.44
New River Gorge NR	Wadeable Stream	Fire Creek	2.00	4.06
New River Gorge NR	Wadeable Stream	Kates Branch (Glade)	2.30	4.33
New River Gorge NR	Wadeable Stream	Kates Branch (New)	1.92	3.72
New River Gorge NR	Wadeable Stream	Keeney Creek	1.99	23.14
New River Gorge NR	Wadeable Stream	Laurel Creek	7.31	71.08
New River Gorge NR	Wadeable Stream	(UNT Meadow Creek 42)	0.95	13.18
New River Gorge NR	Wadeable Stream	Little Laurel Creek	1.81	4.20
New River Gorge NR	Wadeable Stream	Manns Creek	2.89	39.00
New River Gorge NR	Wadeable Stream	Marr Branch	1.14	8.59
New River Gorge NR	Wadeable Stream	Meadow Creek	9.41	74.44
New River Gorge NR	Wadeable Stream	Meadow Fork	0.83	10.41
New River Gorge NR	Wadeable Stream	Mill Branch	1.20	2.68
New River Gorge NR	Wadeable Stream	Panther Branch	1.53	4.43
New River Gorge NR	Wadeable Stream	Pinch Creek	1.89	40.47
New River Gorge NR	Wadeable Stream	Polls Branch	1.70	4.93
New River Gorge NR	Wadeable Stream	Richlick Branch	1.73	3.17

Park	Category	Name	Length (km)	Area (km^2)
New River Gorge NR	Wadeable Stream	River Branch	1.92	4.76
New River Gorge NR	Wadeable Stream	Second Fork	1.96	5.19
New River Gorge NR	Wadeable Stream	Sewell Branch	2.98	4.73
New River Gorge NR	Wadeable Stream	Short Creek	1.27	6.18
New River Gorge NR	Wadeable Stream	Slate Fork - Mill Creek	2.55	16.24
New River Gorge NR	Wadeable Stream	Slater Creek	3.55	8.08
New River Gorge NR	Wadeable Stream	UNT Arbuckle Creek	0.01	3.75
New River Gorge NR	Wadeable Stream	UNT Buffalo Creek	0.61	2.40
New River Gorge NR	Wadeable Stream	UNT Coal Run	0.06	3.21
New River Gorge NR	Wadeable Stream	UNT Dunloup Creek	0.23	17.10
New River Gorge NR	Wadeable Stream	UNT Ephraim Creek	0.84	3.94
New River Gorge NR	Wadeable Stream	UNT Fall Branch	0.47	3.75
New River Gorge NR	Wadeable Stream	UNT Fall Branch 2	0.30	2.90
New River Gorge NR	Wadeable Stream	UNT Farleys Creek	0.05	2.00
New River Gorge NR	Wadeable Stream	UNT Laurel Creek	1.40	3.76
New River Gorge NR	Wadeable Stream	UNT Laurel Creek 2	0.19	2.03
New River Gorge NR	Wadeable Stream	UNT Laurel Creek 3	0.39	2.47
New River Gorge NR	Wadeable Stream	UNT Laurel Creek x	0.00	2.69
New River Gorge NR	Wadeable Stream	UNT Lefthand Fork Meadow Cr	0.56	3.49
New River Gorge NR	Wadeable Stream	UNT Manns Creek 1	0.83	8.15

Park	Category	Name	Length (km)	Area (km^2)
New River Gorge NR	Wadeable Stream	UNT Manns Creek 2	1.14	4.21
New River Gorge NR	Wadeable Stream	UNT Manns Creek 3	0.17	3.16
New River Gorge NR	Wadeable Stream	UNT Manns Creek x	0.02	6.63
New River Gorge NR	Wadeable Stream	UNT Marr Branch	0.31	2.70
New River Gorge NR	Wadeable Stream	UNT Meadow Creek 22	0.76	3.16
New River Gorge NR	Wadeable Stream	UNT Meadow Creek 67	0.46	6.68
New River Gorge NR	Wadeable Stream	UNT Meadow Creek 87	0.18	9.76
New River Gorge NR	Wadeable Stream	UNT New River 21	0.76	3.36
New River Gorge NR	Wadeable Stream	UNT New River 26	1.02	6.61
New River Gorge NR	Wadeable Stream	UNT New River 29	1.74	4.17
New River Gorge NR	Wadeable Stream	UNT New River 30	0.83	3.37
New River Gorge NR	Wadeable Stream	UNT New River 36	0.63	3.58
New River Gorge NR	Wadeable Stream	UNT New River 42	0.68	2.93
New River Gorge NR	Wadeable Stream	UNT New River 52	1.36	4.39
New River Gorge NR	Wadeable Stream	UNT New River 55	0.21	47.19
New River Gorge NR	Wadeable Stream	UNT New River 60	0.28	6.19
New River Gorge NR	Wadeable Stream	UNT New River 61	0.28	12.20
New River Gorge NR	Wadeable Stream	UNT New River 63	0.07	8.16
New River Gorge NR	Wadeable Stream	UNT New River 9	0.27	3.16
New River Gorge NR	Wadeable Stream	UNT Pinch Creek	0.31	2.77

Park	Category	Name	Length (km)	Area (km^2)
New River Gorge NR	Wadeable Stream	UNT Piney Creek	0.65	2.21
New River Gorge NR	Wadeable Stream	UNT Slate Fork - Mill Creek	0.02	3.07
New River Gorge NR	Wadeable Stream	UNT UNT Manns Creek 1	0.65	2.28
New River Gorge NR	Wadeable Stream	UNT UNT New River 26	0.03	2.43
New River Gorge NR	Wadeable Stream	UNT Wolf Creek	0.65	6.14
New River Gorge NR	Wadeable Stream	White Oak Creek	0.03	21.12
New River Gorge NR	Wadeable Stream	Wolf Creek	3.82	44.36
Delaware Water Gap NRA	Large River	Delaware River	69.95	10212.85
Delaware Water Gap NRA	Small River	Bushkill Creek	4.99	409.30
Delaware Water Gap NRA	Small River	Flat Brook	19.32	170.82
Delaware Water Gap NRA	Wadeable Stream	Adams Creek	4.10	19.52
Delaware Water Gap NRA	Wadeable Stream	Caledonia Creek	1.59	2.59
Delaware Water Gap NRA	Wadeable Stream	Conashaugh Creek	2.27	5.40
Delaware Water Gap NRA	Wadeable Stream	Deckers Creek	0.82	2.58
Delaware Water Gap NRA	Wadeable Stream	Dingmans Creek	6.61	44.02
Delaware Water Gap NRA	Wadeable Stream	Dry Brook	1.37	3.22
Delaware Water Gap NRA	Wadeable Stream	Dunnfield Creek	6.34	9.86
Delaware Water Gap NRA	Wadeable Stream	Hornbecks Creek	3.78	23.81
Delaware Water Gap NRA	Wadeable Stream	Jacksonburg Creek	0.20	2.32
Delaware Water Gap NRA	Wadeable Stream	Kittatinny Creek	2.80	4.21

Park	Category	Name	Length (km)	Area (km^2)
Delaware Water Gap NRA	Wadeable Stream	Little Bushkill Creek	2.37	86.55
Delaware Water Gap NRA	Wadeable Stream	Mill Creek	3.71	12.46
Delaware Water Gap NRA	Wadeable Stream	Raymondskill Creek	4.96	62.13
Delaware Water Gap NRA	Wadeable Stream	Sand Hill Creek	1.69	8.64
Delaware Water Gap NRA	Wadeable Stream	Slateford Creek	1.54	7.26
Delaware Water Gap NRA	Wadeable Stream	Spackmans Creek	1.41	2.97
Delaware Water Gap NRA	Wadeable Stream	Toms Creek	4.13	24.28
Delaware Water Gap NRA	Wadeable Stream	UNT Adams Creek	0.24	2.04
Delaware Water Gap NRA	Wadeable Stream	UNT Bushkill Creek	0.40	3.65
Delaware Water Gap NRA	Wadeable Stream	UNT Delaware River 210	0.76	2.15
Delaware Water Gap NRA	Wadeable Stream	UNT Delaware River 214.5	0.03	12.44
Delaware Water Gap NRA	Wadeable Stream	UNT Delaware River 242	0.64	3.90
Delaware Water Gap NRA	Wadeable Stream	UNT Delaware River 246.5	1.15	19.39
Delaware Water Gap NRA	Wadeable Stream	UNT Delaware River 247	0.97	63.61
Delaware Water Gap NRA	Wadeable Stream	UNT Delaware River 247.5	0.03	13.51
Delaware Water Gap NRA	Wadeable Stream	UNT Delaware River 248	1.09	2.73
Delaware Water Gap NRA	Wadeable Stream	UNT Delaware River 249	1.32	5.53
Delaware Water Gap NRA	Wadeable Stream	UNT Dingmans Creek	0.84	2.43
Delaware Water Gap NRA	Wadeable Stream	UNT Flat Brook	1.00	2.94
Delaware Water Gap NRA	Wadeable Stream	UNT Flat Brook 1	0.01	2.36

Park	Category	Name	Length (km)	Area (km^2)
Delaware Water Gap NRA	Wadeable Stream	UNT Flat Brook 2	0.02	41.27
Delaware Water Gap NRA	Wadeable Stream	UNT Flat Brook 3	0.41	3.10
Delaware Water Gap NRA	Wadeable Stream	UNT Flat Brook 4	0.65	5.31
Delaware Water Gap NRA	Wadeable Stream	UNT Toms Creek	0.72	2.47
Delaware Water Gap NRA	Wadeable Stream	UNT Toms Creek 2	0.34	3.40
Delaware Water Gap NRA	Wadeable Stream	UNT UNT Delaware River 247	0.00	0.00
Delaware Water Gap NRA	Wadeable Stream	UNT Vancampens Brook	0.55	2.21
Delaware Water Gap NRA	Wadeable Stream	UNT Vancampens Brook 1	0.16	2.02
Delaware Water Gap NRA	Wadeable Stream	Van Campen Creek	3.17	5.89
Delaware Water Gap NRA	Wadeable Stream	Vancampens Brook	13.20	23.97
Delaware Water Gap NRA	Wadeable Stream	White Brook	2.38	5.48
Delaware Water Gap NRA	Wadeable Stream	Yards Creek	0.81	2.44
Gauley River NRA	Medium River	Gauley River	42.12	3347.71
Gauley River NRA	Medium River	Meadow River	9.52	945.18
Gauley River NRA	Small River	Peters Creek	2.76	135.62
Gauley River NRA	Wadeable Stream	Bucklick Branch	0.64	3.37
Gauley River NRA	Wadeable Stream	Dogwood Creek	0.75	15.88
Gauley River NRA	Wadeable Stream	Hedricks Creek	0.53	12.74
Gauley River NRA	Wadeable Stream	Horseshoe Creek	1.49	11.48
Gauley River NRA	Wadeable Stream	Laurel Creek	1.27	12.16

Park	Category	Name	Length (km)	Area (km^2)
Gauley River NRA	Wadeable Stream	Meadow Creek	1.82	18.53
Gauley River NRA	Wadeable Stream	Ramsey Branch	0.96	9.00
Gauley River NRA	Wadeable Stream	Sugar Creek	1.12	6.86
Gauley River NRA	Wadeable Stream	UNT Gauley River 22	0.26	16.73
Gauley River NRA	Wadeable Stream	UNT Gauley River 26	0.64	3.18
Gauley River NRA	Wadeable Stream	UNT Gauley River 27	1.16	4.44
Gauley River NRA	Wadeable Stream	UNT Gauley River 30	0.54	6.07
Gauley River NRA	Wadeable Stream	UNT Gauley River 31	0.31	6.81
Gauley River NRA	Wadeable Stream	UNT Gauley River 34	0.37	24.86
Gauley River NRA	Wadeable Stream	UNT Laurel Creek	0.03	5.01
Gauley River NRA	Wadeable Stream	UNT Meadow River 2	0.52	4.11
Gauley River NRA	Wadeable Stream	UNT Meadow River 3	0.25	2.86
Gauley River NRA	Wadeable Stream	UNT Meadow River 4	0.59	10.33
Gauley River NRA	Wadeable Stream	UNT Meadow River 5	0.58	2.21
Upper Delaware SRR	Large River	Delaware River	123.43	7989.18
Upper Delaware SRR	Medium River	East Branch	0.05	2188.29
Upper Delaware SRR	Medium River	West Branch	0.10	1735.11
Upper Delaware SRR	Medium River	Lackawaxen River	0.93	1557.39
Upper Delaware SRR	Medium River	Mongaup River	1.65	542.98
Upper Delaware SRR	Small River	Callicoon Creek	2.29	291.83

Park	Category	Name	Length (km)	Area (km^2)
Upper Delaware SRR	Small River	Shohola Creek	0.54	224.31
Upper Delaware SRR	Small River	Equinunk Creek	0.72	150.16
Upper Delaware SRR	Small River	Tenmile River	1.04	127.06
Upper Delaware SRR	Small River	Calkins Creek	0.76	114.73
Upper Delaware SRR	Wadeable Stream	Masthope Creek	1.30	80.85
Upper Delaware SRR	Wadeable Stream	Halfway Brook	1.26	73.69
Upper Delaware SRR	Wadeable Stream	Little Equinunk Creek	0.86	65.45
Upper Delaware SRR	Wadeable Stream	Beaver Brook	1.35	61.25
Upper Delaware SRR	Wadeable Stream	Basket Creek	0.91	58.73
Upper Delaware SRR	Wadeable Stream	Mill Brook	1.08	51.09
Upper Delaware SRR	Wadeable Stream	Hankins Creek	1.68	40.87
Upper Delaware SRR	Wadeable Stream	Shingle Kill	0.25	33.62
Upper Delaware SRR	Wadeable Stream	Twin Lakes Creek	0.63	29.88
Upper Delaware SRR	Wadeable Stream	Beaverdam Creek	0.42	27.68
Upper Delaware SRR	Wadeable Stream	Hollister Creek	1.12	24.67
Upper Delaware SRR	Wadeable Stream	Mitchell Pond Brook	1.17	20.98
Upper Delaware SRR	Wadeable Stream	Pond Eddy Creek	0.47	18.18
Upper Delaware SRR	Wadeable Stream	Pea Brook	1.80	16.71
Upper Delaware SRR	Wadeable Stream	Bush Kill	0.21	16.45
Upper Delaware SRR	Wadeable Stream	Bouchoux Brook	0.74	13.70

Park	Category	Name	Length (km)	Area (km^2)
Upper Delaware SRR	Wadeable Stream	Hoolihan Brook	1.91	12.34
Upper Delaware SRR	Wadeable Stream	Westcoolang Creek	1.47	11.92
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 289.5	1.15	11.61
Upper Delaware SRR	Wadeable Stream	Factory Creek	1.29	11.09
Upper Delaware SRR	Wadeable Stream	Abe Lord Creek	1.07	10.90
Upper Delaware SRR	Wadeable Stream	Panther Creek	1.90	10.69
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 268	0.32	10.37
Upper Delaware SRR	Wadeable Stream	Grassy Swamp Brook	0.77	10.21
Upper Delaware SRR	Wadeable Stream	Fish Cabin Creek	1.02	9.62
Upper Delaware SRR	Wadeable Stream	Narrow Falls Brook	0.39	8.80
Upper Delaware SRR	Wadeable Stream	Cooley Creek	1.22	8.73
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 290	0.90	7.74
Upper Delaware SRR	Wadeable Stream	Humphries Brook	0.97	7.45
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 291	0.82	7.34
Upper Delaware SRR	Wadeable Stream	Stockport Creek	0.88	7.26
Upper Delaware SRR	Wadeable Stream	Weston Brook	1.42	6.50
Upper Delaware SRR	Wadeable Stream	Schoolhouse Creek	0.50	6.12
Upper Delaware SRR	Wadeable Stream	Peggy Run	0.77	5.72
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 275	1.31	5.71
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 324.5	1.09	5.31

Park	Category	Name	Length (km)	Area (km^2)
Upper Delaware SRR	Wadeable Stream	Blue Mill Stream	1.39	4.97
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 301.5	1.23	4.79
Upper Delaware SRR	Wadeable Stream	UNT UNT Del River 268	0.89	4.68
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 293	0.96	4.21
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 277	0.87	4.05
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 328	1.14	3.75
Upper Delaware SRR	Wadeable Stream	UNT Halfway Brook	1.19	3.57
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 300	1.25	3.51
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 301	1.21	3.44
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 306	1.01	3.29
Upper Delaware SRR	Wadeable Stream	UNT Narrow Falls Brook	0.25	3.19
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 304	0.34	2.96
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 327.5	1.11	2.71
Upper Delaware SRR	Wadeable Stream	UNT Peggy Run	0.03	2.61
Upper Delaware SRR	Wadeable Stream	UNT Basket Creek	0.17	2.55
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 263	0.49	2.21
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 276	0.23	2.14
Upper Delaware SRR	Wadeable Stream	UNT Westcoolang Creek	0.46	2.12
Upper Delaware SRR	Wadeable Stream	UNT Grassy Swamp Brook	0.18	2.12
Upper Delaware SRR	Wadeable Stream	UNT Pea Brook	0.30	2.12

Park	Category	Name	Length (km)	Area (km^2)
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 323	0.29	2.05
Upper Delaware SRR	Wadeable Stream	UNT Delaware River 318	0.03	2.03
Bluestone NSR	Medium River	Bluestone River	18.50	1139.45
Bluestone NSR	Wadeable Stream	Little Bluestone River	2.48	87.51
Bluestone NSR	Wadeable Stream	UNT Bluestone River 4	0.25	2.96
Bluestone NSR	Wadeable Stream	UNT Bluestone River 5	1.01	3.62
Bluestone NSR	Wadeable Stream	Jarrell Branch	0.27	2.08
Bluestone NSR	Wadeable Stream	Mountain Creek	0.87	58.30
Bluestone NSR	Wadeable Stream	Indian Branch	1.31	4.87
Allegheny Portage Railroad NHS	Wadeable Stream	Blair Gap Run	2.09	43.26
Allegheny Portage Railroad NHS	Wadeable Stream	Blair Run	0.22	17.04
Allegheny Portage Railroad NHS	Wadeable Stream	Millstone Run	1.37	4.91
Johnstown Flood NMem	Small River	SFLCR	0.92	136.41
Johnstown Flood NMem	Wadeable Stream	UNT SFLCR	0.08	6.72
Fort Necessity NB	Wadeable Stream	UNT Braddock Run	0.11	1.13
Fort Necessity NB	Wadeable Stream	Great Meadows Run	1.62	4.23
Fort Necessity NB	Wadeable Stream	UNT Great Meadows Run	0.60	1.54
Friendship Hill NHS	Wadeable Stream	Dublin Run	0.17	1.11
Friendship Hill NHS	Wadeable Stream	Ice Pond Run	1.07	1.30

Table A.5. Watershed sizes used to define stream and river size categories in the Eastern Rivers and Mountains Network.

Size Category	Watershed Size (km^2)
Large Rivers	5,000 - 20,000
Medium Rivers	500 - 5,000
Small Rivers	100 - 500
Wadeable Streams	2 - 100

Table A.6. Size category, name, park, contributing area (Area; km^2), length in park (Length; km), and relevant monitoring protocol for flowing surface waters in the Eastern Rivers and Mountains Network.

Category	Name	Park	Area	Length	Protocol
Large Rivers	New River	New River Gorge NR	17,815	90.4	River
	Delaware River	Delaware Water Gap NRA	10,213	69.9	River
	Delaware River	Upper Delaware SRR	7,989	123.4	River
Medium Rivers	Gauley River	Gauley River NRA	3,347	42.1	River
	Delaware River (East Branch)	Upper Delaware SRR	2,188	<0.1	River
	Delaware River (West Branch)	Upper Delaware SRR	1,735	0.1	River
	Lackawaxen River	Upper Delaware SRR	1,557	0.9	River
	Bluestone River	Bluestone NSR	1,139	18.5	River
	Meadow River	Gauley River NRA	945	9.5	River
	Brodhead Creek	Delaware Water Gap NRA	670	<0.1	River
	Mongaup River	Upper Delaware SRR	543	1.7	River
Small Rivers	Bushkill Creek	Delaware Water Gap NRA	409	4.9	River
	Piney Creek	New River Gorge NR	352	1.3	River
	Callicoon Creek	Upper Delaware SRR	292	2.3	River
	Shohola Creek	Upper Delaware SRR	224	0.5	River
	Flat Brook	Delaware Water Gap NRA	171	19.3	River
	Glade Creek	New River Gorge NR	164	9.9	River
	Manns Creek	New River Gorge NR	151	9.1	River

Category	Name	Park	Area	Length	Protocol
	Equinunk Creek	Upper Delaware SRR	150	0.7	River
	SFLCR[1]	Johnstown Flood NMem	136	0.9	River
	Peters Creek	Gauley River NRA	136	2.7	River
	Tenmile River	Upper Delaware SRR	127	1.0	River
	Dunloup Creek	New River Gorge NR	125	6.5	River
	Calkins Creek	Upper Delaware SRR	115	0.8	River
	Lick Creek	New River Gorge NR	101	1.3	River
Wadeable Streams[2]	--	New River Gorge NR	≥ 2	112.3	BMI and Streamside Birds
	--	Delaware Water Gap NRA	≥ 2	80.6	BMI and Streamside Birds
	--	Gauley River NRA	≥ 2	13.8	BMI and Streamside Birds
	--	Bluestone NSR	≥ 2	6.2	BMI and Streamside Birds
	--	Allegheny Portage Railroad NHS	≥ 2	3.7	BMI and Streamside Birds
	--	Johnstown Flood NMem	≥ 2	<0.1	BMI and Streamside Birds
	--	Fort Necessity NB	≥ 1	2.3	BMI and Streamside Birds
	--	Friendship Hill NHS	≥ 1	1.2	BMI and Streamside Birds
Ephemeral Streams	--	--	<1 or <2[3]	--	Not sampled

[1] South Fork Little Conemaugh River

[2] Refer to Table A.4 for Wadeable Stream names

[3] Typically this criterion was 2 km2 but it was relaxed to 1 km2 at Fort Necessity NB and Friendship Hill NHS

Table A.7. Floodplain input files and products of the Eastern Rivers and Mountains Network wadeable stream sampling frame. Special Flood Hazard Areas contained in Digital Flood Insurance Rate Maps (DFIRM) from the Federal Emergency Management Agency were equivalent to the 100-year floodplain; these areas were used eliminate wadeable stream sections from the sampling frame due to the transitional character of resident biological communities.

