# Grand Challenges for Integrated U.S. Geological Survey Science—A Workshop Report

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# Executive Summary

The U.S. Geological Survey (USGS) has a long history of advancing the traditional Earth science disciplines and identifying opportunities to integrate USGS science across disciplines to address complex societal problems. The USGS science strategy for 2007–2017 laid out key challenges in disciplinary and interdisciplinary arenas, culminating in a call for increased focus on a number of crosscutting science directions. Ten years on, to further the goal of integrated science and at the request of the Executive Leadership Team (ELT), a workshop with three dozen invited scientists spanning different disciplines and career stages in the Bureau convened on February 7–10, 2017, at the USGS John Wesley Powell Center for Analysis and Synthesis in Fort Collins, Colorado.

The Department of Interior, and the Nation in general, have a vast array of information needs. The USGS meets these needs by having a broadly trained and agile scientific workforce. Encouraging and supporting cross-discipline engagement would position the USGS to tackle complex and multifaceted scientific and societal challenges in the 21st Century.

## Grand Challenges

The workshop focused on identifying “grand challenges” for integrated USGS science, which we defined as follows:

> *A USGS grand challenge for integrated science is a fundamental problem with broad societal consequences and solutions in Earth system science. Our approach to the problem is driven by transformative integration of existing technologies, data, knowledge, and models across related and disparate disciplines and facilitated by new science and technology that will become available in the near future (1 to 10 years).*

Individual participants identified nearly 70 potential grand challenges before the workshop and through workshop discussions. After discussion, four overarching grand challenges emerged. These challenges are “grand” because they are large and important issues without obvious near-term solutions, and the USGS can develop the capabilities to address the challenges through coordinated and strategic research agendas:

- Natural resource security,
- Societal risk from existing and emerging threats,
- Smart infrastructure development, and
- Anticipatory science for changing landscapes.

Participants also identified a “comprehensive science challenge” that highlights the development of integrative science, data, models, and tools—all interacting in a modular framework—that can be used to address these and other future grand challenges:

- Earth Monitoring, Analyses, and Projections (EarthMAP)

EarthMAP is our long-term vision for an integrated scientific framework that spans traditional scientific boundaries and disciplines, and integrates the full portfolio of USGS science: research, monitoring, assessment, analysis, and information delivery.

In this report, we discuss in detail the value proposition and possible next steps for each of the overarching grand challenges, and identify for each a subset of more specific challenges that would provide near-term focus and products.

## Crosscutting Issues

In workshop discussions, numerous crosscutting issues emerged related to completing well-integrated, interdisciplinary science within the Bureau, and to the importance and difficulty of communicating and delivering science information and products to those who can benefit from them. We want to deliver the right products to the right people at the right time. As we address the grand challenges, we should strive to build internal capabilities, processes, governance, and tools that will continue to improve our ability to deliver trusted and useful science to the Nation.

## Possible Next Steps

We identified possible next steps for each of the grand challenges, but further work will be required to define clear research goals and project strategies. Each grand challenge is well suited to be a topic of a “design charrette,” an intensive, collaborative planning effort focused on generating concepts (designs) for solutions to the grand challenge. Workshop participants were enthusiastic about pursuing multiple grand challenges in parallel, creating opportunities to learn through experience and experimentation about the most effective ways to work together to foster integrated science.

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> At a time of accelerating environmental change, the gap is expanding between the comprehensive Earth science information and decision analysis tools that the Nation requires, and what the USGS currently provides.
>
> *–Quote from a workshop participant*

> The USGS is the trusted source for the science of the changing Earth. We promote the Nation's health and prosperity by producing and communicating the best available science describing the complex, dynamic Earth system as it responds to natural forces and human activities. USGS utilizes the ever-increasing body of science and technology to observe, understand, and predict processes occurring upon and beneath the Earth's surface, and employs the power of scientific discovery and integrative collaboration to create advanced knowledge and tools in support of innovative solutions to our nation's most critical economic, energy, and environmental challenges.
>
> *–Summary of "visions of the future USGS" from workshop participants*

## Introduction

The U.S. Geological Survey (USGS) has a long history of advancing the traditional Earth science disciplines and identifying opportunities to integrate USGS science across disciplines to address complex societal problems. The USGS science strategy for 2007–2017 (U.S. Geological Survey, 2007) laid out key challenges in disciplinary and interdisciplinary arenas, culminating in a call for increased focus on a number of crosscutting science directions. Ten years on, to revisit and further the goal of integrated science and at the request of the Executive Leadership Team (ELT), the USGS Council of Senior Science Advisors (COSSA; an internal advisory group of senior scientists established in 2016 under the auspices of the USGS Office of the Director) convened a workshop on February 7–10, 2017, at the John Wesley Powell Center for Analysis and Synthesis in Fort Collins, Colorado. The workshop participants (appendix 1), three dozen scientists selected to represent different disciplines and career stages across the Bureau, are the authors of this report.

By design, the workshop focus was the long-term view and a vision for what integrated science at the USGS can accomplish during the next decade or more. We focused on developing "grand challenges" for integrated USGS science—challenging societal problems with broad consequences and solutions rooted in interdisciplinary science. Although this report offers some possible next steps and ways in which we might pursue those challenges, they are not intended to be comprehensive, and we are not offering an organizational blueprint or detailed prescription of a path forward. The report is meant as broad, cohesive, and bottom-up input to more detailed planning underway by Bureau leaders, who encouraged us to share the results of the workshop openly and directly with our workforce and stakeholders.

## Background

Through implementation of the science strategy detailed in "Facing Tomorrow's Challenges, U.S. Geological Survey Science in the Decade 2007–2017" (U.S. Geological Survey, 2007) and follow-on planning documents, the USGS has made major strides towards addressing the Nation's interrelated and multifaceted Earth science and societal challenges. In each of the USGS Mission Areas, we have produced knowledge that has fundamentally advanced the underlying science and directly supported decision makers (for example, Barber and others, 2012; Booth and others, 2011; Durner and others, 2009; Garcia and others, 2016; Hunter and others, 2010; Karl and others, 2016; Porter and others, 2011; Sanford and Pope, 2013). The next step is to improve our capabilities to work across Mission Areas to address the interconnected problems of today and the future. Population growth, resource use, environmental change, socioeconomic and environmental connectivity, and technological advancement are all accelerating and interacting. Integrated and multidisciplinary science and models are needed to respond to these problems.  Integrated science will increase our ability to understand and predict the interrelated changes happening below, upon, and above the Earth's surface—and how those changes will affect the quality of life for our Nation.

## Workshop Approach

For purposes of the workshop, we defined a grand challenge as follows:

> *A USGS grand challenge for integrated science is a fundamental problem with broad societal consequences and solutions in Earth system science. Our approach to the problem is driven by transformative integration of existing technologies, data, knowledge, and models across related and disparate disciplines and facilitated by new science and technology that will become available in the near future (1 to 10 years).*

The focus of the workshop was the long term—a vision for the next decade or more—but with clear steps identified to achieve this long-term vision while ensuring shorter-term successes as well. Before the workshop, participants were asked to articulate one or more grand challenges in multidisciplinary Earth science that the USGS is well positioned to address. The resulting set of more than 70 potential grand challenges spanned many topics and scopes, ranging from building one grand integrated model of the human-Earth nexus to internal challenges such as effective science planning in a multidisciplinary organization. At the workshop, we winnowed this array to a short list of "overarching grand challenges" where the societal consequences and the societal benefits of addressing the challenge could be articulated clearly, and for which the

USGS has unique capabilities. During the course of the workshop, this subset was the focus of breakout group and plenary discussions.

An underlying premise at the workshop was that the grand challenge efforts will begin by leveraging the Bureau's existing array of data, expertise, clients, and stakeholders. We will then work towards addressing each grand challenge by considering how these existing strengths are progressively integrated. At the time of the workshop, the ELT was discussing the use of "design charrettes," intensive, collaborative planning efforts focused on generating concepts (designs) for solutions to a specific problem, in their planning processes. Each of these grand challenges is well-suited to be the subject of a design charrette, and several of the potential next steps identified below could be input to that process. Over time, and given the right institutional support and funding, common needs and products that are informative and useful at various scales for many grand challenges will be identified (fig. 1). Those commonalities will inform the development of larger scale integrated modeling efforts.

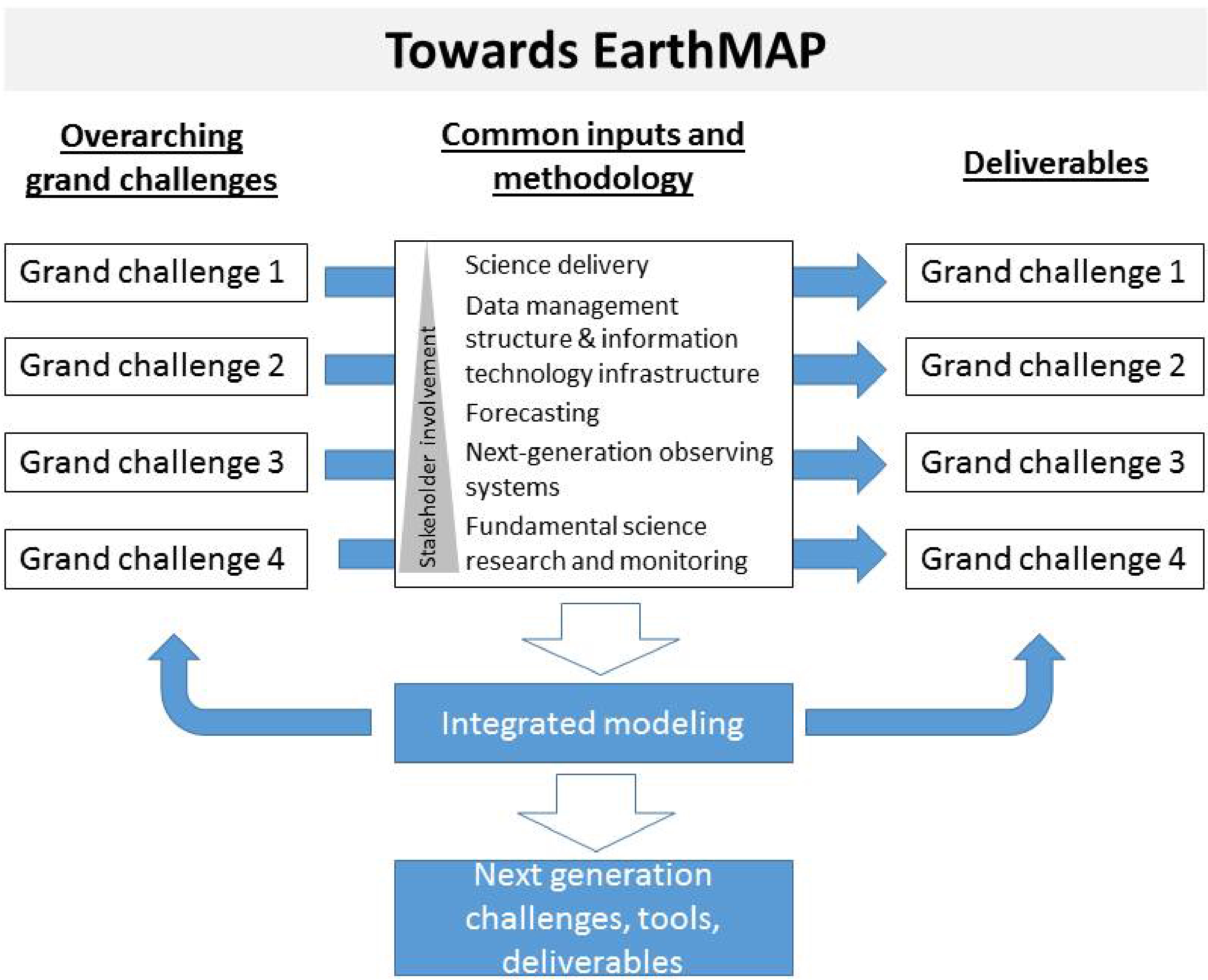


Figure 1. Approach for addressing grand challenges.

## Overarching Grand Challenges

Starting with the full list of grand challenges proposed before the workshop, we used discussion and a participatory, democratic, consensus-based approach to identify a more limited set for detailed discussion and development. This process involved, in some cases, combining and collapsing several of the suggested grand challenges, expanding and amending suggested challenges, and creating new challenges. The four overarching grand challenges identified are the following:

- Natural resource security,
- Societal risk from existing and emerging threats,
- Smart infrastructure development, and
- Anticipatory science for changing landscapes.

For each overarching grand challenge, we developed a joint understanding and description of the value of addressing the challenge, a vision of what its solutions would achieve, and a set of potential products; we also identified obstacles to be overcome to successfully address the challenge. For each overarching grand challenge, we identified a set of potential next steps and a set of related challenges that could provide stepping stones to the larger goal.

Considering all these overarching grand challenges together, and the common elements required to address them, led to a "comprehensive science challenge," highlighting the development of integrative science, data, models, and tools that can be used to address these and other future grand challenges:

- Earth Monitoring, Analyses, and Projections: EarthMAP

EarthMAP is our long-term vision for an integrated scientific framework that spans traditional scientific boundaries and disciplines, and integrates the full portfolio of USGS science: research, monitoring, assessment, analysis, and information delivery. If EarthMAP existed today, it would be a powerful framework and set of tools for addressing the overarching grand challenges identified in this report, as well as future grand challenges. In our vision, the EarthMAP concept and structure will become an integral part of the research lifecycle and will provide a foundation for delivering scientific knowledge to stakeholders in multiple readily understandable ways. This is described further in the "Comprehensive Science Challenge—Earth Monitoring, Analyses, and Projections (EarthMAP)" section.

## Potential Next Steps

If USGS priorities and resources allow a focus on integrated science, we recommend that the ELT pursue multiple (ideally all five) of these challenges simultaneously. Addressing the overarching grand challenges, along with the associated challenges of integrated modeling necessary to build towards EarthMAP, provides the opportunity to explore multiple approaches and for scientists working on different projects to learn from each other as they address interdisciplinary issues. This concept is illustrated in figure 1; synergies from addressing the overarching grand challenges contribute to expanded and improved integrated modeling capabilities, and as integrated modeling concepts are improved, they will better address the overarching grand challenges. This combination will create powerful examples of USGS science bringing direct and tangible value to the Nation, while building the integrated science framework of the future.

In practice, scientists from across the Bureau and, perhaps, the broader scientific community will come together to address these challenges within a framework that promotes contact and integration across disciplines. Although the details of how the USGS will address the grand challenges remain to be worked out by the management and leadership teams, several approaches have been used successfully in the past and can be leveraged in the near term. In addition to the design charrette concept discussed above, and a more traditional request-for-proposal approach, facilitating this type of interdisciplinary science has been the focus at the John Wesley Powell Center for Analysis and Synthesis. In a typical Powell Center study, scientists working in multidisciplinary teams each bring their individual expertise and data to bear on the problem, focusing on producing interdisciplinary results that address the grand challenge. The teams have clear aims, management structure, deadlines, and end-points. Funding is typically provided to cover parts of salaries, hold in-person meetings, and hire postdocs or other junior scientists who bring energy, new skills, and fresh perspectives to the crosscutting issues facing society in a changing world. The use of cross-Bureau working groups including the Powell Center, the Innovation Center, the Community for Data Integration, and the Science and Decisions Center would take advantage of existing capabilities to organize, communicate about, and make progress on these crosscutting issues.

It is worth emphasizing that the approach envisioned here would require neither reorganization nor massive reallocation of resources. It would represent an overlay on top of our continuing work.

## Overarching Grand Challenges

Each section below describes an overarching grand challenge. A strengths, weaknesses, opportunities, and threats (SWOT) analysis completed for each overarching grand challenge during the workshop helped focus discussions and thinking about the unique capabilities the USGS brings to the challenge, key products, and obstacles to be overcome. The results of these discussions are summarized in a value proposition table that highlights the importance of the challenge, a vision of the USGS solution, and key products that would be developed as we address it. The overarching grand challenges are, by design, broad. Fully achieving the vision for each is likely to require perhaps a decade or more, but concrete advances will happen during a shorter period. To begin addressing each grand challenge, we present a possible set of steps that can be taken to make tangible progress towards addressing the challenge and to meet contemporary national science needs. These possible next steps are couched in terms of what could be done within a year of beginning work and then what could be done in the ensuing 4 years. These are not the only possible next steps, and the next steps for every grand challenge are not equally clear. As discussed above, these next steps are intended to be a starting point for more detailed planning processes.

During discussion of each grand challenge we also identified some of the new and emerging science and technologies that could affect our approach to each challenge, and obstacles to success. Many common themes emerged in relevant new science and obstacles; those common themes are summarized in the “Context to the Report” section.

A full list of grand challenges from the workshop is provided in appendix 2: some that were identified before the workshop; some that were identified during the workshop; and some that were added, modified, or extended through individual and collaborative efforts in the week after the workshop. Pointers to a few of these specific challenges are included under each of the overarching grand challenges described below.

## Natural Resource Security

The Natural Resource Security grand challenge is summarized in table 1.

**Table 1.** Natural Resource Security grand challenge summary.

| | |
|---|---|
| Vision | The U.S. Geological Survey provides timely and proactive information on the state of natural resources, threats to the quality and availability of those resources, interactions among resources, opportunities for additional benefits from secure resources, and potential tradeoffs among resource uses and benefits. |
| Why is this important? | The health and prosperity of the Nation relies on natural resources (energy, minerals, soils, biological resources, and water). As demands for and availability of these natural resources change substantially, we need to understand the ramifications of those changes to our well-being, and the opportunities and consequences of alternative approaches to obtaining and maintaining access to those crucial resources. |
| What obstacles need to be overcome? | Lack of widespread understating and use of systems approach to USGS science.<br>Institutional and cultural barriers to interdisciplinary work.<br>Lack of Bureau-wide informatics, modeling, and statistical capacity that links spatially explicit data and models into iterative forecasts. |
| Strategies or the way we work | Synthesize and combine information that is currently created by program, mission area, or sector into analysis-ready delivery.<br>Develop and provide information on the interactions between natural resources and the various sources of change.<br>Build conceptual and quantitative models and approaches that improve fundamental understanding of our Nation's resources and their interactions and inform best practices for resource use and protection. |
| Example products | Information, including datasets, summary data, maps, tables, trend analysis, and decision support tools. This information will include the following:<br>—Past, current, and potential future conditions of resources (including information on the uncertainty about those conditions),<br>—Relations between resources, particularly how changes in any one resource affect other resources and the benefits provided by those resources,<br>—Consequences and tradeoffs of alternative management actions, and<br>—Quantified resource risks associated with natural and human-caused drivers of change.<br>Tools for identifying where on the landscape resource extraction will have greater or lesser effect or cost from a multiresource perspective. |
| Key stakeholders | The Department of the Interior; other Federal, State and local agencies; industry; scientists; nongovernmental organizations; and the public. |

## Possible Next Steps

Within 1 year of beginning work on this challenge, the next step may be to hold a workshop to review case studies, including a systematic review of ways that integrated systems-level approaches have worked and not worked, and make design suggestions for moving forward. Outputs and results of the workshop may include the following:

- Synthesis of lessons learned from integrated systems-level work;
- Directory of national-level resource datasets, and discussions how they have been or could be integrated;
- Identification of obstacles to success and ways to overcome them;

- An established community of people, from the workshop and from existing efforts, who take a systems approach; and
- A call for proposals for near-term targeted projects addressing an integrated natural resource security issue, perhaps through one or more of the existing USGS centers focused on innovation, integration, and multidisciplinary work (for example, the Powell Center, the Science and Decisions Center, the Innovation Center, and the Community for Data Integration).

After the workshop and in the following several years, if the workshop indicates this challenge continues to be worth pursuing, the logical next steps will be to fund and execute several of these near-term targeted projects, identifying, working through, and developing best practices for data management, data sharing, and other problems that are common to interdisciplinary work. A key aspect of this effort will be to study and evaluate the processes themselves as the projects are being carried out. By allowing each project team the freedom to explore and address their issues independently, and studying what does and does not work, we will rapidly improve our ability to address challenging interdisciplinary problems. Next steps for some of the related challenges that are more specific are included in appendix 2, as referenced below.

### Related Challenges

In addition to the steps described above, pursuit of more specific challenges could be a useful way to make progress. Summaries for all the related specific challenges are provided in appendix 2. The interested reader may wish to look first at the following:

- Balancing uses of water for health and prosperity.
- USGS integrated carbon research and resource assessment (ICRRA).
- USGS-led resources survey of the inner solar system.
- Supporting resource managers with integrated multiresource assessment and analyses.
- National-scale assessment of nature’s value to society.

## Societal Risk From Existing and Emerging Threats

The Societal Risk from Existing and Emerging Threats grand challenge is summarized in table 2.

**Table 2.** Societal Risk from Existing and Emerging Threats grand challenge summary.

| | |
|---|---|
| Vision | The U.S. Geological Survey will prepare the Nation to cope with and reduce the risks of existing and emerging threats associated with the Earth system. We will provide directly relevant integrated science that management entities can use in planning and response. This science will leverage existing technologies, data, and models; new science and technology; and community participation and co-creation of knowledge. |
| Why is this important? | Disruptive change threatens the health and livelihood of humans, societies, and our natural environment. As changes accelerate, our ability to cope or adapt will be tested. Understanding and characterizing the full effects of existing and emerging threats, and evaluating how different actions or events can reduce risks or modify adverse effects, are key elements of effective risk management. Disruptive change may come from (1) trends such as increased population and affluence, urbanization, increased connectivity, rapid technological change, climate change, shifts in biodiversity, changed accessibility of natural resources; and (2) events such as geohazards (earthquakes, volcanoes, and tsunamis), droughts, emerging diseases, and geopolitical changes. Identifying and uncovering opportunities that arise from changing conditions through open and accessible scientific research provides benefits for all of society. |
| What obstacles need to be overcome? | Insufficient social science expertise and studies, which are necessary to better understand and communicate societal risks and consequences, and to better engage various communities.<br>Institutional and other barriers to some types of public participation (for example, need for Office of Management and Budget approval for public surveys).<br>Information technology infrastructure, information science expertise, and product delivery mechanisms are not up-to-date (for example, may need more visualizations, mobile apps, and so on).<br>Some aspects of USGS institutional norms: funding models that make it difficult to work across centers, incentive and reward structures that emphasize disciplinary science and individual contributions. |
| Strategies or the way we work | Integrate and synthesize existing and incoming databases and observations to understand critical interdependencies among communities, land, water, and ecosystem resources.<br>Develop process models of those relations.<br>Study and model how ecosystem function responds to change.<br>Interact directly with users, stakeholders, and citizen scientists to understand their needs and to integrate their information and science.<br>Provide Earth system data in forms needed for risk-reduction decisions across the Nation (for example, building codes).<br>Advise risk modelers (for example, insurance and re-insurance) on the use of U.S. Geological Survey Earth system data and science.<br>Support national (for example, Federal, State, Tribal, and local) and global (for example, the United Nations, World Bank [GRDRR], Inter-American Development Bank, and U.S. Agency for International Development) partners in risk reduction decisions that are associated with Earth systems.<br>Deliver critical risk and related information directly to the public (in other words, “make science personal”). |

**Table 2.** Societal Risk from Existing and Emerging Threats grand challenge summary.—Continued

| | |
|---|---|
| Example products | Early-warning systems for geohazards, drought, flood, invasive species, environmental health impacts, mineral and energy supply disruptions, and so on. These systems may include the following:<br>—Systems for monitoring and surveillance (for example, bio-surveillance), and<br>—Tools for modeling and forecasting.<br>Consequence estimates for geohazards, drought, flood, invasive species, environmental health impacts, mineral and energy supply disruptions, and so on. These estimates may include the following:<br>—Synthesis of habitat and species sensitivity (to climate and other factors), and<br>—Models of consequences resulting from complex events.<br>Indicators of significant change that can be used to prompt analysis.<br>"Threats in my backyard" tool to enable any user to estimate their risk and potential losses associated with hazards (building, for example, on ShakeCast, https://earthquake.usgs.gov/research/software/shakecast.php, Wald and others, 2008). |
| Key stakeholders | Insurance companies, corporations, owners, managers and users of critical infrastructure, utilities, the transportation sector, land and resource managers, nongovernmental organizations, and health care providers. |

## Possible Next Steps

If a decision is made to pursue work on this grand challenge, the first step will be to charter a small group focused on building several of the products described in table 2. Allowing that group flexibility and support to pursue multiple and creative solutions, including solutions where success is not guaranteed and failures are seen as stepping stones to future successes, will help advance progress toward the challenge. Within the first year, this group would begin or contribute to efforts to do the following:

- Rekindle conversations on a Biological Disaster Assistance Program.
- Update the Prompt Assessment of Global Earthquakes for Response (PAGER, https://earthquake.usgs.gov/data/pager/) based on all available forms of information (for example, data about reported fatalities to be incorporated in models).
- Develop species distribution modeling that integrates data from multiple platforms, such as eBIRD (http://ebird.org/content/ebird/), iNaturalist (https://www.inaturalist.org/) and the USGS Breeding Bird Survey (https://www.pwrc.usgs.gov/bbs/).
- Use the scenario approaches being explored by the Science Applications For Risk Reduction (SAFRR; https://www2.usgs.gov/natural_hazards/safrr/projects/) program to advance work with partners and coalitions.
- Complete risk research and applications plan.
- Create a community of practice to facilitate sharing of information across programs, Mission Areas, and science centers focused on different dimensions of risk.
- Develop community engagement strategies, potentially building from the Earth Science Information Partners model (http://www.esipfed.org/).

