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## **Developing Enterprise Tools and Capacities for Large-scale Natural Resource Monitoring: A Visioning Workshop**

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## Abbreviations

AIM	Assessment, Inventory, and Monitoring
API	Application Programming Interface
BLM	Bureau of Land Management
DOI	U.S. Department of Interior
NABat	North American Bat Monitoring Program
PNAMP	Pacific Northwest Aquatic Monitoring Partnership
REST	Representational State Transfer
USGS	U.S. Geological Survey

# Developing Enterprise Tools and Capacities for Large-scale Natural Resource Monitoring: A Visioning Workshop

By Jennifer M. Bayer<sup>1</sup>, Jake F. Weltzin<sup>2</sup>, Rebecca A. Scully<sup>1</sup>

## Abstract

In October 2016, the U.S. Geological Survey (USGS), in collaboration with the Pacific Northwest Aquatic Monitoring Partnership (PNAMP, [www.pnamp.org](http://www.pnamp.org)), convened a 30-person workshop, <https://www.pnamp.org/event/5509>, to identify and prioritize development of enterprise systems for programs that monitor the status and trends of species populations and their terrestrial, aquatic, and marine habitats. Participants included representatives from federal natural resource research and land management organizations and nongovernmental organizations that manage natural resource monitoring programs.

Objectives of the workshop were: 1) identify resources that support natural resource monitoring programs working across the data life cycle; 2) prioritize desired capacities and tools to facilitate monitoring design and implementation; 3) identify standards and best practices that improve discovery, accessibility, and interoperability of data across programs and jurisdictions; and 4) contribute to an emerging community of practice focused on natural resource monitoring.

The workshop included review of [MonitoringResources.org](http://MonitoringResources.org), a nonproprietary open access suite of enterprise tools developed and maintained by USGS and PNAMP. Workshop participants learned about

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current and developing applications of this tool set as well as emerging federal requirements for improved discoverability, accessibility, and management of natural resource monitoring data.

Workshop participants identified priorities for additional development of [MonitoringResources.org](https://MonitoringResources.org) including features to query the presence and status of monitoring programs, protocols, and sample sites; support for tracking changes in published protocols and methods; and web services that enable “machine-readable” communication between [MonitoringResources.org](https://MonitoringResources.org) and other enterprise tools or databases.

Participants also agreed that in order to sustain enterprise monitoring tools, the natural resource community must develop a network of people capable of promoting communication, coordination, and collaboration around multijurisdictional, landscape-scale natural resource monitoring. Workshop attendees suggested next steps should include developing a business plan that considers infrastructure needed to develop and sustain expansion of [MonitoringResources.org](https://MonitoringResources.org) use and identifying pilot projects to inform tool development priorities.

## **Introduction**

Monitoring natural resources—water, forests, and animal populations—is required to support effective management of natural resources. However, because monitoring activities are often specific to a discipline, objective, or agency, it is typically difficult to integrate data to answer questions that transcend geopolitical and jurisdictional boundaries. In addition, it is sometimes difficult to discover, access, or use data that have already been collected because of a lack of consistent standards, tools, data catalogs and metadata—all aspects of data and information management—within and across organizations and jurisdictions. How do we improve our ability to store, find, share, integrate, analyze and apply monitoring data and information, particularly in the face of emergent, multi-jurisdictional environmental issues that need prompt and coordinated attention? In other words, in a time of increasingly scarce resources, how can we achieve the enhanced data integration we need to address critical environmental issues in a timely and efficient manner?

One answer may be through the use of enterprise systems. In the business world, organizations use enterprise systems (typically packages of integrated software that support multiple processes) to coordinate, collect, document, and discover data, as well as to design and implement data collection. Similarly, the use of enterprise systems in natural resource science is necessary to support effective large-scale, long-term monitoring, to improve interoperability of data, and to increase our capacity to understand and manage large natural and human-affected landscapes.

One of the goals of the [USGS Status and Trends Program](#) is to develop and promulgate the use of enterprise systems to support the monitoring and management of natural resources by federal agencies and their associated stakeholders and partners. Attaining this goal will require the development of tools and capacities (i.e. information infrastructure) and the development of networks or forums (i.e. human infrastructure) to enhance the capacity for coordination and collaboration among monitoring practitioners and organizations. However, there are few models that include both information and human infrastructure designed to work across jurisdictions and organizations, and that are relatively agnostic as to discipline.

To begin a conversation about the need for enterprise systems to support natural resource monitoring within the federal realm, we convened a 30-person workshop (Supplemental Material 1; Figure 1)



**Figure 1.** 2016 Visioning Workshop: Developing Enterprise Tools & Capacities for Large-Scale Natural Resource Monitoring Participants (photo credit Leah Colasuonno, USGS)



to identify existing systems and prioritize tasks for future development of shared resources for programs that monitor the status and trends of species populations (e.g., bats, fish and migratory birds) and their terrestrial, aquatic, and marine habitats (e.g., forests, grasslands, rivers and ocean coasts) (Weltzin et al. 2017).

Participants included representatives from seven federal natural resource research and land management organizations and three nongovernmental organizations that manage natural resource monitoring programs (Supplemental Material 1).

Objectives of the workshop were:

- identify capacities available to support natural resource monitoring programs working across the data life cycle;
- identify and prioritize new capacities or enterprise tools to facilitate program design, implementation, and operation;
- identify standards and best practices that improve discovery, accessibility, and interoperability of data across programs and jurisdictions; and
- contribute to an emerging community of practice focused on natural resource monitoring.

## **Workshop Approach**

The workshop was designed to understand the needs of natural resource monitoring programs and practitioners, and to determine whether enterprise systems could be developed to better support large-scale, long-term monitoring and the use and reuse of data resulting from monitoring (Supplemental Material 1). We framed the first portion of the workshop around an existing suite of tools – [MonitoringResources.org](https://www.monitoringresources.org) – which is a nonproprietary open-access suite of enterprise monitoring tools developed and maintained by USGS and PNAMP. Then, we used panel discussions, break-out group exercises, and plenary discussions to (1) collectively identify standards and best practices that improve the value of data across the data life-cycle, (2) learn about other relevant tools and systems (e.g., data repositories, visualization tools), (3) discuss support

needed for an emerging community of practice focused on natural resource monitoring, and (4) initiate discussion around the idea of a national forum to support coordination and collaboration among monitoring professionals.

### **Evaluation of an existing system: [MonitoringResources.org](https://www.monitoringresources.org)**

A portion of the workshop was designed to solicit input from monitoring practitioners, program managers and information scientists to inform enhancements to an existing resource, [MonitoringResources.org](https://www.monitoringresources.org), to inform the efficient expansion of these resources beyond their current subject matter and spatial extent. [MonitoringResources.org](https://www.monitoringresources.org) is an online suite of structured enterprise tools and workflows that support monitoring and research protocols, and methods and designs that improve data documentation, discovery and coordination (Bayer et al. in prep; Volk et. al. 2014). [MonitoringResources.org](https://www.monitoringresources.org) was created by the Pacific Northwest Aquatic Monitoring Partnership (PNAMP), a voluntary forum dedicated to enhance the capacity, coordination and collaboration among aquatic monitoring programs in the Pacific Northwest. The initial emphasis of [MonitoringResources.org](https://www.monitoringresources.org) was to support aquatic monitoring in the Pacific Northwest and to make the tools readily available to any stakeholder.

During this portion of the workshop, we asked participants to learn more about [MonitoringResources.org](https://www.monitoringresources.org) and the current applications of the tool, and identify new tools, capacities and projects that [MonitoringResources.org](https://www.monitoringresources.org) could support. We then solicited input to inform effective expansion of the [MonitoringResources.org](https://www.monitoringresources.org) toolset to include terrestrial ecosystems and expand the spatial domain to a national or continental scale. Our premise was that expanding [MonitoringResources.org](https://www.monitoringresources.org) to enterprise capacity would promote inter-program coordination, improve discoverability of data and protocols, facilitate data management, and improve data reuse through better documentation and enhanced metadata. In other words, we asked participants to consider the utility of expanding [MonitoringResources.org](https://www.monitoringresources.org) and the established collaboration support model (using PNAMP as an example) to a national capacity. Specifically, participants

were asked to consider their interest in an enhanced or expanded enterprise system that included both information infrastructure and human infrastructure for collaboration to support monitoring program coordination, design, implementation, documentation, and data discovery.

We first provided a brief introduction to [MonitoringResources.org](https://www.pnamp.org) via a presentation from Rebecca Scully (Table 1). Then, to elaborate on the toolset’s capacity, we asked a small set of users to tell their own story of how they currently use or envision using [MonitoringResources.org](https://www.pnamp.org) (Table 1). These talks described current and developing applications of the [MonitoringResources.org](https://www.pnamp.org) suite of monitoring and information management tools. Applications discussed included those used to assess fish and aquatic habitats in the Columbia River Basin and to develop and document spatially balanced sampling designs in semiarid rangelands. Following the use cases, plenary speakers described emerging federal requirements for data access and information management and illuminated the relevance of enterprise tools to managing the data life cycle as per best practices and emerging federal requirements (Table 1).

**Table 1.** Developing Enterprise Tools and Capacities for Large-scale Natural Resource Monitoring: A Visioning Workshop Presentations.