Park Unit	Input files	Input Source	Final Product
Delaware Water Gap NRA	S_Fld_Har_Ar.shp	This inundation layer developed by DCS Hydraulics (2010) delineated the 100 yr (and 500 yr floodplains) using LiDAR collected in 2008. This layer (100 yr) was favored over the DFIRM layer for DEWA	DEWA_DFIRM_FEMA_100YEAR.shp
	Pennsylvania – Monroe Co. (5/2/2013); Northampton Co. (4/6/2001); Pike Co. (4/6/2001)	DFIRM County Layers	
	New Jersey – Sussex (9/20/2011); Warren (9/20/2011)	DFIRM County Layers	
Gauley River NRA and New River Gorge NR	Fayette (9/30/2010); Mercer (3/02/2005) Nicholas (7/04/2011); Raleigh (9/29/2006); Summers (2/03/2010)	DFIRM County Layers	WVParks_DFIRM_FEMA_100YEAR.shp

Table A.8. Initial wadeable stream length (Initial) and stream length removed for each of four criteria (< 400 m, Boundary Meanders, Remainders <100 m, and River floodplain) resulting in the total wadeable stream length included in the final sampling frame (Final). All lengths are kilometers (km).

Park	Initial	Segments <400 m	Boundary Meanders	Remainders <100 m	Floodplains	Final
Delaware Water Gap NRA	80.6	1.0	0.3	1.2	17.4	60.7
Gauley River NRA	13.8	1.6	0.0	0.5	0.8	10.9
New River Gorge NR	112.3	2.1	3.0	2.8	3.6	100.8

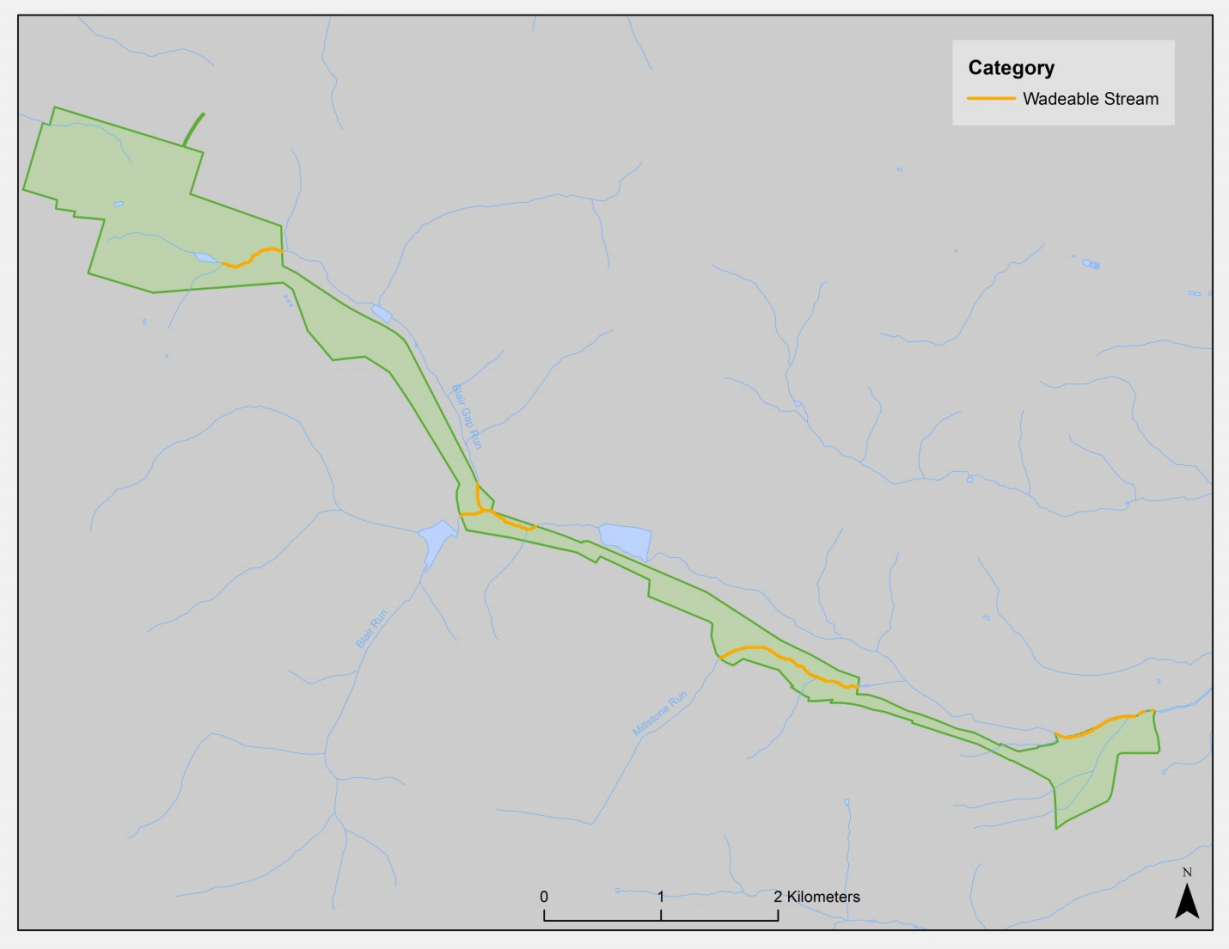

Figure A.1. Allegheny Portage Railroad NHS wadeable streams.

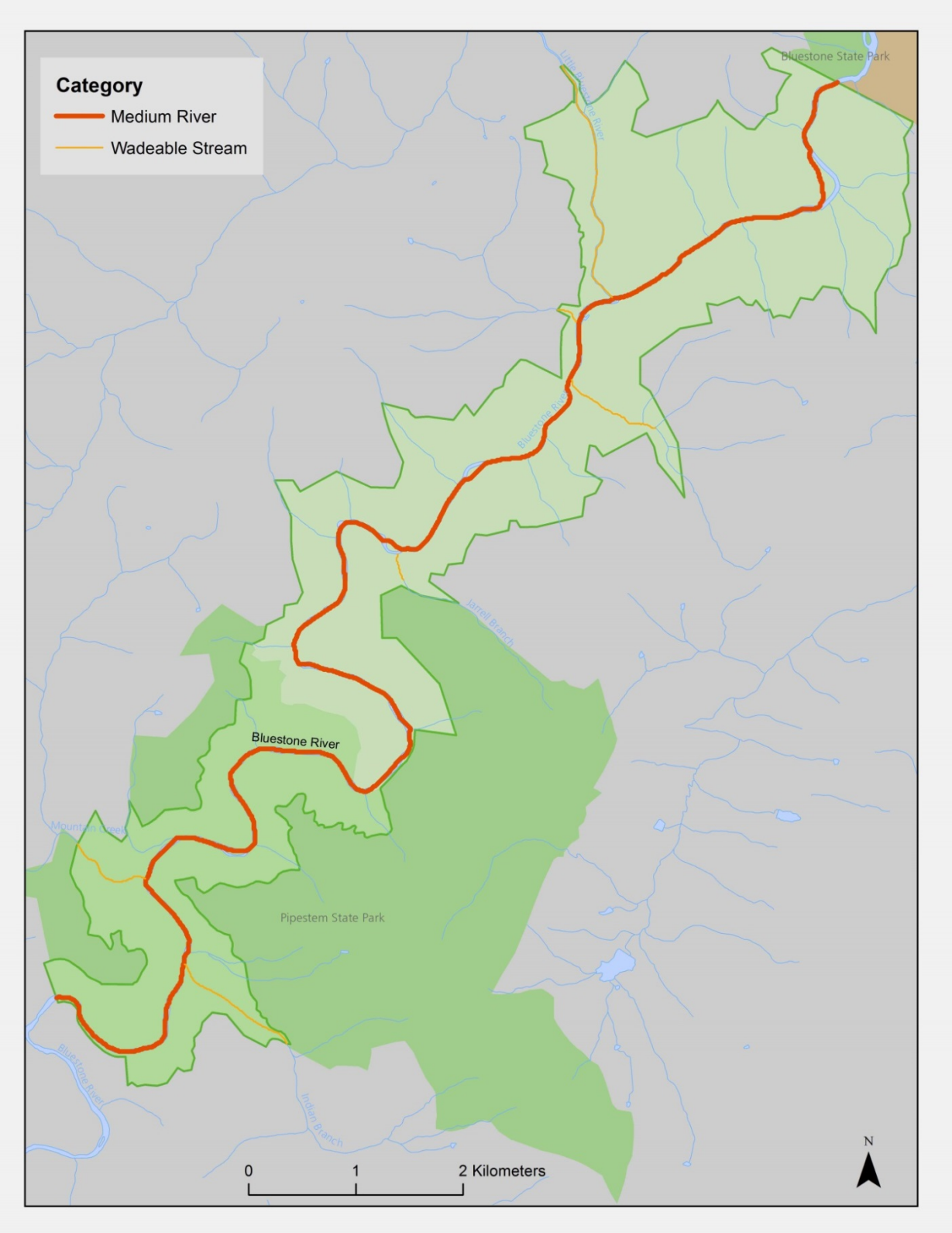

Figure A.2. Medium rivers and wadeable streams at Bluestone NSR.

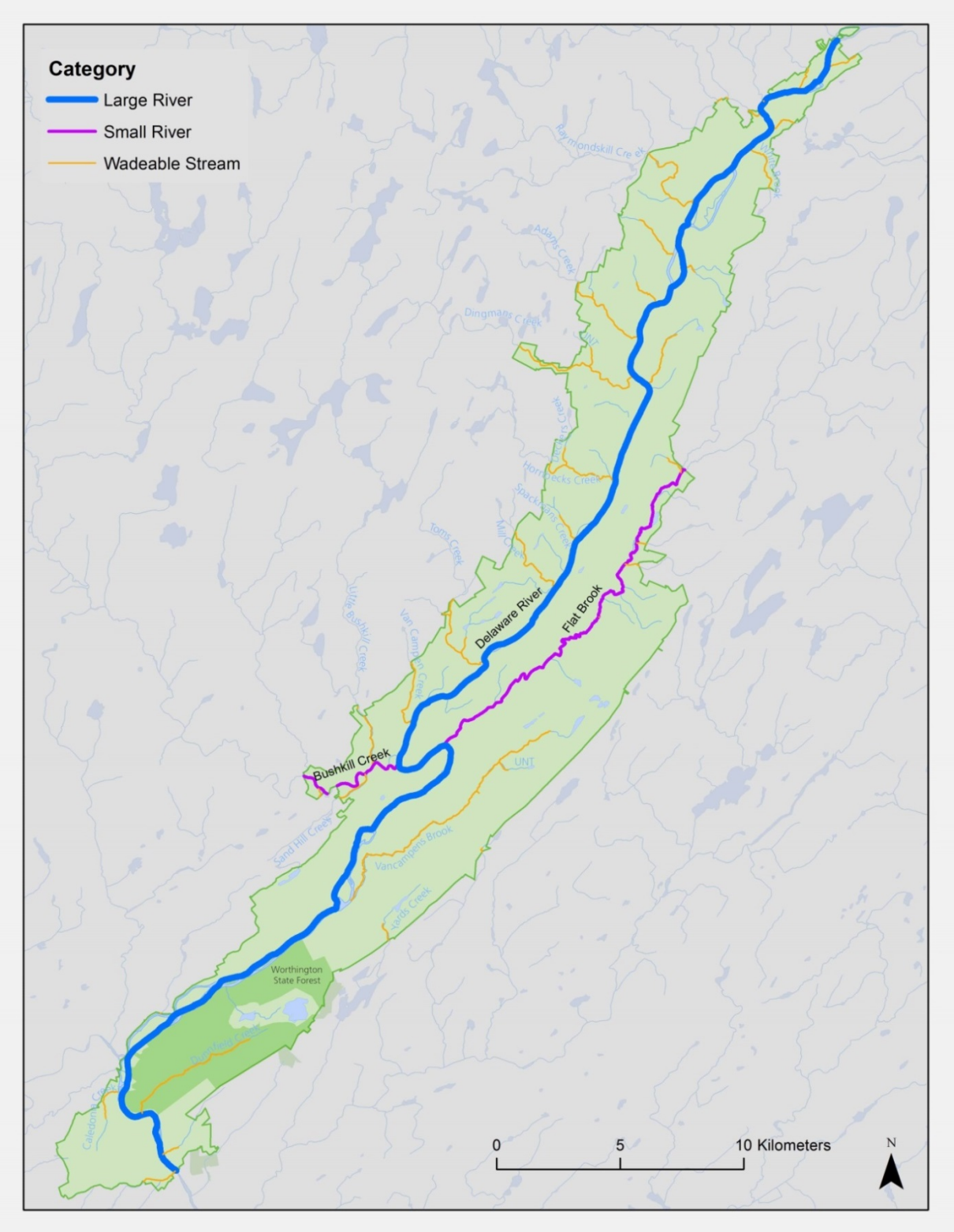

Figure A.3. Large rivers, small rivers, and wadeable streams at Delaware Water Gap NRA.

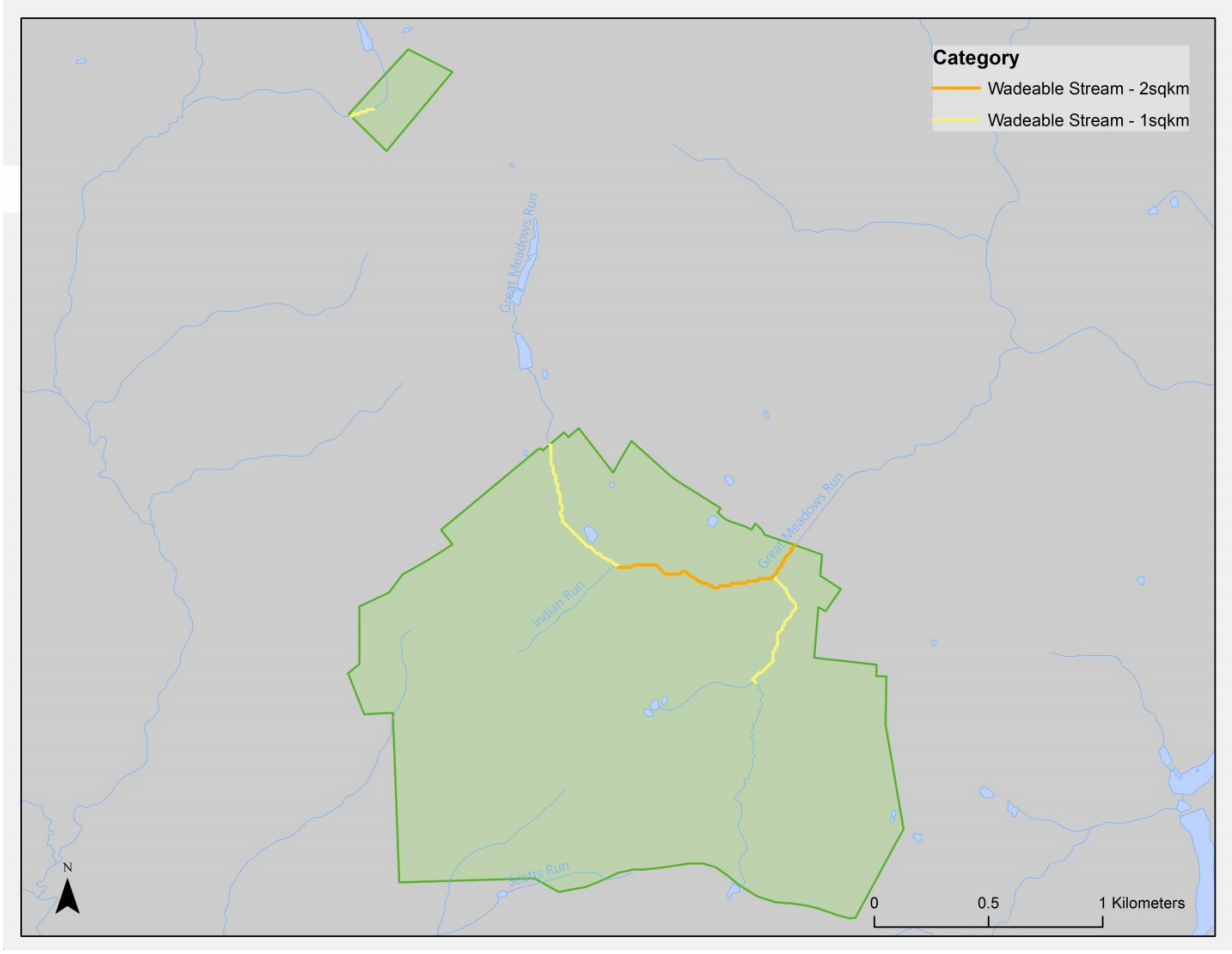

Figure A.4. Wadeable streams at Fort Necessity NB. Note that the 2.0 km^2 minimum watershed area criterion applied to most other parks was set to 1.0 km^2 so that the limited amount of surface water at the park could be delineated and sampled.

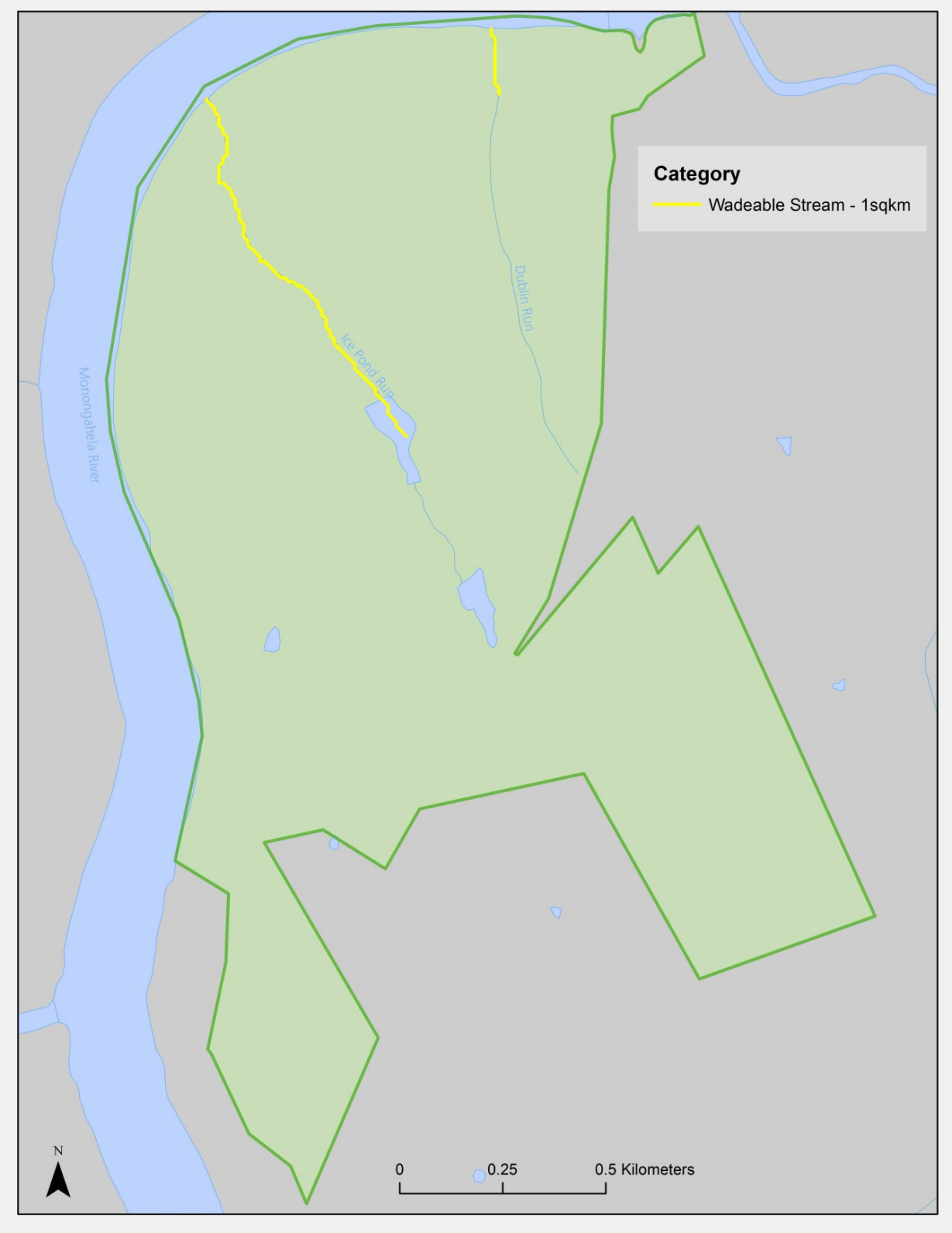

Figure A.5. Wadeable streams at Friendship Hill NHS. Note that the 2.0 km2 minimum watershed area criterion applied to most other parks was set to 1.0 km2 so that the limited amount of surface water at the park could be delineated and sampled.

