AIM National Aquatic Monitoring Framework
Technical Reference 1735-1

Introducing the Framework and Indicators for Lotic Systems

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Introducing the Framework and Indicators for Lotic Systems

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Abstract

This technical reference outlines the concept, development, and applications of the AIM National Aquatic Monitoring Framework—a standardized approach for the Bureau of Land Management (BLM) to quantitatively monitor and assess the condition of aquatic systems on BLM-administered public lands. Through standardizing the means by which data are collected and analyzed, this framework integrates both local- and regional-scale aquatic monitoring activities to more effectively inform BLM management decisions, planning activities, and, thus, the maintenance or improvement of resource conditions on public lands. The initial application of the framework is the development of 11 core indicators for wadeable perennial streams and rivers characterizing water quality (acidity, conductivity, temperature), watershed function and instream habitat quality (pool dimensions, streambed particle sizes, bank stability and cover, floodplain connectivity, large woody debris), and biodiversity and riparian habitat quality (macroinvertebrate biological integrity; canopy cover; vegetative type, cover, and structure). The core indicators are complemented by a set of contingent indicators (e.g., nutrients; suspended sediment; bank angle; vegetative cover, composition, and structure) to address more specific management questions, as well as covariates to help determine the potential of a stream or river to support a set of water quality, geomorphic, or biological conditions. This framework was designed to characterize aquatic conditions at all scales but will initially be implemented at the land use plan, state, and ecoregional scales.

1. The Need for a National Aquatic Monitoring Framework

The Bureau of Land Management (BLM) oversees nearly 250,000 kilometers of perennial lotic systems and more than 52,000 km^2 of wetlands located primarily throughout 12 Western States, including Alaska (BLM 2013a). BLM lotic systems support numerous aquatic species and provide ecosystem services such as drinking water, flood attenuation, and nutrient cycling. The BLM's multiple-use mandate also directs the management of watersheds for activities that potentially impact aquatic resources, such as livestock grazing, timber harvest, mining, energy development, and recreation. Consequently, knowing the conditions and trends of aquatic systems is critical to achieving the BLM mission, which is to "sustain the health, diversity, and productivity of the public lands for the use and enjoyment of present and future generations."

BLM aquatic resource inventory, monitoring, and protection are mandated by federal statutes, including the Federal Land Policy and Management Act of 1976, Clean Water Act of 1977 (as amended), Endangered Species Act of 1973, and others. Collectively, these federal statutes and their implementing regulations and subsequent agency policies aim to ensure the restoration and maintenance of the chemical, physical, and biological integrity of aquatic resources. The effective implementation of these policies requires the use of consistent resource condition and trend data to inform management decisions across multiple spatial scales. For example, at the local scale, BLM field offices must determine the environmental consequences of permitted activities. Regionally, BLM field offices need to assess the effectiveness of land use plans. At the national scale, the BLM is required to report annually on the attainment of Department of the Interior performance standards and on the conditions of aquatic resources in the annual Public Land Statistics publication.

The multiscale data requirements of the BLM are linked by a shared need for information regarding the type, size, number, and location of aquatic resources (i.e., inventory); the status of resources in relation to narrative or numeric standards (i.e., condition); and how condition changes through time (i.e., trend). However, past BLM aquatic monitoring efforts have largely been developed to meet project- or program-specific objectives at local scales. Exceptions include the BLM/U.S. Forest Service (USFS) Aquatic Riparian Effectiveness Monitoring Program and the PACFISH/INFISH Biological Opinion Monitoring Program. Although effective for project-specific needs, the individual development of local monitoring efforts to assess aquatic resource condition commonly results in information that cannot be compared among management areas or aggregated to provide regional and national perspectives of resource condition because of disparate indicators, sampling methods, and survey designs.

In response to the increasingly complex nature of socioenvironmental decisions facing public land managers and the objective of increasing the defensibility and applicability of monitoring data, the BLM undertook efforts that eventually led to the development of the "Assessment, Inventory, and Monitoring Strategy for Integrated Renewable Resources Management" (AIM Strategy) in 2011 (Toevs et al. 2011b). The AIM Strategy is a national strategy designed to facilitate integrated, cross-program resource monitoring at multiple spatial scales of management. The AIM Strategy is a critical component of the BLM's landscape approach (BLM 2013b), which seeks to integrate science and management at scales transcending traditional management boundaries and to achieve objectives of recent Secretarial (3289 and 3330) and Executive (13514) Orders related to climate change and the adoption of a landscape approach to managing public lands. Specifically, through the AIM Strategy, the BLM seeks to integrate both local- and regional-scale monitoring activities to inform condition assessments by establishing core indicators, standardizing field methodologies, using statistically valid sample designs, and developing electronic data capture and storage technologies. Collectively, these efforts will more effectively inform management decisions, planning activities, and, thus, the maintenance or improvement of resource conditions on public lands. Since the publication of the AIM Strategy, the BLM has been implementing the use of the core terrestrial indicators and methods to quantitatively monitor and assess resource condition on public lands.

As a component of the AIM Strategy, this National Aquatic Monitoring Framework (NAMF) provides the rationale and framework for how the BLM can quantitatively monitor and assess the conditions of aquatic resources. This tech reference also presents the aquatic core indicators applicable to wadeable perennial streams (i.e., lotic systems); a separate technical reference will describe the methods for measuring the aquatic indicators. Additional subsequent efforts will focus on nonwadeable perennial streams and lentic systems.

2. BLM Aquatic Monitoring History: Past and Present

Responsible for more land than any other federal agency, the BLM manages resources at spatial scales ranging from individual project locations, to grazing allotments, to ecoregions. The BLM has managed these lands under a multiple-use mandate since 1976, following the passage of the Federal Land Policy and Management Act. In accordance with 43 CFR 4180.1, which became effective in 1995, individual states and regions are required to develop and amend land health standards for each of four fundamentals of rangeland health (hereafter referred to as fundamentals) determined to be critical to sustaining functioning rangeland ecosystems (Table 1). In 2005, with the release of BLM Handbook H-1601-1, "Land Use Planning Handbook," BLM policy determined land health standards as applicable to all ecosystems and management actions (BLM 2005). For aquatic systems, the BLM is required to inventory, monitor, and assess the conditions of instream and riparian habitat, water quality, species, and ecological processes in a four-step process designed to facilitate adaptive management (Figure 1) (BLM 2001). Consequently, the BLM's fundamentals provide a common set of interdisciplinary questions that the BLM seeks to answer from the scale of individual grazing allotments to national-level reporting to ensure the sustainable management of functioning aquatic ecosystems.

Table 1. Descriptions and example aquatic standards and indicators stipulated by 43 CFR 4180.1 for maintaining functioning aquatic ecosystems.

Four Fundamentals	Fundamental Description	Example Aquatic Land Health Standards	Example Aquatic Indicators
Watershed function and instream habitat quality	Watersheds are in, or are making significant progress toward, properly functioning physical condition, including their upland, riparian-wetland, and aquatic components; soil and plant conditions support infiltration, soil moisture storage, and the release of water that are in balance with climate and landform and maintain or improve water quality, water quantity, and timing and duration of flow	Streams: Stream channel form and function are characteristic for the soil type, climate, and landform Riparian: Riparian areas are in proper functioning condition (i.e., vegetation is adequate to dissipate energy, stabilize stream banks, reduce incoming solar radiation, and capture sediment/nutrients)	Width-to-depth ratios, bank stability, residual pool depth, substrate stability, large woody debris Stream temperature, channel substrate, nutrient concentrations, vegetative composition and cover
Water quality	Water quality complies with state water quality standards and achieves, or is making significant progress toward achieving, established BLM management objectives, such as meeting wildlife needs	Water has characteristics to support existing beneficial uses and complies with the Clean Water Act and state standards	Temperature, nutrients, turbidity, acidity, conductivity, macroinvertebrates
Biodiversity and riparian habitat quality for native, threatened and endangered, and/or special status species	Habitats are, or are making significant progress toward being, restored or maintained for federal threatened and endangered species, federal proposed or candidate threatened and endangered species, and other special status species	Healthy, productive, and diverse populations of native and desired plant and animal species and their required habitats are maintained	Composition, diversity, and/or age class of riparian vegetation and/or macroinvertebrates; percentage of fine sediment; bank angle; residual pool depth
Ecological processes	Ecological processes, including the hydrologic cycle, nutrient cycle, and energy flow, are maintained, or there is significant progress toward their attainment, in order to support healthy biotic populations and communities	Composite of the watershed function, water quality, and species/habitat quality standards	See examples from the three previous indicators

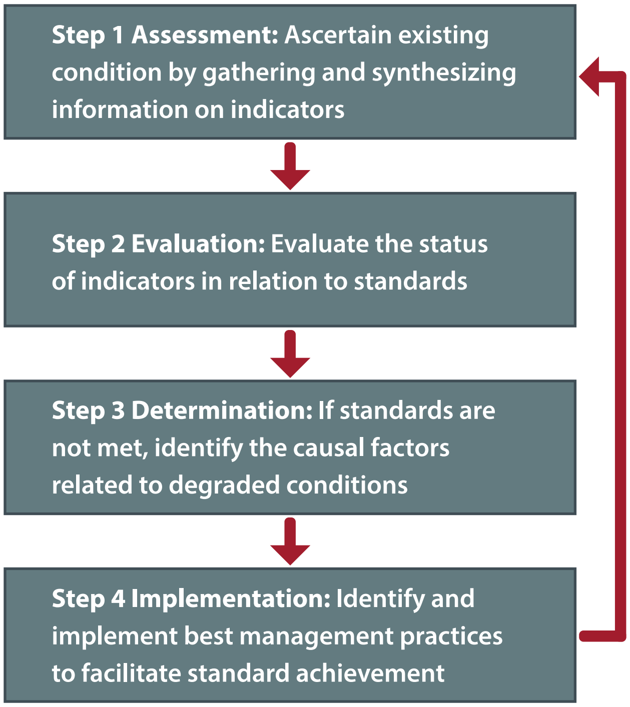


Figure 1. Four-step adaptive management process by which the BLM ensures land health standard attainment.

Land health standards are meant to provide site-specific assessments of grazing impacts and to also facilitate assessments of the cumulative effectiveness of management actions at broader spatial scales. To be effective, the application of land health standards as an adaptive management tool requires resource information that can be: (1) used to make consistent, objective, and credible condition assessments; (2) applied across multiple spatial scales; (3) integrated with data collected by state and federal partners; and (4) applied to multiple resource challenges. Although the BLM's four fundamentals provide a common set of management questions, they do not provide a nationally consistent approach to monitor and assess the condition of aquatic ecosystems among field offices and states (i.e., standardized indicators, field methodologies, and survey designs).

Under 43 CFR 4180, individual BLM states are given the discretion to develop specific land health standards for each of the four fundamentals, as well as the choice of which indicators are used to assess standard attainment. Collectively, 19 sets of standards exist, representing a total of 90 standards and more than 100 suggested indicators (M. "Sherm" Karl, unpublished data). The inconsistent use of indicators and methods to assess standard attainment among BLM field offices, districts, and states results in a wealth of information that cannot be readily compared across time or management areas, combined with data from different programs, or aggregated to provide regional or national perspectives. For example, stream channel width-to-depth ratios are listed as an indicator within all 19 sets of land health standards, but there is no standardized BLM protocol specifying the methods for quantifying this indicator. Thus, the NAMF does not recommend new standards or indicators but, rather, the standardization of methods for measuring a subset of existing indicators.

The inadequacy of the BLM's local-scale approach to assessing resource condition was highlighted in 2004 by the Office of Management and Budget (OMB) when they evaluated the BLM's upland monitoring activities and found "gaps in monitoring of resource conditions to support management decisions…" and that the BLM had no reliable mechanism for reporting on the conditions of public lands above the local scale. The OMB subsequently directed the BLM to analyze its monitoring activities and develop a more comprehensive, cost-effective, and consistently applied monitoring strategy.

Despite similar concerns regarding the BLM's aquatic monitoring efforts, the implementation of a standardized, qualitative assessment tool for aquatic systems has had longstanding precedence in the BLM. Specifically, the BLM's use of proper functioning condition (Prichard et al. 1998) to fulfill the objectives of the "Riparian-Wetland Initiative for the 1990s" demonstrates the BLM's capacity to implement a consistent national strategy (BLM 1990). The initiative laid the groundwork for coordination, education, protection, and restoration of BLM riparian areas. The use of proper functioning condition helped improve the conditions of riparian and wetland areas by focusing attention on the physical attributes and processes important for functioning riparian and aquatic systems and by providing an important communication and conflict resolution tool.

Monitoring programs designed to assess the impacts of anthropogenic activities on aquatic ecosystems at multiple spatial scales have advanced considerably over the last decade. Advances in survey design (Stevens and Olsen 2004; Theobald et al. 2007), indicator development (Hawkins et al. 2000; Kaufmann et al. 2008), and field methodologies (Bunte and Abt 2001; McHugh and Budy 2005; Rehn et al. 2007; Isaak and Horan 2011) have increased the precision, accuracy, and applicability of data collected by regional and national efforts, such as the BLM and USFS Aquatic and Riparian Effectiveness Monitoring Program and PACFISH/INFISH Biological Opinion Effectiveness Monitoring Program, the Environmental Protection Agency (EPA) National Rivers and Streams Assessment, and the U.S. Geological Survey (USGS) National Water-Quality Assessment Program.

In response to the OMB's programmatic evaluation, the increasingly complex management challenges facing public land management agencies (e.g., climate change, wildfires, endangered and sensitive species, invasive species), and the adoption of a landscape approach, the BLM developed the AIM Strategy to integrate and standardize monitoring activities within the BLM, to minimize redundancies in data collection, and to address multiple resource questions at multiple scales. The foundation of the AIM Strategy includes five guiding principles:

1. Nationally prescribed indicators and consistent methods.
2. Statistically valid sample designs.
3. Electronic data acquisition and storage.
4. Analytical tools that enable monitoring data to inform management decisions.
5. Integration of remote sensing technologies.

A new quantitative aquatic monitoring framework is the next logical step to interdisciplinary assessments of riparian and aquatic condition. The first four guiding principles of the AIM Strategy form the cornerstone of the NAMF to develop integrated monitoring at multiple spatial scales of management, while future efforts will attempt to integrate remote sensing technologies. The NAMF also builds on the BLM's history of riparian, fisheries, and water quality management and adopts many of the indicators, methods, and survey design principles common to previous regional and national efforts. This overlap is necessary to maximize compatibility with state and federal partners and to expand upon the robust science of previous efforts.

The use of one set of aquatic indicators across various spatial scales is a new paradigm for the BLM. The NAMF seeks to provide monitoring data to inform local management decisions, as well as those occurring at regional and national scales, in a coordinated, consistent manner (e.g., Figure 2). In addition to addressing landscape-scale management questions, regional- and national-level datasets will also provide context for local decisions through the development of reference site networks and analytical tools for making objective assessments of aquatic resource condition.

