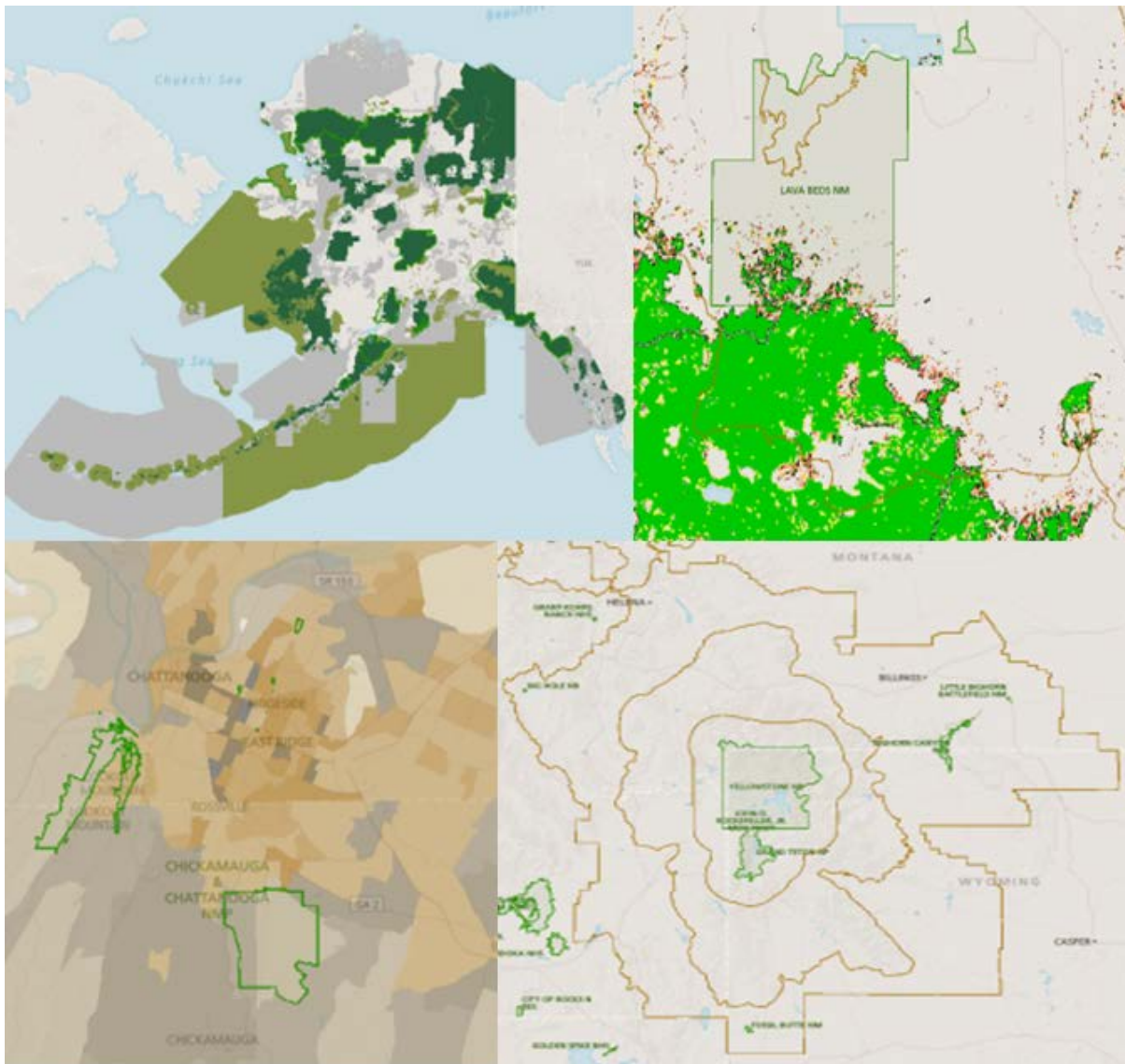




# Protocol for Monitoring Environmental Setting for National Park Service Units

## *Landscape Dynamics, Climate, and Hydrology*

Natural Resource Report NPS/IMD/NRR—2018/1844



**ON THE COVER**

Landscape dynamics visualization examples

Image courtesy of NPS Inventory and Monitoring Division

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# **Protocol for Monitoring Environmental Setting for National Park Service Units**

## ***Landscape Dynamics, Climate, and Hydrology***

Natural Resource Report NPS/IMD/NRR—2018/1844

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Fort Collins, Colorado

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## Executive Summary

Understanding the changing environmental setting of our parks—including vital signs such as land cover, human ecosystem drivers, climate, hydrology, and conservation context—was identified as mission critical by more than 200 of the original 270 I&M natural resource park units. All 32 Inventory & Monitoring Networks identified landscape dynamics and climate as priority vital signs in their long-term monitoring plans, with 31 networks committed to developing one or more monitoring protocols specific to their networks. These vital signs reflected the importance of changing landscape dynamics as drivers of park resource conditions, processes, or the conservation context in which park resources and processes are managed. For example, linkages between landscape dynamics and water resources (water quality, hydrology, and geomorphology), changing species distributions (aquatic and terrestrial, with a focus on exotics), and changes in landscape pattern (habitat fragmentation) and type (land cover, use, and conversion) were the most-cited issues of concern among networks.

The goal of this protocol is to meet two primary needs. The first is to provide information about parks and surrounding areas that is relevant and useful to management and planning.

Results are reported at multiple scales of management relevance—from watersheds, to parks to many parks. The protocol also provides consistent landscape-level information to a variety of National Park Service (NPS) programs, such as Natural Resource Condition Assessments, State of the Park Reports, as well as planned Wilderness Character Assessments, and Resource Stewardship Strategies. The second is to provide summary and raw data (and tools for accessing those data) to NPS staff who need to use environmental settings data to understand the context for status and trends observed in other vital signs being monitored in parks.

For each NPS unit, we have identified a core suite of Areas of Analysis (AOAs) within and surrounding parks, as well as climate monitoring stations, and stream gaging stations. The AOAs used are based on official park or management-area boundaries (and buffers around them), as well as watersheds. For each AOA, or monitoring station, a series of metrics related to land use & cover, climate, and hydrology is generated (a complete list of metrics and descriptions is provided in Appendix C):

- 791 landscape dynamics metrics, where spatial data are used to calculate summary statistics, such as the total or percent area of a parameter.
- 26 climate metrics for stations within, near, or relevant to park units.
- 211 hydrologic measures for stream gaging stations within, near, or in systems that drain into parks.

Implementation of this protocol is designed to evolve over time, with a continual evaluation and addition of new AOAs, new sources of relevant data, and new metrics as resource management needs, source data, and methods for using those data change over time.

## Acknowledgments

This protocol was made possible thanks to the combined effort of many who contributed to the development of the original NPScape effort, and all that went into the subsequent evolution into this protocol. Although the authors are responsible for the text, the underlying data, analyses, and maps used as illustrations and examples reflect the contributions of many others. Pete Budde, Mike Story, Kelsey Greiner, and Thomas Flowe applied their considerable expertise and skills to the project, assisting with data evaluation, acquisition, documentation, and processing. The entire team participated in identifying and developing landscape dynamics metrics, as well as the many other products that include geospatial data, metadata, Standard Operating Procedures, Python scripts and toolboxes, and analyses that have formed the basis for resource briefs and other reports.

We also acknowledge the extensive advice, data, and support we have received from external collaborators. In particular, Kurt Riitters (US Forest Service) generously contributed data on land cover pattern, and his willingness to share processing tips and his deep understanding of landscape ecology has greatly facilitated our efforts. Pat Comer (NatureServe) shared pre-release maps and nationwide data on ecosystem types, and his early advice contributed to the development of our conceptual model for the NPScape legacy project. Collin Homer (USGS EROS Data Center) provided his insight into the process of developing and using land cover data from the National Land Cover Database and the Commission for Environmental Cooperation North American Land Change Monitoring System. Nate Herold (NOAA Coastal Services Center) provided his insight into the process of developing and using the Coastal Change Analysis Program land cover data. Lisa Johnson (National Gap Analysis Program, University of Idaho) worked with us to incorporate corrections to NPS attribute data identified as part of our I&M review of the protected areas database, PAD-US.

Aaron Weed (NPS Northeast Temperate Network) helped with some of the early needs assessments and planning to ensure that the national protocol is designed to meet the many needs of the NPS I&M Networks and their parks.

For the climate component of the protocol, Brent Frakes provided years of leadership, in helping to develop strategies for efficiently making climate station and gridded climate data available to networks and parks, providing significant contributions to what ultimately resulted in the first iteration of the Climate Toolkit described in this protocol. Keith Eggleston (Northeast Regional Climate Center), and Ned Gardiner (NOAA Climate Program Office), and many others provided guidance, input, and review comments to help improve the tools that are now available.

Much of the hydrologic component of this protocol is based upon work by Brian Gregory (NPS Southeast Coast Network) to analyze and deliver meaningful information about stream flows to parks in the Southeast.

Last but not least, we thank the reviewers who helped us improve earlier versions of this report, listed in alphabetical order: Jeff Albright (NPS Water Resources Division), Jocelyn Aycrigg (National Gap Analysis Program, University of Idaho), Rob Daley (NPS Greater Yellowstone Network), Lisa Johnson (National Gap Analysis Program, University of Idaho), Karen Folger (Sequoia and Kings

Canyon National Parks), Lorin Groshong (NPS I&M Klamath Network), Andy Hansen (Montana State University), Mark Huff (NPS I&M North Coast and Cascades Network), Kevin James (NPS I&M Heartland Network), John Kupfer (University of South Carolina), Ben McMillan (NPS I&M Pacific Islands Network), Sean Mohren (NPS I&M Klamath Network), Laura O’Gan (NPS I&M Rocky Mountain Network), and Kurt Riitters (US Forest Service). Josh Lewis provided the last set of eyes on the standard operating procedures before their publication.

# List of Terms

## Acronyms

|         |                                                 |
|---------|-------------------------------------------------|
| ACIS:   | Applied Climate Information System              |
| AOA:    | Area of Analysis                                |
| C-CAP:  | Coastal Change Analysis Program                 |
| CONUS:  | Continental United States                       |
| EPA:    | Environmental Protection Agency                 |
| FDSS:   | Fundamental Daily Streamflow Statistics         |
| HIT:    | Hydrologic Indicator Tools                      |
| HUC:    | Hydrologic Unit Code                            |
| IHA:    | Indicators of Hydrologic Alteration             |
| NADM:   | North American Drought Monitor                  |
| NARA:   | National Archives and Records Administration    |
| NHD:    | National Hydrologic Dataset                     |
| NLCD:   | National Land Cover Database                    |
| NOAA:   | National Oceanic and Atmospheric Administration |
| NWIS:   | National Water Information System (USGS)        |
| PAD-US: | Protected Areas Database of the United States   |
| PDSI:   | Palmer Drought Severity Index                   |
| SOP:    | Standard Operating Procedure                    |
| SPI:    | Standardized Precipitation Index                |
| TNC:    | The Nature Conservancy                          |
| USGS:   | U.S. Geological Survey                          |

## National Park Service Programs & Divisions Referenced in this Protocol

|       |                                                       |
|-------|-------------------------------------------------------|
| NRSS: | Natural Resources Stewardship and Science Directorate |
| IMD:  | Inventory & Monitoring Division                       |

## National Park Service Inventory & Monitoring Networks Referenced in this Protocol

|       |                                    |
|-------|------------------------------------|
| CUPN: | Cumberland Piedmont Network        |
| ERMN: | Eastern Rivers & Mountains Network |
| GLKN: | Great Lakes Network                |
| GRYN: | Greater Yellowstone Network        |
| HTLN: | Heartland Network                  |
| KLMN: | Klamath Network                    |
| NCCN: | North Coast and Cascades Network   |
| NETN: | Northeast Temperate Network        |
| ROMN: | Rocky Mountain Network             |
| SECN: | Southeast Coast Network            |

## **National Park Service Units Referenced in this Protocol**

|       |                                                   |
|-------|---------------------------------------------------|
| ALPO: | Allegheny Portage Railroad National Historic Site |
| APIS: | Apostle Islands National Lakeshore                |
| APPA: | Appalachian National Scenic Trail                 |
| ARPO: | Arkansas Post National Memorial                   |
| BLUE: | Bluestone National Scenic River                   |
| BUFF: | Buffalo National River                            |
| CHAT: | Chattahoochee National Recreation Area            |
| CONG: | Congaree National Park                            |
| CRLA: | Crater Lake National Park                         |
| CUVA: | Cuyahoga Valley National Park                     |
| DEWA: | Delaware Water Gap National Recreation Area       |
| EBLA: | Ebey's Landing National Historical Reserve        |
| EFMO: | Effigy Mounds National Monument                   |
| FLFO: | Florissant Fossil Beds National Monument          |
| FONE: | Fort Necessity National Battlefield               |
| FRHI: | Friendship Hill NHS                               |
| GLAC: | Glacier National Park                             |
| GRPO: | Grand Portage National Monument                   |
| GRSA: | Great Sand Dunes National Park & Preserve         |
| GRTE: | Grand Teton National Park                         |
| GWCA: | George Washington Carver National Monument        |
| HALE: | Haleakalā National Park                           |
| HEHO: | Herbert Hoover National Historic Site             |
| HOBE: | Horseshoe Bend National Military Park             |
| HOCU: | Hopewell Culture National Historic Park           |
| HOME: | Homestead National Monument                       |
| HOSP: | Hot Springs National Park                         |
| INDU: | Indiana Dunes National Lakeshore                  |
| ISRO: | Isle Royale National Park                         |
| JODR: | John D. Rockefeller, Jr. Memorial Parkway         |
| KAWW: | Katahdin Woods and Waters National Monument       |
| KEMO: | Kennesaw Mountain National Battlefield Park       |
| LABE: | Lava Beds National Monument                       |
| LAVO: | Lassen Volcanic National Park                     |
| LEWI: | Lewis and Clark National Historical Park          |
| LIBO: | Lincoln Boyhood National Mem.                     |
| MACA: | Mammoth Cave National Park                        |
| MISS: | Mississippi National River and Recreation Area    |
| MOCR: | Moore's Creek National Battlefield                |
| MORA: | Mount Rainier National Park                       |

|       |                                           |
|-------|-------------------------------------------|
| NERI: | New River Gorge National River            |
| NOCA: | North Cascades National Park              |
| OCMU: | Ocmulgee National Monument                |
| OLYM: | Olympic National Park                     |
| ORCA: | Oregon Caves National Monument & Preserve |
| OZAR: | Ozark National Scenic Riverways           |
| PERI: | Pea Ridge National Military Park          |
| PIPE: | Pipestone National Monument               |
| PIRO: | Pictured Rocks National Lakeshore         |
| REDW: | Redwood National and State Parks          |
| ROMO: | Rocky Mountain National Park              |
| SACN: | Saint Croix National Scenic Riverway      |
| SAJH: | San Juan Island National Historical Park  |
| SLBE: | Sleeping Bear Dunes National Lakeshore    |
| TAPR: | Tallgrass Prairie National Preserve       |
| VOYA: | Voyageurs National Park                   |
| WHIS: | Whiskeytown National Recreation Area      |
| WICR: | Wilson's Creek National Battlefield       |
| YELL: | Yellowstone National Park                 |

# Chapter 1. Introduction

## Background

In 1999, the National Park Service (NPS) Inventory and Monitoring Program initiated a long-term ecological monitoring program known as Vital Signs Monitoring. It was designed to provide the infrastructure to allow more than 270 national park system units to identify and monitor conditions of their highest priority resources (Fancy et al. 2009). Established programmatically under the Natural Resource Challenge, the 32 networks were formed to implement this integrated monitoring program which is tailored to the specific needs of parks located in similar environmental settings. The overarching purpose of natural resource monitoring conducted under this program is to collect data and produce scientifically sound information on the current status of—and long-term trends in—the composition, structure, and function of park ecosystems as well as determine the efficacy of current management practices in sustaining those systems. Efforts implemented under the Vital Signs Monitoring Program seek to address the following five major goals for all parks with significant natural resources:

- Determine the status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

Understanding the changing environmental setting of our parks—including vital signs such as land cover, human ecosystem drivers, climate, hydrology, and conservation context—was identified as mission critical by more than 200 of the original 270 I&M natural resource park units (Fancy and Bennetts 2012). This protocol is designed to complement other network- and national-level monitoring protocols, such as LandTrendr (Kennedy et al. 2010, Antonova et al. 2012), by providing a more extensive yet general set of indicators for understanding the landscape context and environmental setting of parks.

Many park managers have acknowledged that the management of key, defining resources inside parks is challenged by activities outside park boundaries (GAO 1994). Despite the best possible resource management practices being implemented within park units, external anthropogenic stressors originating from such sources as population, housing, and roads have increased over time (Davis and Hansen 2011), and projections suggest that these stressors will in many instances

continue to increase for the foreseeable future (Radeloff et al. 2010, Hansen et al. 2014). To plan and implement actions that preserve park resources “unimpaired for the enjoyment of future generations” (NPS Organic Act of 1916), we must identify important landscape-scale resources, assess levels of protection and risk, and determine appropriate management actions (National Parks Second Century Commission 2009, National Academy of Public Administration 2010, NPS 2011, National Park System Advisory Board (NPSAB) 2012, Machlis and McNutt 2015).

### **Environmental Setting Vital Signs**

The national Park Environmental Settings monitoring protocol produces nationally-standardized status and trend information related to *Landscape Dynamics*, *Climate*, and *Surface Water Dynamics* vital signs. All 32 Inventory & Monitoring Networks identified landscape dynamics and climate as priority vital signs in their long-term monitoring plans, with 31 networks committed to developing one or more monitoring protocols specific to their networks (see Appendix A for full list of citations). The status and condition of park resources is affected by interconnected system drivers at regional- to global scales surrounding parks; climate and surface water dynamics vital signs are inherently linked with landscape dynamics and the suite of vital signs provides an important context (and potential covariates) for understanding patterns and changes in other vital signs monitored at parks (Figure 1). These vital signs were included in conceptual models that identified changing landscape dynamics as drivers of park resource conditions, processes, or the conservation context in which those resources and processes are managed. For example, linkages between landscape dynamics and water resources (water quality, hydrology, and geomorphology), changing species distributions (aquatic and terrestrial, with a focus on exotics), and changes in landscape pattern (habitat fragmentation) and type (land cover, use, and conversion) were the most-cited issues of concern among networks (Table 1).

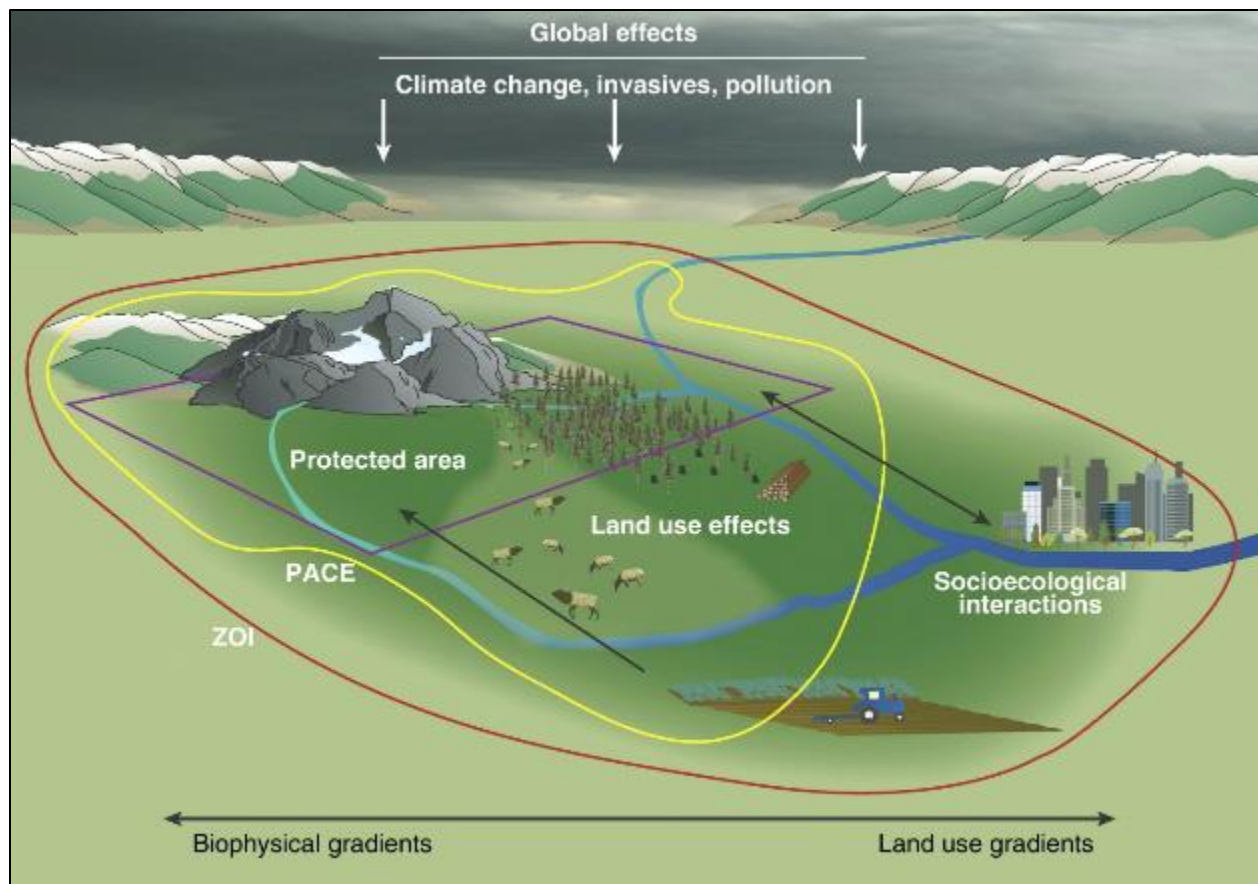


**Figure 1.** Conceptual model of a park depicted in the context of regional and global system drivers. The park lies within a protected-area centered ecosystem (PACE). The still larger zone of interaction (ZOI) includes the region of strong two-way interactions between the PACE and surrounding area affected by human communities, involving ecosystem services, economics, policy, and social values (DeFries et al. 2010). The ZOI may encompass watersheds and ecoregions intersecting the park. Figure drafted by Rob Bennetts; modified from Hansen et al. (2014).

**Table 1.** Reasons that “Landscape Dynamics” was selected as a vital sign by Networks within the National Park Service Inventory & Monitoring Program, based on conceptual models from each network’s monitoring plan.

| Category                                            | Subcategory                         | Number of Networks | Percent |
|-----------------------------------------------------|-------------------------------------|--------------------|---------|
| <b>Drivers of park Resource Conditions</b>          | Climate                             | 32                 | 100     |
|                                                     | Water Quality                       | 29                 | 91      |
|                                                     | Hydrology                           | 29                 | 91      |
|                                                     | Vegetation Composition & Structure  | 27                 | 84      |
|                                                     | Wildlife                            | 25                 | 78      |
|                                                     | Fisheries                           | 19                 | 59      |
|                                                     | Groundwater                         | 13                 | 41      |
|                                                     | Air Quality                         | 12                 | 38      |
|                                                     | Natural Sounds                      | 5                  | 16      |
|                                                     | Night Skies                         | 4                  | 13      |
| <b>Drivers of Park Ecosystem Processes</b>          | Climate                             | 32                 | 100     |
|                                                     | Changing Species Distributions      | 26                 | 81      |
|                                                     | Geology & Geomorphology             | 26                 | 81      |
|                                                     | Altered Fire Regimes                | 17                 | 53      |
|                                                     | Altered Flooding or Flow Regulation | 15                 | 47      |
|                                                     | Disease Incidence & Prevalence      | 8                  | 25      |
|                                                     | Coastal Dynamics                    | 8                  | 25      |
|                                                     | Insect Pest Outbreaks               | 5                  | 16      |
| <b>Conservation Context for Resource Management</b> | Landscape Conversion                | 23                 | 72      |
|                                                     | Landscape Fragmentation             | 20                 | 63      |
|                                                     | Human Dimensions of Adjacent Lands  | 14                 | 44      |
|                                                     | Watershed Development               | 12                 | 38      |
|                                                     | Resource Extraction                 | 11                 | 34      |

## Conceptual Framework

The Park Environmental Settings protocol is developed under a conceptual framework that links measurable attributes of landscapes to resources within parks, focusing on broad-scale factors that are quantifiable over time using consistent data available at regional to national scales. Most data sources used in the protocol are best suited for analysis of areas that are hundreds to thousands of square kilometers, but changes may be detected as measures derived from those sources are repeated over time. Information at these broad scales is increasingly needed to identify wildlife corridors,

isolated habitats, and areas with important resources that may be at risk from projected land use changes around parks.

### ***Driver of Park Ecosystems and Resource Conditions***

Conceptual models and frameworks are useful for illustrating potential connections among key environmental attributes and relate indicators to the evaluation of landscape condition and the context of parks. No single model or framework can meet all needs; we present these select models because they are easily understood, can be applied to most systems, and are readily modified to better represent specific situations or needs. The models are presented in order from more general and broad-scale to more specific and fine-scale.

At the most general level, Figure 2A illustrates factors that are the primary determinants of ecosystem state and sustainability over broad scales of time and space. Five ‘state factors’ (Figure 2A, in upper case) impose fundamental constraints on ecosystem processes and these factors largely determine such features as soil properties (Jenny 1994) and dominant vegetation type (e.g., deciduous forest, tundra, grassland). These state factors are external to the ecosystem, as represented by the circles in Figure 2. The specific characteristics of a particular ecosystem (such as climate, soil resource supply, major functional groups of organisms, and disturbance regime) are determined by ‘interactive controls’ (Figure 2 B), which regulate and respond to ecosystem processes. In this model a significant change to any interactive control will lead to a different ecosystem. Figure 2B includes anthropogenic factors and activities that can significantly alter one or more of the interactive controls, and thus threaten the sustainability of the system. This protocol provides direct measures of some of these general stressors (e.g., land cover types), and indices of others (e.g., road and population density, which are related to vehicle emissions and to night lights).