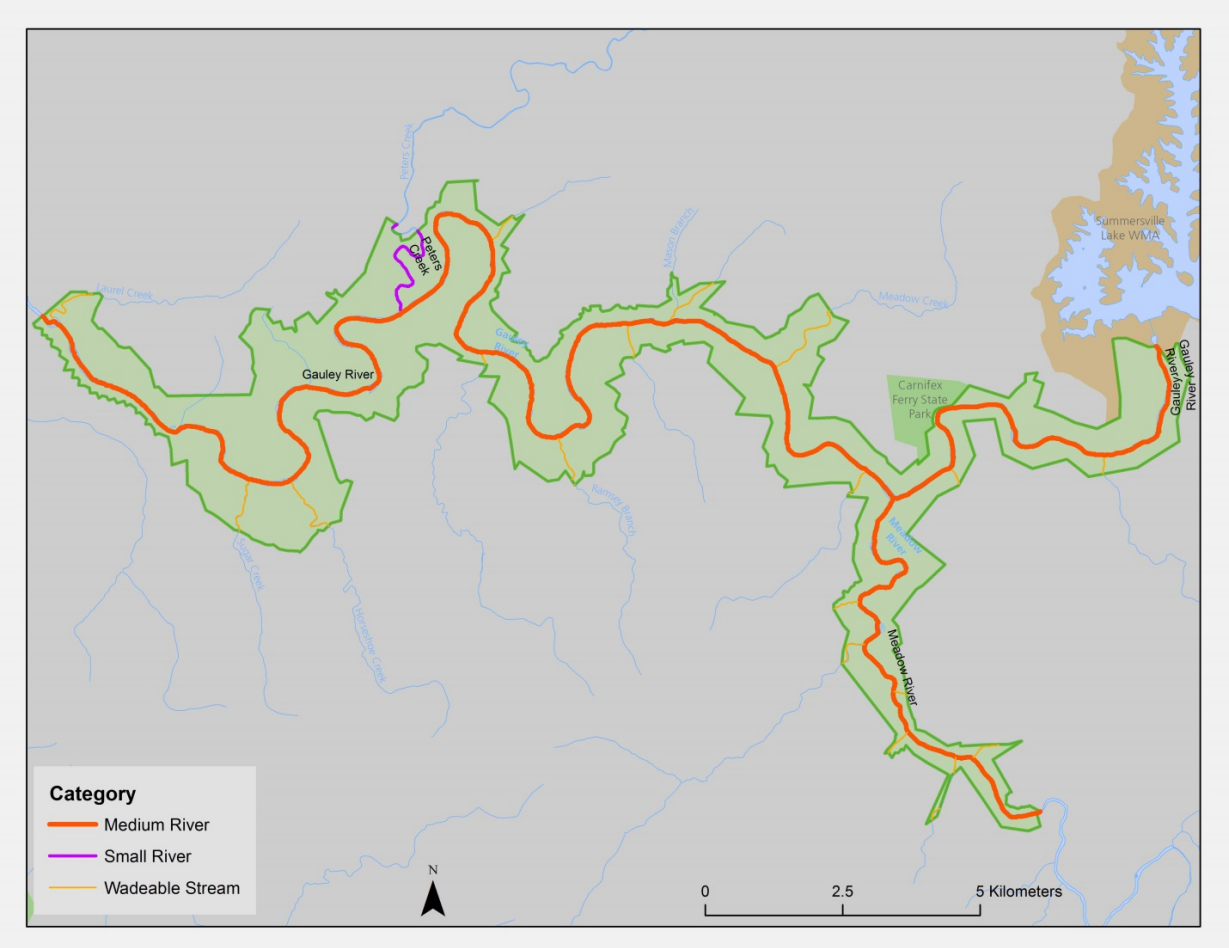

Figure A.6. Medium rivers, small rivers, and wadeable streams at Gauley River NRA.

Figure A.7. Small rivers and wadeable streams at Johnstown Flood NMem.

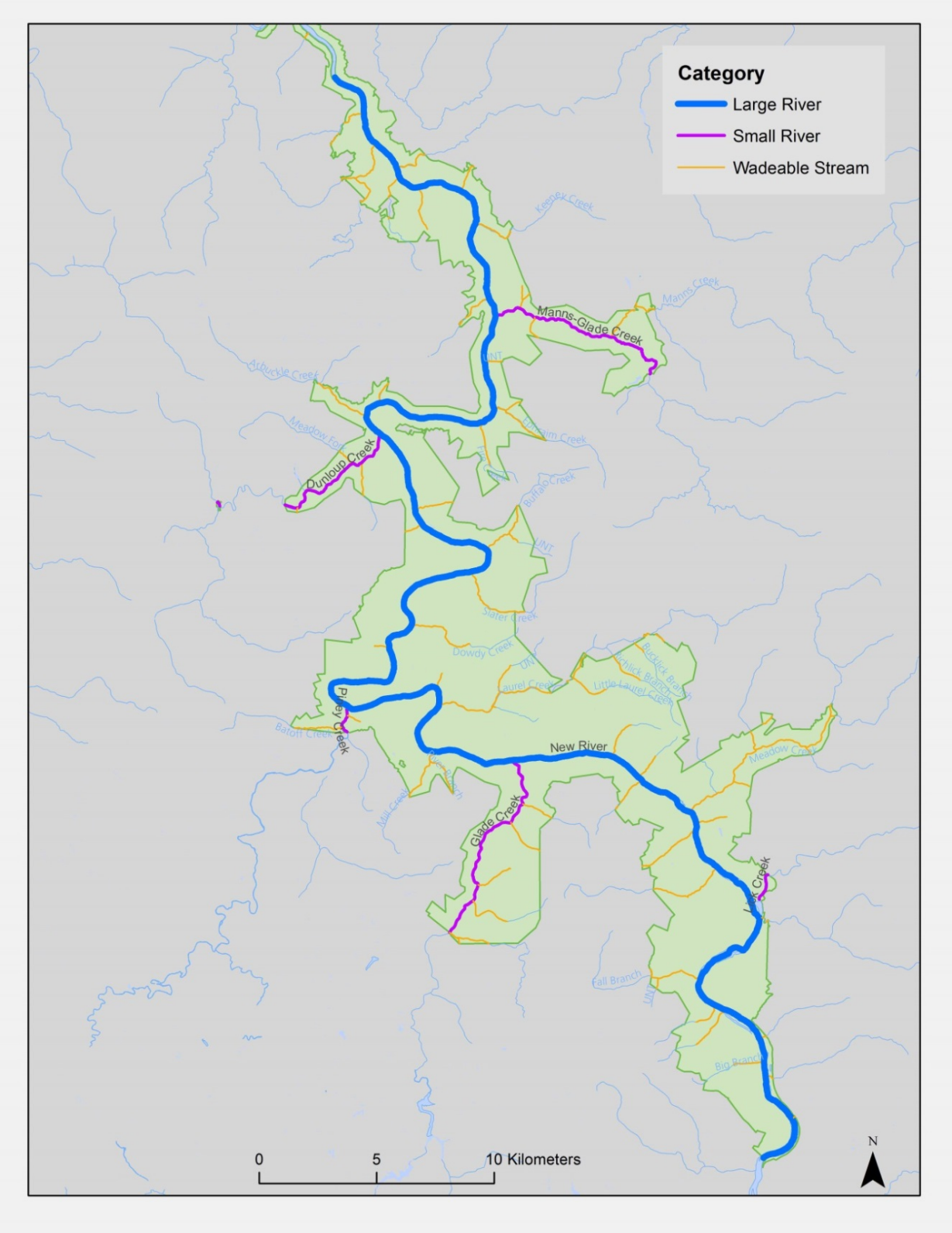

Figure A.8. Large rivers, small rivers, and wadeable streams at New River Gorge NR.

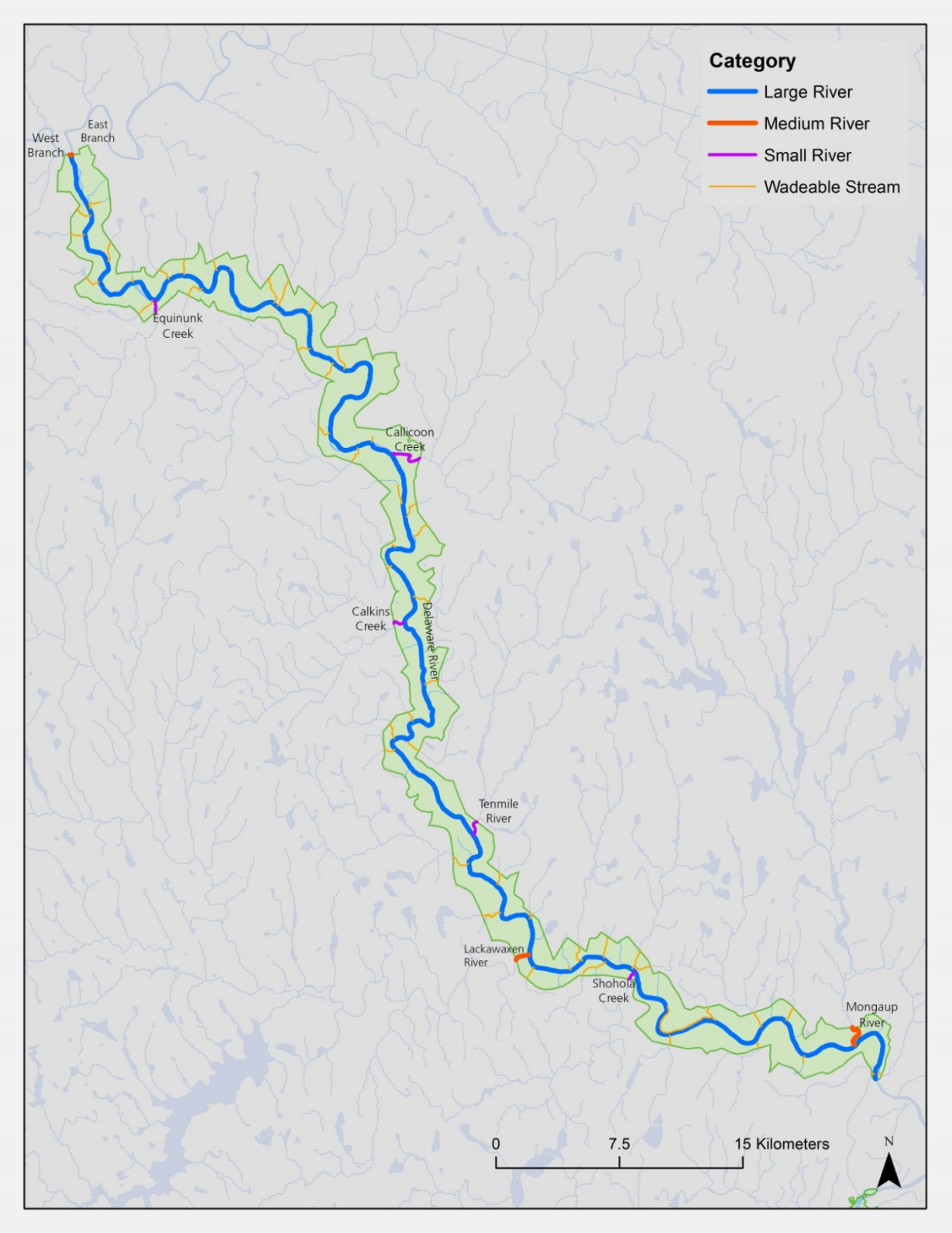

Figure A.9. Large rivers, medium rivers, small rivers, and wadeable streams at Upper Delaware SRR.

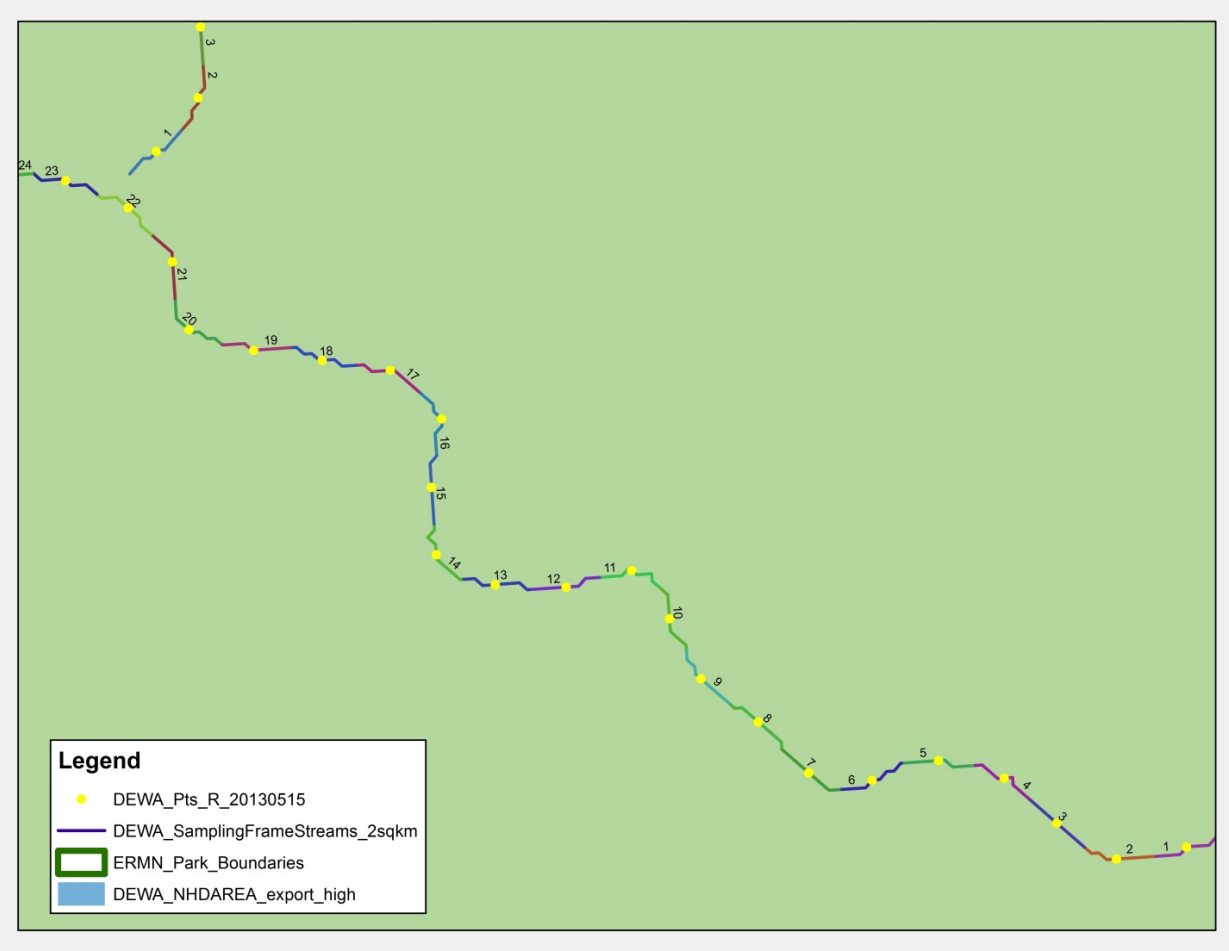

Figure A.10. Wadeable stream section at Delaware Water Gap NRA. The center points (yellow points) of 100 m stream segments (depicted by different colors) defined the sampling frame for the Benthic Macroinvertebrate Monitoring and Streamside Bird Monitoring protocols.

Appendix B. Site Selection

Overview

This appendix describes processes that were used to select co-located BMI and Streamside Bird monitoring sites from the ERMN wadeable stream sampling frame (Appendix A). Sampling site inclusion was limited to wadeable streams at all parks; however, the site selection process differed among parks and was dictated primarily by the amount of cumulative wadeable stream length within each park. At large parks, where randomization of sampling sites was preferred (due to the abundance and cumulative length of wadeable streams), site midpoints were selected using a generalized random tessellation stratified (GRTS) design (Stevens and Olsen 2004). At parks where randomization was illogical (typically small and/or linear parks), index sites were established near stream mouths or downstream-most park boundaries (i.e., as far downstream as possible within NPS-Authorized Boundaries). Selected sites were visited by ERMN staff prior to sampling – sites that were safely accessible and contained appropriate BMI sampling habitat (i.e., riffles) were included as permanent sampling sites (Appendix C).

Site Selection at Large Parks

Sites were selected using a spatially-balanced, random process at three large parks (Delaware Water Gap NRA, Gauley River NRA, and New River Gorge NR) due to the abundance and cumulative length of wadeable streams within their authorized boundaries.

Simple Random Sampling Background

Our approach to site selection was guided by the notion of parsimony – the design should be as straightforward as possible while meeting program objectives. A monitoring program should: (1) be easy to implement and maintain, (2) allow for a broad range of analyses (including those that are unforeseen at implementation), (3) remain understandable when program personnel change, and (4) engender support among stakeholders. Moreover, because the sampling design described here is for two wadeable stream-based protocols (BMI and Streamside Birds) and each protocol has multiple objectives with a corresponding array of response variables, the design could not focus on optimizing a single metric or objective because a design that is optimal for one metric is likely to be suboptimal for others. Simple random sampling is an approach that meets these considerations while providing an objective assessment of the sampled area (Thompson 2002, McDonald 2012). Simple random sampling is well known and mathematically straight forward with established statistical properties; however, it suffers from the fact that it does not guarantee uniform spatial coverage of the area of interest. It is possible for significant *clumps*, and corresponding *holes*, to develop in the spatial coverage of simple random samples.

McDonald (2012) and Olsen et al. (2012) contrast several designs that ensure good ("balanced") spatial coverage and emphasize these designs work well for environmental monitoring because spatial variation is often one of the largest sources of variation in these types of efforts (the other large source is temporal variation). Moreover, these authors argue that when a spatially balanced sample is displayed graphically, viewers are more likely to accept the sample as being representative – and are therefore more likely to accept the value of the estimates of status or trend resulting from

the sample. The ERMN, along with many other networks (Fancy and Bennetts 2012), elected to use a spatially explicit sampling design (a generalized random tessellation stratified [GRTS] design; Stevens and Olsen [2004]) to select BMI and Streamside Bird sampling sites at Delaware Water Gap NRA, Gauley River NRA, and New River Gorge NR.

The GRTS approach is more complex than simple random sampling; however, we used the most basic GRTS algorithm (i.e., unstratified, equal inclusion probability) to ensure spatial balance while explicitly avoiding complexity that would need to be carried through to all subsequent analyses. While there are variance and other estimators specifically for GRTS designs (Stevens and Olsen 2004) this approach does not preclude other estimation and analysis approaches that assume simple random sampling (Olsen et al. 2012; pg. 133) such as occupancy modeling (MacKenzie et al. 2006).

The GRTS technique uses reverse hierarchical ordering to map two-dimensional space (e.g., 100 m segments of the ERMN wadeable stream sampling frame [Appendix A]) into one-dimensional space, by giving each reach an ordered spatial address (e.g., coordinates of 100 m stream segment midpoints). Addresses are randomly ordered in a way that systematic sampling of the addresses results in a spatially balanced random sample (McDonald 2004; Stevens and Olsen 2004) which results in a generally uniform dispersion of selected sampling sites over the area of interest (sampling frame). In practice, the GRTS technique produces an ordered list of potential sample sites where any consecutive series of sites in the list is approximately spatially balanced. Sample sites are selected by proceeding down the ordered list until a sufficient number of sites (Appendix C) are included to meet program objectives.

This approach allows for a flexible sample size, such that sites at the *end* of the list can be added to (or excluded from) the sampling plan while maintaining spatial balance and without compromising overall design integrity (e.g., if sites are added or removed due to funding changes). Any subset of the ordered list has the same properties as the complete list so that consecutive subsets can also be used to define panels, for example. Note that if panels are used (as in this implementation plan), each panel is a spatially balanced sample for the population, allowing status estimates for each time period as well as trend and change estimates across and between time periods (Olsen et al. 2012).

Random Site Selection Process

The software implementation of the GRTS algorithm [*function grts ()*] is available in the *spsurvey* package (Kincaid and Olsen 2012) developed for the R statistical software (R Development Core Team 2012). The *spsurvey* package is available on the R website (http://cran.r-project.org/web/packages/spsurvey/) including a relevant example application with R code of an unstratified, equal probability design for a finite, linear resource (i.e., http://cran.r-project.org/web/packages/spsurvey/vignettes/Finite_Design.pdf).

The implementation required the sample frame to be prepared and imported into R as an ESRI shapefile. The sampling frame in each park was divided into discrete 100 m sampling units (Appendix A) – there were 607, 109, and 1008 units for Delaware Water Gap NRA, Gauley River NRA, and New River Gorge NR, respectively. The R code for each park (Tables B.1 – B.3) draws 256 candidate sites from the total population (64 sites for GARI) and returns them as a new shapefile

in the same projection (UTM) as the input shapefile. The output file contains a unique attribute (e.g., DEWA-001 through DEWA-256) for each site to identify its order in the spatially balanced list as well as the inclusion probability (i.e., weighting factor) for each site (specified to be equal for all sites) [1].

Site Selection at Small and/or Linear ERMN Parks

Sampling sites at comparatively small and/or linear parks (Allegheny Portage Railroad NHS, Bluestone NSR, Fort Necessity NB, and Friendship Hill NHS) were non-randomly selected using a logical approach. Index sites were established near stream mouths or downstream-most park boundaries (i.e., as far downstream possible within NPS-Authorized Boundaries). By definition, data from non-random (index) sites cannot be combined and analyzed to make a statistical inference to stream sections that were not sampled. Wadeable stream protocols do not apply at Johnstown Flood NMem and Upper Delaware SRR because there are few wadeable streams within authorized boundaries where long-term monitoring sites could confidently be established.