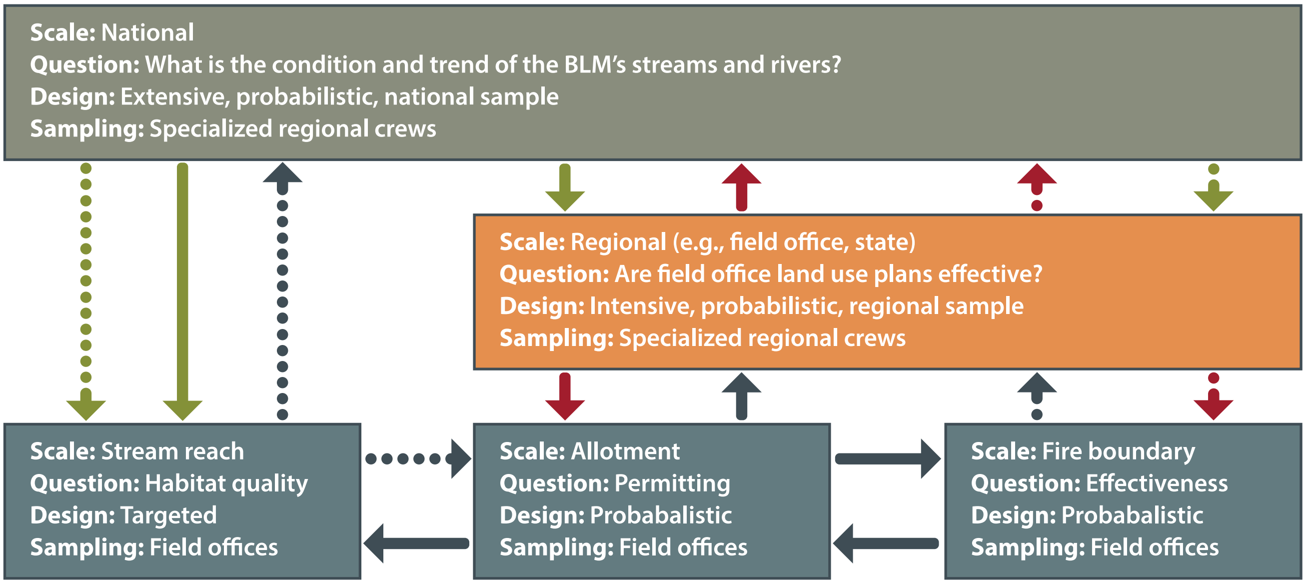


Figure 2. Conceptual diagram of how the BLM can use both probabilistic and targeted sample designs to collect data once and use it for multiple applications across spatial scales (different color boxes). Data integration will be facilitated among spatial scales by: (1) direct application of sample points common to multiple scales (solid arrows); (2) the use of national- and regional-level data to make predictions of the chemical, physical, and/or biological conditions of unsampled stream segments (dashed, downward pointing arrows); and (3) the use of targeted or probabilistic data collected at local scales to test and refine condition predictions for unsampled sites (dashed, upward pointing arrows). Figure modified from Toevs et al. (2011a).

3. Goals and Objectives of the National Aquatic Monitoring Framework

The goal of the NAMF is to evaluate the effectiveness of the BLM's management actions to maintain or improve the chemical, physical, and biological integrity of aquatic systems per BLM policy, plans, and state and federal regulations. The NAMF is not tied to a specific program within the BLM; nor was it created to address any one data need. Rather, it represents a multiprogram framework for the BLM to consistently and quantitatively inform the assessment of aquatic resource condition, including:

- Standardization of BLM aquatic core indicators and sampling methodologies (instream and riparian) used to quantify aquatic and riparian processes and attributes.
- Standardization of the analyses by which the BLM uses aquatic core indicators to assess aquatic resource condition and trend.
- Development of a multiscale (local, regional, national) monitoring framework to assess the chemical, physical, and biological conditions and trends of aquatic systems on BLM-managed public lands. This particular tech reference focuses on wadeable perennial streams and rivers (i.e., lotic systems). Subsequent efforts will focus on nonwadeable perennial streams and lentic systems.

This framework will allow the BLM to achieve the following:

- Meet monitoring requirements stipulated by state and federal policy, laws, and regulations in a timely fashion.
- Assess both the attainment of the BLM's fundamentals (43 CFR 4180.1) and the components of functioning aquatic systems.
- Consistently use BLM monitoring data to inform management decisions and the iterative process of adaptive management.
- Provide a mechanism for the BLM to review and respond to new monitoring and assessment methods in a coordinated manner as they become available.
- Improve the coordination, integration, and efficiency of aquatic monitoring and assessment activities and subsequent results among the BLM's Riparian; Fisheries; and Soil, Water, and Air Programs, as well as with other BLM programs and state and federal agencies.

4. Intended Applications of the National Aquatic Monitoring Framework

The NAMF was designed to facilitate quantitative assessments of all aquatic resources at multiple spatial scales, but it will initially focus on assessing stream and river conditions at the scale of land use plans, field office, states, and ecoregions. For example, in 2013 the BLM initiated the Western Rivers and Streams Assessment using principles of the NAMF to obtain unbiased estimates of stream and river conditions at ecoregional and national scales in collaboration with the EPA (see Section 7.1 for details). In addition, numerous demonstration projects focusing on field office-, district-, and state-scale monitoring are underway, including those in Alaska, California, Colorado, Nevada, and Utah (see Figure 3 and Section 7.2 for more details). The goal is to increasingly implement the NAMF at finer spatial scales, with the objective of conducting BLM-wide land use plan effectiveness monitoring following the guidance issued in the BLM publication "Winning the Challenges of the Future: A Road Map for Success in 2016" (BLM 2011). However, at all scales, if any of the aquatic core or contingent indicators are to be measured, the methods specified herein should be used. See Appendix A for questions regarding the intended applications and implementation of the NAMF.

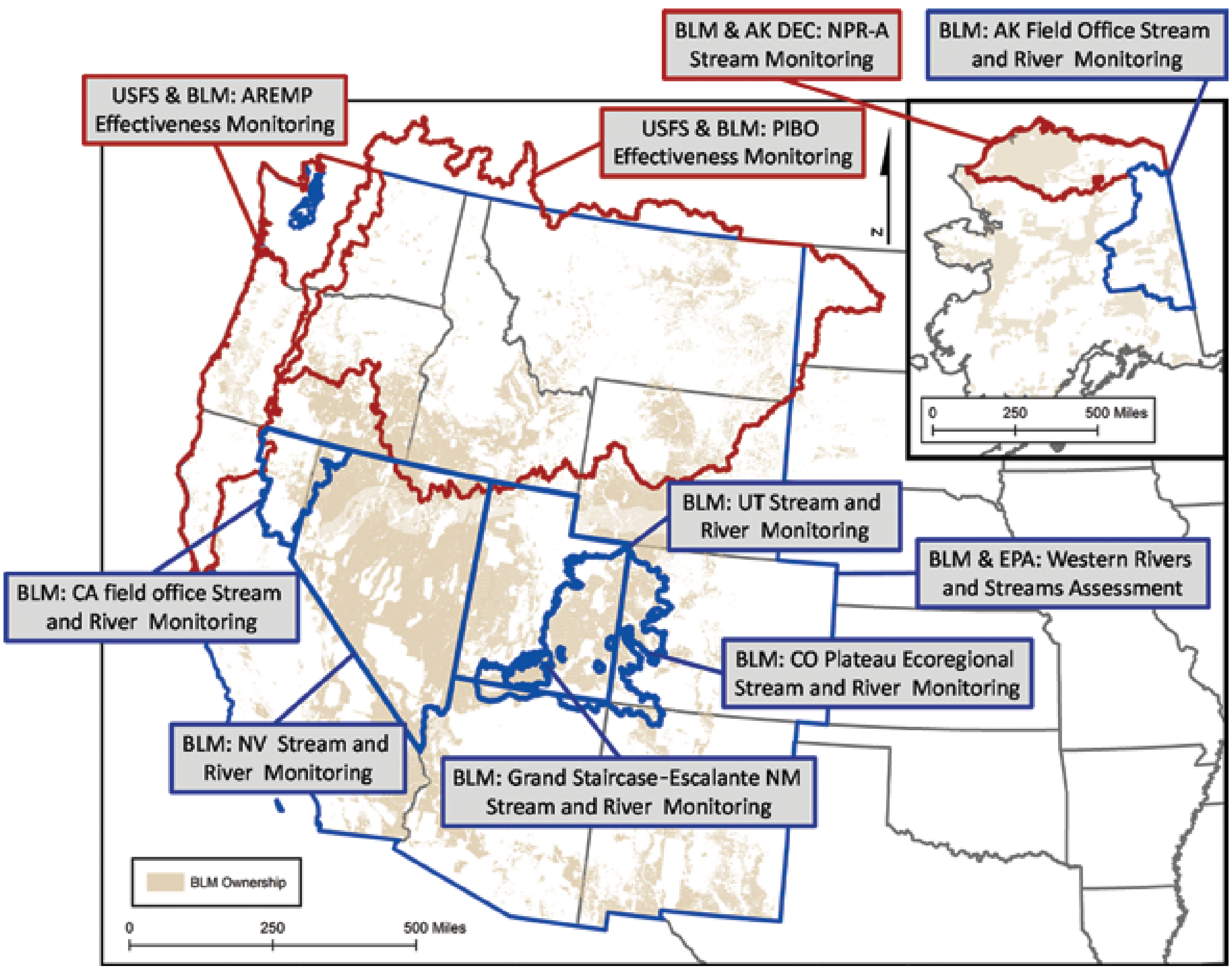


Figure 3. Active National Aquatic Monitoring Framework demonstration projects throughout the Western U.S. and Alaska. Projects highlighted in blue are led by the Bureau of Land Management, while projects outlined in red are new or ongoing collaborative efforts compatible with the NAMF involving the U.S. Forest Service, Environmental Protection Agency, and/or state agencies.

The aquatic *core indicators* represent a consistent, quantitative approach for assessing the attainment of BLM land health standards (Table 1) for perennial wadeable streams and rivers. However, the aquatic core indicators are not expected to be inclusive of all BLM lotic data needs, as additional indicators (i.e., contingent or supplemental) may be required. For example, aquatic *contingent indicators* are to be used when specific problems exist (e.g., excessive nutrient loading, habitat availability for a fish species of management concern, grazing impacts to riparian systems) to assess land health standard attainment or for regional-scale assessments seeking to identify priority stressors requiring additional monitoring. In contrast, *supplemental indicators* may be required to address specific or local resource questions not addressed by the core and contingent indicators (e.g., metals loading, fecal coliform, fish populations) (e.g., Section 7.3). Because of the many supplemental indicators that may be required, specific recommendations are not made in this tech reference. If local monitoring efforts require the collection of indicators not covered by the NAMF to characterize conditions and trends of aquatic ecosystem processes and attributes, the relevant NAMF indicator(s) should also be collected.

Definitions

core indicator: measurable ecosystem component applicable across many different ecosystems, management objectives, and agencies. Core aquatic indicators are recommended for application wherever the BLM implements monitoring and assessment of wadeable perennial streams.

contingent indicator: measureable ecosystem component having the same characteristics of cross-program utility and consistent definition as core indicators, but that are measured only where applicable. Contingent indicators are not informative everywhere and, thus, are only measured when there is reason to believe they will be important for management purposes.

supplemental indicator: a measureable ecosystem component that is specific to a given ecosystem, land use, or management objective. No specific supplemental indicators or associated methodologies are recommended in the NAMF given the diversity of probable indicators.

covariate: measured or derived parameter used to account for natural spatial or temporal variation in a core, contingent, or supplemental indicator (e.g., gradient); covariates help determine the potential of a given stream reach or other aquatic system.

5. National Aquatic Monitoring Framework Development

The NAMF was developed by an interdisciplinary BLM work group, the Aquatic Core Indicator Work Group (ACIWG) (Appendix B), following a five-step process (Figure 4). This process closely follows the steps used to develop the AIM Strategy (Toevs et al. 2011b), AIM core terrestrial indicators and methods (Herrick et al. 2010; MacKinnon et al. 2011), and other multiscale monitoring efforts (Kurtz et al. 2001; Reeves et al. 2004; Kershner et al. 2004), including both internal and external peer review.

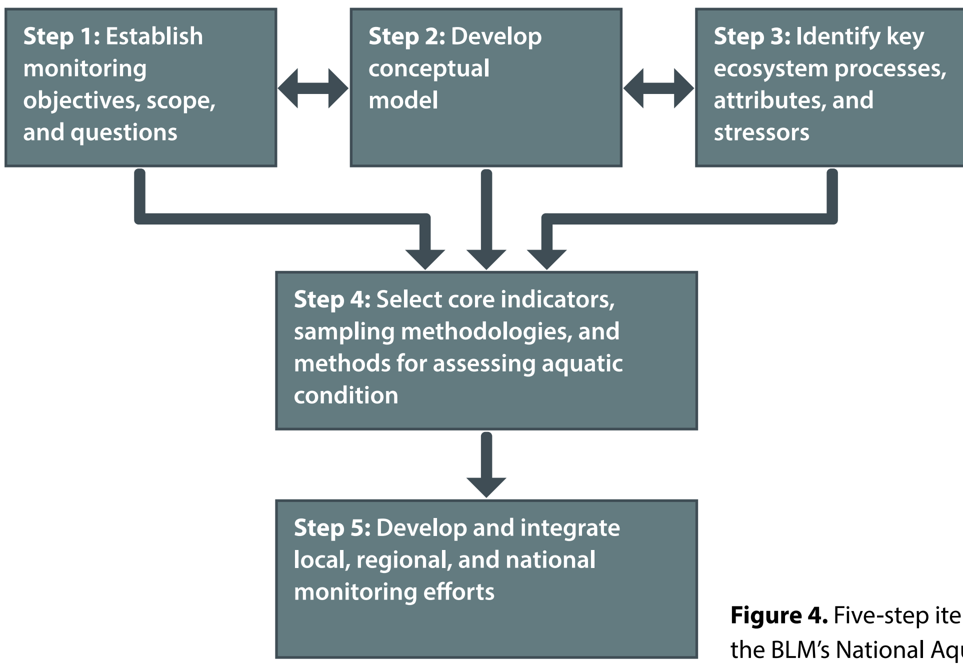


Figure 4. Five-step iterative process for developing the BLM's National Aquatic Monitoring Framework.

5.1 Step 1: Development of Monitoring Questions

Whether applied locally, regionally, or nationally, the BLM's fundamentals (43 CFR 4180.1) are based upon a core set of questions regarding the efficacy of BLM management actions to maintain or improve the conditions of upland and aquatic systems. These include:

I. How intact are the key processes that sustain functioning lotic systems as defined by federal statutes and the BLM's four fundamentals?

   i. What is the condition of key hydrologic processes?

   ii. What is the condition of key geomorphic processes?

   iii. What is the condition of key biological processes?

   iv. What is the condition of key chemical processes?