In the next 4 years, work on building the products described in table 2 will continue, and at least two specific products will be produced and made available: (1) one or more serious game/role playing games or modules for the Extreme Event game developed by the National Academy of Sciences (https://www.koshland-science-museum.org/extreme-event/) to increase understanding of existing and emerging threats; and (2) a "Threats in my backyard" tool to allow any user to explore and understand the existing and emerging threats in a location of interest to them.

### Related Challenges

In addition to the steps described above, pursuit of more specific challenges could be a useful way to make progress. Summaries for all the related specific challenges are provided in appendix 2. The interested reader may wish to look first at the following:

- Minimizing hazards to our natural resources and the health and properity of our communities.
- Coastal change—Complex drivers, myriad consequences.
- A national biosurveillance network for emerging biothreats.
- Science to reduce risk where tectonic plates collide.
- Making science personal (in particular as a way to help communicate risk information).

## Smart Infrastructure Development

The Smart Infrastructure Development grand challenge is summarized in table 3.

Table 3. Smart Infrastructure Development grand challenge summary.

| | |
|---|---|
| Vision | Infrastructure development will be based on a USGS scientific framework that integrates information on the Earth system with planning and engineering to maximize the efficiency of public infrastructure investments while providing sustainable societal and environmental benefits. |
| Why is this important? | Infrastructure development is expensive and inherent to societal growth. Improper planning and development can be costly, dangerous, and environmentally detrimental. The short- and long-term implications of development may not be fully understood in the absence of an integrated science approach. |
| What obstacles need to be overcome? | The USGS does not have core competency in infrastructure development itself; potentially high hurdle to demonstrate our ability to contribute.<br>May need to cultivate a new set of stakeholders.<br>Current USGS organizational structure and lack of integration across Mission Areas and scientific specialties.<br>Perceived competition and conflict with other infrastructure-focused entities. |
| Strategies or the way we work | Engage the community of stakeholders who will most benefit from increased USGS focus on infrastructure.<br>Communicate clearly within the USGS and with stakeholders about current USGS infrastructure-relevant work, and about new directions, capabilities, and emphases.<br>Identify information needed to promote smart infrastructure development.<br>Leverage and integrate current information to support ongoing infrastructure development.<br>Develop new science and information products tailored to the needs of those who plan, build, and manage infrastructure investments. |
| Example products | Science information portal for infrastructure planning (site suitability, design, and visualization) and assessment.<br>Site suitability tools and decision aids to assist in early phases of decision making and exploring balances and tradeoffs.<br>Aggregation of smart sensors to help create a national sensor network that can be leveraged for new areas of science and real time monitoring.<br>New information support structure and data enterprise for publication, discovery, dissemination, and delivery of data. |

**Table 3.** Smart Infrastructure Development grand challenge summary.—Continued

| | |
|---|---|
| Key stakeholders | Agency infrastructure services (the Department of the Interior, Department of Transportation, and States), National Institute of Standards and Technology, private development enterprises, State and local governments, general public, engineering and/or software development industries, industry associations (for example, the American Society of Civil Engineers or the Association of State Floodplain Managers), Sensor development companies and other Interior agencies. |

## Possible Next Steps

The USGS is not well recognized as an engineering agency, yet it has several national and regional programs that inform infrastructure planning and management; for example, we develop and make available seismic design parameters (https://earthquake.usgs.gov/hazards/designmaps/) for use by organizations responsible for building and bridge design codes. We provide critical streamflow data and widely used methods for estimating regional flood-peak flow and low frequency/duration estimates (https://water.usgs.gov/osw/programs/nss/index.html) useful in the design and operation of critical water-related infrastructure. Our 3D Elevation Program (https://nationalmap.gov/3DEP/) collects and manages elevation data critical to several applications in infrastructure planning and design (Lukas and Carswell, 2016). Also, the USGS has a long proven record of providing spatially explicit, multidisciplinary information on the resources related to infrastructure in specific regions (Biewick and others, 2006). During the workshop, we recognized that integrated USGS science could play a larger and pivotal role in informing the maintenance, upgrading, and replacement of America’s infrastructure at a time of uncertain and rapid change. Some next steps to address this grand challenge were only touched on during the workshop: a logical first step was identified and subsequent steps, beyond the first year, were left to be fleshed out.

Potential plans for a first year of effort involve convening an innovation workshop in Earth system support for infrastructure, and developing a detailed description of how the USGS can contribute to this challenge. Results of this workshop will include identifying stakeholders in smart infrastructure, their needs, and a plan for engaging with those stakeholders; and a description of other entities who may be working in this area and identified opportunities for the USGS to add their expertise. If the workshop results indicate that this is a useful area to pursue, a next step would be to establish a working team across Mission Areas and regions to develop a detailed smart infrastructure development program. The program should include plans for: a near- and long-term research plan for basic and applied research to accelerate and improve our ability to apply integrated science to smart infrastructure development; a strategy for working with stakeholders and collaborators; and the development of useful infrastructure development support information and decision tools.

## Related Challenges

In addition to the steps described above, pursuit of more specific challenges described in appendix 2 could be a useful way to make progress:

- Role of Earth subsurface/surface processes in infrastructure planning.
- Infrastructure—Interconnectivity of our science and the built environment.
- Understanding the impacts of proposed geoengineering activities.

## Anticipatory Science for Changing Landscapes

The Anticipatory Science for Changing Landscapes grand challenge is summarized in table 4.

**Table 4.** Anticipatory Science for Changing Landscapes grand challenge summary.

| | |
|---|---|
| Vision | USGS information is strategic and truly anticipatory, supporting actions that can be implemented at the necessary spatial and temporal scales, to better align public investments with a dynamic future. Natural resource managers rely on USGS science to understand multiple and interacting stresses and associated changes to the landscapes, waterways, habitats, and species they manage. This information is critical to their design of management responses and actions, and to their understanding of the effectiveness and effects of those actions. |
| Why is this important? | Resource and land managers must consider multiple, often competing, uses and needs when they make resource management decisions. To achieve their mission and goals, they need timely and high-quality information on how interacting components of landscapes will change over time and under different management actions. Landscapes are now changing dramatically in response to multiple stressors, often abruptly and simultaneously, in nonlinear and potentially irreversible ways. This underscores the urgency to anticipate future conditions and "stay ahead of the game" in land management, and calls for increases in the scope and scale of scientific guidance and management coordination, and strategic anticipatory science and management to achieve widespread and sustainable outcomes. |
| What obstacles need to be overcome? | Difficulties in balancing the broad against the specific (how scalable across decisions would these decision support tools/models actually be?).<br>Time commitments required to work with individual decision makers.<br>Paucity of information on ecological responses for many species.<br>Challenges to collaboration with other entities involved in related efforts. |
| Strategies or the way we work | Develop appropriate infrastructure to ingest and process large fluxes of information.<br>Invest in people, processes, and scientific capacity to enable us to work closely with decision makers through the life-cycle of a decision problem, delivering the right information at the right time.<br>Increase the scope and degree of scientific guidance and management coordination, and strategic anticipatory science and management to achieve widespread and sustainable outcomes.<br>Develop and deploy modeling tools that can predict the strength and direction of feedback responses to global changes, and the effect of management actions on those feedback responses. |
| Example products | Clearinghouse of vital datasets (for example, experimental studies, long-term permanent plot or other historical data, paleoecological records, alluvial stratigraphic records, and so on) for improving predictions<br>Data portals that continuously ingest and assimilate spatio-temporal data on the landscape, including the following:<br>—Biological data including survey results, environmental deoxyribonucleic acid (eDNA), fishing and hunting data, and so on.<br>—Near surface (critical zone) inputs including soil moisture, vadose zone interactions, and shallow groundwater processes.<br>Predictions of the consequences of successional pathways and different management actions across a landscape that explicitly links to large drivers of change, cascading effects, and regional connectivity.<br>Adaptive management decision support tools that are user-friendly, spatially-explicit, and transferrable across systems and problem spaces, and capable of enabling decisions dynamically at regional scales. |
| Key stakeholders | Other Department of the Interior Bureaus, decision makers and managers at all levels and entities who have a say in how our land and resources are managed, and the public. |

### Possible Next Steps

The quickest and most effective way to make progress on this challenge is to build from recent successes—for example, to build from USGS Priority Ecosystems Science Projects (https://access.usgs.gov/about.html)—and extend those concepts to multiple ecosystems, habitats, and species nationwide.

If work on this challenge is begun, a potential first year plan is to establish interdisciplinary/inter-Mission Area team to begin implementation. This might take the form of a Powell Center working group focused on completing a stepping stone project, with the goal of wider adoption of the process. Products of this working group will include the following:

- Systematic scientific review of successful integrated science efforts.
- Focused analysis of what capacities create successful integrative projects in the broader science community, for example, considering modern approaches to decision-focused wildlife or landscape conservation in the face of global change.
- Identification of potential barriers to success, from a social science perspective.
- Visioning meeting for a joint DOI-U.S. Department of Agriculture (USDA) group focused on anticipatory science for changing landscapes.
- Identified opportunities and applications for iterative ecological forecasting.

If this remains a priority topic for the USGS, in the following several years, these efforts will be continued and additional activities to promote expansion of work added. These additional activities may include:

- Forming a joint DOI-USDA group for landscapes.
- Providing a funding opportunity that incentivizes working across missions to address this topic.
- Creating an operational adaptive management/decision support tool that updates regularly (like a forecast system); deploying computer model emulators in a natural resource management context.

### Related Challenges

In addition to the steps described above, pursuit of these more specific challenges could be a useful way to make progress. Summaries for all the related specific challenges are provided in appendix 2. The interested reader may wish to look first at.

- Environmental forecasting in the short- and near-term.
- Predict and mitigate impacts of changing connectivity on human and ecological health.
- Ecosystem adaptation.
- National synthesis of species sensitivity to climatic changes.

## Comprehensive Science Challenge—Earth Monitoring, Analyses, and Projections (EarthMAP)

The natural systems and resources that we rely upon for our livelihood, security, and well-being are changing in accelerating and nonlinear ways, as is the potential exposure of our citizens to a range of natural hazards and environmental threats. Understanding the scientific context of these changes well enough to provide relevant science, guidance, and solutions requires an integrated scientific framework that is coupled with decision analysis tools. This comprehensive system would span traditional scientific boundaries and disciplines. In our view, the USGS of the future will maintain a solid core of continually evolving Earth system characterization products—base observation and measurement data, process and response models, assessments and projections, maps and decision analysis tools. We will also acquire Earth system data from a variety of external sources. The components of this system will be modular and interactive, and they will be scalable from national to regional to local levels. The umbrella term for this comprehensive product is “EarthMAP” (fig. 2). This is our “moon shot.”

We termed development of EarthMAP a “comprehensive science challenge”—if EarthMAP existed today, it would provide be a powerful framework and set of tools for addressing any and all the overarching grand challenges, as well as future grand challenges. In the EarthMAP vision, USGS scientific data, information, and knowledge will be cohesively organized and linked with input from the broader scientific community. The EarthMAP vision and structure will become an integral part of the research lifecycle, providing a foundation for delivering scientific knowledge to stakeholders in multiple readily understandable ways. Our aim is to be able to synthesize and deliver the right information, in the right format, at the right time and to the right audiences to address important questions quickly and efficiently.

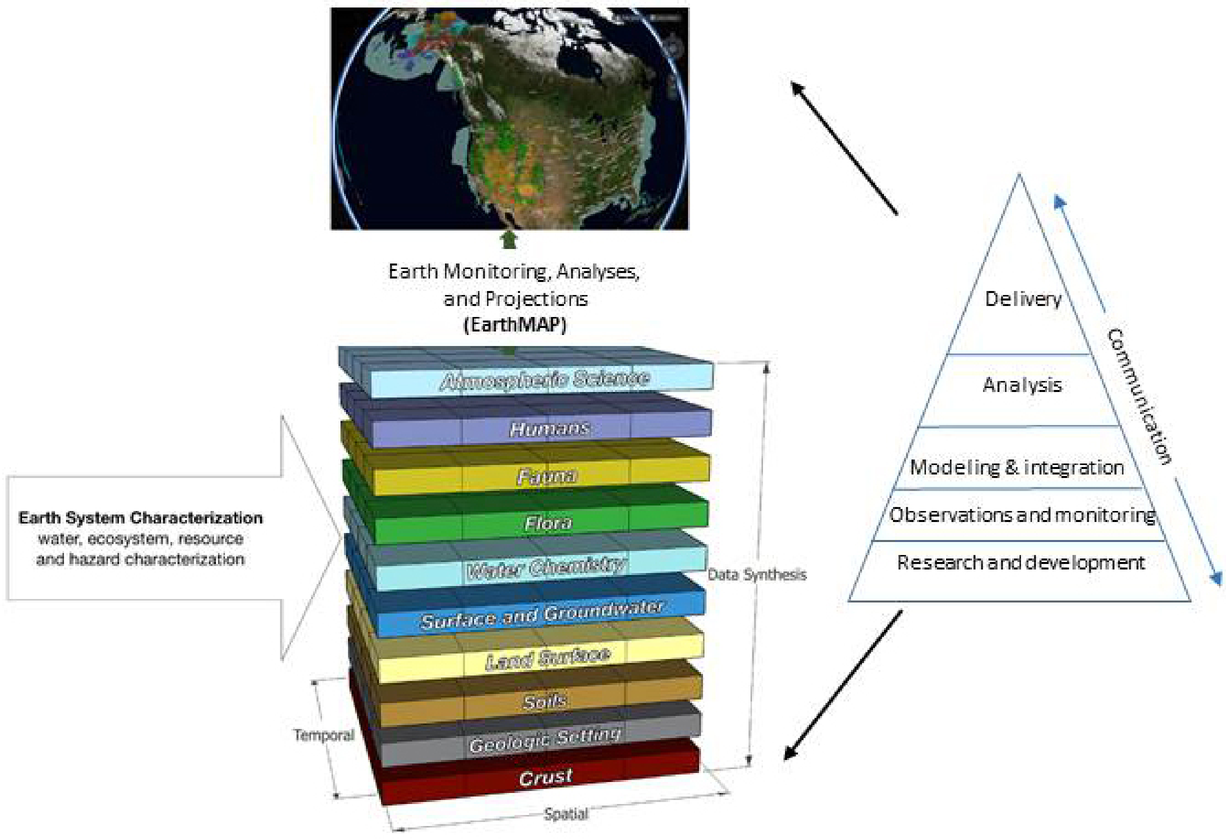


Figure 2. Earth Monitoring, Analyses, and Projections (EarthMAP) structure.

## Possible Next Steps

EarthMAP is a long-term vision and a comprehensive science challenge. It involves modifying the way we think about, carry out, and communicate our science; and it will be built over time as we leverage our traditional strengths and newer multidisciplinary approaches. EarthMAP also requires advances in both our technological and modeling infrastructure.

Integrated models, at multiple scales, will be a key element of EarthMAP; data and model interoperability and integrated modeling represent both near-term needs and opportunities to begin building EarthMAP's technical infrastructure while addressing the overarching grand challenges. There are several directions that this model-focused work could take. During the workshop, a number of attendees focused their attention on the issues associated with integrated modeling: they considered how national scale data and model products can be linked and integrated, and how existing local and regionally integrated data and models might be "scaled up" to address questions at different scales, and how either or both of these approaches could serve as a foundation for EarthMAP. There was a great deal of enthusiasm for this topic—we believe that national and (or) nationally consistent integrated cross-disciplinary modeling is an exciting opportunity. Postworkshop discussions were held focusing on involvement of the Community for Data Integration in support of the overall concept.

Given the variety of approaches to integrated modeling, we believe this effort would benefit significantly from a "design charrette" to create a joint vision of how the data structures and model development should proceed. This charrette should involve a diverse group of modeling experts with different experiences and different perspectives on data inputs, model development, integration, and information delivery. What is clear however, is that the USGS has the expertise to begin building the EarthMAP foundations and infrastructure today.

### Related Challenges

Summaries for various integrated modeling approaches that could be implemented, modified, or combined as part of creating a comprehensive EarthMAP are included in appendix 2. The interested reader might look at the following:

- Creation of TERRACAST—A modular modeling system for multidisciplinary land and water forecasting for the Nation.
- CONUS integrated modeling framework to assess impacts of climate change on biological, geological, and hydrological resources.
- Vision 20–21—Hindcasting, forecasting, and nowcasting of the Nation's land and water over the 20th–21st centuries through system modeling.
- Quantifying Earth system processes (Earth "gaging").

## Context to the Report

In the broadest sense, the impetus for this workshop was the recognition that societal, technological, and environmental drivers of change external to the USGS are evolving rapidly, requiring us to respond. In this section, we first provide an overview of these drivers. We then focus specifically on one aspect: the new and emerging science and technology that we must stay abreast of and that may affect our approaches to these and future grand challenges. Emerging science and technology issues were considered during all the individual grand challenge discussions, during which common themes emerged. Those common themes are described below. Finally, we discussed obstacles that need to be overcome that are likely to be common to any challenges that we focus on. These common obstacles are likewise summarized below.

### Workshop Motivation—Drivers of Changes

Over the summer of 2016, COSSA identified profound environmental, technological, and societal trends that are likely to play out during the next few decades, and that will propel the need for USGS expertise and demand long-term Bureau planning. Six major areas of rapid change listed below provide challenges and opportunities for the USGS as we address each of the overarching grand challenges.

- *Environmental Change.*—Rapidly intensifying changes in climate and land/resource use will propagate into a web of formidable consequences to the Nation and the planet.
- *Population increase.*—Rising global population and increasing affluence with attendant demands on a wide range of resources will exacerbate environmental changes. As populations increase, so will human risks, especially in flood plains, along fault zones, and in coastal areas.
- *Changing geographic connectivities.*—Vulnerabilities to environment and society are nested and connected even over long distances by geophysical and climatic processes; and the accelerated flows of organisms (including people), resources, and information exacerbate this vulnerability. Increasingly, environmental change will involve interacting and ever-changing climatic, ecological, and socioeconomic teleconnections that often transcend regional and national boundaries. In many cases we may lack understanding of connectivities that are natural and long-standing, much less how they might be shifting over time and space.
- *Scientific advancements.*—The coming years may see rapid advances in climatic predictability in the long and short term, and at unprecedented spatial resolution. Experts from complementary disciplines will quickly need to gauge opportunities and retool theory, data collection and management, and differentiate the influence of climatic variability and change from other influences on coupled environmental and human systems.
- *Information Technology (IT).*—Continued exponential expansion in IT capabilities will permit data storage processing and manipulation far beyond today's capabilities. On-demand storage, processing, hardware, and software are changing the paradigm for methods in scientific computing and analysis. Not only do current computing resources allow scientists to adapt to the age of "big data," but the scalability of the resources enable scientific investigation at massive, heterogeneous scales not previously thought possible (NITRD/NCO, 2016). These IT resources will be necessary to answer the increasingly complex, interdisciplinary, and computationally intensive scientific questions that are most important to the Nation and the world.
- *Growth in observing and analytical capabilities.*—A revolution is underway in ground, air, and space-borne sensors capable of providing essential Earth system data at unprecedented spatial and temporal resolutions. There are also exponentially expanding capabilities to characterize nature. Deoxyribonucleic acid released by organisms to the environment (eDNA) can now be measured rapidly and inexpensively; these data will soon provide probes into major ecosystem-related issues including inventory and monitoring of species, early detection of invasive species, and spread of zoonotic (vector-borne) diseases.

## Common Themes—New and Emerging Science and Technologies

New and emerging science and technologies will affect our ability to address the grand challenges, and the approaches that we can take to those challenges. New science and technologies will increase our ability to acquire data, monitor the status of natural resources, and detect threats and disruptions early; improve our ability to monitor those threats and disruptions as they evolve; augment the amount and quality of information available to inform our understanding; enhance our ability to model complex systems; and diversify the avenues available to communicate relevant science information. We identified examples of new and emerging science and technologies directly relevant to each overarching grand challenge. While the specifics varied across the challenges, some common themes appeared.

- *New ways to collect primary data.*—Examples include ubiquitous Earth observation data, remote sensing (Pellerin and others, 2016), biosensors, wireless sensors, in situ fluorometry, use of drones (Anderson and Gatson, 2013), snapshot data (analysis of camera/video data), proximal sensor, tracking, and monitoring technologies (for example, for wildlife), data collected directly from the public through mobile technology, biometrics and wearable technology, volunteered digital information, collaborative data collection, data collected without attribution (for example, data on population movements to better understand exposure and vulnerability and better target communications), and environmental DNA (Klymus and others, 2015)
- *Changes in the type, quantity and quality of available data.*—Specific improvements discussed include: improved resolution of spatial data (for example, data at the field scale of resolution, both horizontally and vertically); improved environmental and increasing availability of biological data (Falcone and others, 2015; Lepak and others, 2015); availability of soundscape and audio survey data; data collected collaboratively, and through public participation and citizen science.
- *New ways to extract, discover, and process data.*—This includes the use of data mining (for example, automated data extraction, tracking of geopolitical events, and social media reporting) and improved data processing (for example, image recognition software for dealing with visual data. This also includes the use of Cloud technology for high performance computing and integrated data processing.
- *Fundamental science advances, including expanded use to genomics (Tyler and others, 2007; Richter and others, 2014), bioinformatics, DNA chip technology, and high throughput toxicity screening (Francy and others, 2015; Leet and others, 2015).*—For the smart infrastructure development grand challenge, advances in material science and changes in building materials were identified as potential advances affecting the grand challenge.
- *New and improved modeling and forecasting capabilities.*—This topic includes both modeling approaches and model results or output (for example, Oelsner and others, 2017). New or improved models and approaches may focus on: models at new scales (for example, regional sea level rise); improved approaches for complex, systems-level problems (for example, Bayesian network analysis that update prior information using new data and analyses; Amstrup and others, 2008); statistical emulators (Schnorbus and Cannon, 2014); phenomenological models; and more generally the use of spatial data as a substitute for temporal data in modeling. New and improved modeling result would include improved, credible predictive and forecasting capabilities, especially better spatial and temporal climate forecasting, including very fine-scale forecasts in short (weeks to months), near (seasonal to decadal), and long term.
- *New and improved computing capabilities.*—Our abilities to store and process data and to develop, run, and extract meaning from increasing complex models continues to improve as computing capabilities increase. Examples include increased processing power, bigger faster better computers/networks, large scale network consortiums, machine learning

approaches, model-data fusion, and leveraging partner and university super computing resources (for example, Fienen and others, 2016).

- *Improved understanding of how USGS science is or can be used and communicated.*—This includes both an increased emphasis on the use of decision science to increase the usefulness of science products and advances in decision science, leading to improved understanding how people make decisions and how our science information is or is not being used (Jacobson and others, 2015); value-of-information analyses and new ways to develop and communicate our science products. Examples of new communication approaches include "serious games" such as the Extreme Event game developed by the National Academy of Sciences (https://www.koshland-science-museum.org/extreme-event/; Wein and Labiosa, 2013), "hackathons" that bring computer programmers and others together for short intensive design sessions focused on specific problems, "story maps" (https://www.usgs.gov/center-news/using-story-maps-communicate-usgs-science), increased use of on-line mapping (https://cida.usgs.gov/quality/rivers/home) and other graphical tools, and potentially, increased use of virtual reality tools for data exploration and communication.

## Common Themes—Obstacles to be Overcome

To accomplish any of the grand challenges requires that we think and work in new and possibly uncomfortable ways. In the sections above, obstacles to addressing each grand challenge were identified and common themes emerged. In addition, several of the challenges initially submitted for possible discussion at the workshop focused on internal obstacles to successful integration USGS Science, and those themes were repeated in the common themes across grand challenges (see "Internal challenges" in appendix 2).