Presentation Title	Presenter	Organization	Link to presentation
MonitoringResources.org Overview Presentation	Rebecca Scully	USGS	<a href="https://www.pnamp.org/document/5743">https://www.pnamp.org/document/5743</a>
Developing web tools to document monitoring protocols: an example from the Columbia River Basin	Russell Scranton	BPA	<a href="https://www.pnamp.org/document/5745">https://www.pnamp.org/document/5745</a>
Bureau of Land Management Assessment, Inventory, and Monitoring Program	Jason Karl	USDA	<a href="https://www.pnamp.org/document/5744">https://www.pnamp.org/document/5744</a>
North American Bat Monitoring Program	Patricia Stevens	USGS	<a href="https://www.pnamp.org/document/5746">https://www.pnamp.org/document/5746</a>
Data Release Workflow: Making more of our Fisheries Data	Daniel Wieferich	USGS	<a href="https://www.pnamp.org/document/5747">https://www.pnamp.org/document/5747</a>
Use case for a monitoring protocol and method registry for marine biological observations and other Darwin Core-based systems	Sky Bristol	USGS	<a href="https://www.pnamp.org/document/5778">https://www.pnamp.org/document/5778</a>
Potential for Collaborative Monitoring: Power in Numbers	Kathi Irvine	USGS	<a href="https://www.pnamp.org/document/5579">https://www.pnamp.org/document/5579</a>
Public Access/Open Data Progress and Challenges	Vivian Hutchison	USGS	<a href="https://www.pnamp.org/document/5742">https://www.pnamp.org/document/5742</a>
Active Registry of Monitoring Protocols and Methods	Sky Bristol	USGS	<a href="https://www.pnamp.org/document/5777">https://www.pnamp.org/document/5777</a>

## **Identifying and prioritizing tools, resources and infrastructure needed for monitoring**

Next, we gathered information from workshop participants via several techniques designed to create opportunity for discussion and learning across jurisdictions and backgrounds. We started with an all-hands exercise to identify interests, needs, and ideas regarding tools and infrastructure needed for monitoring planning and coordination. We then used the results of this exercise to inform topics for small group focused discussions where we delved into participants' reactions to [MonitoringResources.org](https://MonitoringResources.org) as well as other ideas shared during the use cases (Supplemental Material 2).

Then, we used small breakout groups to identify existing tools, resources and gaps for large-scale, long-term, multi-jurisdictional monitoring, with a focus on specific topics: sampling design; protocols and methods; project implementation; data management (metadata and compliance); and data delivery and visualization (Supplemental Material 3). This was followed by a plenary discussion of what might be needed to start development of a larger scale community of practice focused on natural resource monitoring.

## **Future directions for national-scale monitoring**

We concluded with a plenary exercise to generate ideas and prioritize actions. Specifically, we conducted action planning targeted at two questions: 1) "What's next for [MonitoringResources.org](https://MonitoringResources.org)?" whereby we looked for major gaps (in terms of enterprise tools) and input as to where the [MonitoringResources.org](https://MonitoringResources.org) team should focus their development efforts next and 2) "Towards a national monitoring network?", which was an open brainstorm session to elicit any ideas or reactions to the idea of a facilitated partnership for coordination and collaboration at a national scale.

## Workshop Results

### Assessment of tools, resources, gaps and priorities

We received a great deal of input during the workshop from multiple exercises designed to identify existing tools and resources, gaps, and priorities for large-scale, long-term, multi-jurisdictional monitoring. Workshop participants identified over 60 existing tools, best practices or resources in each of the following six topics: sample design; protocols and method; project implementation; data management; and data delivery and visualization sample designs. Results are presented in Supplemental Material 3, where they are separated into resources and gaps for each topic.

In general, responses fell into four themes: (1) need for persistent, thorough documentation of protocols, methods and design and connecting this with results of monitoring; (2) coordination of monitoring design and addressing scalability issues that arise from integration across programs; (3) need for tools to track implementation of monitoring; need for facilitated discussion around methods for collection, QA/QC, and analyses of data; and (4) using these documentation efforts to ultimately improve discoverability of monitoring activities and results. These themes are summarized and discussed in more detail in the following sections.

### Documentation of Protocols and Methods

Across programs, we heard interest in the concept of linking documentation of how data were collected to the data themselves. Related to this idea, tracking versions of documentation and making those changes discoverable is very important to support analysis of long term datasets and analyses involving multiple data sources. Providing persistent documentation so that data can be reused and understanding of why inference could change through time is critical to appropriate data reuse over time and across jurisdictions. We heard strong interest in the desire to link data collection events or results to the version of

the protocol applied to create the resulting data and to make it possible to identify when protocols change enough to change data. Robust documentation of how data were collected, analyzed and quality assured is of interest across programs.

In addition to interest in persistent documentation of methods, a number of participants suggested [MonitoringResources.org](https://www.monitoringresources.org) could house discussions regarding implementation of monitoring methods. Participants suggested a facilitated forum for dialogue among experts and where others could pose questions might support advancement in quality of data as well as consistency of methods, which is a big factor in interoperability of resulting data. This could also include support for creation of new methods. By providing access to robust documentation of past protocols, [MonitoringResources.org](https://www.monitoringresources.org) could support scientists building new methods to understand what has happened in the past and why a particular method was applied. Across programs, participants expressed interest in ability to identify best practices for all aspects of monitoring from design considerations, site selection, to individual data collection methods.

### Coordination of Monitoring Design

The need to document monitoring design and to support creation of designs at a variety of scales was heard from many participants. It was recognized that [MonitoringResources.org](https://www.monitoringresources.org) could be valuable in supporting scalable monitoring efforts, especially the idea of coordination so that partners collecting a set of core data elements at a local level could inform national analysis while providing them flexibility to add their own methodology to support their local objectives (similar to the BLM Assessment, Inventory and Monitoring (AIM) program use case, presented in this workshop, see Table 1). Whereas scaling of information from a local scale to a national scale could prove to be difficult, there is a need to inform local monitoring about the value of their role in contributing to a national monitoring effort. Coordination would need to address the requirement for protocols and designs to be compatible with the national protocol and design. Some

participants use published recommendations for structured documentation of long term monitoring protocols per Oakley et al. (2003), which was also used to structure [MonitoringResources.org](https://www.monitoringresources.org).

## Tools to Track Monitoring Implementation

Once monitoring actions have been planned, the plan must be implemented by agencies, states, tribes, and private citizens. When coordinating sampling across multiple partners, it is difficult and time consuming to track exactly when, where and what sampling took place: field implementation often differs from plan. Knowing the exact date and data collected at a location in real time would allow for protocols and study designs to be adjusted during the field season. Additionally, it would streamline reporting, data discover and metadata creation after sampling.

Participants recommend we continue to examine the [North American Bat Monitoring Program \(NABat\)](#) pilot project (presented in this workshop, see Table 1) to track the implementation of a Master Sample across North America. They recommend we use the NABat pilot to learn lessons and make improvements to the toolset to support tracking implementation of a plan, streamlining creation of metadata, simplifying the creation of output to use in the field and reporting.

## Improving Discoverability of Monitoring Activities and Results

Across all workshop participants, we saw interest in knowing “who is doing what, where, when, and how?” The desire to modify [MonitoringResources.org](https://www.monitoringresources.org) to support this at a national scale was, in fact, the highest priority of the group. Participants also expressed strong interest in adapting [MonitoringResources.org](https://www.monitoringresources.org) to better facilitate coordination of planned monitoring activities as well as data sharing after data are collected. A number of participants suggested that adjusting the toolset to sort and present information based on subject matter may be necessary when trying to create an enterprise system that accommodates multiple subject matters (e.g., bat monitoring and fish habitat monitoring).

## Summary of gaps and needs as identified by participants

Many tools and resources are specific to a subject matter, agency or are only useful to a specific user. There is some overlap in functionality between [MonitoringResources.org](https://MonitoringResources.org) and some of the tools identified but there are no tools that duplicate [MonitoringResources.org](https://MonitoringResources.org). Gaps identified indicated that more tools or improvements to current tools are needed to support monitoring but the biggest need identified was for best practices, data standards and communication. To generate best practices, data standards and establish communication for monitoring and information sharing across agencies, jurisdictions and subject matter a forum would be needed to coordinate, collaborate and bring together subject matter experts. Workshop participants suggested such a forum could address several specific gaps which are high priorities, including: creation of linkages from data to protocols, designs and implementation notes; facilitation of agreement on data dictionaries; and development of automated processes for data delivery, quality assurance and quality control.

## Next steps for [MonitoringResources.org](https://MonitoringResources.org)

Based on their understanding of [MonitoringResources.org](https://MonitoringResources.org), within the context of their collective understanding of existing resources and identified gaps, participants identified and prioritized suggested actions for next steps for [MonitoringResources.org](https://MonitoringResources.org) (Supplemental Material 2). During this session, we heard the strongest interest in additional development of existing elements of the [MonitoringResources.org](https://MonitoringResources.org) toolset, including the query tools and content to answer “who is doing what, where, when, and how?” questions; strengthening versioning of protocols; and increasing capacity to deliver and track master sample implementation.

The second highest ranked priority was development of web services, or Application Programming Interfaces (APIs), which is software code (e.g., REST) that enables machine to machine communication. This suggests that partners are ready to consider how this enterprise system could connect to other systems.



Other priorities identified included adding tools for developing quantitative objectives for monitoring, which could be included with protocols. This might include standards for temporal, spatial and response designs. We heard participants offer that they are interested in use of this tool to provide guidance so that we strive to make the most of limited funding for data collection and analyses.