Table B.1. R code used to select sites at Delaware Water Gap NRA using the GRTS function.

```
#Delaware Water Gap NRA GRTS Draw May 15, 2013. Unstratified, equal probability, with spatial balance.
Floodplain and small rivers excluded. Flow accumulation equals 2 square kilometers.
#Load the spsurvey package
library(spsurvey)
#Read the attribute table from the shapefile
att<- read.dbf("DEWA_for_R_20130515")
#Display the initial six lines of the attribute data frame
head(att)
#Create the design list. One panel with 256 sites.
Equaldsgn <- list(None=list(panel=c(Panel1=256), seltype="Equal"))
#Generate random seed
zz <- round(runif(1)*1000000)
print(zz)
#Call the set.seed function so the draw is reproducible
#manually paste zz into set.seed below, then save $ run
set.seed(876467) # arbitrary digits
#Select the sample using GRTS.
DEWA.Sites<- grts(design=Equaldsgn,
DesignID="DEWA",
type.frame="finite",
src.frame="shapefile",
in.shape="DEWA_for_R_20130515",
att.frame=att,
shapefile=TRUE,
out.shape="DEWA_from_R_20130515",
prj="DEWA_for_R_20130515")
```

[1] Final shapefiles were named DEWA_Pts_R_20130515 (Delaware Water Gap NRA) and NERI_Pts_R_20130515 GARI_Pts_R_20150302 (New River Gorge NR)

Table B.2. R code used to select sites at Gauley River NRA using the GRTS function.

```
#Gauley River NRA GRTS Draw March 16, 2015. Unstratified, equal probability, with spatial balance. Floodplain
and small rivers excluded. Flow accumulation equals 2 square kilometers.
#Load the spsurvey package
library(spsurvey)
#Read the attribute table from the shapefile
att<- read.dbf("GARI_for_R_20150302")
#Display the initial six lines of the attribute data frame
head(att)
#Create the design list. One panel with 64 sites.
Equaldsgn <- list(None=list(panel=c(Panel1=64), seltype="Equal"))
#Generate random seed
zz <- round(runif(1)*1000000)
print(zz)
#Call the set.seed function so the draw is reproducible
#manually paste zz into set.seed below, then save $ run
set.seed(263909) # arbitrary digits
#Select the sample using GRTS.
GARI.Sites<- grts(design=Equaldsgn,
DesignID="GARI",
type.frame="finite",
src.frame="shapefile",
in.shape="GARI_for_R_20150302",
att.frame=att,
shapefile=TRUE,
out.shape="GARI_from_R_20150316",
prj="GARI_for_R_20150302")
```

Table B.3. R code used to select sites at New River Gorge NR using the GRTS function.

```
#New River Gorge NR GRTS Draw May 15, 2013. Unstratified, equal probability, with spatial balance.
#Floodplain and small rivers excluded.
#Flow accumulation equals 2 square kilometers.
#Load the spsurvey package
library(spsurvey)
#Read the attribute table from the shapefile
att<- read.dbf("NERI_for_R_20130515")
#Display the initial six lines of the attribute data frame
head(att)
#Create the design list. One panel with 256 sites.
Equaldsgn <- list(None=list(panel=c(Panel1=256), seltype="Equal"))
#Generate random seed
zz <- round(runif(1)*1000000)
print(zz)
#Call the set.seed function so the draw is reproducible
#manually paste zz into set.seed below, then save $ run
set.seed(807182) # arbitrary digits
#Select the sample using GRTS.
NERI.Sites<- grts(design=Equaldsgn,
DesignID="NERI",
type.frame="finite",
src.frame="shapefile",
in.shape="NERI_for_R_20130515",
att.frame=att,
shapefile=TRUE,
out.shape="NERI_from_R_20130515",
prj="NERI_for_R_20130515"
```

Appendix C. Sampling Site Evaluation and Inclusion

Site Inclusion at Large Parks

Site evaluation criteria at Delaware Water Gap NRA, Gauley River NRA, New River Gorge NR, and Upper Delaware SRR included: public (i.e., NPS) ownership, access, safety, and suitable habitat.

Ownership Evaluation

Sampling sites were not established on private lands because of uncertainty related to future access/permission. Public ownership was evaluated with GIS using the most recent property ownership maps provided by park staff.

The authorized boundary of Upper Delaware SRR encompasses approximately 26,000 ha; however, only about 12 ha are owned by the NPS. Furthermore, only 5% of the land (approximately 1,225 ha) within the authorized boundary is held by public entities (i.e., Federal Government, Commonwealth of Pennsylvania, State of New York, or Sullivan County Parks). Similarly, Gauley River NRA was not included because only 13% (1.7 km) of the total wadeable stream length (13.0 km) within the authorized boundary occurs on public land; the remainder occurs on private inholdings. However, due to the enabling legislation and ability to acquire land over time, sampling should occur within Gauley River NRA once sufficient land has been acquired by the NPS.

Sites located on private property at Delaware Water Gap NRA and New River Gorge NR were not permanently excluded but were instead held in a *dormant* state because it is conceivable that these sites may become available if the NPS purchases relevant parcels. The protocol lead and data manager will contact park staff every two years for updated parcel ownership maps and sampling will be initiated at *dormant* sites that come under NPS ownership.

Site Reconnaissance

Despite the familiarity of the parks and sites acquired by ERMN staff from 2007 through 2012, assessing *safety* and *suitable habitat* was difficult compared to determining land ownership and could not be done entirely using a GIS. Ideally, complete knowledge of the *safety* and *habitat* features of all sites would have been known, which would have allowed us to exclude inappropriate sites from the sampling frame *a priori*, but this was not possible. Instead, all potential sites on NPS property at Delaware Water Gap NRA and New River Gorge NR remained in the sampling frame and were available to be selected. After the draw of 256 sites (Appendix B), we used available imagery, digital elevation models, terrain features, trail and road access, and personal experience to exclude many sites due to safety considerations. Field visits were subsequently conducted to evaluate all remaining sites in the spring of 2013 and 2014.

ERMN staff evaluated each site (in order, beginning with DEWA-001 and NERI-001) for inclusion until 68 sites were included (32 sites at Delaware Water Gap NRA and 36 sites at New River Gorge NR; more at the latter due to greater total wadeable stream length). The number of sampling sites chosen was based on prior experience, available funding, and logistical constraints, as well as statistical evaluation of the design's ability to meet program objectives (Appendix D). Two teams, each with two experienced ERMN employees, visited each site to determine whether sites should be

included based on safety considerations. Simultaneously, sites were assessed to ensure that the intended target stream habitat (riffles with abundant cobble) was present (Figure C.1) to align with BMI sampling procedures. Although rare, habitat at some sites at both parks was atypical (e.g., low gradient sandy bottom streams; Figure C.2); consequently, those sites were excluded from the sampling frame.

Figure C.1. Section of Toms Creek (Delaware Water Gap NRA) depicting typical riffle-cobble habitat included in Eastern Rivers and Mountains Network wadeable stream protocols.

Figure C.2. Section of Polls Branch at New River Gorge NR depicting boggy, slow moving, sandy bottom habitat not included in Eastern Rivers and Mountains Network wadeable stream protocols.

Delaware Water Gap NRA

We evaluated 39 sites (Table C.1) to reach the target of 32 sites at Delaware Water Gap NRA (Table C.2; Figure C.3). Three of the evaluated sites are *dormant*, including two on private inholdings and one that is currently *in* a small, man-made impoundment. This site will be sampled in the future if it is restored to a wadeable stream condition. Four sites were excluded due to inappropriate habitat – all sites were deemed to be safely accessible. After 32 sites were confirmed and included, two sampling panels were created by assigning the first 16 sites in the list to *Panel 1* (even years, first sampled in 2014) and the second 16 sites to *Panel 2* (odd years, first sampled in 2015). Should all three currently dormant sites become active, two will be included in Panel 1 and one will be included in Panel 2.

Table C.1. Unique generalized random tessellation stratified (GRTS) design identifier (ID), site name, sampling status, and Universal Transverse Mercator coordinates for 39 sampling sites evaluated at Delaware Water Gap NRA. Numbers in Site Name denote hectometers (100 m units) upstream from stream mouths (confluence with larger stream) or outpour point crossing park boundary.

GRTS_ID	Site Name	Status	UTM X	UTM Y
DEWA-001	Caledonia Creek 13	IN	487886.000002	4535590.715730
DEWA-002	Van Campen Creek 12	IN	501306.000002	4551390.789920
DEWA-003	Deckers Creek 03	IN	508126.000002	4560679.563480
DEWA-004	Dingmans Creek 05	IN	510507.309445	4563458.999990
DEWA-005	Dunnfield Creek 03	IN	489355.684708	4535878.684700
DEWA-006	Toms Creek 20	IN	503146.000002	4553997.834740
DEWA-007	Spackmans Creek 08	IN	507886.000002	4558254.710660
DEWA-008	Dingmans Creek 57	IN	506845.519353	4565149.480640
DEWA-009	Vancampens Brook 28	OUT - HABITAT	501733.915411	4546286.915400
DEWA-010	Vancampens Brook 95	IN	506406.190299	4549499.190290
DEWA-011	Adams Creek 14	IN	510296.000002	4566385.760360
DEWA-012	Adams Creek 33	IN	509178.892134	4567381.892120
DEWA-013	Little Bushkill Creek 01	IN	499552.414242	4549172.585750
DEWA-014	Vancampens Brook 43	IN	502936.169379	4546649.169370
DEWA-015	Dingmans Creek 39	IN	508093.128660	4564351.871330
DEWA-016	Raymondskill Creek 31	DORMANT - PRIVATE	512979.842182	4572158.999990
DEWA-017	Caledonia Creek 03	DORMANT - POND	488131.025261	4536378.999990
DEWA-018	Toms Creek 07	IN	503427.632062	4553128.999990
DEWA-019	Hornbecks Creek 23	OUT - HABITAT	507755.523034	4560158.523020
DEWA-020	Mill Creek 25	IN	506146.784780	4557508.215210

GRTS_ID	Site Name	Status	UTM X	UTM Y
DEWA-021	Dunnfield Creek 61	OUT - HABITAT	493851.857865	4538114.857850
DEWA-022	Toms Creek 25	IN	503122.957793	4554465.957780
DEWA-023	UNT Dingmans Creek 07	IN	509576.000002	4564897.284270
DEWA-024	Raymondskill Creek 38	DORMANT - PRIVATE	512568.803053	4572516.196940
DEWA-025	Vancampens Brook 22	IN	501306.930563	4545939.930550
DEWA-026	UNT Vancampens Brook 05	IN	504990.142136	4548268.999990
DEWA-027	Adams Creek 03	IN	510913.976193	4565571.023800
DEWA-028	White Brook 15	IN	517122.357349	4571482.642640
DEWA-029	Sand Hill Creek 08	IN	498795.353860	4547899.000000
DEWA-030	Yards Creek 07	IN	499556.000002	4542285.568540
DEWA-031	Dingmans Creek 30	IN	508815.971372	4564368.971360
DEWA-032	Raymondskill Creek 13	IN	512939.680909	4571538.999990
DEWA-033	Dunnfield Creek 26	IN	491153.207794	4536916.207780
DEWA-034	Toms Creek 03	IN	503655.500029	4552868.999990
DEWA-035	Hornbecks Creek 15	IN	508396.208588	4560248.999990
DEWA-036	Mill Creek 12	IN	506350.713745	4556428.999990
DEWA-037	Dunnfield Creek 53	OUT - HABITAT	493197.801949	4537790.801940
DEWA-038	Vancampens Brook 76	IN	504936.000002	4548818.213560
DEWA-039	Adams Creek 21	IN	509913.229802	4566721.770190

Table C.2. Unique GRTS site identifier (ID), site name, and sampling panel for 32 sampling sites at Delaware Water Gap NRA. Numbers in Site Name denote hectometers (100 m units) upstream from stream mouths (confluence with larger stream) or outpour point crossing park boundary.

GRTS ID	Site Name	Panel
DEWA-011	Adams Creek 14	1
DEWA-012	Adams Creek 33	1
DEWA-001	Caledonia Creek 13	1
DEWA-003	Deckers Creek 03	1
DEWA-004	Dingmans Creek 05	1
DEWA-015	Dingmans Creek 39	1
DEWA-008	Dingmans Creek 57	1
DEWA-005	Dunnfield Creek 03	1
DEWA-013	Little Bushkill Creek 01	1
DEWA-020	Mill Creek 25	1
DEWA-007	Spackmans Creek 08	1
DEWA-018	Toms Creek 07	1
DEWA-006	Toms Creek 20	1
DEWA-002	Van Campen Creek 12	1
DEWA-014	Vancampens Brook 43	1
DEWA-010	Vancampens Brook 95	1
DEWA-027	Adams Creek 03	2
DEWA-039	Adams Creek 21	2
DEWA-031	Dingmans Creek 30	2
DEWA-033	Dunnfield Creek 26	2
DEWA-035	Hornbecks Creek 15	2
DEWA-036	Mill Creek 12	2
DEWA-032	Raymondskill Creek 13	2
DEWA-029	Sand Hill Creek 08	2
DEWA-034	Toms Creek 03	2
DEWA-022	Toms Creek 25	2
DEWA-023	UNT Dingmans Creek 07	2
DEWA-026	UNT Vancampens Brook 05	2
DEWA-025	Vancampens Brook 22	2
DEWA-038	Vancampens Brook 76	2
DEWA-028	White Brook 15	2
DEWA-030	Yards Creek 07	2

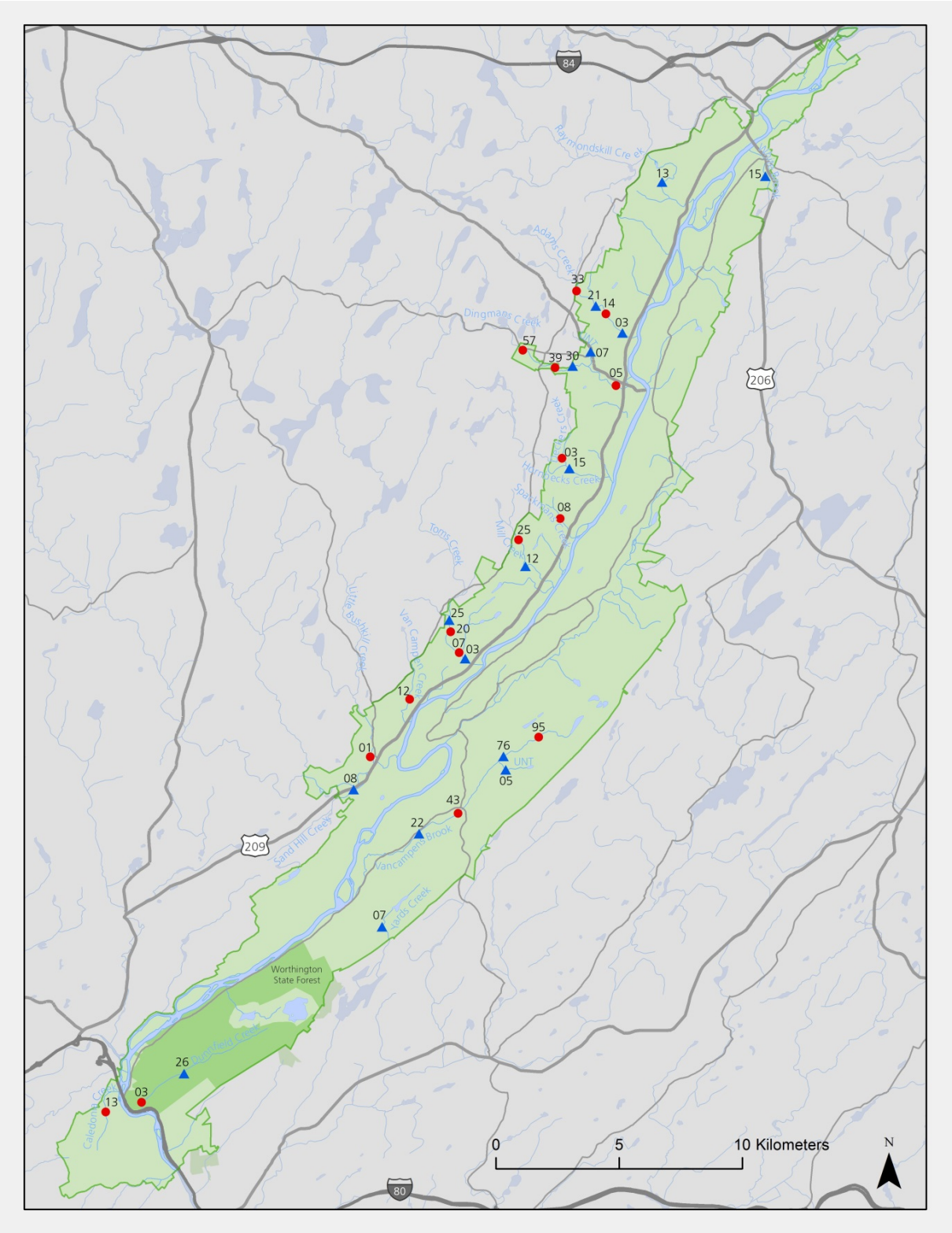

Figure C.3. Benthic macroinvertebrate and Streamside Bird sampling sites sampled in Panel 1 (even years; red circles) and Panel 2 (odd years; blue triangles) at Delaware Water Gap NRA. Numbers denote hectometers (100 m unit) upstream from stream mouths (confluence with larger stream) or outpour point crossing park boundary.

New River Gorge NR

We evaluated 85 sites at New River Gorge NR (Table C.3) to reach the target of 36 sites (Table C.4; Figure C.4). Sixteen sites were *dormant* on private inholdings and 8 sites were excluded because they were inaccessible either due to unsafe conditions or private land that prohibited safe access. Due to steepness of the gorge and other areas of the park, an additional 20 sites had to be excluded based solely on unsafe conditions. Five sites were excluded due to inappropriate habitat (e.g., sandy-bottomed wetlands). After the 36 sites were finalized, two sampling panels were created by assigning the first 18 sites in the list to *Panel 1* (even years, first sampled in 2014) and the second 18 sites to *Panel 2* (odd years, first sampled in 2015). Should all 16 currently dormant sites become active, eight would be included in each sampling panel.

The number of sampling sites per park is currently not proportional to total wadeable stream length per park (100.8 km or 62% for New River Gorge NR; 60.7 km or 38% for Delaware Water Gap NRA); however, if all 19 currently dormant sites are eventually included, the number of sampling sites per park will be proportional to the total wadeable stream length (52 sites or 60% at New River Gorge NR and 35 sites or 40% at Delaware Water Gap NRA). More importantly, the current number of sites in each park is likely to meet program objectives (Appendix D).

It should be noted that the input shapefile for the GRTS draw for New River Gorge NR erroneously contained duplicates for 73 sites; 7% of the total number of sites in the sampling frame (all sites along four streams at the north end of the park had duplicate records in the shapefile; a mistake discovered in October 2014, after the 2014 field season). While this error doubled the inclusion probability for these sites, all were excluded from the sampling plan due to safety, access, and habitat considerations. Therefore, there is not an immediate need to account for these different inclusion probabilities through differential weighting during analysis. Should that change, all original input files, code, products, weights, etc. associated with the sampling design are archived and available from the protocol lead and data manager.

Table C.3. Unique generalized random tessellation stratified (GRTS) design identifier (ID), site name, sampling status, and Universal Transverse Mercator coordinates for 85 sampling sites evaluated at New River Gorge NR. Numbers in *Site Name* denote hectometers (100 m units) upstream from stream mouths (confluence with larger stream) or outpour point crossing park boundary.

GRTS_ID	Site Name	Status	UTM X	UTM Y
NERI-001	Meadow Fork 1	IN	491945.77413	4199617.22587
NERI-002	UNT 1 Manns Creek 8	OUT - ACCESS	499542.38583	4206775.38583
NERI-003	Wolf Creek 14	OUT - SAFETY	492785.00000	4212004.37832
NERI-004	Farleys Creek 8	DORMANT - PRIVATE	507065.00000	4181719.03104
NERI-005	Buffalo Creek 16	IN	498877.05883	4196890.05883
NERI-006	Ephraim Creek 23	OUT - SAFETY	499954.91888	4200738.08112
NERI-007	Panther Branch 7	OUT - SAFETY	503743.12122	4185596.12122
NERI-008	Mill Branch 4	DORMANT - PRIVATE	507301.88077	4176094.88077
NERI-009	Slater Creek 20	IN	497972.83852	4193398.00000
NERI-010	Manns Creek 1	OUT - SAFETY	503049.07315	4204992.07315
NERI-011	Meadow Creek 17	IN	507853.26382	4185766.26382
NERI-012	Kates Branch (Glade) 5	OUT - SAFETY	497275.00000	4180501.33478
NERI-013	Dowdy Creek 16	OUT - HABITAT	495998.10137	4192494.89863
NERI-014	Short Creek 9	DORMANT - PRIVATE	496995.00000	4212007.02909
NERI-015	Meadow Creek 76	DORMANT - PRIVATE	511982.86844	4187875.86844
NERI-016	River Branch 4	IN	495672.53674	4186838.00000
NERI-017	Camp Creek 7	OUT - SAFETY	492435.04551	4198918.04551

GRTS_ID	Site Name	Status	UTM X	UTM Y
NERI-018	Keeney Creek 10	IN	498155.53324	4209427.46677
NERI-019	Wolf Creek 3	OUT - SAFETY	492849.36286	4212913.63714
NERI-020	Farleys Creek 5	DORMANT - PRIVATE	507207.15041	4181960.15041
NERI-021	Fire Creek 17	IN	497845.00000	4199620.57359
NERI-022	UNT 2 Manns Creek 5	OUT - SAFETY	499605.00000	4205380.18898
NERI-023	UNT 52 New River 3	DORMANT - PRIVATE	507096.98485	4184358.00000
NERI-024	Big Branch 10	IN	508483.07612	4174088.00000
NERI-025	Dowdy Creek 30	OUT - HABITAT	496792.27922	4191838.00000
NERI-026	Little Laurel Creek 6	IN	501845.00000	4190130.89322
NERI-027	UNT Lefthand Fork Meadow Creek 4	OUT - ACCESS	509801.89252	4188734.89252
NERI-028	Pinch Creek 14	OUT - SAFETY	497443.84140	4179308.00000
NERI-029	Wolf Creek 30	OUT - HABITAT	492723.45449	4211259.54551
NERI-030	Marr Branch 7	OUT - SAFETY	491915.00000	4214238.12232
NERI-031	Meadow Creek 83	DORMANT - PRIVATE	512185.00000	4188475.57426
NERI-032	River Branch 6	IN	495820.53743	4186712.46257
NERI-033	UNT 29 New River 8	DORMANT - PRIVATE	495533.31988	4197808.00000
NERI-034	UNT 21 New River 1	IN	497799.54059	4203892.54058
NERI-035	Fern Creek 11	OUT - HABITAT	494726.15324	4212509.15324