II. What are the causal factors contributing to departures from land health standards and/or beneficial uses?

III. What are the sources of observed stressors?

IV. How has the condition of key aquatic resources changed through time?

5.2 Steps 2 and 3: Prioritization of Lotic Ecosystem Attributes, Processes, and Stressors for the Development of Aquatic Core and Contingent Indicators

Determining the conditions and trends of stream and river systems requires a consideration of the attributes and processes critical to sustaining functioning lotic ecosystems. The ACIWG followed the BLM's four fundamentals and proper functioning condition (Prichard et al. 1998; Gregory et al. 1991) and characterized functioning lotic ecosystems as the integrated product of hydrologic, geomorphic, chemical, and biotic processes (Figure 5). Collectively, the interaction of hydrologic processes with channel structure/stability, riparian vegetation, and water quality determine the habitat suitability for aquatic biota, one of the primary beneficial uses of BLM streams and rivers. The ACIWG used these four ecosystem processes and their associated attributes to guide the selection of aquatic core and contingent indicators.

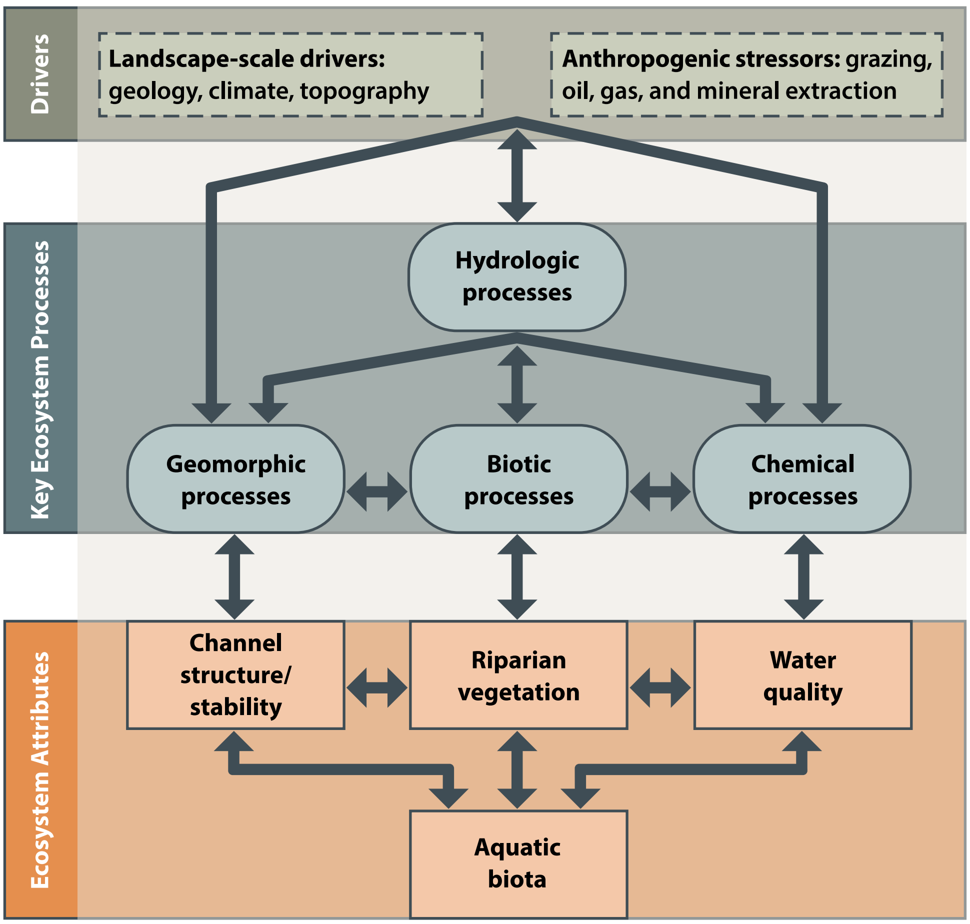


Figure 5. Conceptual model of the key ecosystem processes (ovals) and their interactions within functioning aquatic ecosystems as mediated by example intrinsic and extrinsic drivers of aquatic ecosystems (dashed squares). The ecosystem attributes panel (squares) represents example structural attributes that the BLM frequently manages and monitors given the complexity of directly monitoring ecosystem processes. Note that the listed ecosystem attributes and drivers are not exhaustive but, rather, examples resulting from the interactions of hydrologic, geomorphic, biotic, and chemical processes that are of management relevance to the BLM. This model is adapted from Gregory et al. (1991).

Ideally, the BLM would directly measure the ecosystem attributes and processes necessary to sustain functioning lotic systems, but the inherent complexity of lotic systems frequently necessitates that the BLM focus on surrogates (i.e., either those that affect or are affected by ecosystem processes) that can be repeatedly quantified. Thus, the ACIWG considered aquatic core and contingent indicators to be structural or functional measures that either directly or indirectly quantify the condition of lotic ecosystem attributes or processes. To prioritize attributes for each of the four key ecosystem processes (Figure 5), the ACIWG referenced the BLM's land health standards and the conceptual framework of stressor-response models (Noon et al. 1999) to help identify those components of lotic systems for which the BLM is required to report on locally, regionally, and nationally (e.g., thermal, sediment, and nutrient regimes). Specifically, the ACIWG reviewed state-specific standards and indicators used by the BLM to determine attainment of the four fundamentals (e.g., Table 1).

Second, the ACIWG used the conceptual framework of stressor-response model relationships to prioritize attributes for indicator development (Noon et al. 1999). Specifically, group members used findings from published studies and their best professional judgment to conceptualize the mechanisms by which land uses (e.g., grazing, timber harvest, oil and gas development, recreation) impact key ecosystem attributes and processes and how the magnitude and direction of the impacts vary as a function of intrinsic drivers. For example, with more than 80% of western riparian areas affected (Kauffman et al. 1997), livestock grazing can act as an extrinsic stressor to stream systems via multiple pathways (Figure 6). Reductions in vegetative cover can increase thermal loading, thus increasing stream temperature and changing instream biotic assemblages (Tait et al. 1994; Beschta 1997; Herbst et al. 2012). Similarly, alterations to vegetative composition and cover can initiate changes in channel morphology and increase fine sediment loading (Knapp and Matthews 1996; Coles-Ritchie et al. 2007; Herbst et al. 2012); however, the degree of alteration can depend on the intrinsic drivers of local climate, lithology, and topography. Such predictive or anticipatory models identify the linkages among critical ecosystem attributes, monitoring indictors, anthropogenic disturbances, and management actions and, ideally, the guidance for ameliorating adverse impacts to lotic systems.

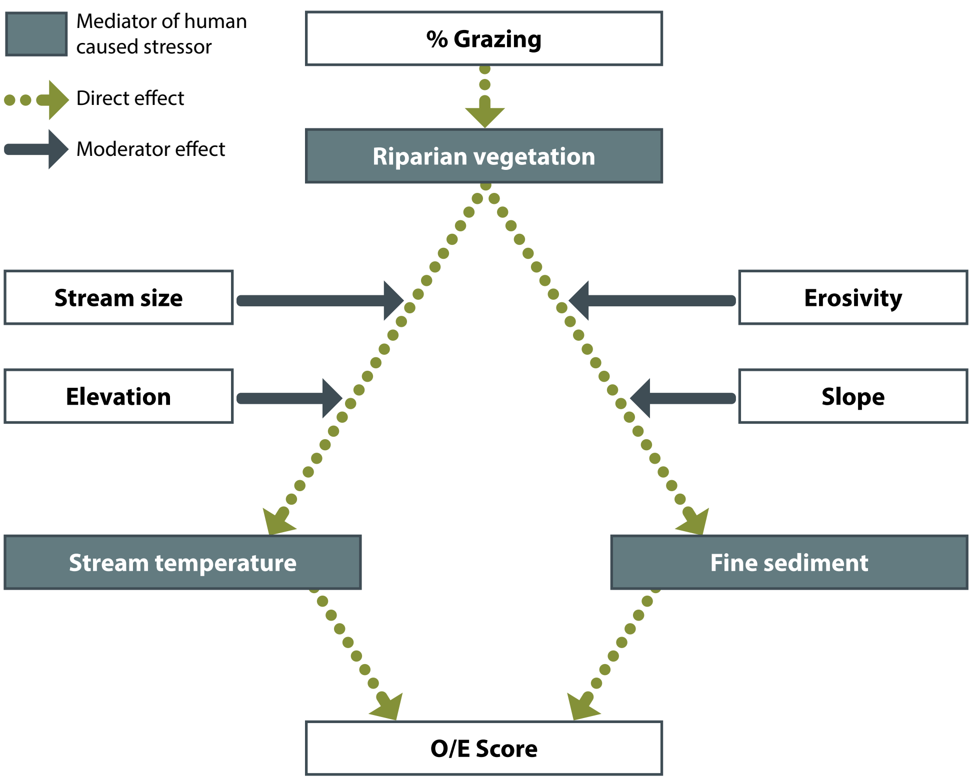


Figure 6. Example stressor-response conceptual model for the effects of cattle grazing on macroinvertebrate biological integrity (observed/expected [O/E] score) as mediated by riparian vegetation, stream temperature, and fine sediment (shaded boxes and dashed arrows). The degree to which alterations to vegetative composition and cover increase stream temperature and fine sediment can be moderated by stream size, elevation, erosivity of local lithologies, and slope (white boxes and solid arrows).

Cumulatively, based on BLM land health standards and conceptual stressor-response models, BLM program leads identified 19 candidate ecosystem attributes and indicators mandated by policy and/or critical to BLM stream and river management (Table 2). To prioritize the specific attributes for which aquatic core and/or contingent indicators would be developed, the ACIWG surveyed 72 BLM program leads and field office personnel (Appendix C). Of the 19 attributes considered, cations and anions, metals, and, to a lesser extent, water storage and yield and instream productivity were the only attributes not consistently ranked as top BLM priorities (Appendix C, Figure C1); however, no attributes were ranked as unimportant.

Table 2. Ecosystem attributes and indicators for each of the four key lotic ecosystem processes that were prioritized for aquatic core indicator development by surveying BLM personnel. Attributes identified as less important are italicized. The attributes were initially identified from the BLM's land health standards and conceptual stressor-response models.

Geomorphic attributes and indicators
Sediment regime (supply and transport)
Channel dimensions/shape
Habitat complexity
Energy dissipation and retention capacity
Bank conditions (angle, stability, cover)
Hydrologic attributes and indicators
Natural flow regime (timing, magnitude, duration and frequency of high- and low-flow events)
Hydrologic connectivity (lateral, longitudinal, vertical)
Water storage and yield
Hillslope processes (surface runoff, infiltration, erosion rates)
Chemical attributes and indicators
Thermal regime
Nutrient cycling, loads, concentrations
General water chemistry: pH, conductivity, dissolved oxygen
Cations and anions
Metals
Biotic attributes and indicators
Instream biotic integrity
Riparian biotic integrity
Instream productivity
Riparian productivity
Wood production and recruitment

It should not be surprising that all evaluated attributes were consistently ranked as critical to sustaining functioning lotic systems given the central role played by nearly all of the attributes for maintaining functioning lotic systems. Rather, the results reinforce the need for the BLM to develop a comprehensive and interdisciplinary approach to aquatic monitoring. Therefore, the NAMF must be inclusive of the hydrologic, geomorphic, biotic, and chemical processes of functioning lotic systems in order to meet both policy requirements and to help field staff adequately assess lotic ecosystem function. As a result, aquatic core and contingent indicators were sought for the priority attributes, while also considering the lesser ranked attributes.

5.3 Step 4: Selection of Aquatic Core and Contingent Indicators

Core and contingent indicators were selected for each of the priority attributes using a three-phase, iterative process that parallels steps used to develop the BLM's AIM Strategy (Toevs et al. 2011b), AIM core terrestrial indicators and methods (Herrick et al. 2010; MacKinnon et al. 2011), and other existing aquatic monitoring programs (Noon et al. 1999; Kershner et al. 2004). Specific steps in the process included: (1) inventorying indicators and field methodologies used by existing Western U.S. stream and river monitoring programs; (2) using selection criteria to screen potential indicators (Table 3); and (3) internal and external peer review.

Table 3. Criteria used to select aquatic core and contingent indicators following the guidance of Noon et al. (1999) and Kurtz et al. (2001) in a two-stage process.

Stage 1A: Conceptual relevance
Indicator is relevant to monitoring question(s)
Indicator is relevant to ecological function
Stage 1B: Response variability
Can be measured with minimal sampling error
Experiences minimal natural temporal variability (within and among years)
Environmental factors controlling natural spatial variability are well understood
Stage 2A: Interpretability and usability
Analytical framework exists for making condition determinations
Direct linkage exists to management actions and policy
Is responsive to disturbances or management actions on time scales relevant to management decisions
Data is of sufficient quality to be useful and credible
Stage 2B: Feasibility of implementation
Can be collected using a minimal number of methods
Cost is not prohibitive to obtain desired accuracy and precision
BLM has the capacity with minimal additional training
Overlaps with existing BLM methods
Overlaps with existing state and federal agencies

The inventory of existing state and federal monitoring programs identified more than 45 different field measurements and associated indicators used to assess the conditions of western streams and rivers (Appendix D, Tables D1 and D2). The ACIWG distilled this list of candidate indicators by applying the selection criteria of Noon et al. (1999) and Kurtz et al. (2001) in a two-stage process (Table 3). Individual indicators were first evaluated in terms of conceptual relevance, response variability, and interpretability and usability. The remaining indicators were evaluated in regards to feasibility of implementation. This process resulted in the selection of 11 aquatic core indicators, six contingent indicators, and two covariates (Table 4).

Table 4. Core and contingent aquatic indicators for use in wadeable perennial streams. The indicators are grouped by the BLM's four fundamentals (43 CFR 4180.1). Specific field methodologies for the core and contingent indicators are presented in Appendix E.

Four Fundamentals	Indicator	Core	Contingent
Water quality	Acidity	X	
	Conductivity	X	
	Temperature	X	
	Total nitrogen and phosphorous		X
	Turbidity		X
Watershed function and instream habitat quality[1]	Residual pool depth, length, and frequency	X	
	Streambed particle sizes	X	
	Bank stability and cover	X	
	Floodplain connectivity	X	
	Large woody debris	X	
	Bank angle[2]		X
	Ocular estimate of instream habitat complexity[2]		X
	Thalweg depth profile		X
Biodiversity and riparian habitat quality	Macroinvertebrate biological integrity	X	
	Ocular estimates of riparian vegetative type, cover, and structure	X	
	Canopy cover	X	
	Quantitative estimates of riparian vegetative cover, composition, and structure		X
Ecological processes	See indicators from other fundamentals[3]	NA	NA

[1]In addition to the core and contingent watershed function and instream habitat quality indicators, the ACIWG recommends the measurement of bankfull width and slope as covariates.

[2]Bank angle and ocular estimate of instream habitat complexity were included as contingent indicators to be collected in all regional and national surveys on a research basis; see text for additional details.