In addition to suggested improvements and new additions to [MonitoringResources.org](https://www.monitoringresources.org), workshop participants suggested iterative learning through use of pilot projects would be essential. Specific pilot project ideas included:

- support for continental scale design and protocol documentation for the North American Bat Monitoring Program;
- pilot use for protocol documentation as part of USGS Ecosystems Mission Area effort to bolster project documentation;
- add protocol documentation to the BLM AIM Strategy's use of the toolset,
- support continental scale design and protocol documentation for the Monarch Conservation Science Partnership; and,
- create a nested sample design to support monitoring design integration across scales.

### **Towards a national monitoring network?**

As we wrapped up the workshop, we discussed the need for human infrastructure, including the idea of a forum or framework to help develop a national monitoring network. When asked about interest in coordination and collaboration across jurisdictions and communities of practice, workshop participants were encouraging -- but stopped short of demanding -- a national monitoring framework. Rather, they supported the idea of "human infrastructure" to begin to develop a community of practice focused on large scale natural resource monitoring. To this end, participants recommended we develop a business plan to describe the concept of a "monitoring consortium" that would facilitate collaboration as well as guide and support the

development of enterprise tools such as [MonitoringResources.org](https://MonitoringResources.org), including options for integration with other systems, roles and expectations for partners, and projections of necessary resources.

## Workshop Summary

The workshop was a successful start to exploration of expansion of [MonitoringResources.org](https://MonitoringResources.org), yielding significant input regarding priorities for additional development of the tool set, such as features to query the presence and status of monitoring programs, protocols, and/or sample sites; support for tracking changes in published protocols and methods; and web services that enable “machine-readable” communication between [MonitoringResources.org](https://MonitoringResources.org) and other enterprise tools or databases.

Participants also agreed that a network of people capable of promoting communication, coordination, and collaboration around multijurisdictional, landscape-scale natural resource monitoring is necessary in order to sustain enterprise monitoring tools. Workshop attendees suggested next steps should include developing a business plan that considers infrastructure needed to develop and sustain expansion of use of [MonitoringResources.org](https://MonitoringResources.org) and identifying pilot projects to inform tool development priorities.

Over the next three years, we will focus on the development of pilot tasks identified at the workshop, creation of a business plan to describe potential structure and requirements to support [MonitoringResources.org](https://MonitoringResources.org) and further discussion with all interested parties regarding a monitoring colloquium for enhancement of coordination and collaboration across programs and jurisdictions.

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- Weltzin, J. F., Bayer, J.M., and Scully R.A. 2017. Defining opportunities for collaboration across data life cycles, Eos, 98. (<https://doi.org/10.1029/2017E007268>)

# Supplemental Material 1. Workshop Materials

## Workshop Invitation and Introduction Letter to Participants

We are excited to have you participate in our upcoming workshop and discussions about development and provision of enterprise resources for large-scale, long-term monitoring programs.

This workshop will focus on identifying requirements for consistent design, data collection and data management across organizational boundaries to support development and implementation of monitoring programs and activities by stakeholders charged with managing natural resources. We will leverage on prior work by identifying desired enhancements to an existing web resource - [MonitoringResources.org](https://MonitoringResources.org) - that will ultimately support a diversity of national-scale monitoring programs through provision of online tools and services to support communication, coordination and collaboration around natural resource monitoring.

## Why Use Tools to Collaborate Around Monitoring?

Individual natural resource monitoring programs have evolved in response to different organizational mandates, jurisdictional needs, issues and questions. While some issues are unique to particular entities, there is much common ground. To manage resources and to understand complex questions such as ecosystem services, we need to understand status and trends of biodiversity -- i.e., the distribution, abundance, and health of natural and managed plant and animal populations and communities -- and the structure and function of ecosystems at a variety of spatial and temporal scales.

To gather sufficient information to inform decisions, whether via new data collection efforts or by using extant data from disparate sources, improved coordination is needed. Coordination improves the discoverability, accessibility and usability of information, increases the quantity and quality of scientific information, improves the timeliness of information collection and analysis and delivery, increases efficiencies and minimizes duplication of effort across jurisdictions, and improves communication among stakeholders on supply- and demand-sides.

## What is MonitoringResources.org?

[MonitoringResources.org](https://MonitoringResources.org) was developed by the Pacific Northwest Aquatic Monitoring Partnership ([PNAMP](#)) to provide online public structured documentation of monitoring and research protocols, methods and designs in a consistent format to improve data documentation, discovery and collaboration among partners in the Pacific Northwest. However, the tools may be accessed and used by any entity or individual who wishes to use them. Existing and new stakeholders in the federal realm have requested an expansion of the scope of MonitoringResources.org and associated tools to support continental-scale, terrestrial monitoring. USGS is considering strategic investments in expanded enterprise capacity for large-scale, long-term monitoring, and

has convened this workshop to solicit guidance and to help prioritize development activities in support of natural resource monitoring in the federal realm.

### **Workshop Goals**

Our long-term goal is to provide a forum for large-scale natural resource monitoring programs to collaborate towards development and enhancement of enterprise resources for monitoring program coordination, design, implementation, documentation, and data discovery. At this first workshop, you will:

- Learn more about [MonitoringResources.org](https://MonitoringResources.org) and current applications of the tool
- Help identify new tools, capacities and projects that [MonitoringResources.org](https://MonitoringResources.org) could support
- Identify standards and best practices that improve the value of data across the data life-cycle
- Learn about other relevant tools and systems (e.g., data repositories, visualization tools)
- Contribute to an emerging community of practice focused on natural resource monitoring

**Table 1-1.** Participants in the Developing Enterprise Tools and Capacities for Large-scale Natural Resource Monitoring: A Visioning Workshop.

<b>Name</b>	<b>Organization</b>
Jen Bayer	U.S. Geological Survey
Zack Bowen	U.S. Geological Survey
Sky Bristol	U.S. Geological Survey
Sarah Burnett	Bureau of Land Management
Michael Carnes	Sitka Technology Group
Meg Dethloff	U.S. Geological Survey
Scott Donahue	Bonneville Power Administration
Sean Finn	U.S. Fish & Wildlife Service
Brent Frakes	National Park Service
Healy Hamilton	NatureServe
Viv Hutchison	U.S. Geological Survey
Kathi Irvine	U.S. Geological Survey
Jason Karl	USDA Agricultural Research Service
Rasa Keanini	Bonneville Power Administration
Simon Kingston	National Park Service
Dan Kocol	National Park Service
Derek Masaki	U.S. Geological Survey
Jeff Morissette	DOI North Central Climate Science Center
Scott Nelson	U.S. Geological Survey
Jana Newman	U.S. Fish & Wildlife Service
Tony Olsen	US EPA Western Ecology Division
Andrea Ostroff	U.S. Geological Survey
Tom Philippi	National Park Service
David Pyke	U.S. Geological Survey
Jennifer Sauer	U.S. Geological Survey
John Sauer	U.S. Geological Survey
Russell Scranton	Bonneville Power Administration
Becca Scully	U.S. Geological Survey
Keith Steele	Sitka Technology Group
Patricia Stevens	U.S. Geological Survey
Andrea Thorpe	NEON, Inc.
Jake Weltzin	U.S. Geological Survey
Daniel Wieferich	U.S. Geological Survey

**Table 1-2.** Agenda for the Developing Enterprise Tools and Capacities for Large-scale Natural Resource Monitoring: A Visioning Workshop – October 12-13, 2016 – USGS Powell Center Fort Collins, Colorado

Day 1, October 12 <sup>th</sup>	
8:00	Arrive, enjoy a light breakfast in the room, get settled
8:30	Open the meeting ( <i>Jen Bayer, USGS PNAMP</i> ) Welcome to the USGS Powell Center for Analysis & Synthesis ( <i>Jill Baron, USGS</i> ) Round robin introductions ( <i>all</i> )
9:15	Workshop Goals, Outcomes, and Agenda Review ( <i>Jen Bayer</i> )
9:20	Introduction: setting the stage ( <i>Jake Weltzin, USGS</i> )
9:35	MonitoringResources.org overview and introduction to use cases ( <i>Jen Bayer &amp; Becca Scully, USGS PNAMP</i> )
9:55	<ul style="list-style-type: none"> <li>• Use Case: Bonneville Power Administration &amp; the Columbia River Basin’s Fish and Wildlife Program (<i>Russell Scranton, BPA</i>)</li> <li>• Use Case: Bureau of Land Management Assessment &amp; Inventory Monitoring Program (<i>Jason Karl, USDA ARS</i>)</li> <li>• Use Case: North American Bat Monitoring Program (<i>Patricia Stevens, USGS FORT</i>)</li> </ul>
10:25	Break
10:45	<ul style="list-style-type: none"> <li>• Use Case: USGS Ecosystems’ Mission Area eDNA Pilot Project (<i>Daniel Wieferrich, USGS CSASL</i>)</li> <li>• Use Case: OBIS and Marine Biodiversity Monitoring and Essential Variables (<i>Sky Bristol, USGS CSASL</i>)</li> <li>• Use Case: The Potential for Collaborative Monitoring: Power in Numbers (<i>Kathi Irvine, USGS NOROCK</i>)</li> </ul>
11:15	Use Case Panel Discussion ( <i>Use case presenters</i> )
12:00	Lunch
1:00	Public Access/Open Data Progress & Challenges ( <i>Vivian Hutchison, USGS CSASL</i> )
1:15	Data Life Cycle Relevance ( <i>Sky Bristol, USGS CSASL</i> )
1:30	Your Turn: Reaction, identification of interests, needs, ideas ( <i>All participants, round robin</i> )
2:45	Break