GRTS_ID	Site Name	Status	UTM X	UTM Y
NERI-036	UNT Fall Branch 2	IN	505025.00000	4177499.06015
NERI-037	Laurel Creek 47	IN	499568.84792	4190061.84792
NERI-038	Arbuckle Creek 2	IN	492325.76795	4201747.23205
NERI-039	Camp Branch 10	OUT - SAFETY	503372.05321	4188045.05321
NERI-040	Polls Branch 14	OUT - HABITAT	498543.49242	4182288.00000
NERI-041	UNT Laurel Creek 3	IN	498255.00000	4190093.89358
NERI-042	Bucklick Branch 3	IN	504260.64971	4191752.35029
NERI-043	Meadow Creek 39	IN	508985.93410	4187258.93410
NERI-044	Laurel Creek 8	IN	496547.26891	4189305.73109
NERI-045	Craig Branch 20	DORMANT - PRIVATE	495203.78680	4209589.21320
NERI-046	UNT Wolf Creek 3	DORMANT - PRIVATE	491909.80589	4211708.00000
NERI-047	Sewell Branch 2	OUT - SAFETY	506411.56166	4183844.56166
NERI-048	Mill Creek 12	IN	494975.00000	4186254.71920
NERI-049	UNT Buffalo Creek 6	IN	499050.85786	4196292.14214
NERI-050	Ephraim Creek 8	IN	498869.52783	4201563.47217
NERI-051	Butcher Branch 2	OUT - SAFETY	493822.32732	4211555.32732
NERI-052	Fall Branch 7	IN	506017.19755	4178045.80245
NERI-053	Slater Creek 13	IN	497495.00000	4193784.18168

GRTS_ID	Site Name	Status	UTM X	UTM Y
NERI-054	Arbuckle Creek 5	IN	492067.50740	4201848.00000
NERI-055	UNT 52 New River 5	DORMANT - PRIVATE	507275.90097	4184408.90097
NERI-056	Second Fork 16	OUT - ACCESS	499697.81426	4183228.00000
NERI-057	UNT 42 New River 1	DORMANT - PRIVATE	495665.00000	4190185.48737
NERI-058	Richlick Branch 17	IN	504224.64466	4190418.35534
NERI-059	Meadow Creek 58	IN	510536.47234	4187846.52766
NERI-060	Bills Branch 6	OUT - ACCESS	499841.79087	4184921.20913
NERI-061	Coal Run 1	OUT - SAFETY	497694.84734	4206567.84734
NERI-062	Wolf Creek 9	OUT - SAFETY	492965.00000	4212386.38842
NERI-063	Sewell Branch 24	DORMANT - PRIVATE	504808.97761	4182571.97761
NERI-064	Batoff Creek 7	IN	490850.13771	4188358.00000
NERI-065	Meadow Fork 6	IN	491644.14462	4199968.85538
NERI-066	UNT UNT 1 Manns Creek 5	OUT - ACCESS	499259.64466	4207002.64466
NERI-067	Wolf Creek 17	OUT - SAFETY	492599.36822	4211828.00000
NERI-068	Farleys Creek 20	DORMANT - PRIVATE	506137.82538	4181200.82538
NERI-069	Buffalo Creek 4	IN	498070.87088	4196213.87088
NERI-070	Ephraim Creek 25	OUT - SAFETY	500111.74819	4200648.00000
NERI-071	Panther Branch 5	OUT - ACCESS	503842.11617	4185755.11617

GRTS_ID	Site Name	Status	UTM X	UTM Y
NERI-072	Big Branch 9	IN	508578.93398	4174078.00000
NERI-073	Slater Creek 25	OUT - SAFETY	498418.99076	4193268.00000
NERI-074	Manns Creek 24	IN	504615.00000	4206077.14798
NERI-075	Meadow Creek 12	IN	507494.06072	4185517.06072
NERI-076	Kates Branch (Glade) 9	OUT - SAFETY	497515.77904	4180438.77904
NERI-077	Dowdy Creek 2	IN	494770.21861	4192728.00000
NERI-078	Short Creek 10	DORMANT - PRIVATE	497029.66880	4212092.66880
NERI-079	Meadow Creek 75	DORMANT - PRIVATE	511940.44203	4187793.44203
NERI-080	Mill Creek 1	IN	495322.09138	4187145.09138
NERI-081	UNT 29 New River 13	OUT - ACCESS	495983.61425	4197928.00000
NERI-082	Keeney Creek 15	IN	498514.62712	4209158.00000
NERI-083	Wolf Creek 5	OUT - SAFETY	492858.86034	4212734.13966
NERI-084	Kates Branch (New) 18	OUT - ACCESS	506712.57359	4174928.00000
NERI-085	Laurel Creek 61	IN	501567.37037	4190810.37037

Table C.4. Unique GRTS site identifier (ID), site name, and sampling panel for 36 sampling sites at New River Gorge NR. Numbers in *Site Name* denote hectometers (100 m units) upstream from stream mouths (confluence with larger stream) or outpour point crossing park boundary.

GRTS ID	Site Name	Panel
NERI-038	Arbuckle Creek 2	1
NERI-024	Big Branch 10	1
NERI-042	Bucklick Branch 3	1
NERI-005	Buffalo Creek 16	1
NERI-021	Fire Creek 17	1
NERI-018	Keeney Creek 10	1
NERI-037	Laurel Creek 47	1
NERI-044	Laurel Creek 8	1
NERI-026	Little Laurel Creek 6	1
NERI-011	Meadow Creek 17	1
NERI-043	Meadow Creek 39	1
NERI-001	Meadow Fork 1	1
NERI-016	River Branch 4	1
NERI-032	River Branch 6	1
NERI-009	Slater Creek 20	1
NERI-034	UNT 21 New River 1	1
NERI-041	UNT Laurel Creek 3	1
NERI-036	UNT to Fall Branch 2	1
NERI-054	Arbuckle Creek 5	2
NERI-064	Batoff Creek 7	2
NERI-072	Big Branch 9	2
NERI-069	Buffalo Creek 4	2
NERI-077	Dowdy Creek 2	2
NERI-050	Ephraim Creek 8	2

GRTS ID	Site Name	Panel
NERI-052	Fall Branch 7	2
NERI-082	Keeney Creek 15	2
NERI-085	Laurel Creek 61	2
NERI-074	Manns Creek 24	2
NERI-075	Meadow Creek 12	2
NERI-059	Meadow Creek 58	2
NERI-065	Meadow Fork 6	2
NERI-080	Mill Creek 1	2
NERI-048	Mill Creek 12	2
NERI-058	Richlick Branch 17	2
NERI-053	Slater Creek 13	2
NERI-049	UNT to Buffalo Creek 6	2

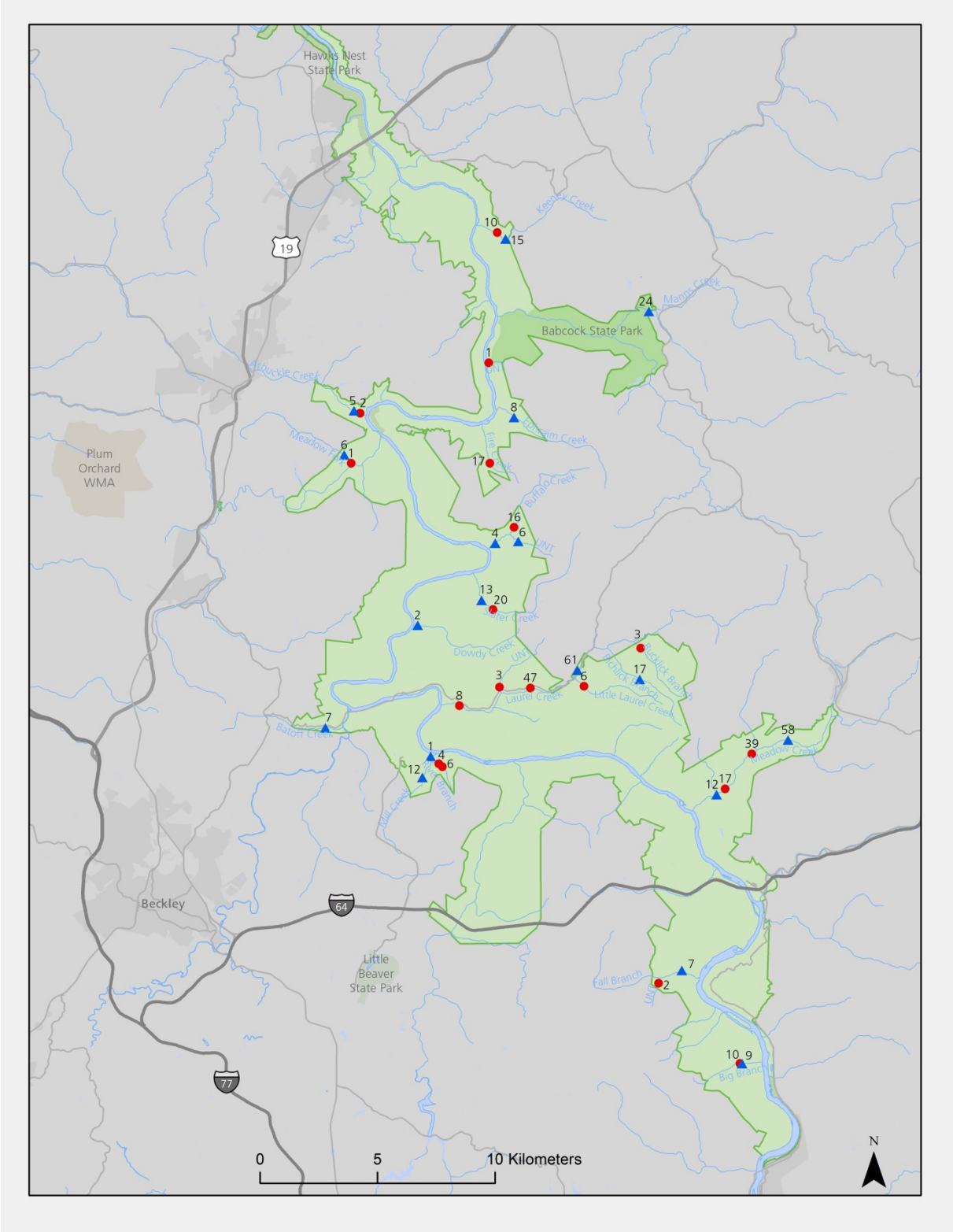

Figure C.4. Benthic macroinvertebrate and Streamside Bird sampling sites sampled in Panel 1 (even years; red circles) and Panel 2 (odd years; blue triangles) at New River Gorge NR. Numbers denote hectometers (100 m unit) upstream from stream mouths (confluence with larger stream) or outpour point crossing park boundary.

Site Inclusion at Small and/or Linear Parks

Sampling sites were not selected at Johnstown Flood NMem because: (1) South Fork Little Conemaugh River (SFLCR) was too large to meet the wadeable stream definition (Appendix A) and (2) a tributary to SFLCR met the wadeable stream criteria but was prohibitively short (< 90 m on NPS land) to sample for any water-based ERMN protocol.

Four sampling sites were selected at Bluestone NSR near the mouths of tributaries to the Bluestone River – all of these sites are sampled in Panel 1 (Figure C.5). Six sites were selected throughout Western Pennsylvania parks for sampling in Panel 2 and were evenly distributed (two sites per park) among Allegheny Portage NHS (Figure C.6), Fort Necessity NB (Figure C.7), and Friendship Hill NHS (Figure C.8)

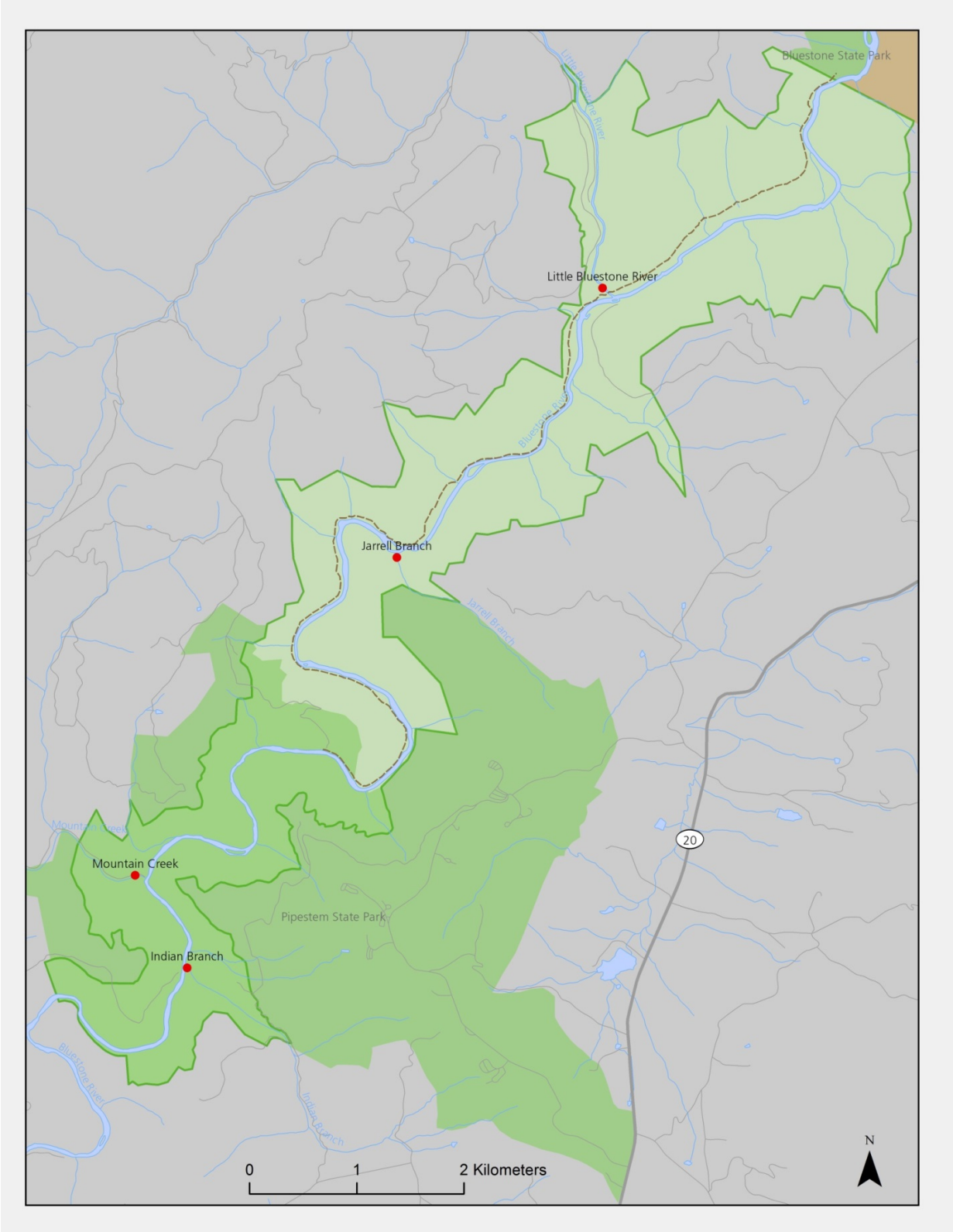

Figure C.5. Benthic macroinvertebrate and Streamside Bird sampling sites sampled in Panel 1(even years) at Bluestone NSR.

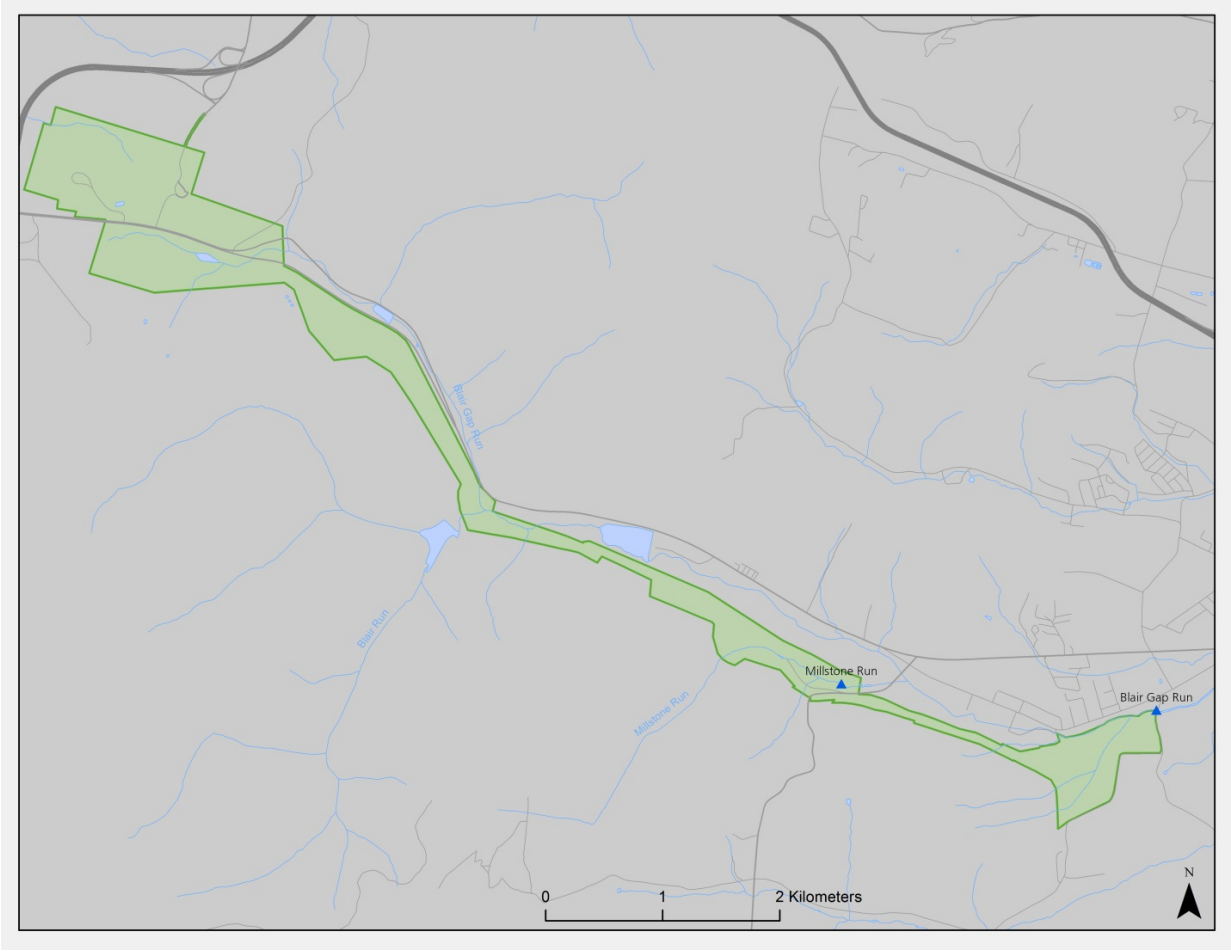

Figure C.6. Benthic macroinvertebrate and Streamside Bird sampling sites sampled in Panel 2 (odd years) at Allegheny Portage Railroad NHS.

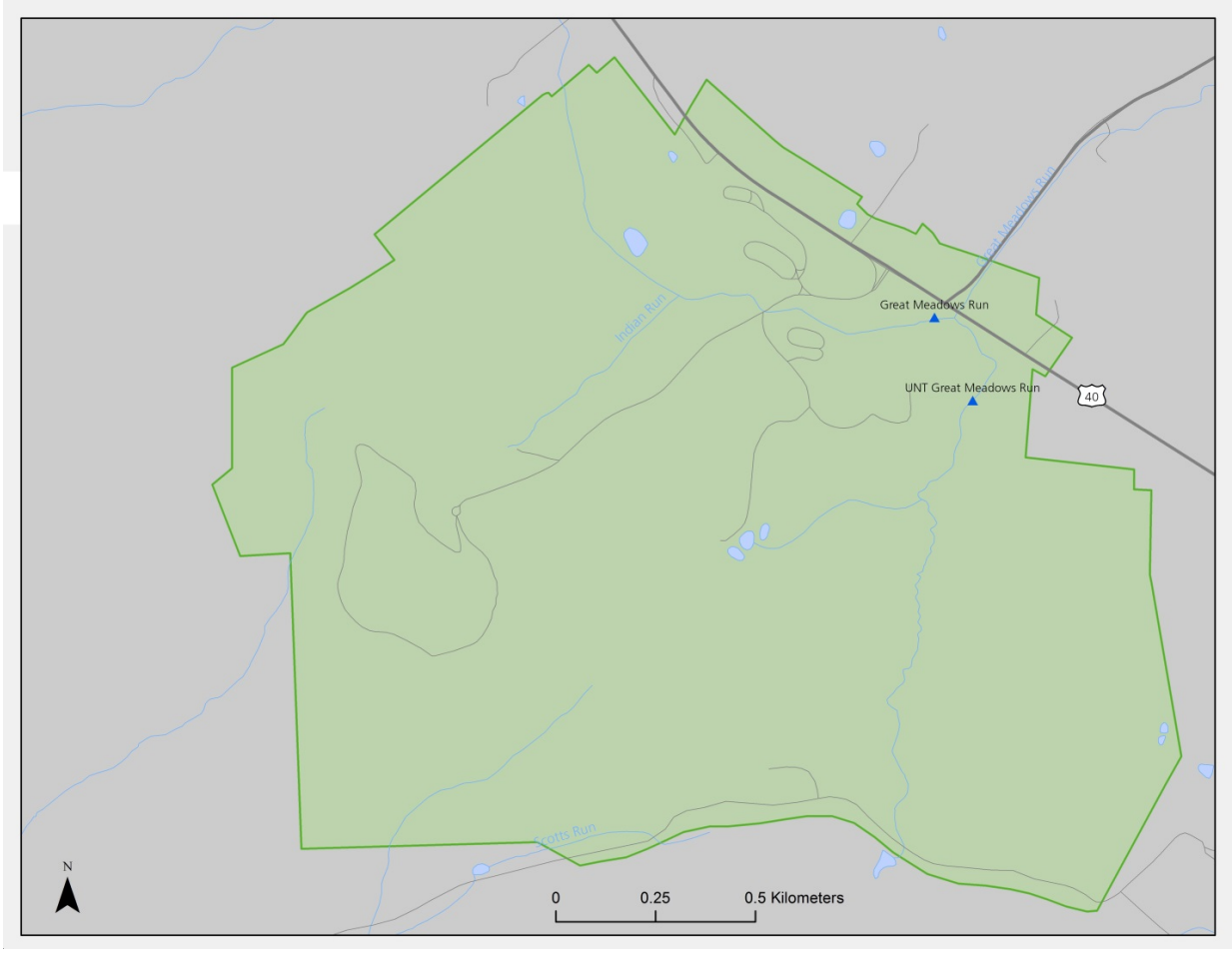

Figure C.7. Benthic macroinvertebrate and Streamside Bird sampling sites sampled in Panel 2 (odd years) at Fort Necessity NB.