[3]Indicators used to assess ecosystem function are redundant with other indicators, such as temperature; total nitrogen and phosphorous; streambed particle sizes; macroinvertebrate biological integrity; and ocular estimates of riparian vegetative type, cover, and structure.

5.3.1 Water Quality Indicators

The core water quality indicators include acidity, conductivity, and temperature, and the contingent water quality indicators include total nitrogen and phosphorous and turbidity (Table 4). Nutrient and turbidity monitoring are only recommended where problems are suspected to exist, given the expense and time required to characterize nutrient and sediment loading. Conversely, base flow grab samples are recommended for regional and national monitoring efforts to help prioritize stressors and to associate with macroinvertebrate biological integrity.

The core and contingent indicators are not meant to be representative of all state water quality standards. Rather, the indicators are meant to help determine the common chemical stressors resulting from land uses, such as irrigation water withdrawals and return flows, grazing, mining, timber harvest, and other activities occurring on or near public lands. Additionally, the core and contingent indicators can be measured in an efficient, cost-effective manner. Although one-time grab samples can be used to identify potential water quality priorities that require additional sampling and/or to make correlations with macroinvertebrate biological integrity estimates, monitoring to determine the attainment of state water quality standards requires the sampling frequency of each indicator to be consistent with individual state standards.

5.3.2 Watershed Function and Instream Habitat Quality Indicators

Assessments of the physical functioning of stream and river systems are a major component of the BLM's fundamentals (Table 1). The "watershed function and instream habitat quality" fundamental calls for assessments of whether channel form and function are characteristic for the region, while the "biodiversity and riparian habitat quality" fundamental requires the maintenance or improvement of aquatic habitat for threatened and endangered, proposed or candidate threatened and endangered, and other special status species (i.e., similar to the maintenance of cold- or warm-water fisheries under the Clean Water Act). To assess watershed function and instream habitat quality, the ACIWG identified five core indicators (residual pool depth, length, and frequency; streambed particle sizes; bank stability and cover; floodplain connectivity; and large woody debris) and three contingent indicators (bank angle, ocular estimate of instream habitat complexity, and a thalweg depth profile for computation of relative bed stability) (Table 4). Ocular measures of instream habitat complexity are recommended for use in conjunction with quantitative field parameters, while the BLM works to develop a multimetric habitat index that incorporates quantitative measurements of attributes such as substrate, large woody debris, pools, and bank angle (e.g., Al-Chokhachy et al. 2010). Similarly, the BLM should initially measure bank stability and cover and bank angle to ensure accurate and precise information is gained regarding streambank condition. Lastly, for more intensive monitoring of the balance between sediment supply and the capacity of the stream to transport the sediment load, the measurement of a longitudinal depth profile is recommended for computation of relative bed stability following the methods of Kaufmann et al. (2008, 2009).

Of the myriad physical habitat indicators that could be measured, the ACIWG chose these indicators because of their relevance across all BLM lands, their capacity to obtain accurate and precise field measurements, their ubiquitous use by other monitoring programs, and the BLM's ability to use the data to objectively assess aquatic resource condition. For example, the ACIWG generally selected against stage-dependent indicators because of the potential for high, interannual temporal variability (e.g., wetted width, discharge). Whereas some indicators both directly measure habitat quality and are applicable to understanding spatial variability in biological condition, as measured by aquatic macroinvertebrates (e.g., excessive fine sediment), other indicators require the measurement of multiple instream attributes for the computation of an array of additional geomorphic and habitat-related indicators (e.g., relative bed stability).

5.3.3 Biodiversity and Riparian Habitat Quality Indicators

The "biodiversity and riparian habitat quality" fundamental will be assessed through the use of three core and one contingent indicator (Table 4). Macroinvertebrate biological integrity will be used to quantify the intactness of instream aquatic assemblages to directly address the "biodiversity and riparian habitat quality" fundamental, while also providing information on the "water quality" fundamental. Riparian habitat quality and intactness will be measured by either ocular or quantitative estimates of the riparian vegetative type, cover, and structure, depending on the particular monitoring application. Specifically, ocular estimates are recommended for use in regional-scale assessments (e.g., land use plan or larger spatial-scale monitoring) or where general information is sought regarding the intactness of riparian areas to buffer against anthropogenic stressors (e.g., thermal, sediment, or nutrient loading), to promote properly functioning channel form and function, and/or to provide wildlife habitat, among other functions. In contrast, quantitative estimates of riparian vegetative cover, composition, and structure (the contingent indicator) are recommended for local, site-specific estimates of riparian conditions and trends, to assess the impacts of a particular land use (e.g., grazing), or when conducting habitat assessments for riparian obligate species.

In addition to directly monitoring riparian vegetation, the ACIWG recommends the measurement of canopy cover as a core indicator.

Canopy cover directly measures the capacity of riparian vegetation to mitigate thermal loading and, thus, moderate stream temperatures (Beschta 1997; Johnson and Jones 2000), while also providing information on the amount of potential leaf litter and other terrestrial organisms to subsidize aquatic food webs (Cummins 1974; Baxter et al. 2005). The ACIWG would like to incorporate additional lines of evidence regarding the biological integrity of instream assemblages, and field offices are encouraged to do so through the addition of supplemental indicators (e.g., periphyton, fishes). However, the costs associated with data collection and sample processing are currently prohibitive for BLM-wide implementation.

5.3.4 Covariates

The chemical, physical, and biological potential of stream and river systems naturally varies across the landscape (reviewed in Allan 2004), and thus, the ACIWG recommends the measurement of two field-based covariates: slope and bankfull width (Table 4). Slope and bankfull width are critical for interpreting several of the habitat indicators, particularly residual pool depth, length, and frequency and streambed particle size distributions. Additional covariates can be computed from site coordinates and geographic information systems (e.g., watershed area, precipitation, geology, soil types) for the computation of observed/expected type indices and general data interpretation. Lastly, the ACIWG recommends the establishment of photo points and the use of a qualitative assessment of the extent and type of anthropogenic impacts adjacent to or within the assessed reach.

Collectively, the core and contingent indicators provide multiple lines of evidence for quantifying the chemical, physical, and biological conditions and trends of lotic resources. The core indicators represent the minimum measurements for quantitatively reporting on the attainment of BLM lotic land health standards (i.e., water quality, watershed function and instream habitat quality, biodiversity and riparian habitat quality, and ecological processes), but the indicators have broad applicability to monitoring and assessment needs, including beneficial use attainment under the Clean Water Act, the establishment of baseline conditions, and land use plan effectiveness monitoring. Priority was given to indicators that can be precisely measured and analyzed in a consistent, cost-effective manner to make credible condition estimates from Alaska to New Mexico. For example, aquatic macroinvertebrates directly measure biological integrity and are also indicative of water quality and instream physical habitat given their sensitivities to stressors such as nutrient, thermal, and sediment loading (reviewed in Bonada et al. 2006). By selecting an indicator and sampling methodology currently used by all 50 states and numerous federal agencies (USEPA 2002), the BLM can readily adopt networks of existing reference sites and subsequent tools for making credible biological condition determinations.

5.3.5 Aquatic Core Indicator Methods

An indepth description of the field methodologies is beyond the scope of this document. Rather, the proposed methods for the aquatic core and contingent indicators are outlined in Appendix E, and a forthcoming technical reference will serve as the field manual. In general, the ACIWG seeks to maximize compatibility of field measurement techniques with the EPA's National Rivers and Streams Assessment protocol (USEPA 2009), the USFS and BLM PACFISH/INFISH Biological Opinion Effectiveness Monitoring Program (Archer et al. 2012), the Aquatic and Riparian Effectiveness Monitoring Program (Lanigan 2010), and the BLM's multiple indicator monitoring protocol (Burton et al. 2011). Because these are among the most ubiquitously used protocols throughout the Western U.S., their use will allow the BLM to leverage millions of monitoring dollars spent by states and other agencies.

Despite the computation of similar indicators among agencies, the utilized field methodologies are frequently incomparable. Furthermore, protocols for some indicators (e.g., pebble counts, bankfull width, residual pool depth) (Whitacre et al. 2007; Roper et al. 2010) have been shown to have lower observer variability than others. Therefore, when choosing specific methods, the BLM will weigh the geographic extent over which a particular method is used, with the repeatability of the field measurements among observers. In some instances, protocols will be modified to maximize compatibility among agencies, while still providing the requisite information for the BLM. For example, for quantifying streambed particle size distributions, the BLM will consider actual measurement of streambed particles, as opposed to qualitative categorization (e.g., USEPA 2009), measuring a total of 210 bed particles at 21 transects from the active channel (i.e., scour line to scour line) and noting which pebbles are collected from the wetted channel. These modifications would facilitate data integration among BLM, EPA, and USFS protocols. Similarly, protocols such as the EPA's ocular estimates of riparian vegetative and human impacts will be supplemented in forthcoming technical references to increase relevance to BLM lands and management questions. The BLM will engage with its partners to conduct protocol overlap comparison studies to understand the comparability of indicator values among programs.

5.3.6 Aquatic Core Indicator Condition Determinations

The attainment of BLM land health standards is evaluated on an individual basis for each unique indicator. This approach is akin to a limiting factor analysis, in which the failure to meet any one component of a standard can initiate changes in management. Objective evaluations of whether standards are met (i.e., the evaluation phase in Figure 1) therefore requires accurate and precise condition assessments. A critical factor in this process is the use of benchmarks or reference conditions for comparing observed indicator values at test sites to those expected to naturally occur under minimal human influence. For example, total nitrogen values characterize ambient nutrient concentrations at a single point in time, but without appropriate benchmarks, such measurements lack context and cannot be used to assess condition and potential eutrophication. Because of the paucity of knowledge regarding pre-European stream and river conditions, least disturbed or minimally impacted sites are commonly used to establish reference conditions (Hughes et al. 1994; Stoddard et al. 2006; Hawkins et al. 2010) and will be used in conjunction with the NAMF when possible.

A central challenge to accurately assessing condition is the ability to effectively discriminate between natural sources of spatial variability (i.e., intrinsic drivers) and anthropogenic anomalies (i.e., extrinsic drivers) (Figure 5). Intrinsic drivers of natural environmental gradients include climate, geology, vegetation, and topography. For example, sediment loading to streams naturally varies from site to site as a product of climate, vegetative composition and cover, erosivity of local lithologies, and topography. However, anthropogenic drivers such as grazing, road construction and maintenance, and timber harvest can increase fine sediment loading to streams above historical levels (Wood and Armitage 1997; Belsky et al. 1999).

With the exception of chemical constituents, the BLM has traditionally established benchmarks by using narrative criteria or professional judgment or by selecting individual reference site(s) similar in most aspects to test sites except for potential anthropogenic impacts. Condition assessments are made by comparing individual indicators between a test site and the paired reference site, narrative criteria, or professional judgment regarding stream potential. Although these approaches are feasible and have been effectively used, they have significant drawbacks capable of limiting the BLM's use of monitoring data to inform assessments, especially when applied to a sample population containing a large number of sites of unknown condition. These include: (1) the subjective interpretation of narrative standards; (2) the considerable expense of identifying paired reference and test reaches; and (3) the difficulty of identifying replicate stream reaches given the multitude of confounding factors that can occur (Hawkins et al. 2010).

By using the NAMF, the BLM will attempt to overcome these limitations by standardizing field measurement techniques with those of other state and federal agencies, which will allow the BLM to use existing networks of reference sites, so long as they are inclusive of environmental gradients throughout BLM lands. This represents a fundamental shift in the BLM's approach away from single-site or theoretical reference conditions, to establishing benchmarks from site-specific, modeled predictions or the range of variability observed across regional reference sites—both of which are widely used by state and federal regulatory agencies. In instances in which reference networks are inadequate or monitoring seeks to determine causation, paired site designs may be advantageous as the BLM works to expand the environmental representativeness of reference networks.

The preferred method of establishing least disturbed conditions will be the use of multisite, empirical models (e.g., Appendix E, Tables E1 and E2). Such models account for natural environmental gradients and will be used to make predictions of chemical, physical, or biological values expected at a site in the absence of anthropogenic impairment. This approach works by modeling the natural spatial variability among reference sites for a given indicator using geospatial predictors. For example, Hill et al. (2013) were able to use nine readily available GIS-derived variables (e.g., air temperature, watershed area, reservoir index) to explain 87% of the spatial variability in mean summer stream temperature (root-mean-square deviation of 1.9°C) among reference sites throughout the conterminous U.S. In addition to stream temperature, models have been or are being developed for macroinvertebrate biological integrity through the use of observed/expected or multimetric indices (e.g., Hawkins 2006; Hargett et al. 2007; Vander Laan et al. 2013), total nitrogen and phosphorous (Olson 2012), conductivity (Olson and Hawkins 2012), and instream habitat complexity (Al-Chokhachy et al. 2010). Such approaches are advantageous because they provide spatially explicit predictions of expected reference conditions with known levels of accuracy and precision that can be used to establish thresholds of impairment that minimize over- or underprotection (i.e., type I versus type II errors) of aquatic resources. However, additional analyses are needed to better understand the performance of models developed for large spatial scales when applied to regional or local scales (e.g., Ode et al. 2008).

For indicators lacking predictive models (e.g., Appendix E, Tables E1 and E2), the BLM can use state or agency standards or regional reference thresholds to assess condition (Hughes et al. 1986; Paulsen et al. 2008). The regional reference threshold approach involves the use of networks of sampled reference sites (least disturbed) located within a relatively homogenous physiographic region (e.g., Level III ecoregions) (Omernik 1987). The observed variance among sites regarding chemical, physical, or biological indicators is used as an estimate of the range of natural variability to set condition thresholds. Thresholds are established at the extremes of reference site distributions (e.g., 5th or 95th percentile for large woody debris and fine sediment, respectively) to identify significant departures from reference. For example, the 95th and 75th percentiles of reference site entrenchment values (i.e., floodplain connectivity) for the Colorado Plateau ecoregion can be used to separate "significant departure," "moderate departure," and "minimal departure" from reference conditions, respectively. In other words, a site would be categorized as disturbed or having significant departure if the entrenchment value was greater than that observed among 95% of reference sites in a given physiographic region. Where protocols are concordant, the BLM can use the regional reference threshold approach established by the EPA's National Rivers and Streams Assessment program for the indicators lacking empirical models (e.g., Appendix E) (e.g., Stoddard et al. 2005).

Lastly, to facilitate adaptive management where individual BLM land health standards are not attained under the four fundamentals (43 CFR 4180.1), the BLM must identify the likely causes of impairment in the "determination" phase (Figure 1). Stressor identification is commonly accomplished through a two-stage process in which a suite of field-based stressors resulting from intensified land uses are measured (e.g., increased nutrient, thermal, or sediment loading). This information can be used to ascertain which stressors are most widespread, the impacts of stressor(s) on aquatic biota, and the likely changes in stream health resulting from reductions in stressor levels (e.g., Van Sickle and Paulsen 2008; Vander Laan et al. 2013).