3:15	Your reaction to MonitoringResources.org Discussion in small groups, topics based on previous work
4:45	Adjourn Day 1
5:30	Optional Get Together at The Mayor of Old Town

<b>Day 2, October 13<sup>th</sup></b>	
8:00	Arrive, enjoy a light breakfast in the room, get settled
8:30	Orientation to the Day - recap Day 1, review agenda ( <i>Jen Bayer</i> )
8:40	Confirming Needs & Matching to Existing Capacities: identify existing tools, resources and gaps ( <i>All</i> )
10:00	Break
10:15	Consideration of Human Infrastructure: Developing a community of practice focused on natural resource monitoring) ( <i>All</i> )
11:15	Idea Generation & Prioritization of Actions ( <i>All</i> )
12:15	Lunch
1:15	Action Planning - What's next for MonitoringResources.org? ( <i>All</i> )
2:30	Action Planning - Towards a national monitoring network? ( <i>All</i> )
3:30	Wrap Up
3:45	Adjourn



## Instructions for Workshop Exercises

### Day 1. 3:15 – 4:30 *“Your reaction: MonitoringResources.org. Discussion in small groups”*

We will break into 5 small groups of 5 or 6 people per group. We may need a volunteer note taker, who will capture notes in response to the questions below. We will have 45 minutes for discussion, and then reconvene as a whole for reporting out. Please ask a volunteer to report out a short summary in approximately 5 minutes.

1. If you're already using any of the tools provided by MonitoringResources.org, please consider the following questions:
  - Which tool(s) are you using already?
  - Briefly describe the application.
  - Is the tool sufficient as-is, or could it benefit from additional development or functionality?
2. If you're not using any of these tools, please consider the following questions:
  - Does the tool suite seem like it could be useful for your organization?
  - What additional information would you need before you decided to use one or more of these tools?
  - Are there tools or functions that MonitoringResources.org does not apparently provide but that would be useful to you?
  - Which tool(s) would you be most/least likely to use, and for what application? [Alternatively, what applications do you have that that could potentially benefit from the tools at MonitoringResources.org?]
  - Which of your existing programs or activities would benefit most from the tool or tools?
  - What issues might keep you from using the tools at MonitoringResources.org?
  - What issues/concerns might affect your willingness to share information with MonitoringResources.org?
3. Whether you're using MonitoringResources.org or not, please consider the following questions:
  - Do these tools overlap with tools you already have and use within your organization?
  - What tools are you currently using for:
    - Design support
    - Method documentation

- Map display (sites)
- Data visualization
- Metadata compliance
- Open data access compliance
- How can the tools provided by MonitoringResources.org better interface with tools you are already using?

**Day 2. 8:40 – 10:00 “Confirming Needs & Matching to Existing Capacities: identify existing tools, resources and gaps”**

For this agenda item, we will do small group discussion “café style”. There are stations for each topic below (5 total). You will have three rounds to visit stations – i.e. you will need to choose 3 of the 5 topics. At each station, you will be asked to help us begin to identify existing tools, resources and known gaps on the flip charts. Round 1 will be 20 minutes; Round 2 will be 15 minutes; and Round 3 will be 10 minutes. We will complete the exercise by reporting out from each station and asking for any additional information to be added (30 minutes).

1. Sampling Design
2. Protocols and methods
3. Project implementation
4. Data management (metadata & compliance)
5. Data delivery & visualization

**Day 2. 1:15 – 2:30 “What’s next for MonitoringResources.org?”**

- What are the major gaps (in terms of enterprise tools) we’ve not considered here today?
- Are you or any other organization developing tools/resources to fill the gaps, would you consider integrating the MonitoringResources.org tools into your development?
- Where should the MonitoringResources.org team focus their development efforts next?
  - Of the existing resources, which would you identify as the highest priority for further development?
  - Of the identified gaps, which could be filled by new MonitoringResources.org development?
- Can you suggest projects that might benefit from some aspect of MonitoringResources.org and would participate in a pilot integration?

- Would you be willing to participate in the development of a collaborative pilot project?
- Are there opportunities to interact with other federal monitoring activities not present here (LTER, LTAR, NEON, etc.) Which organizations should we work with next?
- Are there opportunities for this activity to support or draw from other national or international activities (e.g., IPBES, GEO-BON)? (Are there other international analogs to this activity?)
- Would you be willing to participate in a 'steering committee' to help define the future directions of MonitoringResources.org?

**Day 2. 2:30 – 3:30 “What’s next for human infrastructure?”**

- What are the next steps in terms of community development?
- Would you or your organization participate in a Community of Practice related to large-scale, long-term monitoring? What would you want to get out of it?
- Would you participate in a conference (e.g., panel session or presentations) in 2017 or beyond as a way to build community engagement?
- Would you be willing to participate in a 'steering committee' to help define the future directions of a national monitoring framework?

**Additional questions for this discussion**

- Who else not at this meeting would be interested in supporting either the human infrastructure or the enterprise tools?
- What other resources are available to communicate, conduct outreach, and garner support for this work?

## Supplemental Material 2. Weighted Priorities for MonitoringResources.org Development

**Table 2-1.** Weighted priorities for MonitoringResources.org development vetted by participants at the Developing Enterprise Tools and Capacities for Large-scale Natural Resource Monitoring: A Visioning Workshop

MonitoringResources.org Development Ideas	Weighted Priority
Build out <a href="https://www.monitoringresources.org">MonitoringResources.org</a> map and query tool to support data discovery showing, who is working on where and what and how they are monitoring?	23
Fully functional RESTful API that allows us to write software from the system that does not use our web application.	13
Create a <a href="https://www.monitoringresources.org">MonitoringResources.org</a> business plan to describe the proposed build out and the expectations of partners.	9
Support for versioning to track changes in protocols. Identify when protocols change enough to alter data and therefore alter inference.	9
Modify <a href="https://www.monitoringresources.org">MonitoringResources.org</a> to deliver and track master sample implementation.	7
Tools for developing quantitative objectives for monitoring. Would include standards for temporal, spatial and response.	8
Develop and promote the use of standardized sample frame, to create coordination across subject matters.	5
Tools support the production and maintenance of data dictionary across subject matters.	3
Place for the design and general structure, protocols, and can be stored and accessible to other references and to meet the data requirements the world is imposing on us. And a place to put that data.	4
Improve <a href="https://www.monitoringresources.org">MonitoringResources.org</a> an authoritative source of protocols. Create a way to crosswalk methods and protocols.	2

Build <a href="https://MonitoringResources.org">MonitoringResources.org</a> to harvest information from the data sources and build tools to summarize data for discovery. Allow users to query by protocol, so users can summarize information based on all projects implementing protocols.	2
Create a national composite view to connect who is doing, what, where, when and how and put that into spatial context with what others are doing. Build in querying tool to support discovery of information.	2
Outreach on <a href="https://MonitoringResources.org">MonitoringResources.org</a> to improve awareness, for example could do a roadshow to the science centers.	3
In <a href="https://MonitoringResources.org">MonitoringResources.org</a> add additional options for spatially balanced designs within the tool, currently only support GRTS.	1
Improvements to <a href="https://MonitoringResources.org">MonitoringResources.org</a> tools to support use of past designs in conjunction with use of current master sample.	1
Monitoring the conservation estate at a coarse scale (changes to land use patterns and how that will affect ecological process).	0
Process for partners to come, review, and comment on schemas for protocols.	0
<a href="https://MonitoringResources.org">MonitoringResources.org</a> to facilitate between the US Army Corps and the states so that we can learn from the habitat rehabilitation projects being done. Facilitate the gathering of information off old hard drives.	0
Tool to coordinate performance indicators and standards for indicators (reporting and visualization).	0
In <a href="https://MonitoringResources.org">MonitoringResources.org</a> eliminate the limitations on dealing with really large master samples, point limitations and attributing master samples.	0
Provide an infrastructure where feds can cross and share metadata across feds and not feds (communication/collaboration).	0
In <a href="https://MonitoringResources.org">MonitoringResources.org</a> Provide a way to draw a polygon on a map and find out who is monitoring there, which feds are doing what, where and when.	0
Reference library to tell us about RFPs or tool library, ways to grab lessons learned (Centralized resources for discovering).	0
A crosswalk of language between organizations. Ontology of definitions.	0
Clear linkages to the data repositories and the scheme for the data.	0

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## Supplemental Material 3. Identification of Existing Tools and Gaps