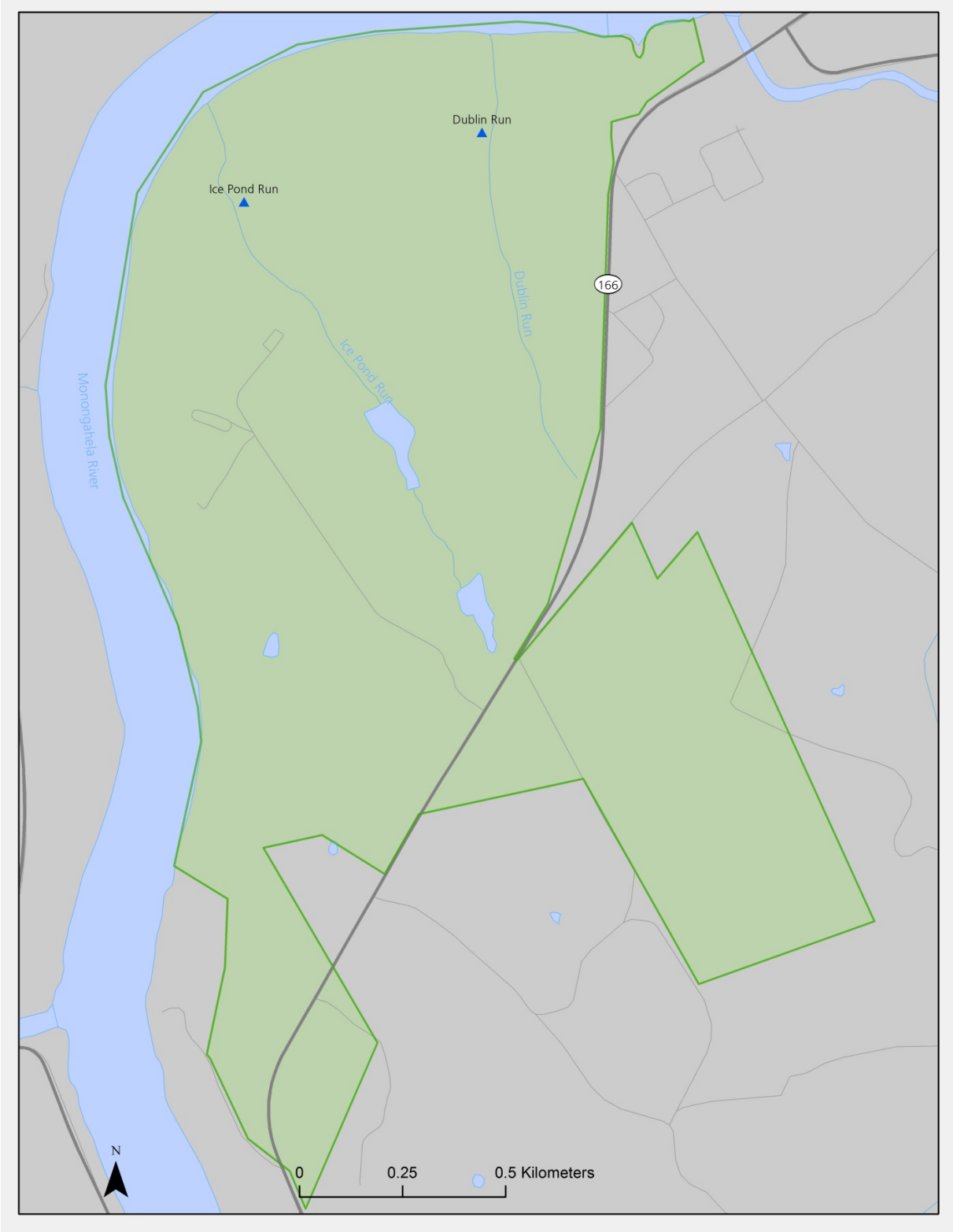

Figure C.8. Benthic macroinvertebrate and Streamside Bird sampling sites sampled in Panel 2 (odd years) at Friendship Hill NHS.

Appendix D. Random Sampling Design Power Analysis

This appendix describes the approach and simulation models used to evaluate trend detection capability of BMI monitoring based on random and non-random selection of ERMN sampling sites.

Trend Detection

An effective monitoring program must be able to detect changes or trends in the condition of park resources within a reasonable time period and with reasonable statistical confidence. Power analysis is a useful tool for evaluating the performance of ecological monitoring programs (e.g., quantifying detectable trends and confidence; Peterman 1990; Fairweather 1991; Hatch 2003). Statistical power is the probability of rejecting the null hypothesis when it is, in fact, false (i.e., detecting a trend when a trend is present). Several factors influence the ability to detect change over time, including sample size (number of sites sampled), the probability of a type-I error (α), the probability of a type-II error (β), trend magnitude, and variance. Type-I error, or ‘‘false change,’’ refers to falsely detecting a trend when no trend is present. Type-II error, or ‘‘missed change,’’ refers to wrongly concluding that no trend is present when, in fact, there is a trend. Statistical power is defined as $1 - \beta$. Common values of α and β range from 0.01 to 0.2 (Gibbs et al. 1998).

One way to evaluate different sampling designs with power analysis is to use estimated variance components within a simulation framework (e.g., Wagner et al. 2007, Perles et al. 2014). The structure of variance, not just total variance, can influence trend detection capabilities (Wagner et al. 2007); consequently, a component of variance approach has been advocated to quantify variability in ecological data when evaluating temporal trends and monitoring ecological systems (Urquhart et al. 1998; Larsen et al. 2001; Kincaid et al. 2004). Under this framework, total variance is partitioned into five components, including:

(a) spatial variation (site-to-site);

(b) coherent temporal variation (year-to-year) affecting all sites in a similar manner;

(c) ephemeral temporal variation (i.e., a site x year interaction) corresponding to independent yearly variation at each site;

(d) trend variation corresponding to site-specific deviations from any long-term average trend; and

(e) residual variation which includes observer error and other unexplained sources of variation.

Not only is power analysis useful for investigating effectiveness among sampling designs and indicators, it can help determine how variance components affect power to detect trends for a given sampling design (Urquhart et al. 1998). This is important because, depending on the structure of the variance, power to detect trends may be increased by altering the sampling design.

Objectives

Preserving the condition of park resources unimpaired in perpetuity is the fundamental management objective of the NPS (NPS 2006). Indeed, this *anti-degradation* or *no decline in condition* management objective captures the essence of the NPS mission and forms the underpinnings of the NPS ecological monitoring program (Fancy et al. 2009). This primary management objective was formalized as a statistical objective of having sufficient power (0.80) to detect a 1% annual decline in resource condition within ten years of sampling ($\alpha = 0.05$) for both the streamside bird monitoring protocol (Marshall et al. 2015) and the BMI monitoring protocol. This objective can refer to a park-wide average condition (based on random site selection) or to individual index sites (non-random site selection).

This appendix describes a variance components approach using pilot data collected from the BMI monitoring program to (1) assess the trend detection capability of this indicator and (2) investigate how several sampling design choices affect the ability to detect temporal trends in BMI communities. These choices included: (a) using a sample-every-year design versus an every-other-year panel design; (b) using a simple panel versus a connected panel design (where some plots are sampled every year); and (c) decreasing the trend magnitude effect size (from 1.0 to 0.5% change in an indicator·year^{-1}).

Statistical simulations were performed during 2014 (using data collected during 2007-2013) to evaluate if the ERMN BMI sampling level is sufficient to meet program objectives. The primary management objective of *no decline in the condition of park resources* was formalized as a statistical objective of having sufficient power (i.e., 80%) to detect a 1% annual decline in resource condition within ten years of sampling. Power analyses were performed separately for randomly selected sites (i.e., large parks such as New River Gorge NR) and non-randomly selected index sites (i.e., comparatively small and/or linear parks such as Fort Necessity NB; Appendix B).

Random Sampling Design – Large Parks

Methods

Sixty-eight sites were selected for sampling streamside birds (Marshall et al. 2016) and BMI in Delaware Water Gap NRA (n = 32 sites) and New River Gorge NR (n = 36 sites) using a random, probability based design (Appendix C). Sampling occurs annually but all sites are divided into two equal sampling panels such that each site is sampled every other year (taking two years to sample all 68 sites). The initial number of sites and sampling panels were based on prior experience, available funding, and logistical constraints that were identified during 2007-2013.

Data were collected in New River Gorge NR and Delaware Water Gap NRA from 2007 – 2013 prior to the 2013 decision to correct several mistakes in the initial sampling design. These *pilot* data were assumed to be appropriate for the simulations described here to reflect the likely performance of the current sampling design because the only difference was the sampling locations (field and lab methods were identical). Only pilot sampling sites that fell within the sampling frame of the current design (Appendix A) were included in these analyses.

The multi-metric index of biotic integrity (MIBI) was developed to describe the integrity of stream benthic macroinvertebrate communities (Herlihy et al. 2008). The MIBI consists of seven metrics that are commonly used for bioassessment and biomonitoring (Klemm et al. 2003) – higher MIBI scores indicate higher biotic integrity. The MIBI was calculated for each park, site, and sampling year from 2008 – 2013 (Tables D.1 and D.2).

Table D.1. Benthic macroinvertebrate multi-metric index of biotic integrity (MIBI) values for pilot data collected at New River Gorge NR. Data were collected at 23 sites during spring (2009-2013) using methods described in this implementation plan. Data were considered *pilot* because they were collected from different sampling locations, not because the field or lab methods differed from the current plan.

Site Name	2009	2010	2011	2012	2013
Laurel Creek	76.1	60.0	80.5	72.9	72.9
Bucklick Branch	57.2	72.5	62.6	61.7	*
Meadow Creek	61.2	*	*	*	*
UNT Meadow Creek	58.0	65.7	58.0	58.1	59.4
Keeney Creek	57.5	56.8	60.2	61.6	57.7
Little Laurel Creek	50.3	63.8	57.0	51.9	60.2
Ephraim Creek	52.6	55.7	59.4	59.0	53.1
Fall Branch	54.0	67.3	55.0	47.0	49.7
Mill Creek	53.0	56.1	56.4	52.3	48.6
Slater Creek	46.2	57.6	54.0	56.3	52.4
Buffalo Creek	44.4	64.4	59.5	46.0	51.7
UNT Laurel Creek (Highland Mtn.)	61.4	55.2	48.0	52.1	48.3
UNT Buffalo Creek	45.0	61.5	55.7	50.7	51.0
Davis Branch	62.0	54.9	43.3	47.7	*
Big Branch	38.8	64.2	56.2	51.0	47.2
Batoff Creek	48.8	51.1	39.5	58.8	39.9
Fire Creek	42.6	46.8	55.6	45.7	37.9
UNT Laurel Backus	36.4	49.1	41.3	43.2	41.1
Camp Branch	43.7	36.3	44.7	39.5	38.0
Richlick Branch	32.5	39.8	46.0	37.7	40.4

Site Name	2009	2010	2011	2012	2013
Dowdy Creek	32.6	39.1	39.3	40.2	41.7
Wolf Creek	30.0	*	*	*	*
Arbuckle Creek	22.8	18.5	26.1	18.4	15.9
Mean	**48.1**	**54.1**	**52.3**	**50.1**	**47.7**

Table D.2. Benthic macroinvertebrate multi-metric index of biotic integrity (MIBI) values for pilot data collected at Delaware Water Gap NRA. Data were collected at 18 sites in the fall (2008-2012) using methods described in this implementation plan. Data were considered *pilot* because they were collected from different sampling locations, not because the field or lab methods differed from the current plan.

Site Name	2008	2009	2010	2011	2012
Raymondskill Creek	58.8	63.6	63.6	75.0	63.2
Adams Creek	65.0	63.6	49.3	71.2	63.2
Toms Creek	45.7	65.0	68.8	60.9	60.9
Mill Creek	55.5	61.8	54.7	55.8	68.0
Vancampens Brook (Millbrook Village)	59.4	63.2	62.9	54.0	55.2
Little Bushkill Creek	60.9	55.4	60.0	*	*
Caledonia Creek	57.1	56.9	60.4	56.7	59.4
Fuller Brook	58.1	*	60.7	54.8	58.3
Spackmans Creek	53.8	58.5	56.5	57.9	56.5
Hornbecks Creek	38.1	60.6	65.1	51.8	63.3
Dunnfield Creek	53.5	55.8	44.7	46.5	58.6
UNT Dingmans Creek	29.0	53.1	41.8	70.8	54.7
Van Campen Creek	42.3	50.8	40.8	64.8	47.7
Slateford Creek	41.0	51.6	49.5	47.5	45.9
Dingmans Creek	27.7	44.5	38.6	48.5	58.3
White Brook	41.8	39.0	40.6	45.9	45.9
UNT Toms Creek	45.8	55.7	24.2	39.8	37.6

Site Name	2008	2009	2010	2011	2012
UNT Delaware River (Sunfish Pond)	42.4	44.2	30.9	38.7	40.4
Mean	**48.6**	**55.5**	**50.7**	**55.3**	**55.1**

A linear mixed model that assumed Gaussian errors was used to estimate variance components in both indices. Estimation was done with the R statistical software (R Development Core Team 2012). Example R code is in Table D.3. The mixed model used for the analyses was:

$$(1) \qquad y_{ijk} = \mu + a_i + year_j(\lambda + t_i) + b_j + c_{ij} + e_{ijk}$$

where y_{ijk} is the $\log_e$-transformed indicator from the kth sample for site i in year j, and μ and **λ** are the intercept and slope fixed effects (i.e., the population-average intercept and trend), respectively. The a_i is a random effect for site i, representing site-to-site (spatial) variability, independent and identically distributed (iid) as $N(\sigma_a^2)$; b_j is a random effect for the jth year (coherent temporal variability), iid as $N(0, \sigma_b^2)$; t_i is a random effect for the trend for site i, iid as $N(0, \sigma_t^2)$; c_{ij} is the site × year interaction (ephemeral temporal variability), iid as $N(0, \sigma_c^2)$; e_{ijk} is the unexplained error (residual error), independent as $N(0, \sigma_e^2)$. The year covariate (*year*) is the jth year minus the mean year (i.e., grand-mean centered). This standardization of year was performed to provide numerical stability. We estimated variance components using restricted maximum likelihood and considered all analyses significant at $P < 0.05$.

Next, we used a simulation approach to examine the statistical power to detect temporal trends in the MIBI. Simulations followed the approach outlined in Perles et al. (2014) but a synopsis is as follows:

- 500 simulations were performed for each indicator and sampling scenario.
- During each simulation, a 30-year time series of an indicator was simulated for the number of potential sampling sites available in each park under the current sampling plan (n = 600 Delaware Water Gap NRA; n = 1,000 New River Gorge NR; see Appendix A) using the estimated spatial and temporal components of variation.
- A population-average temporal trend (**λ**) was then specified (e.g., a decrease of 1% of the indicator·year^{-1}); however, each individual site could deviate from this population-average trend, with the deviation dependent on the magnitude of the trend variance component (t_i).

Simulated data were sampled from the population of sites using one of the designs of interest: (a) sample every year, (b) sample with a two panel design (half the sites sampled each year), or (c) sample with a connected two panel design (half the sites sampled each year with a common panel where three to six sites are sampled every year). The number of sites sampled was 32 for Delaware Water Gap NRA and 36 for New River Gorge NR (i.e., the same number of sites in the current design).

Table D.3. Example R code for linear mixed model used to estimate variance components of the benthic macroinvertebrate multi-metric index of biotic integrity (MIBI) from 18 sites at Delaware Water Gap NRA, 2008-2013. Code provided by Dr. Tyler Wagner (USGS PA Cooperative Fish and Wildlife Research Unit).

```
# rm(list=ls())
library(reshape2)
library(arm)

dat <- read.table('DEWA MIBI_forR.txt', header=T, na.strings='NA')
dim(dat)
head(dat)

# Reshape data from wide to long
dat2 <- reshape(dat, direction="long", varying=list(names(dat)[2:6]), v.names="MIBI",
      idvar=c("Site_Name"), timevar="Year", times=2008:2012)

dim(dat2)
head(dat2)

# Sort by site
dat2 <- dat2[order(dat2$Site_Name) , ]
head(dat2,12)

# Quick plot of MIBI over time
plot(log(MIBI)~Year, data=dat2, col=Site_Name, pch=16)

# standardize year
dat2$yearZ <- (dat2$Year - mean(dat2$Year))/sd(dat2$Year)

# Create year as a categorical variable
dat2$yearC <- as.factor(dat2$Year)
summary(dat2)

#--------- Variance components model
# (1|yearC) = coherent temporal variance
# (0 + yearZ|Site_Name) = allow each site to have own linear trend [trend variance]
# (1|Site_Name) = site variance

m1 <-  lmer(log(MIBI) ~ 1 + yearZ + (1|yearC) + (0 + yearZ|Site_Name) + (1|Site_Name) , data=dat2)
summary(m1)

# coef(m1)$Site_Name[,1]
# coef(m1)$Site_Name[,2]
```

During each simulation (i.e., every year of the sampling process), the model outlined in Equation 1 was used to test the null hypothesis that $\hat{\lambda} = 0$, and the test statistic was calculated and compared to a critical value (with $\alpha = 0.05$). Because the data generated depict a situation in which we know the null hypothesis is false (i.e., a trend of pre-specified magnitude was incorporated into the data), power was estimated as the percentage of trials (i.e., of 500 simulations) that rejected the null hypothesis.

All parameter estimation and simulation was conducted using the Random Effects module of AD Model Builder (ADMB) statistical programming software for fitting nonlinear models (http://admb-project.org; Fournier et al. 2012).

Results

Partitioning of Variance Using Mixed Models

The fixed slope, total variance, and percent of total variance in different variance components were calculated for each park (Table D.4). Note that ephemeral temporal variation could not be estimated (and is likely > 0.0) because repeat samples were not collected within an annual sampling window for either protocol. The slope provides an estimate of the yearly change occurring for the MIBI over the sampling period.

Total variance for the MIBI was minimal compared to other plant and animal populations (Gibbs et al. 1998, Wagner et al. 2007, Perles et al. 2014). Total variance was split between spatial and residual variance in both parks and some coherent temporal variation (i.e., annual variation affecting all sites in a similar manner) was evident in the MIBI at both parks (less so at New River Gorge NR). This component can limit trend detection capability because it cannot be controlled by adding more sites or revisiting sites within a year (Larsen et al. 2001). The high percentage of the total variance contained in residual variance term in all cases does not necessarily refer solely to observer error while collecting field measurement. It refers to all of the remaining unexplained variation, which includes temporal variation and ephemeral temporal variation that could not be estimated separately by the model.

Power to Detect Trends in Resource Condition

Overall, the simulations indicated that the current sampling plan for the MIBI in both parks will likely yield 80% power to detect a 1% annual decline in resource condition within ten years of sampling (Table D.5) and therefore meet program objectives. Not surprisingly, sampling all sites every year yielded higher estimated power compared to the two panel design (sample half the sites each year); however, the expected gain in trend detection capability was minimal and therefore determined to not outweigh the substantial cost savings and logistical efficiency of paneling.

The sample every year, panel, and connected panel designs had similar power estimates for detecting temporal trends (Figures D.1 and D.2). Note that the more conservative trend of 0.5% decline of the MIBI·year^{-1} is depicted for New River Gorge NR compared to the 1.0% trend depicted for Delaware Water Gap NRA. Within the first 5 years, some of the connected panel designs initially exhibited slightly higher power than the simple panel design, but this advantage was not retained in subsequent years. This pattern was similar regardless of the number of sites in the common panel (ranging from 3 to 6). Similarly, Urquhart et al. (1993) and Perles et al. (2014) found that a connected panel design had the greatest benefit to trend detection within the first four to eight years of sampling with negligible benefit thereafter.

Table D.4. Percent of total variance in each of five variance components, total variance and slope estimated by mixed models for the multi-metric index of biotic integrity for stream benthic macroinvertebrates, based on pilot data collected at New River Gorge NR and Delaware Water Gap NRA, 2007-2013.

Park	Percent Spatial	Percent Coherent Temporal	Percent Ephemeral Temporal*	Percent Trend	Percent Residual	Total Variance	Slope	Slope Standard Error
New River Gorge NR	82	3	0	0	15	0.0842	-0.0109	0.0259
Delaware Water Gap NRA	46	7	0	6	41	0.0493	0.0396	0.0331

* Ephemeral temporal variation could not be estimated because there were no repeat samples collected within an annual sampling window.

Table D.5. Power to detect linear temporal trends in the multi-metric index of biotic integrity for stream benthic macroinvertebrates from pilot data collected at New River Gorge NR and Delaware Water Gap NRA, 2007-2013.