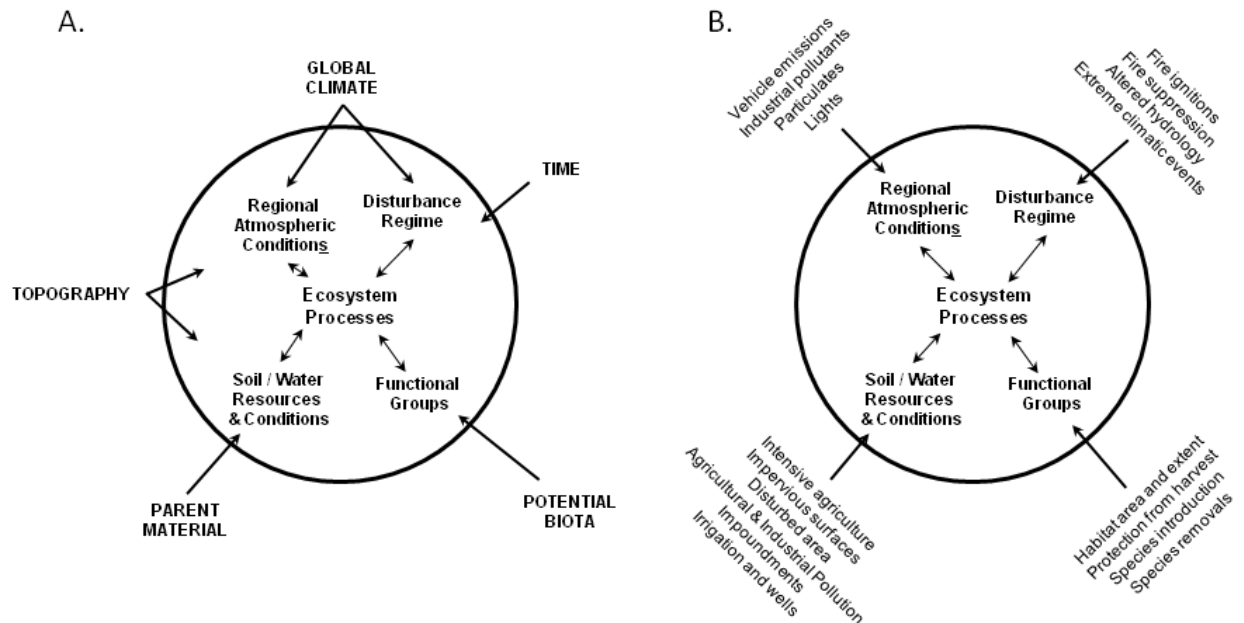


**Figure 2.** (A) General ecosystem model showing primary constraints (upper case) and ecosystem attributes or 'interactive controls' (lower case). (B) Factors that commonly alter ecosystems at local to landscape scales. Modified from Chapin et al. (1996) and Miller (2005).

### **Context for Resource Management and Conservation**

Resources of concern in parks are nested within and depend on the larger surrounding natural areas (Figure 3). Consider by way of example a resource of management concern within a particular NPS unit. Human activities external to the unit can compromise surrounding areas, which may increase stress on that resource of concern. Resource management actions can alleviate, mitigate (or in some cases aggravate) undesirable effects.

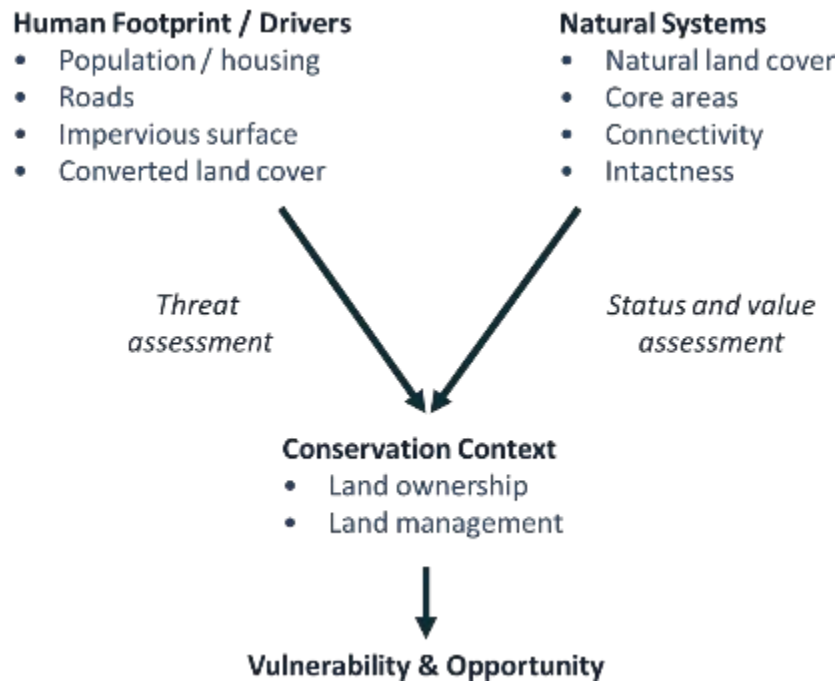


**Figure 3.** Broad categories of measures considered in this protocol, and how they contribute to understanding the landscape context of parks and park resources.

Together, the measures in Figure 3 describe landscape condition at a range of spatiotemporal scales. Historical information provides a context for change: how, and how fast, did we reach our present state or condition? Historical baselines, rates, and magnitudes of change help determine the urgency of decisions, and they provide a social context important for understanding and relating to people who experienced these changes. The relationships between park natural resources, nearby protected areas, and connecting corridors can determine opportunities for preserving resources. Taken in combination, the historic, current, and future projections (not derived as a part of this protocol), measures of park environmental settings can help identify and evaluate opportunities to prevent resource damage or loss, assess actions for restoration, and identify key areas or threats to park resources.

The conceptual models illustrated in Figure 2 and Figure 3 provide general frameworks for considering landscape-scale factors that affect park resources, but more-detailed models are necessary to directly link landscape variables mechanistically to ecological processes and specific resources. At this finer level of resolution, the more-detailed model in Figure 4 links landscape changes associated with land use intensification to key ecological processes and effects on natural resources, and it identifies attributes suitable for monitoring. The ecological relationships and processes articulated in Figure 4 are common to many parks, and they provide a basis for evaluating the potential effects of landscape-scale drivers on park natural resources. Key attributes include natural disturbances (e.g., fire, floods), critical habitats (e.g., for species of management concern), ecological flows (e.g., pollutants, nutrients, energy, water), and both direct and indirect effects of humans (e.g., poaching, noise, behavioral disturbance).

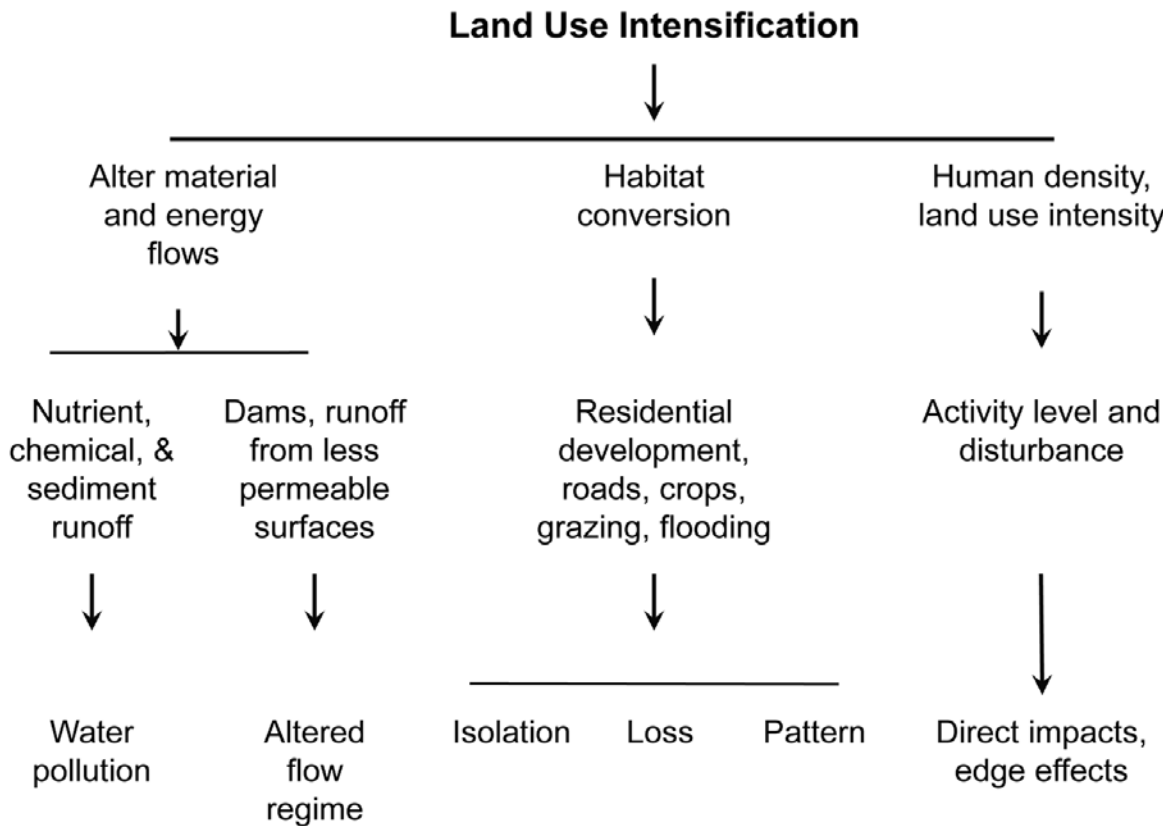


**Figure 4.** Mechanistic links between attributes of land use intensification and natural resource condition, depicting the relationships described by Hansen & DeFries (2007).

### Protocol Scope and Approach

The goal of this protocol is to meet two primary needs. The first is to provide information about parks and surrounding areas that is relevant and useful to management and planning. Results are reported at multiple scales of management relevance—from watersheds, to parks to many parks (Monahan and Gross 2012, Hansen et al. 2014). The protocol also provides consistent landscape-level information to NRSS programs, such as Natural Resource Condition Assessments (e.g., Bennetts et al. 2012, Thorne et al. 2013), State of the Park Reports (e.g., NPS 2014), as well as planned Wilderness Character Assessments, and Resource Stewardship Strategies.

Second is to provide summary and raw data to IMD (and other staff) who need to use environmental settings data to understand the context for status and trends observed in other vital signs being monitored in parks. Data (and tools for accessing it) have been developed to provide internal and external scientists access to a core set of data to be used for analyses.

The use of regionally- to nationally-consistent data maximizes the benefits of centralized processing of measures that are important to the vast majority of parks. Local data usually require separate and often unique processes for acquisition, aggregation, and analysis. Hence, there is little benefit – and great cost – to centralized acquisition and processing of data when the availability, content, and format differs among sites, especially under a national protocol servicing such a broad geography.

The Park Environmental Settings protocol focuses on monitoring based on regionally- to nationally-standardized source data, with procedures to evaluate the suitability of alternate data sources as they become available. However, it is assumed that data sources and methods for analysis and reporting will continue to evolve and methods described in this protocol will have to be updated as technology and approaches change.

Achievement of this protocol's analysis and reporting goals will require close coordination and partnership with scientific and data management staff from other units within NPS as well as external agencies and programs. Central to these efforts is a commitment to leverage work being done by others so as to integrate protocol findings with existing Service-wide and external tools and platforms for analysis, reporting, and decision support.

### **Development Process & History**

The landscape dynamics component of the Park Environmental Settings protocol is based on the NPScape project. Climate and hydrology components were added because vital signs (circa 2000-2004) and Inventories 2.0 (circa 2016) scoping sessions respectively indicated needs for climate and stream hydrology information. NPScape, established by the I&M Program in 2008, provided landscape-level data, standardized analytical and visualization tools, guidance on interpreting results, and park example case studies to assist I&M networks with developing their own landscape dynamics monitoring protocols. However, in 2013, feedback from an I&M-wide survey revealed consensus among networks in the need for a national landscape dynamics monitoring protocol in which essentially all aspects of the workload – from protocol development to final reporting – be handled by the I&M Central Office rather than networks.

This protocol addresses both stated needs, delivering, in consultation with networks, landscape dynamics, climate, and stream hydrology metrics to parks by:

- Expanding the scope beyond landscape dynamics metrics to include other significant drivers of park environmental setting such as measures pertaining to climate and surface water dynamics / hydrology,
- Analyzing and reporting data at watershed scales (in addition to park boundaries and buffers) so as to provide data relevant to parks and networks for understanding potential landscape-scale drivers of water resources,
- Defining monitoring objectives (and methods) to measure change in landscape dynamics parameters over time, and
- Establishing an implementation framework to integrate landscape dynamics data into park planning and management, evaluate new or alternate data sources and analysis tools, and add new landscape dynamics parameters to meet evolving network analysis and park management needs.

## Chapter 2. Monitoring Objectives

### National-Level Objectives

Monitoring objectives are designed to address two primary needs—to help NPS managers and scientists better understand how aspects of the landscape surrounding parks affect (or potentially affect) resources within parks, and to provide data that can be used as covariates for understanding responses observed in other vital signs monitored within parks.

Following the conceptual models for coupled park-human ecosystems in Figure 3, the objectives of the protocol are as follows, with the specific metrics to be calculated and monitored over time listed in Appendix C:

### *Landscape Dynamics*

1. Determine the status and change over time in human drivers of landscape change (such as the extent and distribution of the human population, housing, and roads) in areas within, surrounding, and draining into parks. Anthropogenic impacts on park resources may originate directly from the behaviors of humans, or indirectly from the roads, houses, landscaping, and other infrastructure used to support humans. Although the extent of impact is often difficult to measure, data on human population characteristics (e.g., population change, economic status, and housing density) usually provide information that is a direct indication of the magnitude of anthropogenic impacts to lands adjacent to parks. Cultural, political, and socioeconomic factors all contribute to land use decisions (Naveh 1995, Nassauer 2005, With 2005) and are widely used indicators of landscape quality or threats to biodiversity (Cincotta et al. 2000, Nassauer 2005). Because human land uses tend to expand over time (Wade et al. 2003), and we can make projections into the future, these data provide a window into potential threats to park resources.
2. Determine the status and change over time in attributes of the natural system (such as the extent and distribution of land cover composition and pattern) in areas within, surrounding, and draining into parks. The importance of habitat area is readily apparent for parks, but it is nonetheless difficult to identify a small suite of indicators that adequately describe area characteristics in ways that generally inform decisions on how to manage park resources. This fundamental difficulty accounts for the number and complexity of landscape dynamics indicators that address land cover composition.

Most or all of the land cover composition and pattern (next section) indicators monitored under this protocol can be used to assess important attributes of plant and animal habitat. These attributes include indices of availability, connectivity, patch sizes and structure, and multi-scale context. The most important habitat features vary according to question, species, or issue. Land cover composition and pattern indicators are designed to be diverse enough to provide useful information for a very wide range of analyses.

Patterns in land cover composition, configuration, and connectivity reflect the dynamics of natural ecological processes (Watt 1947), biophysical constraints (Whittaker 1967, Stephenson 1990), and extensive modification resulting from a long history of human occupation and habitat modification (Heilman Jr. et al. 2002, Riitters et al. 2002, Mann 2005, Schulte et al. 2007). In turn, these land cover patterns help shape overall patterns in biological diversity, including the complex array of species occurring in an area, movements of individual organisms, and flows of energy and material (Levin 1981, Noss 1990, Dunning et al. 1992, Franklin 1993, Taylor et al. 1993, Turner 2005, Hansen and DeFries 2007).

3. Determine the status and change over time in the conservation context (such as the extent, distribution, and type of ownership and level of protection) in areas within, surrounding, and draining into parks<sup>1</sup>. The traditional response to preserving biodiversity has been the creation or expansion of protected areas. Yet the conservation status or stewardship of land surrounding these protected areas often dictates and directs potential changes in land use that can have profound impacts on park resources (GAO 1994, Hansen and DeFries 2007). Impacts – positive or negative – can be categorized by changes in the effective size of reserves, in ecological flows, in the size of critical habitat, and in the amount of exposure to humans (Hansen and DeFries 2007). Within each category, Hansen & DeFries (2007) distinguish the types of mechanisms that drive change, such as species area effects, trophic structure, migration habitats outside parks, and hunting and poaching. A common feature of these drivers is that they are known, or at least strongly postulated, to be directly related to land use intensification.

Knowing the condition and changes of land stewardship and resulting land use near and adjacent to parks is important for assessing current threats and impacts and for evaluating how the situation around parks might change in the future. For example, broad-scale patterns of habitat conversion (e.g., to urban or agriculture) and protection (stewardship) have been used to estimate conservation risk and help identify areas that were at greatest risk both nationally (Svancara et al. 2009) and globally (Hoekstra et al. 2005). Combined with patterns of potential threats (e.g., roads, development), assessments of the level of resource protection have also helped identify areas at risk and refine conservation strategies on a statewide basis (Theobald 2003).

## **Climate**

4. Determine the current status and historical trends in air temperature, precipitation, and bioclimatic measures at multiple temporal scales (e.g., daily, monthly, seasonal, annual, and decadal) and spatial scales (e.g., individual stations and aggregated stations such as climate divisions). Climate change is one of several landscape-scale factors that will shape park

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<sup>1</sup> This monitoring objective will not be implemented at the time of publication due to known errors in the source data.

ecosystems for the next several decades. The synergistic effects of climate and land- use change drivers will combine to frame the resource management challenges of the future. Meteorological information is necessary to interpret and understand changes in species composition and abundance, community structure, water flow and chemistry, and related landscape processes. In short, understanding the role of weather and climate as a driver of park ecosystems is key to understanding other vital signs monitored by the 32 Networks. Secondly, data analyzed as a part of this protocol will allow for the evaluation of how climate patterns and trends near parks compare to regional, national, and even global trends, as well as predicted future changes. These data and assessments will be particularly valuable to parks in the development and implementation of climate adaptation plans.

## **Hydrology**

5. Determine the current status and historical trends of stream discharge, environmental flows, and indicators of hydrologic alteration in surface waters upstream, bordering, or within park boundaries, including the frequency, duration, and magnitude of peak flow events within those water bodies. The hydrologic output of a watershed is a function of land characteristics, human use, weather and climate conditions, urbanization, and soil characteristics. As a result, stream flow characteristics are some of the most appropriate and useful indicators for assessing aquatic ecosystem integrity, and for monitoring environmental changes over time. They also provide key support data for interpreting other vital signs indicators including water quality, threatened and endangered aquatic species, wetlands, and riparian habitat. Hydrologic variation plays a key part in structuring the biotic diversity within river ecosystems by controlling critical habitat conditions within the river channel, the floodplain, and hyporheic zones. A stream's flow regime is a primary governing factor which is largely responsible for determining the type and magnitude of various physical and ecological processes that occur in a stream system (Puckridge et al. 1998).

Although other environmental factors and characteristics of a stream influence the overall condition of a stream and its biological communities, a stream's flow is thought of as the master variable (Power et al. 1995). Stream flow has been shown to provide important conceptual and empirical linkages between watershed conditions, in-stream habitats, and the biotic integrity of stream biological communities. The large amount of uncertainty associated with many projections for changes in water availability due to climate change (Miller and Yates 2006, Brekke et al. 2009), and resultant changes to stream flows, means that more data are likely needed before the direction and magnitude of the influence can be determined with certainty.

In addition to informing other park vital signs monitoring, these objectives are intended to inform standardized regional- to national-level reporting (e.g., Natural Resource Condition Assessments, State of the Park Reports, Resource Stewardship Strategies, etc.)

## **Network- and Park-Level Objectives**

In addition to these programmatic objectives, park-specific monitoring objectives will be established in consultation with Networks. These park-specific objectives are important for deciding the particular combinations of landscape variables and Areas of Analysis (AOAs) to regularly report as part of the protocol. For example, Saguaro National Park is comprised of two subunits separated by the city of Tucson; monitoring objectives are especially concerned with understanding changes in human population (affecting local recreation pressures) and housing (affecting connectivity to broader landscapes; Monahan et al. 2012).

Additionally, landscape dynamics data are intended to enhance the interpretation of data collected in other vital signs monitoring protocols. This is achieved by using results as predictor variables or covariates in models and analyses described by other protocols. For example, landscape dynamics data have been used by the NPS Southern Colorado Plateau Network to analyze results from their upland vegetation protocol (Thomas et al. 2015), by the NPS Great Lakes Network to provide additional landscape context in other landscape dynamics monitoring reports (Kirschbaum et al. 2012), and by Glacier National Park in a multi-scale watershed condition model (Kleindl et al. 2015).

## **Objectives Addressed in Other Efforts**

The national landscape dynamics protocol is intended to complement other monitoring efforts conducted at the network and national scales (as well as those beyond IMD/NPS). Of particular note:

- Monitoring changes in the type, extent, and persistence of areas impacted by disturbance events or land management activities (wildfire, prescribed fire, exotic plant treatment, insect pest outbreaks, overwashes, etc.) will be addressed in the national Land Management & Disturbance protocol (this is a second-tier protocol not currently in development).
- Monitoring parcel-scale changes in land use development in areas near or adjacent to park lands will not be included in national IMD protocols at this time. However, procedures for doing this have been developed by IMD and are available for implementation at the park- or network level (NPS 2013).
- Many networks have developed and implemented LandTrendr-based protocols to evaluate changes in landscape pattern (see Kennedy et al. 2010, Antonova et al. 2012, Townsend et al. 2012). The national landscape dynamics protocol is designed to complement those ongoing efforts rather than assume responsibility for their long-term implementation (for a discussion on the tractability of nationalizing these efforts see Kennedy et al. 2011).

## **Chapter 3. Areas of Analysis, Monitoring Locations, and Frequency of Analysis**

The locations or extent of data used in this protocol are driven by the availability of those data from external sources rather than being selected to detect change within a sampling design. Measures associated with landscape dynamics objectives (objectives 1-3), and gridded climate data (objective 4) are censused or measured for entire areas of interest. Both non-gridded climate data and hydrologic data are measured at a set of finite locations. Although that set of finite locations may be thought of as a sample design, NPS has almost no control over the selection of those locations. Because there tends to be at most a handful of sites within an area of interest, and those sites tend to be sentinel sites or a convenience sample rather than a probability sample, this protocol does not attempt design-based or model-based inferences to the un-sampled parts of the areas of interest. Therefore, the focus of this chapter is describing the areas of interest relevant for different questions and scales of data.

### **Ecologically Relevant Areas of Analysis**

Landscape attributes important to understanding status and trends of park resources often vary with spatial extent, so this protocol evaluates landscape measures within a variety of Areas of Analysis (AOAs). Ecologically relevant AOAs include the landscape within the park itself and the ‘boundary’ area immediately adjacent to the park (e.g., within 1-3 km), the local area surrounding a park (e.g., within approximately 15-40 km), one or multiple watersheds that drain into (or originate within) the park. Additionally, parks may define issue-driven AOAs at the sub-park to regional scales to address planning and management needs. Depending on the issues at hand, park managers frequently consider multiple AOAs within a broad “zone of interaction” to develop effective management strategies for responding to local, regional, and global influences (Figure 1)(DeFries et al. 2010, Hansen et al. 2014).

For each measure to be monitored under the five monitoring objectives, data will be collected, analyzed, and reported at multiple spatial scales corresponding to AOAs relevant to park management (Table 2, Table 3).

**Table 2.** Areas of Analysis (AOAs) used in landscape dynamics as of Fall 2018.

| Category                                            | AOA Type        | Spatial Extent                        | Total Number of AOAs |
|-----------------------------------------------------|-----------------|---------------------------------------|----------------------|
| <b>Within and Adjacent-to-Park AOAs<sup>a</sup></b> | Park, 3km, 30km | CONUS                                 | 762                  |
|                                                     | Park, 3km, 30km | Alaska                                | 48                   |
|                                                     | Park, 3km, 30km | Hawaii                                | 27                   |
|                                                     | Park, 3km, 30km | US Virgin Islands                     | 6                    |
|                                                     | Park, 3km, 30km | American Samoa                        | 3                    |
|                                                     | Park, 3km, 30km | Guam                                  | 3                    |
|                                                     | Park, 3km, 30km | Commonwealth Northern Mariana Islands | 3                    |
| <b>Watershed AOAs<sup>b</sup></b>                   | HUC12           | CONUS                                 | 3,879                |
|                                                     | HUC12           | Alaska                                | 2,657                |
|                                                     | HUC12           | Hawaii                                | 108                  |
|                                                     | HUC12           | US Virgin Islands                     | 6                    |
|                                                     | HUC12           | American Samoa                        | 4                    |
|                                                     | HUC12           | Guam                                  | 6                    |
|                                                     | HUC12           | Commonwealth Northern Mariana Islands | 2                    |
| <b>Custom AOAs<sup>c</sup></b>                      | Custom          | Service-wide                          | 718                  |

<sup>a</sup> Areas of Analysis derived from park boundaries. Number of AOAs for Park-based AOAs are summed over the three types (Park, 3km, 30km)

<sup>b</sup> Hydrologic Unit Code (HUC) 12 level watershed Areas of Analysis.

<sup>c</sup> Custom Areas of Analysis are provided by Park/Network/Cooperator; the total number of custom AOAs is expected to increase over time as new areas are identified.

**Table 3.** Relationship between monitoring objectives, categories of environmental setting measures, and non-custom Areas of Analysis (AOAs). Note that each measure contains two or more metrics that will be calculated and analyzed for change or trends over time (discussed in Chapter 4).

| Monitoring Objective                                                       | Measure                                 | Park | Local Area<br>(3 and 30km) | Watershed |
|----------------------------------------------------------------------------|-----------------------------------------|------|----------------------------|-----------|
| <b>Pattern and Extent of Landscape Attributes (Monitoring Objective 1)</b> | Natural Land Use / Land Cover           | X    | X                          | X         |
|                                                                            | Morphological Spatial Pattern           | –    | X                          | –         |
|                                                                            | Land Cover Pattern Density              | –    | X                          | –         |
| <b>Human Drivers of Landscape Change (Monitoring Objective 2)</b>          | Impervious Developed Surface            | –    | –                          | X         |
|                                                                            | Converted Land Use / Land Cover         | X    | X                          | X         |
|                                                                            | Human Population Size & Density         | –    | X                          | –         |
|                                                                            | Roads                                   | –    | X                          | X         |
| <b>Conservation Context (Monitoring Objective 3)<sup>2</sup></b>           | Protection Status                       | –    | X                          | X         |
| <b>Climate (Monitoring Objective 4)</b>                                    | Air Temperature                         | X    | X                          | X         |
|                                                                            | Precipitation                           | X    | X                          | X         |
|                                                                            | Derived Climate Measures                | X    | X                          | X         |
| <b>Hydrology (Monitoring Objective 5)</b>                                  | Discharge                               | X    | –                          | X         |
|                                                                            | Hydrologic Index Tools Metrics          | X    | –                          | X         |
|                                                                            | Fundamental Daily Streamflow Statistics | X    | –                          | X         |
|                                                                            | Indicators of Hydrologic Alteration     | X    | –                          | X         |

### ***Within- and Adjacent-to-Park Areas***

To inform park management activities, the most relevant spatial scale of network analyses and ecological interpretations of protocol metrics will be the landscape area within and adjacent to park boundaries (Figure 5). Wildlife may move among areas within the park, plants disperse and colonize, and development and visitor use have impacts that extend spatially from their locations within the park. This is also the scale where NPS management has the greatest control over landscape change. The size, spatial location, and geographical context of the park determine each park’s environmental setting and how it compares to the surrounding area.