**Table 3-1.** Existing Sample Design Tools and Resources identified by workshop participants.

Tool/Resources	Additional Information
GRTS Design	Generalized Random Tessellation Stratified (GRTS) is an approach for drawing spatial samples. GRTS is a form of spatially-balanced sampling that is a probability design and supports design-based inferences to the entire area, and also is approximately spatially-balanced, so that no points in the target population are too far from a sampled point, and few sampled points are close together.
GIS	A geographic information system (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data
ArcGIS Sample Design Tools	The Sampling Design Tool for ArcGIS 10.0 provides a means to effectively develop sampling strategies. The tool was produced as part of an iterative process of sampling design development, whereby existing data informs new design decisions. ( <a href="http://www.arcgis.com/home/item.html?id=ecbe1fc44f35465f9dea42ef9b63e785">http://www.arcgis.com/home/item.html?id=ecbe1fc44f35465f9dea42ef9b63e785</a> )
EPA Tools	EPA host resources to support users in selecting a Sample Design ( <a href="https://www.epa.gov/quality/selecting-sampling-design">https://www.epa.gov/quality/selecting-sampling-design</a> )
MonitoringResources.org Sample Design Tool	MonitoringResources.org Sample Design tool walks a user through documenting and selecting sites. MonitoringResources.org supports two types of designs the GRTS designs and opportunistic. ( <a href="https://www.monitoringresources.org/Designer/Design/Index">https://www.monitoringresources.org/Designer/Design/Index</a> )
MonitoringResources.org Master Sample Library	MonitoringResources.org stores master samples and associated metadata to be used in the Sample Design tool. The Sample Design tool supports users in defining sample frames, stratifying sites and selecting sites from the master sample by applying the GRTS algorithm. ( <a href="https://www.monitoringresources.org/Sites/Master/Index">https://www.monitoringresources.org/Sites/Master/Index</a> )

R	R is a language and environment for statistical computing and graphics. There are multiple packages that support designing monitoring. ( <a href="https://www.r-project.org/">https://www.r-project.org/</a> )
R Shiny (GRTS app)	A web application framework for R which turns your analyses into interactive web applications. ( <a href="https://shiny.rstudio.com/">https://shiny.rstudio.com/</a> )
National Park Service (NPS) GRTS Design Guidance	Guidance including R packages developed by the NPS to support GRTS design ( <a href="https://science.nature.nps.gov/im/datamgmt/statistics/r/advanced/grts.cfm">https://science.nature.nps.gov/im/datamgmt/statistics/r/advanced/grts.cfm</a> )
RSP Survey Package	R functions to implements algorithms for design and analysis of probability surveys. The functions are tailored for Generalized Random Tessellation Stratified survey designs. ( <a href="https://www.rdocumentation.org/packages/spsurvey/versions/3.3">https://www.rdocumentation.org/packages/spsurvey/versions/3.3</a> )
Published Paper: Using GIS To Generate Spatially Balanced Random Survey Designs for Natural Resources Application	Theobald, David M., et al. "Using GIS to generate spatially balanced random survey designs for natural resource applications." Environmental Management 40.1 (2007): 134-146
Upper Mississippi River Restoration Program: Sample Design Tools	The mission of the Upper Mississippi River Restoration Program Long Term Resources Monitoring (LTRM) is to support decision makers with the information and understanding needed to maintain the Upper Mississippi River System as a viable multiple-use river ecosystem. LTRM website curates sample designs for the LTRM program. ( <a href="https://www.umesc.usgs.gov/ltrmp/stats/statistics.html">https://www.umesc.usgs.gov/ltrmp/stats/statistics.html</a> )
Visual Sample Plan (VSP)	VSP is a software tool that supports the development of a defensible sampling plan based on statistical sampling theory and the statistical analysis of sample results to support confident decision making. ( <a href="http://vsp.pnnl.gov/">http://vsp.pnnl.gov/</a> )

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**Table 3-2.** Gaps identified in Sample Design tools and resources identified by workshop participants.

Gaps in Tool/Resources	Additional Information
Trainings for monitoring practitioners	Face to face or web trainings to support monitoring practitioners creating sample designs.
Promote, share and refine the STRIDE process/framework	Promote, share and refine the STRIDE (Spatial, Temporal, Response and Inference) design principals outlined in the Salmon Monitoring Advisor.
Identify elements common to all design types	Facilitate the identification of common elements of designs to support the building of tools to span across multiple design types and subject matter experts.
Promote the North American Bat (NABat) Monitoring Program process as an example	Promote NABat as an example of building an integrated sample design across large spatial scales.
Provide best practices for the field biologist, with the resources to select sites	Work to provide resources, best practices and guidance similar to the DOI Adaptive Management handbook. Create a standard best practices documentation that can be applied to multiple subject matters.
Tools to track the implementation of the design across the landscape "The realized design"	Build tools to track the implementation of a design. <a href="https://www.monitoringresources.org">MonitoringResources.org</a> supports building of designs, but needs improvements to the tracking and implementation of the design. Include a standard language (drop downs) for recording information on implementation of sample designs, but also have the ability to fill in a long comment.
Improvements to <a href="https://www.monitoringresources.org">MonitoringResources.org</a> tools for documenting designs	Add additional metadata documentation to <a href="https://www.monitoringresources.org">MonitoringResources.org</a> tools to support the documentation and sharing of GIS layers, code and additional attributes related to the sample design.
Expand <a href="https://www.monitoringresources.org">MonitoringResources.org</a> 's support for existing designs	<a href="https://www.monitoringresources.org">MonitoringResources.org</a> supports the creation of new designs, <a href="https://www.monitoringresources.org">MonitoringResources.org</a> does not have the tools to import designs that were created in another user interface, such as R.
Expand <a href="https://www.monitoringresources.org">MonitoringResources.org</a> 's capacity for data discovery	<a href="https://www.monitoringresources.org">MonitoringResources.org</a> can do more to support data discovery associated with designs and support tools to integrated designs.



Use [MonitoringResources.org](https://MonitoringResources.org) to share information.

Update to [MonitoringResources.org](https://MonitoringResources.org) Master Sample Attribute Update tool

Expand [MonitoringResources.org](https://MonitoringResources.org) to add version control for design changes

Expand [MonitoringResources.org](https://MonitoringResources.org) to support other types of designs (i.e. Effectiveness Design)

Use [MonitoringResources.org](https://MonitoringResources.org) to share the best practices for creating sample designs.

Improvements to the [MonitoringResources.org](https://MonitoringResources.org) tools to support users adding attributes to existing Master Samples stored in the [MonitoringResources.org](https://MonitoringResources.org) Master Sample Library

Add functionality to [MonitoringResources.org](https://MonitoringResources.org) to track versions, so that changes through time can be documented.

Build tools into [MonitoringResources.org](https://MonitoringResources.org) including tools to implement and track different design types, such as support for effectiveness designs, MBACI etc.

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**Table 3-3.** Existing methods and protocols tools and resources identified by workshop participants.

<b>Tool/Resources</b>	<b>Additional Information</b>
Published National Ecological Observatory Network (NEON) protocols	NEON has published protocols are stored at: <a href="http://www.data.Neonscience.org">www.data.Neonscience.org</a>
Forest Inventory and Analysis (FIA) Program of the U.S. Forest Service (USFS) protocols	FIA is a USFS project providing the information needed to assess America's forests. Protocols and methods can be found at: <a href="http://www.fia.fs.fed.us/">www.fia.fs.fed.us/</a>
Assessment, Inventory, and Monitoring (AIM) and National Resources Inventory (NRI) Methods and Protocols	Bureau of Land Management (BLM) and Natural Resources Conservation Service (NRCS) published methods and protocols for sampling can be found at <a href="http://aim.landscapetoolbox.org/data-collection/field-sampling/">http://aim.landscapetoolbox.org/data-collection/field-sampling/</a>
Published Paper: Detailing the selection of methods	Toeve, Gordon R., et al. "Consistent indicators and methods and a scalable sample design to meet assessment, inventory, and monitoring information needs across scales." <i>Rangelands</i> 33.4 (2011): 14-20.
Published Manual: Grassland, Shrubland and Savanna Ecosystems Monitoring published by the Jornada Research Station	Zhang, Chunhua. "Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems." <i>Environments</i> 35.2 (2007): 100-102. ( <a href="https://jornada.nmsu.edu/">https://jornada.nmsu.edu/</a> )
National Environmental Methods Index (NEMI)	NEMI is a searchable database that allows scientists and managers to find and compare analytical and field methods for all phases of environmental monitoring. ( <a href="https://www.nemi.gov/home/">https://www.nemi.gov/home/</a> )
Published Handbook: Describing monitoring plant and animal populations	Elzinga, C. L. Salzer, D. W. Willoughby, J. W. and Gibbs, J. P. "Monitoring plant and animal populations: a handbook for field biologists." John Wiley & Sons, 2009.
Published Paper: National Park documentation of vital signs monitoring	Davis, Gary E. "National Park stewardship and 'vital signs' monitoring: a case study from Channel Islands National Park, California." <i>Aquatic Conservation: Marine and Freshwater Ecosystems</i> 15.1 (2005): 71-89.