- *Existing institutional barriers to integrated work.*—The knowledge base within the USGS is broad at the Bureau level, yet specialized at the individual level. Limits to disciplinary integration frequently arise from a lack of sufficient contact across disciplinary boundaries and from funding challenges for inter-Mission Area work. Another challenge is the difficulty in discovering the research of colleagues within and among Mission Areas. Although many examples exist of integrated, multi-mission area work being conducted successfully in the USGS, in all of these cases we discussed, there were significant barriers to working across these boundaries. There is an opportunity to learn from past successful (and unsuccessful) attempts at integration to identify specific barriers and to reduce those barriers through the grand challenges.
- *Need for diversity and additional expertise.*—The USGS needs both new types of expertise and expansion of existing capacity in targeted areas. Research has shown that more diverse teams are more productive, more successful and more impactful (Rock and Grant, 2016). Increasing diversity within the USGS will improve our science. In addition, we identified three broad types of expertise needed to move the USGS toward accomplishing the grand challenges: data science, decision science, and social science. In particular, we believe it is important to have and recognize data scientists as peers who are directly included in our science research and delivery. While IT infrastructure is also identified as a need (below), it is inclusion of data scientists throughout our processes that will best address the perceived bottleneck between research needs and computational tools.

- *Need for additional and new modeling expertise.*—The USGS has a very strong modeling history and set of modeling expertise. However, much of that expertise is discipline-specific, and traditional approaches to modeling have been poorly equipped to deal with the coming deluge of data, information, and demand. We will need to strengthen our skills and capacity for interdisciplinary modeling, statistics, forecasting, and information and science delivery.
- *Need for new, expanded IT infrastructure.*—The information volume and content provided by observing systems is rapidly evolving. Conducting up-to-date science requires integrating our operations, data, and support services to accomplish our mission responsibilities. Operating independently is costly, inefficient, and harms our ability to communicate our science in a clear and compelling way. The USGS should evolve to an organization where high-performing and state-of-the-art information technology is a major accelerant for scientific discovery and not a hurdle to be overcome.
- *Engagement with existing, new, and future stakeholders.*—Delivering relevant science requires understanding the needs and interests of those stakeholders who can benefit from our work. This means identifying both existing and potential end-users, and engaging them throughout the process of science creation. It also means thinking beyond the present to anticipate who our stakeholders might be years and decades from now.
- *Increasing collaboration and developing meaningful interfaces with other science agencies and scientists.*—Collaboration with other science providers and with end-users of our information will be especially critical as we expand from our traditional strengths as discipline-based science providers to creating and providing decision-relevant integrated science to a wide range of stakeholders.
- *Enabling the culture.*—The culture of USGS, like an ecosystem, is a changing environment. The USGS needs to embrace changes to our culture and continue to reward and encourage new ways of advancing our mission. Remaining set in our ways is a cultural attitude we cannot afford to continue. Stovepipe thinking and inconsistent architectures will only serve the few, not the many.

## A New Science Vision for the USGS

Throughout the workshop, participants were challenged to describe their own vision for a more integrated and forward looking USGS that truly addresses “science for a changing world.” The 22 individual contributions are all included in appendix 3.

Many if not most of the vision statements mentioned in some way that their vision for the USGS of the future includes the expectations that we (1) carry out integrated and interdisciplinary science, (2) are able to predict or project changes in the Earth system, and (3) regularly create and deliver science that is used to support decision making.

Almost half of the draft vision statements mentioned that the USGS will continue to focus on Earth systems science and natural resources, and that we will address the need to understand a dynamically evolving planet, including the natural and human sources of change and the effect of change on people, communities, the economy, and the environment. Many also mentioned that the USGS will take advantage of new ways of obtaining science information (new technologies, data sources, and so on), and will strive to make information available to everyone who needs, wants, or can benefit from it. There was also mention of the continuation of fundamental science, in addition to science for decision support, as a core part of the USGS portfolio.

Finally, several vision statements emphasized that the USGS of the future will continue to be respected as unbiased, trusted, objective science providers; and that we will collaborate more outside of our traditional boundaries, with other agencies and researchers and with engaged citizens.

Combining these elements, we offer a starting point for a comprehensive vision for integrated science and the future USGS.

> The USGS promotes the Nation's health and prosperity by producing and communicating the best available science that describes the complex, dynamic Earth system as it responds to natural forces and human activities. We do this by linking science and information from many sources and seamlessly interweaving global, national, and local scales. The USGS exploits the ever-increasing body of science and technology to observe, understand, and predict processes occurring above, upon, and beneath the Earth's surface, so as to inform decisions concerning protection from natural hazards and competing needs and uses of natural resources.
>
> The USGS has scientific breadth, technical capacity, data assets, and the trust of its diverse stakeholders. We maximize the benefits of these attributes through a multidisciplinary framework that incorporates our individual parts and converges them into a scientifically powerful, societally relevant, and forward-looking whole. The USGS embraces the notion of organizational structures as semipermeable membranes, and makes a strong institutional commitment to integrative and collective effort.
>
> The USGS serves the Nation by empowering citizens and decision makers alike to make informed choices regarding the use and management of natural resources, the protection of lives and the built environment from natural hazards and threats to environmental health, and the ability to adapt to a rapidly changing environment. USGS integrated science achieves this vision by fusing an Earth systems approach to research and problem solving with a collaborative approach to engaging stakeholders in project design and development. The agency actively seeks opportunities to capitalize on emerging technologies, harness big data, and leverage external partnerships across multiple sectors. USGS is recognized as a leader in advancing Earth science research and in providing actionable scientific information in forms that are accessible and usable by multiple stakeholders. The USGS is committed to the principles of open science and fully-reproducible research, making available and accessible the full scope of our research process, including data, software, and annotated scientific workflows, in order to support the integrity of our scientific findings and accelerate the pace of new discovery.
>
> The USGS strategically manages its workforce for an optimal blend of scientific, engineering, and operational staff and research infrastructure that balances key abilities to respond to emergencies, pursue and answer fundamental research questions, and broadly conduct transdisciplinary science to address pressing societal challenges. The agency attracts and retains top talent by nurturing a creative, diverse and engaged workforce with ready access to rigorous training and rich cross-disciplinary interactions spanning the natural and social sciences, engineering, data science, and design. A diverse, integrated, and technologically-advanced USGS workforce will develop solutions for urban and rural, human and natural populations

that are clearly communicated to the public. The ideal USGS employee is willing to both learn and teach, lead and follow, has deep expertise but can communicate across disciplines, and is dedicated to the highest quality of science and public service delivered with a sense of enterprise, versatility, proactivity, professionalism, and collaborative spirit.

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# Appendixes

# Appendix 1. Workshop Participants

Table 1–1. Workshop participants and their backgrounds, in alphabetical order.

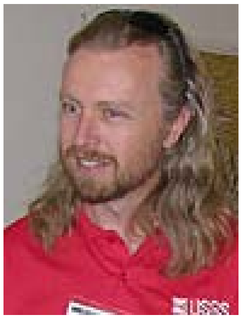
| Participant | Information |
|---|---|
|  | **Baron, Jill S.:** I'm an ecosystem ecologist, and I study biogeochemical cycling of nitrogen. Much of this research occurs in a long-term ecological research and monitoring site in Rocky Mountain National Park: Loch Vale watershed, where we have 35 years of continuous records showing effects of atmospheric nitrogen deposition to terrestrial and aquatic environments, and now its interactive effects with warming summer temperatures. As a member of a large international network, the International Nitrogen Management System, we are documenting methods for tools and methods for understanding the nitrogen cycle, quantifying global and regional nitrogen use, benefits and impacts, and developing demonstration projects for science-based management. My research is based out of the Natural Resource Ecology Laboratory, Colorado State University. I'm Co-Director, with Marty Goldhaber, of the U.S. Geological Survey (USGS) Powell Center.<br><br>Profile: https://www.usgs.gov/staff-profiles/jill-baron?qt-staff_profile_science_products=0#qt-staff_profile_science_products |
|  | **Betancourt, Julio L:** I'm a research hydrologist and ecologist interested in how climate influences terrestrial ecosystems at scales critical for understanding natural processes, detecting and forecasting spatiotemporal variability and change, and managing resources and hazards. I am the Council of Senior Science Advisors (COSSA) Co-Chair and one of the organizers of the meeting.<br><br>Profile: https://www.usgs.gov/staff-profiles/julio-betancourt |
|  | **Bristol, Sky:** I lead a biogeographic characterization program in Core Science Systems. My science background is in environmental contaminants transport and species impact investigation, but I've spent the majority of my career working on more effectively applying data and information technologies to science and decision making. I'm interested in designing and building components of a global linked data, information, and knowledge system that ultimately shares our collective understanding of the whole earth system, gives societies tools for decision analysis, and accelerates the pace of scientific discovery. My team and I are pursuing these ideas right now through improving the characterization of biological species, their relationship with habitats, characterization of conservation measures through time, and the potential impact of changes to the biodiversity in ecosystems.<br><br>Profile: https://www.researchgate.net/profile/Sky_Bristol |

**Table 1–1.** Workshop participants and their backgrounds, in alphabetical order.—Continued

| Participant | Information |
| --- | --- |
|  | **Cantrill, Mary:** I am the Integration Officer, Integration Team, Office of Budget, Planning, and Integration. Before joining the USGS a year ago, I occupied a similar post at the Army Research Lab's Program and Budget Office. |
|  | **Exeter, Paul:** I am the USGS Chief Technology Officer, out of the Office of Enterprise Information, formally Geospatial Information Office. I am a USGS Science Center and USGS mission-focused information technology (IT) professional, who has spent the last 16 years of my career supporting and collaborating with USGS scientists across the Nation. I welcome the opportunity to network and help you find ways to complete your science with IT as an enabler, not a complication.<br><br>Profile: https://www.usgs.gov/staff-profiles/paul-exter |
|  | **Focazio, Michael J.:** I am Program Coordinator for the Toxic Substances Hydrology and Contaminant Biology programs in the Environmental Health Mission Area. My science background is in hydrology, modeling, and fate/transport of environmental contaminants with a focus on drinking water. I believe the science throughout our Bureau can contribute to the health and prosperity of ourselves, our economy, and our ecosystems—or it can collect dust in old reports on our bookshelves. The former is far more challenging than the latter, and that's why I love to come to work every day! |
|  | **Goldhaber, Martin B.:** I'm a geochemist working on landscape scale geochemical processes. I previously was the co-chair of the Bureau Science Strategy. I am COSSA Co-Chair and one of the organizers of the meeting. I also am the Co-Director of the Powell Center.<br><br>Profile: https://www.usgs.gov/staff-profiles/martin-goldhaber |

**Table 1–1.** Workshop participants and their backgrounds, in alphabetical order.—Continued

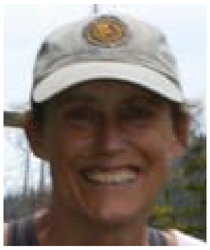
| Participant | Information |
|---|---|
|  | **Haines, John W.:** I'm Program Coordinator for the Coastal and Marine Geology Program and evangelist (gadfly?) for coordinated and ambitious USGS efforts to meet the science and information needs of coastal* communities, resource managers, and a whole lot of other "users." I'm a physical oceanographer, and I'm interested in integration of USGS observational capabilities and research to provide national, landscape-scale, and local forecasts of coastal* vulnerability and the physical, human, and environmental consequences of coastal* change to inform policy and management that reduces risk and enhances resilience. ***Substitute some other "landscape" for coastal and I'm still interested. |
|  | **Hay, Lauren E.L.:** I'm lead scientist for the Modeling of Watershed Systems group (https://wwwbrr.cr.usgs.gov/projects/SW_MoWS/index.html), National Research Program, Lakewood, Colorado. I'm a research hydrologist who is trying to improve our understanding of precipitation-runoff processes.<br><br>Profile: https://www.usgs.gov/staff-profiles/lauren-hay |
|  | **Hsu, Leslie:** I'm the coordinator for the USGS Community for Data Integration. My background is in geomorphology, debris flow erosion, bedload transport, geoinformatics, data models, and data systems for researchers. I'm currently very interested in tools for scientific programming and collaboration, and facilitating scientific communities of practice.<br><br>Profile: https://www.usgs.gov/staff-profiles/leslie-hsu |
|  | **Jenni, Karen E.:** I'm a Decision Scientist with the Science & Decisions Center. I am one of the organizers and facilitator for the workshop. I have spent my career as a professional decision consultant and was excited to bring those skills into the USGS when I arrived in the spring of 2016. My focus is on applying decision science tools to large-scale energy, environmental, and natural resource management issues; my passion is bringing people together to support resource management decisions with sound science. I have B.S. in Mathematical and Computational Sciences from Stanford University, and an M.S. and Ph.D. in Engineering and Public Policy from Carnegie Mellon University. Prior to joining the USGS, I was the founder of Insight Decisions, LCC, a Principal at Geomatrix Consultants, and a Senior Manager at Applied Decision Analysis. |

**Table 1–1.** Workshop participants and their backgrounds, in alphabetical order.—Continued

| Participant | Information |
|---|---|
|  | **Labson, Victor:** I am Director of the USGS Office of International Programs. As a research geophysicist, I have focused on the application of ground and airborne geophysical methods to quantitative imaging of the Earth with applications that include deep crustal mapping, mineral resource appraisals, geologic hazards, environmental contamination, national security issues, and water supply development and quality. As part of the *Deepwater Horizon* oil spill response, I led the Mass Balance Team of the Flow Rate Technical Group. My recent scientific focus has been on the understanding of the relation of the chemical and physical properties of the Earth to resultant geophysical phenomena. |
|  | **Lafferty, Kevin:** I am a marine ecologist with the Western Ecological Research Center, and am based at University of California, Santa Barbara (UCSB), where I am Associate Director of the UCSB Coal Oil Point Natural Reserve. My research focuses on infectious diseases in marine systems with regards to fishing, aquaculture, food webs, climate change, biodiversity loss, restoration, behavior, population regulation, endangered species, and introduced species. In addition, my work on malaria, schistosomiasis, and toxoplasmosis has relevance for how human health responds to global change. |
|  | **Ludwig, Kristin A.:** I'm a Staff Scientist in the Natural Hazards Mission Area. I'm a marine geologist, and I support the Department of the Interior (DOI) Strategic Sciences Group, which develops multidisciplinary scenarios to inform disaster response and recovery. I am interested in how science is best used, coordinated, and communicated across agencies, disciplines, and sectors to improve resilience. |
|  | **Milly, Paul C.:** I'm a Research Hydrologist and work on hydrology-climate interactions at a global scale. I do model development and application in this research. I'm stationed at National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey.<br><br>Profile: https://www.usgs.gov/staff-profiles/paul-christopher-damian-milly |
|  | **Morelli, Toni Lyn:** I'm a Research Ecologist with the Northeast Climate Science Center, based at the University of Massachusetts in Amherst. My research focuses on translational ecology, using field studies, geospatial analyses, ecological modeling, and genetic techniques to facilitate natural resource management and habitat and species conservation in the face of climate and land use change.<br><br>Profile: http://necsc.umass.edu/people/toni-lyn-morelli |

Table 1–1. Workshop participants and their backgrounds, in alphabetical order.—Continued

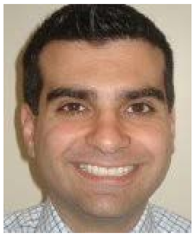
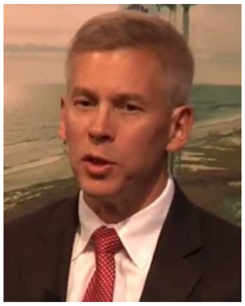
| Participant | Information |
|---|---|
|  | **Morman, Suzette A.:** I am a Research Geologist and a Registered Nurse since the early 1990s, I returned to school to pursue my interest in understanding environmental exposures to humans. My research interests include the use of *in vitro* bioaccessibility tests to examine geogenic materials and related health effects, exposure science, and natural disasters.<br><br>Read more: https://minerals.usgs.gov/science/geo-envir-health-models-min-deps/index.html |
|  | **Nassar, Nedal Talal:** I am Chief of the Materials Flow Section at the National Minerals Information Center based in Reston. As an industrial ecologist, I am keenly interested in applying a systems-based approach to gain a more complete understanding of human-Earth interactions and their impacts. Specifically, the section that I lead provides research and analysis on the global anthropogenic stocks and flows of nonfuel mineral commodities that are critical for the economy and national security. |
|  | **Newman, Timothy R.:** I'm the USGS Land Remote Sensing Program Coordinator. I'm responsible for managing the program that operates the Landsat satellites and provides the Nation's portal to the largest archive of remotely sensed land data in the world. I'm responsible for providing program policy, oversight, and guidance; formulating and executing budgets; interfacing with senior Administration and Congressional staff; building international Earth observation partnerships; and interacting with the aerospace and remote sensing industries. I also oversee the development of remote sensing science and applications. Before joining the USGS about 10 years ago, I served in the U.S. Air Force in a variety of space system assignments, including engineering, operations, acquisition, and future architecture design, retiring as a Lieutenant Colonel. |
|  | **Ostroff, Andrea:** I'm the Program Manager of the Fisheries Program in Ecosystems, Massachusetts, and USGS Drought Coordinator. I'm a biologist interested in connectivity of USGS science, programs, and people. |

Table 1–1. Workshop participants and their backgrounds, in alphabetical order.—Continued

| Participant | Information |
|---|---|
|  | **Read, Jordan S.:** I'm Chief of Data Science for the Office of Water Information. I study lake and reservoir responses to climate change and other stressors and lead a Data Science team that works on reproducible research, nontraditional science communication, and applications of scientific computing.<br><br>Profile: https://www.usgs.gov/staff-profiles/jordan-s-read |
|  | **Reed, Sasha C.:** I'm a Research Ecologist based out of Moab, Utah, and am part of the Southwest Biological Science Center. I am a biogeochemist, and so I really like tracking carbon, nitrogen, and phosphorus around Earth's terrestrial ecosystems (particularly drylands and tropical rain forests). Most of my research focuses on understanding how and why ecosystems respond to change, and with each project, I strive to determine the dynamic controls over fundamental processes with the ultimate goal of providing information to help maintain the functioning of our planet.<br><br>Profile: https://www.usgs.gov/staff-profiles/sasha-c-reed |
|  | **Shapiro, Carl D.:** I am the Director of the Science and Decisions Center and have been an economist at the USGS for many years. Our focus is on increasing the use and value of science in decision making with emphasis in five cross-cutting science areas: (1) ecosystem services; (2) decision science including adaptive management; (3) participatory science including crowd sourcing and citizen science; (4) natural resource economics including natural resource (ecosystem services) valuation and value of scientific information; and (5) resilience and sustainability. |
|  | **Smith, Richard A.:** I'm a Hydrologist with the National Water Quality Assessment Project (Water Mission Area) in Reston. I'm a developer of the SPARROW watershed model, and I'm interested in integrated physical and biogeochemical modeling of watersheds for the dual purposes of process understanding and water resources management. Most of my work has been at a large (regional) scale. I'm currently especially interested in the use of remotely sensed data in water quality forecasting. |

Table 1–1. Workshop participants and their backgrounds, in alphabetical order.—Continued

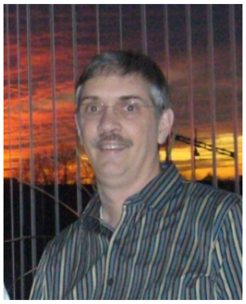
| Participant | Information |
| --- | --- |
|  | **Sanford, Ward E.:** I am a Research Hydrologist with the National Research Program (NRP) in Reston. My expertise is in groundwater flow and transport. I use numerical simulation and environmental tracers to better understand flow and transport processes. I have been working with the Chesapeake Bay Program to help quantify the movement of anthropogenic nutrients to streams and coastal systems, and I have been working with a team developing a national groundwater model of the contiguous United States that will simulate water table and base-flow responses to changes in climate. |
|  | **Sohl, Terry L.:** I'm a Research Physical Scientist at USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota. I'm a geographer and land-cover mapper and modeler. |
|  | **Stets, Edward (Ted):** I'm a Research Ecologist with the National Research Program in Boulder, Colorado. I study the biogeochemistry of fluvial systems (rivers and streams). I'm especially interested in how these systems respond to climate and anthropogenic forcing. I use a variety of tools in my work including primary field observation, modeling, data synthesis, and national-scale status and trend assessment. I have studied carbon more than anything else but am also interested in nutrients and major ion chemistry. My supervisor once welcomed me to the USGS by saying it's a job where you get a Ph.D. every 5 years. So far, that's been true with me and I really love it.<br><br>Profile: https://www.usgs.gov/staff-profiles/edward-stets |
|  | **Terando, Adam J.:** I'm a Research Ecologist (and climatologist) at the Southeast Climate Science Center. I study how large-scale anthropogenic drivers affect ecosystems and ecosystem processes. I mainly focus on modeling climate change and urbanization impacts in the Southeast and U.S. Caribbean, and am also interested in how natural resource decision makers can better use our science capabilities to craft adaptation strategies that will be robust and resilient. I'm also involved with the U.S. National Climate Assessment as the Coordinating Lead Author for the Southeast Region.<br><br>Profile: https://www.usgs.gov/staff-profiles/adam-terando |

**Table 1–1.** Workshop participants and their backgrounds, in alphabetical order.—Continued

| Participant | Information |
|---|---|
|  | **Tillitt, Donald E.:** I'm Branch Chief of Biochemistry & Physiology at the Columbia Environmental Research Center, Columbia, Missouri. I'm a research toxicologist with interests in the effects of anthropogenic chemicals on fish and wildlife populations, evaluation of causal linkages between chemical stressors and adverse outcomes in fish and wildlife, and development of sublethal indicators of chemical exposure. Additional research interests include untoward effects of vitamin B1 deficiency in fish and wildlife populations.<br><br>Profile: https://www.cerc.usgs.gov/StaffMembers.aspx?ContentId=328 |
|  | **Tischler, Mike:** I am the Director of the USGS National Geospatial Program (NGP). The NGP provides the digital geospatial foundation for the United States, and is responsible for designing, planning, and executing the national topographic mapping program. I provide management oversight and direction to the NGP including The National Map, the National Geospatial Technical Operations Center, the 3D Elevation Program, the National Hydrography Dataset, the U.S. Topo Map Series, research activities performed at the Center of Excellence for Geospatial Information Science (CEGIS), and geospatial data and information in response to natural disasters. I also serve as the DOI representative to the Domestic Names Committee of the U.S. Board on Geographic Names. Prior to joining the USGS, I worked as the U.S. Army Corps of Engineers Geospatial Research Laboratory in Alexandria, Virginia, providing strategic and technical oversight to a variety of basic and applied geospatial research projects. I earned my B.S. in Soil Science from North Dakota State University (2000), my M.S. in Soil and Water Science from the University of Florida (2003), and my Ph.D in Earth Systems and GeoInformation Science at George Mason University (2015). I live in Fairfax, Virginia, with my wife and twin 6-year olds. |
|  | **Toccalino, Patricia:** I'm Western Regional Program Officer for the National Water Quality Program. My expertise lies at the interfaces between environmental chemistry, toxicology, risk assessment, and contaminant fate and transport. I evaluate the occurrence and potential human-health significance of contaminants in drinking-water resources, including chemical mixtures and emerging contaminants.<br><br>Profile: https://www.usgs.gov/staff-profiles/patty-toccalino |
|  | **Wald, David J.:** I'm a Supervisory Research Geophysicist at the National Earthquake Information Center (NEIC), Golden, Colorado. My primary role is as leader of research, development, and operations of critical several real-time earthquake hazard and impact assessment systems here at the NEIC. These systems are used both for post-earthquake response as well as for pre-earthquake mitigation.<br><br>Profile: https://www.usgs.gov/staff-profiles/david-wald |

**Table 1–1.** Workshop participants and their backgrounds, in alphabetical order.—Continued

| Participant | Information |
|---|---|
|  | **Waldrop, Mark P.:** I'm Project Chief for the Mechanisms of Carbon Stabilization in Soil (MECCAS) Project. My background is in soil microbiology and biogeochemistry. I have a team of about 8 people. We work on the impacts of permafrost thaw on ecosystem carbon balance in Alaska (it's big!), and we work on understanding how soil organic matter is actually formed and sequestered, which is critical for creating good carbon cycle models.<br><br>Profile: https://www.usgs.gov/staff-profiles/mark-p-waldrop |
|  | **Wein, Anne:** I'm with the Western Geographic Science Center, Menlo Park, California, and I develop multiple hazard scenarios (earthquake, winter storm, tsunami) with Science Application for Risk Reduction (SAFRR). I coordinate and conduct analyses across multiple hazards, damages, and consequences (including economic). I study the communication of earthquake forecasts with GNS Science, New Zealand. I experimented with integrating science in serious (digital) games. I'm interested in tackling problems through multidisciplinary and multiorganizational collaborations. |
|  | **Weltzin, Jake:** I'm Program Manager for Status & Trends within Ecosystems, Massachusetts, and Director of the USA National Phenology Network. I'm a plant ecologist, science administrator, information manager, and program builder.<br><br>Profile: https://www.usgs.gov/staff-profiles/jake-f-weltzin |
|  | **Zimmerman, Christian E.:** I was recently named Center Director for the Alaska Science Center. I was a Research Fish Biologist for 14 years, and my research interests ranged from population genetics to the relation of physical drivers and biotic response in aquatic ecosystems. For the last 2 years, I have been Chief of the Water, Ice, and Landscape Dynamics Office at the Alaska Science Center. In this role, I worked with a team of scientists across the Water, Ecosystems, and Climate and Land Use Change Mission Areas that included water monitoring and investigations, glaciology, permafrost studies, fire science, landscape ecology, remote sensing, and fish/aquatic ecology. As a group, we took a landscape view of systems and collaborated on an integrated ecosystem study of a watershed with components that ranged from glaciers to the nearshore marine environment. On January 19th, I became the Center Director of the Alaska Science Center, an integrated science center with research that spans multiple mission areas and scientific disciplines.<br><br>Profile: https://alaska.usgs.gov/staff/staffbio.php?employeeid=211 |

# Appendix 2. Grand Challenge Summaries

As described in the main body of this report, participants and some members of the Council of Senior Science Advisors (COSSA) submitted potential grand challenges for integrated U.S. Geological Survey (USGS) science prior to the workshop, generating a set of almost 70 suggestions. During the workshop, we used discussion and a participatory, consensus-based approach to identify a more limited set for comprehensive discussion, leading to the four Overarching Grand Challenges and the Comprehensive Science Challenge (EarthMAP) described in the report. Potentially, many of the original or "incoming" grand challenges could have been fleshed out in similar detail. And in fact, several of them were expanded upon in the workshop but ultimately were not selected as overarching grand challenges, and after the workshop several participants provided additional information on a few of the contributed ideas for challenges.