Once candidate stressors are identified, the more arduous and costly process of identifying the land use(s) or permitted activities causing exceedances for a given stressor can be undertaken by local field offices. This process can also be informed by empirical modeling that relates land uses to stressor exceedances (e.g., Vander Laan et al. 2013). Both stressor identification and source determinations are contingent upon being able to distinguish natural from anthropogenic gradients, as well as discerning among multiple causes of degradation.

5.4 Step 5: Development and Integration of Local, Regional, and National Monitoring and Assessment Efforts

Under the principles of the AIM Strategy, the NAMF seeks to increase the BLM's capacity to collect data once and use it for multiple applications across spatial scales (e.g., Figure 2). The BLM's four fundamentals provide a common thread that links monitoring efforts at disparate spatial scales, by dictating a common set of questions and chemical, physical, and biological indicators regardless of spatial scale (Table 1). Consequently, monitoring data collected at regional scales to track the overall conditions of aquatic resources can also be used at local scales, with supplemental points, to assess the efficacy of land use management plans or regulations for permitted activities (e.g., grazing permit renewals). Additionally, data from the aquatic core and contingent indicators can be used in conjunction with season of use or other disturbance indicators to make linkages between permitted activities and observed condition and trend.

Historically, local and regional data needs have been viewed as disparate efforts vying for limited monitoring funding. The resulting product has been the overwhelming collection of local, site-specific aquatic monitoring data. In turn, larger scale data needs have been met by compiling locally collected data via "data calls" and aggregating these results to answer questions at broader spatial scales (e.g., use of proper functioning condition for Public Land Statistics reporting). This approach is viable only if locally selected sites unbiasedly characterize the target population, but the large majority of BLM monitoring sites are systematically selected because of targeted management questions, access issues, the location of restoration projects, or the selection of "representative" reaches (i.e., key areas, designated monitoring areas). Consequently, the representation of the condition estimates derived from these data aggregation exercises is unknown and subject to considerable bias (Paulsen et al. 1998; Schreuder et al. 2001).

To start, the NAMF will be used by targeting four complementary scales of monitoring: BLM land use plans and state, ecoregional, and West-wide surveys. At the broadest scale, the BLM is implementing the Western Rivers and Streams Assessment—a survey of the condition of BLM streams and rivers throughout the contiguous Western U.S. under the NAMF (see Section 7.1). The spatially extensive network of sample points resulting from the Western Rivers and Streams Assessment is a starting point for finer scale assessments of BLM lotic systems at state and land use plan scales. For example, the Western Rivers and Streams Assessment, EPA's National Rivers and Streams Assessment, and efforts by individual state regulatory agencies will result in more than 40 sample sites on BLM lands throughout Colorado, Idaho, Nevada, and Oregon between 2013 and 2015 alone. To capitalize on these efforts, the AIM implementation team is working with state program leads to intensify the Western Rivers and Streams Assessment sampling network to enable finer scale condition estimates at the state, district, and/or land use plan scales (e.g., a minimum of 50 sites at the state scale and 25 at the land use plan scale, but sample sizes will ultimately depend on the extent of perennial streams and environmental heterogeneity). In all instances, monitoring data is being collected by specialized field crews dedicated to NAMF efforts.

Example objectives of these efforts include land use plan effectiveness monitoring, step downs of BLM rapid ecoregional assessments, and the identification of ubiquitous stressors to establish more intensive regional management and monitoring priorities (e.g., Section 7.2 and 7.3). The AIM implementation team will also work collaboratively with the Aquatic and Riparian Effectiveness Monitoring Program and the PACFISH/INFISH Biological Opinion Effectiveness

Monitoring Program to integrate sample points for the States of California, Idaho, Montana, Oregon, Washington, and Wyoming, which will result in significantly higher sample sizes for select indicators (e.g., streambed particle sizes; residual pool depth, length, and frequency; bank stability and cover; macroinvertebrate biological integrity). Lastly, projects are ongoing in Alaska to assess the impacts of placer mining (see Section 7.3) and to assess effectiveness of land use plans and regional mitigation strategies, such as the one being developed in the National Petroleum Reserve. Collectively, the use of consistent, quantitative aquatic core indicators and methods, probabilistic survey designs, and data acquisition and management tools will allow the BLM to collect data once and use data across spatial scales and programmatic needs in a cost-effective manner.

The use of data among spatial scales is contingent upon selecting sites in an unbiased manner to ensure representativeness of the target population. For example, a large proportion of site selection for the aforementioned monitoring efforts will be done using a generalized random tessellation stratified (GRTS) survey design (Stevens and Olsen 2004), unless more robust methods of site selection are identified. The GRTS design is preferred over traditional simple or stratified random sample survey designs because it improves the spatial balance or distribution of sites and is applicable to both discrete objects (e.g., wetlands) and linear networks (e.g., streams) (Stevens and Olsen 1999). Currently, GRTS designs are ubiquitously used by state and federal agencies (e.g., EPA National Aquatic Resource Surveys, Aquatic and Riparian Effectiveness Monitoring Program, PACFISH/INFISH Biological Opinion Effectiveness Monitoring Program, and California's Surface Water Ambient Monitoring Program). The unbiased or statistically valid condition estimates resulting from these surveys can be integrated with the survey designs of other studies and have known levels of confidence (e.g., the proportion of BLM streams [±10%] in the conterminous U.S. that fall below the threshold for good condition for a given indicator with 95% confidence).

In addition to probabilistic surveys, the NAMF seeks to both support and integrate the results of targeted monitoring efforts (e.g., restoration effectiveness monitoring, key area monitoring for grazing permit renewals, or habitat suitability analyses). An example benefit of using the aquatic core and contingent indicators for local, targeted monitoring efforts is the availability of existing state or regional reference conditions to allow field office personnel to make objective and credible condition assessments regardless of how sites are selected. For example, the collection of benthic macroinvertebrates with the core indicator methodology allows a field office hydrologist to put results from their single benthic macroinvertebrate sample in the context of state biological condition criteria used to assess macroinvertebrate biological integrity without sampling reference sites; this capacity is already being implemented by the BLM's National Aquatic Monitoring Center and has greatly improved the BLM's capacity to use bioindicators to inform management decisions. Similar efforts exist or are underway for chemical and physical indicators.

6. Next Steps

Through the Western Rivers and Streams Assessment, the BLM is currently monitoring the conditions and trends of lotic systems in a consistent, coordinated manner at a national scale, while numerous field- and state-level deployments are also underway (Figure 3). To incorporate the NAMF into the business practices of the BLM, the AIM implementation team will work with Washington Office and state office program leads, the National Operations Center, and the National Riparian Service Team to:

1. Publish a tech reference of the field methodologies for collection of the aquatic core and contingent indicators for lotic systems.
2. Develop trainings for third party and field office-level collection of the NAMF indicators.
3. Build capacity within the BLM and among sister agencies to implement the NAMF through the use of specialized field crews.
4. Develop electronic data capture and storage capabilities to support collection of the aquatic core and contingent indicators.
5. Publish a tech reference of the aquatic core and contingent indicators for lentic systems and corresponding field methodologies.
6. Develop or augment policy for use of the NAMF to meet the BLM's monitoring needs.
7. Develop remote sensing techniques to augment and increase the efficiency of field data collection.
8. Assess the performance of select indicators (e.g., bank angle and ocular estimate of instream habitat complexity) and the compatibility of protocols among agencies.

7. Example Applications of the National Aquatic Monitoring Framework

7.1 Example of National-Scale Implementation: The Western Rivers and Streams Assessment

Monitoring objective: The Western Rivers and Streams Assessment is a survey of the conditions of BLM streams and rivers throughout the contiguous Western U.S. conducted in collaboration with the EPA. The objective of this effort is to generate unbiased, quantitative condition estimates from which regional and national aquatic priorities can be established and future conditions can be compared.

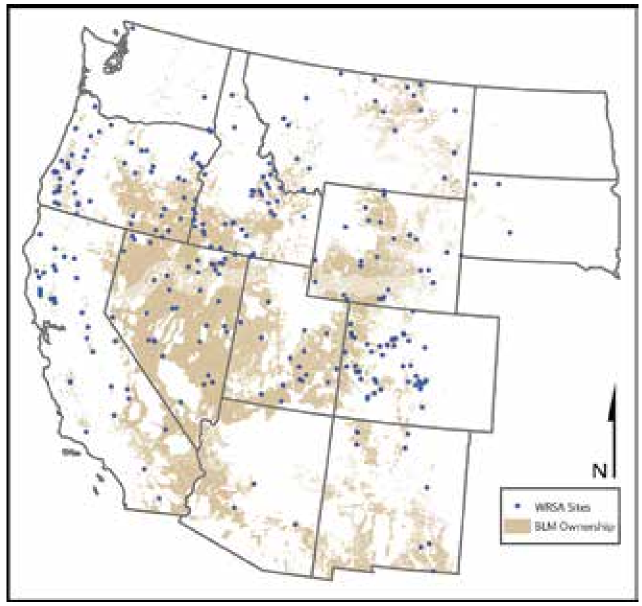
Site selection: The sampling design is a probability-based selection of wadeable and nonwadeable perennial stream and river reaches from the National Hydrography Dataset. The random selection of sample reaches will result in unbiased or statistically valid condition estimates of all BLM streams and rivers with known levels of confidence. Site selection was stratified such that condition estimates will be made for at least three different spatial scales: (1) West-wide; (2) three EPA western physiographic regions; and (3) seven aggregated Level III ecoregions that encompass 95% of the linear extent of BLM rivers and streams in the contiguous Western U.S.

Monitoring indicators: All NAMF aquatic core and contingent indicators are being collected except for quantitative estimates of riparian vegetative cover, composition, and structure. Furthermore, the Western Rivers and Streams Assessment is piloting the EPA's protocol for nonwadeable rivers.

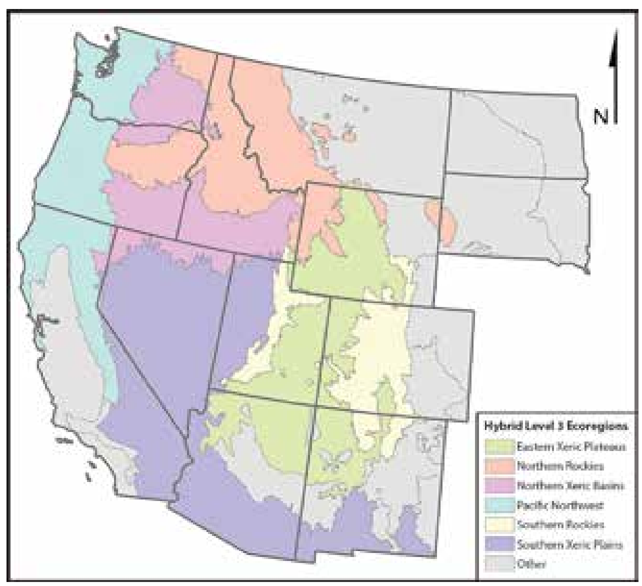
Field sampling: Field data are being collected by technicians from the National Aquatic Monitoring Center using electronic data capture and storage technologies.

Data applications: The Western Rivers and Streams Assessment will answer three central questions:

1. What percentage of BLM streams and rivers are in good, fair, or poor biological condition?



Spatial distribution of the more than 300 WRSA sample points to be collected.

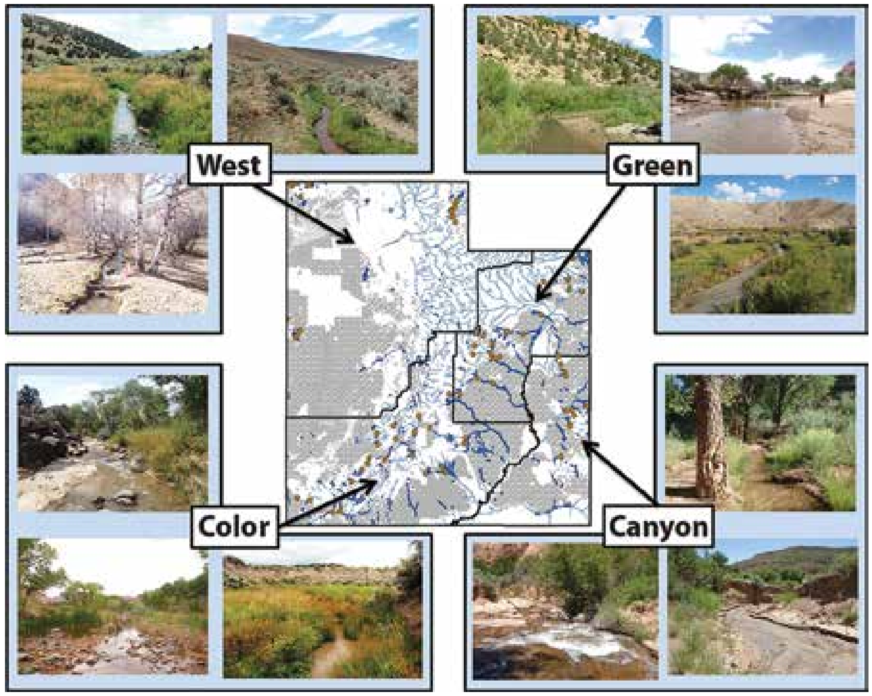


Seven hybrid Level III ecoregions to be used for WRSA reporting.

2. What is the linear extent of streams and rivers experiencing stressors such as nutrient, salinity (i.e., conductivity), and fine sediment loading and invasive invertebrates?

3. What is the risk posed by the observed stressors to biological condition?

7.2 Assessing BLM Utah Stream and River Condition and the Factors Associated with Departures from Land Health Standards: A Pilot of the NAMF



Monitoring objective: The objective of this effort was to pilot the NAMF by assessing the attainment of Utah aquatic land health standards, identifying and ranking stressors contributing to degraded conditions, and prioritizing indicators and geographic areas for more intensive monitoring and determinations.

Site selection: Site selection was probabilistic. Random points were stratified by BLM Utah districts. In total, 77 random reaches were sampled between 2011 and 2012.

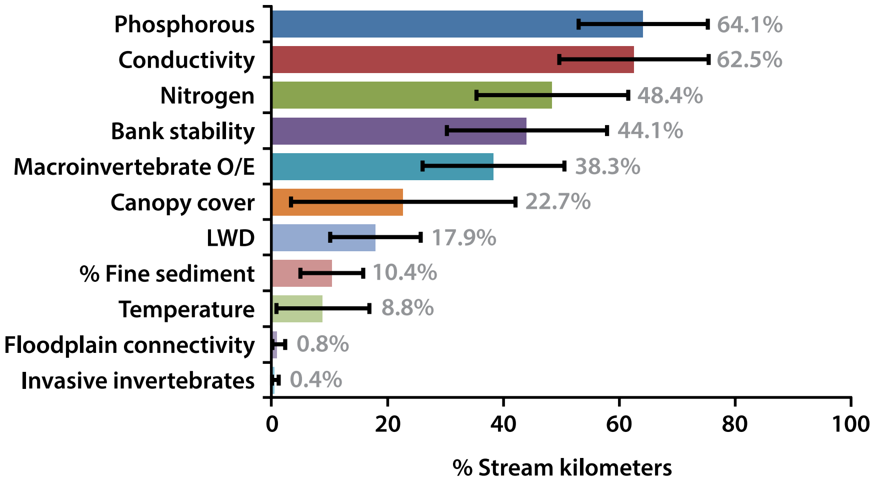
Monitoring indicators: *Pilot aquatic core indicators:* Water quality (conductivity and temperature), watershed function and instream habitat quality (streambed particle sizes, bank stability and cover, large woody debris, floodplain connectivity), and biodiversity and riparian habitat quality (macroinvertebrate biological integrity and canopy cover).