Bio Data	The U.S. Geological Survey (USGS) BioData Retrieval system provides access to aquatic bioassessment data (biological community and physical habitat data) collected by USGS scientists from stream ecosystems across the nation. USGS scientists collect fish-, aquatic macroinvertebrate-, and algae-community samples and conduct stream physical habitat surveys as part of its fundamental mission to describe and understand the Earth. ( <a href="https://aquatic.biodata.usgs.gov/landing.action">https://aquatic.biodata.usgs.gov/landing.action</a> )
Published Methods: Terrestrial vegetation monitoring	Bonham, Charles D. "Measurements for terrestrial vegetation." John Wiley & Sons, 2013.
Washington Department Fish and Wildlife (WDFW) ecological integrity assessments: Monitoring and Evaluation of Wildlife Areas in Washington (Draft)	The Washington Department of Fish and Wildlife (WDFW) serves Washington's citizens by protecting, restoring, and enhancing fish and wildlife on private and public lands, such as those supported by the Bonneville Power Administration (BPA). In order to make informed management decisions aimed at maintaining or protecting ecological integrity, credible data on how human activities affect the chemical, physical, and biological integrity of ecological systems needs to be collected (USEPA 2002) ( <a href="http://wdfw.wa.gov/publications/01314/">http://wdfw.wa.gov/publications/01314/</a> )
NatureServe online data system	The NatureServe Network empowers people to sustain biodiversity by making sure everyone has access to the knowledge they need to be better stewards of our shared lands and waters. NatureServe is an authoritative source of comprehensive, decision-quality biodiversity data. ( <a href="http://www.natureserve.org/">http://www.natureserve.org/</a> )
Published Methods: BLM and USFS published sampling vegetation methods	The intent of this interagency monitoring guide is to provide the basis for consistent, uniform, and standard vegetation attribute sampling that is economical, repeatable, statistically reliable, and technically adequate. ( <a href="https://www.blm.gov/nstc/library/pdf/samplveg.pdf">https://www.blm.gov/nstc/library/pdf/samplveg.pdf</a> )
BLM and USFS utilization studies and residual measurements	The intent of this interagency monitoring guide is to provide the basis for consistent, uniform, and standard utilization studies and residual measurements that are economical, repeatable, statistically reliable, and technically adequate. ( <a href="https://www.blm.gov/nstc/library/pdf/utilstudies.pdf">https://www.blm.gov/nstc/library/pdf/utilstudies.pdf</a> )
USGS and EPA have many standard protocols and methods	No specific example
The Landscape Toolbox	The Landscape Toolbox is a coordinated system of tools and methods for implementing land health monitoring and integrating monitoring data into management decision-making. ( <a href="http://www.landscapetoolbox.org/">http://www.landscapetoolbox.org/</a> )

<p>Fire Ecology Assessment Tool (FEAT) and Fire Effects Monitoring and Inventory Protocol (Firemon) Tools Idaho Department Fish and Game (IDFG) Multi-Species Baseline Initiative (MBI)</p>	<p>FFI (FEAT/FIREMON Integrated) is an interagency plot-level monitoring software application designed to assist managers with collection, storage, and analysis of ecological information. (<a href="https://www.frames.gov/partner-sites/ffi/ffi-home/">https://www.frames.gov/partner-sites/ffi/ffi-home/</a>) The Multi-Species Baseline Initiative (MBI) is a collaboration of organizations that monitor wildlife and microclimate across the Idaho Panhandle and adjoining mountain ranges (<a href="https://idfg.idaho.gov/baseline">https://idfg.idaho.gov/baseline</a>)</p>
<p>Multi-Agency Rocky Intertidal Network (MARINE) Sampling Partnership</p>	<p>MARINE is a partnership of agencies, universities, and private groups committed to determining the health of the rocky intertidal habitat and providing this information to the public. The MARINE Monitoring Protocol Handbook details the standardized core protocols used by survey teams at over 100 established core sites across the Pacific Coast and New England. (<a href="https://www.marine.gov/index.htm">https://www.marine.gov/index.htm</a>)</p>
<p>Published Methods and Protocols: Colorado Park &amp; Fish and Wildlife invasive species documentation</p>	<p>Protocols and methods published by Colorado Park and Wildlife can be found at: <a href="http://cpw.state.co.us/aboutus/Pages/Invasive-Species-Program.aspx">http://cpw.state.co.us/aboutus/Pages/Invasive-Species-Program.aspx</a></p>
<p>Avian Knowledge Networks (AKN) Tools</p>	<p>The Avian Knowledge Network (AKN) is a partnership of people, institutions and government agencies supporting the conservation of birds and their habitats based on data, the adaptive management paradigm, and the best available science. The AKN provides tools, methods, protocols for sampling. (<a href="http://www.avianknowledge.net/index.php?page=home">http://www.avianknowledge.net/index.php?page=home</a>)</p>
<p>Bird Conservancy of the Rockies</p>	<p>Bird Conservancy of the Rockies conserves birds and their habitats through an integrated approach of science, education and land stewardship. The Bird Conservancy offers protocols, methods to monitor birds (<a href="http://www.birdconservancy.org">www.birdconservancy.org</a>)</p>
<p>Existing mapping and technical protocols</p>	<p>No specific example, but there are many existing mapping protocols.</p>

Upper Mississippi River Restoration  
Program: Methods

The mission of the Upper Mississippi River Restoration Program Long Term Resources Monitoring (LTRM) is to support decision makers with the information and understanding needed to maintain the Upper Mississippi River System as a viable multiple-use river ecosystem. LTRM curates multiple data collection protocols on their website.

([https://www.umesc.usgs.gov/reports\\_publications/ltrmp/fish/fish\\_methods.html](https://www.umesc.usgs.gov/reports_publications/ltrmp/fish/fish_methods.html))

The Integrated Resources Management  
Application (IMRA) Portal

The Integrated Resource Management Applications (IRMA) Portal provides easy access to National Park Service applications that manage and deliver resource information to parks, partners and the public. (<https://irma.nps.gov/Portal>)

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**Table 3-4.** Gaps identified in methods and protocol tools and resources identified by workshop participants.

<b>Gaps in Tool/Resources</b>	<b>Additional Information</b>
Leadership towards consolidation of protocols	There are many protocols that can be applied to collect monitoring data. Monitoring practitioners need leadership towards consolidation of protocols.
Best practices on selecting methods and assessing uncertainty in methodology	There are many methods for monitoring. Monitoring practitioners need guidance on how to select the correct method for achieving the study objectives. Guidance needs to be developed for assessing the uncertainty associated with a method.
Clearinghouse of the tradeoff of using different protocols	To select protocols users need to understand the cost and benefits of each approach. To learn from others experiences a central documentation of the tradeoffs needs to be created.
Guidelines on methods selections	Develop guidelines on methods selection based on resources available such as staff, time, equipment, etc.
Best practices for selecting indicators and methods based on objectives	Designing a monitoring program is difficult, monitoring practitioners often know their objectives, but can be uncertain how to select indicators and methods to achieve those objectives. Provide monitoring practitioners tools to select methods and indicators based on objectives. Include citation, list of users of the method, publication information, and organizations applying that methodology.
Versioning of methods	Flag changes to methods. Flag when large enough changes to data collection and analysis are made to alter the data results, "glue" the documentation on to the data.
Landscape scale discovery tool	Tools to support discovery of methods applied based on the area of inference.
Facilitation of regional monitoring efforts	Bring regional monitoring efforts together to discuss application of methods, design, implementation and analysis.
Documentation of uncertainty associated with methodology	Develop tools to document variance associated with methodology. Also provide tools to document how variance is calculated.

**Table 3-5.** Existing project implementation tools and resources identified by workshop participants.

<b>Tool/Resources</b>	<b>Additional Information</b>
General Standard Operating Procedures	A standard operating procedure, or SOP, is a set of step-by-step instructions compiled by an organization to help workers carry out routine operations. SOPs aim to achieve efficiency, quality output and uniformity of performance, while reducing miscommunication and failure to comply with industry regulations.
National Park Services (NPS) Standard Operating Procedures	The NPS has a set of standard operating procedures for implementing sampling.
General communication with partners	Traditionally projects are implemented by consistent communication between partners, using emails, phone calls, face to face meetings, etc.
Land Treatment Digital Library (LTDL)	The Land Treatment Digital Library (LTDL) was created by the U.S. Geological Survey to catalog legacy land treatment information on Bureau of Land Management lands in the Western United States. The LTDL can be used by federal managers and scientists for compiling information for data-calls, producing maps, generating reports, and conducting analyses at varying spatial and temporal scales. The LTDL currently houses 34,433 treatments from BLM lands across 14 states. ( <a href="https://ltdl.wr.usgs.gov/">https://ltdl.wr.usgs.gov/</a> )
The Landscape Toolbox	The Landscape Toolbox is a coordinated system of tools and methods for implementing land health monitoring and integrating monitoring data into management decision-making. ( <a href="http://www.landscapetoolbox.org/">http://www.landscapetoolbox.org/</a> )
National Ecological Observation Network (NEON) SOPs for data	NEON’s Standard Operating Procedures (SOP) allow for data and metadata to be flagged if there is a variation from the protocol during sampling.
National Ecological Observatory Network (NEON) protocols contingency plans	NEON has built in contingencies plans so when sample conditions warrant a change in protocol there are specific guidelines/contingencies for staff to follow.
Established peer review of the sample implementation process	Often when implementing sampling, sample plans peer reviewed. Consult subject matter experts to determine the most effective data collection process.

**Table 3-6.** Gaps identified in project implementation tools and resources identified by workshop participants.

Gaps in Tool/Resources	Additional Information
Ways to Document alteration of protocols during data collection	Process for documenting diversions from the protocol. Clear annotations of when and why diversions from the protocol occurred. Ability to easily document variations and links back to original protocol. Make variations easily visible in the data display
Quality Assurance and Quality Control "gold standard" vs what you can afford	Documented best practice for data QA/QC and the acceptable alternative when funding is unpredictable.
Defined process for building mobile device data collection	Best practices for the creation of mobile data collection devices. Provide information to understand the basics of what type of data is to be collected and the options available for creating that system.
Definition of protocols and projects	Promoting a clear and established definition of projects, procedures, protocols, standard operation procedures, and methods.
Mechanisms for communication with partners	Best practices and tools for communication with many partners at a national scale (Example: NABat).
Training	Improved access to trainings for protocol implementation. For example post training on YouTube, have centralized field trainings, etc.
Track data's external dependencies	Provide ways to track data dependency on external data and connections between data.
Real time project tracking	Displayed and accessible to data as soon as it has been uploaded.
Tracking sample design implantation	A way to share and track what sites are proposed to be sampled and if the sites were sampled (planned vs. actual)
Establish standard language	Establish a standardize language to describe changes in data that would alter analysis, so it is easier to determine what qualifies as a change. Provide a process for annotating this information in the data.