For completeness and transparency, this appendix includes all of the original grand challenge descriptions as well as those further developed during and after the workshop. While the challenges are organized into categories of similar type, they are not edited for consistence or consolidated, and overlapping challenges have been retained—each is presented here as submitted.

In this appendix, we group the challenges into the seven categories listed below. Most are identified as being most closely related to one of the four overarching grand challenges or the comprehensive science challenge:

- Natural resource security
- Societal risks from existing and emerging threats
- Smart infrastructure development
- Anticipatory science for changing landscapes
- EarthMAP (Monitoring, Analyses, and Projections)

There were also two categories that were more focused on communication and delivery of USGS science, or on internal issues, than on challenges with broad societal consequences. In some cases, these challenges point to specific obstacles that will need to be overcome as we address the grand challenges:

- Science communication and delivery, and
- Internal USGS challenges.

Within each of these seven categories, we first present all of the challenges submitted by participants prior to the workshop. Each of these initial challenges was prepared following a short template, and each description has a similar structure. Challenges that were discussed during the workshop, and those that were expanded upon by one or more participants in the week following the workshop, are presented after the initial challenges. The level of detail and the types of description provided for these challenges varies significantly across the challenges.

Table 2–1 lists each of the challenges organized by the larger related challenge, by how or where the challenge was developed, and provides links to the longer description of each challenge.

Table 2–1. List of all challenges identified as part of the workshop process.

| | |
|---|---|
| **2.1 Challenges most closely related to the natural resources security grand challenge** | |
| **2.1.1** Challenges proposed prior to the workshop | Balancing competing societal needs in a changing climate<br>Science-informed tradeoffs for societal decision making<br>Supporting resource managers with integrated multi-resource assessment and analyses<br>Improve and implement feasible and rigorous methods to value our nation's natural resources<br>Cryosphere to oceans—Hydrology, biogeochemistry, and ecosystem response to physical drivers using a national water model<br>Continental cross site coordinated research to validate carbon cycle models and estimate carbon sequestration rates, patterns, limitations, vulnerabilities, and unknowns<br>Defining environmental baselines<br>Big landscape science<br>Global food security<br>Energy development—The good and the bad<br>LEWIS and CLARC—Land, ecosystem and water integrated survey (LEWIS) and climate and resource change (CLARC)<br>Molecular biology of geologic environments |
| **2.1.2** Challenges developed further during or after the workshop | Balancing uses of water for health and prosperity<br>USGS-led resources survey of the inner solar system (discussed by the group, then expanded upon after the workshop)<br>National-scale assessment of nature's value to society<br>Securing the Nation's mineral resource needs in the age of rare minerals<br>USGS Integrated Carbon Research and Resource Assessment (ICRRA) |
| **2.2 Challenges most closely related to the societal risks from existing and emerging threats grand challenge** | |
| **2.2.1** Challenges proposed prior to the workshop | Resilient systems<br>Reducing uncertainty in predicting risk from natural and human-caused hazards<br>Minimizing hazards to natural resources and the health and prosperity of our communities<br>Integrated flood science<br>Impacts of sea level rise<br>Understanding and managing fire as a catalyst for rapid and persistent landscape transformations under current and future climates<br>Future drought<br>Water and land deformation<br>A national biosurveillance network for emerging biothreats<br>Ecological and societal implications of rapid Arctic warming<br>Nutritional quality in altered ecosystems<br>Advanced risk research and applications<br>Incorporating climate science despite uncertainty |
| **2.2.2** Challenges developed further during or after the workshop | Coastal change—Complex drivers, myriad consequences<br>National climate response metrics<br>Science to reduce risk where tectonic plates collide<br>Predict and mitigate harmful effects of freshwater eutrophication<br>Past, present, and future interactions among land use, water, and vegetation under anthropogenic and climatic drivers of change |

**Table 2–1.** List of all challenges identified as part of the workshop process.—Continued

| | |
|---|---|
| **2.3 Challenges most closely related to the smart infrastructure development grand challenge** | |
| **2.3.1** Challenges proposed prior to the workshop | Role of earth subsurface/surface processes in infrastructure planning<br>Infrastructure—Interconnectivity of our science and the built environment |
| **2.3.2** Challenge developed after the workshop | Understanding the impacts of proposed geoengineering activities |
| **2.4 Challenges most closely related to the anticipatory science for changing landscapes grand challenge** | |
| **2.4.1** Challenges proposed prior to the workshop | Predict and mitigate impacts of changing connectivity on human and ecological health<br>National synthesis of species sensitivities to climatic changes<br>Ecosystem adaptation<br>Ecological forecasting: An emerging imperative<br>Importance of Subseasonal-to-Seasonal (s2s) climatic forecasts to environmental prediction and risk Management<br>Short-term prediction capabilities<br>National-scale hydroclimatic forecasts based on seasonal andand low-frequency SST variability<br>Improving spatial information at the field scale of resolution (20 m) for predicting disturbance occurrence, effects, and resistance/resilience<br>Anticipate Environmental (ecological), societal, and economic impacts of snow, ice, and permafrost change |
| **2.4.2** Challenges developed further during or after the workshop | Environmental forecasting in the short and near term |
| **2.5 Challenges most closely related to integrated modeling for the EarthMAP comprehensive science challenge** | |
| **2.5.1** Challenges proposed prior to the workshop | Development of a National Land System Model (NLSM)<br>Quantifying Earth system processes (Earth “gaging”)<br>CONUS integrated modeling framework to assess impacts of climate change on biological, geological, and hydrological resources<br>Near-real-time model updating and data integration<br>National land-system model framework and parameterization |
| **2.5.2** Challenges developed further during or after the workshop | Creation of TERRACAST—A modular modeling system for multidisciplinary land and water forecasting for the Nation<br>Vision 20-21— Hindcasting, forecasting, and nowcasting of the Nation’s land and water over the 20th–21st Centuries through system modeling |
| **2.6 Challenges most closely related to science communication and delivery** | |
| **2.6.1** Challenges proposed prior to the workshop | Making science personal<br>Intelligently and systematically select and use the most appropriate data and information amidst the current and coming data deluge<br>Improve decision-making through better communication and translation<br>Future-ready data systems<br>Integrated science data<br>Employ intelligent systems to capitalize on the inter-related roles of people, computers, and information<br>Heads-up (push) spatially controlled notifications of real events<br>Demonstrating and evaluating the value of scientific information (VOI)<br>Communication, relevance, and use of USGS science<br>The value of science multiplies with translation<br>Science communication—Continuous, coordinated, conversation |

**Table 2–1.** List of all challenges identified as part of the workshop process.—Continued

| | |
|---|---|
| 2.7 Internal USGS challenges | |
| **2.7.1** Challenges proposed prior to the workshop | Reproducibility and science reporting |
| | Incentivizing actionable science |
| | Relevant science metrics |
| | Integrating economics and the social/behavioral sciences into USGS' science portfolio |
| | Science of solutions |
| | Strategic portfolio allocation across axes of science engagement |
| | Scientific entrepreneurship |
| | Interdisciplinary infrastructure—Semistovepipe technologies |
| | Planning across the science continuum |
| | Focus on programs and end goals, not projects |
| | Role of postnormal science in the prioritization of USGS science |
| | Diversifying the Bureau |
| | Strategic bureau management—From blue sky to muddy boots |

## 2.1 Challenges Most Closely Related to Natural Resource Security

### 2.1.1 Challenges Proposed Prior to the Workshop

#### Balancing Competing Societal Needs in a Changing Climate

Click to
Return to list of related challenges

**Problem statement:** Climate change is altering hydrologic regimes, warming inland waters, and indirectly and directly impacting ecosystem services. Competing societal needs, such as clean water and domestic food, place additional demands on our Nation's land and water resources. We need a framework that supports retrospective analysis and enables us to ask prospective policy and management questions.

**Science and/or society impact:** Balancing competing societal needs in a changing climate will be one of the greatest environmental challenges of the century.

**Scope of integration:** In order to understand the impacts of climate change and interactions between various coupled human-natural systems, we need to develop a knowledge framework that traverses our traditional disciplinary divides. Integrated process-based modeling combined with innovative data practices will create connections between Mission Areas, and challenge and inspire our technical staff.

#### Science-Informed Tradeoffs for Societal Decision Making

Click to
Return to list of related challenges

**Problem statement:** We all make decisions every day that affect the planet. Some of them have immediate effect while others take decades or centuries to become measurable. We're in a race against time to begin making wiser decisions as a global human society if we are to retain viability of our planetary home, and we cannot continue conducting our affairs in the same way if we are to do so.

**Science and/or society impact:** Imagine being able to ask a simple "should I…?" question at a personal to community scale and have the "web of science" respond with the current best estimate of possible scenarios that might play out in response to that decision

**Scope of integration:** The USGS needs to be a major contributor to and consumer of a developing global seamless data network in which all of our scientific information is organized and fully mobilized for immediate use and application to science questions and societal decision analysis.

#### Supporting Resource Managers with Integrated Multiresource Assessments and Analyses

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**Problem statement:** Land and resource managers want to make wise decisions that will not be second-guessed, inherently flawed, or result in catastrophic disaster. They need those decisions to be backed up by good science that addresses all the resources they manage, how they affect each other, and how changes in those resources affect people who use them.

**Science and/or society impact:** Equipping managers with good integrated science about multiple natural resources in terms that communicate well with stakeholders will improve decision making and remove roadblocks to action.

**Scope of integration:** This challenge requires integration between all USGS disciplines, as well as collaboration with the land and resource managers who use (or who could use) USGS science products.

## Improve and Implement Feasible and Rigorous Methods to Value our Nation's Natural Resources

Click to
Return to list of related challenges

**Problem statement:** Many natural resources such as clean water or storm protection from barrier islands are not valued in markets, even though they can have significant societal benefits. Decision makers need information on these values in order to understand tradeoffs and to make informed resource management decisions.

**Science and/or society impact:** Understanding natural resource values will facilitate consideration of tradeoffs and advance informed resource management decision making. It will also increase the use and value of scientific information by extending its use in resource management decisions.

**Scope of integration:** Valuing natural resources requires integration of biological and physical science with economic and social science information across different landscape scales.

## Cryosphere to Oceans—Hydrology, Biogeochemistry, and Ecosystem Response to Physical Drivers Using a National Water Model

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**Problem statement:** Changes in permafrost and glaciers pose significant challenges and have implications to freshwater and nearshore ecology (nationally important commercial and subsistence fisheries), hydrologic threats to infrastructure, and oceanographic and sea-level change. These changes have societal impacts to all coastal communities.

**Science and/or society impact:** Spatial and forecasting tools that allow society, policy makers, and resource and community planners to plan for the range of possible future conditions will play an important role in minimizing risk in future planning scenarios.

**Scope of integration:** The USGS is uniquely poised to integrate its expertise in hydrology, glaciology, geology, and biology, toward the goal of forecasting hydrologic, terrestrial, and ecosystem response built upon a national water model.

## Continental Cross-Site Coordinated Research to Validate Carbon Cycle Models and Estimate Carbon Sequestration Rates, Patterns, Limitations, Vulnerabilities, and Unknowns

Click to
Return to list of related challenges

**Problem statement:** Guidance regarding biological carbon sequestration on U.S. lands is lacking. There is no cross-continental network of sites to provide quantitative information on carbon sequestration that is coordinated (for cross-site synthesis), flexible (to allow hypothesis driven research), and user focused (to provide directed information to decision makers).

**Science and/or society impact:** Fills a crucial data need in a future commodity (carbon) critical to mediating global change, for which pools and fluxes are poorly constrained and models have large error.

**Scope of integration:** Multisite coordination, multidisciplinary in scope, from across sites accessed by the USGS requires new thinking in terms of cross-site synthesis and data integration.

## Defining Environmental Baselines

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**Problem statement:** Defining baseline conditions is a critical step in most environmental assessments, including those conducted by governmental and nongovernmental organizations for a broad array of ecosystems. But the science required to determine appropriate baselines for most environmental metrics is complicated by a paucity of reference sites unaffected by human activities; natural variation in appropriate metrics, with the resulting need to adjust for time and place; and practical issues surrounding the choice of baselines, and the resulting need to offer a range of alternatives.

**Science and/or society impact:** Comparison of current environmental conditions to those largely unaffected by human activities is often required by regulation; natural baselines are also inherently interesting points of comparison in most environmental issues. Improving the science behind the establishment of environmental baselines will carry large societal benefits in establishing water and air quality standards to biodiversity assessments, and to valuations of economic losses caused by natural disasters.

**Scope of integration:** Scope of this challenge covers all Mission Areas of the USGS because interest exists for essentially all environments and ecosystems, and is a required task for many governmental and nongovernmental organizations.

## Big Landscape Science

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**Problem statement:** Particularly in these times of nonsteady state dynamics, understanding how ecosystems function and respond to change is both critical and difficult.

**Science and/or society impact:** It would be powerful to achieve large and difficult missions through a coordinated effort of multiple groups.

**Scope of integration:** The USGS is uniquely capable of addressing complicated landscape questions because of (1) our ability to do long-term research (in other words, not as connected to the academic 3-year funding cycle) and (2) the incredible breadth and depth of our expertise and tools. We could improve our cross-system, cross-center, cross-Mission Area coordination to better focus on ecosystem issues such as drought, energy development, and climate change.

## Global Food Security

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**Problem statement:** The threat of famine is a persistent global issue that goes beyond the predictive abilities of today’s Famine Early Warning System. Drought is a primary predictor, but natural hazards such as earthquake and volcanic eruption, wildfire, and wildlife, livestock, and human disease originating in wildlife should be better incorporated.

**Science and/or society impact:** Potential for preserving lives and quality of life.

**Scope of integration:** All components of the USGS.

## Energy Development—The Good and the Bad

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**Problem statement:** We rely on large amounts of energy, and acquisition of both traditional and alternative energy has enormous effects on our land and water systems (including public lands).

**Science and/or society impact:** A unified, national approach for determining the potential for and consequences of different types of energy acquisition could help support decisions about where, when, and how to incorporate different energy sources into our national energy portfolio.

**Scope of integration:** Work would vastly improve our understanding of and decision making about energy extraction and production. Incorporate a "systems approach" to evaluating and contextualizing energy development within an ecological framework.

## LEWIS and CLARC—Land, Ecosystem and Water Integrated Survey (LEWIS) and Climate and Resource Change (CLARC)

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**Problem statement:** What are the critical interdependencies among the Nation's land, water, and ecosystem resources; and how do these interdependencies respond to changes in climate and resource management?

**Science and/or society impact:** LEWIS will be dedicated to observations and database integration, while CLARC will be committed to understanding processes and interdependencies. By investing in the integration of existing datasets with ongoing observations of land, water, and ecosystem resources, and by applying these data to the understanding of critical interdependencies, the USGS can become a much more significant contributor to interagency plans and programs.

**Scope of integration:** This program would (1) gather and integrate information across the multiple land, water, and ecosystem resources that are susceptible to climate change and human management; (2) integrate historical information with ongoing observation of changes in these resources in order to provide a continuous long-term record of the complex interactive effects of past and present climate and human influences; and (3) meet the public need for integrated resource information that can be used by resource managers and citizens who are concerned about critical interdependencies.

## Molecular Biology of Geologic Environments

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**Problem statement:** There has been a revolution in genomic sciences such that genomics can now reveal system history, behavior, and evolution. Genomics is the basis of biological disciplines but has not fully transferred to geologic disciplines. It has the potential to tell us a great deal about the deep subsurface, deep time, and system evolution.

**Science and/or society impact**: Molecular data by its very nature is data rich and could provide additional insight into the history and functioning of soils, sediments, and ecosystems.

**Scope of integration:** Multiple types of geologic studies utilizing core stratigraphy, age gradients, and depth profiles can be integrated with genomic analysis of microbial communities. Implementation would require continued investment in genomics and/or partnerships with external agencies such as the DOE and the Joint Genome Institute.

### 2.1.2 Challenges Developed Further During or After the Workshop

The challenges presented below represent ideas that were developed during the workshop (balancing uses of water for health and prosperity) and several that were expanded on by one or more workshop participants after the workshop. We did not request a specific format or a specific level of detail for the challenges developed after the workshop, so there is a great deal of variability in some of the descriptions in this section. As with the "Overarching Grand Challenges" in the main report, more work will be required to move from any of these ideas to clear research goals and strategies.

#### Balancing Uses of Water for Health and Prosperity

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The challenge of balancing uses of water for health and prosperity was fully discussed and developed during the workshop. 0 presents the value proposition summary for this challenge in the same format as those presented in the main text.

Table 2–2. Balancing Uses of Water for Health and Prosperity challenge summary.

| | |
|---|---|
| Vision | The U.S. Geological Survey will help to minimize conflict and risk related to competing uses of water by providing science and tools that clarify the competing demands and tradeoffs, enabling both rapid decision making and long-term planning. |
| Why is this important? | Growing demands for water (for example, ecological needs, agriculture, energy development, industry, domestic supply) plus the possibility of decreasing quantity and quality from natural and anthropogenic stressors require society to balance competing demands. |
| What obstacles need to be overcome? | Fragmented resources and internal business model make sharing resources difficult.<br>Lack of data scientists.<br>Information technology infrastructure limitations; need to be able to accommodate real-time data collection and processing.<br>Lack of interdisciplinary modeling capacity and data exchange. |
| Strategies or the way we work | Conducting interdisciplinary research including planned and coordinated monitoring.<br>Creating and using strong, comprehensive observation networks.<br>Optimizing the existing monitoring network.<br>Strengthening and adding to the monitoring networks, especially through new innovative technologies such as ecological indicators, water-quality indices, soil moisture, snow pack, and seamless topography/bathymetry.<br>Leveraging external data streams.<br>Promoting interoperability of community data sources. |

**Table 2–2.** Balancing Uses of Water for Health and Prosperity challenge summary.—Continued

| | |
|---|---|
| Example products | Multiscale (temporal and spatial) tools for improving situational awareness from local to regional to national and global scales.<br>Early Warning System—network of real-time sensors and ecological indicators to provide warning of water shortages or pending conflicts, and to enable rapid response.<br>Hindcasts.<br>Forecasts on multiple timeframes—subseasonal to seasonal, interannual, decadal.<br>Tools that facilitate "citizen science" by enabling the public to report on local conditions, and that in turn report real-time on local conditions and also serve as educational forum. |
| Key stakeholders | Public health, industry, agricultural users, water agencies, land managers, infrastructure planners, and natural resource managers. |

### New and Emerging Science

Whatever new science and technologies emerge, the USGS is sufficiently adaptable in that we will be able to incorporate those advances into our data collection, modeling, and forecasting. Of particular relevance for this grand challenge is the very rapid growth of all types of earth observation data (for example, soil moisture) and the expansion of sensor technology (for example, the ability to remotely measure organic contaminants). The Water Mission Area expects to have a national groundwater model completed within the next 4 years.

### Possible Next Steps

Because of the large size of this challenge, our near-term focus will be on understanding the issues and supporting decisions about balancing water needs under a drought situation in a particular region. In the first year of work, we will:

- Identify available hydrologic and ecologic data resources and their suitability and quality for this purpose. Based on that understanding, we will:
    - Determine data gaps,
    - Optimize and strengthen existing sampling networks, and
    - Plan new data collection efforts.
- Identify interoperability opportunities with cooperators and with ourselves.

Within the 4-year timeframe, we will:

- Understand linkages between assets identified above,
- Conduct sensitivity analyses (for example, scenarios of increasing or decreasing water supply), which brings in cross-Mission Area expertise,
- Combine with process-based ecological models, and
- Work iteratively with stakeholders to build the scenarios they are interested in and results and outputs that they need.

In the longer term, we will build geospatial tools that combine changes in geochemistry, bathymetry, and other factors, from headwaters to the coast, and provide tools to inform people of risks and to reduce the chances of catastrophic drought impacts on ecosystems, drinking-water supplies, or agriculture, and so on.

## USGS-Led Resources Survey of the Inner Solar System

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**Problem statement:** As the government and private sectors continue to explore space and eventually colonize the Inner Solar System, there is a need to identify the natural resources of the rocky planets and asteroids required to build and sustain this effort, as well as to provide scientific expertise to guide resource extraction.

**Science and/or society impact:** Akin to the need to survey the U.S. West in the 1800s—the original mission of the USGS—we could establish ourselves as a leading agency in an exciting, future-oriented mission based on our core capabilities. USGS expertise could help drive the Nation's Inner Solar System exploration activities, provide needed direction and focus to NASA, deliver good cross-disciplinary science, and serve U.S. business interests in the economic exploitation of these resources. The potential benefits to industry and the American public would resonate throughout our society.

**Scope of integration:** Integrates multiple USGS capabilities, including energy and minerals for identification and optimal extraction techniques, astrogeology for mapping, remote sensing for optimizing sensing technologies, ecosystems to identify potential ecological resources and life forms, environmental health to investigate exposures to microbes and inorganics, hazards to better understand mitigation of asteroid impacts, and water for engineered water sources (for humans and propellant).

**Vision:** Working with the National Aeronautics and Space Administration (NASA) in the coming decades, the USGS intends to expand our capabilities in both the terrestrial and extraterrestrial dimensions, improving our knowledge of the Earth, and mapping the natural resources of asteroids and planets, while providing our geologic, hydrologic, biologic, and remote sensing expertise to develop the assessments needed for the Nation's exploitation of Solar System resources.

### Possible Next Steps

In the first year:

- Establish a multidisciplinary USGS Solar System Survey Team, with geologic, hydrologic, biologic, and remote sensing expertise; define scope, charter, plan of work, and a regular meeting schedule.
- Develop and approve an agreement with NASA on its Asteroid Redirect Mission (ARM) to provide technical assistance to NASA and provide the USGS with experience in collecting the data needed for resource assessments; assist NASA with selection of the target asteroid, to include characterization of the natural resource potential of ARM targets; also assist NASA with selecting the boulder to be returned, ensuring inclusion of a sample that includes water and/or water ice, if possible.
- Determine resources needed to extend USGS spectral libraries to asteroids (need for collecting spectra in vacuum, variety of grain sizes, irradiation levels).
- Determine resources needed to create a systematic and reliable database on the petrology and composition of meteorite samples (this does not currently exist but is a prerequisite for usable asteroid resource assessments).
- Expand partnerships with groups collecting spectra of asteroids to build a systematic catalog (the current catalogs created by the astronomy community are too incomplete and disparate for resource assessments).