Contingent indicators: Total nitrogen and phosphorous.

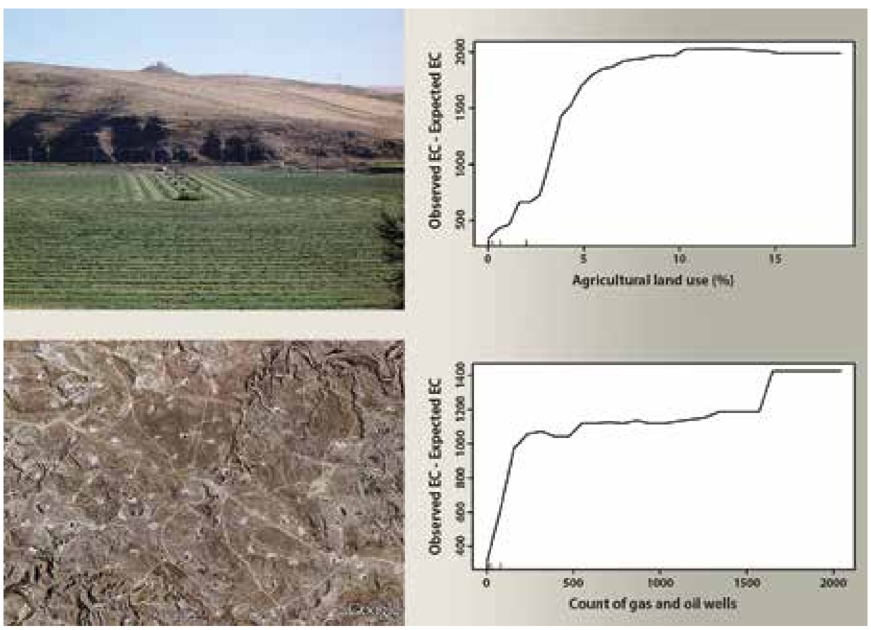
Field sampling: Field data were collected by technicians from the National Aquatic Monitoring Center.

Example results and data applications:

- Thirty-six percent of BLM Utah wadeable streams had minimal departure from reference conditions across all indicators. Of the four BLM Utah districts, the West Desert and Color Country were in the best condition, while the Green River and, to a lesser extent, Canyon Country had the greatest extent of stressors.
- Across the state, water quality impacts were the most pervasive stressors—specifically, elevated levels of total phosphorous (64% of stream kilometers), nitrogen (48%), and conductivity (62%).
- The prevalence of excessive conductivity was highly correlated with the percent of the watershed in agriculture, the number of oil and gas wells, and the length of hydrologically altered streams.
- Using this information, the BLM is working with the Utah Department of Water Quality to intensify water quality monitoring efforts and to identify the sources for observed exceedances. Preliminary results suggest that upstream land uses occurring both on (e.g., oil and gas development) and off BLM lands (e.g., agriculture, irrigation return flows) are contributing to water quality exceedances.



Percentage of Utah wadeable stream kilometers having significant departure from reference conditions.



Modeled relationships between percent agricultural land use in a watershed and excessive conductivity concentrations (top) and the number of oil and gas wells and excessive conductivity (bottom).

7.3 Example of Field Office Implementation to Meet Multiple Lotic Data Needs: AIM-Monitoring in the Eastern Interior Field Office, Alaska

Monitoring objective: The objective of this effort is to establish quantitative baseline conditions; to monitor the effectiveness of land use plans; and to assess the impacts of placer mining on BLM streams.

Site selection: Site selection is targeted and random. Random points were stratified by land use planning boundaries, and targeted points were located on mining operations. Between 2014 and 2016, 65 random reaches and 20 targeted reaches will be sampled.

Monitoring indicators: *Aquatic core indicators:* Water quality (acidity, conductivity, temperature), watershed function and instream habitat quality (pool dimensions, streambed particle sizes, bank stability and cover, large woody debris, floodplain connectivity), and biodiversity and riparian habitat quality (macroinvertebrate biological integrity; canopy cover; ocular estimates of riparian vegetative type, cover, and structure).

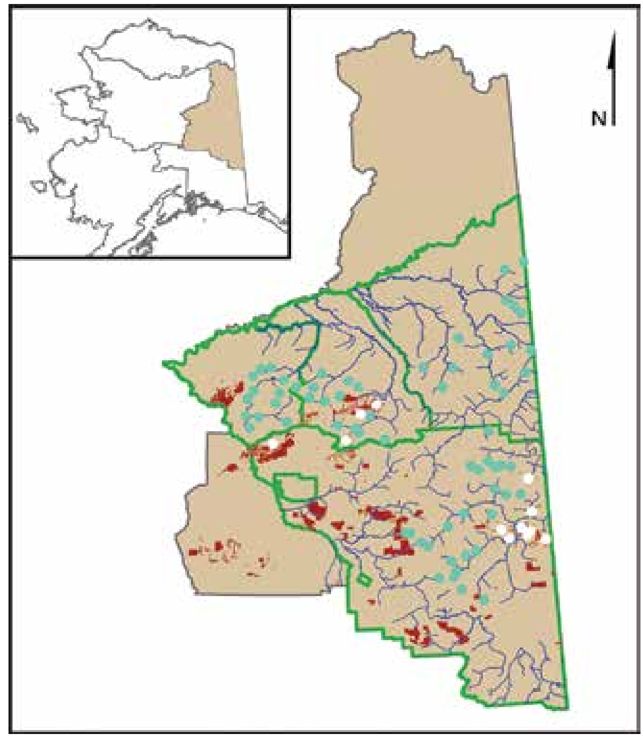
Contingent indicators: Turbidity, thalweg depth profile, ocular estimate of instream habitat complexity.

Supplemental indicators: Fish assemblage composition, surveyed channel cross sections.

Field sampling: Field data are being collected by personnel from the Eastern Interior Field Office, assisted by technicians from the National Aquatic Monitoring Center.

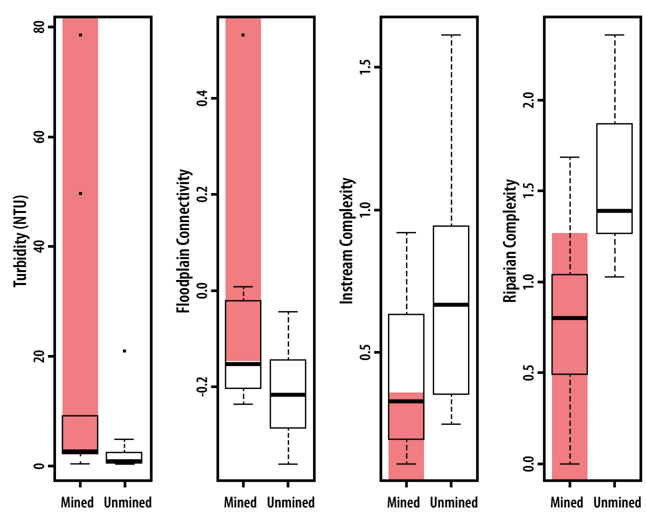
Data applications:

- Establishment of chemical, physical, and biological baseline conditions from which future changes (i.e., trend) can be assessed.
- Quantification of the differences between stream reaches reclaimed following placer mining and least disturbed conditions.



Probabilistic (blue) and targeted (white) mining sites in the Eastern Interior Field Office in Alaska. Green polygons are land use planning boundaries, and mining areas are shown in red.

- Establishment of baseline conditions for the density and distribution of resident fishes from which future changes (i.e., trend) can be assessed.
- Establishment of regional hydraulic geometry curves using the supplemental channel cross-section data to assist in the reclamation of placer mined streams.



Example preliminary results for water quality, riparian, and instream conditions between mined and unmined sites, in which values falling within the red shading for mined sites indicate deviation from potential natural conditions.

Appendix A: Questions Regarding Implementation of the National Aquatic Monitoring Framework

Is the National Aquatic Monitoring Framework (NAMF) a new BLM monitoring program?

The NAMF is new, but many of its components build upon existing BLM monitoring and assessment programs. For example, the NAMF does not recommend indicators new to the BLM but, rather, consistent methods to measure some of the most common indicators contained within the land health standards (and to functioning stream systems). In addition to core indicators, the NAMF promotes integrated data collection throughout the BLM by providing guidance for selection of sample reaches, electronic data capture and storage and tools for consistent data analysis, and interpretation to inform management questions. Rather than a new process, the NAMF can be thought of as a standardized approach for how the BLM can meet multiple monitoring requirements in a consistent, quantitative, and credible manner.

What are common applications of the NAMF?

This framework has been designed to address several BLM monitoring needs, including:

- Land use plan assessments and effectiveness monitoring.
- Regional mitigation strategies.
- Restoration effectiveness monitoring.
- Assessing landscape-scale impacts resulting from permitted uses (e.g., grazing, oil and gas development, mining).
- Prioritizing stressors to inform more intensive monitoring efforts.
- Establishing ecoregional-, state-, or field office-level baseline conditions and trends.
- Collecting national-scale data for Department of the Interior reporting measures and the annual Public Land Statistics publication.

Is the NAMF intended to replace local-scale monitoring efforts?

No, local monitoring to meet site- or project-specific data needs may require indicators beyond the NAMF aquatic core and contingent indicators. The AIM Strategy allows for flexibility to collect data on supplemental indicators to meet project-specific needs, in addition to the core and contingent indicators (see supplemental monitoring indicators in Section 7.3). Data collected under the NAMF should complement existing monitoring programs, not necessarily replace them, especially when supplemental information is needed to inform management of a particular land use. In developing the AIM Strategy, a review of numerous field office monitoring programs revealed similarities in the types of required data, particularly the need for information regarding the locations, amounts, conditions, and trends of aquatic resources. In such instances, the land health standards provide a framework for the monitoring and assessment of the condition of a consistent set of indicators, and the NAMF specifies a set of methods for doing so regardless of the spatial scale of inference.

Do I have to collect all of the aquatic core indicators anytime stream monitoring is conducted?

No, the core and contingent indicators may not be applicable to some monitoring types (e.g., use-based, compliance, restoration efficacy). However, where information for a core or contingent indicator(s) is required, the NAMF methods should be followed. If baseline condition and trend information is sought for a stream or population of streams, the NAMF should be applied.

How is data collected at coarse spatial scales, such as Level III ecoregions, states, or field offices, relevant to individual field offices?

The use of core indicators and consistent methods allows data to be compared among sites and through time, while minimizing sample error associated with disparate data collection methodologies. For example, sample points collected at the field office scale can be applied to local questions such as grazing permit renewals; however, additional sample points may be required (see the following question regarding probability-based site selection).

A second way to leverage data collected at broader spatial scales is for interpretation of locally collected data. Since BLM core monitoring data will now mesh with data collected by other field offices and agencies, locally collected data can be compared to the range of conditions among existing reference site networks to assess degrees of departure. Reference, or least disturbed, conditions set expectations for the conditions one would expect to occur in the absence of anthropogenic activities and thus facilitate objective data interpretation. The use of existing reference networks and analytical tools can save considerable time and money during local monitoring efforts, while also increasing the certainty and defensibility of management decisions.

Why should I randomly locate sample points?

Most monitoring programs benefit from a mix of targeted and probability-based (i.e., random) site selection. Targeted sites are appropriate for site-specific evaluations, where known problems occur, or to isolate the geographic extent of impacts, but when used as "representative" sites, they are subject to different interpretations of what is "representative" and may incorporate bias. Thus, targeted sites only allow the BLM to learn about the set of sampled locations and may underestimate the variability of indicators within the sampling area. Given the thousands of stream kilometers contained within any field office, probability-based site selection is a credible and efficient way to estimate the condition and trend of the entire population with known levels of uncertainty. Additionally, probability-based sample selection allows monitoring locations selected for one application to be used for other applications but at different spatial scales (i.e., data recycling in a statistically valid manner).

How are local or site-specific problems evaluated by the NAMF?

The NAMF is applicable to both local and regional monitoring questions. For both scales of questions, supplemental indicators may be required (e.g., fish assemblage composition and surveyed channel cross sections from Section 7.3) to address project-specific questions. Additionally, "season of use" type indicators may be required to assess local, use-based impacts (e.g., bank alteration and residual stubble height for cattle grazing). Such indicators can be used to inform decisions regarding the use(s) associated with the condition and trend of the NAMF indicators (e.g., the determination phase of a land health assessment). Furthermore, local condition and trend type questions may change the method by which sample points are located. For systems experiencing localized impacts such as placer mining (e.g., Section 7.3) or small-scale restoration, site selection could be targeted (i.e., nonrandom) to ensure sampling occurs in the impacted or restored area, respectively.

I have been collecting data for multiple years on one of the core indicators but using a different method. Do I need to change the method, and if so, how will historical data be incorporated?

The objective of the AIM Strategy is to standardize a minimum set of indicators and the methods for measuring the indicators across the BLM; therefore, it is recommended that field offices use the core indicator methodologies in instances where an NAMF indicator is being measured. To assess the feasibility of jointly analyzing "old" and "new" monitoring data, the BLM recommends simultaneous sampling using both methods for a period of time to assess the comparability of the resulting indicator values. In instances where two methods produce disparate results, correction factors can be applied if the magnitude and direction of the deviation is consistent through time.

Appendix B: BLM Aquatic Core Indicator Work Group and External Science Advisory Team

Table B1. BLM interdisciplinary working group, assembled to develop aquatic core indicators, and members of the external science advisory team.