Park	Power to detect- 1%·year^{-1} after 10 years Two Panels	Power to detect- 1%·year^{-1} after 10 years Every Year	Power to detect- 0.5%·year^{-1} after 5 years Two Panels	Power to detect- 0.5%·year^{-1} after 5 years Every Year
New River Gorge NR	0.97	0.98	0.64	0.69
Delaware Water Gap NRA	0.78	0.80	0.58	0.61

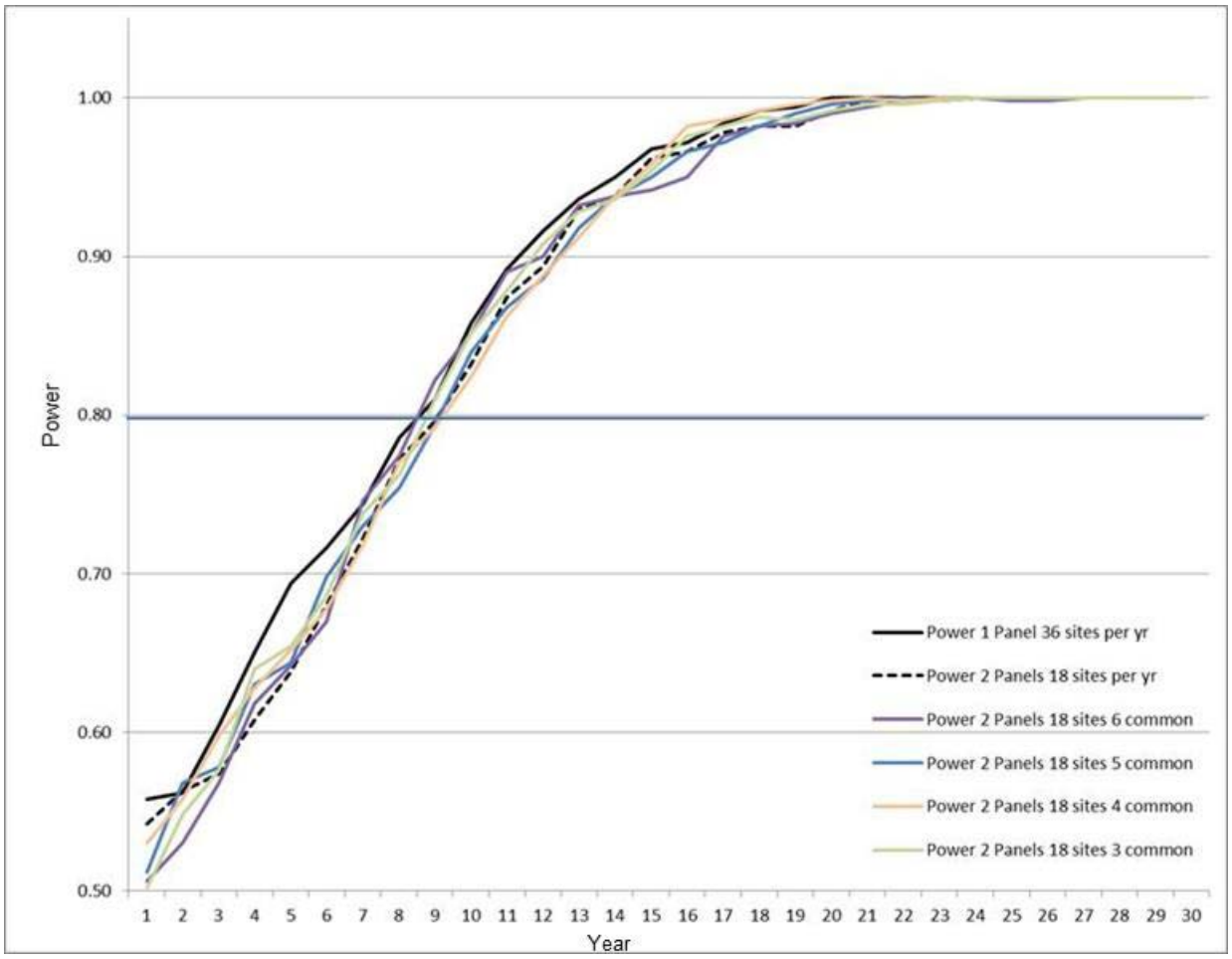

Figure D.1. Power to detect a linear -0.5% annual decline in the benthic macroinvertebrate Multi-metric Index of Biotic Integrity at New River Gorge NR based on pilot data collected 2009 – 2013 using six different sampling designs.

Limitations of this Approach

Several important caveats and assumptions should be considered when interpreting these results:

1. Pilot data used in these analyses came from sampling locations that are not part of the current sampling plan so it must be assumed that these data are representative of what will be encountered at current sampling locations.

2. Ephemeral temporal variation could not be estimated separately because only one sample was collected in each year at each site. It is likely that this component of variation is >0.0; consequently, these power estimates are likely to be a *best case* scenario.

3. Despite the obvious advantages of having multiple years of data from multiple sites collected in the same manner in the same streams (if not exactly the same sites), the time series available was relatively short compared to the anticipated multi-decade duration of the monitoring program; moreover, remnants of two hurricanes (Irene and Sandy) and a tropical storm (Lee) during 2010 and 2011 likely introduced atypical MIBI variability among years.

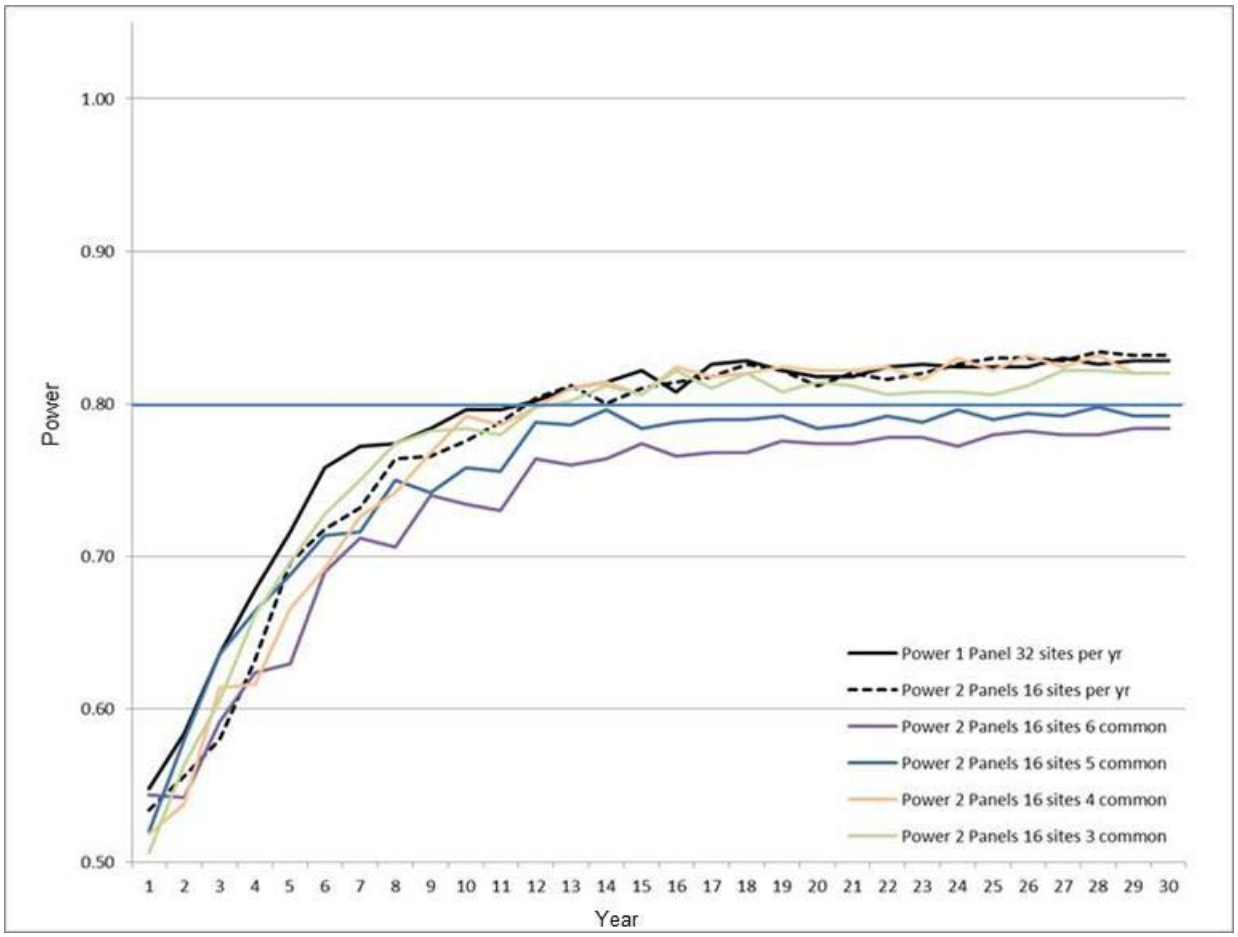

Figure D.2. Power to detect a linear –1.0% annual decline in the benthic macroinvertebrate Multi-metric Index of Biotic Integrity at Delaware Water Gap NRA based on pilot data collected 2008 – 2012 using six different sampling designs.

4. Longer (or different) time series may produce different estimates of variance and its components.

5. All simulations evaluated the power to detect linear trends which aligned with the current management objectives as stated. If, however, the objective were to detect abrupt shifts in system state or other non-linear dynamics, these simulations may not be particularly informative.

Regardless, these results provided meaningful guidance by allowing the evaluation of several sampling designs with regard to temporal trend detection in important resource indicators. Similar analyses will be conducted periodically as new data are collected in an ongoing effort to ensure the sampling plan meets program objectives.

Appendix E: Non-Random Sampling Design Power Analysis

Overview

This appendix describes the approach and simulation models used to evaluate trend detection capability in resource condition at Allegheny Portage Railroad NHS, Bluestone NSR, Fort Necessity NB, and Friendship Hill NHS. Ten non-random *index* sites were established near the downstream end of each wadeable stream in these parks – four sites were selected at Bluestone NSR whereas two sites were selected at each of the other parks (Allegheny Portage Railroad NHS, Fort Necessity NB, and Friendship Hill NHS).

Benthic macroinvertebrate (BMI) communities are sampled at each site, every other year. After identifying and enumerating these samples, a variety of BMI community metrics and indices are calculated to track the ecological integrity of these wadeable stream sites. The multi-metric index of biotic integrity (MIBI; Herlihy et al. 2008) was used for this power analysis because it is widely used and the ERMN will use it frequently in the future.

Trends will be evaluated independently at each site with a sampling objective of having sufficient power (i.e., 80%) to detect a 1% annual decline in resource condition within ten years. This objective, which is in the context of preserving park resource condition (i.e., anti-degradation), was arbitrary and ambitious given the potential for ecological variability among years (e.g., torrential stream flows due to tropical storms). Nonetheless, this power analysis was conducted to evaluate the likelihood of meeting this sampling objective and to investigate the extent to which the following scenarios affect the ability to detect temporal trends at index sites: (a) using a sample-every-year design versus (b) a sample every-other-year design; (c) increasing the trend magnitude effect size (from -1.0 to -3.0% change in resource condition·year-1); and (d) removing the proportion of variance associated with existing linear trends in the pilot data.

Methods

Pilot data used for this analysis were collected annually between 2008 and 2013 at eight of 10 sites. The initial (pilot) sampling design was changed during 2013 to correct several errors and to implement the sample every other year design (based on power analysis results). These pilot data were assumed to be reasonable for the simulations described here because the only substantive differences were the: 1) sampling *location* within each stream (field and lab methods were identical) and 2) *sampling season* for ALPO (pilot data were collected in the fall whereas the current sampling plan calls for spring sampling). Moreover, the pilot data were collected annually, which should allow a meaningful evaluation of sampling *less* frequently.

Program MONITOR (Gibbs and Ene 2010) was used to estimate power to detect trends in the MIBI under the four scenarios described above for each site (with the exception of Great Meadows Run at Fort Necessity NB because it was sampled only twice). Each simulation is based on the 2007-2013 average MIBI score and standard deviation (SD) for each site unless otherwise stated.

All simulations were designed to detect a *decreasing* trend based on the anti-degradation context of this monitoring program; however, similar results were expected for an *increasing* trend. The first

scenario (sample every year) was parameterized in the *Survey design* section of MONITOR to sample one site annually for 30 years. The *Design type* used was Simple Regression and *Measure type* was set to Normal. The *Variance type* was set to Total. In the *Trends* section, *Deterministic/Regression-type* was chosen to estimate power values for a -1% trend. The *Variance to mean relationship* was set to *Constant SD*. In the *Simulation* section, the model was set to run 1,000 iterations using a one-tailed distribution, with no rounding of values or truncation and the significance value (alpha-level) was set to 0.05. The simulation model was run for each year, stepping through a 30-year period, and each model out (power estimate) was transferred to tabular form.

To simulate the *sample every other year* scenario, the *Survey design* section of MONITOR was changed to sample one site every other year for 30 years; additionally, the trend magnitude was changed from -1% to -3% per year in the *Trends* section of MONITOR. All other parameters remained unchanged.

The final scenario was based on the observation that a substantial portion of total variance in MIBI scores at some sites was due to a linear trend in the pilot data (i.e., a linear increase or decrease in MIBI scores during the four to five years of sampling). It did not seem appropriate or informative to evaluate the ability to detect a *decline* in resource condition (i.e., MIBI scores) when the pilot data were, in reality, suggesting a significant *increase* in condition. The linear regression coefficient of determination (R^2) which estimates the percentage of the total variance in the MIBI that can be explained by a linear relationship between MIBI and time (sampling year) was used to partition out this source of variation. This scenario was parameterized in the same way as the sample every other year with a -1% trend scenario; however, the total variance was reduced by the percentage indicated by the R^2 value, leaving only the residual variance (expressed as the SD for input to program MONITOR).

Results

The average MIBI score ranged among sites from 14.2 (Ice Pond Run) to 63.2 (Millstone Run; Table E.1; Figures E.1 – E.4). Ice Pond Run consistently had a low MIBI score which resulted in the lowest SD; substantially lower than all other sites. Among the remaining sites, SD ranged from approximately 3.5 to 8.5, which greatly influenced trend detection capability.

Five of seven sites (excluding Great Meadows Run because it was only sampled twice) showed positive slopes, two of which were significantly different from zero (Table E.1 and Figures E.1 – E.4). The mean MIBI scores at Blair Gap Run and Little Bluestone River showed significant positive linear trend (8% and 10%·year^{-1}, respectively) over the five years of sampling. The mean MIBI score at Dublin Run declined at a 3%·year^{-1} rate and Ice Pond Run showed no change (slope = 0). These linear trends contributed to a substantial proportion of the total variance in some cases – for example, 93% of the variance associated with Little Bluestone River MIBI scores is explained by the linear trend.

Table E.1. Multi-metric index of biotic integrity (MIBI) scores and linear regression statistics for stream benthic macroinvertebrates from eight sites at four National Park Service units sampled between 2008 and 2013.

Park	Site Name	2008	2009	2010	2011	2012	2013	Average	SD[1]	Slope[2]	R^{2*}	*p-value*	SD Residual
ALPO	Millstone Run	53.7	64.9	65.2	61	71.3	.	63.2	6.5	3.1	0.57	0.14	2.8
ALPO	Blair Gap Run	43.7	49.4	50.9	64.0	58.5	.	53.3	8.0	4.4	0.77	0.05	1.9
BLUE	Mountain Creek	.	38.8	60.0	52.3	48.5	54.2	50.8	7.9	1.9	0.15	0.52	6.7
BLUE	Little Bluestone River	.	43.2	49.2	58.2	61.7	63.2	55.1	8.6	5.3	0.93	0.01	0.6
FONE	Great Meadows Run	.	41.2	.	.	.	19.8	30.5	15.1	-5.4	1.00	.	0.0
FONE	UNT[3] Great Meadows Run	.	.	56.6	56.3	52.0	62.3	56.8	4.2	1.3	0.15	0.61	3.6
FRHI	Dublin Run	.	37.9	44.0	37.7	35.0	36.5	38.2	3.4	-1.2	0.29	0.34	2.4
FRHI	Ice Pond Run	.	14.3	14.3	13.8	.	14.3	14.2	0.3	0.0	0.01	0.74	0.2

[1] SD = standard deviation

[2] slope = regression slope

[*] R^2 = regression coefficient of determination,

[3] UNT = Unnamed tributary

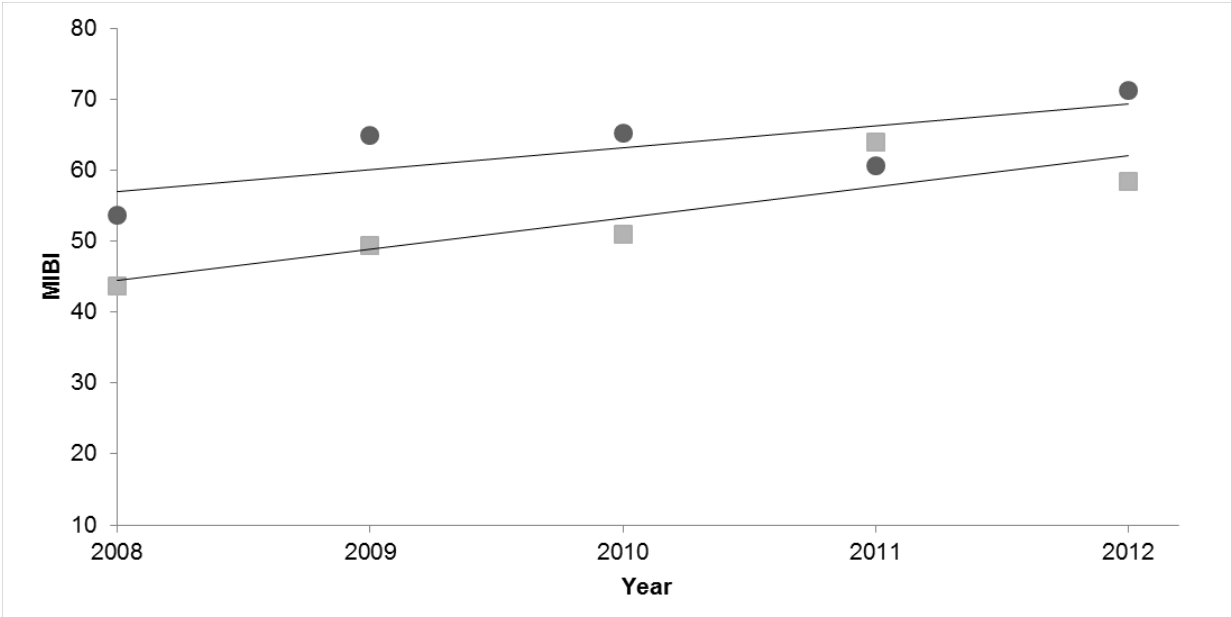

Figure E.1. Simple linear regression of Multi-metric Index of Biotic Integrity (MIBI) scores (from 2008-2013) at two Allegheny Portage Railroad NHS sites (circles = Millstone Run; squares = Blair Gap Run).

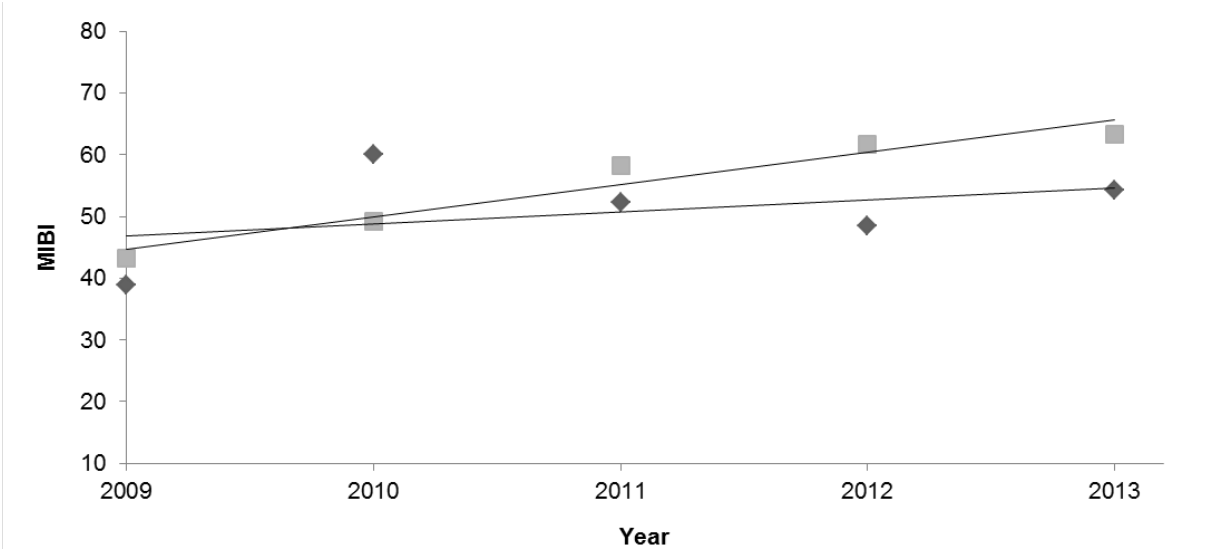

Figure E.2. Simple linear regression of Multi-metric Index of Biotic Integrity (MIBI) scores (from 2009-2013) at two Bluestone NSR sites (diamonds = Mountain Creek; squares = Little Bluestone River).

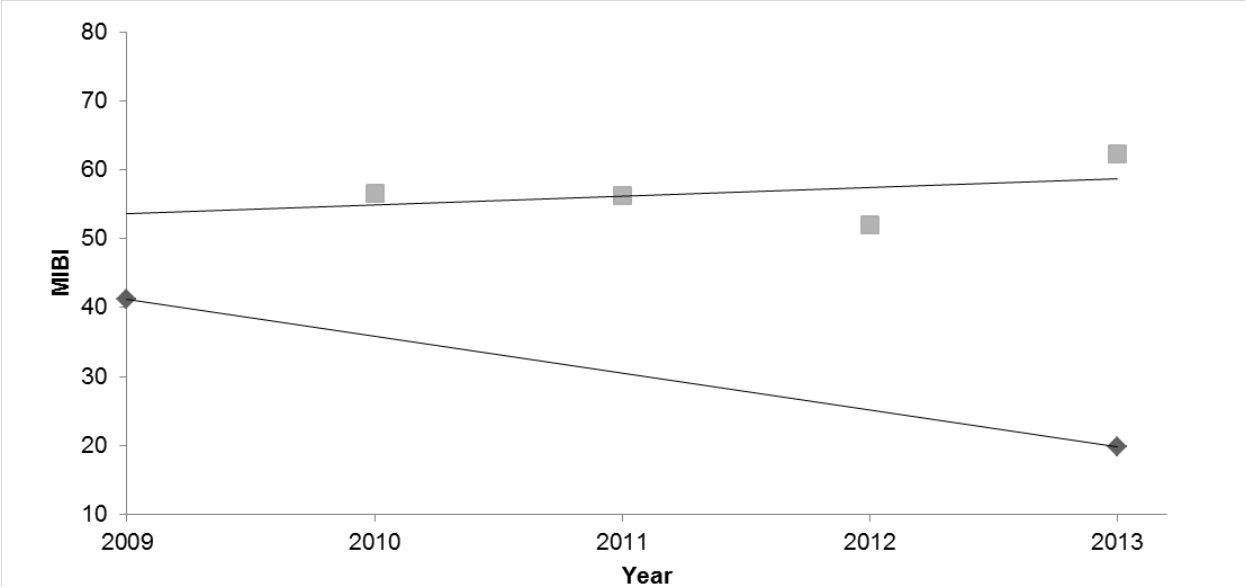

Figure E.3. Simple linear regression of Multi-metric Index of Biotic Integrity (MIBI) scores (from 2009-2013) at two Fort Necessity NB sites (diamonds = Great Meadow Run; squares = Unnamed tributary to Great Meadows Run).