- Complete USGS studies in asteroid mineral identification from recovered meteorite sample spectra.
- Compile a virtual compendium of all current USGS astrogeology holdings charting natural resources across the Solar System; begin planning for the significant increase in data holdings coming in future years.
- Begin partnering with commercial companies interested in “off-world” mining; compile user needs, establish cooperative research agreements, and host the first USGS-sponsored workshop dedicated to the Solar System Survey.
- Partner with NASA’s existing Centennial Challenge team to design a challenge unique to this mission (perhaps a Regolith Sample Spectral Characterization in Low Earth Orbit); issue a request for information (RFI) with NASA in 2017 and plan for a technology demonstration the following year.
- Conduct an economic analysis that examines the current supply and demand dynamics of targeted resources (platinum group metals and water) and evaluates the economics of recovering these from near-Earth objects.

By the end of the fourth year:

- The multidisciplinary USGS Solar System Survey Team, with geologic, hydrologic, biologic, and remote sensing expertise, will be considered the preeminent body for providing resource assessments of the Inner Solar System, providing crucial and reliable data to U.S. Government and business decision makers.
- The USGS will be an important partner to NASA in its Asteroid Redirect Mission (ARM), providing expertise based on natural resource exploitation potential; this mission will have launched by 2021; the USGS will have a leadership role in in-place resource utilization assessments.
- The first formal USGS resource assessment for asteroids will be published; this compendium of all currently identified natural resources across the Solar System will be the “go-to” report for companies interested in “off-world” mining; the USGS will be a key player in maintaining catalogs of asteroid spectra.
- The USGS will serve as the requirements provider for the NASA-built survey missions, as well as the technical advisor for natural resource extractions; the USGS will archive and disseminate all scientific data collected.
- The USGS will partner with commercial companies to provide technical advice regarding asteroid site selection for resource extraction; in return, these companies will allow the USGS to host and share their data.
- The annual USGS-sponsored workshops dedicated to the Solar System Survey will grow in size and scope every year, with hundreds of representatives from every major firm anticipating future business opportunities in space, and including representatives of Congress and international partners.
- The USGS will partner with NASA on new “Centennial Challenges” every year, leading to more complex missions proving advanced concepts.

## National-Scale Assessment of Nature's Value to Society

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**Problem statement:** The benefits nature provides—known as ecosystem services—are critical to the Nation's prosperity and well-being; yet, aside from a growing number of case studies, our ability to track and predict these services, their values, and changes over time remains limited at the national scale.

**Science and/or society impact:** Abundant and diverse scientific discovery is possible through synthetic, integrative study of human-natural systems. Better understanding of the benefits nature provides may lead to increased societal benefits through improved natural resource management; increased understanding of and coherent tradeoffs between food, energy, water security, and human health; better understanding of cost-efficiencies and co-benefits to be gained from "green infrastructure;" and improved private-sector environmental management.

**Scope of integration:** Understanding nature's benefits requires integrated analysis of biophysical systems (for example, ecology, hydrology) and socioeconomics. Watershed and landscape scale studies (typically using field data as inputs) must be scaled up and integrated with satellite remote sensing. Socioeconomic research must be designed to allow national scale application. Ecosystem services is a cross-cutting theme that touches all USGS Mission Areas.

**Vision:** The USGS is a leader in producing a national ecosystem service assessment—first produced every 4–5 years and eventually annually. The assessment is spatially explicit at high resolution (for example, 30 m), uses consistent data and methods over time (generates useful time series), and includes both biophysical measures and monetary values as appropriate. The data are well integrated with the national economic accounts and provide a clear picture of the value nature provides to the Nation's economy and society.

### Possible Next Steps

By the end of the first year, outcomes of this work will be:

- The USGS has a strong understanding of the data and metrics needed by Federal agencies and the private sector to make better natural resource decisions, and how as an agency it can add unique value to a national ecosystem service assessment.
- The USGS works with its own scientists, agency partners, and academics to (1) understand key data sources and gaps, including which observation systems/platforms can best address data gaps; (2) screen the best existing data and models; (3) develop science strategies to fill data gaps; and (4) use existing data and models to produce proof-of-concept national assessment data. This includes strong intra- and inter-agency teams that share a common goal and vision.
- The USGS develops an initial national, time series assessment for select ecosystem services (dating back to, for example, 2001) on a 5-year basis and works with its scientific partners to critique and refine its data and methods.
- The USGS and its partner researchers develop an actionable strategy to fill data gaps, including scaling up monetary values to the national scale.

At the end of 4 years:

- The USGS has strong buy-in for production of national ecosystem service data. There is demand for regular production of the assessment and its use in decision making.

- Strategies are under development to address complex scientific challenges in ecosystem services prediction (for example, to more fully understand interactions between ecosystem service demand, reliability, risks, and vulnerabilities).
- There are clear roles for partners to inform this effort within and outside the agency.
- Data and models have been integrated to the point where they can be easily updated with the introduction of new data sources (for example, to re-backcast a time series using new data/methods or to expand to a new additional year's data). This provides a clear picture of how natural systems change affects the capacity to deliver services demanded by the Nation.
- Interpolation and extrapolation methods have been tested to determine the needed frequency of primary data collection and understand how to best interpolate/extrapolate key data sources.
- Tangible progress on valuation data makes its incorporation into the assessment possible to an increasing degree.
- Ecosystem services data are beginning to be generated on an annual basis and incorporated into national economic accounts

## Securing the Nation's Mineral Resource Needs in the Age of Rare Metals

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**Problem statement:** Demand for mineral resources continues to grow with an increasingly affluent global population. This is especially the case for the geologically scarce minor metals for which demand has increased markedly with the rapid advancement of technologies that require their use. Examples include highly specialized applications such as renewable energy generation and storage technologies, high-temperature super alloys for jet engines, and night vision equipment. Uninterrupted access to these minor metals is thus crucial for both economic development and national security. A confluence of factors, including the concentration of production in a few politically or socially unstable countries, lack of adequate substitutes, and little to no postconsumer recycling, has raised concerns regarding the reliability of supply for minor metals on which the United States is currently highly import reliant.

**Science and/or society impact:** Impacts include: (1) improving the reliability of supply by reducing the import reliance of the United States, especially the reliance on countries that may not be entirely stable or friendly to the United States; (2) increasing the competitiveness of the U.S. industrial base; and (3) reducing potential impacts on human health and ecosystems

**Scope of integration:** The USGS is uniquely positioned to not only provide a better understanding of this multifaceted problem but to also provide valuable insights into possible solutions that may alleviate the risk of a supply restriction and reduce our import reliance. This grand challenge requires the involvement of virtually all Mission Areas in characterizing the potentially available resources (both below and above ground) in the United States and quantifying the energy, water, and land use requirements, as well as the impacts on air, water, ecosystems, and human health that would result from the development of the most promising subset of those resources. This task also requires an understanding of future resource requirements under conditions of changing global and domestic demographics, affluence, urbanization, security, and climate, as well as the potential for supply disruptions from natural hazards that could impact mining and processing operations and related critical infrastructure. Other Federal agencies that could be involved are the Department of Commerce (DOC), the

U.S. Environmental Protection Agency (EPA), the Bureau of Land Management (BLM), the Department of Homeland Security (DHS), the Department of Defense (DOD), and the Department of Energy (DOE).

Table 2–3. Securing the Nations Mineral Resource Needs challenge summary.

| | |
|---|---|
| Vision | Risk of resource supply disruption is minimized resulting in (1) reduced reliance (and, in turn, increased leverage) on unstable or unfriendly nations; (2) increased competitiveness of U.S. industries; and (3) reduced potential impacts on human health and ecosystems. |
| Why is this important? | Uninterrupted access to mineral and energy resources is crucial for both economic development and national security. A confluence of factors has, however, raised concerns regarding the reliability of supply of some of the resources on which the United States is currently highly import reliant. |
| What obstacles need to be overcome? | Organizational silos inherent in Mission Areas. |
| Strategies or the way we work | Integrating science and analyses across Mission Areas.<br>Engaging with external partners across Government and industry.<br>Developing products iteratively and updating them regularly. |
| Example products | An early-warning system that identifies which resources are at the highest risk of a supply disruption updated on an annual basis. This would include resource supply and demand scenarios.<br>An assessment to determine which set of strategies (for example, supply diversification, substitute development, enhanced recycling) is most effective at reducing said risk.<br>A comprehensive and continuous assessment of domestic energy and mineral resources including mineral resources above ground (for example, contained in materials that are currently in-use that can eventually be recycled) under various economic and technological scenarios.<br>An assessment of energy, water, and land use requirements needed to develop specific domestic resources and the impacts on air, water, human health, and ecosystems that can be expected if said resources are developed. This would include a comparison against the impacts that result from current (foreign) operations to determine potential net environmental benefits from developing domestic resources. |
| Key stakeholders | Other Federal agencies (for example, Defense Logistics Agency, Department of Homeland Security, Department of Energy, Department of Commerce, Department of State, intelligence agencies), and industry (producers and users). |

## USGS Integrated Carbon Research and Resource Assessment (ICRRA)

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**Problem statement:** Many of the Nation’s natural resources are sustained and constrained by the cycling of carbon. Guidance regarding carbon management is focused on carbon sequestration but does not provide information needed by resource managers to anticipate the diverse impacts of carbon-cycle change on land, water, and ecosystem resources.

**Society and/or science Impact**: Fills a crucial data need in an increasingly important resource (carbon) with growing economic potential and increasing consideration in land management decisions. Carbon is also critical to mediating global change, yet future projections of Carbon storage and cycling under different management and climate scenarios are poorly constrained

**Scope of integration:** This effort would integrate the full breadth of USGS multidisciplinary carbon expertise, which extends across all Mission Areas and reflects scientific support of the extensive DOI resource management portfolio. Site-specific studies would be integrated with multiscalar models and synthesis products. Research focused on process understanding would be integrated with the resource assessment needs and focus of stakeholders. The scientific scope would go beyond the current focus on carbon mass and greenhouse gases. The effort would provide information about changes in the cycling of carbon related not only to climate but also to changes in land and water management practices.

**Vision:** The USGS provides scientific information required by the Department of the Interior (DOI) to manage a substantial extent of the Nation's natural resources. As part of fulfilling this mission, USGS scientists study a vast array of carbon cycling processes that are intrinsic to diverse resources and locations. The breadth of this expertise is used by the DOI's extensive management portfolio, which includes offshore resources, water resources, fossil fuels, minerals, forests, rangelands, wetlands, parks, and wildlife refuges. By combining carbon research with wide-ranging resource assessment, the USGS provides information about changes in the cycling of carbon related not only to climate but also to changes in land and water management practices. This broad perspective is essential to understanding the dynamic web of interactions that link changes in carbon cycling across multiple locations, scales, and processes. By integrating carbon research and comprehensive resource assessment, the USGS provides cutting-edge science needed to support wise resource management and to inform societal decisions concerning resource utilization.

Key stakeholders include the carbon research community, academic researchers, land managers (for example, BLM, U.S. Fish and Wildlife Service [FWS], The Nature Conservancy, The National Park Service [NPS], U.S. Department of Agriculture [USDA]), and economists interested in the cost of carbon and carbon markets.

### Possible Next Steps

To kick this effort off, immediate support from the Executive Leadership Team and Program Managers would be used to:

- Help fund a workshop to bring the carbon research community together;
- Provide flexibility in research goals of individual researchers such that they can be more involved in a networked integrated project; and
- Provide resources for travel, database activities, and to fill identified gaps in methods/approaches at individual locations.

By the end of the first year, the goal will be to:

- Establish the network of USGS carbon research community (CRC) scientists and site locations.
- Have a workshop with the CRC to determine common research questions and the degree of overlap in methodologies, approaches, and ecosystems within the study. Examine current carbon model forecasts for carbon sequestration and loss at site locations. Discuss model-data fusion, initial science questions to address, database and standard operating procedure requirements, gaps in expertise, and funding and other opportunities. Define scope, write a charter, and design a plan of work and a regular meeting schedule.

In the 4-year time frame:

- The multisite multidisciplinary USGS CRC will have a mature network of sites, common methods and approaches and hypotheses to test, a common database structure to work together effectively, and several synthesis meetings to write several papers. The questions to be addressed within the first 4 years by this network could include:
  - What are appropriate methods with which to quantify carbon accretion or loss across multiple temporal and spatial scales?
  - What are the biggest uncertainties in our ability to assess, model, and manage for carbon?
  - What factors increase the vulnerability and resiliency of soil carbon in different landscape settings?
  - How do we identify hot spots of carbon vulnerability or opportunities for sequestration?
  - How well do studies constrain carbon mass balance within ecosystems? Are we missing major fluxes such as lateral fluxes, deep dissolved organic carbon losses, or losses due to erosion?
- Integrated science will be used to assess impacts and tradeoffs to other resources under multiple climate and land use change scenarios. Questions include:
  - How does uncertainty in estimation of biological carbon sequestration affect the value of carbon as natural capital?
  - How can different land management strategies affect the future state of carbon in the landscape?

## 2.2 Challenges Most Closely Related to Societal Risk from Existing and Emerging Threats

### 2.2.1 Challenges Proposed Prior to the Workshop

#### Resilient Systems

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**Problem statement:** In a world of constant change, communities (and the systems that support these communities) need to be more resilient and adaptive to disruptions. Human systems rely upon the availability of dependable resources. Environmental variability, climate change, and economic cycles can interact to cause disruptive change in resource availability. Our ability to anticipate and manage for disruptive change requires improved understanding of how to make systems resilient and/or adaptable to change.

**Science and/or society impact:** A successful outcome will enable better anticipation, recognition, avoidance, and management of disruptive environmental change.

**Scope of integration**: Resilient societal systems can be promoted through near-term forecasting, contingency planning, and understanding the structure of tipping points and discontinuities.

## Reducing Uncertainty in Predicting Risk from Natural and Human-Caused Hazards

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**Problem statement:** People are increasingly exposed to natural and human-caused hazards and associated risks. Decision makers from all sectors require actionable and often tailored information to improve situational awareness and mitigate adverse consequences.

**Science and/or society impact:** The USGS will provide knowledge and tools for reducing risk to health, well-being, prosperity, and the natural resources that underpin society.

**Scope of integration:** Iterative product development between users and scientists will enable incorporation of the best science, tailored to user needs, into hazard assessments and risk products. Requires an enterprise safety management framework, collaboration, supporting infrastructure, integrated science, baseline establishment, and a past, present and future perspective.

## Minimizing Hazards to Natural Resources and the Health and Prosperity of Our Communities

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**Problem statement:** The Earth provides water, air, soils, energy, minerals, and other natural resources that are critical to our health, well-being, and economies. Natural and man-made disasters such as hurricanes, spills, and other hazards threaten the natural resources that fuel the Nation's economic sectors, offer recreational opportunities, and provide sustenance for healthy and prosperous communities.

**Science and/or society impact:** Society will benefit from science products that help prioritize and balance decisions regarding threats to health and economy. The mutual benefits from these products will be realized in private industry and municipalities, as well as our communities and families.

**Scope of integration:** The integration of data, tools, and models require collaborative research among experts in public health, natural resources, and related Earth and biological sciences, as well as economics.

## Integrated Flood Science

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**Problem statement:** Flood is one of most destructive natural hazards in terms of economic damage, and global flood damages to natural, rural and urban landscapes and infrastructures have risen steeply over the past half century. Floods are essential for many ecosystem, geomorphological, and agricultural practices.

**Science and/or society impact:** Rapid response capability in the face of flood forecasts and eventual flood impacts.

**Scope of integration:** The USGS's unique range of skills bear on understanding, prediction, and responses to major floods. These skills include hydrography, hydrology, hydraulics, geomorphology and sediment transport, engineering, paleoscience, flood geology, biology and habitats, geography, inundation modeling and mapping, remote sensing, hazards planning mitigation and recovery, water quality, and economics. We have an opportunity to dovetail with the National Oceanic and Atmospheric Administration (NOAA)'s multiagency National Water Model initiative (http://water.noaa.gov/documents/wrn-national-water-model.pdf).

## Impacts of Sea Level Rise

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**Problem statement:** Sea level rise is a complex, time-dependent national and international problem with multiple causes and variable/time-dependent effects depending on location, geologic history, climate, oceanic process, conservation objectives, and human infrastructure.

**Science and/or society impact:** Land deformation in coastal areas with groundwater withdrawals, glacio-isostatic adjustment, tectonic processes, river engineering, coastal flooding/permanent inundation, storm surges, tsunamis/high tides, saltwater intrusion, waterlogging of soils and infrastructure, land use change, and human migration.

**Scope of integration:** Sustained, coordinated, cross-cutting, Bureau-wide, interagency, public/private effort to evaluate causes, magnitude, timing and consequences; integrates several individual and project activities already underway and motivates new research, mapping, monitoring, and forecasting at all timescales.

## Understanding and Managing Fire as a Catalyst for Rapid and Persistent Landscape Transformations Under Current and Future Climates

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**Problem statement:** Climate changes and human activities have altered fire patterns and behaviors. Wildfires can rapidly and persistently reorganize ecosystems by extensive tree mortality, altered soils and hydrology, and large erosion events. Recovery of ecological systems may be delayed or altogether impeded, resulting in emergence of novel ecosystems.

**Science and/or society impact:** Provides critical information, models, and maps describing climate-driven changes in fire patterns and behavior; impacts of fire on ecosystem properties; predictions of future fire behavior, fire effects, and ecosystem resilience and recovery; and potential management strategies to mitigate or adapt to changing conditions.

**Scope of integration:** Requires expertise in biological and physical sciences and climatology, understanding of multiscale processes (from tree to atmosphere), and application and development of complex ecosystem and fire modeling tools. Demands close collaboration among scientists and managers across multiple disciplines and agencies to interpret results and apply them toward improved management strategies to achieve desired future conditions.

## Future Drought

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**Problem statement:** As temperatures rise, droughts could become more frequent, prolonged, and extensive, reducing freshwater supplies for humans, wildlife, aquatic and terrestrial ecosystems.

**Science and/or society impact:** Understanding and monitoring of ground and surface waters and ecological responses are critical for mitigating drought impacts. Water limitations can affect agriculture, energy and mineral production, human health at risk due to increased dust generation, and expansion of mosquitoes and other insect-borne diseases; ecosystem effects include large-scale disturbances, such as wildfires, insect outbreaks, and animal and plant die-offs, with huge economic impacts.

**Scope of integration:** All USGS Mission Areas have responsibility to deliver fundamental, integrated science of the systemic time-dependency of drought and its impacts, both short and long term, across managed and unmanaged systems, and at the continental scale.

## Water and Land Deformation

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**Problem statement:** Pumping and storage of water cause ground subsidence and associated stress redistribution in active fault systems that can cause earthquakes. Natural and induced pore fluid pressure changes can trigger earthquakes. Rheology of viscoelastic layers beneath the lower crust is a direct function of temperature and water content. The nature of volcanism is dramatically affected by interactions with water.

**Science and/or society impact:** Overlaying existing data and associated models could enable correlations between long-term, seasonal, and human induced hydrologic changes with many forms of permanent and transient deformation from the surface down to below the brittle crust.

**Scope of integration:** The USGS is the premier agency that monitors the spatiotemporal distribution of surface water and groundwater but also monitors volcanoes and earthquakes with seismograph networks, contributes to geodetic measures of continuous deformation, conducts systematic light detection and ranging (lidar) measures, and generates satellite imagery.

## A National Biosurveillance Network for Emerging Biothreats

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**Problem statement**: Invasive species and disease in natural systems cost the economy billions of dollars each year; it is critical to get out ahead of the continuing spread of these bio-threats through situational awareness monitoring that works across taxa, geo-political boundaries, and jurisdictions (so we can work smarter, not harder).

**Science and/or society impact**: Knowing when and where bio-threats are likely to occur, and why, will enable targeted surveillance monitoring and geo-spatial control, increasing efficiency and minimizing costs and impact.

**Scope of integration**: Because of opposing spatio-temporal geometries (rare/episodic/cryptic events at national scales), we need integrated, real-time observing and reporting systems, using a variety of tools and technologies from eDNA to satellites to data assimilation, across distributed observing networks, with consistent methodologies and enterprise tools that promote data integration and delivery.

## Ecological and Societal Implications of Rapid Arctic Warming

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**Problem statement:** The Arctic is warming at twice the global rate. Environmental changes are already widespread and anticipated to accelerate. Many communities are presently threatened by deteriorating permafrost and growing coastal erosion. The resiliency of important industries (for example, fisheries), as well as subsistence livelihoods and cultural traditions, will be further challenged in the coming decades.

**Science and/or society impact:** Science must play a dominant role in helping guide effective long-term adaptation strategies during the 21st century. The rapidly changing Arctic warrants early and strategic efforts toward achieving that goal. Outcomes directly benefiting the Artic will also benefit imminent efforts at mid latitudes.

**Scope of integration:** The USGS is uniquely poised to integrate its expertise in hydrology, glaciology, geology and biology, toward the goal of forecasting not only the types of environmental changes that are most likely, but also the rates at which that those changes will manifest.

## Nutritional Quality in Altered Ecosystems

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**Problem statement:** Altered ecosystems, and consequently foodwebs, are common, due to physical changes in habitat structure and flows, invasive species, climate change, and chemical and nutrient pollution, as well as other factors. An often unrecognized outcome of an altered ecosystem are changes in the nutritional status of the foodweb, leading to impaired ecosystem health, population declines, and even extinctions.

**Science and/or society impact:** Species loss, recreational losses, commercial economic impacts, agricultural impacts, and loss of ecological integrity are all possible with declining nutritional quality in an ecosystem.

**Scope of integration:** Integration of Earth sciences with ecological and health sciences, modeling and data management, endpoints of populations and communities, other agencies, and state and private cooperators.

## Advanced Risk Research and Applications

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**Problem statement:** With increasing human population, more people are exposed to natural hazard risk. Decision makers require actionable and often tailored information to improve situational environmental awareness and mitigate adverse consequences. New emphasis on dialogues and iterative product development with users will enable incorporation of user needs into hazard assessments and risk products.

**Science and/or society impact:** The USGS will provide partners with the best information possible for decision making and planning. Incorporation of risk will expand the scope and impact of USGS science, both fundamental and applied.

**Scope of integration:** USGS scientific and technical staff including natural and social sciences, engineering, design, and information technology; agency and nongovernmental organization (NGO) collaborators, policy makers, emergency managers, and the public. Users range from individuals deciding where to work/live to nations and international groups developing policies to efficiently manage system-level threats.

## Incorporating Climate Science Despite Uncertainty

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**Problem statement:** Resource managers are aware that climate change is an important consideration. However, most are also all too aware of how the uncertainties in climate change projections and lack of knowledge about ecological responses impede clear predictions of species and system responses. As a result, many managers are not incorporating climate change into their thinking; they are more comfortable with the status quo approach than taking on the uncertainty.

**Science and/or society impact:** Most conservation and management actions are taken without considering climate change, and are thus less effective or even misguided. How do we convince managers not to look away?

**Scope of integration:** Most research results used to inform management at the local, State, or Federal level could be considering climate change, and yet most management is not.

The USGS can learn from each other, across disciplines—uncertainty has been dealt with for forever.

### 2.2.2 Challenges Developed Further During or After the Workshop

Several of the challenges presented below were discussed in some depth at the workshop but where not selected for development as overarching grand challenges. Others are challenges that were expanded on by one or more workshop participants after the workshop. We did not request a specific format or a specific level of detail for the challenges developed after the workshop, so there is a great deal of variability in some of the descriptions in this section. As with the "Overarching Grand Challenges" in the main report, more work will be required to move from any of these ideas to clear research goals and strategies.

#### Coastal Change—Complex Drivers, Myriad Consequences

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**Problem statement:** The response of coastal landscapes (beaches, marshes and estuaries—Arctic to tropical) to storms, erosion and sea-level rise has economic and public safety costs—and impacts ecosystem health and services. Risk reduction, conservation, and restoration decisions require science and tools to forecast diverse drivers and consequences of coastal change across spatial and temporal scales.

**Science and/or society impact:** An observational and modeling foundation provides new science opportunities at all scales. Investments to reduce risk, and conserve and restore ecosystems and wildlife will be made with an understanding of the complete range of consequences and benefits—anticipating future changes and reflecting the scales at which processes act and landscapes and ecosystems respond.

**Scope of integration:** Physical/ecological research and modeling; landscape-scale mapping; innovative observational tools and networks; decision science; user engagement; and partnerships in observations, research, and delivery. USGS integrated science, accelerated by post-Sandy studies, has resulted in forecasts, for realistic sea level rise and management scenarios, of coastal geomorphic change and its consequences at large spatial scales.

Meeting this challenge requires integration across all USGS science disciplines and a commitment to ensuring that data, models, tools and information systems are reliable, accessible and up-to-date.