The landscape immediately adjacent to the park has a large effect on permeability or connections between the park and the surrounding landscape, and thus on the importance of landscape attributes in the broader area (Hansen and DeFries 2007). Roads and highly developed areas can act as barriers

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<sup>2</sup> Measures for Conservation Context will not be calculated at the time of protocol implementation due to errors in the source data. However, source data will be made available for use in analysis and reporting.

to movement of wildlife between the park and surrounding areas, isolating park resources from important habitats outside the park. Land cover characteristics at this local scale can have a strong effect on fire management strategies and the probability that wildfires ignited on the surrounding lands will burn into the park. Activities and processes occurring within the area immediately adjacent to a park are sufficiently close that even small effects can propagate into the park and affect park resources. Housing adjacent to the park boundary can increase pet-wildlife interactions, exotic plant introductions from yards and gardens, and the ignition frequency of small fires. Roads near park boundaries provide additional visitor access, and may increase the potential for poaching within the park.

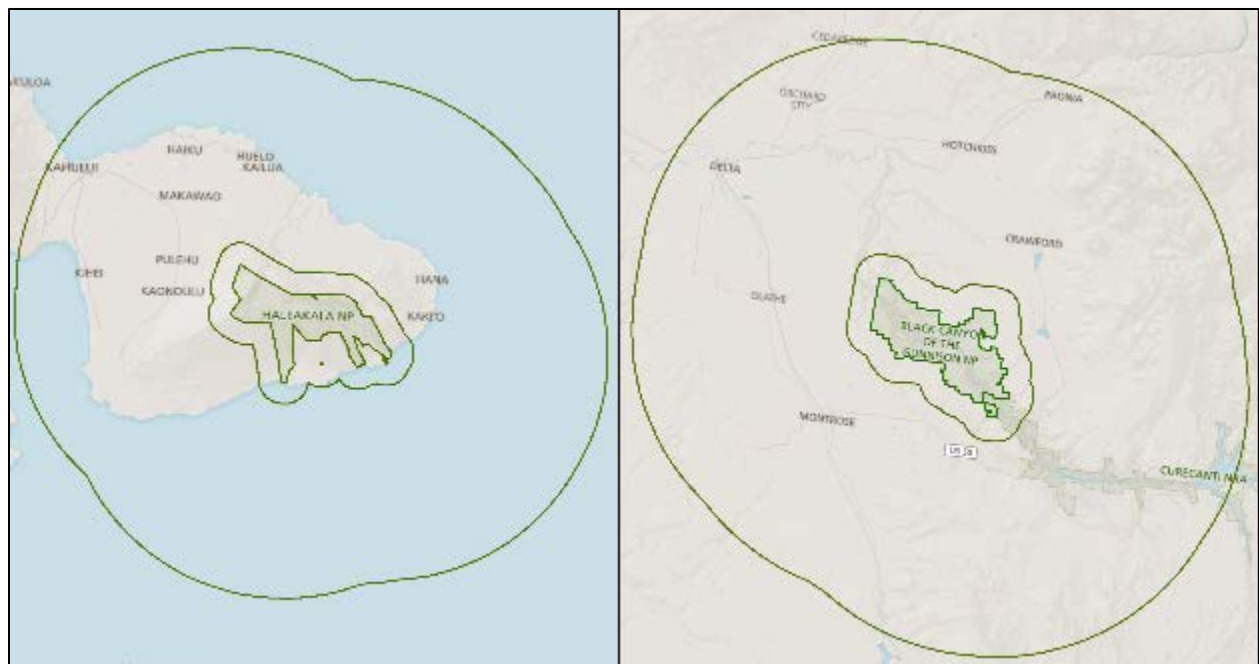


**Figure 5.** Examples of park-based AOAs for Hawaii (HALE, left) and CONUS (BLCA, right); Park level, 3km buffer, and 30km buffer.

Although monitoring of landscape and other measures of environmental context within and immediately adjacent ( $< 3$  km) to the park is important, few regional- to national-scale datasets are suited to analysis and reporting at scales appropriate to all parks in the System. Local aerial photography and fine-scale vegetation maps, county property records, and county/state road and traffic data are usually more appropriate for analyses that focus on relatively small parks, or targeted areas within a few kilometers of a park (Monahan et al. 2015). Similarly, monitoring stations collecting climate and hydrologic data may not be located in areas representative of park conditions. Although measures of environmental setting will be collected, analyzed, and reported at the within-and-adjacent-to park scale, they may not be appropriate for all parks.

Many ecological processes operate at a local scale on the order of 15-40 km. Specific examples include the propagation of wildland fires, dispersal of local pollutants, daily to weekly movements of birds and larger mammals, and yearly to multi-decadal dispersal of amphibians, reptiles, and smaller

mammals. There is no unique and uniform distance that defines the local scale, and for most reporting purposes we use 30 km from the park boundary as a consistent distance for quantifying landscape effects of this type. This value corresponds with boundaries for protected-area centered ecosystems (PACEs, Hansen et al. 2011), which more mechanistically describe the local park areas that are important for supporting ecological systems and processes (Figure 1).

### **Watersheds**

Watershed boundaries also constitute important AOAs (Figure 6), largely because of the downhill and downstream transport of materials and energy. For example, landscape processes in the upstream watershed affect hydrology, water chemistry, and aquatic biota; aboveground and belowground flows can rapidly transmit the effects of actions outside parks to aquatic resources within park boundaries. When there is intensive development in the upstream contributing area to a park, the effects of upstream activities may constitute the most important stressors or drivers of aquatic conditions within the unit. Boundaries from HUC-12 watersheds intersecting with park boundaries will be used as one of several core AOAs used for all parks in the NPS System.

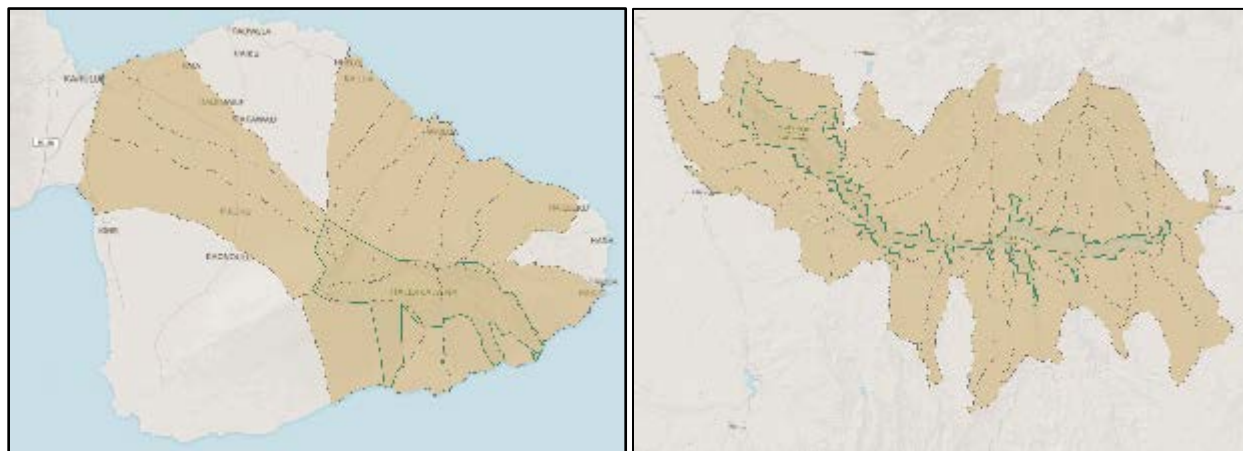


**Figure 6.** HUC12 Watersheds, Examples of HUC12 Watershed AOAs for Hawaii (HALE, left), and CONUS (BLCA/CURE, right).

[https://irmaservices.nps.gov/arcgis/rest/services/LandscapeDynamics/LandscapeDynamics\\_AOA\\_HUC12\\_Webmercator/MapServer](https://irmaservices.nps.gov/arcgis/rest/services/LandscapeDynamics/LandscapeDynamics_AOA_HUC12_Webmercator/MapServer)

### **Custom Areas of Analysis**

Finally, beyond the ecologically relevant AOAs described above, parks may identify other AOAs relevant to resource management. Examples include viewsheds affecting visitor experience, local travel zones encompassing communities near parks, and planning areas whose boundaries have been delineated to promote local partnerships (Figure 7). Landscape attributes at broader, regional scales often affect park resources on time scales of decades to centuries. This regional perspective is necessary to plan for or respond to issues such as the ability of altered landscapes to support regional biodiversity and to evaluate impacts from broad-scale drivers like climate change. As the NPS confronts challenges of global change, a regional perspective will be essential for long-term conservation of biodiversity (NPS 2010).

This protocol supports monitoring of any AOAs identified by parks, provided they are scaled appropriately in relation to the source data used to estimate the landscape indicators (Table 4 and Table 5).

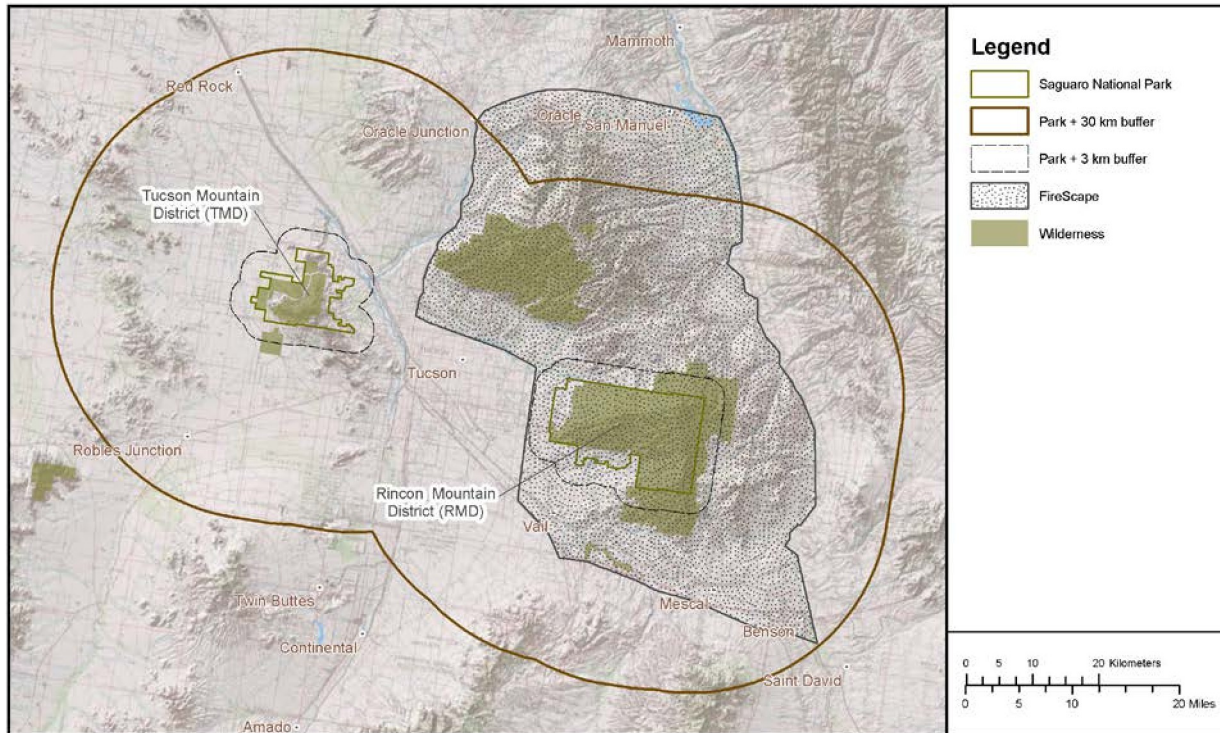


**Figure 7.** Areas of Analysis for Saguaro National Park, including the FireScope boundary used by the park to coordinate with partners on fire planning (Monahan et al. 2013).

**Table 4.** Park-scale custom Areas of Analysis (AOAs) for which landscape dynamics data will be analyzed and reported. Once established, AOAs will be incorporated in all future analysis and reporting.

| Network | Custom AOA Description                                       | Parks                                                                                    | Calendar Year Implemented |
|---------|--------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------|
| CUPN    | KGWB Basins, Major Surface Basins                            | MACA                                                                                     | 2016                      |
| ERMN    | Watershed                                                    | ALPO; BLUE; DEWA; FONE; FRHI; NERI                                                       | 2016                      |
| GLKN    | AreasReview response: <sup>a</sup>                           | APIS; GRPO; INDU; ISRO; MISS; PIRO; SACN; SLBE; VOYA                                     | 2016                      |
| GRYN    | GRYN_Areas Review response: <sup>b</sup>                     | GRTE; JODR; YELL                                                                         | 2016                      |
| HTLN    | Watersheds                                                   | ARPO; BUFF; CUVA; EFMO; GWCA; HEHO; HOCU; HOME; HOSP; LIBO; OZAR; PERI; PIPE; TAPR; WICR | 2016                      |
| KLMN    | PM                                                           | CRLA; LABE; LAVO; ORCA; REDW; WHIS                                                       | 2016                      |
| MEDN    | Areas <sup>c</sup>                                           | SAMO                                                                                     | 2018                      |
| NCCN    | LPa01                                                        | EBLA; LEWI; MORA; NOCA; OLYM; SAJH                                                       | 2016                      |
| NCCN    | PACE, Protected Areas                                        | MORA; NOCA; OLYM                                                                         | 2016                      |
| NETN    | HUC10 Shell, Subsections                                     | APPA                                                                                     | 2016                      |
| NETN    | HUC10, HUC10_Shell, Subsection                               | KAWW                                                                                     | 2016                      |
| ROMN    | ROMN_FLFO, SEI GLAC, WEI ROMO, SEI ROMO, WEI GRSA, ROMN_ROMO | FLFO, GLAC, GRSA, ROMO                                                                   | 2017                      |
| SECN    | Watershed                                                    | HOBE, KEMO, CHAT, OCMU, CONG, MOCR                                                       | 2016                      |

<sup>a</sup> Areas dataset contains park-specific custom polygons. Example: GLKN\_APIS\_AOA\_AnalysisArea

<sup>b</sup> GRYN\_Areas dataset contains park-specific custom polygons. Example GRYN\_GRTE\_JODR\_Grouped\_AOA\_Area

<sup>c</sup> MEDN Areas dataset contains park-specific custom polygon for Ecological Management Zone

**Table 5.** Landscape-scale custom Areas of Analysis (AOAs) for which landscape dynamics data will be analyzed and reported. Once established, AOAs will be incorporated in all future analysis and reporting.

| Custom AOA Description                                      | Spatial Extent                                                     | Calendar Year Implemented |
|-------------------------------------------------------------|--------------------------------------------------------------------|---------------------------|
| Bird Conservation Units                                     | Central CONUS                                                      | 2016                      |
| Area (Florida), Area (USVI)                                 | SE Florida; USVI Islands                                           | 2017                      |
| Islands                                                     | Pacific Islands (Hawaii, Guam, American Samoa, CN Mariana Islands) | 2016                      |
| Bighorn Habitat                                             | Mojave                                                             | 2016                      |
| Crown Majors AOAs, Crown Management Areas, Crown Watersheds | Crown of the Continent                                             | 2017                      |

## Frequency of Analysis

The frequency of analysis varies by data source (Table 6). Landscape dynamics metrics derived from imagery or other geospatial datasets are calculated as new or updated data become available from source providers (typically once every five years). Metrics derived from census data are updated once every 10 years. Climate and hydrology objectives are updated no less frequently than annually, although because those metrics are based on daily data published more frequently than annually, interim data products and analyses may be conducted on a case-by-case basis.

**Table 6.** Frequency at which measures of park environmental setting will be acquired or calculated by monitoring objective.

| Monitoring Objective                                                       | Measure                                 | Frequency                                           |
|----------------------------------------------------------------------------|-----------------------------------------|-----------------------------------------------------|
| <b>Pattern and Extent of Landscape Attributes (Monitoring Objective 1)</b> | Natural Land Use / Land Cover           | Every five years or as source data become available |
|                                                                            | Morphological Spatial Pattern           | Every five years or as source data become available |
|                                                                            | Land Cover Pattern Density              | Every five years or as source data become available |
| <b>Human Drivers of Landscape Change (Monitoring Objective 2)</b>          | Impervious Developed Surface            | Every five years or as imagery is available         |
|                                                                            | Converted Land Use / Land Cover         | Every five years or as imagery is available         |
|                                                                            | Human Population Size & Density         | Every ten years                                     |
|                                                                            | Roads                                   | Annually                                            |
| <b>Conservation Context (Monitoring Objective 3)</b>                       | Protection Status                       | Annually                                            |
| <b>Climate (Monitoring Objective 4)</b>                                    | Air Temperature                         | Annually                                            |
|                                                                            | Precipitation                           | Annually                                            |
|                                                                            | Derived Climate Measures                | Annually                                            |
| <b>Hydrology (Monitoring Objective 5)</b>                                  | Discharge                               | Annually                                            |
|                                                                            | Hydrologic Index Tools Metrics          | Annually                                            |
|                                                                            | Fundamental Daily Streamflow Statistics | Annually                                            |

## Ability to Detect Change

This protocol does not include a power analysis because it does not specify national-scale trend analyses. The major factors determining power to detect trends or changes of a given magnitude are year to year fluctuations, and the duration and completeness of the period of record. Both of these factors vary across the continent, so statistical power will also vary across parks or areas of analyses for specific questions, and be driven by properties of the specific subsets used in the analyses.

Instead of retrospective power analyses for each application, a more appropriate approach will be to estimate confidence intervals around all trend estimates to characterize the uncertainty about those estimates, and the range of plausible values.

## Chapter 4. Methods

### General Framework

The protocol for evaluating environmental settings around NPS park units does not involve collection of any new data, but instead leverages data available from other sources, including those available from other state and federal agencies, and IMD monitoring networks (Figure 8). This includes internal NPS inventory sources that provide information about AOAs of interest to parks and networks, as well as locations of monitoring stations with metadata pertaining to monitored parameters and their respective periods of record.

The IMD program will develop and/or use tools to calculate summary statistics and derived measures of management relevance for objectives related to landscape dynamics, climate, and surface water dynamics. In most cases NPS will not store or manage source data, but will cite those sources as appropriate. To the greatest extent possible, this protocol relies on summary statistics and derived measures available from data providers. This chapter focuses on methods to calculate summary statistics (metrics) and derived measures; analyses to address monitoring objectives related to detecting change and trends will be conducted on source data and derived measures, as described in Chapter 6.

Additional derived measures may be added over time based on new methods and data sources upon evaluation of methods and recommendations by one or more protocol advisory boards (see Chapter 7).

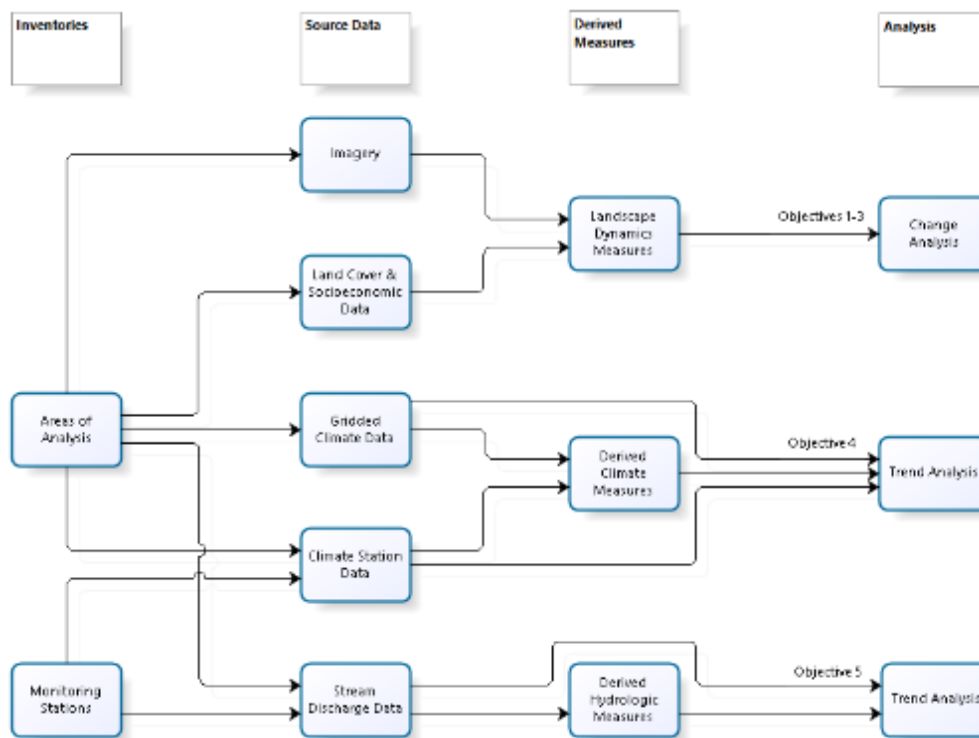


**Figure 8.** General workflow for harvesting, processing, and analyzing data as a part of the NPS Park Environmental Settings Monitoring Protocol.

## Inventories

This protocol relies on two data sources currently managed by IMD external to this protocol: a geodatabases that houses AOA features, and an enterprise database containing monitoring stations of interest inside and outside of park boundaries. Management of the AOA features will move under the Inventories 2.0 Managed Areas effort while monitoring station features will be part of the Monitoring Locations inventory.

## Areas of Analysis

The suite of AOAs as noted in the sampling design discussion (Chapter 3) is updated annually, derived from updates and changes to park boundaries promulgated by the NPS Land Resources Division (SOP 2.11.3; Kineth and Nelson 2018l, k) and amended annually based on park- or network-provided custom AOAs used to address science needs (SOP 2.11.8; Kineth and Nelson 2018i). These data are available via services at:

- Protocol-specific Areas of Analysis (park-based):  
[https://irmaservices.nps.gov/arcgis/rest/services/LandscapeDynamics/LandscapeDynamics\\_AOA/MapServer](https://irmaservices.nps.gov/arcgis/rest/services/LandscapeDynamics/LandscapeDynamics_AOA/MapServer)
- Protocol-specific Areas of Analysis (watershed):  
[https://irmaservices.nps.gov/arcgis/rest/services/LandscapeDynamics/LandscapeDynamics\\_AOA\\_HUC12/MapServer](https://irmaservices.nps.gov/arcgis/rest/services/LandscapeDynamics/LandscapeDynamics_AOA_HUC12/MapServer)

- Protocol-specific custom Areas of Analysis:  
[https://irmaservices.nps.gov/arcgis/rest/services/LandscapeDynamics/LandscapeDynamics\\_AOA\\_Custom/MapServer](https://irmaservices.nps.gov/arcgis/rest/services/LandscapeDynamics/LandscapeDynamics_AOA_Custom/MapServer)
- Boundaries and ancillary data:  
[https://irmaservices.nps.gov/arcgis/rest/services/IMDDData/IMD\\_Boundaries\\_WebMercator/MapServer](https://irmaservices.nps.gov/arcgis/rest/services/IMDDData/IMD_Boundaries_WebMercator/MapServer).

AOA features are retained in perpetuity with active vs. altered AOAs denoted with a combination of feature attributes. In cases where AOAs change (such as when park boundaries are adjusted), the area is considered a new AOA and statistics for all metrics over all source years are calculated to allow for evaluation of changes in the new area. Inactive AOA features and the metrics calculated for them are retained and flagged in the respective staging database.

### ***Monitoring Stations***

The IMD Central Office also maintains a database of monitoring station locations with location, parameters measured, and periods of record for each parameter. This includes climate stations from ACIS, and streamflow gaging stations from USGS & EPA. Climate and gaging stations managed in the NPS Aquarius system (used for some Network-based monitoring) will be integrated after data from vital sign networks have been uploaded and QA/QCed. Other stations of interest are added as new stations are identified, AOAs are updated, or new relevant data sources become available. Data pertaining to monitoring stations, parameters measured, and their respective periods of record will be made available via web services.

### ***Other Inventory Data***

A third inventory pertaining to resource management thresholds may be developed and integrated with this protocol in the future to assist with reporting status and trend information in the context of ecological, regulatory, or management thresholds of interest to parks.

### **Source Data**

Data sources used for this protocol include:

**Applied Climate Information System (ACIS).** ACIS aggregates and publishes daily, monthly, and annual summary statistics of temperature and precipitation from long-term monitoring stations from several sources and is constantly evolving to incorporate additional data sources and generate new and improved data products (DeGaetano et al. 2015, National Oceanic and Atmospheric Administration Regional Climate Science Centers 2017). Climate data available in ACIS consist of observations collected from a variety of federal, regional, state, and local weather and climate networks. Both archive-quality historical data and near-real-time data ingested from operational data transmission streams are available. ACIS data are primarily used for the generation of operational climate products. New data are continually added.

**Parameter-elevation Relationships on Independent Slopes Model (PRISM).** Climate normals (1981-2010) for temperature and precipitation from the PRISM project (Daly et al. 2008).

NPS maintains an archive of long-term PRISM 800m grids for 1895-present covering the continental U.S.

**Snow Telemetry (SNOTEL) and SnowCourse.** The Natural Resource Conservation Service maintains a network of snow telemetry stations for which snow-water-equivalent normals (1981-2010) are calculated (Natural Resource Conservation Service National Water and Climate Center 2017).

**North American Drought Monitor (NADM).** National Oceanic and Atmospheric Administration's National Centers for Environmental Information (2017) North American Drought Monitor generates broadly accepted indices including Palmer drought severity (PDSI) and standardized precipitation (SPI) for 1895 to the present (National Oceanic and Atmospheric Administration National Centers for Environmental Information 2017).

**National Water Information System (NWIS).** USGS and EPA are working together to make water quality and hydrologic data available through consistent web services through the Water Quality Portal at [www.waterqualitydata.us](http://www.waterqualitydata.us). This includes access to data collected at approximately 1.5 million sites across the US and territories, including water flow levels in streams (U.S. Geological Survey Water Resources 2017).