**Table 3-7.** Existing data management tools and resources identified by workshop participants.

Tool/Resources	Additional Information
Department of the Interior (DOI) Metadata Standard	The DOI has a metadata standard scientists can use to publish information about a datasets. ( <a href="https://www2.usgs.gov/datamanagement/describe/metadata.php">https://www2.usgs.gov/datamanagement/describe/metadata.php</a> )
Federal Geographic Data Committee (FGDC) spatial data compliance	The Federal Geographic Data Committee (FGDC) is an organized structure of Federal geospatial professionals and constituents that provide executive, managerial, and advisory direction and oversight for geospatial decisions and initiatives across the Federal government. ( <a href="https://www.fgdc.gov/">https://www.fgdc.gov/</a> )
Geospatial metadata validation service	Federal Geographic Data Committee provides list of Geospatial Metadata tools. ( <a href="https://www.fgdc.gov/metadata/geospatial-metadata-tools">https://www.fgdc.gov/metadata/geospatial-metadata-tools</a> )
Privacy laws on location data	There are privacy laws related to location data and personally identifiable information (PII).
Service Catalog (ServCat)	Service Catalog or ServCat - a Web application available to Fish and Wildlife Service employees that compiles documents and organizes data, such as reports, surveys, databases, geospatial data and images. ( <a href="http://www.fws.gov/Refuges/NaturalResourcePC/landM/serviceCatalog.html">www.fws.gov/Refuges/NaturalResourcePC/landM/serviceCatalog.html</a> )
DataStore	Google Cloud Platform “Cloud DataStore” is a highly-scalable NoSQL database for your web and mobile applications. ( <a href="https://cloud.google.com/datastore/">https://cloud.google.com/datastore/</a> )
National Park Service (NPS) protocol tracker	The Integrated Resource Management Applications (IRMA) Portal provides easy access to National Park Service applications that manage and deliver resource information to parks, partners and the public. ( <a href="https://irma.nps.gov/Portal">https://irma.nps.gov/Portal</a> )
National Park Service (NPS) Natural Resources Database Template (NRDT)	The National Park Service Inventory and Monitoring (I&M) Program's Natural Resource Database Template (NRDT) is a set of Microsoft Access relational database tables that parks and networks can use to develop applications for capturing natural resource inventory and monitoring data. ( <a href="http://science.nature.nps.gov/im/datamgmt/applications/template/">http://science.nature.nps.gov/im/datamgmt/applications/template/</a> )
National Park Service (NPS) Data Management Resources and Tools	The National Park Service (NPS) Inventory and Monitoring (I&M) Programs Data Management tools are a set of tools that manage and support data management. ( <a href="http://science.nature.nps.gov/im/datamgmt/dmtools.cfm">http://science.nature.nps.gov/im/datamgmt/dmtools.cfm</a> )

National Park Service (NPS) Inventory and Monitoring (I&M) Database Metadata Extractor	The National Park Service Inventory and Monitoring (I&M) Programs Data Management tools to support Metadata creation. ( <a href="http://science.nature.nps.gov/im/gis/metadata.cfm">http://science.nature.nps.gov/im/gis/metadata.cfm</a> )
MonitoringResources.org	<a href="https://www.monitoringresources.org/">MonitoringResources.org</a> is a suite of online tools designed to support documentation of Methods, Protocols, and Study Designs. <a href="https://www.monitoringresources.org/">MonitoringResources.org</a> provides tools to support reporting and metadata file creation. ( <a href="https://www.monitoringresources.org/">https://www.monitoringresources.org/</a> )
DataCite	Locate, identify, and cite research data with the leading global provider of DOIs for research data. ( <a href="https://www.datacite.org/">https://www.datacite.org/</a> )
Registry of Research Data Repositories (RE3 Data)	<a href="http://www.re3data.org/">Re3data.org</a> is a global registry of research data repositories that covers research data repositories from different academic disciplines. It presents repositories for the permanent storage and access of data sets to researchers, funding bodies, publishers, and scholarly institutions. <a href="http://www.re3data.org/">Re3data.org</a> promotes a culture of sharing, increased access, and better visibility of research data. ( <a href="http://www.re3data.org/">http://www.re3data.org/</a> )
Data Basins	Data Basin is a science-based mapping and analysis platform that supports learning, research, and sustainable environmental stewardship. ( <a href="https://databasin.org/">https://databasin.org/</a> )
Landscape Conservation Cooperatives (LCC) Metadata Editor	The Arctic LCC has developed a Project Tracking System (PTS) to electronically manage the metadata and data associated with projects. The PTS is used to track projects throughout all stages of development, from receipt of proposals through delivery of final products. ( <a href="https://lccnetwork.org/project/arctic-lcc-project-tracking-system">https://lccnetwork.org/project/arctic-lcc-project-tracking-system</a> )
Online Metadata Editor (OME)	Online Metadata Editor (OME) -This tool will ask you simple, jargon-free questions about your dataset and produce a standardized metadata record. ( <a href="https://www1.usgs.gov/csas/ome/">https://www1.usgs.gov/csas/ome/</a> )
Science Data Catalog	The USGS Science Data Catalog provides seamless access to USGS research and monitoring data from across the nation. Users have the ability to search, browse, or navigate a map-based interface to discover data. ( <a href="http://data.usgs.gov/datacatalog/">http://data.usgs.gov/datacatalog/</a> )
U.S. Geological Survey (USGS) Metadata Workbench	The Data Release Workbench familiarizes you with the necessary elements for USGS data release and provide some tools to help you. The checklist is simply that - a checklist. It is intended only for you to track your progress. ( <a href="https://data.usgs.gov/datarelease/pages/login">https://data.usgs.gov/datarelease/pages/login</a> )

U.S. Geological Survey (USGS)  
Data Management Support

The USGS Data Management Web site contains various resources, such as handouts, dictionaries, and the Data Management Association (DAMA) “Data Management Body of Knowledge”, and DAMA Dictionary. The USGS Data Management Resources page contains links to all of these items, located all in one place for easy access. (<https://www2.usgs.gov/datamanagement/training.php>)

Metadata Wizard

The Metadata Wizard is a fully functional ArcGIS Toolbox that allows for streamlined FGDC-CSDGM metadata creation and editing for geospatial professionals working in the ESRI software environment. (<https://www.sciencebase.gov/catalog/item/5227a570e4b0767cef419fb8>)

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**Table 3-8.** Gaps identified in data management tools identified by workshop participants.

<b>Gaps in Tool/Resources</b>	<b>Additional Information</b>
Define how users comply to metadata standard	Define and share what level of compliance to metadata is required for particular entity.
Automated Quality Assurance and Quality Control	Automatic quality assurance and quality control of data systems.
Sample design metadata documentation standards	Documentation standards for Sample Design Metadata
Improve modularity of methods in Service Catalog (ServCat)	Service Catalog or ServCat - a Web application available to Fish and Wildlife Service employees that compiles documents and organizes data, such as reports, surveys, databases, geospatial data, and images. ServCat could improve data management by improving modularity of methods. ( <a href="http://www.fws.gov/Refuges/NaturalResourcePC/landM/serviceCatalog.html">www.fws.gov/Refuges/NaturalResourcePC/landM/serviceCatalog.html</a> )
<a href="http://MonitoringResources.org">MonitoringResources.org</a> improve reporting tools	Improvements to <a href="http://MonitoringResources.org">MonitoringResources.org</a> support for post season reporting.
<a href="http://MonitoringResources.org">MonitoringResources.org</a> alignment with open data requirements	Align <a href="http://MonitoringResources.org">MonitoringResources.org</a> capability with USGS open source data requirements.
Common registries with persistent resources	Centralized, accessible consistent list of data registries with long-term resource identifiers. (i.e. Digital Object Identifiers).
Understanding of other agencies solutions to data management	Provide resources to understand data management solutions being applied by other large agencies such as NOAA and NASA.