**Table 2–4.** Coastal Change and Resilient Coastal Landscapes challenge summary.

| | |
|---|---|
| Vision | The USGS provides the scientific information, knowledge, and tools required to ensure that decisions about land and resource use, management practices, and future development in the coastal zone and adjacent watersheds can be evaluated with a complete understanding of the probable effects on coastal ecosystems and communities, and a full assessment of their vulnerability to natural and human-driven changes—so that the consequences of coastal change are anticipated and effective actions are taken to reduce risk to lives and livelihoods and preserve and enhance the benefits of coastal landscapes. |
| Why is this important? | The economic, human and environmental health and safety of our coastal landscapes and communities are threatened by natural and man-made disasters and persistent coastal change. From major urban centers, to DOI-managed lands and resources, to remote island and Arctic communities—the costs and consequences of coastal change are becoming ever more apparent. Tools are needed to anticipate coastal change and to support strategies to reduce risk and loss. |
| What obstacles need to be overcome? | Current inability to integrate—in planning, prioritization, and execution—USGS capabilities that span observations, research, and decision science and result in truly integrated products.<br>Current inability to share—across the USGS as an organization—ownership for sustained, reliable, and expanded development of high-value integrated products.<br>Failure to translate research and/or site-specific products to capacity building. (We need to build the infrastructure to move from "pilot" to regional/national implementation.)<br>Inability to reliably evaluate impact, usability, and limitations of our products through use/application. |
| Strategies or the way we work | Develop physical, geochemical, and ecological geospatial observations at spatial and temporal scales suitable for development of integrated models of coastal response; integrated assessments and forecasts; and tools that enable policy and management decisions across scales.<br>Establish data and delivery frameworks that enable researchers and other users to efficiently find, access, and use both integrated information and constituent data and knowledge to expand use, usability, and spatial availability. The depth, breadth, and application of our data and research expands.<br>Develop consistent approaches to economic and other valuations of coastal resources (land and landforms, waters, and living resources) to provide decision-relevant measures of costs, consequences and risk of coastal change and management responses.<br>Ensure that research products (increased understanding) are provided with a clear pathway for translation to decision support.<br>Engage users in definition of data, research, and integrated application needs; evaluate the use and usability of our products; identify gaps in delivery; and assess the accuracy of our forecasts and assessments as demonstrated through use. Results guide our science prioritization and planning. |

**Table 2–4.** Coastal Change and Resilient Coastal Landscapes challenge summary.—Continued

| | |
|---|---|
| Example products | Integrated assessments of the character/value and vulnerability of critical resources (habitat, landforms, species). For example: Assessments of the structure and distribution of tidal marshes; their value (wave attenuation, carbon sequestration, habitat provision and use by key species); and their vulnerability to coastal change processes, development and use pressures, and extreme events.<br>Integrated forecasts of the anticipated change in the character/value and vulnerability of critical resources as a consequence of natural and human processes and management strategies. For example: Forecasts of the future condition of tidal marshes and the values they provide under plausible scenarios of natural change, sea level rise, human use and development, and management actions.<br>Expanded assessments of the consequences of coastal change to include critical resources (groundwater resources), priority USGS directions (human and ecological exposure and effects to contaminants), and resource-connections that require USGS expertise (impacts of watershed/riverine fluxes on the health of coastal waters and ecosystems). For example: Assessments of nutrient, sediment, and freshwater delivery to coastal receiving waters and forecasts of the consequence of changing hydrologic systems on coastal water quality and ecosystem health and productivity. |
| Key stakeholders | Federal, State, and local resource managers, coastal zone planners, emergency management and public safety staff, and government and academic researchers. |

## Possible Next Steps

Effective investment in coastal resilience requires a sustained national effort to:

1. Provide the foundational observational (geospatial, monitoring) data, suitable for integration across scales, to characterize changing coastal conditions and vulnerability, and to document and forecast coastal change and resilience;
2. Understand critical processes driving coastal change in diverse coastal settings and the consequences of landscape change on ecosystem services (“resource value”);
3. Develop and deliver real-time and long-term forecasts of coastal change hazards and the consequences of coastal change (in terms of changing “services” or “value”) to inform planning, management, and actions that enhance coastal resilience; and
4. Improve access to, use, usability, and integration of data products for coastal zone researchers, managers, planners, and the emergency preparedness and response communities.

Some immediate next steps that could be taken are:

- Identify prototype products that would demonstrate USGS ability to plan and execute integrated products of clear and compelling value across decision-making scales.
- Identify organizational responsibility for all components (observations, delivery, modeling, and research) required for integrated products—and ensure requirements of planning, execution, delivery, and integration are met.
- Identify products that will meet specific user-demands while laying out a pathway for increasing the geographic scope (spatial scale), breadth (increasing social/environmental relevance), and use/usability of those products.
- Identify approaches to evaluate and improve the effectiveness of applications, through use and resultant outcomes, of resulting products.

## National Climate Response Metrics

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**Problem statement:** Climate change drives slow, comprehensive changes to the Earth system. There currently is no agreed-upon set of metrics to describe how climate change is affecting resources and infrastructure in the United States. The USGS is positioned to provide these comprehensive metrics and issue reports on the state of the climate and the outcomes of climate change.

**Science and/or society impact:** Immediate, high-profile impact. Likely to have large stakeholder buy-in. Information could be used at multiple temporal and spatial scales.

**Scope of integration:** Because of the comprehensive nature of climate change effects, the strategic goals of all USGS Mission Areas will be affected to some extent. Each Mission Area would define metrics of climate influence to feed into an annual report of climate effects.

Table 2–5. National Climate Response Metrics challenge summary.

| | |
|---|---|
| Vision | At appropriate time intervals (1–3 years), the USGS will issue high-level reports of the effects of climate drivers on issues of national and regional importance. The metrics will encompass climate effects on the economy, human well-being, ecological resources, water, energy production, and mineral extraction. |
| Why is this important? | The effects of climate change and variability on national resources and economic output are not well understood, even as our ability to describe climate change and climate variability in terms of atmospheric and oceanic temperature has advanced significantly in recent decades. Development of national climate response metrics will provide an integrated scientific basis to plan for climate change and variability. |
| What obstacles need to be overcome? | Poor understanding of the effects of climate change/variability needs to be developed.<br>The understanding that does exist is poorly integrated across the USGS.<br>Lack of datasets of the appropriate length and frequency upon which to base our improved understanding.<br>Inevitable growing pains early in the process. |
| Strategies or the way we work | Review the current state of knowledge and theory on how climate affects resources and economic drivers.<br>Recognize national versus regional or local climate effects.<br>Identify relevant timescales of climate responses. Some will be immediate (annual, seasonal), others manifest over a number of years.<br>Seek input from critical stakeholder about which climate responses are of highest interest and utility. |
| Example products | Regular high-level reports of the effects of climate on the U.S. economy and resource base.<br>Scientific progress in the field of climate responses.<br>Improved ability to manage and predict the effects of variability and climate change. |
| Key stakeholders | Federal science and policy agencies, including other DOI agencies, State and local governments, general public, academia, and nonprofit science agencies, land managers, and agricultural interest. |

### Possible Next Steps

Convene a working group to address the feasibility of this project. Critical inputs will include assessments of USGS capabilities, relevant literature, and integration of current scientific thinking on the topic.

## Science to Reduce Risk Where Tectonic Plates Collide

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**Problem statement:** Subduction zone events (for example, earthquakes, volcanoes, tsunamis, and landslides) pose significant threats to lives, economic vitality, and cultural/natural resources domestically and globally. One such event will likely occur in the United States in coming decades.

**Science and/or society impact:** Reduced uncertainties and enhanced ability to support science-based decision making at neighborhood to national-scales, will inform actions and policies that improve resilience.

**Scope of integration:** Risk reduction relies on collaboration across the USGS and continuing partnerships among researchers, industry, land-use planners, engineers, policy-makers, insurance providers, emergency managers and responders, business owners, the media, and the public. The USGS has unique multidisciplinary expertise, monitoring capabilities, and responsibilities to provide tools and information that guide and facilitate safety and resilience-building actions.

Table 2–6. Science to Reduce Risk where Tectonic Plates Collide challenge summary.

| | |
|---|---|
| Vision | Coastal communities inhabiting subduction zones will be better prepared to cope with inevitable subduction zone hazard events by using science-based decision making and tools available at the neighborhood to national-scales to reduce uncertainty. |
| Why is this important? | Subduction zone events (for example, earthquakes, volcanoes, tsunamis, landslides) pose significant threats to lives, economic vitality, and cultural/natural resources both domestically and globally. One such event will likely occur in the United States in the coming decades, and recent emergency response exercises have demonstrated that subduction zone communities are underprepared. |
| What obstacles need to be overcome? | Lack of funds focused on subduction zone science. |
| Strategies or the way we work | Improving the application of USGS science to successfully reduce risk from subduction zone events relies on whole-community efforts, with continuing partnerships among scientists within and outside of the USGS and with key stakeholders listed below. |

**Table 2–6.** Science to Reduce Risk where Tectonic Plates Collide challenge summary.—Continued

| | |
|---|---|
| Example products | Information about when and where plate-interface earthquake- and tsunami-generating stresses build, likely sites of unstable submarine slopes and shallow crustal earthquakes, and undersea volcanic activity.<br>Tools delineating tsunami and storm inundation areas, shallow faults, landslide-vulnerable hillsides, and sediment and debris flow paths, extending from offshore to the continental interior.<br>Chronologies of multiple past subduction zone events spanning thousands of years, which guide forecasts of future events.<br>Simulations of ground shaking from great earthquakes to help guide infrastructure engineering and design.<br>Hazard and risk mapping tools conveying expected neighborhood-scale variations in earthquake shaking and ground failure, tsunami waves, landslides, volcanic eruptions, and the effects of these events.<br>Assessments of the likelihood of cascading subduction-zone events.<br>Warning systems delivering notice of coming strong earthquake shaking, volcanic eruptions, and landslides, in time to take life- and property-saving measures.<br>Updating forecasts of aftershocks, land-level changes, volcanic mud flows, ash clouds, and ground failures to guide response and recovery. |
| Key stakeholders | Researchers (academic/other agencies), utility managers, land-use planners, engineers, policy-makers, insurance providers, emergency managers, business owners, the media, and the public. |

### Possible Next Steps

- Promote the forthcoming USGS Subduction Zone Science plan both internally and externally; encourage scientists to find ways to tie in to the plan.
- Identify subduction zone science as an agency priority, with language in the USGS Budget Justification providing guidance on developing projects aimed at advancing subduction zone science.
- Provide "seed funding" to jumpstart elements of this research.
- Continue to foster relationships with the National Science Foundation (NSF), the National Academies and the private sector (for example, Moore Foundation), who have also been exploring different elements of subduction zone science.

## Predict and Mitigate Harmful Effects of Freshwater Eutrophication

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**Problem statement:** Eutrophication of freshwaters can lead to hypoxia, changes in nutrient/carbon cycling, alteration of aquatic food webs, decreased resilience of aquatic ecosystems, increased susceptibility to emerging contaminants, and harmful algal blooms (HABs), which produce some of the most powerful natural toxins known to man. Yet decades of piecemeal efforts to address this global issue have been ineffectual.

**Science and/or society impact:** Systematically predicting freshwater eutrophication will inform national mitigation efforts. Benefits include reduced risks to human, economic, animal, and environmental health.

**Scope of integration:** Predicting and mitigating freshwater eutrophication requires integration across air, water, land use, climate, ecosystem, and natural resources disciplines, synthesizing existing networks of remotely sensed and land-based continuous and discrete data streams. The USGS can leverage Bureau-wide science in areas where we have leadership along with Federal partners to realize Congress' intent for the interagency Harmful Algal Blooms and Hypoxia Research and Control Act (2012).

**Vision:** Illnesses, loss of human and animal life, and threats to ecosystem health caused by freshwater eutrophication will be minimized on national and global scales. Economic impacts due to loss of recreational and tourism revenues, decreased property values, increased drinking-water treatment costs, and commercial fisheries losses will be substantially reduced.

### Possible Next Steps

By the end of the first year:

- Establish a USGS Freshwater Eutrophication Team with expertise from across Mission Areas. Define goals, objectives, and charter for the team.
- Identify the utility and limitations of real-time sensors that measure eutrophication effects (for example, nutrients, dissolved oxygen, dissolved organic matter, algae, cyanobacteria, and pH) for use in early warning systems.
- Work with sensor manufacturers to address sensor limitations.
- Begin expanding the national network of real-time sensors.
- Determine data gaps, and optimize and strengthen existing sampling networks.
- Develop a nationally consistent sampling plan for collecting new data from the Nation's freshwater resources (for example, streams, groundwater, lakes, and reservoirs).
- Identify stakeholder needs.

By the end of the fourth year:

- Continue expanding the national network of real-time sensors covering nationally representative aquatic ecosystems.
- Collect, analyze, and perform quality-control checks on samples collected nationwide from representative recreational water bodies and sources of drinking water. Coordinate sampling with the placement of real-time sensors to maximize the utility of the data.
- Obtain higher-resolution land-use information to help inform models.
- Examine diurnal changes in eutrophication.
- Determine whether eutrophication is accelerating and whether changes in eutrophication correlate with changes in HAB outbreaks.
- Obtain more data on sediments and internal loading of nutrients to receiving waters.
- Quantify nutrient loading from external and internal sources to a statistically representative number of lakes/reservoirs and identify the role of varying nutrient composition in HAB proliferation.
- Improve estimates of the economic impacts due to annual losses resulting from freshwater eutrophication and HABs (estimated at $2.2 billion/year in Dodds and others, 2009).
- Develop regional-scale models that identify inland lakes/reservoirs most at risk for increasing HABs and hypoxia, which can lead to an early warning system for freshwater HABs in recreational and drinking waters.
- Develop scenarios that could result under different nutrient-loading conditions (for example, something like the Ark Storm [Atmospheric River 1000 Storm] scenarios) that can be used to communicate findings with stakeholders.

## Past, Present, and Future Interactions Among Land Use, Water, and Vegetation Under Anthropogenic and Climatic Drivers of Change

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**Problem statement:** Anthropogenic and climatic drivers directly influence interactions among land use, water resources, and natural vegetation. Assessments of past and present interactions are needed to improve our ability to cope with anticipated future change.

**Science and/or society impact:** Economic and societal well-being rely on the Nation's land and water resources. An understanding of the past will inform future scenarios, enabling scientists, land and resource managers, and policy makers to anticipate future change and make decisions that optimize societal benefits.

**Scope of integration:** Through coordination of existing Mission Areas, data sources, and expertise, the USGS is positioned to address these interactions across space and time. However, the integrative approach will require interagency and academic collaboration across disciplines (land use, climate, socioeconomics, hydrology, and more).

**Vision:** In collaboration with other Federal agencies and academia, USGS researchers across all Mission Areas will measure and model interactions among land use, water, and vegetation across space and time. Past and present interactions will be assessed within the context of both anthropogenic and natural driving forces of change, and information that will be used to inform the modeling of future interactions. Scenario-based modeling will enable society to anticipate and adapt to future change within a framework that recognizes and quantifies uncertainties in future landscape, climate, and socioeconomic conditions.

### Possible Next Steps

Research questions related to this issue include:

- What are the historical interactions among land use, hydrology, climate, and other ecological processes, and how can that information be used to inform assessment of future interactions?
- What are the likely future changes in land use and water availability (both surface water and aquifer resources) under a changing climate?
- How can agricultural land owners adapt to likely changes in climate and water availability to maintain food security and economic well-being?
- How will changes in land use, including likely regional declines in irrigation, impact regional weather and climate variability?
- How will changes in climatic extremes (for example, drought and severe weather) likely impact regional- to national-scale water availability and land use?
- What are the key uncertainties in modeling interactions among climate, land use, vegetation, and water, and how can they be reduced to improve the quality of ecological forecasts and resource planning?

As a first set of steps to begin addressing this challenge, in the first year:

- Identify key project partners, establishment of project team and partner roles.
- Assess of mapping and measurement needs for current and historical interactions.
- Reconstruct historical land use, water, and vegetation conditions to support assessment of historical interactions for pilot region.
- Conduct a pilot assessment of historical/current interactions among land use, vegetation change, climate change, and water availability and use, including identification of key biophysical and socioeconomic driving forces of change and quantitative linkages/feedbacks.

By end of the second year, the goals would be to:

- Establish preliminary future modeling framework using simple "waterfall" approach to model linkage (sharing of final model run data).
- Conduct an initial investigation of anticipatory model sensitivities and feedbacks, exploring each model link.
- Begin development of regional- and national-scale socioeconomic and climate scenarios.

And by the end of the fourth year:

- Develop and distribute standardized databases of historical and current hydrologic, climate, land use, and vegetation data to support analysis and modeling efforts.
- Complete quantitative assessment of linkages among model elements for historical and current time frames.
- Complete development of conceptual/theoretical framework for formal model integration, including real-time feedbacks among climate, land use, vegetation, and water availability and use.
- Complete portfolio of nationally and globally relevant climate and socioeconomic scenarios that capture uncertainties in future landscape, climate, and hydrologic processes.
- Demonstrate an application of integrated modeling framework at broad regional (or national) scale, with production of spatially explicit maps of key land use, vegetation, and hydrologic variables.
- Quantify uncertainties from data inputs, model linkages, and scenario assumptions.
- Create decision support tools facilitating access and analysis of model results by scientists and other stakeholders.
- Publish peer-reviewed papers summarizing national-scale assessment of land use and land change, vegetation, and water interactions under multiple climate and socioeconomic scenarios.

## 2.3 Challenges Most Closely Related to Smart Infrastructure Development

### 2.3.1 Challenges Proposed Prior to the Workshop

#### Role of Earth Subsurface/Surface Processes in Infrastructure Planning

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**Problem statement:** Apply Earth system science to help upgrade and extend the life of the Nation's (and world's) infrastructure in a world in which both the directions and rates of change are constantly evolving.

**Science and/or society impact:** National map with layers of probability over a given period of time for storm flooding and erosion, changes in drainage and sedimentation patterns, wildfires, sea level rise, expected inundation from storms and tsunamis, seismic shaking, biotic changes, population change patterns, and associated water pumping and delivery needs, as well as combined landscape changes from these factors.

**Scope of integration:** Requires expertise from many Federal agencies. The USGS will provide decision support tools that links mapping tools with knowledge of geologic hazards and substrates, hydrological processes, water supply consequences, land use/land cover change, and resource implications to make future projections.

#### Infrastructure—Interconnectivity of Our Science and the Built Environment

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**Problem statement:** USGS science has enormous potential value to human endeavors, particularly with regard to population migration, property use, construction, and development. Yet, decision-support tools require integration of hazard with exposure, vulnerability, and loss analyses to reduce societal risks.

**Science and/or society impact:** Decision-making for national urbanization and infrastructure investments can be improved using USGS science. Ubiquitous on-site and in-place monitoring will provide observations for wide-ranging, yet currently data-limited efforts will improve our science and benefit society.

**Scope of integration:** Nationwide infrastructure investment will facilitate on-site and in-place monitoring (for example, structural health monitoring and smart sensors) and a better understanding of the built environment, increasing the use of USGS science in decision-making. Scientific evaluation of the causes and impacts of exposures and hazards on the built environment will flourish with interagency and public/private enterprises.

### 2.3.2 Challenge Developed After the Workshop

#### Understanding the Impacts of Proposed Geoengineering Activities

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**Problem statement:** Geoengineering is the deliberate, large-scale manipulation of environmental processes affecting the Earth's climate, in an attempt to counteract the effects of global warming. The USGS has the broad multidisciplinary, scientific expertise to understand and inform stakeholders on the potential impacts of geoengineering activities on the atmosphere, land resources, and aquatic systems.

**Science and/or society impact**: Geoengineering has the potential to affect the environmental processes that make the planet habitable and could have impacts affecting the security of the United States and other countries. The USGS can provide unbiased science and support fact-based decision making on implementing or detecting geoengineering activities.

**Scope of integration:** Evaluating geoengineering proposals will involve cross-Bureau expertise, as well as interagency and public/private sector cooperation. It will include identifying the magnitude, timing, and consequences of proposed activities and forecast future scenarios of environmental conditions. Assessments will include identifying the required research and monitoring regimes necessary to make knowledgeable decisions on whether to proceed.

## 2.4 Challenges Most Closely Related to Anticipatory Science for Changing Landscapes

### 2.4.1 Challenges Proposed Prior to the Workshop

#### Predict and Mitigate Impacts of Changing Connectivity on Human and Ecological Health

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**Problem statement:** The global environment and society are vulnerable to interconnected changes in geophysical and climatic process. Human and ecological health can be threatened by natural and man-made events (drought, natural disasters, climate change, contamination, and urbanization) through the emergence of diseases, pathogens, and toxins.

**Science and/or society impact:** Disease outbreaks have broad societal consequences on agriculture, resource extraction, water use, ecological services, and ecosystem structure.

**Scope of integration:** The integration of data, tools, and models require collaborative research among experts in public health, medicine, natural resources, and related Earth and biological sciences.

#### National Synthesis of Species Sensitivities to Climatic Changes

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**Problem statement:** USGS scientists often work closely with natural resource managers to help plan for and adapt to climate change (or at least we strive to do this). But developing robust adaptation strategies is often stymied by a lack of climate sensitivity information specific to the biota in question. Clever inferences abound, but few parameterizations exist that could confidently be deployed in decision models.

**Science and/or society impact:** Smartly and gracefully adapting to climate change will increase the likelihood that the resources and wildlife the Nation most values will be able to persist and thrive.

**Scope of integration:** Many of these sensitivities are conditional on the response of other parts of the environment to anthropogenic change. So integration across Mission Areas is critical.

## Ecosystem Adaptation

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**Problem statement:** Trends in climate patterns will gradually move temperatures, season lengths, and precipitation patterns outside the range of historic variation. As such, plants, animals, and even entire ecosystems, will be confronted with novel environmental conditions. Understanding how these species and ecosystems will adapt and change is key to predicting future ecosystems distributions and associated ecosystem services.

**Science and/or society impact:** Understanding and predicting ecosystem resilience and adaptation is key to predicting future ecosystem patterns. Ecosystem patterns dictate land use such as agriculture and other development. This information facilitates planning for infrastructure and food security.

**Scope of integration:** Understanding the potential for adaptation for individual species integrates behavioral and genetic plasticity with movement and dispersal potential as projected onto geomorphological and climate predictions. Individual species may change as a function of numbers, distributions, and/or morphology. As species change so will the corresponding ecosystems and the way in which they function. This work integrates biology, genetics, mapping, hydrology, geology, and climate predictions into a broad decision-making framework.

## Ecological Forecasting—An Emerging Imperative

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**Problem statement:** The world is a complex system. Decision makers need better information on the consequences of their decisions, especially the tradeoffs involved. Ecology must become more predictive in order to be useful to society.

**Science and/or society impact:** Not all things are connected equally. While complex systems can behave in surprising ways, forecasting, if done iteratively and quantitatively, can reduce surprise. Our ability to understand and manage for changes in climate, land use, biogeochemical cycles, and native and invasive species depend on it.

**Scope of integration:** Forecasting requires a new direction in ecology with close connection between models and data. Statistical, modeling, model-data fusion, and informatics tools, including automated workflows, are necessary to predict the state of ecosystems and services with fully specified uncertainties and explicit scenarios.

## Importance of Subseasonal-to-Seasonal (s2s) Climatic Forecasts to Environmental Prediction and Risk Management

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**Problem statement:** Fast advances are anticipated in s2s forecasts, including day-of-year metrics that constrain the growing season, shape the water cycle, and help formulate adaptive responses to both climate variability and change. A decade from now, forecasts of environmental conditions made about 2 weeks to 12 months in advance will become as widely used as weather forecasts are today (National Academies of Sciences, Engineering, and Medicine, 2016). Entities that do best job of linking s2s predictions to meaningful hydrological, ecological, and socioeconomic processes and impacts will become indispensable.

**Science and/or society impact:** Advanced fundamental understanding of seasonal cycle on Earth, including variability and change. Provide most sought-after information imaginable: what water managers, resource managers, and private ventures nationwide really need to save lives, protect property, increase economic vitality, protect the environment, and inform policy choices.

**Scope of integration:** A national water model is essential but will require a more complex blend of deterministic and statistical modeling; and much stronger understanding of Earth system processes, past trends, and integration across multiple disciplines than required for nowcasting and short-range forecasting.

### Short-Term Prediction Capabilities

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**Problem statement:** Climate, economics, and antecedent conditions impart structure to the ability of natural systems to sustain utilization and recover from disturbance. This is known intuitively by local managers but understood very poorly at regional and national scales. Data aggregation and computing offers the opportunity to describe and predict likely scenarios of resource condition in the near term (months to seasons).