**Land Cover.** Datasets from the National Land Cover Database (NLCD; Multi-Resolution Land Characteristics Consortium 2011, U.S. Geological Survey Multi-resolution Land Characteristics Consortium 2014, Homer et al. 2015) and the Coastal Change Analysis Program (C-CAP) are sources for the land cover (NLCD and C-CAP) and pattern (NLCD) metrics (NOAA, 2005b, a, c, d, e, 2007a, b, c, 2010a, b, c, d, e, f, 2011a, b, 2012a, b, c).

**U.S. Census Bureau.** Metrics for population total and density, and road density and area without roads patches are derived from decadal Census block group datasets and summary files (U.S. Census Bureau 1990, 1991, 2001, 2011b, a, 2016a), and annual TIGER road feature datasets (U.S. Census Bureau 2010, 2015, 2016d, f, e, c, b), respectively. At the time of writing, a source for housing density metrics had not been chosen, however Census products may be used after source evaluations are completed.

**National Hydrography Dataset.** Metrics for area without roads require erasure of waterbodies defined by the nationwide high-resolution geodatabase within this dataset (USGS 2017).

**Other Sources.** Continuous climate and hydrologic data collected by NPS park and network staff and climate or hydrologic data not available from originating source via services may be acquired from the NPS Aquarius Web Data Portal (<https://irma.nps.gov/aqwebportal/>) or the NPS Data Store (<https://irma.nps.gov/DataStore/>). Protected area and ownership metrics will be derived from the Protected Areas of the United States dataset (PAD-US; U.S. Geological Survey National Gap Analysis Program 2016) when the dataset meets the data source evaluation criteria applied in this protocol (see *Quality Assurance and Quality Control* below).

## Derived Measures

A series of derived metrics is calculated for each AOA based on underlying source landscape dynamics, climate and hydrology data. A complete list of metrics and descriptions is provided in Appendix C. This includes:

- 791 landscape dynamics metrics for each AOA (Table 7, Appendix C). Spatial data within the boundary of the AOA is used to calculate summary statistics by measure, such as area of a metric, or percent area of a metric within an AOA.
- 26 climate metrics for stations within local-area AOAs surrounding park units and other stations of interest identified by parks and networks (Table 8; Appendix C). To the greatest extent possible, calculations of derived measures will be acquired from the source data providers when available.
- 211 hydrologic measures for stream gaging stations within park watershed AOAs (Table 11; Appendix C). Metrics will be calculated based on water year.

For processing details, see the table of standard operating procedures (SOPs) in Appendix B.

**Table 7.** Landscape dynamics measures, associated parameters, and overview of methods used. Numbers in parentheses indicate the number of metrics in each category. Specific metric descriptions are provided in Appendix C.

| Monitoring Objective                                                       | Measure                               | Parameter                  | Metric Description                                                                                         |
|----------------------------------------------------------------------------|---------------------------------------|----------------------------|------------------------------------------------------------------------------------------------------------|
| <b>Pattern and Extent of Landscape Attributes (Monitoring Objective 1)</b> | Natural Land Use / Natural Land Cover | Natural Land Cover         | Total (113) and Percent Area (113) per natural land cover class                                            |
|                                                                            | Natural Land Use / Natural Land Cover | Natural Land Use           | Total (1) and Percent (1) Area classified as natural                                                       |
|                                                                            | Morphological Spatial Pattern         | Morphological Class        | Total (42) and Percent (42) Area per morphological class                                                   |
|                                                                            | Morphological Spatial Pattern         | Core Patch Frequency       | Frequency of Core class patches, by patch size (8)                                                         |
|                                                                            | Morphological Spatial Pattern         | Patch Cover Type Frequency | Frequency of cover type patches (all classes), by patch size (4)                                           |
|                                                                            | Land Cover Pattern Density            | Density Class              | Total (126, 36) and Percent Area (126, 36) per density class, per individual class, and per class group    |
| <b>Human Drivers of Landscape Change (Monitoring Objective 2)</b>          | Impervious Developed Surface          | Impervious Surface Class   | Total and % Area per Impervious Surface Class (18)                                                         |
|                                                                            | Impervious Developed Surface          | Impervious Patch Size      | Average, minimum, and maximum patch size and total number of patches classified as impervious surface (36) |

**Table 8 (continued).** Landscape dynamics measures, associated parameters, and overview of methods used. Numbers in parentheses indicate the number of metrics in each category. Specific metric descriptions are provided in Appendix C.

| Monitoring Objective                                                          | Measure                                   | Parameter                        | Metric Description                                              |
|-------------------------------------------------------------------------------|-------------------------------------------|----------------------------------|-----------------------------------------------------------------|
| <b>Human Drivers of Landscape Change (Monitoring Objective 2) (continued)</b> | Impervious Developed Surface              | Impervious Patch Frequency       | Frequency of patches by size (varies) and class (9)             |
|                                                                               | Converted Land Use / Converted Land Cover | Converted Land Cover             | Total (36) and Percent (36) Area per converted land cover class |
|                                                                               | Converted Land Use / Converted Land Cover | Converted Land Use               | Total and percent area classified as converted (2)              |
|                                                                               | Human Population Size & Density           | Number of People                 | Area-Weighted Population Total (1)                              |
|                                                                               | Human Population Size & Density           | Area-Weighted Population Density | Area-Weighted Population Density (people per sq.km) (1)         |
|                                                                               | Human Population Size & Density           | Housing Density                  | Total and Percent Area per Housing Density Class <sup>a</sup>   |
|                                                                               | Roads                                     | Road Length                      | Total length of roads (1)                                       |
|                                                                               | Roads                                     | Road Density                     | Length of roads per sq. km (1)                                  |
|                                                                               | Roads                                     | Roadless area                    | Area of patches without roads (1)                               |
| <b>Conservation Context (Monitoring Objective 3)</b>                          | Roads                                     | Roadless Patch Frequency         | Frequency of patches of area without roads, by patch size (1)   |
|                                                                               | Protection Status                         | Area Protected                   | Total and percent area per Protection Category 2                |
|                                                                               | Protection Status                         | Ownership Type                   | Total and percent area per Ownership Category (2)               |
|                                                                               | Protection Status                         | Ownership Frequency              | Frequency of ownership per Ownership Category (1)               |
|                                                                               | Protection Status                         | Ownership Summary                | Sum of all area per Ownership Category (1)                      |

<sup>a</sup> Number of metrics unknown at this time.

**Table 9.** Climate measures, associated parameters, and overview of methods used (Monitoring Objective 4). Numbers in parentheses indicate the number of metrics in each category. Specific metric descriptions for derived measures are provided in Appendix C.

| Measure                      | Parameter                    | Metric Description                                                                                                                                         |
|------------------------------|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Air Temperature <sup>a</sup> | Temperature                  | Station and gridded temperature data from stations or areas within and surrounding parks                                                                   |
| Precipitation <sup>a</sup>   | Precipitation                | Station and gridded precipitation data from stations or areas within and surrounding parks. Includes separate parameters for liquid and snow precipitation |
| Derived Climate Measures     | Station Threshold Exceedance | Number of days above or below thresholds of interest for temperature (6) and precipitation (8)                                                             |
|                              | Growing Season               | Number of days between the last and first frost of each calendar year.                                                                                     |
|                              | Degree Days                  | Heating (1) and cooling (1) degree days                                                                                                                    |
|                              | Gridded Departures           | Monthly temperature (3), precipitation (3), and snowpack (1) departures from climate normals                                                               |
|                              | Drought                      | Monthly Palmer Drought Severity Index and Standardized Precipitation Index                                                                                 |

<sup>a</sup> Parameters that are provided from source data

**Table 10.** Surface water dynamics measures and description of associated parameters (Monitoring Objective 5: Hydrology). Numbers in parentheses indicate the number of metrics in each category. Specific metric descriptions are provided in Appendix C.

| Measure                                 | Parameters                                    | Description (number of metrics)                                                                                                                                                                                         | Reference               |
|-----------------------------------------|-----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| Discharge <sup>a</sup>                  | Discharge                                     | Daily average discharge                                                                                                                                                                                                 | USGS 2017               |
| Hydrologic Index Tool Metrics           | Event Duration                                | Indices describing the duration of high (24), and low (20) flow conditions                                                                                                                                              | Henriksen et al. (2006) |
|                                         | Event Frequency                               | Indices describing the frequency of high (11) and low (3) flow conditions                                                                                                                                               | Henriksen et al. (2006) |
|                                         | Flow Magnitude                                | Indices describing the magnitude of average (45), high (27), and low (22) flow conditions                                                                                                                               | Henriksen et al. (2006) |
|                                         | Flow Timing                                   | Indices describing the timing of average (3), high (3), and low (4) flow conditions                                                                                                                                     | Henriksen et al. (2006) |
|                                         | Rates of Change                               | Indices (9) that describe the rate of change of flow conditions                                                                                                                                                         | Henriksen et al. (2006) |
| Fundamental Daily Streamflow Statistics | Seasonal Signal                               | Indices (7) to describe and classify streams based on daily stream flow signal, including mean, coefficient of variation, skewness, kurtosis, the autoregressive lag-one, correlation coefficient, amplitude, and phase | Archfield et al. (2014) |
| Indicators of Hydrologic Alteration     | Monthly Water Conditions                      | Mean or median value of flow for each calendar month (12)                                                                                                                                                               | TNC (2007)              |
|                                         | Annual Extreme Water Conditions               | Annual minimum, maxima; number of zero-flow days, and base flow index (12)                                                                                                                                              | TNC (2007)              |
|                                         | Timing of annual extreme water conditions     | Julian dates of each annual 1-day maximum and minimum (2)                                                                                                                                                               | TNC (2007)              |
|                                         | Frequency and duration of high and low pulses | Number and duration of high and of low pulses each water year (4)                                                                                                                                                       | TNC (2007)              |
|                                         | Rate and frequency of water condition changes | Rise and fall rates, and the number of hydrologic reversals (3)                                                                                                                                                         | TNC (2007)              |

<sup>a</sup> Parameters that are provided from source data.

## Quality Assurance and Quality Control

Full data quality standards and procedures outlined in the protocol's Data Quality Standards document (Nelson et al. 2018).

### Data Source Evaluation

All data sets used in this protocol must be published and fully-documented so that their suitability for use can be evaluated for sufficient quality and quantity. Data adequacy of each potential data source

is evaluated using the framework described in Landres et al. (2017). Data adequacy is the reliability of the data to assess changes or trends in parameters or derived metrics based on the data, and considers both data quality and data quantity. It should be noted that not all metrics are suitable for use with all areas of interest; this will be driven by the size and shape of the area of interest, the metric(s) under consideration, and the scale, resolution, or other metric-specific data quality standards (Nelson et al. 2018). The adequacy of data for use in calculating metrics outlined in this protocol will be conducted by the protocol lead as source data become available.

For climate and hydrologic data, sources are evaluated for data adequacy at the provider and station level (Table 10 - Table 12), with an expectation that few stations will have complete data records during the entirety of their periods of record. Metrics will only be calculated for stations and portions of each station's period of record where data are determined to be adequate for analysis.

For landscape dynamics data, sources are evaluated for data adequacy at the provider level and by evaluating suitability for use in calculating metrics for AOAs (Table 13). It is understood that not all data sources are suitable for use in calculating metrics for all AOAs, as either spatial resolution or spatial extent of the source may be unsuitable or insufficient. Metrics will only be calculated for AOAs where data are determined to be adequate for analysis.

### ***Data Quality***

In the context of Landres et al. (2017), data quality refers to the level of confidence about the data source and whether the data are of sufficient quality to reliably identify trends in the measure. Data quality is assessed by the data's accuracy (the degree to which the data express the true condition of the measure and not other sources of variation affecting the measure), reliability (the degree to which the data follow established or well-developed scientific protocols), and relevance (the degree to which the data are spatially and temporally appropriate for the measure). However, metric values may be important to support resource management even in cases where significant trends cannot be detected (or may not be possible). IMD is only using data/information/products from credible sources with known levels of quality and completeness sufficient to calculate the metrics outlined above.

### ***Data Quantity and Completeness***

Data adequacy is also informed by the level of confidence that source data sets are complete, which can vary by data source and by location within any given data source. In determining the best available scientific information for an AOA, "available" refers to information that currently exists in a useful form, and that does not require further data collection, modification, or validation. IMD is using only data/information/products with sufficient quantity of data to calculate metrics.

**Table 11.** Hydrologic monitoring stations with relevant data for implementation of the National Park Environmental Setting monitoring protocol as of November 18, 2018 [POR = Period of Record].

| Station Type | Data Set | No. Of Potential Stations | Stations With Mean Daily Flow Data | Stations Where Metrics Can Be Calculated | Active Stations |
|--------------|----------|---------------------------|------------------------------------|------------------------------------------|-----------------|
| USGS & EPA   | NWIS     | 11,290                    | 1,507                              | 1,247                                    | 519             |

**Table 12.** Climate monitoring stations within 30km of parks with relevant data from 1957 forward (as of December 31, 2017). Period of record of 1957 to present used for prototyping methods.

| Station Type | Data Set   | No. Of Potential Stations | Active Stations for Partial POR<br>(from 1957 forward) | Active HCN Stations for Partial POR<br>(from 1957 forward) | Active Stations with Metrics for Partial POR<br>(from 1957 forward) |
|--------------|------------|---------------------------|--------------------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------------|
| NOAA/NCDC    | GHCN-Daily | 11,911                    | 3,129                                                  | 0                                                          | 3,127                                                               |
| COOP         | –          | 9,925                     | 1,216                                                  | 141                                                        | 1,216                                                               |
| WBAN         | –          | 1,004                     | 331                                                    | 331                                                        | 331                                                                 |
| SNOTEL       | –          | 212                       | 184                                                    | 184                                                        | 184                                                                 |
| RAWS         | –          | 597                       | 356                                                    | 356                                                        | 356                                                                 |
| NWSLI        | –          | 97                        | 1                                                      | 1                                                          | 1                                                                   |
| WMO          | –          | 162                       | 13                                                     | 13                                                         | 13                                                                  |
| <b>Total</b> | –          | <b>23,908</b>             | <b>5,230</b>                                           | <b>141</b>                                                 | <b>5,228</b>                                                        |

**Table 13.** Counts of active climate monitoring stations within 30km of parks summarized by climate parameter (as of December 31, 2017). Period of record of 1957 to present used for prototyping methods.

| Climate Parameter | No. Active Stations Collecting Parameter | No. Metrics Using Parameter |
|-------------------|------------------------------------------|-----------------------------|
| mint              | 1,941                                    | 2                           |
| maxt              | 1,938                                    | 2                           |
| gdd               | 1,941                                    | 1                           |
| cdd               | 1,941                                    | 1                           |
| hdd               | 1,941                                    | 1                           |
| avgt              | 1,941                                    | 2                           |
| pcpn              | 4,871                                    | 5                           |
| snow              | 4,449                                    | 3                           |

**Table 14.** General suitability of landscape dynamics source data for implementation of the National Park Environmental Setting monitoring protocol, by AOA type (For more on AOAs, see Chapter 3). Where ● = All AOAs; ◐ = Some AOAs; and ○ = No AOAs.

| Data Source               | Park                                      | 3km  | 30km | HUC12 | Custom <sup>a</sup> |
|---------------------------|-------------------------------------------|------|------|-------|---------------------|
| NLCD – Land Cover         | ◐                                         | ◐    | ●    | ●     | ●                   |
| NLCD – Impervious Surface | ○                                         | ○    | ○    | ●     | ●                   |
| C-CAP – Land Cover        | ◐                                         | ◐    | ●    | ●     | ●                   |
| TIGER Roads               | ○                                         | ○    | ●    | ●     | ●                   |
| US Census Block Groups    | ○                                         | ○    | ●    | ○     | ●                   |
| Census Housing Density    | None – No adequate data source identified | None | None | None  | None                |
| PAD-US                    | None – No adequate data source identified | None | None | None  | None                |

<sup>a</sup> where requested

#### ***Qualification Of Environmental Settings Metrics based on Underlying Data Quality***

Metrics are calculated for all AOAs or stations for all parks, but are qualified based on the following:

**Potentially Suspect.** Metric values are based on periods of record or source data that contain missing values (i.e., reporting first/last frost days for periods where data are missing during beginning/end of winter seasons).

**Metric Value Confidence.** Metric values are data based on insufficient periods of record are clearly identified as high-confidence (based on periods of record >20 years), medium-confidence (based on periods of record between 10 and 20 years), and low-confidence (based on periods of record <10 years).

**Updated.** Metric values that are re-calculated due to updated/revised source data (typical of raster sources used for calculating landscape dynamics metrics), or changes in analysis code (when provided by a 3rd party). Values that are changed will be clearly identified as “updated” with a reference to the prior version of published data.

## Chapter 5. Data Handling and Management

This chapter focuses on tools and workflows to acquire and process third party source data in support of monitoring objectives described in Chapter 2. Inventory and source data are provided through other initiatives inside and outside the National Park Service. Because those data sets are not all created by NPS, IMD will manage only re-formatted source data and products produced from it when meeting protocol objectives. Generally, source data (see Chapter 4) are acquired on annual, 5-year, or decadal intervals. Depending on the source, pre-processing may be applied then data are staged for metric calculation (Table 14). After quality assurance and control workflows are complete, metric statistics are loaded into the staging databases and metadata and documentation are updated. The staging database serves as the source for subsequent analysis and reporting functions. Re-formatted source data and metric statistics are archived on the NPS Data Store (Figure 9).

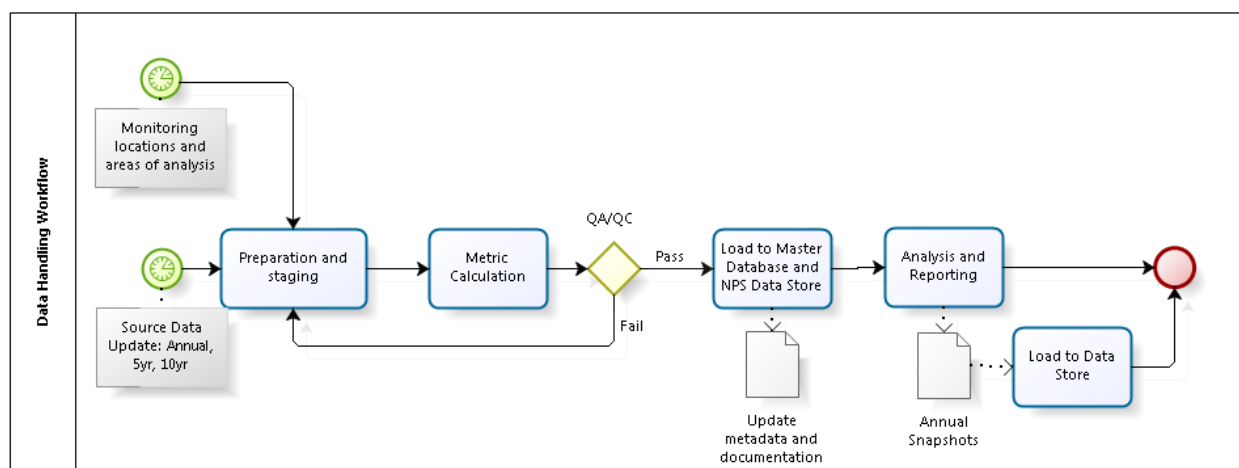


**Figure 9.** Data handling workflow.

See Appendix B for the complete list of SOPs used in this protocol.

### Data Acquisition and Pre-Processing

Availability of data varies by provider with intervals spanning one, five, and ten years. For selected sources, additional pre-processing is completed (Table 14). Pre-processing workflows vary by source and may include standardizing classifications, spatial re-projection, or re-formatting rows. Processed source data are uploaded to Data Store for archiving.

**Table 15.** Data source publication schedule and whether pre-processing is necessary prior to metric calculation.

| Source                                                                   | Access Schedule                                               | Pre-processing Needed? |
|--------------------------------------------------------------------------|---------------------------------------------------------------|------------------------|
| Applied Climate Information System (ACIS)                                | Annual (January)                                              | Yes (some)             |
| Parameter-elevation Relationships on Independent Slopes Model (PRISM)    | Annual (January)                                              | No                     |
| North American Drought Monitor (NADM)                                    | Annual (January)                                              | No                     |
| Snow Telemetry (SNOTEL) and SnowCourse                                   | Annual (January)                                              | No                     |
| National Land Cover Database (NLCD)                                      | Five years (2001, 2006, 2011, forward)                        | Yes                    |
| Coastal Change Analysis Program (C-CAP)                                  | Varies: biennial to five years depending on processing extent | Yes                    |
| National Hydrography Dataset                                             | Annual (September)                                            | Yes                    |
| U.S. Census Bureau.- TIGER Roads                                         | Annual (September)                                            | Yes                    |
| U.S. Census Bureau.-Census Block Groups and Demographic Data             | Decadal                                                       | Yes                    |
| National Water Information System (NWIS)                                 | Annual (January)                                              | Yes                    |
| U.S. Geological Survey Protected Areas of the United States <sup>a</sup> | Annual to biennial                                            | Probably               |

<sup>a</sup> Source not implemented at time of protocol inception due to data quality issues (see Chapter 5).

### ***Landscape Dynamics***

Data are not collected directly for this protocol component. Source data from external creators vary by landscape dynamics monitoring objective (see Chapter 4).

In all cases, data are downloaded from their source and staged for metric derivation. If necessary, source data may be re-formatted by re-projecting and clipping to processing areas (Table 15, Figure 10). See SOPs 2.11.9-2.11.15 for further detail.

**Table 16.** Spatial extent and references for source data used in calculating landscape dynamics metrics

| Processing Area                | Spatial Reference                           | Datum and Transformation                                                | Well-known ID <sup>a</sup> |
|--------------------------------|---------------------------------------------|-------------------------------------------------------------------------|----------------------------|
| Continental U.S. (CONUS)       | USA Contiguous Albers Equal Area Conic USGS | NAD83                                                                   | 102039                     |
| Alaska                         | Alaska Albers Equal Area Conic              | NAD83                                                                   | 3338                       |
| Hawaii                         | UTM Zone 5N                                 | NAD83                                                                   | 26905                      |
| Guam                           | WGS_1984_UTM_Zone_55N                       | NAD83<br>WGS_1984_(ITRF00)_To_NAD_1983                                  | 32655                      |
| Mariana Islands (Saipan)       | WGS_1984_UTM_Zone_55N                       | NAD83<br>WGS_1984_(ITRF00)_To_NAD_1983                                  | 32655                      |
| American Samoa                 | NAD_1983_HARN_UTM_Zone_2S                   | NAD83<br>WGS_1984_(ITRF00)_To_NAD_1983 +<br>NAD_1983_HARN_To_WGS_1984_2 | 2195                       |
| Puerto Rico and Virgin Islands | USA Contiguous Albers Equal Area Conic USGS | NAD83                                                                   | 102039                     |

<sup>a</sup> The well-known identifier denotes the ID for the spatial reference as cataloged by Environmental Systems Research Institute (2017c) and the Open Geospatial Consortium (2017). This identifier can be interpreted by different software vendors and represents a common interchange format for spatial references.

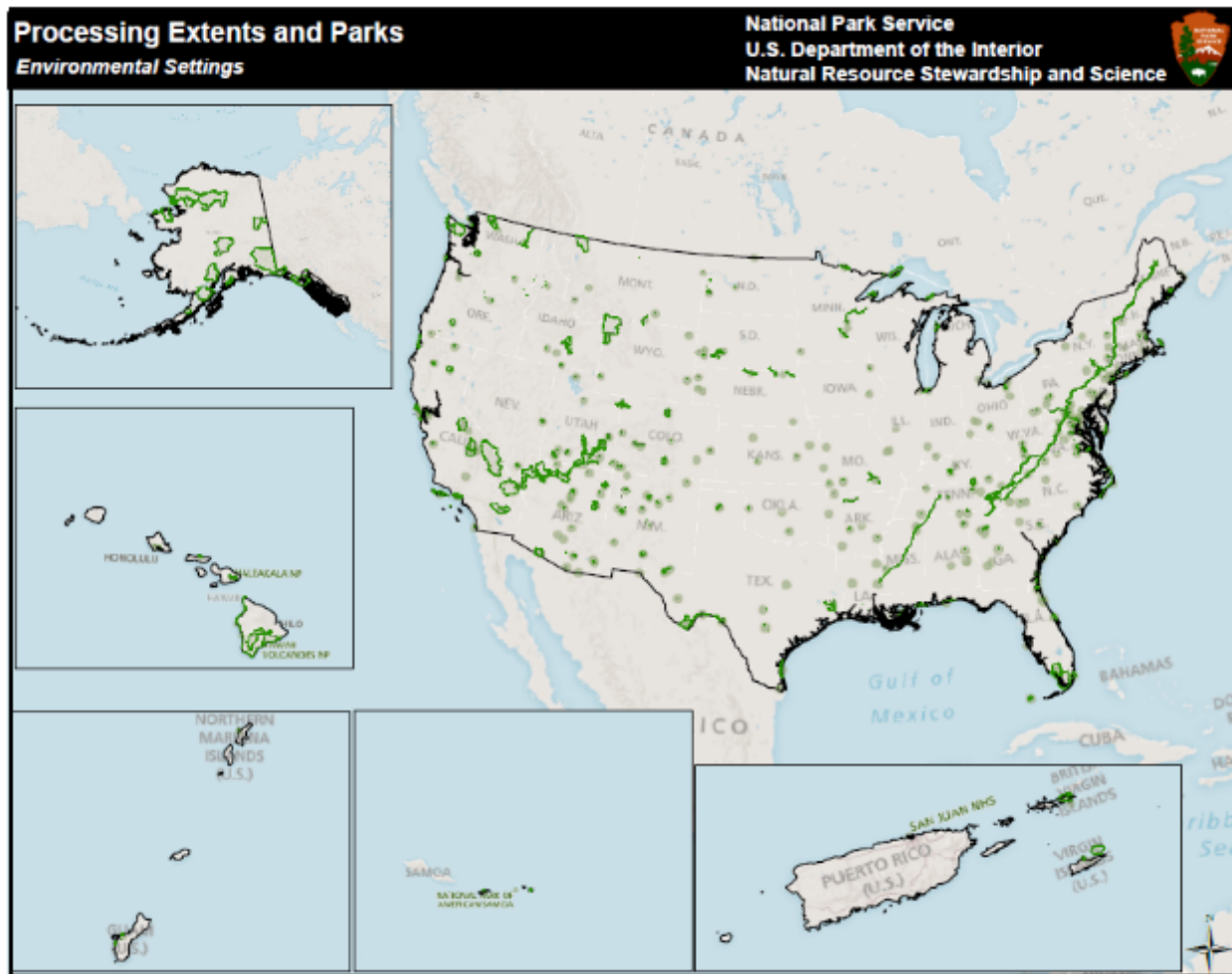


**Figure 10.** Processing areas used for calculating landscape dynamics metrics as a part of the Park Environmental Setting monitoring protocol (continental U.S., Alaska, Hawaii, American Samoa, Northern Mariana Islands, Puerto Rico, U.S. Virgin Islands). Park boundaries shown for reference.