**Table 3-9.** Existing data delivery and visualization tools and resources identified by workshop participants.

Tool/Resources	Additional Information
National Park Service (NPS) Water Quality Visualizer	The National Park Services provides a Water Quality Visualizer. This visualizer presents the results of long-term monitoring of streams in National Capital Region Network (NCRN) parks. It displays in graph format NCRN water monitoring data from 2005 through 2014. New data will continue to be added as it is collected. ( <a href="http://science.nature.nps.gov/im/units/ncrn/monitor/water_quality/visualizer.cfm">http://science.nature.nps.gov/im/units/ncrn/monitor/water_quality/visualizer.cfm</a> )
Natural Resource Publications Management (NRPM)	The National Park Services provide a website with information about the Natural Resource Reports (NRR), Natural Resource Data Series (NRDS), and the legacy Natural Resource Technical Reports (NRTR) report series. ( <a href="http://www.nature.nps.gov/publications/NRPM/#nrtr">http://www.nature.nps.gov/publications/NRPM/#nrtr</a> )
Integration of Resource Management Applications (IRMA)	The Integrated Resource Management Applications (IRMA) Portal provides easy access to National Park Service applications that manage and deliver resource information to parks, partners, and the public. IRMA is a portfolio of tools and applications, and the beginnings of a "one-stop" for data and information on park-related resources. ( <a href="http://science.nature.nps.gov/im/datamgmt/IRMA.cfm">http://science.nature.nps.gov/im/datamgmt/IRMA.cfm</a> )
Integrated Resources Management Portal (IRMP)	This site provides information about the Natural Resource Reports (NRR), Natural Resource Data Series (NRDS), and the legacy Natural Resource Technical Reports (NRTR) report series. ( <a href="https://irma.nps.gov/Portal">https://irma.nps.gov/Portal</a> )
StoryMaps	ESRI Story Maps let you combine authoritative maps with narrative text, images, and multimedia content. They make it easy to harness the power of maps and geography to tell your story. ( <a href="https://storymaps.arcgis.com/en/how-to/">https://storymaps.arcgis.com/en/how-to/</a> )
.csv files	A CSV is a comma separated values file which allows data to be saved in a table structured format.
.xls	XLS is a file extension for a spreadsheet file format created by Microsoft for use with Microsoft Excel.
.kml	KML is a file format used to display geographic data in an Earth browser such as Google Earth. KML uses a tag-based structure with nested elements and attributes and is based on the XML standard. ( <a href="https://developers.google.com/kml/documentation/kml_tut">https://developers.google.com/kml/documentation/kml_tut</a> )

ArcGIS	ArcGIS is a geographic information system (GIS) for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database. ( <a href="https://www.arcgis.com/home/index.html">https://www.arcgis.com/home/index.html</a> )
ArcMap	Use ArcMap, ArcCatalog, ArcGlobe, or ArcScene, to create maps, perform spatial analysis, manage geographic data, and share your results. ( <a href="http://desktop.arcgis.com/en/arcmap/">http://desktop.arcgis.com/en/arcmap/</a> )
Open layers	Open sources GIS data layers.
Portable Network Graphics (PNG)	Portable Network Graphics (PNG) is a raster graphics file format that supports lossless data compression.
Darwin Core	The Darwin Core is a body of standards. It includes a glossary of terms (in other contexts these might be called properties, elements, fields, columns, attributes, or concepts) intended to facilitate the sharing of information about biological diversity by providing reference definitions, examples, and commentaries. ( <a href="http://rs.tdwg.org/dwc/">http://rs.tdwg.org/dwc/</a> )
EnviroAtlas	EnviroAtlas provides interactive resources for exploring the benefits people receive from nature or "ecosystem goods and services" (EGS). EGS are critically important to human health and well-being, but they are often overlooked. EnviroAtlas allows users to access, view, and analyze diverse information to better understand the potential impacts of various decisions. ( <a href="https://www.epa.gov/enviroatlas">https://www.epa.gov/enviroatlas</a> )
Schema.org	Schema.org is a collaborative, community activity with a mission to create, maintain, and promote schemas for structured data on the Internet, on web pages, in email messages, and beyond. ( <a href="http://schema.org/">http://schema.org/</a> )
Secure File Transfer Protocol (FTP)	The File Transfer Protocol (FTP) standard process for the transfer of files between client and server computers.
Data Basin	Data Basin is a science-based mapping and analysis platform that supports learning, research, and sustainable environmental stewardship. ( <a href="https://databasin.org/">https://databasin.org/</a> )
Reports/ Manuscripts	Data and information are often delivered in reports, manuscripts and peer review papers.
Figshare	Figshare is an online digital repository where researchers can preserve and share their research outputs, including figures, datasets, images, and videos. It is free to upload content and free to access, in adherence to the principle of open data. ( <a href="https://figshare.com">https://figshare.com</a> )

SEAD DataNet	SEAD offers data management, curation, and publication services to researchers that require reliable cyberinfrastructure and an enhanced ability to manage, integrate, interpret, share, curate, and preserve data. SEAD's web-based data services are powerful, user-friendly, and tailored to the requirements of smaller projects. ( <a href="http://sead-data.net/about/">http://sead-data.net/about/</a> )
Custom websites	Specific programs build websites to deliver information. Example: Breeding bird survey
GIT hub	GitHub is a development platform inspired by the way you work. From open source to business, you can host and review code, manage projects, and build software alongside millions of other developers. ( <a href="https://github.com/">https://github.com/</a> )
Jupyter	The Jupyter Notebook is a web application that allows you to create and share documents that contain live code, equations, visualizations and explanatory text. Uses include: data cleaning and transformation, numerical simulation, statistical modeling, machine learning, and much more. ( <a href="http://jupyter.org/">http://jupyter.org/</a> )
Tableau	Tableau can help anyone see and understand their data. Connect to almost any database, drag and drop to create visualizations, and share with a click. ( <a href="http://www.tableau.com/">www.tableau.com/</a> )
U.S. Geological Survey (USGS) Biodiversity Information Serving Our Nation (BISON)	USGS Biodiversity Information Serving Our Nation (BISON) is a unique, web-based Federal mapping resource for species occurrence data in the United States and its Territories. Researchers collect species occurrence data and records of an organism at a particular time in a particular place, as a primary or ancillary function of many biological field investigations. ( <a href="https://bison.usgs.gov/">https://bison.usgs.gov/</a> )
Environmental Protection Agency (EPA) Exchange Network	The Environmental Information Exchange Network (EIEN) is an Internet-based system used by state, tribal, and territorial partners to securely share environmental and health information with one another and the EPA. ( <a href="https://www.epa.gov/exchangenetwork">https://www.epa.gov/exchangenetwork</a> )
U.S. Geological Survey (USGS) ScienceBase	ScienceBase is an Open Source project that provides current documentation about its structure, information model, services, directory, and repository. The wiki provides guidance for using services to interact with the Science API, including JSON examples. Links to examples showing use of ScienceBase services are also provided. ( <a href="https://www.sciencebase.gov/catalog/">https://www.sciencebase.gov/catalog/</a> )

Leaflet	An open-sources JavaScript library for mobile-friendly interactive maps. ( <a href="http://leafletjs.com/">http://leafletjs.com/</a> )
Bureau of Land Management (BLM) Landscape Data Portal	The Assessment, Inventory, and Monitoring (AIM) Strategy implements standard data collection and storage so that information is readily accessed, aggregated, and shared. This is accomplished through electronic, onsite data capture and centralized data management through BLM’s national geospatial infrastructure. ( <a href="http://aim.landscapetoolbox.org/data-management-project-evaluation/databases/">http://aim.landscapetoolbox.org/data-management-project-evaluation/databases/</a> )
National Ecological Observatory Network (NEON) - Analysis	NEON measures a diverse suite of biological, physical, chemical, and ecological characteristics at field sites across the continent. NEON data are sent to headquarters after site construction is complete and data collection begins. The Observatory processes these measurements to derive standard, quality-assured data products that support greater understanding of complex ecological processes at local, regional, and continental scales. Available NEON data, supporting metadata, science designs, data collection documentation, and data processing documentation are accessible through the NEON Data Portal. ( <a href="http://data.neonscience.org/home">http://data.neonscience.org/home</a> )
Integrated Ocean Observing System (IOOS)	The Integrated Ocean Observing System (IOOS®) is a national-regional partnership working to provide new tools and forecasts to improve safety, enhance the economy, and protect our environment. Integrated ocean information is available in near real time, as well as retrospectively. Easier and better access to this information is improving our ability to understand and predict coastal events – such as storms, wave heights, and sea level change. Such knowledge is needed for everything from retail to development planning. ( <a href="https://ioos.noaa.gov/data/contribute-data/data-access-services/">https://ioos.noaa.gov/data/contribute-data/data-access-services/</a> )
Upper Mississippi River Restoration Program: Data Visualization Tools	The mission of the Upper Mississippi River Restoration Program Long Term Resources Monitoring (LTRM) is to support decision makers with the information and understanding needed to maintain the Upper Mississippi River System as a viable multiple-use river ecosystem. LTRM curates multiple data visualization tools. ( <a href="https://www.umesc.usgs.gov/data_library/tools/data_visualization_tools.html">https://www.umesc.usgs.gov/data_library/tools/data_visualization_tools.html</a> )
Apache Drill	Schema-free SQL Query Engine for Hadoop, NoSQL and Cloud Storage. ( <a href="https://drill.apache.org">https://drill.apache.org</a> )

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**Table 3-10.** Gaps identified in data delivery and visualization tools identified by workshop participants.

<b>Gaps in Tool/Resources</b>	<b>Additional Information</b>
Connection of data to metadata	Best practices, tools, and guidance for connecting data to metadata.
Tracking and sharing of implementation details	Support for documentation of implementation details. A system or way to describe how the realized sample differs from the sampling plan and how that difference could impact the data results.
Data Standards	Best practices, tools, and support for creating and using data standards.
Documentation of analysis methods	Tools for documentation, sharing and reuse of analysis methods
Data filters based on security and sensitivity of the data	Tools to filter and share data based on user roles, therefore creating tools to hide security data from certain users.
Tools to support integration of data from many portals	Best practices, tools, and support for integrating data from multiple different sources
Support for data curation	Cost effective best practices, tools, and support for curation of data over time.
Support for ontology development	Best practices, tools, and support for developing ontology related to monitoring data collection, analysis, and sharing.
Improved use of existing geospatial framework	Tools for sharing existing geospatial framework to allow for more reuse of existing geospatial framework.