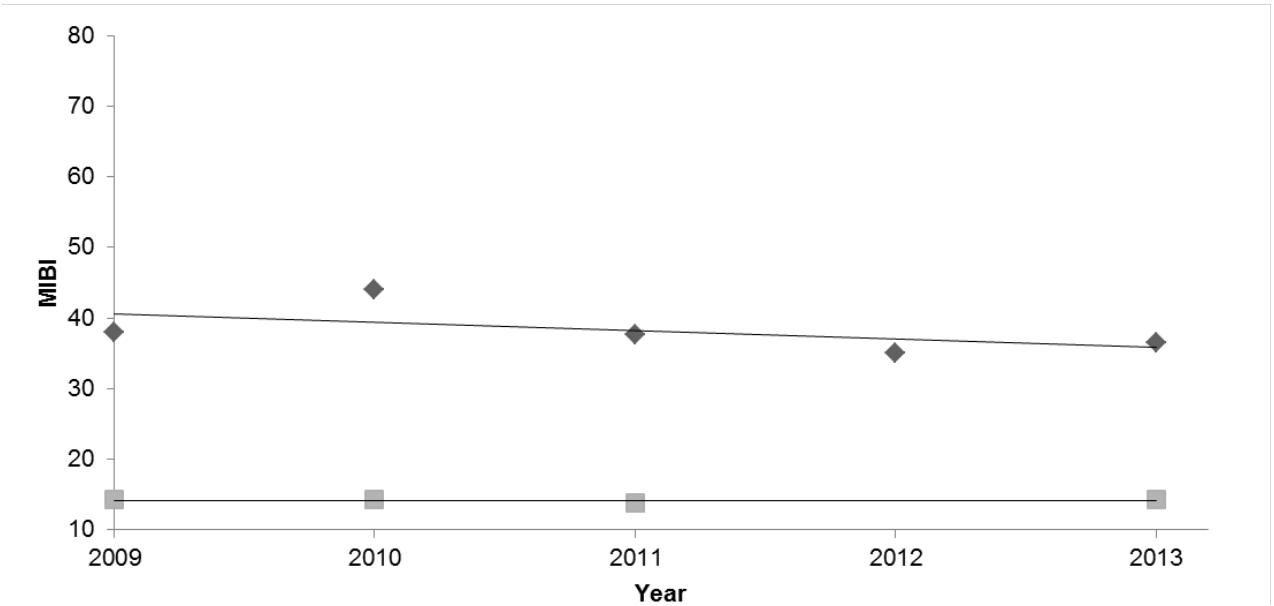

Figure E.4. Simple linear regression of Multi-metric Index of Biotic Integrity (MIBI) scores (from 2009-2013) at two Friendship Hill NHS sites (diamonds = Dublin Run; squares = Ice Pond Run).

Power to Detect Trends in Resource Condition

Based on this analysis, the two-panel sampling design used for BMI monitoring at ERMN index sites will have sufficient power (i.e., 80%) to detect a 1% annual decline in resource condition within ten years of sampling at only one site (Ice Pond Run; Figures E.5-E.8). Detecting a 1% annual decline (with 80% power) would only be statistically significant after: (1) 20 years of sampling at UNT to Great Meadows Run and (2) at least 30 years at the remaining sites. These results were not surprising

because the BMI community (and MIBI statistics used as model inputs) in Ice Pond Run was depauperate and very similar among years – the same five aquatic insect taxa were found each year in Ice Pond Run whereas other index sites were much more variable among years and yielded as many as 39 taxa.

As expected, the simulations suggested that power would increase at all sites with increased sampling (i.e., every year); however, the ERMN made the decision that the modest increase in power does not justify the doubled (and potentially unsustainable) sampling effort. It seems that shifts will have to be more dramatic than a relatively subtle 1% to be statistically significant. This is illustrated by the fact that all sites had sufficient power (80%) to detect a 3% annual decline in 10-18 years; moreover, significant trends were *already* detected in only five years of monitoring for two sites with large MIBI increases (Blair Gap Run and Little Bluestone River) in five years of sampling.

Intuitively, it was the same two sites (Blair Gap Run and Little Bluestone River) for which removing the portion of total variance due to these linear *increases* most dramatically improved the ability to detect *declining* trends through simulation. Blair Gap Run, Little Bluestone River, and Millstone Run all met the original sampling objective based on the simulations where the SD was reduced proportional to the R^2 value. The site at Mountain Creek exhibited low power under all four scenarios indicating that more time will be necessary to establish a *baseline* – it may be difficult to ever confidently detect a 1% change (positive or negative) within 10 year periods at sites that are as interannually variable.

While it is somewhat disconcerting that few sites could meet the primary sampling objective as stated, these simulations demonstrated the fact that large changes can (and have been) detected in short time periods. If the program lasts beyond 20 years, it appears that very subtle changes in stream condition will be detectable with high power.

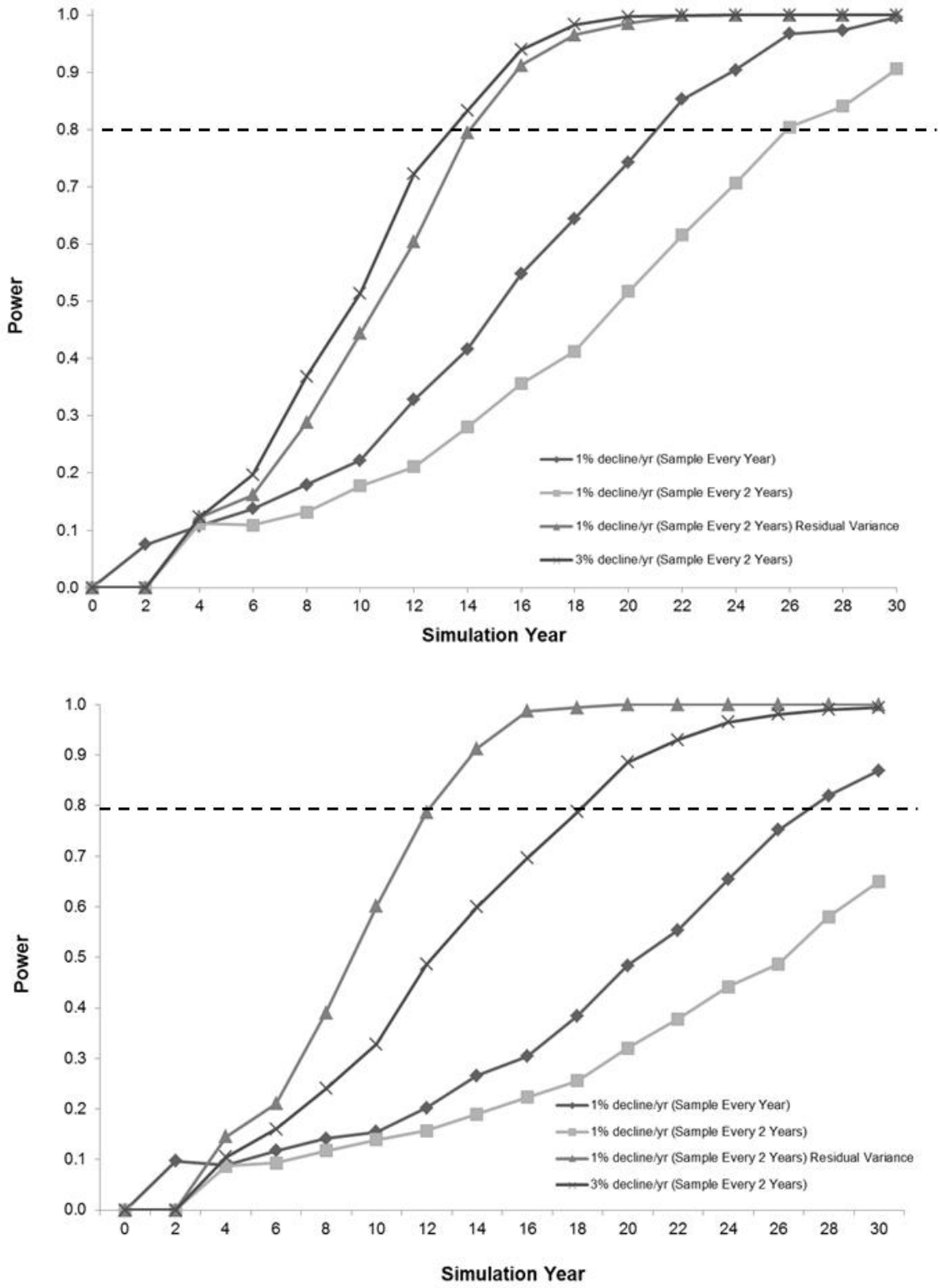

Figure E.5. Power to detect linear declines in resource condition at two sampling sites at Allegheny Portage Railroad NHS [Millstone Run (top) and Blair Gap Run (bottom)] based on 2008-2012 pilot data and simulated under four scenarios. Horizontal line at 80% power added for reference.

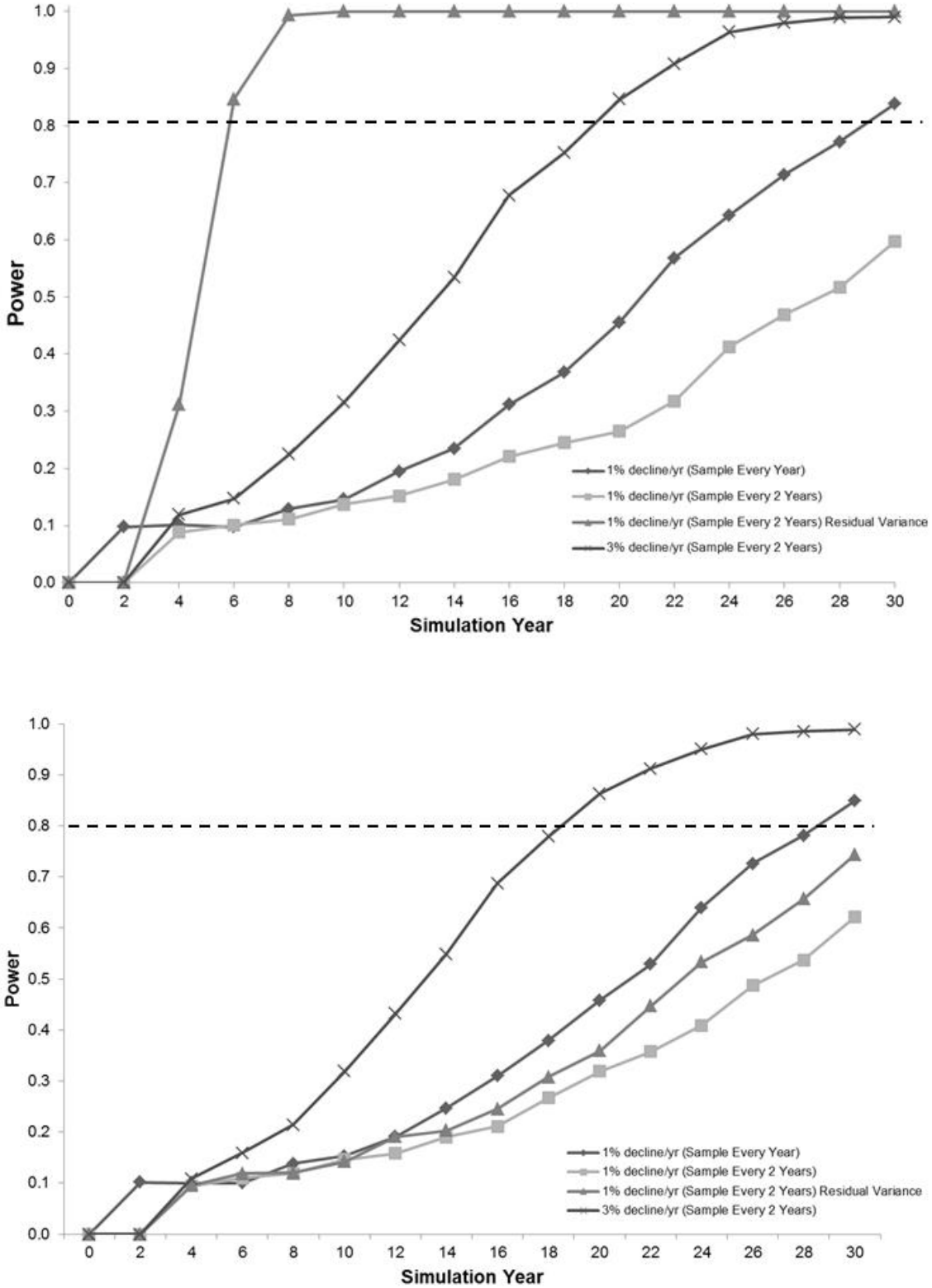

Figure E.6. Power to detect linear declines in resource condition at two sampling sites at Bluestone NSR [Little Bluestone River (top) and Mountain Creek (bottom)] based on 2009-2013 pilot data and simulated under four scenarios. Horizontal line at 80% power added for reference.

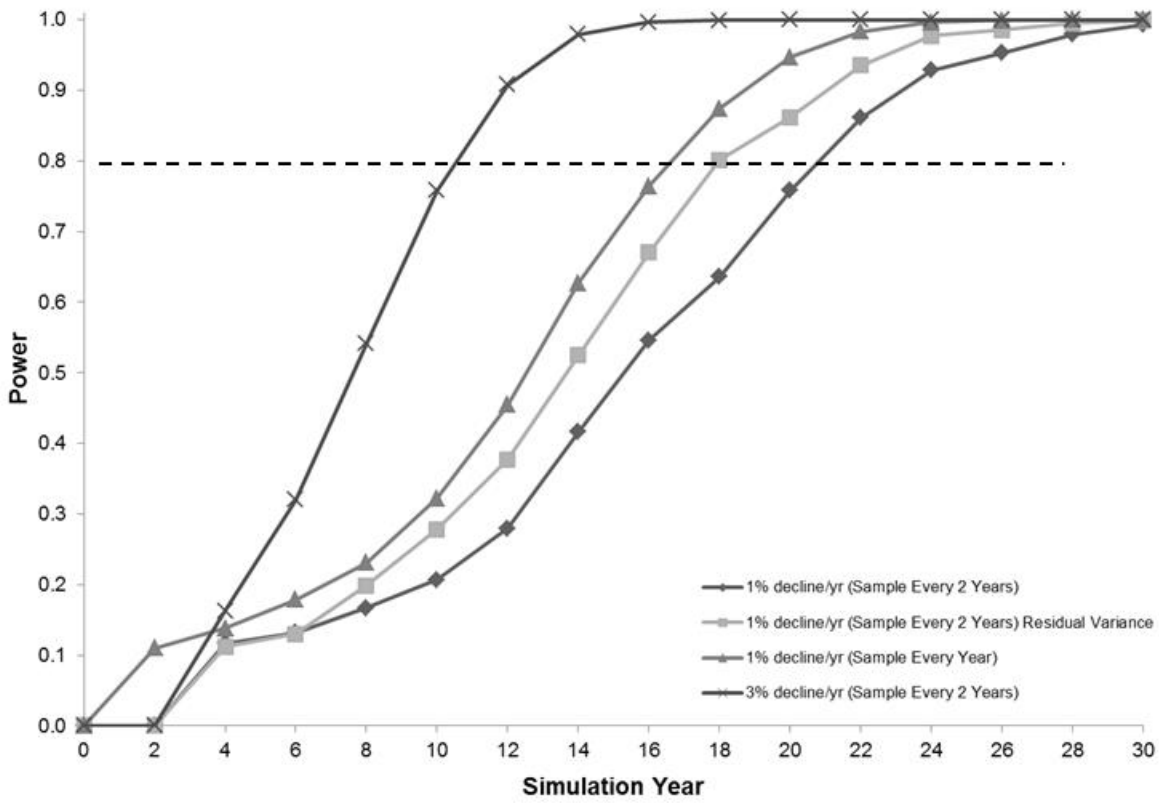

Figure E.7. Power to detect linear declines in resource condition at the Unnamed Tributary to Great Meadows Run sampling site in Fort Necessity NB based on 2009-2013 pilot data and simulated under four scenarios. Horizontal line at 80% power added for reference.

Limitations of this Approach

Several important caveats and assumptions should be considered when interpreting these results:

1. Pilot data used in these analyses came from sampling locations that are not part of the current sampling plan (despite being from the same streams) so it must be assumed that these data are representative of what will be encountered at the current sampling locations.
2. Despite the obvious advantages of having multiple years of data from multiple sites collected in the same manner in the same streams (if not exactly the same sites), the time series available was relatively short compared to the intended multi-decade duration of the monitoring program. Longer (or different) time series may produce different mean estimates and variance, and therefore, power estimates.
3. All simulations evaluated the power to detect linear trends that aligned with the stated objective (i.e., a 1% change within 10 years). If, however, the objective were to detect abrupt shifts in system state or other non-linear dynamics, these simulations may not be as informative. Regardless, these results provided meaningful guidance by evaluating several sampling designs with regard to temporal trend detection in an important resource indicator.

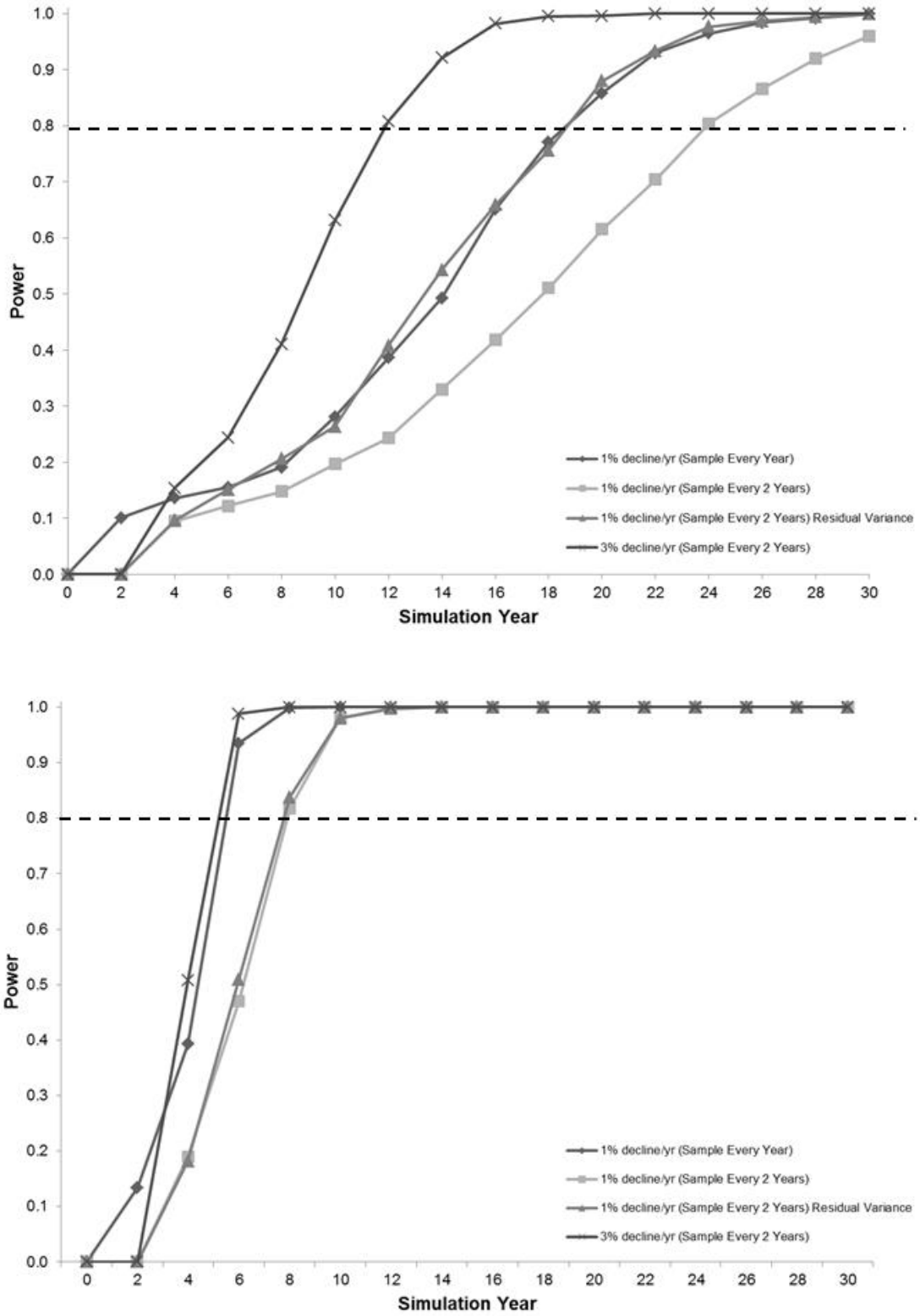

Figure E.8. Power to detect linear declines in resource condition at two sampling sites at Friendship Hill NHS [Dublin Run (top) and Ice Pond Run (bottom)] based on 2009-2013 pilot data and simulated under four scenarios. Horizontal line at 80% power added for reference.

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