### **Climate**

Like landscape dynamics, the climate metrics of this protocol are summarized from source data generated by external organizations. Metrics for temperature and precipitation parameters are derived from weather station readings vended by ACIS (DeGaetano et al. 2015, National Oceanic and Atmospheric Administration Regional Climate Science Centers 2017). For gridded metrics, interpolated long-term format raster data from PRISM (Daly et al. 2008) is used. NPS maintains a license for with PRISM data with an 800m spatial resolution. Climate normals (1981-2010) for temperature and precipitation are accessed from the PRISM project. Snow-water-equivalent normals (1981-2010) are calculated by the Natural Resource Conservation Service National Water and Climate Center (2017). Palmer drought severity (PDSI) and standardized precipitation (SPI) indices for 1895 to the present are maintained by the National Oceanic and Atmospheric Administration's National Centers for Environmental Information (2017).

The IMD Environmental Setting Toolkit (Nelson 2018a), written in Python and R languages (R Foundation 2017), is used to access and summarize those data. The Toolkit provides standardized techniques for determining parameter availability, period of record, and access to parameter records for historic weather stations (ACIS) and historic modeled raster surfaces (PRISM, Northwest Alliance for Computational Science and Engineering 2017) for protocol AOAs.

Planned sources for additional parameters and metrics (i.e. projected data) will be determined as need, funding, and other resources allow. And, tools and packages created via partnerships with external agencies may be leveraged.

### **Hydrology**

Hydrologic measures are calculated for stream gaging stations with daily discharge data using R and custom software applications to pull station and flow data from data services available through the USGS/EPA Water Quality Portal. Flow data used in this protocol at the time of publication are not “managed” locally by IMD. The general process is as follows:

1. Stations of interest are identified based on proximity to NPS units or as identified by park or network personnel.
2. For each station, “periods of record of interest” are identified for analysis. This includes
  - a. All periods of record from station initiation to the end of the period of record in one-year increments based on water year.
  - b. Any periods of record of interest identified by park or network personnel, which may be informative for investigating differences before and after events that may affect hydrology.
3. For each period of record X station of interest combination, metrics describing flow characteristics are calculated. These are updated annually.

Upon protocol publication, only data collected and available through the Water Quality Portal will be used for analysis of hydrologic measures, but network- or park-collected data may be considered in the future on a case-by-case basis pending an evaluation of data suitability.

### **Generation and Management of Derived Measures**

Overall, calculations are automated by looping through sets of AOA polygons (Kinseth and Nelson 2018j). Initial output tables are quality checked (see SOPs) and then loaded into database tables as provisional records. Acquisition and derivation occurs annually as source data and AOAs are updated.

If an area of analysis polygon changes or a new one is added, output tables are re-calculated and values are quality checked. Original output records for an area of analysis are flagged in the database tables. If an area of analysis polygon is removed, the original output records are flagged but retained in the master database (Kinseth and Nelson 2018g, i).

## Landscape Dynamics

All landscape dynamic metrics are generated from sources via Python tools that take advantage of the geospatial functions within the ArcGIS for Desktop and ArcPro applications (Figure 11) (Environmental Systems Research Institute 2017a, b).

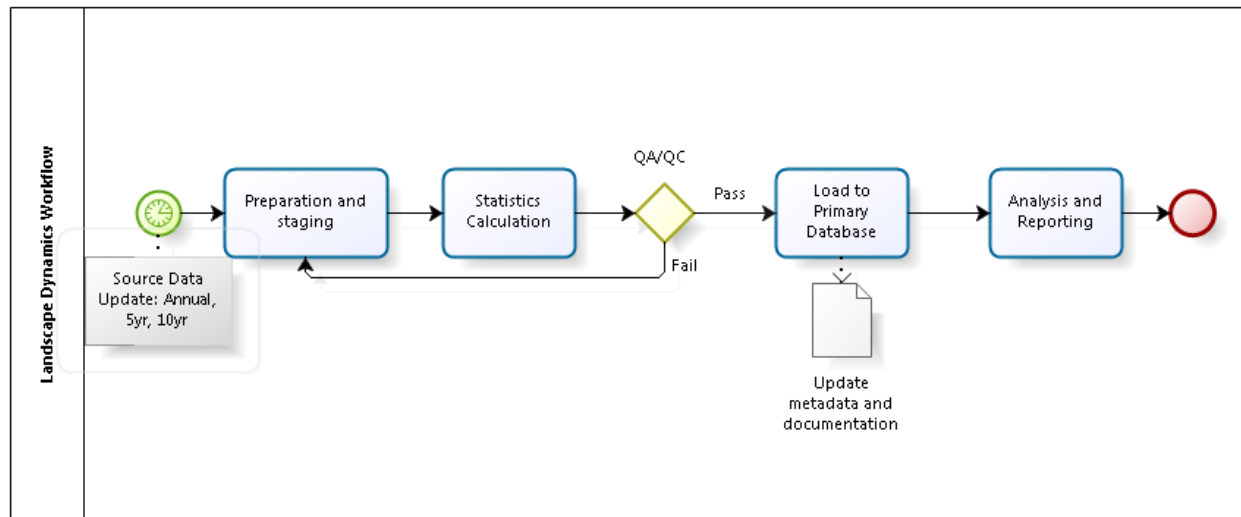


**Figure 11.** Generalized workflow for generating landscape dynamics metrics.

The landscape morphology metrics rely on software from the European Centre Joint Research Commission (Vogt 2017). The outputs from this package are inputs to the Python tools noted above.

Source data are extracted or clipped by area of analysis polygons (standard and custom) and metrics are calculated on these extracts to produce area statistics. Techniques used include:

- direct tabular summaries, as either independent or grouped categories (land cover, landscape morphology) (Kinseth and Nelson 2018g, b, h, d)
- spatial region grouping (impervious surface, landscape morphology) (Kinseth and Nelson 2018b, e)
- moving window calculation followed by tabular summary (landscape density) (Kinseth and Nelson 2018c)
- density as persons/area or roads/area (population and roads) (Kinseth and Nelson 2018e, f)
- patch area calculation (impervious surface, landscape morphology, roads) (Kinseth and Nelson 2018b, a, d)

## Climate

Most metrics derived from weather stations and modeled historic rasters (Appendix C) are acquired directly from ACIS or PRISM using functions within the IMD Environmental Setting Toolkit. Candidate stations are filtered spatially by park-level area of analysis polygon, then data are

requested using the summarization and aggregation capabilities inherent in ACIS or, for raster metrics, via the Toolkit (Nelson 2018b). The same process is applied to metrics derived from raster interpolations with the area of analysis polygon used as a direct input (Figure 12).

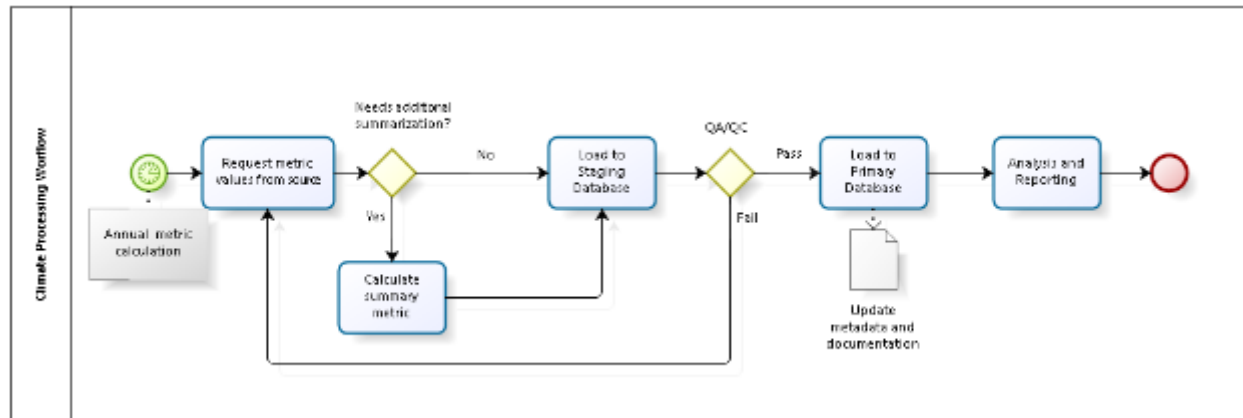


**Figure 12.** Generalized workflow for climate metric calculation.

Metrics requiring post-download summarization include:

- Monthly temperature departures
- Monthly precipitation departures
- Snow-water-equivalent departure
- Palmer drought severity indices (standard, hydrologic and z-index)
- Standardized precipitation index

Note: Indices like the Palmer drought severity and standard precipitation are calculated by the source and summarized by area of analysis via spatial clipping and tabular collation. The following metrics are either calculated derived by comparing climate normals to interim metric values that are calculated directly or are calculated directly:

- Above/Below Normal Temperature or Precipitation Days
- Micro-drought

### **Hydrology**

Calculation of metrics generally follows three steps. This SOP covers the calculation of metrics and QA/QC of resultant data. Note that only some QA/QC procedures have been developed at the time of protocol publication.

- Reviewing and updating stations of interest and periods of record of interest (SOP 3.3.3; DeVivo 2018a)

- Calculating metrics for each period of record (SOPs 3.3.1 and 3.3.2; DeVivo 2018b, c)
  - Storing metric data in protocol database where calculations succeed
  - Storing null data and qualification flag for instances where calculations fail
- Quality Assurance and Control (SOPs 3.3.1 and 3.3.2; DeVivo 2018b, c)
  - For periods of record where calculations succeed, evaluation of whether analysis code reproduces published results (from USGS) and flagging of data incorrectly reproduced. Data will be flagged by metric across all stations and periods of record.
  - For periods of record where calculations fail, evaluation of the period of record and one or more of the following:
    - Truncating the period of record to remove data gaps at the beginning or end. The period of record is qualified as differing from the published period of record with an explanation.
    - Splitting of the period of record to periods before and after discontinuities.
    - Estimation or interpolation of missing data. Metrics calculated using interpolated or estimated data are qualified as based on incomplete data records.
  - For each period of record, metrics are also qualified based on underlying data adequacy, which will be used to inform trend analyses. This will be based on a combination of the duration of the period of record, the type of calculations used in deriving metrics (seasonal averages vs. rolling averages), and the amount of estimated vs. measured data included in the analysis.

Processing of hydrologic metrics is completed using a series of the R scripts discussed above and an MS Access database that serves as an interface between R and the staging SQL database for hydrologic data. Locations and instructions for using the scripts are contained in SOPs 3.3.1-3.3.3 (DeVivo 2018a, b, c).

### **Data Storage**

Three staging SQL Server databases are used in this protocol (SOP 4.1.2; Nelson and Kinseth 2018). The staging databases are type-specific (landscape dynamics, climate, hydrology) and serve as targets for initial loads and data quality operations (Figure 13). These databases are relationally-normalized using foreign keys and constraints and follow database design recommendations specified in the IMD Database Standards guidance (Frakes et al. 2015) as well as minimum implementation standards (Frakes and Kinsgston 2017).

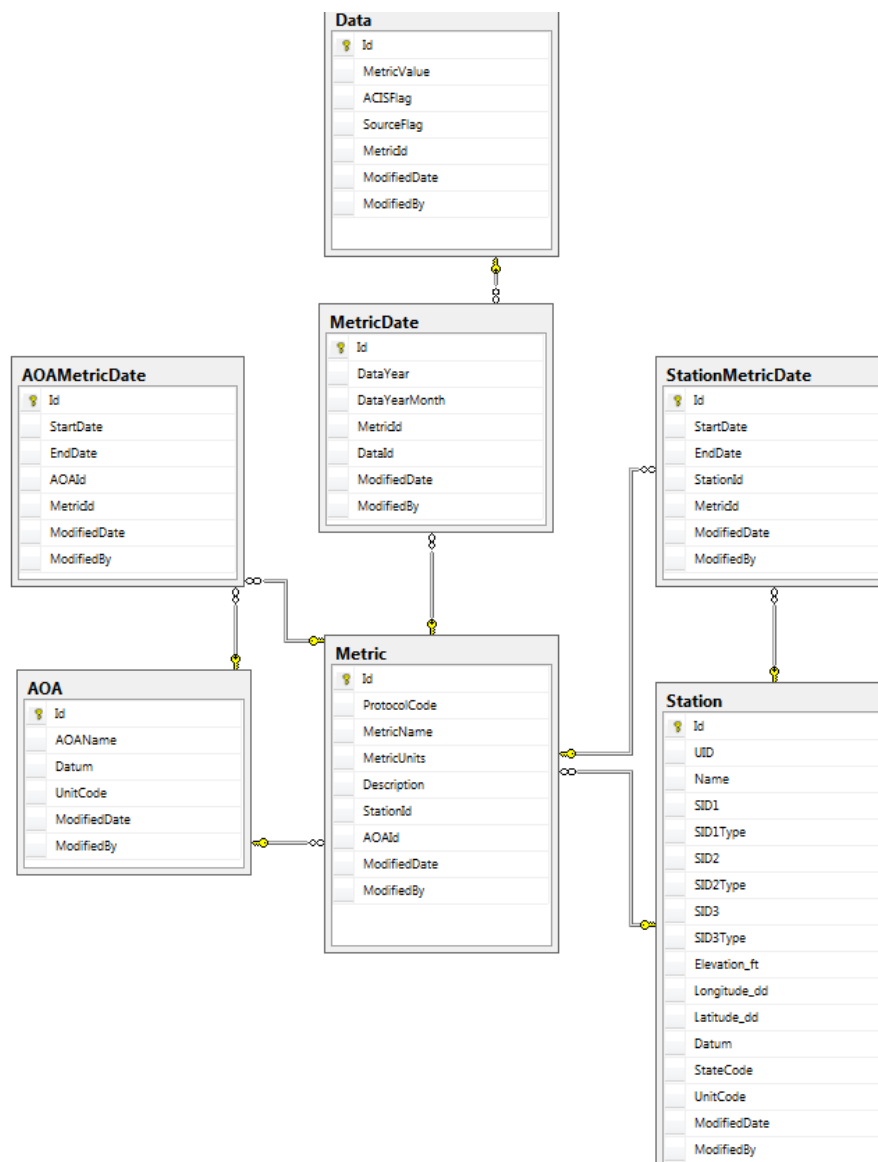


**Figure 13.** Example Staging Database entity relationship diagram for climate metrics.

Reporting databases are optimized for data delivery in tabular or spatial format and are populated from the staging databases. These databases are the source for data and services (SOP 4.1.2; Nelson and Kinseth 2018), annual snapshots, and interactive reports. And, databases from IMD Inventory 2.0 efforts may be used.

### **Data Publication, Dissemination, and Archives**

Re-formatted source data (landscape dynamics), AOAs, and selected seamless products (landscape morphology and density, road density, areas without roads) are published and disseminated via the NPS Data Store. Climate and hydrology sources are documented with Data Store records containing links to the external sources. Each Data Store record containing data files or links will be assigned a document object identifier (DOI). Reports are also published and disseminated via Data Store and will be assigned DOIs.

Data Store references are backed up daily to the Denver Data Center storage area network. Data files are backed up incrementally nightly and fully weekly.

Source and derived data are backed up daily to a storage array located in the Fort Collins office. Offsite backups are made monthly. The staging and reporting databases are backed up weekly to the Denver Data Center storage area network and copies of the backup files are placed on the Fort Collins storage array (weekly) and on the offsite backup (monthly). Staging databases are backed up as needed.

### **Data Services**

Data services, sourced from the staging or reporting databases, are available within the NPS intranet. These services vend metric records and can be queried and subset by park and vital sign network. See SOPs 4.1.2 and 7.1.1 for details (Kinseth et al. 2018, Nelson and Kinseth 2018).

### **Map Services**

Spatially enabled map, feature, and image services for AOAs and selected seamless products are available publically via IMD's ArcGIS Server site (<https://irmaservices.nps.gov/arcgis/rest/services>) and NPS ArcGIS Online (<https://nps.maps.arcgis.com/home/index.html>).

### **Metadata**

All sources used to generate landscape dynamics metric have FGDC-compliant spatial metadata (Federal Geographic Data Committee 1998) which includes data set identification information, data quality information, entity and attribute information, spatial reference information, distribution information, and contact information. Map, feature, and image service metadata is created by importing the FGDC elements of the source dataset and adding processing information.

Metric data records (landscape dynamics, climate, hydrology) vended through data services and cumulative reports include the following metadata documentation: data source, park and network codes, metric codes, data quality information, and links to detailed metadata. Additionally, data shared via reports and visualization tools has usage metadata that includes locational details, spatial reference, topical keywords, and use limitations.

### **Data Certification**

Quality assurance and quality control are applied to derived metrics. When complete, metric records are assigned a provisional data processing level. Upon approval of this protocol, metric records will be promoted to "Accepted" (NPS 2016). After the protocol's Quality Assurance Plan is approved and implemented, records meeting all QA/QC criteria will be "Certified" (DeVivo in review).

### **Records Management**

The following protocol components are managed as formal long-term permanent records – Category A.2 (NPS 2012) and are archived in the NPS Data Store:

- Protocol Narrative
- SOPs for data processing and analysis

- Quality Assurance Plan and Data Quality Statement
- Peer review forms
- Manuscript submittal forms
- Code used for disseminated analyses

Additionally, these data products (see Chapter 6) are considered formal records:

- Data sets used for analysis
- Annual snapshots of derived measures
  - Review Response: A snapshot is a temporally-based (usually annual) extraction of data records. See Chapter 6 for details.

Formal accession to NARA will occur as capabilities are developed for intake of records from NPS systems such as Data Store.

Interim versions of derived measures, staging datasets, and reference documents are retained as local records on shared network drives and as holdings on NPS Data Store references.

The record retention schedule varies by item type (Table 16). See:

<https://sites.google.com/a/nps.gov/in2-technology-and-information-resources/employee-center/programs/records-mgt/d-o-11d-guide?pli=1>

**Table 17.** Records retention schedule for Environmental Settings Protocol.

| Record Type           | Disposition Schedule                                                                  |
|-----------------------|---------------------------------------------------------------------------------------|
| Permanent (long-term) | Every three years: removed from active workspace<br>Retained in archive in perpetuity |

## Chapter 6. Analysis and Reporting

Routine data analysis and data reporting is expected to be conducted by protocol lead and other central office staff. Interpretation and integration of information produced as a part of this protocol will require coordination and collaboration among protocol, network, park, and external program staff. This will largely depend on the subject matter expertise at the network and park levels.

### **Data Reports & Data Releases**

Data will be published annually via three means: data reports, data releases made available through the NPS Data Store, and data services.

**Data Releases.** Cumulative data “snapshots” will be posted to the Data Store for all derived metrics for all AOAs and stations of interest annually. This will include documentation of source data used in analysis, and any changes to data or data quality since the last release (it is expected that as source data are updated to higher-quality versions some prior-calculated metrics will need to be revised). These data will be published with a static DOI to allow for persistent access and citation. Data will be published as a national dataset with information to allow for querying subsets by park, network, and region. Data will be published by data “type” (i.e., landscape dynamics, climate, and hydrology), and may be further partitioned based on the frequency of updates (i.e., census-driven measures will likely only be updated once every ten years).

**Data Reports.** Data reports will be produced and released with all data releases. The intent is to document the steps used in processing, an evaluation of the source data’s adequacy with regard to calculation of protocol metrics, and a summary of data qualifications for any metrics calculated. Data reports will be fully-documented and allow for reproducibility of results by independent end-users.

**Data Services.** Data will also be made available via data and map services to allow for integration with data analysis and reporting tools, including ArcGIS, NPS ArcGIS Online (AGOL), R, Python, and the NPS Park Atlas. Services will be available for the entire dataset and for the most-current data to support varying needs within the NPS.

### **Park or Area of Analysis Assessments**

Results from this protocol are ideal for summarizing at the park scale or by any AOAs defined by NPS units. For example, metrics may be used to report status or trends in metrics as a part of park resource management and planning (i.e., wilderness character monitoring, Natural Resource Condition Assessments, or viewshed analyses). The metrics used for evaluating changes are expected to vary based on the size and shape of the AOA, the management need, and the adequacy of the underlying source data. To support initial development of project plans, condition assessments, and evaluation criteria, two standard reports will be developed that summarize:

**Available Data.** The environmental setting data available for any particular AOA, including the years for which landscape dynamics data are available, periods of record for climate

parameters, and periods of record for hydrologic data and whether those data are from stations within, draining into, or near the AOA.

**Relevant Metrics.** A complete list of relevant metrics for any given AOA that includes metric descriptions, the latest value, and whether there is sufficient quantity of data to assess change or trends (the ability to detect change or trends will depend on other factors that at this time are unknown).

### **Data Visualization and Exploration**

Annual releases via data services may be shared via interactive web-based visualization tools. Basic data exploration and summary outputs will be developed that will include a combination of automated data summary reports, resource briefs, and development of content to be published through the NPS content management system.

IMD will develop tools for web-based reporting of status, change, and trends of all metrics, with the ability to build custom reports on subsets of metrics to support specific needs.

### **Analysis of Change and Trends**

Analysis of change is dependent on the amount and type of data available, the spatial scale over which trends are to be detected, and the metric(s) of interest. Because changes and trends are intended to be analyzed at the station/park/AOA scale, the methods for conducting such analyses will vary.

It is expected that several metrics will start with methods designed to identify significant change between discrete time periods to methods that use regression after sufficient data become available, which is typically five metric values. For data where sufficient data exists, multiple regression models exist for analysis of data and the appropriate model will be chosen by the Protocol Lead in consultation with a statistician based on the properties of the data used for each metric. When conducting trend analyses, we will estimate confidence intervals around all trend estimates to characterize the uncertainty about those estimates, and the range of plausible values.

### **Synthesis Reports and Publications**

Synthesis reports that include a broader look at landscape dynamics, climate, and surface water dynamics using more sophisticated data analysis techniques will be published beginning in the third year of protocol implementation and annually thereafter. Synthesis reports are intended to use environmental settings data to address specific NPS planning or conservation questions, while concurrently testing methods, assumptions, and adequacy of data to meet intended needs. Initial focus will include an analysis of metrics based on continuous climate and surface water dynamics data. Synthesis reporting may be done in partnership with other NPS programs (i.e., the Climate Response Program, Water Resources Division, or the IMD Networks) or other federal and state agencies. Wherever appropriate, findings will be published in scientific journals to allow IMD to reach a broader scientific community and promote investigation by members of the scientific community, either independently or in cooperation with the NPS.

## Chapter 7. Personnel Requirements and Training

### Personnel and Qualifications

The staffing model currently implemented for this protocol relies on Central Office IMD staff to implement data processing and reporting SOPs as well as partnerships, and advisory groups to facilitate protocol evolution. Key staff includes two scientists with sufficient statistical analysis skills to analyze and interpret data within their area of subject matter expertise, a science information specialist responsible for overall management and integration of data into systems for long-term storage and retrieval and development of tools to assist with decision support. Additionally, protocol implementation is supported by a full-time GIS specialist and one or more student interns to process data according to the protocol's SOPs. Primary duties of key positions are as follows:

#### ***Protocol Lead / Landscape Ecologist***

- Overall responsibility for ensuring implementation of the protocol as described herein
- Lead ecologist for analyzing and interpreting landscape dynamics and climate data
- Developing and testing new landscape dynamics and climate metrics and requisite SOPs relevant to emerging needs at the park, network, and national program level
- Evaluating new data landscape dynamics and climate data sources for suitability for use in meeting monitoring objectives
- Coordinating with park, network, and other program staff to integrate protocol findings into park management and operations (with an emphasis on landscape dynamics and climate information).
- Leading synthesis and external publication efforts

#### ***Water Resource Specialist***

- Lead ecologist responsible for analyzing and interpreting surface water dynamics data
- Developing and testing new surface water dynamics metrics and requisite SOPs relevant to emerging needs at the park, network, and national program level
- Evaluating new hydrologic data sources for suitability for use in meeting monitoring objectives
- Coordinating with park, network, and other program staff to integrate protocol findings into park management and operations (with an emphasis on hydrologic information).
- Contributing synthesis and external publication efforts

#### ***Science Information Specialist***

- Developing tools for data processing, automated reporting and analysis, visualization, and dissemination.

- Facilitating partnerships to integrate protocol data and data services into existing decision support tools available within NPS such as the Park Atlas.
- Contributing to synthesis and external publication efforts.
- Leading data publication efforts.

### ***GIS Specialist***

- Developing tools for processing for landscape dynamics data
- Implementing SOPs related to landscape dynamics
- Assisting with development of new methods and SOPs for processing, analyzing, and reporting landscape dynamics data

### ***Student Interns***

- Implementing SOPs related to climate and surface water dynamics
- Testing development of new methods and SOPs for landscape dynamics, climate, and hydrologic data

### **Training**

This protocol requires no specific training; it is assumed that personnel responsible for implementation of the protocol have the requisite knowledge, skills, and abilities to conduct tasks for which they are responsible.

### **Key Partnerships**

#### ***Data Analysis Workgroup (Ad-hoc)***

Since its inception, an informal workgroup has contributed to the IMD Climate Toolkit. This approach will be broadened to the landscape dynamics and hydrology components of the protocol.

Tools written in Python (Python Software Foundation 2017) and R (R Foundation 2017) are developed in a collaborative process allowing multiple staff the ability to contribute to processing and analysis workflows. Two types of code repositories in Git format facilitate this interactivity. Microsoft Team Foundation Server (TFS) holds master code and resides on servers in the Denver Data Center. GitHub allows contributions from staff outside the IMD Central Office, including partners in other agencies (URL changes in October). Periodically, code is reconciled from GitHub to the TFS repository. In both repositories, suggestions for enhancements and new functionality can be made and tracked.

#### ***Protocol Advisory Group(s)***

Implementation of the protocol will include chartering of one or more advisory groups to help advise IMD on emerging needs and priorities related to analysis and reporting of landscape dynamics, climate, and surface water dynamics data and derived metrics. The advisory group will be made up of (at a minimum), network staff, staff from other NRSS divisions (Climate Response Program,

Environmental Quality Division, Biological Resource Division, and Water Resources Division), and protocol implementation staff to ensure representation from a broad suite of users of resultant data.