Name	Title	Affiliation
Scott Miller	Aquatic Ecologist/Director	BLM, National Aquatic Monitoring Center
Bryce Bohn	Hydrologist/Program Lead	BLM, Idaho Riparian and Soil, Water, and Air Programs
Dan Dammann	Hydrologist	BLM, Swiftwater Field Office
Melissa Dickard	Aquatic Ecologist/Program Lead	BLM, National Riparian and Fisheries Programs
Mark Gonzalez	Riparian/Wetland Ecologist and Soil Scientist	BLM, National Riparian Service Team
Justin Jimenez	Fisheries Biologist/Program Lead	BLM, Utah Riparian and Fisheries Programs
Ed Rumbold	Hydrologist/Program Lead	BLM, Colorado Soil, Water, and Air Program
Steve Smith	Riparian Ecologist/Program Lead	BLM, National Riparian Service Team
Karl Stein	Fisheries Biologist/Program Lead	BLM (retired), California Fisheries, Riparian, and Soil, Water, and Air Programs
Emily Kachergis	Landscape Ecologist/Program Implementation Lead	BLM, Assessment, Inventory, and Monitoring Program
Gordon Toevs	Soil Scientist/Program Lead	BLM, Assessment, Inventory, and Monitoring Program
Matt Varner	Fisheries Biologist/Program Lead	BLM, Alaska Fisheries Program
Daren Carlisle	Aquatic Ecologist/Program Lead	U.S. Geological Survey, National Water-Quality Assessment Program
Chuck Hawkins	Aquatic Ecologist/Director	Utah State University, Department of Watershed Sciences, Western Center for Monitoring and Assessment
Jason Karl	Ecologist	Agricultural Research Service, Jornada Experimental Range
Steve Paulsen	Aquatic Ecologist, Chief	Environmental Protection Agency, Western Ecology Division, Aquatic Monitoring and Bioassessment Branch
Brett Roper	Aquatic Ecologist, Program Lead	U.S. Forest Service, Fish and Ecology Unit
Stephanie Miller	Fisheries Biologist/Program Lead	BLM, Aquatic and Riparian Effectiveness Monitoring Program
John Van Sickle	Environmental Statistician	Environmental Protection Agency (retired), Western Ecology Division

Appendix C: BLM Survey to Prioritize the Selection of Aquatic Core Indicators

To prioritize the lotic ecosystem attributes and stressors for which field-derived aquatic core indicators would be selected, the Aquatic Core Indicator Work Group (ACIWG) administered a survey of BLM program leads and field office personnel. Specifically, the ACIWG sought to prioritize the lotic ecosystem attributes that the BLM needs to report on locally, regionally, and nationally to meet aquatic monitoring requirements associated with 43 CFR 4180.1, the Federal Land Policy and Management Act, the Clean Water Act, land use management plans, and other policy and management decisions requiring condition and trend data.

To accomplish this, the ACIWG solicited the participation of 72 BLM program leads and field office personnel from the Soil, Water, and Air (1010); Riparian (1040); and Fisheries (1120) Programs. The ACIWG e-mailed instructions and an Internet link to the survey participants (administered through SurveyMonkey). Survey participants were given 2 weeks to complete the survey.

The ACIWG asked survey participants to rate their technical knowledge of riparian ecology, aquatic ecology (including fisheries), hydrology, geomorphology, and water chemistry. Participants then rated each of the candidate lotic ecosystem attributes (Table C1) against a set of ranking criteria (Table C2). Lastly, participants rated a list of stressors (e.g., hydrologic alterations; nutrient, thermal, and sediment loading) and land use practices (e.g., grazing, mining, roads, logging, recreation) against a similar set of selection criteria (Table C2).

Table C1. Ecosystem attributes and indicators for each of the four key lotic ecosystem processes that were prioritized for aquatic core indicator development by surveying BLM personnel. Attributes identified as less important are italicized. The attributes were initially identified from the BLM's land health standards and conceptual stressor-response models.

Geomorphic attributes and indicators
Sediment regime (supply and transport)
Channel dimensions/shape
Habitat complexity
Energy dissipation and retention capacity
Bank conditions (angle, stability, cover)
Hydrologic attributes and indicators
Natural flow regime (timing, magnitude, duration and frequency of high- and low-flow events)
Hydrologic connectivity (lateral, longitudinal, vertical)
Water storage and yield
Hillslope processes (surface runoff, infiltration, erosion rates)
Chemical attributes and indicators
Thermal regime
Nutrient cycling, loads, concentrations
General water chemistry: pH, conductivity, dissolved oxygen
Cations and anions
Metals
Biotic attributes and indicators
Instream biotic integrity
Riparian biotic integrity
Instream productivity
Riparian productivity
Wood production and recruitment

Table C2. Ranking criteria used to prioritize the lotic ecosystem attributes and stressors for which aquatic core indicators would be developed. Survey participants ranked the attributes and stressors as: (2) strongly agree, (1) agree, (0) neither agree nor disagree, (-1) disagree, (-2) strongly disagree, or (NA) for insufficient knowledge.

	Application	
Attribute raking criteria	Attributes	Stressors
Relevant to characterizing the condition of lotic and riparian systems across all BLM lands	X	
Responsive to changes in key ecosystem processes, stressors, and/or management actions	X	
Target of BLM policy and management across all BLM lotic systems	X	X
Attribute can be adequately measured with field indicators	X	X
Affects the function of lotic and riparian systems across a majority of BLM lotic systems		X

Survey Participation and Expertise

A total of 47 people completed the entire survey for a response rate of 65%. The majority of survey participants identified their area of expertise as either aquatic ecology (46%) or hydrology (39%), with less than 15% of participants identifying themselves as geomorphologists, riparian ecologists, soil scientists, or wildlife ecologists (data not shown); however, a majority of participants noted that they manage multiple programs within the BLM (e.g., Riparian and Fisheries). Despite the stated area of expertise, 45% or greater of survey participants identified themselves as proficient, but not an expert, in riparian ecology, geomorphology, and aquatic ecology, while participant knowledge of hydrology and water chemistry were more varied (Table C3).

Table C3. Survey participants' stated knowledge of different components of lotic ecosystems.

	Little to no knowledge	Novice	Moderate	Proficient, but not an expert	Technical expert
Riparian ecology	0.0% (0)	4.3% (2)	19.1% (9)	61.7% (29)	14.9% (7)
Aquatic ecology	0.0% (0)	12.8% (6)	14.9% (7)	44.7% (21)	27.7% (13)
Hydrology	0.0% (0)	4.3% (2)	29.8% (14)	34.0% (16)	31.9% (15)
Geomorphology	0.0% (0)	14.9% (7)	23.4% (11)	46.8% (22)	14.9% (7)
Water chemistry	0.0% (0)	19.1% (9)	40.4% (19)	29.8% (14)	10.6% (5)

Survey Analysis

The ACIWG used weighted averaging to assess the overall importance of individual attributes within the four ecosystem process categories (Table C1). Specifically, the ACIWG multiplied survey participant ratings for each of the four selection criteria per attribute by their corresponding expertise ratings and divided by the total possible score. Final scores ranged from one (strongly agree) to negative one (strongly disagree) and were averaged among all 47 participants (± 95% confidence intervals). Lastly, to understand variability among overall ratings, the ACIWG assessed individual attribute ratings for each of the four selection criteria using weighted averaging.

Survey Results

Overall, participants agreed or strongly agreed (weighted score: 0.5 and 1, respectively) that the large majority of identified attributes were critical to maintaining functional BLM lotic systems (Figure C1). The notable exceptions were cations and anions, metals, and, to a lesser extent, water storage and yield and instream productivity; however, in very few instances did individuals disagree or strongly disagree (weighted score: -0.5 and -1, respectively) with the importance of any individual attribute.

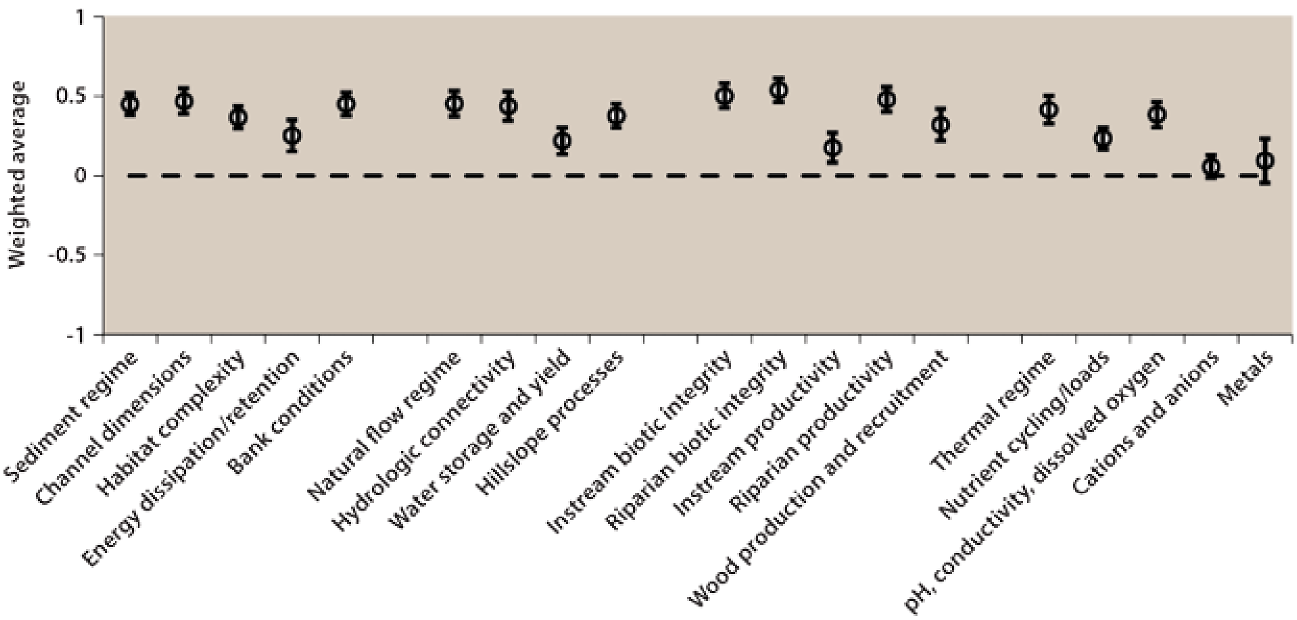


Figure C1. Weighted average (± 95% confidence intervals) attribute ratings compared within and among ecosystem process categories. Weighted averages (y-axis) range from 1 to -1, in which 1 indicates that the participant strongly agreed and -1 that the participant strongly disagreed with the evaluation criteria statement.

All top ranking attributes scored relatively consistently among the four individual selection criteria, except for the criteria related to BLM policy and management priorities and, to a lesser extent, the adequacy of field measurement capabilities (Figure C2). For example, the top ranking hydrogeomorphic attributes (channel dimensions/shape, sediment regime, natural flow regime, hydrologic connectivity) were all rated as being twice as important to maintaining functioning aquatic systems as they are to BLM policy and management on average. Only riparian biotic integrity and riparian productivity had an average score above 0.5 (agree) for both being a target of BLM policy and management and relevant to ecosystem integrity. Lastly, sediment regime was the only highly rated attribute that scored poorly on the adequacy of field measurements.

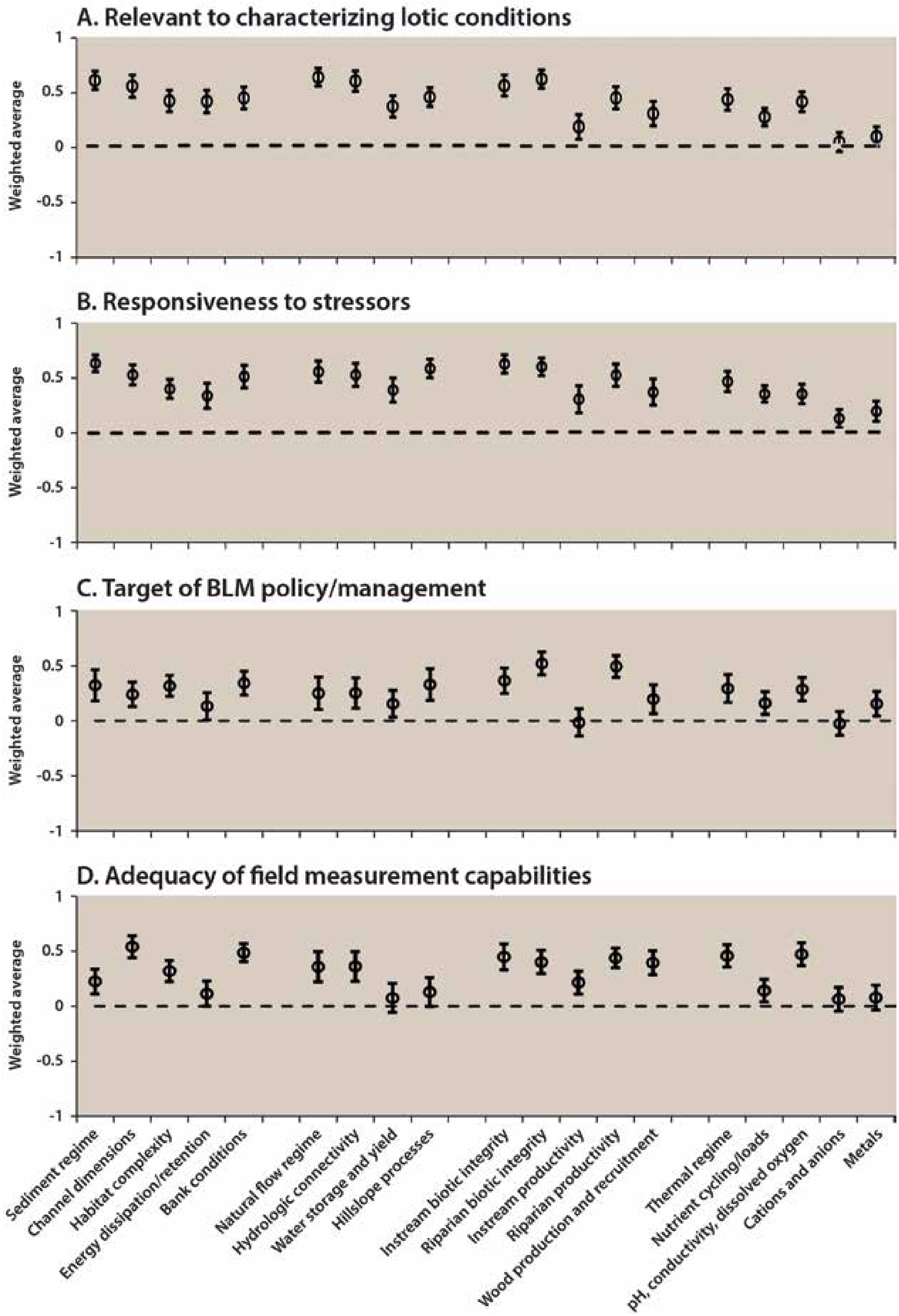


Figure C2. Expertise weighted average ratings (± 95% confidence intervals) of individual lotic ecosystem attributes against each of the four selection criteria. Weighted averages (y-axis) range from 1 to -1, in which 1 indicates that the participant strongly agreed and -1 that the participant strongly disagreed with the evaluation criteria statement.

Of the evaluated instream stressors, hydrologic alterations, thermal loading, and sediment loading were consistently ranked moderate (i.e., participants agreed that the stressor met the criteria on average) across the three stressor selection criteria (Figure C3). Only the rating of nutrient loading differed appreciably, with respondents approaching neutral on average (i.e., participants neither agree nor disagree). Across the four selection criteria, respondents rated the four stressors highest on relevance to the conditions of functioning lotic systems and lowest on adequacy of measurement, particularly for hydrologic alterations (data not shown). For the land uses considered, grazing and roads rated among the highest land use threats followed by mining, recreation, and logging (Figure C4), although no significant differences were observed.