**Science and/or society impact:** Agriculture, resource extraction, water use, ecological services, and ecosystem structure.

**Scope of integration:** This effort requires cross-disciplinary information and model development. Interactions with short-term, predictable climatic cycles along with longer-time and poorly described mesoscale events (economics, El Nino Southern Oscillation [ENSO], and so on) can provide insight into Earth system responses.

### National-Scale Hydroclimatic Forecasts Based on Seasonal and Low-Frequency Sea Surface Temperature (SST) Variability

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**Problem statement:** Water and natural resource management are complicated by variability and shifts in hydroclimatic regimes related to seasonal, annual, decadal, and multidecadal SST variability. SSTs interact with the atmosphere and create near hemispheric scale perturbations in atmospheric circulation and energy and moisture transport, affecting present and lagged land-surface hydroclimatic variations. SST variations may provide a means to constrain hydroclimatic variability and trends variability.

**Science and/or society impact:** Help water and natural resource managers to better prepare for shifts in flood, drought, extreme event, and disturbance regimes; and set realistic planning and treatment objectives.

**Scope of integration:** National-scale hydroclimatic forecasts, and associated forecasts of hydrological and ecological effects, based on seasonal and low frequency SST variability. Forecasts will be in the form of probabilities of above normal, normal, or below normal conditions, and occurrence of extreme events.

### Improving Spatial Information at the Field Scale of Resolution (20 m) for Predicting Disturbance Occurrence, Effects, and Resistance/Resilience

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**Problem statement:** This is the scale on which many abiotic factors vary and on which individual plants interact (compete), and animals move, behave, and interact; and scale on which mechanistic modeling can effectively simulate effects of floods, droughts, seasonal flow patterns, fires, insect and disease outbreaks, storm surges, coastal hypersalinity events, biological invasions, and energy and mineral extractions.

**Science and/or society impact:** <nothing listed>.

**Scope of integration:** Basic USGS contribution is to combine topography, hydrology, mineral cycles, and ecology information at the "field-scale" into spatially explicit models that project changes from past and future disturbances. First products would be set of spatially explicit landscape/regional models (10–1000 square km) that link topography, hydrology, and ecological foundation species (vegetation), and perhaps some nutrient cycles at key geographic sites. Although continental coverage would be ideal, ongoing work at the landscape/regional scale can benefit from additional effort, including greater availability of topographic data with the degree of elevational accuracy to meet problem needs (3D Elevation Program, 3DEP); and ability to identify vegetation to the genus or species level, and types of stress, damage, and morbidity using aerial imagery and drones.

#### Anticipate Environmental (Ecological), Societal, and Economic Impacts of Snow, Ice, and Permafrost Change

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This challenge was articulated and explored in the workshop discussions; it was not selected for the same level of detailed development as some of the others.

**Problem statement:** We propose an interconnected series of models, data products, and analyses that use coupled climate projections to examine the impact of physical drivers on changes in snow, ice, and permafrost to predict response in ecosystem and society (including resilience and vulnerability). We foresee a tool that will serve predictions in a spatial and temporal context to understand how changes in the cryosphere will influence landscape, land cover, hydrology (flow and water quality), and biotic response, and so on.

### 2.4.2 Challenges Developed Further During or After the Workshop

The challenges presented below are all challenges that were expanded on by one or more workshop participants after the workshop. We did not request a specific format or a specific level of detail for the challenges developed after the workshop, and different individuals developed each challenge, so there is a great deal of variability in some of the descriptions in this section. As with the "Overarching Grand Challenges" in the main report, more work will be required to move from any of these ideas to clear research goals and strategies.

#### Environmental Forecasting in the Short- and Near-Term

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**Problem statement:** Much of what will happen over the next 20 years will depend on how near-term climate variability and change will affect present environmental states and trajectories.

**Science and/or society impact:** Quest for near-term environmental forecasting will motivate and guide new monitoring and integrated science initiatives. It will also instantly engage USGS stakeholders, policy makers, and the public in adapting to both climate variability and change.

**Scope of integration:** Climatic predictability at seasonal to multiannual time scales is advancing rapidly, but near-term forecasting of the associated environmental responses will require new theory, models, data streams, and operations in many disciplines. As with climatic forecasting, more accurate estimates than now available will be needed to quantify initial conditions, memory, and spatiotemporal dynamics in environmental systems.

Table 2–7. Environmental Forecasting in the Short and Near term challenge summary.

| | |
|---|---|
| Vision | Trusted and credible forecast products that are essential to daily decision making in nearly all sectors of society.<br>Full nationwide engagement of newly-motivated clients and stakeholders, policy makers, and general public in adaptation to both climate variability and change.<br>Improved optimization of many facets of seasonal and annual planning and decisions across both the public and private sector that have a life cycle of weeks to years. |
| Why This is Important | The nonlinear and chaotic nature of the Earth's climate system limits skillful predictions of climate statistics at intermediate timescales (month to years). Significant advances on the horizon, however, could dramatically accelerate societal demand for all kinds of environmental forecasts.<br>A decade from now, forecasts of climatic conditions made about 2 weeks to 12 months (short term: subseasonal to seasonal, or s2s) and even several years in advance (near term) may become as widely used as weather forecasts are today (https://www.nap.edu/catalog/21873/next-generation-earth-system-prediction-strategies-for-subseasonal-to-seasonal; http://s2sprediction.net/file/documents_publications/bams-d-14-00139_E1_1.pdf; https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter11_FINAL.pdf).<br>Skillful temperature predictions a few years in advance (near term) could also be possible (https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter11_FINAL.pdf).<br>Entities that do best job of linking these climatic predictions to meaningful hydrological, ecological, and socioeconomic processes and impacts in the short and near term will become indispensable. This is some of the most sought-after information imaginable—what water managers, resource managers, energy providers, and private ventures nationwide really need to make more effective decisions.<br>Short- and near-term environmental forecasting will help save lives, protect property, increase economic vitality, protect the environment, and inform policy decisions.<br>Critical for situational awareness, emergency planning, and management of risks to the built and natural worlds. Would benefit management of: water, forest and range, energy, infrastructure, food production, transportation, human and wildlife diseases, and temperature extremes. Market applications include business planning and futures markets.<br>More specific examples include:<br>River flow forecasting, dam operations management, and ecological flows.<br>Winterizing of parks, monuments, and refuges.<br>Allocation of resources to wildfire suppression or prescribed burning across regions.<br>Advance warning of water or vector-borne disease outbreak potential.<br>Recreation planning. |

**Table 2–7.** Environmental Forecasting in the Short and Near term challenge summary.—Continued

| | |
|---|---|
| What obstacles need to be overcome | Many aspects of the Earth's climate may be inherently unpredictable at timescales of seasons and years; short and near term climatic predictions may never match the level of confidence associated with tomorrow's (or even next week's) weather forecast.<br>Environmental forecasting at these timescales, banking on rapid advances in climate predictability, is a calculated risk, but the potential for success could be transformational.<br>Successful implementation is a long-term goal, which is likely to proceed slowly and unevenly, especially in the beginning stages. Patience and focus will be fundamental to success.<br>The USGS traditionally has devoted little or no effort on developing forecasting products on any timescale, much less the short and near term, and devotes very little research to short and near term environmental predictability. To make any significant headway, we would have to put immediate emphasis on the Research-to-Operations that would lead us there quickly and efficiently.<br>Competition with NOAA, NASA, and other Federal agencies, with academia, or with large and small decision support outfits in private industry that currently serve the agricultural community ([for example, the Climate Corporation, https://www.climate.com/; Zedx, Inc., https://www.zedxinc.com/company/).<br>Bureau scientific expertise is not optimized to achieve this goal. Personnel and skills development will need to proceed along with stronger relationships with NOAA and academia.<br>Observation networks will need to be optimized for the identification of degrees and geographies of spatiotemporal autocorrelation in environmental responses to climate. In particular, biological observation networks (except for birds and most recently plant phenology) have been designed for assessment rather than prediction.<br>Many scientific disciplines will require rapid and sustained development of new theory, data, and models to address this challenge; time is of the essence.<br>Not only our current scientists, but also our current stakeholders, may be either unwilling or ill equipped to take full advantage of advances in short and near term climatic forecasting. The payoff, however, could be high, as short and near term forecasting could dramatically change how a lot of wildlife management actions are conducted, since weather dictates so much of this (for example, When can we burn? Should we open up the flood gates? When will the sturgeon arrive?). |

**Table 2–7.** Environmental Forecasting in the Short and Near term challenge summary.—Continued

| | |
|---|---|
| Strategies or the way we work | Quest for short- and near-term environmental forecasting capabilities will motivate and guide integrated science initiatives requiring extensive informatics, computing and modeling capabilities, as well as cutting-edge sensor technologies and monitoring approaches.<br>Short- and near-term environmental forecasting will require new theory, models, data streams, and operations in many disciplines.<br>More accurate estimates than now available will be needed to quantify initial conditions, memory, and spatiotemporal dynamics in environmental systems.<br>For example, climate, economics, and antecedent conditions impart structure to the ability of natural systems to sustain utilization and recover from disturbance. This is known intuitively by local managers but understood very poorly at regional and national scales. Data aggregation and computing offers the opportunity to describe and predict likely scenarios of resource condition in the near term (months to seasons).<br>NOAA will play a significant role with their new operational prediction using the National Water Model, but NOAA is not equipped to get to the hydrologic side of subseasonal to seasonal prediction. This will require a more complex blend of deterministic and statistical modeling, and a much stronger understanding of hydrologic and ecological processes, past trends, and integration across multiple disciplines than is required for nowcasting and shorter-range (days to weeks) forecasting, which (merely) requires good numerical weather prediction and quantitative temperature precipitation forecasts that, in hydrology for example, can be coupled to relatively simple surface and subsurface models and routing schemes. Even the simplest ecological models are presently unavailable for nowcasting and shorter-range forecasting, much less for subseasonal to multiyear forecasts.<br>The short and near-casting arena requires much better handling of every facet that affects system memory and predictability, as well as a great deal of consideration to geospatial scaling needed to make subseasonal-to-seasonal predictions meaningful at local and regional scales.<br>Will strengthen partnerships with public and private entities, with routine engagement with external users to develop products iteratively.<br>National Phenology Network and Operational Earthquake Forecasting are already starting to work in this mode, but few other sectors in USGS are operating this way. |

**Table 2–7.** Environmental Forecasting in the Short and Near term challenge summary.—Continued

| | |
|---|---|
| Examples Products | Exhaustive list of potential products, sensors, and networks that take advantage of existing observational networks.<br>Forecasts can be in the form of day-of-year metrics, algorithms that integrate weather over weeks to months [for example, PDSI, accumulated growing degree days (GDD), spring indices], probabilities of above normal, normal, below normal conditions, and extreme values.<br>Forecasts window could be days, weeks, months, or in rare cases years, each temporal scale requiring different capacities and decision making.<br>NEARCasting of:<br>• Water use and demand at every level and scale.<br>• Stream temperature and high/low flows.<br>• Water-quality problems likely to arise based on local conditions, climate, and projected anthropogenic stressors.<br>• Ecological drought.<br>• Lake temperatures and levels.<br>• Water use equivalent during spring months.<br>• Timing and duration of the flammable fire season.<br>• Leafout and leaf senescence of dominant plants.<br>• Flowering of plant species with greatest relevance to pollinators, asthmatics, and tourists.<br>• Seed production for masting species.<br>• Population abundance and arrivals for both obligate and facultative migrants; fish reproduction, migration, and abundance.<br>• Local to regional plant and animal population fluctuations outbreaks of wildlife diseases.<br>• Anticipatory planning and scheduling of ecosystem restoration treatments to ensure feasibility and maximum success.<br>• Winterizing of parks, monuments, and refuges. |
| Key Stakeholders | NOAA, NASA, USDA-FS, ARS, NRCS, DOD, all Federal and State land and natural resource management agencies, DOI CSCs and LCCs, USDA-DOI Joint Fire Sciences Program, NGOs, USGS NPN and its many partners, CDC, USGCRP, specifically National Climate Assessment, private industry, including agricultural and recreational, and the general public. |

## Possible Next Steps

In years 1 and 2:

- Develop a statistical and experimental long-lead forecast system for streamflow in basins that are strongly teleconnected to global SST variations, and work with water planners and managers to evaluate performance of these experimental forecasts.
- Form a Powell Center Working Group to evaluate best opportunities, knowledge gaps, and feasibility in different sectors of the USGS.
- Use Science Decisions Center to collect information from USGS scientists and stakeholders on most useful forecast products that could inform current or future decisions.

- Fund and plan Joint USGS-NOAA-NASA sponsored workshop, perhaps associated with the Innovation Center for Earth Science, Powell Center, CDI, and NCCWSC, to identify applications and establish partnerships and pilot projects with other agencies and private industry. The focus could be on the suite of data products outlined above.
- Issue a nationwide RFP on Environmental Forecasting in the Near and Short Term.
- Use and grow the National Phenology Network to accelerate and further focus phenological monitoring, development of next generation continental-scale phenological models and a few trailblazing subseasonal-to-seasonal forecasting products.
- Broadly motivate Bureau scientists to use long-term and spatially-distributed observations, process-level understanding, and models to identify patterns and sources of short and near term environmental predictability and their forcing, and conduct comparable predictability and skill estimation studies.

By end of year 2, the goal is to hire five early career hydroclimatologists across Water, Climate and Land Use, Ecosystems, Hazards, and Environmental Health tasked with collaborating and developing an integrated bureau-wide program in environmental forecasting in the short and the near term. They can be guided and mentored by the remaining cadre of hydroclimatologists in the Bureau.

In years 3 and 4, prioritize and test suite of signature USGS short and near term environmental forecasting products and operationalize multiple applications.

## 2.5 Challenges Most Closely Related to Integrated Modeling for EarthMAP

### 2.5.1 Challenges Proposed Prior to the Workshop

#### Development of a National Land-System Model (NLSM)

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**Problem statement:** How do natural and human forces (land use, land management, water use, landscape, geological setting, and changing climate) affect quantity and quality of Nation's waters, the vegetation upon its landscapes, the riverine environment, and the cycling of chemicals through its landscapes and waterways?

**Science and/or society impact:** Generate new understanding of the whole land system; inform and help focus and prioritize science, policy, and management.

**Scope of integration:** The NLSM will use observations and process-based mathematical models to estimate movement of water mass, energy, sediment, major species, and targeted minor chemical species through the landscape and surface and ground waters, with accounting for water use by humans and vegetation. It will track carbon and vegetation dynamics in response to climate variations, nutrient availability, natural disturbances, and land-management practices.

## Quantifying Earth System Processes (Earth "Gaging")

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**Problem statement:** What is our state of knowledge (in time and space) for each Earth system process? There are no agreed upon objective quantifications for each component of the earth system. Without these quantifications we cannot objectively (1) evaluate observation or process algorithms, (2) demonstrate model effectiveness, and (3) do meaningful model intercomparison or assessment studies.

**Science and/or society impact:** Decision making needs to be based on science that is getting the right answers for the right reasons. Intermediate and final processes can be evaluated against the best available Earth gaging information to define our knowledge gaps and improve process representation. So let's build better models, but let's make sure they represent all Earth processes to best of our ability.

**Scope of integration:** Integrated science requires state of the art process understanding based on expert knowledge. Understanding and quantifying the earth system is central towards achieving goals of each mission area. The USGS is uniquely positioned to accomplish this with our history of crosscutting, unbiased science in Earth process representation.

## CONUS Integrated Modeling Framework to Assess Impacts of Climate Change on Biological, Geological, and Hydrological Resources

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**Problem statement:** Need for an integrated model that can be driven by downscaled climate scenarios to evaluate impacts of climate change on multiple resources and hazards.

**Science and/or society impact:** A more deliberate framework for working closely and iteratively with stakeholders to identify the key management issues, which impact models are available or need to be developed to address them, and to design the integrated model so that it can support multiple impact models.

**Scope of integration:** Potential to draw on expertise across USGS. Would foster (1) modeling of feedbacks among the bio/geo/hydro processes in integrated model; (2) further downscaling of climate model output to address impacts at appropriate spatial and temporal scales; (3) further development of impact models, some of which don't exist because outputs required to drive conceptual impact models haven't been available; and (4) interactions among managers in resource management agencies, stakeholders interested in the resources, and USGS scientists.

## Near-Real-Time Model Updating and Data Integration

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**Problem statement:** There is an impressive and rapidly growing, yet less than organized, movement underway for collecting near-real-time data information in a variety of forms. Such data are becoming more rapid, accurate, and accessible. We need the capability to update all USGS predictive models [for example, earthquake loss estimates] with near-real-time (NRT) observational constraints. Data collection, fusion, and model integration requires advances in data/model integration.

**Science and/or society impact:** Finessed forecasting abilities will provide improved societal decision-making during continuous as well pre-post-event situational awareness. Improved strategic, economic, and human capital decisions will follow.

**Scope of integration:** Comprehensive, continuous, data/model integration and Bayesian updating requires crosscutting, Bureau-wide, interagency, and public/private efforts. Data integration includes imagery, drones, ubiquitous smart-sensor data, crowd-sourcing, and citizen science [Example: Earthquake loss modeling]. Predictive model updating requires integration of modeling technologies and methodologies, which cross all USGS disciplines and capabilities. The USGS is uniquely positioned to help collect, analyze, and take advantage of the data flowing from these new data technologies.

#### National Land-System Model Framework and Parameterization

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**Problem statement:** To create a national scale EarthMAP, a consistent modeling framework, new algorithms, and compatible data need to be built, developed, and acquired.

**Science and/or society impact:** Consistent community land modeling framework to support interdisciplinary science across the geoscience community. Necessary to best inform decisions about policy, land management, recreation, acquisition, construction, and so on.

**Scope of integration:** Scope and create the computational framework, models, addressing system, and data layers necessary to support a fully 3D atmosphere-to-subsurface open, standards-based National Land-System Model. Develop and implement a voxel-based standard for data acquisition and parameterization. Develop (potentially) new fully 3D algorithms for earth systems for HPC/cloud compatibility, scaling, and efficiency.

### 2.5.2 Challenges Developed Further During or After the Workshop

#### Creation of TERRACAST—A Modular Modeling System for Multidisciplinary Land and Water Forecasting for the Nation

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As discussed in the main report, we envision developing the EarthMAP through related but parallel efforts: the grand challenges articulated in the workshop focus on addressing issues with clear, direct, and important societal consequences. While each of these will contribute to the development of EarthMAP and the overall modular science framework, there is also benefit to addressing the modeling challenges directly.

Table 2–8. Modular Modeling System for Multidisciplinary Land and Water Forecasting for the Nation challenge summary.

| | |
|---|---|
| Vision | Create a nationally consistent, locally informed, stakeholder-relevant set of modeling tools with improved process characterization. This includes assessment and simulation of Earth processes across varied spatial and temporal scales and domains, from national to local, from near-term to long-term, and integrating modeled output from partners to provide the best available information relevant to stakeholders. Improved process characterization will facilitate research, development, deployment, and application of integrated multidisciplinary system of models. |
| Why is this important? | The Nation needs improved ability to characterize terrestrial, hydrologic, and ecological processes at multiple scales to better inform decision making about natural resource management. To achieve this, an integrated suite of nationally consistent, locally informed and stakeholder-relevant models are needed. |

**Table 2–8.** Modular Modeling System for Multidisciplinary Land and Water Forecasting for the Nation challenge summary.—Continued

| | |
|---|---|
| What obstacles need to be overcome? | Lack of current communication between model developers.<br>A 3D geologic framework needs to be developed so that aquifers across the country can be included in the groundwater model.<br>Additional resources to accelerate the overall project.<br>Bureau-wide IT resources to provide infrastructure support. |
| Strategies or the way we work | Identify and evaluation all relevant modeling efforts at the USGS.<br>Establish high-efficiency data and other communication links between model developers.<br>Develop multiple electronic portals for data and information delivery to scientists, managers, and the public.<br>Support USGS systems for comprehensive data release.<br>Continually add and upgrade models to the system to expand the scope and effectiveness of USGS service to stakeholders. |
| Example products | National, high-resolution (< 1-km) modeling system will produce output at three temporal scales: (1) current conditions, (2) short-term forecasts to support adaptive response, and (3) longer-term forecasts to compare alternative management scenarios (see above).<br>Interdisciplinary system will include modules for land use and cover, soil conditions (for example, moisture, microbiome activity) surface water and groundwater quantity and quality (for example, floods, droughts, nutrient and toxic constituent fluxes), ecological conditions, and socioeconomic conditions.<br>Multidisciplinary metrics for current and forecasted conditions summarized to the spatial framework of the hydrographic network to enable ecological flow and accumulation analyses.<br>Ecological modules will include system-focused models (for example, nutrient cycling, forests, grasslands, stream/lake metabolism, multispecies faunal groups), as well as specific population models of wildlife resources.<br>Socioeconomic modules will include valuation models and resource optimization model. |
| Key stakeholders | State and local natural resource managers and governments, USGS scientists cooperating with resource managers, private development enterprises, environmental engineering firms, other DOI Bureaus and other Federal agencies (NOAA, USDA, USFS, DOE), and the general public. |

## Possible Next Steps

**1-year and 4-year modeling plans:** The outline below describes the operational steps that would be required to design and assemble the first-generation modular land/water modeling system. The integrated system of models would be designed to support a specific set of multidisciplinary products conceived by USGS professionals and selected by Bureau and Department leadership to serve the general public, natural resource managers, and the scientific community. The first-generation modeling system would (1) be based largely on currently operational, large-scale USGS models (especially those which have been successfully integrated in previous transdisciplinary research); and (2) be assembled over a 4-year period. The nonmodeling aspects of product development would proceed simultaneously through multidisciplinary teams of USGS scientists, and product release could occur at the end of the period.

The "first-generation" product selection would be constrained, in part, by existing models and capabilities. An important additional task during the 4-year period, beyond model development for the first set of products, would be to identify and acquire additional modeling capabilities to support future product development.

First-year activities:

- Conduct a comprehensive assessment of currently operational, national/regional-scale USGS modeling activities.
- Design a modular modeling system to be assembled over a 4-year period (see below).
    - Together with USGS leadership, identify a set of feasible 4-year products representing the four COSSA Workshop overarching grand challenges (Natural Resource Security, Reducing Societal Risk from Existing and Emerging Threats, Smart Infrastructure Development, and Anticipatory Science for Changing Landscapes).
    - Design a modular modeling system required for a 4-year plan.
    - Establish operational relationships with non-USGS data and modeling activities required to support the modular modeling system in carrying out the four-year plan (for example, NASA/NOAA observational data and Land Information System, EPA's Support Center for Regulatory Atmospheric Modeling air quality modeling).

4-year plan:

- Assemble a modular modeling system as required for the selected products.
- Test assembled models through "hindcasting" and other verification activities.
- In consultation with USGS leadership and nonmodeling teams, identify and develop the next generation of products and the modeling capabilities required to support those products.

Three examples of potential first-generation products:

1. Spatially detailed 30-year forecasts of land use change and lake, stream, and coastal water quality conditions based on alternative agricultural crop and management scenarios (for example, high commodity export rate compared to high domestic biofuel production compared to high rate of forest carbon sequestration). This set of products would require integration of land use, shallow groundwater, unsaturated zone, surface water, and water quality models. Land use and hydrologic model integration would operate in a multidirectional manner to produce a set of subproducts intended for both land-use planning (subject to water availability and quality constraints) and water resource management (subject to changing land values and use).
2. Optimized coastal resource management guidance using the above integrated modeling system to minimize costs of controlling nutrient flux to U.S. coastal waters based on selection and location of nutrient control technologies. (A prototype of this system of models has been constructed using a national-scale SPARROW model, a cost model of total nitrogen control technologies, and an optimization algorithm.)
3. Short-term (1-year) forecasts of fish mercury concentrations based on integration of long-range weather forecasts, an air quality model, and a USGS model of fish (and loon) mercury concentration in New England lakes (Shanley and others, 2012).

## Vision 20–21—Hindcasting, Forecasting, and Nowcasting of the Nation's Land and Water Over the 20th–21st Centuries Through System Modeling

Click to
Return to list of related challenges
Return to main text

**Problem statement:** Physical, chemical, and biological changes at the earth's surface, already extensive and rapid, are expanding and accelerating. Understanding these changes requires characterization of interactions among processes that have historically been studied in isolation. Progress requires a systems approach using a comprehensive, process-based national land model.

**Science and/or society impact:** Scientifically, Vision 20–21 will yield numerous new insights into interactions among disparate land-system processes. Societally, it will provide science-based information on past and present states of the land system, as well as "what-if" scenarios of possible futures, all of which will inform the actions of resource managers and other decision makers.