#### **NOAA**

IMD and the NPS Climate Response Program are working with NOAA to develop tools to streamline access and delivery of current and historical climate data from 17 external climate monitoring programs through the ACIS platform. Future areas of collaboration include developing methods for new climate metrics, technical assistance on analysis and interpretation of data, and development of reporting and visualization tools that are shared among NPS programs and applications.

## **Chapter 8. Operational Requirements**

### **Annual Workload**

This protocol is conducted year-round requiring close coordination between the Protocol Lead and other project staff to coordinate activities (Table 17). Major tasks include incorporation of new and updated AOA's and Monitoring Stations of Interest in the fall, processing of landscape dynamics metrics in the winter, and processing of climate and surface water dynamics metrics in the spring. The summer time period is the suggested period for publication and dissemination of data and updating web-based reporting portals.

Advisory board meetings will be held in the late summer / early fall of each year to adjust annual workplans as needed to meet emerging park, network, and national program needs.

### **Permitting Requirements**

No state, federal, or park permitting or compliance is required to implement this protocol.

### **Facilities and Equipment**

Equipment required to implement the protocol are minimal; limited to desktop computers required for routine data processing and analysis.

### **Operation Costs**

Implementation of the Park Environmental Settings protocol costs roughly \$306,000 per year (FY17 dollars) with personnel representing the majority of costs (98%) required (Table 18). An additional \$150,000 in one-time project costs are also required for contracts and agreements to build infrastructure to support reporting and analysis applications (Table 19). Annual equipment maintenance and repair costs are minimal (less than \$3,000 per year).

**Table 17.** Annual implementation schedule for various components of the National Park Environmental Setting protocol.

| Topic              | Task                                                        | Deadline | JANUARY            | FEBRUARY | MARCH                 | APRIL     | MAY      | JUNE                    | JULY           | AUGUST      | SEPTEMBER  | OCTOBER              | NOVEMBER             | DECEMBER             |
|--------------------|-------------------------------------------------------------|----------|--------------------|----------|-----------------------|-----------|----------|-------------------------|----------------|-------------|------------|----------------------|----------------------|----------------------|
| All                | Reminder on custom AOAs                                     | August 1 | –                  | –        | –                     | –         | –        | –                       | Reminder       | –           | –          | –                    | –                    | –                    |
|                    | Custom AOAs due from networks                               | Sept 1   | –                  | –        | –                     | –         | –        | –                       | –              | Custom AOAs | –          | –                    | –                    | –                    |
|                    | SOPs reviewed                                               | Oct 1    | –                  | –        | –                     | –         | –        | –                       | –              | –           | SOP Review | –                    | –                    | –                    |
|                    | Areas of analysis updates                                   | Oct 15   | –                  | –        | –                     | –         | –        | –                       | –              | –           | –          | AOA Updates          | –                    | –                    |
| Climate            | Annual source downloads                                     | Feb 1    | Download           | –        | –                     | –         | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Source QA/QC and staging                                    | –        | QA/QC              | –        | –                     | –         | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Change tracking checks                                      | –        | Change tracking    | –        | –                     | –         | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Statistics calculation and QA/QC                            | –        | –                  | Stats    | –                     | –         | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Upload to master database                                   | –        | –                  | Upload   | –                     | –         | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Update metadata and post items to Data Store                | –        | –                  | –        | Post data             | –         | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Generate annual snapshots, post to Data Store               | –        | –                  | –        | Post annual snapshots | –         | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Review and update on-line reports and viz tools             | –        | –                  | –        | –                     | Review    | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Archive annual data                                         | –        | –                  | –        | –                     | –         | Archive– | –                       | –              | –           | –          | –                    | –                    | –                    |
| Hydrology          | Metric calculation & QA/QC                                  | –        | –                  | –        | –                     | Run stats | QA/QC    | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Add Metric Values to Master Database                        | –        | –                  | –        | –                     | –         | –        | Append Data             | –              | –           | –          | –                    | –                    | –                    |
|                    | Generate annual snapshots, metadata, and post to Data Store | –        | –                  | –        | –                     | –         | –        | –                       | Post Snapshots | –           | –          | –                    | –                    | –                    |
|                    | Review and update on-line reports and viz tools             | –        | –                  | –        | –                     | –         | –        | Review and update tools | –              | –           | –          | –                    | –                    | –                    |
| Landscape Dynamics | Annual data downloads (roads, hydro)                        | Oct 1    | –                  | –        | –                     | –         | –        | –                       | –              | –           | Download   | –                    | –                    | –                    |
|                    | 5-year data downloads (land cover)                          | Dec 1    | –                  | –        | –                     | –         | –        | –                       | –              | –           | –          | –                    | Download             | –                    |
|                    | 10-year data downloads (population)                         | Dec 1    | –                  | –        | –                     | –         | –        | –                       | –              | –           | –          | –                    | Download             | –                    |
|                    | Source processing, QA/QC and staging                        | –        | –                  | –        | –                     | –         | –        | –                       | –              | –           | –          | Processing and QA/QC | Processing and QA/QC | Processing and QA/QC |
|                    | Change tracking checks                                      | –        | –                  | –        | –                     | –         | –        | –                       | –              | –           | –          | –                    | Change tracking      | –                    |
|                    | Statistics calculation and QA/QC                            | –        | Stats              | –        | –                     | –         | –        | –                       | –              | –           | –          | –                    | Stats (annual)       | –                    |
|                    | Upload to master database                                   | –        | –                  | Upload   | –                     | –         | –        | –                       | –              | –           | –          | –                    | –                    | Upload (annual)      |
|                    | Update metadata and post items to Data Store                | –        | Post data (annual) | –        | Post data             | –         | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Generate annual snapshots, post to Data Store               | –        | –                  | –        | Post annual snapshots | –         | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Review and update on-line reports and viz tools             | –        | –                  | –        | –                     | Review    | –        | –                       | –              | –           | –          | –                    | –                    | –                    |
|                    | Archive Data                                                | –        | –                  | –        | –                     | –         | –        | –                       | –              | Archive     | –          | –                    | –                    | –                    |

**Table 188.** Estimated annual operating costs for implementation of the IMD Park Environmental Settings Monitoring Protocol. Based on FY2017 costs for staff duty stationed in Fort Collins, Colorado.

| Category                                | Item                                | Cost (FY 2017) | Notes                       |
|-----------------------------------------|-------------------------------------|----------------|-----------------------------|
| <b>Personnel</b>                        | Landscape Ecologist (Protocol Lead) | 94,258         | 0.8 FTE, GS-12 Step 4       |
|                                         | Water Resource Specialist           | 28,021         | 0.2 FTE, GS-13 Step 4       |
|                                         | Science Information Specialist      | 69,624         | 0.5 FTE, GS-12 Step 10      |
|                                         | GIS Technician                      | 81,248         | 1.0 FTE, GS-9 or Equivalent |
|                                         | Student Intern                      | 26,812         | 0.5 FTE, GS-5 or Equivalent |
|                                         | <b>Total Personnel</b>              | <b>299,962</b> | –                           |
| <b>Non-Personnel Costs</b>              | Computer Equipment                  | 3,000          | –                           |
|                                         | <b>Total Non-personnel</b>          | <b>3,000</b>   | –                           |
| <b>Travel</b>                           | Protocol Advisory Board Meeting     | 3,000          | –                           |
|                                         | <b>Total Travel Costs</b>           | <b>3,000</b>   | –                           |
| <b>Total Annual Implementation Cost</b> |                                     | <b>305,962</b> | –                           |

**Table 199.** Estimated one-time project costs required (based on FY 2019 data) for implementation of the IMD Park Environmental Settings Monitoring Protocol. Based on FY2017 dollars.

| Contracts & Agreements                  | Cost (FY 2017) | Partner |
|-----------------------------------------|----------------|---------|
| Climate                                 | 50,000         | NOAA    |
| <b>Total Contracts &amp; Agreements</b> | <b>50,000</b>  | –       |
| <b>Total One-time Project Costs</b>     | <b>50,000</b>  | –       |

## Safety

Implementation of this protocol has minimal risks as all activities take place in an office setting. Protocol implementation staff will follow the general guidelines set forth in the NPS Occupational Safety and Health Program (Directors Order #50B, September 2008). These procedures are generally outlined as follows:

1. Adhere to established occupational safety and health procedures, including those contained within Reference Manual 50B.
2. Work collaboratively with supervisors to develop and use job hazard analyses or equivalent for all routine tasks, and help develop and use site-specific safety plans for non-routine, complex, multi-phase jobs.
3. Properly use and maintain required clothing and/or personal protective equipment.

4. Maintain a level of personal wellness and fitness as needed for assigned work tasks.
5. Identify and, where appropriate, correct unsafe conditions and work practices.
6. Report unsafe/unhealthful conditions and/or operations to his or her immediate supervisor or the appropriate chain of command.
7. Report mishaps, including minor accidents and "near-hits," to a supervisor as soon as possible, but in no case later than the end of the work shift.
8. Participate in establishing a safe working culture, and practice safe work procedures, even when working alone.

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## Appendix A. Vital Signs Monitoring Plans

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## Appendix B. Standard Operating Procedures

To ensure consistent procedures Network-wide as Standard Operating Procedures (SOPs are revised, updated, and re-published), the IMD Central Office maintains a single library of SOPs that are shared across all nationally-managed inventory and monitoring efforts. All approved SOPs are published in the National Park Service (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 (IRMA) portal at <http://irma.nps.gov>.

All IMD Central Office SOPs conform to a standard three-part numbering system to aid in the identification of the portion(s) of the program to which the procedures apply (Table B-1). Because SOPs are regularly updated, the Central Office maintains the complete collection of the most recent and working versions of all Central Office SOPs, housed on the IMD SharePoint at:

<https://nrss.sharepoint.nps.gov/div/imd/co/planning/Forms/AllItems.aspx?RootFolder=%2Fdiv%2Fimd%2Fco%2Fplanning%2FScience&FolderCTID=0x012000D9C32792294CA042B45AEF3504E8837C&View=%7B8362921E%2D7E69%2D44A2%2DA147%2D89FB943AFC28%7D>.

The subset of the Central Office's SOPs are necessary for the implementation of the Park Environmental Setting Monitoring Protocol is listed in Table B-2.

**Table B-1.** Numbering system and categories for Standard Operating Procedures (SOPs) used by the Environmental Settings Protocol. Within each category, SOPs are numbered sequentially as they are produced.

| Category                                            | SOP Number | Topic                                                                                                                                                                               |
|-----------------------------------------------------|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>1. Data Collection and Acquisition</b>           | 1.1.x      | General data collection or acquisition shared by multiple inventory & monitoring efforts (i.e., those related to GIS, GPS location, photopoints, or use of shared instrumentation). |
|                                                     | 1.2.x      | Water & Sediment Quality and Chemistry                                                                                                                                              |
|                                                     | 1.3.x      | Water Quantity                                                                                                                                                                      |
|                                                     | 1.4.x      | Wildlife                                                                                                                                                                            |
|                                                     | 1.5.x      | Plants                                                                                                                                                                              |
|                                                     | 1.6.x      | Weather & Climate                                                                                                                                                                   |
|                                                     | 1.7.x      | Geophysical                                                                                                                                                                         |
|                                                     | 1.8.x      | Acoustic                                                                                                                                                                            |
|                                                     | 1.9.x      | Light / Night Sky                                                                                                                                                                   |
|                                                     | 1.10.x     | Socioeconomics                                                                                                                                                                      |
|                                                     | 1.11.x     | Remote Sensing                                                                                                                                                                      |
| <b>2. Data Handling, Processing, and Management</b> | 2.1.x      | Data management procedures shared by multiple inventory & monitoring efforts, such as those pertaining to reporting, file management.                                               |
|                                                     | 2.2.x      | Water & Sediment Quality and Chemistry                                                                                                                                              |
|                                                     | 2.3.x      | Water Quantity                                                                                                                                                                      |
|                                                     | 2.4.x      | Wildlife                                                                                                                                                                            |
|                                                     | 2.5.x      | Plants                                                                                                                                                                              |
|                                                     | 2.6.x      | Weather & Climate                                                                                                                                                                   |
|                                                     | 2.7.x      | Geophysical                                                                                                                                                                         |
|                                                     | 2.8.x      | Acoustic                                                                                                                                                                            |
|                                                     | 2.9.x      | Light / Night Sky                                                                                                                                                                   |
|                                                     | 2.10.x     | Socioeconomics                                                                                                                                                                      |
|                                                     | 2.11.x     | Geoprocessing                                                                                                                                                                       |
| <b>3. Data Analysis</b>                             | 3.x.x      | Data Analysis. (subcategories follow those of data collection and management)                                                                                                       |
| <b>4. Reporting &amp; Communications</b>            | 4.x        | Reporting & Communications.                                                                                                                                                         |
| <b>5. Safe Operations</b>                           | 5.x        | Safety.                                                                                                                                                                             |
| <b>6. Program Administration</b>                    | 6.x        | Program Administration                                                                                                                                                              |
| <b>7. Technical Documentation</b>                   | 7.1.x      | Database Documentation                                                                                                                                                              |
|                                                     | 7.2.x      | Systems & Services Documentation                                                                                                                                                    |

**Table B-2.** Standard Operating Procedures required to implement the IMD Park Environmental Setting Monitoring Protocol. The subject category, SOP number, title, and Integrated Resources Management Applications (IRMA) record numbers are provided.

| Subject                | SOP#   | Citation                                                                                                                                                                                                                                                                                                               | IRMA Record Number      |
|------------------------|--------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| <b>Data Management</b> | 2.11.2 | Kinseth, M. and L. Nelson. 2018. NPS unit boundary processing: Park operational administrative boundaries. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—2.11.2. National Park Service, Fort Collins, Colorado.                                                                             | <a href="#">2256634</a> |
|                        | 2.11.3 | Kinseth, M. and L. Nelson. 2018. NPS unit boundary processing: Reconciliation of official Lands Division and park operational administrative boundaries. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—2.11.3. National Park Service, Fort Collins, Colorado.                               | <a href="#">2256638</a> |
|                        | 2.11.4 | Kinseth, M. and L. Nelson. 2018. NPS unit boundary processing: Boundaries for use for analysis and reporting by the Inventory & Monitoring Division. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—2.11.4. National Park Service, Fort Collins, Colorado.                               | <a href="#">2256648</a> |
|                        | 2.11.5 | Kinseth, M. and L. Nelson. 2018. NPS unit boundary processing: Boundaries for use for analysis and reporting as a part of the IMD Environmental Settings Protocol. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—2.11.5. National Park Service, Fort Collins, Colorado.                     | <a href="#">2256760</a> |
|                        | 2.11.6 | Kinseth, M. and L. Nelson. 2018. NPS Unit Boundary Processing: Boundary-derived areas of analysis for Use as a Part of the IMD Environmental Settings Protocol Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—2.11.6. National Park Service, Fort Collins, Colorado.                         | <a href="#">2256760</a> |
|                        | 2.11.7 | Kinseth, M. and L. Nelson. 2018. Creating HUC12 areas of analysis for use with the IMD Environmental Settings Protocol. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—2.11.7. National Park Service, Fort Collins, Colorado.                                                                | <a href="#">2257569</a> |
|                        | 2.11.8 | Kinseth, M. and L. Nelson. 2018. Creating custom areas of analysis for use as a part of the IMD Environmental Settings Protocol. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—2.11.8. National Park Service, Fort Collins, Colorado.                                                   | <a href="#">2257579</a> |
|                        | 2.11.9 | Kinseth, M. and L. Nelson. 2018. Processing land cover source data to derive landscape dynamics metrics: Anderson Level 1 and 2 classification, and natural vs. converted land use Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—2.11.9. National Park Service, Fort Collins, Colorado. | <a href="#">2244308</a> |

**Table B-2 (continued).** Standard Operating Procedures required to implement the IMD Park Environmental Setting Monitoring Protocol. The subject category, SOP number, title, and Integrated Resources Management Applications (IRMA) record numbers are provided.

| Subject                            | SOP#    | Citation                                                                                                                                                                                                                                                                            | IRMA Record Number      |
|------------------------------------|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| <b>Data Management (continued)</b> | 2.11.10 | Kineth, M. and L. Nelson. 2018. Processing source data to derive landscape dynamics metrics: NHD high-resolution source data. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—2.11.10. National Park Service, Fort Collins, Colorado.                  | <a href="#">2257609</a> |
|                                    | 2.11.11 | Kineth, M. and L. Nelson. 2018. Processing land cover source data to derive landscape dynamics metrics: Impervious surface. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—2.11.11. National Park Service, Fort Collins, Colorado.                    | <a href="#">2257611</a> |
|                                    | 2.11.12 | Kineth, M. and L. Nelson. 2018. Processing source data to derive landscape dynamics metrics: Population source data. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—2.11.12. National Park Service, Fort Collins, Colorado.                           | <a href="#">2257682</a> |
|                                    | 2.11.13 | Kineth, M. and L. Nelson. 2018. Processing source data to derive landscape dynamics metrics: Road source data. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—2.11.13. National Park Service, Fort Collins, Colorado.                                 | <a href="#">2257624</a> |
|                                    | 2.11.14 | Nelson, L. and M. Kineth. 2018. Processing source data to derive landscape dynamics metrics: Area without roads. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—2.11.14. National Park Service, Fort Collins, Colorado.                               | <a href="#">2244311</a> |
|                                    | 2.11.15 | Nelson, L. and M. Kineth. 2018. Processing land cover source data to derive landscape dynamics metrics: Pattern. Inventory & Monitoring Program Standard Operating Procedure NPS/IMD/SOP—2.11.15. National Park Service, Fort Collins, Colorado.                                    | <a href="#">2244333</a> |
|                                    | 2.11.16 | Kineth, M. and L. Nelson. In Development. Processing land cover source data to derive landscape dynamics metrics: Housing density source data. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—2.11.16. National Park Service, Fort Collins, Colorado. | TBD                     |
|                                    | 2.11.18 | Kineth, M. 2018. Maintenance and management of the landscape dynamics data viewer for use as part of the IMD Environmental Settings Protocol. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—2.11.18. National Park Service, Fort Collins, Colorado.      | <a href="#">2257621</a> |
|                                    | 2.11.19 | Kineth, M. and L. Nelson. 2018. Processing land cover source data to derive landscape dynamics metrics: Protected area data. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—2.11.19. National Park Service, Fort Collins, Colorado.                   | <a href="#">2257683</a> |

**Table B-2 (continued).** Standard Operating Procedures required to implement the IMD Park Environmental Setting Monitoring Protocol. The subject category, SOP number, title, and Integrated Resources Management Applications (IRMA) record numbers are provided.

| <b>Subject</b>       | <b>SOP#</b> | <b>Citation</b>                                                                                                                                                                                                                                                                                    | <b>IRMA<br/>Record<br/>Number</b> |
|----------------------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| <b>Data Analysis</b> | 3.3.1       | DeVivo, J. C. 2018. Calculation of Hydrologic Indicator Tools metrics and Fundamental Daily Streamflow Statistics. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—3.3.1. National Park Service, Fort Collins, Colorado.                                                  | <a href="#"><u>2257684</u></a>    |
|                      | 3.3.2       | DeVivo, J. C. 2018. Calculation of Indicators of Hydrologic Alteration metrics. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—3.3.2. National Park Service, Fort Collins, Colorado.                                                                                     | <a href="#"><u>2257686</u></a>    |
|                      | 3.3.3       | DeVivo, J. C. 2018. Acquiring and Preparing Mean Daily Flow Data for use in Calculation of Hydrologic Metrics as a part of the IMD Environmental Settings Protocol. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—3.3.3. National Park Service, Fort Collins, Colorado. | <a href="#"><u>2257687</u></a>    |
|                      | 3.6.1       | Nelson, L. 2018. Processing climate metrics as a part of the IMD Environmental Settings Protocol. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—3.6.1. National Park Service, Fort Collins, Colorado.                                                                   | <a href="#"><u>2257730</u></a>    |
|                      | 3.11.1      | Kineth, M. and L. Nelson. 2018. Calculating statistics for national landscape dynamics metrics: Pattern density. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.1. National Park Service, Fort Collins, Colorado.                                               | <a href="#"><u>2257628</u></a>    |
|                      | 3.11.2      | Kineth, M. and L. Nelson. 2018. Quality assurance and quality control for landscape dynamics metrics: Pattern density. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.12. National Park Service, Fort Collins, Colorado.                                        | <a href="#"><u>2257639</u></a>    |
|                      | 3.11.3      | Kineth, M. and L. Nelson. 2018. Calculating statistics for national landscape dynamics metrics: Total and percent area per national land cover category. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.3. National Park Service, Fort Collins, Colorado.       | <a href="#"><u>2257649</u></a>    |
|                      | 3.11.4      | Kineth, M. and L. Nelson. 2018. Calculating statistics for national landscape dynamics metrics: Area without roads. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.4. National Park Service, Fort Collins, Colorado.                                            | <a href="#"><u>2257650</u></a>    |
|                      | 3.11.5      | Kineth, M. and L. Nelson. 2018. Calculating statistics for national landscape dynamics metrics: Impervious surface. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.5. National Park Service, Fort Collins, Colorado.                                            | <a href="#"><u>2257669</u></a>    |

**Table B-2 (continued).** Standard Operating Procedures required to implement the IMD Park Environmental Setting Monitoring Protocol. The subject category, SOP number, title, and Integrated Resources Management Applications (IRMA) record numbers are provided.

| Subject                          | SOP#    | Citation                                                                                                                                                                                                                                                                                            | IRMA Record Number      |
|----------------------------------|---------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| <b>Data Analysis (continued)</b> | 3.11.6  | Kinseth, M. and L. Nelson. 2018. Calculating statistics for national landscape dynamics metrics: Total and percent area for natural and converted land cover. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.6. National Park Service, Fort Collins, Colorado.   | <a href="#">2257670</a> |
|                                  | 3.11.7  | Kinseth, M. and L. Nelson. 2018. Calculating statistics for national landscape dynamics metrics: Population density and total population. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.7. National Park Service, Fort Collins, Colorado.                       | <a href="#">2244325</a> |
|                                  | 3.11.8  | Kinseth, M. and L. Nelson. 2018. Calculating statistics for national landscape dynamics metrics: Road density. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.8. National Park Service, Fort Collins, Colorado.                                                  | <a href="#">2257671</a> |
|                                  | 3.11.9  | Kinseth, M. and L. Nelson. 2018. Quality assurance and quality control for landscape dynamics metrics: Total and percent area per national land cover category. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.9. National Park Service, Fort Collins, Colorado. | <a href="#">2257672</a> |
|                                  | 3.11.10 | Kinseth, M. and L. Nelson. 2018. Quality assurance and quality control for landscape dynamics metrics: Total and percent area for natural and converted lands. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.10. National Park Service, Fort Collins, Colorado. | <a href="#">2257673</a> |
|                                  | 3.11.11 | Kinseth, M. and L. Nelson. 2018. Quality assurance and quality control for landscape dynamics metrics: Total and percent area for impervious surface. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.11. National Park Service, Fort Collins, Colorado.          | <a href="#">2257674</a> |
|                                  | 3.11.12 | Kinseth, M. and L. Nelson. 2018. Quality assurance and quality control for landscape dynamics metrics: Pattern density. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.12. National Park Service, Fort Collins, Colorado.                                        | <a href="#">2257675</a> |
|                                  | 3.11.13 | Kinseth, M. and L. Nelson. 2018. Quality assurance and quality control for landscape dynamics metrics: Pattern morphology. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.13. National Park Service, Fort Collins, Colorado.                                     | <a href="#">2257676</a> |

**Table B-2 (continued).** Standard Operating Procedures required to implement the IMD Park Environmental Setting Monitoring Protocol. The subject category, SOP number, title, and Integrated Resources Management Applications (IRMA) record numbers are provided.

| <b>Subject</b>                            | <b>SOP#</b> | <b>Citation</b>                                                                                                                                                                                                                                                                     | <b>IRMA<br/>Record<br/>Number</b> |
|-------------------------------------------|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|
| <b>Data Analysis<br/>(continued)</b>      | 3.11.14     | Kineth, M. and L. Nelson. 2018. Quality assurance and quality control for landscape dynamics metrics: Population density and total population. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.14. National Park Service, Fort Collins, Colorado. | <a href="#">2257677</a>           |
|                                           | 3.11.15     | Kineth, M. and L. Nelson. 2018. Quality assurance and quality control for landscape dynamics metrics: Area without roads. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.15. National Park Service, Fort Collins, Colorado.                      | <a href="#">2257679</a>           |
|                                           | 3.11.16     | Kineth, M. and L. Nelson. 2018. Quality assurance and quality control for landscape dynamics metrics: Road density. Inventory & Monitoring Program Standard Operating Procedure NPS/NRSS/IMD/SOP—3.11.16. National Park Service, Fort Collins, Colorado.                            | <a href="#">2257680</a>           |
| <b>Reporting &amp;<br/>Communications</b> | 4.1.1       | Kineth, M. and L. Nelson. 2018. Publishing to Data Store. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—4.1.1. National Park Service, Fort Collins, Colorado.                                                                                            | <a href="#">2257681</a>           |
|                                           | 4.1.2       | Nelson, L. and M. Kineth. 2018. Creating and maintaining data services for the IMD Environmental Settings Monitoring Protocol. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—4.1.2. National Park Service, Fort Collins, Colorado.                       | <a href="#">2257722</a>           |
|                                           | 4.1.3       | Reporting procedures as a part of the IMD Environmental Settings Monitoring Protocol. Inventory & Monitoring Division Standard Operating Procedure NPS/IMD/SOP—4.1.3. National Park Service, Fort Collins, Colorado.                                                                | <a href="#">2257732</a>           |
| <b>Technical<br/>Documentation</b>        | 7.1.1       | Kineth, M., L. Nelson, and S. Schupbach. 2018. Inventory and monitoring database documentation: Environmental Setting Protocol. Inventory & Monitoring Division Standard Operating Procedure NPS/NRSS/IMD/SOP—7.1.1. National Park Service, Fort Collins, Colorado.                 | <a href="#">2257676</a>           |

## Appendix C. Definitions of Derived Metrics Used for Analysis.

Metrics are derived for Areas of Analysis (see Chapter 3), or climate/hydrological monitoring stations from data sources that meet data quality criteria as specified in Chapter 4 (Table C-1). These metrics are categorized by the type of change they document (see Chapter 6). See Chapter 5 for details on data handling and management.

### Landscape Dynamics

Derived metrics for landscape dynamics are calculated from external sources which vary by measure.