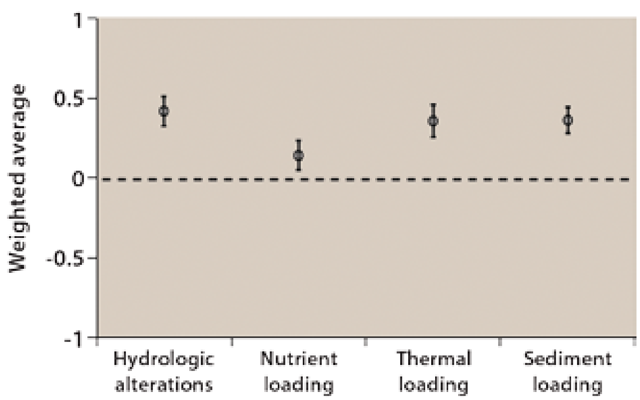


Figure C3. Weighted average (± 95% confidence intervals) pollutant/stressor ratings. Weighted averages (y-axis) range from 1 to -1, in which 1 indicates that the participant strongly agreed and -1 that the participant strongly disagreed with the evaluation criteria statement.

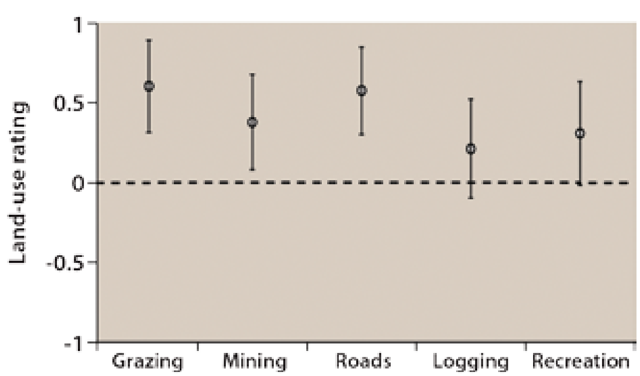


Figure C4. Average (± 95% confidence intervals) land use ratings across three of the rating criteria (Table C2). Ratings range from 1 to -1, in which 1 indicates that the participant strongly agreed and -1 that the participant strongly disagreed with the evaluation criteria statement.

Survey Conclusions

Given the critical role played by nearly all of the considered attributes for maintaining functioning lotic systems, it should not be surprising that a large majority of attributes were consistently ranked as critical to sustaining functioning lotic systems. Rather, these results reinforce the need for the BLM to develop a comprehensive and interdisciplinary approach to aquatic monitoring. This approach must be inclusive of the chemical, physical, and biological attributes of lotic systems to meet policy requirements and to adequately assess lotic ecosystem health.

The only notable exceptions for core indicator development were cations and anions, metals, and, to a lesser extent, water storage and yield and instream productivity. The ACIWG does not recommend developing core indicators for metals or cations and anions but, rather, suggests a general water quality screening using conductivity and the use of more project-specific contingent indicators where problems are thought to occur. This cursory check will flag excessive cations or anions but will not discriminate among the dissolved constituents contributing to high ionic activity. Furthermore, this cursory check will not tell the BLM anything about potential metal loading, which will need to be addressed on a case-by-case basis through the use of contingent indicators (e.g., where acid mine drainage is a known problem). For the other lower ranking attributes, the ACIWG does not recommend the selection of direct measurements, which might be hard to identify. Rather, the ACIWG recommends indirect measures of energy dissipation (e.g., large woody debris, channel unit types, bank stability), water storage and yield (e.g., floodplain interaction, vegetative composition), and instream productivity (e.g., ambient nutrient concentrations, macroinvertebrates).

Appendix D: Inventory of Existing Field Parameters and Sample Methodologies

The Aquatic Indicator Work Group (ACIWG) inventoried 10 existing state and federal monitoring programs, as well as BLM monitoring guidance, to identify field parameters and associated indicators commonly used to quantify the conditions and trends of perennial streams and rivers throughout the Western U.S. (Table D1). This inventory was not meant to be comprehensive of all lotic monitoring protocols but, rather, a representative compilation of actively used methods. The informal criteria for inclusion in the ACIWG's review were: (1) lotic monitoring protocol designed for wadeable or nonwadeable streams in the Western U.S.; (2) monitoring focused on condition and trend assessments of multiple stream functions; (3) protocol commonly implemented at state, regional, or national scales; and (4) quantitative or semiquantitative, field-based methodologies collected at the reach scale.

More than 45 different candidate indicators were inventoried, of which greater than half (26) were common to more than 50% of the monitoring programs (Table D2). Measurements of biogeochemical processes were the most parsimonious, with 83% of monitoring indicators common to at least 50% of the inventoried monitoring programs; the most common indicators were water temperature, specific conductance, pH, alkalinity, dissolved oxygen, total nitrogen and phosphorous, and total suspended solids. The most pervasive hydrogeomorphic field measurements (i.e., common to more than 80% of inventoried programs) were fine sediment; bankfull and wetted channel width and depth measurements; channel gradient; residual pool depth; and channel unit type, extent, and dimensions. Biotic field parameters were the most disparate among programs, with three-quarters of the parameters common to less than 50% of the programs. The most common biotic parameter (90%) was macroinvertebrate assemblage composition.

Table D1. State and federal monitoring programs inventoried to identify potential indicators to quantify the geomorphic, hydrologic, chemical, and biotic components of perennial lotic ecosystems in the Western U.S.

Developing Agency	Title/Author	Geographic Applicability	Intended Use
State of California, Surface Water Ambient Monitoring Program	Standard Operating Procedures for Collecting Benthic Macroinvertebrate Samples and Associated Physical and Chemical Data for Ambient Bioassessments in California (SWAMP 2007b)	Wadeable streams throughout the State of California	Monitoring the chemical, physical, and biological conditions and trends of streams and rivers
BLM	Multiple Indicator Monitoring (MIM) of Stream Channels and Streamside Vegetation (Burton et al. 2011)	Wadeable streams throughout the Western U.S.	Monitoring the conditions and trends of stream banks, riparian vegetation, and stream channels
BLM	Soil and Water Conservation on Rangelands (Karl et al. 2010)	Wadeable rangeland streams throughout the Western U.S.	Monitoring the sustainability of land uses on western public rangelands
BLM	Fundamentals of Rangeland Health - Land Health Standards (Karl, unpublished compilation of BLM land health standards)	Wadeable rangeland streams throughout the Western U.S. on BLM land	Assessments of the health of western public rangelands
National Park Service (NPS), Klamath Network Inventory and Monitoring Program	Klamath Network Vital Signs Monitoring Plan (Sarr et al. 2007)	Six NPS units throughout Oregon and Washington	Monitoring the chemical, physical, and biological integrity of NPS lotic systems
Environmental Protection Agency	National Rivers and Streams Assessment: Field Operations Manual (USEPA 2009)	Wadeable and nonwadeable perennial streams throughout the U.S.	Monitoring the chemical, physical, and biological conditions and trends of wadeable and nonwadeable lotic systems
Environmental Protection Agency	Monitoring Protocols to Evaluate Water Quality Effects of Grazing Management on Western Rangeland Streams (Bauer and Burton 1993)	Wadeable rangeland streams throughout the Western U.S.	Monitoring grazing impacts on water quality and physical habitat of western streams
U.S. Forest Service/ BLM	Field Protocol Manual: Aquatic and Riparian Effectiveness Monitoring Program (Lanigan 2010)	Public lands encompassed by the Northwest Forest Plan	Monitoring the conditions and trends of 6th field watersheds in the Pacific Northwest
U.S. Forest Service/ BLM	PACFISH/INFISH Biological Opinion Effectiveness Monitoring Program for Streams and Riparian Areas: 2012 Sampling Protocol for Stream Channel Attributes (Archer et al. 2012)	Interior Columbia River Basin	Monitoring the physical and biological components of aquatic and riparian systems within the range of steelhead and bull trout
U.S. Geological Survey	National Water-Quality Assessment Program (USGS-NAWQA)	Ground and surface water resources throughout the U.S.	Monitoring the chemical, physical, and biological conditions and trends of lotic systems

Table D2. Frequency of indicator use among the 10 inventoried state and federal monitoring programs.

Key Ecosystem Process	Candidate Indicator	Percent Usage among the 10 Inventoried Programs
Hydrogeomorphic processes	Pebble count	100%
	Bankfull width	90%
	Wetted width	90%
	Channel gradient or water surface slope	90%
	Channel unit type and linear or aerial extent (e.g., pool, riffle, run)	90%
	Residual pool depth[1]	90%
	Water depth[1]	80%
	Instantaneous discharge	60%
	Embeddedness/fine sediment[2]	60%
	Bankfull and/or incision depth	60%
	Bank angle	60%
	Streambank stability[2]	60%
	Water velocity[1]	30%
	Flood prone width	30%
	Streambank undercut distance	30%
	Streambank height	20%
	Longitudinal thalweg profile[2]	10%
	Channel constraint, debris torrents, and recent floods[2]	10%
	Greenline-to-greenline width	10%
Biogeochemical processes	Temperature[2]	90%
	Specific conductance	90%
	Dissolved oxygen	60%
	Alkalinity	60%
	pH	60%
	Nitrogen and phosphorous	60%
	Total suspended solids	60%
	Additional water quality parameters listed	60%
	Turbidity	50%
	Dissolved organic carbon	50%
	Dissolved inorganic carbon	40%
	Fecal coliform	20%

(table continued on next page)

Table D2. (continued) Frequency of indicator use among the 10 inventoried state and federal monitoring programs.

Biotic processes and other	Photos	100%
	Macroinvertebrate assemblage composition	90%
	Large woody debris	50%
	Rapid assessment of various anthropogenic stressors	50%
	Algal assemblage composition[2]	40%
	Periphyton biomass and chlorophyll concentrations	40%
	Organismal cover: filamentous algae, macrophytes, large woody debris, overhanging vegetation	40%
	Fish assemblage composition and measurements	40%
	Riparian vegetation: qualitative estimates of canopy cover or structure or type	30%
	Riparian vegetation: composition and cover quantified	30%
	Invasive species[2]	30%
	Amphibians[2]	20%
	Stubble height	20%
	Woody plant species use	20%
	Sediment community metabolism	10%
	Coarse particulate organic matter	10%

[1]The percentage of surveyed programs using this indicator might be underrepresented in the current inventory.

[2]Indicator is frequently assessed qualitatively, and/or methodologies vary greatly among monitoring programs.

Appendix E: Aquatic Core and Contingent Indicator Field and Analytical Methods

Table E1. **Methods to be considered for the measurement and analysis of the aquatic core indicators. The aquatic core indicators are grouped by the BLM's four fundamentals (43 CFR 4180.1). The likely core indicator-compatible protocols are indicated by superscripts, and partially compatible protocols are indicated by superscripts enclosed in brackets.**

	Indicator	Field Method	Condition Determination
Water quality[1]	Acidity (pH)	In situ: multiparameter sonde[2]	Regional reference conditions[2]; state standards
	Conductivity	In situ: multiparameter sonde[2,[4,5]]	Observed/expected[3]; state standards
	Temperature	In situ: multiparameter sonde[2] or thermistor[4,[5]]	Observed/expected[6]; state standards
Watershed function and instream habitat quality	Residual pool depth, length, and frequency	Measure all qualifying pools within the reach[4,[5,7]]	Land use plan objectives; regional reference conditions
	Streambed particle sizes	210 particles from active channel[7,[2,4,5]]	Regional reference conditions[2]
	Bank stability and cover	Left and right bank measurements at a minimum of 21 transects[7,[4]]	Land use plan objectives; regional reference conditions
	Large woody debris	Count and measure all pieces throughout reach[2,[4,5]]	Covariate for bed stability, pools, other; indicator of habitat complexity
	Floodplain connectivity	Bankfull and terrace depths measured at 11 transects[2]	Regional reference conditions[2]
Biodiversity and riparian habitat quality	Macroinvertebrate biological integrity	1 Surber/kick net per each of 11 transects[2,[4,5]]	Observed/expected or multimetric indices; state standards
	Ocular estimates of riparian vegetative type, cover, and structure	Ocular vegetative type, cover, and structure estimates at 11 transects[2,8]	Regional reference conditions[2]; land use plan objectives
	Canopy cover	6 densiometer readings at 11 transects[2]	Regional reference conditions[2]; land use plan objectives

[1]The temporal resolution of water quality protocols will need to be intensified for assessments of state water quality standards.

[2]USEPA 2009

[3]Olson and Hawkins 2012

[4]Archer et al. 2012

[5]Lanigan 2010

[6]Hill et al. 2013

[7]Burton et al. 2011

[8]The Environmental Protection Agency National Rivers and Streams Assessment riparian vegetative protocol will be supplemented with additional vegetative categories specific to BLM lands.

Table E2. **Methods to be considered for the measurement and analysis of the aquatic contingent indicators and covariates. The aquatic core indicators are grouped by the BLM's four fundamentals (43 CFR 4180.1). The likely compatible protocols are indicated by superscripts, and partially compatible protocols are indicated by superscripts enclosed in brackets.**

	Indicator/Covariate	Field Method	Condition Determination
Water quality[1]	Total nitrogen and phosphorous	Grab sample for lab analysis[2]	Observed/expected[3]; regional reference conditions[2]
	Turbidity	In situ: turbidometer[4] or grab sample for lab analyses[2]	State standards
Watershed function and instream habitat quality	Ocular estimate of instream habitat complexity	Ocular instream cover estimate: large woody debris, vegetation, undercuts, boulders, etc.[2]	Regional reference conditions[2]
	Bank angle	Left and right bank at 21 transects[6]	Regional reference conditions
	Thalweg depth profile	100-plus intertransect measurements of thalweg water depth[2]	Regional reference conditions[2]
Biodiversity and riparian habitat quality	Quantitative estimates of riparian vegetative cover, composition, and structure	Left (21) and right (21) bank greenline-based quadrats.[5] Plot numbers are suggested minima	Ecological site descriptions; Land use plan objectives
Covariates/other	Slope	Elevation change over entire reach length[6,[2,7]]	NA: Covariate used to model pools, bed stability, and others
	Bankfull width	One measurement at each of 11 transects[6,[2,7]]	NA: Covariate used to model pools, bed stability, and others
	Photos	Photo points[6]	NA
	Human impacts	Ocular estimate of human activities at each of 11 transects[2,8]	NA

[1]The temporal resolution of water quality protocols will need to be intensified for assessments of state water quality standards.

[2]USEPA 2009

[3]Olson and Hawkins 2012

[4]SWAMP 2007a

[5]Burton et al. 2011

[6]Archer et al. 2012

[7]Lanigan 2010

[8]The Environmental Protection Agency National Rivers and Streams Assessment human impacts protocol will be supplemented with additional human influences specific to BLM lands.

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