- Land cover:
  - National Land Cover Dataset (Homer, et al., 2015, Multi-Resolution Land Characteristics Consortium, 2011, U.S. Geological Survey, 2014)
  - Coastal Change Analysis Program (National Oceanic and Atmospheric Administration, Office for Coastal Management, 2005, 2007, 2010, 2011, 2012)
- Landscape pattern:
  - National Land Cover Dataset (Homer, et al., 2015, Multi-Resolution Land Characteristics Consortium, 2011, U.S. Geological Survey, 2014)
- Population:
  - U.S. Census block groups (U.S. Census Bureau, 2011a, 2011b, 2001, 1991, 1990)
- Roads:
  - U.S. Census TIGER line files (U.S. Census Bureau, 2010, 2015, 2016)
- Conservation Status: not implemented at time of protocol inception
- Housing: not implemented at time of protocol inception

The metric alphanumeric code preceding each definition refers to the category of landscape dynamics metric that is to be calculated. For example, LC1-1 is the first Land Cover Class metric.

- LC1/2# - Land Cover Level 1 class metrics
- LC3/4# – Land Cover Level 2 class metrics
- LNAT# - Land Cover Natural class metrics
- LCONV# – Land Cover Converted class metrics
- LPI# - Impervious Surface class metrics

- PM# - Pattern Morphology class metrics
- PDEN# - Land Cover Density metrics
- HDD# - Housing metrics
- PTT#, PDD# - Human population metrics
- RDD# - Road Density metrics
- AWR# - Area without roads metrics
- CAP#, COW# - Conservation Status metrics

**Table C-1.** Definitions for landscape dynamics metrics calculated as a part of the NPS Park Environmental Settings Monitoring Protocol. Metrics are calculated for each area of analysis. Detection of change will be based on “any-change” criteria as discussed in Chapter 6.

| <b>Metric</b>                                                     | <b>Definition</b>                                                                                                         |
|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| LC1-1 to LC1-18                                                   | Class <sup>a</sup> Area of each Anderson Level 1 land cover class, in km <sup>2</sup>                                     |
| LC2-1 to LC2-18                                                   | Percent <sup>b</sup> Area per Anderson Level 1 land cover class, in km <sup>2</sup>                                       |
| Any changeLC3-1 to LC3-131                                        | Class <sup>a</sup> Area of each Anderson Level 2 class, in km <sup>2</sup>                                                |
| LC4-1 to LC4-131                                                  | Percent <sup>b</sup> Area per Anderson Level 2 class, in km <sup>2</sup>                                                  |
| LNAT1                                                             | Class <sup>a</sup> Area of class Natural as defined in SOP XX, in km <sup>2</sup>                                         |
| LNAT2                                                             | Percent <sup>b</sup> Area of class Natural as defined in SOP XX, in km <sup>2</sup>                                       |
| LCONV1                                                            | Class <sup>a</sup> Area of class Converted, in km <sup>2</sup>                                                            |
| LCONV2                                                            | Percent <sup>b</sup> Area of class Converted, in km <sup>2</sup>                                                          |
| LPI1-1 to LPI1-9                                                  | Class <sup>a</sup> Area of each grouped impervious surface class, in km <sup>2</sup>                                      |
| LPI2-1 to LPI2-9                                                  | Percent <sup>b</sup> Area per impervious class, in km <sup>2</sup>                                                        |
| LPI_PF1 to LPI_PF9                                                | Frequency of patches classified as impervious surface, by grouped impervious surface class, in km <sup>2</sup>            |
| LPI_AVG1 to LPI_AVG9                                              | Average patch size classified as impervious surface, per grouped impervious class, in km <sup>2</sup>                     |
| LPI_MIN1 to LPI_MIN9                                              | Minimum patch size classified as impervious surface, per grouped impervious class, in km <sup>2</sup>                     |
| LPI_MAX1 to LPI_MAX9                                              | Maximum patch size classified as impervious surface, per grouped impervious class, in km <sup>2</sup>                     |
| LPI_TOT1 to LPI_TOT9                                              | Total number of patches of impervious surface, per grouped impervious class                                               |
| PM1-1 to PM1-7;<br>PM2-1 to PM2-7                                 | Class <sup>a</sup> Area for each of seven morphological classes and two edge widths, in km <sup>2</sup>                   |
| PM3-1 to PM3-7;<br>PM4-1 to PM4-7                                 | Percent <sup>b</sup> Area for each of seven morphological classes and two edge widths, in km <sup>2</sup>                 |
| PM_PF_CORE1-1 to PM_PF_CORE1-4;<br>PM_PF_CORE2-1 to PM_PF_CORE2-4 | Frequency of patches classified as morphology class “Core”, by cover type, patch size, and edge width, in km <sup>2</sup> |
| PM_PF1 to PM_PF4                                                  | Frequency of patches by cover type, by patch size, in km <sup>2</sup>                                                     |
| PDEN[1, 2, 3, 4, 5, 6]-1 to PDEN[1, 2, 3, 4, 5, 6]-21             | For window sizes [7, 13, 27, 81, 243, 729], class area for each of 21 density classes, in km <sup>2</sup>                 |

<sup>a</sup> Class Area = (Class cell count \* 900m) / 1,000,000;

<sup>b</sup> Percent Area = (Total Area / Class Area) \* 100

**Table C-1 (continued).** Definitions for landscape dynamics metrics calculated as a part of the NPS Park Environmental Settings Monitoring Protocol. Metrics are calculated for each area of analysis. Detection of change is will be based on “any-change” criteria as discussed in Chapter 6.

| <b>Metric</b>                                               | <b>Definition</b>                                                                                                                                                                                  |
|-------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PDEN[7, 8, 9, 10, 11, 12]-1 to PDEN[7, 8, 9, 10, 11, 12]-21 | For window sizes [7, 13, 27, 81, 243, 729], percent area <sup>b</sup> of patches for each of 21 density classes, in km <sup>2</sup>                                                                |
| PDEN_G[1, 2, 3, 4, 5, 6]-1 to PDEN_G[1, 2, 3, 4, 5, 6]-6    | For window sizes [7, 13, 27, 81, 243, 729], class area <sup>a</sup> of patches in each of six grouped density classes, in km <sup>2</sup>                                                          |
| PDEN_G[8, 9, 10, 11, 12]-1 to PDEN_G[8, 9, 10, 11, 12]-6    | For window sizes [7, 13, 27, 81, 243, 729], percent area <sup>b</sup> of patches in each of six grouped density classes, in km <sup>2</sup>                                                        |
| HDD1-1 to HDD1-?                                            | Total area per housing density class, in km <sup>2</sup>                                                                                                                                           |
| HDD2-1 to HDD2-?                                            | Percent area per housing density class, in km <sup>2</sup> . Classification scheme and number/type of classes for housing density is to be determined after identification of adequate data source |
| PTT                                                         | Weighted population total, measured as the number of people per habitable area                                                                                                                     |
| PDD                                                         | Area-weighted population density, in people/ km <sup>2</sup>                                                                                                                                       |
| RDD2                                                        | Total length of roads, in km.                                                                                                                                                                      |
| RDD1                                                        | Road Density, length of roads per km <sup>2</sup>                                                                                                                                                  |
| AWR1                                                        | Area of patches without roads, in km <sup>2</sup>                                                                                                                                                  |
| AWR2                                                        | Frequency of patches without roads, in km <sup>2</sup>                                                                                                                                             |
| COW1                                                        | Area by owner, for each of XX ownership categories as defined by the protected areas database/ program, in km <sup>2</sup>                                                                         |
| COW2                                                        | Percent area by owner, for each of XX ownership categories as defined by the protected areas database/ program, in km <sup>2</sup>                                                                 |
| COW3                                                        | Sum area by owner, for each of XX ownership categories as defined by the protected areas database/ program, in km <sup>2</sup>                                                                     |
| COW4                                                        | Frequency of ownership for each of XX ownership categories as defined by the protected areas database/ program, in km <sup>2</sup>                                                                 |
| CAP1                                                        | Area per each of four protection categories, as defined by the protected areas database/ program, in km <sup>2</sup>                                                                               |
| CAP2                                                        | Percent area per each of four protection categories, as defined by the protected areas database/ program, in km <sup>2</sup>                                                                       |
| CAP3                                                        | Sum area per each of four protection categories, as defined by the protected areas database/ program, in km <sup>2</sup>                                                                           |
| CAP4                                                        | Frequency of four protection categories, as defined by the protected areas database/ program, in km <sup>2</sup>                                                                                   |

<sup>a</sup> Class Area = (Class cell count \* 900m) / 1,000,000;

<sup>b</sup> Percent Area = (Total Area / Class Area) \* 100

## Climate

Temperature and precipitation data from monitoring station records and gridded data sets are used to calculate several derived metrics (Table C-2 and Table C-3). Note most derived measures are provided by ACIS, the Applied Climate Information System (DeGaetano et al. 2015). Climate normals from the Parameter-elevation Relationships on Independent Slopes Model (PRISM) project (Daly et al. 2008) and snow-water-equivalent normal from the NRCS SNOTEL and SnowCourse programs (Natural Resource Conservation Service, National Water and Climate Center, 2017) are used in the comparative metrics (Table C-2). Indices including Palmer drought severity (PDSI) and standardized precipitation (SPI) are accessed from NOAA's National Centers for Environmental Information (2017) NADM website.

The alphanumeric code preceding each definition refers to the category of climate metric that is to be calculated. For example, CST1 is the first climate station temperature metric.

- CST# - Climate: station temperature metrics
- CSP# - Climate: station precipitation metrics
- CGT# - Climate: gridded temperature metrics
- CGP# - Climate: gridded precipitation metrics

**Table C-2.** Definitions for derived temperature and precipitation metrics based on climate station data calculated as a part of the NPS Park Environmental Settings Monitoring Protocol. Detection of change is assumed to be based on statistical regression techniques except for stations with less than 5 years of data, in which case change would be based on a 5% difference threshold between initial and final measures (for measures based on comparison to normals) or a 10% difference threshold between initial and final measures (for all other measures).

| <b>Metric</b> | <b>Definition</b>                                                                                                                                           |
|---------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CST1          | Hot Days. number of days during the calendar year when the maximum daily temperature equals 90°F (32°C) or above.                                           |
| CST2          | Cold Days. number of days during the calendar year when the maximum daily temperature equals 32°F (0°C) or below.                                           |
| CST3          | Sub-Freezing Days. number of days during the calendar year when the minimum daily temperature equals 32°F (0°C) or below; typically happens at night.       |
| CST4          | Sub-Zero Days. number of days during the calendar year when the minimum daily temperature equals 0°F (-17.8°C) or below; typically happens at night.        |
| CST5          | Growing Degree Days. Sum of positive difference between observed temperature and a temperature corresponding to a minimum development threshold (TBASE).    |
| CST6          | Heating Degree Days. Sum of negative difference between observed temperature and a baseline of 65°F. Calculated annually from January 1 to December 31.     |
| CST7          | Cooling Degree Days. Sum of positive difference between observed temperature and a baseline of 65°F. Calculated annually from July 1 to June 30.            |
| CST8          | Above Normal Temperature Days. Number of days above long-term climate normal (calculated monthly and annually).                                             |
| CST9          | Below Normal Temperature Days. Number of days below long-term climate normal (calculated monthly and annually).                                             |
| CSP1          | Heavy Precipitation Days. Number of days during the calendar year with $\geq 1.0$ in (25 mm) liquid precipitation.                                          |
| CSP2          | Extreme Precipitation Days. Number of days during the calendar year with $\geq 2.0$ in (51 mm) liquid precipitation.                                        |
| CSP3          | Micro-drought. Number of strings of seven or more consecutive days during the calendar year without a trace ( $< .01$ in / 0.3 cm) of liquid precipitation. |
| CSP4          | Measurable Snow Days. Number of days during the calendar year with measurable ( $\geq 0.1$ in [0.3 cm]) snow.                                               |
| CSP5          | Moderate Snow Days. Number of days during the calendar year with $\geq 3.0$ in (7.6 cm) of snow.                                                            |
| CSP6          | Heavy Snow Days. Number of days during the calendar year with $\geq 5.0$ in (12.7 cm) of snow.                                                              |
| CSP7          | Above Normal Precipitation Days. Number of days above long-term climate normal (calculated monthly and annually).                                           |
| CSP8          | Below Normal Precipitation Days. Number of days below long-term climate normal (calculated monthly and annually).                                           |

**Table C-3.** Definitions for derived temperature and precipitation metrics based on gridded climate data that are calculated as a part of the NPS Park Environmental Settings Monitoring Protocol. Detection of change is assumed to be based on statistical regression techniques except for stations with less than 5 years of data, in which case change would be based on a 5% difference threshold between initial and final measures (for measures based on comparison to normals) or a 10% difference threshold between initial and final measures (for all other measures).

| Metric | Definition                                                                                    |
|--------|-----------------------------------------------------------------------------------------------|
| CGT1   | Monthly temperature departures from average monthly average temperature (% of climate normal) |
| CGT2   | Monthly temperature departures from average monthly minimum temperature (% of climate normal) |
| CGT3   | Monthly temperature departures from average monthly maximum temperature (% of climate normal) |
| CGP1   | Monthly departures from average monthly average precipitation (% of climate normal)           |
| CGP2   | Monthly departures from average monthly minimum precipitation (% of climate normal)           |
| CGP3   | Monthly departures from average monthly maximum precipitation (% of climate normal)           |
| CGP4   | Snow-Water Equivalent Departures from average (% of climate normal)                           |
| CGP5   | Monthly Palmer Drought Severity Index                                                         |
| CGP6   | Standardized Precipitation Index                                                              |

## Hydrology

### ***Hydrologic Indices (Modified from Henricksen et al. 2006)***

The following information for the 171 hydrologic indices is from Olden and Poff (2003). The USGS revised a limited number of the formula and (or) definitions when deemed appropriate. A USGS Scientific Investigations Report in preparation will document these changes. The Olden and Poff (2003) article contains 12 additional references from which the indices were derived. Two of these articles are referenced here because they provide examples and additional explanation for complex indices.

The alphanumeric code preceding each definition refers to the category of the flow regime (magnitude, frequency, duration, timing, and rate of change) and type of flow event (A, average, L, low, and H, high) the hydrologic index was developed to describe. Indices are numbered successively within each category. For example, MA1 is the first index describing magnitude of the average flow condition.

- MA# - Magnitude, average flow event ML# -Magnitude, low flow event MH# - Magnitude, high flow event
- FL# - Frequency, low flow event FH# - Frequency, high flow event
- DL# - Duration, low flow event DH# - Duration, high flow event
- TA# - Timing, average flow event TL# -Timing, low flow event TH# -Timing, high flow event

- RA# - Rate of change, average event

Following each definition, in parentheses, are (1) the units of the index, and (2) the type of data, temporal or spatial data, from which the upper and lower percentile limits (for example, 75/25) are derived (Table C-4). Temporal data are from a multiyear daily flow record from a single stream gage. For example, index MA1– mean for the entire flow record – uses 365 mean daily flow values for each year in the flow record to calculate the mean for the entire flow record. Consequently, there are 365 values for each year to calculate upper and lower percentile limits. However, formulas for 60 of the indices do not produce a range of values from which percentile limits can be calculated. MA5 (skewness), for example, the mean for the entire flow record divided by the median for the entire record results in a single value, and thus, upper and lower percentile limits cannot be calculated. NJHAT uses spatial data, values for each stream gage for all the streams within a stream type, to compute limits. Upper and lower percentile limits are calculated from the 31 MA5 values from the 31 stream gages that were identified from the classification analysis as Stream type A.

Exceedence and percentile are used in the calculation for a number of indices. Note the difference – a 90 percent exceedence means that 90 percent of the values are equal to or greater than the 90 percent exceedence value, while a 90th percentile means that 10 percent of the values are equal to or greater than the 90th percentile value.

**Table C-4.** Metric definitions for the 171 Hydrologic Indices calculated as a part of the NPS Park Environmental Settings Monitoring Protocol (from Henriksen et al 2006). Detection of change is assumed to be based on statistical regression techniques except for stations with less than 5 years of data, in which case change would be based on a 10% difference threshold between initial and final measures.

| <b>Metrics</b> | <b>Definition</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MA1            | Mean of the daily mean flow values for the entire flow record (cubic feet per second – temporal).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| MA2            | Median of the daily mean flow values for the entire flow record (cubic feet per second – temporal).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| MA3            | Mean (or median - Use Preference option) of the coefficients of variation (standard deviation/mean) for each year. Compute the coefficient of variation for each year of daily flows. Compute the mean of the annual coefficients of variation (percent - temporal).                                                                                                                                                                                                                                                                                                                                             |
| MA4            | Standard deviation of the percentiles of the logs of the entire flow record divided by the mean of percentiles of the logs. Compute the log10 of the daily flows for the entire record. Compute the 5th, 10th, 15th, 20th, 25th, 30th, 35th, 40th, 45th, 50th, 55th, 60th, 65th, 70th, 75th, 80th, 85th, 90th, and 95th percentiles for the logs of the entire flow record. Percentiles are computed by interpolating between the ordered (ascending) logs of the flow values. Compute the standard deviation and mean for the percentile values. Divide the standard deviation by the mean (percent - spatial). |
| MA5            | The skewness of the entire flow record is computed as the mean for the entire flow record (MA1) divided by the median (MA2) for the entire flow record (dimensionless - spatial).                                                                                                                                                                                                                                                                                                                                                                                                                                |
| MA6            | Range in daily flows is the ratio of the 10 percent to 90 percent exceedence values for the entire flow record. Compute the 5 percent to 95 percent exceedence values for the entire flow record. Exceedence is computed by interpolating between the ordered (descending) flow values. Divide the 10 percent exceedence value by the 90 percent value (dimensionless – spatial).                                                                                                                                                                                                                                |
| MA7            | Range in daily flows is computed like MA6 except using the 20 percent and 80 percent exceedence values. Divide the 20 percent exceedence value by the 80 percent value (dimensionless - spatial).                                                                                                                                                                                                                                                                                                                                                                                                                |

| Metrics   | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MA8       | Range in daily flows is computed like MA6 except using the 25 percent and 75 percent exceedence values. Divide the 25 percent exceedence value by the 75 percent value (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                                                                             |
| MA9       | Spread in daily flows is the ratio of the difference between the 90th and 10 <sup>th</sup> percentile of the logs of the flow data to the log of the median of the entire flow record. Compute the log10 of the daily flows for the entire record. Compute the 5th, 10th, 15th, 20th, 25th, 30th, 35th, 40th, 45th, 50th, 55th, 60th, 65th, 70th, 75th, 80th, 85th, 90th, and 95th percentiles for the logs of the entire flow record. Percentiles are computed by interpolating between the ordered (ascending) logs of the flow values. Compute MA9 as (90th – 10th) /log10(MA2) (dimensionless – spatial). |
| MA10      | Spread in daily flows is computed like MA9 except using the 20th and 80th percentiles (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| MA11      | Spread in daily flows is computed like MA9 except using the 25th and 75th percentiles (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| MA12-MA23 | Means (or medians - Use Preference option) of monthly flow values. Compute the means for each month over the entire flow record. For example, MA12 is the mean of all January flow values over the entire record (cubic feet per second – temporal).                                                                                                                                                                                                                                                                                                                                                          |
| MA24-MA35 | Variability (coefficient of variation) of monthly flow values. Compute the standard deviation for each month in each year over the entire flow record. Divide the standard deviation by the mean for each month. Average (or median - Use Preference option) these values for each month across all years (percent – temporal).                                                                                                                                                                                                                                                                               |
| MA36      | Variability across monthly flows. Compute the minimum, maximum, and mean flows for each month in the entire flow record. MA36 is the maximum monthly flow minus the minimum monthly flow divided by the median monthly flow (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                        |
| MA37      | Variability across monthly flows. Compute the first (25th percentile) and the third (75th percentile) quartiles (every month in the flow record). MA37 is the third quartile minus the first quartile divided by the median of the monthly means (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                   |
| MA38      | Variability across monthly flows. Compute the 10th and 90th percentiles for the monthly means (every month in the flow record). MA38 is the 90th percentile minus the 10th percentile divided by the median of the monthly means (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                   |
| MA39      | Variability across monthly flows. Compute the standard deviation for the monthly means. MA39 is the standard deviation times 100 divided by the mean of the monthly means (percent – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                |
| MA40      | Skewness in the monthly flows. MA40 is the mean of the monthly flow means minus the median of the monthly means divided by the median of the monthly means (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                         |
| MA41      | Annual runoff. Compute the annual mean daily flows. MA41 is the mean of the annual means divided by the drainage area (cubic feet per second/square mile – temporal).                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| MA42      | Variability across annual flows. MA42 is the maximum annual flow minus the minimum annual flow divided by the median annual flow (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| MA43      | Variability across annual flows. Compute the first (25th percentile) and third (75th percentile) quartiles and the 10th and 90th percentiles for the annual means (every year in the flow record). MA43 is the third quartile minus the first quartile divided by the median of the annual means (dimensionless – spatial).                                                                                                                                                                                                                                                                                   |
| MA44      | Variability across annual flows. Compute the first (25th percentile) and third (75th percentile) quartiles and the 10th and 90th percentiles for the annual means (every year in the flow record). MA44 is the 90th percentile minus the 10th percentile divided by the median of the annual means (dimensionless – spatial).                                                                                                                                                                                                                                                                                 |

| <b>Metrics</b> | <b>Definition</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MA45           | Skewness in the annual flows. MA45 is the mean of the annual flow means minus the median of the annual means divided by the median of the annual means (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                |
| ML1-ML12       | Mean (or median - Use Preference option) minimum flows for each month across all years. Compute the minimums for each month over the entire flow record. For example, ML1 is the mean of the minimums of all January flow values over the entire record (cubic feet per second – temporal).                                                                                                                                                                                                                      |
| ML13           | Variability (coefficient of variation) across minimum monthly flow values. Compute the mean and standard deviation for the minimum monthly flows over the entire flow record. ML13 is the standard deviation times 100 divided by the mean minimum monthly flow for all years (percent – spatial).                                                                                                                                                                                                               |
| ML14           | Compute the minimum annual flow for each year. ML14 is the mean of the ratios of minimum annual flows to the median flow for each year (dimensionless – temporal).                                                                                                                                                                                                                                                                                                                                               |
| ML15           | Low flow index. ML15 is the mean of the ratios of minimum annual flows to the mean flow for each year (dimensionless – temporal).                                                                                                                                                                                                                                                                                                                                                                                |
| ML16           | Median of annual minimum flows. ML16 is the median of the ratios of minimum annual flows to the median flow for each year (dimensionless – temporal).                                                                                                                                                                                                                                                                                                                                                            |
| ML17           | Base flow. Compute the mean annual flows. Compute the minimum of a 7-day moving average flow for each year and divide them by the mean annual flow for that year. ML17 is the mean (or median - Use Preference option) of those ratios (dimensionless – temporal).                                                                                                                                                                                                                                               |
| ML18           | Variability in base flow. Compute the standard deviation for the ratios of 7-day moving average flows to mean annual flows for each year. ML18 is the standard deviation times 100 divided by the mean of the ratios (percent – spatial).                                                                                                                                                                                                                                                                        |
| ML19           | Base flow. Compute the ratios of the minimum annual flow to mean annual flow for each year. ML19 is the mean (or median - Use Preference option) of these ratios times 100 (dimensionless – temporal).                                                                                                                                                                                                                                                                                                           |
| ML20           | Base flow. Divide the daily flow record into 5-day blocks. Find the minimum flow for each block. Assign the minimum flow as a base flow for that block if 90 percent of that minimum flow is less than the minimum flows for the blocks on either side. Otherwise, set it to zero. Fill in the zero values using linear interpolation. Compute the total flow for the entire record and the total base flow for the entire record. ML20 is the ratio of total flow to total base flow (dimensionless – spatial). |
| ML21           | Variability across annual minimum flows. Compute the mean and standard deviation for the annual minimum flows. ML21 is the standard deviation times 100 divided by the mean (percent – spatial).                                                                                                                                                                                                                                                                                                                 |
| ML22           | Specific mean annual minimum flow. ML22 is the mean (or median - Use Preference option) of the annual minimum flows divided by the drainage area (cubic feet per second/square mile – temporal).                                                                                                                                                                                                                                                                                                                 |
| MH1-MH12       | Mean (or median - Use Preference option) maximum flows for each month across all years. Compute the maximums for each month over the entire flow record. For example, MH1 is the mean of the maximums of all January flow values over the entire record (cubic feet per second – temporal).                                                                                                                                                                                                                      |
| MH13           | Variability (coefficient of variation) across maximum monthly flow values. Compute the mean and standard deviation for the maximum monthly flows over the entire flow record. MH13 is the standard deviation times 100 divided by the mean maximum monthly flow for all years (percent – spatial).                                                                                                                                                                                                               |
| MH14           | Median of annual maximum flows. Compute the annual maximum flows from monthly maximum flows. Compute the ratio of annual maximum flow to median annual flow for each year. MH14 is the median of these ratios (dimensionless – temporal).                                                                                                                                                                                                                                                                        |

| Metrics | Definition                                                                                                                                                                                                                                                                                                                                                                              |
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| MH15    | High flow discharge index. Compute the 1 percent exceedence value for the entire data record. MH15 is the 1 percent exceedence value divided by the median flow for the entire record (dimensionless – spatial).                                                                                                                                                                        |
| MH16    | High flow discharge index. Compute the 10 percent exceedence value for the entire data record. MH16 is the 10 percent exceedence value divided by the median flow for the entire record (dimensionless – spatial).                                                                                                                                                                      |
| MH17    | High flow discharge index. Compute the 25 percent exceedence value for the entire data record. MH17 is the 25 percent exceedence value divided by the median flow for the entire record (dimensionless – spatial).                                                                                                                                                                      |
| MH18    | Variability across annual maximum flows. Compute the logs (log10) of the maximum annual flows. Find the standard deviation and mean for these values. MH18 is the standard deviation times 100 divided by the mean (percent – spatial).                                                                                                                                                 |
| MH19    | <p>Skewness in annual maximum flows. Use the equation:</p> $MH19 = \frac{N^2 \times \sum(qm^3) - 3N \times \sum(qm) \times \sum(qm^2) + 2 \times (\sum(qm))^3}{N \times (N-1) \times (N-2) \times stddev^3}$ <p>where:</p> <p>N = Number of years</p> <p>qm = Log10(annual maximum flows)</p> <p>stddev = Standard deviation of the annual maximum flows (dimensionless – spatial).</p> |
| MH20    | Specific mean annual maximum flow. MH20 is the mean (or median - Use Preference option) of the annual maximum flows divided by the drainage area (cubic feet per second/square mile – temporal).                                                                                                                                                                                        |
| MH21    | High flow volume index. Compute the average volume for flow events above a threshold equal to the median flow for the entire record. MH21 is the average volume divided by the median flow for the entire record (days – temporal).                                                                                                                                                     |
| MH22    | High flow volume. Compute the average volume for flow events above a threshold equal to three times the median flow for the entire record. MH22 is the average volume divided by the median flow for the entire record (days - temporal).                                                                                                                                               |
| MH23    | High flow volume. Compute the average volume for flow events above a threshold equal to seven times the median flow for the entire record. MH23 is the average volume divided by the median flow for the entire record (days - temporal).                                                                                                                                               |
| MH24    | High peak flow. Compute the average peak flow value for flow events above a threshold equal to the median flow for the entire record. MH24 is the average peak flow divided by the median flow for the entire record (dimensionless – temporal).                                                                                                                                        |
| MH25    | High peak flow. Compute the average peak flow value for flow events above a threshold equal to three times the median flow for the entire record. MH25 is the average peak flow divided by the median flow for the entire record (dimensionless – temporal).                                                                                                                            |
| MH26    | High peak flow. Compute the average peak flow value for flow events above a threshold equal to seven times the median flow for the entire record. MH26 is the average peak flow divided by the median flow for the entire record (dimensionless – temporal).                                                                                                                            |
| MH27    | High peak flow. Compute the average peak flow value for flow events above a threshold equal to 75th percentile value for the entire flow record. MH27 is the average peak flow divided by the median flow for the entire record (dimensionless – temporal).                                                                                                                             |

| Metrics                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Definition                                                                                                                                                                                                                                                                                          |
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| FL1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Low flood pulse count. Compute the average number of flow events with flows below a threshold equal to the 25th percentile value for the entire flow record. FL1 is the average (or median - Use Preference option) number of events (number of events/year – temporal).                            |
| FL2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Variability in low pulse count. Compute the standard deviation in the annual pulse counts for FL1. FL2 is 100 times the standard deviation divided by the mean pulse count (percent – spatial).                                                                                                     |
| FL3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Frequency of low pulse spells. Compute the average number of flow events with flows below a threshold equal to 5 percent of the mean flow value for the entire flow record. FL3 is the average (or median - Use Preference option) number of events (number of events/year – temporal).             |
| FH1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | High flood pulse count. Compute the average number of flow events with flows above a threshold equal to the 75th percentile value for the entire flow record. FH1 is the average (or median - Use Preference option) number of events (number of events/year – temporal).                           |
| FH2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Variability in high pulse count. Compute the standard deviation in the annual pulse counts for FH1. FH2 is 100 times the standard deviation divided by the mean pulse count (number of events/year – spatial).                                                                                      |
| FH3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | High flood pulse count. Compute the average number of days per year that the flow is above a threshold equal to three times the median flow for the entire record. FH3 is the mean (or median – Use Preference option) of the annual number of days for all years (number of days/year – temporal). |
| FH4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | High flood pulse count. Compute the average number of days per year that the flow is above a threshold equal to seven times the median flow for the entire record. FH4 is the mean (or median - Use Preference option) of the annual number of days for all years (number of days/year – temporal). |
| FH5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Flood frequency. Compute the average number of flow events with flows above a threshold equal to the median flow value for the entire flow record. FH5 is the average (or median - Use Preference option) number of events (number of events/year – temporal).                                      |
| FH6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Flood frequency. Compute the average number of flow events with flows above a threshold equal to three times the median flow value for the entire flow record. FH6 is the average (or median - Use Preference option) number of events (number of events/year – temporal).                          |
| FH7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Flood frequency. Compute the average number of flow events with flows above a threshold equal to seven times the median flow value for the entire flow record. FH6 is the average (or median - Use Preference option) number of events (number of events/year – temporal).                          |
| FH8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Flood frequency. Compute the average number of flow events with flows above a threshold equal to 25 percent exceedence value for the entire flow record. FH8 is the average (or median - Use Preference option) number of events (number of events/year – temporal).                                |
| FH9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Flood frequency. Compute the average number of flow events with flows above a threshold equal to 75 percent exceedence value for the entire flow record. FH9 is the average (or median - Use Preference option) number of events (number of events/year – temporal).                                |
| FH10                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Flood frequency. Compute the average number of flow events with flows above a threshold equal to median of the annual minima for the entire flow record. FH10 is the average (or median - Use Preference option) number of events (number of events/year – temporal).                               |
| <p>Note - 1.67-year flood threshold (Poff, 1996) - For indices FH11, DH22, DH23, DH24, TA3, and TH3 compute the log10 of the peak annual flows. Compute the log10 of the daily flows for the peak annual flow days. Calculate the coefficients for a linear regression equation for logs of peak annual flow versus logs of average daily flow for peak days. Using the log peak flow for the 1.67 year recurrence interval (60th percentile) as input to the regression equation, predict the log10 of the average daily flow. The threshold is 10 to the log10 (average daily flow) power (cubic feet/second).</p> |                                                                                                                                                                                                                                                                                                     |

| Metrics | Definition                                                                                                                                                                                                                                                            |
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| FH11    | Flood frequency. Compute the average number of flow events with flows above a threshold equal to flow corresponding to a 1.67-year recurrence interval. FH11 is the average (or median - Use Preference option) number of events (number of events/year – temporal).  |
| DL1     | Annual minimum daily flow. Compute the minimum 1-day average flow for each year. DL1 is the mean (or median - Use Preference option) of these values (cubic feet per second – temporal).                                                                              |
| DL2     | Annual minimum of 3-day moving average flow. Compute the minimum of a 3-day moving average flow for each year. DL2 is the mean (or median - Use Preference option) of these values (cubic feet per second – temporal).                                                |
| DL3     | Annual minimum of 7-day moving average flow. Compute the minimum of a 7-day moving average flow for each year. DL3 is the mean (or median - Use Preference option) of these values (cubic feet per second – temporal).                                                |
| DL4     | Annual minimum of 30-day moving average flow. Compute the minimum of a 30day moving average flow for each year. DL4 is the mean (or median - Use Preference option) of these values (cubic feet per second – temporal).                                               |
| DL5     | Annual minimum of 90-day moving average flow. Compute the minimum of a 90day moving average flow for each year. DL5 is the mean (or median - Use Preference option) of these values (cubic feet per second – temporal).                                               |
| DL6     | Variability of annual minimum daily average flow. Compute the standard deviation for the minimum daily average flow. DL6 is 100 times the standard deviation divided by the mean (percent – spatial).                                                                 |
| DL7     | Variability of annual minimum of 3-day moving average flow. Compute the standard deviation for the minimum 3-day moving averages. DL7 is 100 times the standard deviation divided by the mean (percent - spatial).                                                    |
| DL8     | Variability of annual minimum of 7-day moving average flow. Compute the standard deviation for the minimum 7-day moving averages. DL8 is 100 times the standard deviation divided by the mean (percent - spatial).                                                    |
| DL9     | Variability of annual minimum of 30-day moving average flow. Compute the standard deviation for the minimum 30-day moving averages. DL9 is 100 times the standard deviation divided by the mean (percent - spatial).                                                  |
| DL10    | Variability of annual minimum of 90-day moving average flow. Compute the standard deviation for the minimum 90-day moving averages. DL10 is 100 times the standard deviation divided by the mean (percent - spatial).                                                 |
| DL11    | Annual minimum daily flow divided by the median for the entire record. Compute the minimum daily flow for each year. DL11 is the mean of these values divided by the median for the entire record (dimensionless – temporal).                                         |
| DL12    | Annual minimum of 7-day moving average flow divided by the median for the entire record. Compute the minimum of a 7-day moving average flow for each year. DL12 is the mean of these values divided by the median for the entire record (dimensionless – temporal).   |
| DL13    | Annual minimum of 30-day moving average flow divided by the median for the entire record. Compute the minimum of a 30-day moving average flow for each year. DL13 is the mean of these values divided by the median for the entire record (dimensionless – temporal). |
| DL14    | Low exceedence flows. Compute the 75 percent exceedence value for the entire flow record. DL14 is the exceedence value divided by the median for the entire record (dimensionless – spatial).                                                                         |
| DL15    | Low exceedence flows. Compute the 90 percent exceedence value for the entire flow record. DL14 is the exceedence value divided by the median for the entire record (dimensionless – spatial).                                                                         |

| <b>Metrics</b> | <b>Definition</b>                                                                                                                                                                                                                                                            |
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| DL16           | Low flow pulse duration. Compute the average pulse duration for each year for flow events below a threshold equal to the 25th percentile value for the entire flow record. DL16 is the median of the yearly average durations (number of days – temporal).                   |
| DL17           | Variability in low pulse duration. Compute the standard deviation for the yearly average low pulse durations. DL17 is 100 times the standard deviation divided by the mean of the yearly average low pulse durations (percent – spatial).                                    |
| DL18           | Number of zero-flow days. Count the number of zero-flow days for the entire flow record. DL18 is the mean (or median - Use Preference option) annual number of zero-flow days (number of days/year – temporal).                                                              |
| DL19           | Variability in the number of zero-flow days. Compute the standard deviation for the annual number of zero-flow days. DL19 is 100 times the standard deviation divided by the mean annual number of zero-flow days (percent – spatial).                                       |
| DL20           | Number of zero-flow months. While computing the mean monthly flow values, count the number of months in which there was no flow over the entire flow record (percent – spatial).                                                                                             |
| DH1            | Annual maximum daily flow. Compute the maximum of a 1-day moving average flow for each year. DH1 is the mean (or median - Use Preference option) of these values (cubic feet per second – temporal).                                                                         |
| DH2            | Annual maximum of 3-day moving average flows. Compute the maximum of a 3day moving average flow for each year. DH2 is the mean (or median - Use Preference option) of these values (cubic feet per second – temporal).                                                       |
| DH3            | Annual maximum of 7-day moving average flows. Compute the maximum of a 7day moving average flow for each year. DH3 is the mean (or median - Use Preference option) of these values (cubic feet per second – temporal).                                                       |
| DH4            | Annual maximum of 30-day moving average flows. Compute the maximum of 30day moving average flows. Compute the maximum of a 30-day moving average flow for each year. DH4 is the mean (or median - Use Preference option) of these values (cubic feet per second – temporal). |
| DH5            | Annual maximum of 90-day moving average flows. Compute the maximum of a 90day moving average flow for each year. DH5 is the mean (or median - Use Preference option) of these values (cubic feet per second – temporal).                                                     |
| DH6            | Variability of annual maximum daily flows. Compute the standard deviation for the maximum 1-day moving averages. DH6 is 100 times the standard deviation divided by the mean (percent – spatial).                                                                            |
| DH7            | Variability of annual maximum of 3-day moving average flows. Compute the standard deviation for the maximum 3-day moving averages. DH7 is 100 times the standard deviation divided by the mean (percent – spatial).                                                          |
| DH8            | Variability of annual maximum of 7-day moving average flows. Compute the standard deviation for the maximum 7-day moving averages. DH8 is 100 times the standard deviation divided by the mean (percent – spatial).                                                          |
| DH9            | Variability of annual maximum of 30-day moving average flows. Compute the standard deviation for the maximum 30-day moving averages. DH9 is 100 times the standard deviation divided by the mean (percent – spatial).                                                        |
| DH10           | Variability of annual maximum of 90-day moving average flows. Compute the standard deviation for the maximum 90-day moving averages. DH10 is 100 times the standard deviation divided by the mean (percent – spatial).                                                       |

| <b>Metrics</b> | <b>Definition</b>                                                                                                                                                                                                                                                                                                                    |
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| DH11           | Annual maximum of 1-day moving average flows divided by the median for the entire record. Compute the maximum of a 1-day moving average flow for each year. DH11 is the mean of these values divided by the median for the entire record (dimensionless – temporal).                                                                 |
| DH12           | Annual maximum of 7-day moving average flows divided by the median for the entire record. Compute the maximum daily average flow for each year. DH12 is the mean of these values divided by the median for the entire record (dimensionless – temporal).                                                                             |
| DH13           | Annual maximum of 30-day moving average flows divided by the median for the entire record. Compute the maximum of a 30-day moving average flow for each year. DH13 is the mean of these values divided by the median for the entire record (dimensionless – temporal).                                                               |
| DH14           | Flood duration. Compute the mean of the mean monthly flow values. Find the 95th percentile for the mean monthly flows. DH14 is the 95th percentile value divided by the mean of the monthly means (dimensionless – spatial).                                                                                                         |
| DH15           | High flow pulse duration. Compute the average duration for flow events with flows above a threshold equal to the 75th percentile value for each year in the flow record. DH15 is the median of the yearly average durations (days/year – temporal).                                                                                  |
| DH16           | Variability in high flow pulse duration. Compute the standard deviation for the yearly average high pulse durations. DH16 is 100 times the standard deviation divided by the mean of the yearly average high pulse durations (percent – spatial).                                                                                    |
| DH17           | High flow duration. Compute the average duration of flow events with flows above a threshold equal to the median flow value for the entire flow record. DH17 is the average (or median - Use Preference option) duration of the events (days – temporal).                                                                            |
| DH18           | High flow duration. Compute the average duration of flow events with flows above a threshold equal to three times the median flow value for the entire flow record. DH18 is the average (or median - Use Preference option) duration of the events (days – temporal).                                                                |
| DH19           | High flow duration. Compute the average duration of flow events with flows above a threshold equal to seven times the median flow value for the entire flow record. DH19 is the average (or median - Use Preference option) duration of the events (days – temporal).                                                                |
| DH20           | High flow duration. Compute the 75th percentile value for the entire flow record. Compute the average duration of flow events with flows above a threshold equal to the 75th percentile value for the median annual flows. DH20 is the average (or median - Use Preference option) duration of the events (days – temporal).         |
| DH21           | High flow duration. Compute the 25th percentile value for the entire flow record. Compute the average duration of flow events with flows above a threshold equal to the 25th percentile value for the entire set of flows. DH21 is the average (or median - Use Preference option) duration of the events (days – temporal).         |
| DH22           | Flood interval. Compute the flood threshold as the flow equivalent for a flood recurrence of 1.67 years. Determine the median number of days between flood events for each year. DH22 is the mean (or median - Use Preference option) of the yearly median number of days between flood events (days – temporal).                    |
| DH23           | Flood duration. Compute the flood threshold as the flow equivalent for a flood recurrence of 1.67 years. Determine the number of days each year that the flow remains above the flood threshold. DH23 is the mean (or median - Use Preference option) of the number of flood days for years in which floods occur (days – temporal). |

| Metrics | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
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| DH24    | Flood-free days. Compute the flood threshold as the flow equivalent for a flood recurrence of 1.67 years. Compute the maximum number of days that the flow is below the threshold for each year. DH24 is the mean (or median - Use Preference option) of the maximum yearly no-flood days (days – temporal).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| TA1     | <p>Constancy. Constancy is computed via the formulation of Colwell (see example in Colwell, 1974). A matrix of values is compiled where the rows are 11 flow categories and the columns are 365 (no February 29th) days of the year. The cell values are the number of times that a flow falls into a category on each day. The categories are:</p> <ul style="list-style-type: none"> <li>• <math>\log(\text{flow}) &lt; .1 \times \log(\text{mean flow})</math>,</li> <li>• <math>.1 \times \log(\text{mean flow}) \leq \log(\text{flow}) &lt; .25 \times \log(\text{mean flow})</math></li> <li>• <math>.25 \times \log(\text{mean flow}) \leq \log(\text{flow}) &lt; .5 \times \log(\text{mean flow})</math></li> <li>• <math>.5 \times \log(\text{mean flow}) \leq \log(\text{flow}) &lt; .75 \times \log(\text{mean flow})</math></li> <li>• <math>.75 \times \log(\text{mean flow}) \leq \log(\text{flow}) &lt; 1.0 \times \log(\text{mean flow})</math></li> <li>• <math>1.0 \times \log(\text{mean flow}) \leq \log(\text{flow}) &lt; 1.25 \times \log(\text{mean flow})</math></li> <li>• <math>1.25 \times \log(\text{mean flow}) \leq \log(\text{flow}) &lt; 1.5 \times \log(\text{mean flow})</math></li> <li>• <math>1.5 \times \log(\text{mean flow}) \leq \log(\text{flow}) &lt; 1.75 \times \log(\text{mean flow})</math></li> <li>• <math>1.75 \times \log(\text{mean flow}) \leq \log(\text{flow}) &lt; 2.0 \times \log(\text{mean flow})</math></li> <li>• <math>2.0 \times \log(\text{mean flow}) \leq \log(\text{flow}) &lt; 2.25 \times \log(\text{mean flow})</math> <math>\log(\text{flow}) \geq 2.25 \times \log(\text{mean flow})</math></li> </ul> <p>The row totals, column totals, and grand total are computed. Using the equations for Shannon information theory parameters, constancy is computed as:</p> <p><u><math>1 - (\text{uncertainty with respect to state})</math></u><br/> <math>\log(\text{number of state})</math><br/> (dimensionless – spatial).</p> |
| TA2     | <p>Predictability. Predictability is computed from the same matrix as constancy (see example in Colwell, 1974). It is computed as:</p> <p><u><math>1 - (\text{uncertainty with respect to interaction of time and state} - \text{uncertainty with respect to time})</math></u><br/> <math>\log(\text{number of state})</math><br/> (dimensionless – spatial).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| TA3     | Seasonal predictability of flooding. Divide years up into 2-month periods (that is, Oct-Nov, Dec-Jan, and so forth). Count the number of flood days (flow events with flows > 1.67-year flood) in each period over the entire flow record. TA3 is the maximum number of flood days in any one period divided by the total number of flood days (dimensionless – temporal).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| TL1     | Julian date of annual minimum. Determine the Julian date that the minimum flow occurs for each water year. Transform the dates to relative values on a circular scale (radians or degrees). Compute the x and y components for each year and average them across all years. Compute the mean angle as the arc tangent of y-mean divided by x-mean. Transform the resultant angle back to Julian date (Julian day – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

| Metrics | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
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| TL2     | <p>Variability in Julian date of annual minima. Compute the coefficient of variation for the mean x and y components and convert to a date (Julian day – spatial).</p> <p>Note - 5-year flood threshold (Poff, 1996) – For TL3 and TH3, compute the log10 of the peak annual flows. Compute the log10 of the daily flows for the peak annual flow days. Calculate the coefficients for a linear regression equation for logs of peak annual flow versus logs of average daily flow for peak days. Using the log peak flow for the 5-year recurrence interval (20th percentile) as input to the regression equation, predict the log10 of the average daily flow. The threshold is 10 to the log10 (average daily flow) power (cubic feet per second).</p> |
| TL3     | Seasonal predictability of low flow. Divide years up into 2-month periods (that is, Oct-Nov, Dec-Jan, and so forth). Count the number of low flow events (flow events with flows $\leq$ 5 year flood threshold) in each period over the entire flow record. TL3 is the maximum number of low flow events in any one period divided by the total number of low flow events (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                      |
| TL4     | Seasonal predictability of non-low flow. Compute the number of days that flow is above the 5-year flood threshold as the ratio of number of days to 365 or 366 (leap year) for each year. TL4 is the maximum of the yearly ratios (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| TH1     | Julian date of annual maximum. Determine the Julian date that the maximum flow occurs for each year. Transform the dates to relative values on a circular scale (radians or degrees). Compute the x and y components for each year and average them across all years. Compute the mean angle as the arc tangent of y-mean divided by x-mean. Transform the resultant angle back to Julian date (Julian day – spatial).                                                                                                                                                                                                                                                                                                                                    |
| TH2     | Variability in Julian date of annual maxima. Compute the coefficient of variation for the mean x and y components and convert to a date (Julian days - spatial).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| TH3     | Seasonal predictability of nonflooding. Computed as the maximum proportion of a 365-day year that the flow is less than the 1.67-year flood threshold and also occurs in all years. Accumulate nonflood days that span all years. TH3 is maximum length of those flood-free periods divided by 365 (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                             |
| RA1     | Rise rate. Compute the change in flow for days in which the change is positive for the entire flow record. RA1 is the mean (or median - Use Preference option) of these values (cubic feet per second/day – temporal).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| RA2     | Variability in rise rate. Compute the standard deviation for the positive flow changes. RA2 is 100 times the standard deviation divided by the mean (percent – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| RA3     | Fall rate. Compute the change in flow for days in which the change is negative for the entire flow record. RA3 is the mean (or median – Use Preference option) of these values (cubic feet per second/day – temporal).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| RA4     | Variability in fall rate. Compute the standard deviation for the negative flow changes. RA4 is 100 times the standard deviation divided by the mean (percent – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| RA5     | Number of day rises. Compute the number of days in which the flow is greater than the previous day. RA5 is the number of positive gain days divided by the total number of days in the flow record (dimensionless – spatial).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| RA6     | Change of flow. Compute the log10 of the flows for the entire flow record. Compute the change in log of flow for days in which the change is positive for the entire flow record. RA6 is the median of these values (cubic feet per second – temporal).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| RA7     | Change of flow. Compute the log10 of the flows for the entire flow record. Compute the change in log of flow for days in which the change is negative for the entire flow record. RA7 is the median of these log values (cubic feet per second/day – temporal).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

| Metrics | Definition                                                                                                                                                                                                                      |
|---------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| RA8     | Number of reversals. Compute the number of days in each year when the change in flow from one day to the next changes direction. RA8 is the average (or median - Use Preference option) of the yearly values (days - temporal). |
| RA9     | Variability in reversals. Compute the standard deviation for the yearly reversal values. RA9 is 100 times the standard deviation divided by the mean (percent – spatial).                                                       |

### ***Fundamental Daily Streamflow Statistics***

Archfield et al. (2014) identified seven indices calculated from daily stream flows that can be used to for hydroecological classification of stream systems (Table C-5).

**Table C-5.** Metric definitions for the seven fundamental statistics of daily streamflow calculated as a part of the NPS Park Environmental Settings Monitoring Protocol (from Archfield 2014). Detection of change is assumed to be based on statistical regression techniques except for stations with less than 5 years of data, in which case change would be based on a 10% difference threshold between initial and final measures.

| Metric    | Definition                                                                                                                                                                                                                                                                                                                                 |
|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| lam1      | Mean of the daily streamflow for the period of record.                                                                                                                                                                                                                                                                                     |
| tau2      | Coefficient of L-variation (Hosking and Wallis, 1997, eqn. 2.61) of the daily streamflow for the period of record.                                                                                                                                                                                                                         |
| tau3      | L-skewness (Hosking and Wallis, 1997, eqn. 2.60 with r equal to 3) of the daily streamflow for the period of record.                                                                                                                                                                                                                       |
| tau4      | L-kurtosis (Hosking and Wallis, 1997, eqn. 2.60 with r equal to 4) of the daily streamflow for the period of record.                                                                                                                                                                                                                       |
| ar1       | Autoregressive lag-one correlation coefficient of the daily streamflow for the period of record. First, the streamflow time series is deseasonalized by subtracting the long-term monthly mean streamflow from each of the days in the respective month and then standardized to have a zero mean and unit variance.                       |
| amplitude | Amplitude of the seasonal signal of the daily streamflow for the period of record. Streamflow is first standardized to have a zero mean and unit variance, a regression of streamflow versus $\sin(2\pi y)$ and $\cos(2\pi y)$ is performed and amplitude is then computed from the regression coefficients as given by Warner (1998).     |
| phase     | Phase shift of the seasonal signal of the daily streamflow for the period of record. Streamflow is first standardized to have a zero mean and unit variance, a regression of streamflow versus $\sin(2\pi y)$ and $\cos(2\pi y)$ is performed and phase shift is then computed from the regression coefficients as given by Warner (1998). |

### ***Indicators of Hydrologic Alteration***

Indicators of Hydrologic Alteration (IHA) is a program developed by the Nature Conservancy (TNC) that calculates 67 ecologically relevant metrics related to stream flows characteristic of natural and altered hydrologic systems (TNC 2007). This protocol only implements the 33 IHA metrics (Table C-6).

**Table C-6.** Indicators of Hydrologic Alteration metrics calculated as a part of the NPS Park Environmental Settings Monitoring Protocol (from TNC 2007). Detection of change is assumed to be based on statistical regression techniques except for stations with less than 5 years of data, in which case change would be based on a 10% difference threshold between initial and final measures.

| Metrics                                                            | Definition                                                                                                                                                                                                                                                                                                                                                                                       | Ecosystem Influences                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Magnitude of monthly water conditions (MONAVG1-12)                 | Mean or median flow for each calendar month                                                                                                                                                                                                                                                                                                                                                      | <ul style="list-style-type: none"> <li>Habitat availability for aquatic organisms</li> <li>Soil moisture availability for plants</li> <li>Availability of water for terrestrial animals</li> <li>Availability of food/cover for furbearing mammals</li> <li>Reliability of water supplies for terrestrial animals</li> <li>Access by predators to nesting sites</li> </ul> <p>Influences water temperature, oxygen levels, photosynthesis in water column</p>                                                                                                                                                                                                                                                                                                                                             |
| Magnitude and duration of annual extreme water conditions (AE1-12) | Annual minima, 1-day mean<br>Annual maxima, 1-day mean<br>Annual minima, 3-day means<br>Annual maxima, 3-day means<br>Annual minima, 7-day means<br>Annual maxima, 7-day means<br>Annual minima, 30-day means<br>Annual maxima, 30-day means<br>Annual minima, 90-day means<br>Annual maxima, 90-day means<br>Number of zero-flow days<br>Base flow index: 7-day minimum flow/mean flow for year | <ul style="list-style-type: none"> <li>Balance of competitive, ruderal, and stress- tolerant organisms</li> <li>Creation of sites for plant colonization</li> <li>Structuring of aquatic ecosystems by abiotic vs. biotic factors</li> <li>Structuring of river channel morphology and physical habitat conditions</li> <li>Soil moisture stress in plants</li> <li>Dehydration in animals</li> <li>Anaerobic stress in plants</li> <li>Volume of nutrient exchanges between rivers and floodplains</li> <li>Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments</li> <li>Distribution of plant communities in lakes, ponds, floodplains</li> <li>Duration of high flows for waste disposal, aeration of spawning beds in channel sediments</li> </ul> |
| Rate and frequency of water condition changes (WCC1-3)             | Rise rates: Mean or median of all positive differences between consecutive daily values<br><br>Fall rates: Mean or median of all negative differences between consecutive daily values<br><br>Number of hydrologic reversals                                                                                                                                                                     | <ul style="list-style-type: none"> <li>Drought stress on plants (falling levels)</li> <li>Entrapment of organisms on islands, floodplains (rising levels)</li> <li>Desiccation stress on low-mobility streamedge (varial zone) organisms</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

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