**Scope of integration:** The challenge is to integrate across USGS's scientific disciplines and Mission Areas; across observations, process understanding, and modeling; and across technological advances in big data, computing, and information delivery.

**Vision:** The USGS uses a national land-modeling system to integrate observations, understanding, and knowledge of external forcings (including human activity) for estimation of past, present, and future states of the Nation's waters and land, in order to support resource managers, planners, emergency responders, and the public in pursuit of health and prosperity. Satellite-based platforms and national networks of on-site sensors deliver a continuous flood of real-time data on the physical, chemical, and biological status of the Nation's land. These data are fed into an integrated suite of models representing our best current understanding of land-system processes. Combined with advanced statistical techniques, the modeling system creates optimal estimates of the land-system state and parameters, including land deformation, surface and subsurface water flows, chemical, sediment, and thermal transport and fate, aquatic habitat, vegetation cover and status, and abundance of key faunal species. The same modeling system is periodically run in background under past and future forcing in order to produce centennial-scale time-space reconstructions and projections. All data products are delivered seamlessly through the internet, on demand, upon request by any interested entity. Meanwhile, researchers use the modeling system as one tool in their search for understanding of earth-system behavior, leading to new process descriptions that, over time, are fed back into the modeling system.

### Possible Next Steps

By the end of the first year:

- Identification of variables to be included in stage-1 (that is, first prototype) coupled model.
- Identification of existing component models.
- Definition and population of component-model teams and overall coupled-model team.
- Design and draft code of model coupler. The coupler is the interface for communication among the component models, which will perform aggregation and disaggregation in space and time as needed.
- Creation off "wrappers" for component models that will allow them to interface with the coupler.

- Completion of prototype coupled model and demonstration of a national-scale, multidecadal simulation.

By the end of the fourth year:
- Solicitation and consideration of feedback from test-users.
- Freeze of stage-1 model and handoff to newly formed data-assimilation and information-delivery teams.
- Experimental ingestion of observational information relevant to state variables of stage-1 model.
- Experimental delivery of stage-1 model output as provisional “data.”
- Identification of stage-2 variables and processes; population of new component-model team(s).
- Refinement of stage-1 component models based on experience with prototype model.
- Completion and demonstration of stage-2 model, including near-real-time data assimilation.

In subsequent years:
- Data delivery “goes live.”
- Relevant process research.
- Ongoing collection of user feedback.
- Continuing development, addition, and maturation of component models.
- Continuing development of data-assimilation methods.

## 2.6 Challenges Regarding Science Communication and Delivery

All but one challenge in this section of the appendix were identified prior to the workshop. Several aspects of these challenges are recognized in the overarching grand challenges in the main text, but no specific science delivery and communication challenge was developed in detail on its own during or after the workshop.

### 2.6.1 Challenges Proposed Prior to the Workshop

#### Making Science Personal

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This challenge was developed at the workshop and inspired by “heads-up spatially controlled notifications of real events.”

**Problem statement:** USGS science impacts the public at large, but many of the current products and services are directed at decision makers or policy makers. Most USGS science is currently communicated at scales incompatible with the needs of individual users. The grand challenge would be to connect USGS science at a personal level to interact with individuals, at their level of need and utility.

**Science and/or society impact:** Integrating science in daily life; more personal relationship with science.

**Scope of integration:** This could be house-level hazard/flood/water/minerals assessment, “What’s in my backyard” applications, or other finer grained applications; ability to disseminate estimates of risk to parcel level, and geofencing.

## Intelligently and Systematically Select and Use the Most Appropriate Data and Information Amidst the Current and Coming Data Deluge

Click to
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**Problem statement:** The available data and information for scientific analysis is increasing exponentially from new remote sensing options to the internet of things. The computational capacity to analyze these data is available or will be soon. However, not all data and information should be used for all purposes.

**Science and/or society impact:** Society is deluged with "facts" and figures from thousands of sources with very different motivations. We need to consistently build trust in science and scientists if we want people to pay attention to the decision options we articulate. Part of how we do that is to be transparent about what data we use and don't use and why.

**Scope of integration:** Across all science disciplines and activities in the USGS, we need systematic, sustainable, and scalable methods for recording how we make data selection decisions, annotating fitness for purpose, and making the provenance for our scientific findings transparent.

## Improve Decision Making Through Better Communication and Translation

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**Problem statement:** The public buys a lot of science and uses little of it. Even when they are aware of our research, decision makers are often overwhelmed by scientific uncertainty (for example, related to climate change) and thus do not incorporate results into their decisions. Potential solutions (knowledge coproduction, decision-centered research) are not well rewarded under current metrics and incentives. We need to foster the ability to work closely with stakeholders to deliver science on a well-organized continuum linking foundational research with practice. New emphasis on dialogues, iterative product development, value of information, and more easily accessible data dissemination and analysis tools will help.

**Science and/or society impact:** Increasingly valued science and public support; stakeholders engaged with the science/derivative products and together; and improved public well-being and opinion of environmental issues.

**Scope of integration:** Cross-discipline (biological, physical, and social sciences) in the USGS and with other agencies and stakeholders.

## Future-Ready Data Systems

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**Problem statement:** USGS data systems have served us well in the past but are not well calibrated to take advantage of improvements in observations that offer much greater spatial and temporal resolution. Moreover, these systems are often separate, Mission Area-specific, and not often discoverable, accessible, and usable.

**Science and/or society impact:** All aspects of USGS benefit from real-time, vetted, seamless, free, combinable data on flexible, creative and evolving platforms.

**Scope of integration:** Improvements in technology and capacity that allow us to integrate and analyze disparate data streams. This integration will require a super structure that effectively ingests observations and model outputs across Mission Areas while also delivering immediate value to the public.

## Integrated Science Data

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**Problem statement:** Data are more powerful when they can be easily accessed and linked to other data sources. USGS data are decades behind the state of the art, and that puts our efforts at risk of becoming obsolete.

**Science and/or society impact:** The public could see and use our breadth of expertise in the way it now sees and uses USGS quads and earthquake measurements. This could put USGS in the lead for how science products are shared and used.

**Scope of integration:** All aspects of the USGS benefit from real-time, vetted, seamless, free, combinable data on flexible, creative, and evolving platforms.

## Employ Intelligent Systems to Capitalize on the Interrelated Roles of People, Computers, and Information

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**Problem statement:** We need to increase our capability to create, manage, and understand data and information from the scale of personal computers to globally distributed systems, and automatically inform relevant parties of the results.

**Science and/or society impact:** Example: intelligently integrating existing sensor systems for interdisciplinary analysis as in the case of environmental seismology, where seismic networks inform natural hazards monitoring for floods and landslides.

**Scope of integration:** "Information and Intelligent Systems" is a division of the National Science Foundation devoted to the topics above. USGS science and monitoring can likewise benefit from geoscientist and computer scientist interaction, innovative data management, and suitable computing support to create so-called intelligent systems.

## Heads-Up (Push) Spatially Controlled Notifications of Real Events

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**Problem statement**: Society depends on timely information to respond to changing environmental conditions; USGS data and information and research products are not necessarily considered or recognized as go-to products, in part because they are not produced and delivered dynamically.

**Science and/or society impact**: Save lives and money with real-time hazard information; this subscription service enables users to customize their notifications; provides an application for USGS teams to work towards.

**Scope of integration:** Imagine a heads-up notification displayed on your phone as you drive or hike: "FLOODED STREAM AHEAD, SLOW DOWN!" or, "WARNING, TICK SEASON UNDERWAY." This would require integration across disciplines, including geospatial assessments, high performance models, real-time delivery of information, validation tools, data-model assimilation, uncertainty assessments, and customizable GUIs.

## Demonstrating and Evaluating the Value of Scientific Information (VOI)

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**Problem statement**: The USGS needs to demonstrate and evaluate the benefits from our scientific information. With tight budgets, there will be additional need to demonstrate a return on investments in science by documenting the benefits from USGS scientific information. This understanding of the value of scientific information is critical for decision makers to understand the tradeoffs among alternative research investments.

**Science and/or society impact**: VOI studies provide information on the benefits provided by science in societal decisions and inform choices on applying scientific information in decision making.

**Scope of integration**: This challenge requires integration among USGS scientific information, societal choices and decisions, and the economics and social sciences required to measure VOI.

## Communication, Relevance, and Use of USGS Science

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**Problem statement:** A broad swath of USGS science is largely unknown to the general public. A lack of modern dissemination and readily available analysis tools limits applicability for scientists.

**Science and/or society impact:** Active and timely engagement with the public and the resultant awareness of USGS science improves public well-being and influences public opinion of environmental and conservation issues. Flexible, easily accessible data dissemination and analysis tools facilitate the use of USGS science by scientists and decision makers.

**Scope of integration:** Improved use of social media and traditional media outlets to maximize public exposure of our research. Partnerships with private industry will likely be necessary to modernize USGS science dissemination. Development of analysis and decision-support tools will require collaborative exchanges with stakeholders, with continuous engagement to ensure relevance.

## The Value of Science Multiplies with Translation

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**Problem statement:** Translation of science into tangible outcomes for multiple purposes of education, relationships, and decision making goes beyond current USGS expertise. Challenges include partnering with necessary expertise, interfaces between translation steps (for example, downstream models have to be adapted to new science products), review processes for large interdisciplinary projects; evolving context (people, land use, technology). Project management is complex.

**Science and/or society impact:** Translation adds value to science, provides insights into effects and interdependencies throughout society. Stakeholders engage with the science and derivative products and together.

**Scope of integration:** Across multiple physical (for example, geological) sciences and multiple disciplines (science, engineering, environmental, social sciences); and across multiple USGS centers, multiple USGS missions, and multiple organizations.

#### Science Communication—Continuous, Coordinated, Conversation

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**Problem statement:** Science communication is: (1) an interaction with diverse audiences; we need to know what/how they need information. Politicians can have an influence, perhaps reflecting the fears of panicked members of the public (2) a continuous communication spanning warnings (for example, earthquake early warnings), situational awareness, forecasts (for example, operational earthquake forecasting), assessments and the communication phases are developed in isolation; and (3) one of many communication roles (for example, emergency managers, public health, media) and can be less effective in isolation. Communication strategies are lacking.

**Science and/or society impact:** More effective communication and use of science; input on information needs for decision making.

**Scope of integration:** Across physical sciences; across phases of products, between physical scientists, social scientists and artists, among multiple communication roles.

## 2.7 Internal USGS Challenges

All challenges in this section of the appendix were identified prior to the workshop. Several aspects of these challenges are recognized in the overarching grand challenges in the main text, but no specific internal challenge was developed in detail on its own during or after the workshop.

### 2.7.1 Challenges Proposed Prior to the Workshop

#### Reproducibility and Science Reporting

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**Problem statement:** The lack of reproducibility is an emerging crisis in several scientific fields and a potential problem in most fields that don't measure reproducibility. Irreproducible results damage society, waste funds, and undermine scientific credibility. The USGS has a brand based on science integrity and continues to move forward with new efforts on data openness.

**Science and/or society impact:** Better use of public funds, increased trust in science, sounder policy decisions.

**Scope of integration:** All aspects of USGS science would benefit from a reconsideration of reproducibility.

#### Incentivizing Actionable Science

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**Problem statement:** The USGS could be doing excellent translational science work, doing actionable science by working closely with stakeholders to really understand their information needs. However, this is very time-consuming process and is perhaps not adequately supported and rewarded in the current USGS framework. In the context of the Climate Science Centers, research scientists are asked to work closely with users and deliver information that is rightsized, right timed, and so on.

Creating an institution that fosters the ability to work closely with users and which delivers science on a well-organized continuum linking foundational research with practice is a Grand Challenge.

**Science and/or society impact:** The more actionable the science, the bigger the impact!

**Scope of integration:** This is an issue for academic as well as federal scientists, but our (Federal) mandate is more focused on actionable science

## Relevant Science Metrics

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**Problem statement:** Science, science agencies, and scientists are increasingly evaluated based on flawed science metrics, like the h-index. But these indices are easy to improve.

**Science and/or society impact:** The public deserves high science impact per dollar they spend. Without relevant metrics, this is difficult to achieve.

**Scope of integration:** The USGS is an ideal agency to test new ways to evaluate science impact across multiple levels. Understanding how we do our science would benefit the research grade evaluation (RGE) process and provide relevant incentives for our workforce.

## Integrating Economics and the Social/Behavioral Sciences Into the USGS's Science Portfolio.

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**Problem statement:** USGS physical and biological science is critical to societal decisions. Integrating biophysical science with social, behavioral, and economic (SBE) science can enhance its use and value in decision making. Challenges include cultural and institutional issues, including terminology and methods, as well as organizational history and tight budgets.

**Science and/or society impact:** Many societal choices and decisions are expressed in human or monetary terms which require connecting USGS biophysical science results with SBE science. This connection will advance the use and value of USGS science.

**Scope of integration:** The intent is to fully integrate SBE science into USGS' research portfolio, although level of effort and capacity need to be considered and decided upon.

## Science of Solutions

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**Problem statement:** Much of our research focuses on reducing the uncertainty and improving our understanding of the consequences of anthropogenic change, and this is important work. So too though is focusing on solutions to these issues, and we could do to focus research on solutions (mitigation, adaptation, maintenance of ecosystem services, and beyond).

**Science and/or society impact:** Solutions inherently feel more positive and bring people together in a way that refining consequences does not. People would be drawn to science that integrates a study of impacts with a study of solutions. More solution-oriented science and would attractive to Congress, and the general public.

**Scope of integration:** This spans all mission areas; solutions that are useful to decision makers would require collaboration among Mission Areas.

## Strategic Portfolio Allocation Across Axes of Science Engagement

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**Problem statement:** Is it possible to develop and operate a science agency that strategically operates on three axes of scientific engagement? Specifically, gradients of: (1) basic-translational science, (2) breadth vs. depth of focus, and (3) disciplinary-interdisciplinary work.

**Science and/or society impact:** A unifying strategy for scientific investment will clarify USGS objectives and highlight the value of our work to the nation. It will also help our scientists to situate their role and trajectory within the USGS. A thoughtful, integrated, and balanced scientific portfolio makes a society healthy, wealthy, and wise.

**Scope of integration:** Effectively serving the Nation's needs by providing science that keeps us on a sustainable pathway will require investments and integration across all three axes, but the level of investment must be carefully considered given the makeup of our primary stakeholders and their most pressing decisions.

## Scientific Entrepreneurship

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**Problem statement:** Scientific advances happen irregularly and among a sea of failures. In this regard, science is an entrepreneurial endeavor. As such, it is fostered by creativity, regular contact, and the ability form, dissolve, and re-form working groups and overarching areas.

**Science and/or society impact:** Unknown, but potentially very large. Historical evidence suggests that in the long term creative successes move society forward and eventually touch stakeholders in meaningful ways.

**Scope of integration:** As a science agency, one priority must be to advance the scientific endeavor. Scientists must be given a degree of freedom to pursue interests across boundaries of traditional lines of inquiry and to integrate promising avenues from a wide array of disciplines.

## Interdisciplinary Infrastructure—Semistovepipe Technologies

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**Problem statement:** From a technology perspective, our USGS Mission and Science areas operate independently of each other. While collaboration exists, and is encouraged, the technology behind it is not interdisciplinary. Science data is local to the office or Mission area (and at times the project level) and not located in a manner that explores interdisciplinary boundaries. Our IT infrastructure does not support such an environment that allows scientists to view sensor or mission created data across our landscape.

**Science and/or society impact:** Broaden the USGS scope of science to include an across-the-landscape focus where sensors collect data across the USGS, not based on Mission Area, but Bureau-wide mission integration**.**

**Scope of integration:** Challenging to change the USGS culture to support integrated data and consistent data architectures that are available to any consumer and not based on location or discipline.

## Planning Across the Science Continuum

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**Problem statement:** Need to manage our work across a spectrum from foundational science to applied solutions. USGS science planning is mostly about identifying topics, but there is little integration to address the need for translation, application, and so on. And often little or no link with end uses and decision making.

**Science and/or society impact:** Reduction in "random acts of science" and increase in solutions that are targeted to users' problems and efficiently moved from conceptual research (foundational, blue sky) along a continuum to more-applied research to tools and technical assistance.

**Scope of integration:** USGS science planning should explicitly consider the "boundary roles" and linkages with users that will ensure use and impact.

## Focus on Programs and End Goals, Not Projects

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**Problem statement:** At least some parts of the USGS are more like academic institutions—Principal Investigators identify topics and seek funding, with little integration across similar topics. Program Coordinators and Regional Directors share control, with the result that Principal Investigators work largely on their own.

**Science and/or society impact:** Increased efficiency and impact for the science we undertake.

**Scope of integration:** Similar activities should be considered as part of a bundle, with a reasonably defined scientific end goal and a plan for how multiple research lines (projects, programs) can contribute that goal, and the ability to say when the goal has been reached.

## Role of Postnormal Science in the Prioritization of USGS Science

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**Problem statement:** The norm is for transdisciplinary study of societally-relevant complex systems/issues to proceed with no independent observers and poorly controlled management or policy "experiments." Societal relevance and simplifications of science implies judgements and evaluations. USGS programmatic science decisions, including prioritization and implementation of long-term grand challenges, should embrace post-normal science (PNS), a novel approach for the use of science on issues where "facts [are] uncertain, values in dispute, stakes high and decisions urgent."

**Science and/or society impact:** Fundamental to almost all USGS Grand Challenges so that they can be made most relevant for societal use and as "objective" as possible. Human challenges of meaningfully constructing/using integrated models or forecasting tools are as large as the technology challenges.

**Scope of integration:** PNS requires collaboration between USGS biophysical and social scientists, and with external parties in behavioral and decision sciences as needed; greater stakeholder engagement and structured participatory processes (for example, adaptive management, joint-fact-finding, participatory modeling), greater recognition of the role of biases, beliefs, heuristics, and values, solutions and structured processes for addressing them.

### Diversifying the Bureau

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**Problem statement:** STEM fields are struggling with how to increase diversity in the professional ranks. Many of the fixes tried over the last few decades still have not brought equal representation, for women and especially for many racial and ethnic minorities.

**Science and/or society impact:** Research on the subject has shown that, across disciplines and environments, more diverse teams are more productive, more successful and more impactful. Thus, increasing diversity can make USGS better. Moreover, it could help increase diversity outside of the USGS and the federal government by providing mentors and examples, which have been shown to have a strong positive impact on minority recruitment and retention.

**Scope of integration:** This is a problem across USGS.

### Strategic Bureau Management—From Blue Sky to Muddy Boots

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**Problem statement:** Perception by some in and outside of the Bureau that we do projects, not "programs" or "lines of business" or "bundles of work leading to a desired endpoint." The USGS is a mix of technical assistance, hobby science, one-off projects for managers, data collection without a research purpose, and deep exploratory research. We appear not to strategically consider what part of the science spectrum (blue sky to muddy boots) we are operating in, what is above and below us in the chain, and how to most effectively manage across this chain. We do not adequately support, reward, expect, incent, and so on. the co-production of actionable science.

**Science and/or society impact:** Increasingly valued science and public support

**Scope of integration:** Creating an institution that fosters the ability to work closely with users and which delivers science on a well-organized continuum linking foundational research with practice**.**

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# Appendix 3. Science Visions for the U.S. Geological Survey

Throughout the workshop, participants were challenged to describe, in a few ambitious sentences, their own vision for a more integrated and forward looking U.S. Geological Survey (USGS) that truly addresses “science for a changing world.” The results of this exercise are included here, in the original wording of the participants. Figure 3–1 represents a “word cloud” built directly from those contributions.

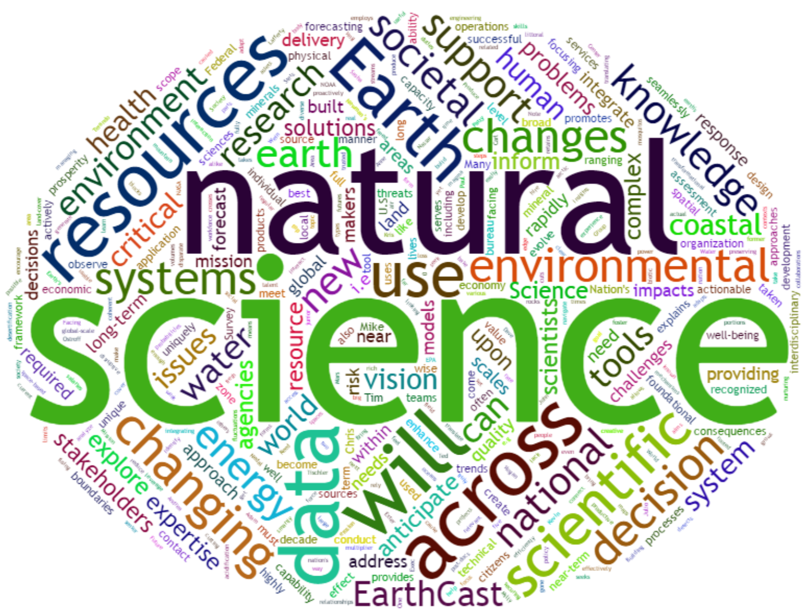


**Figure 3–1.** Elements of visions for the U.S. Geological Survey from the workshop participants.

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Through implementation of the science strategy, “Facing Tomorrow’s Challenges, U.S. Geological Survey Science in the Decade 2007–2017” (USGS Circular 1309), and follow-on planning documents, the USGS has taken major strides towards addressing the Nation’s interrelated natural science and societal challenges. Over this decade, we have gone from an agency organized around discipline specific studies (for example, geology, hydrology, biology, geography) to a mission oriented approach focused on climate and land use, ecosystems, energy and minerals, environmental health, natural hazards, and water needs. In each of these mission areas, we have produced knowledge that has both fundamentally advanced the underlying science and directly supported decision makers. But as we learn more about our rapidly changing natural and built environments, we have come to appreciate that even these broad research areas are themselves highly interconnected. Population growth, resource use, environmental change, socioeconomic and environmental connectivity, and technological advancement are all accelerating and interacting, and we must respond with integrated science and models; predict changes in water quantity, quality, and demand; safeguard communities from disease and natural hazards; sustain thriving economies; and promote healthy ecosystems in a changing and uncertain world.

We propose a vision and strategy that unites and integrates all USGS's formidable capabilities. Our vision takes advantage of USGS strengths and our unique position as a nonregulatory Federal science agency with expertise spanning the full range of natural science disciplines, our presence and collaboration with stakeholders nationwide, and our national and international scope and responsibilities. Over the next decade, we will take advantage of advances in sensor technologies, integrated modeling, and high-performance computing to observe, understand, and forecast human and environmental interactions and change across spatial and temporal scales, in real time, over the near and the long term, and under varying future scenarios. Our long-term goal is integrated science and earthcasting (that is, USGS EarthCAST), the delivery of geospatial data, national maps, and decision support tools that account for complex, multiscaled, system interactions; anticipate the likelihood and consequences of evolving threats; quantify both societal risk and scientific uncertainty; and help guide societal adaptation and mitigation.

No other earth science agency has the scientific breadth, technical capacity, and data assets as the USGS. However, the fully realized potential of those aspects of USGS cannot be achieved in the absence of a tool that can incorporate our individual parts, and evolve them into a more scientifically powerful and forward-looking Bureau. Our vision of EarthCast is that once initiated it will be a continually evolving, multidisciplinary integration, visualization, and prediction tool that is rooted in USGS science. We anticipate that initially EarthCast architects will need to focus on a limited set of areas of environmental concern where we feel confident USGS has the data resources, scientific understanding, and technical capability to demonstrate its present and future value. It is critically important that the initial conceptual demonstration of EarthCast is highly successful—like the Apollo missions! One example we have often discussed is the impact, and spatial and temporal occurrence of future severe droughts. As the utility and application rate of EarthCast grows, we expect scientists across the Bureau will continually seek to propose new and innovative ideas to increase its scope and capabilities. In this manner, we envision that EarthCast will also become not only a science integrator but a connector of scientists across all of USGS. In essence, EarthCast is expected to become a critical aspect of the fabric of the USGS.

For the USGS to truly meet the mission of science for a changing world, our organization must integrate our science and operations, our data, and our science support services (Information Technology/Human Resources, Administration) infrastructure to complete our science missions. Operating independently is costly, inefficient, and lessons the ability of our science to sing. The USGS should evolve into an organization where both the public and our employees can find, get, and use our valuable data and information the USGS hallmarks without delay.

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The USGS is the premier source of unbiased knowledge about the Nation's ever-changing natural resources. Our innovative science supports human well-being, healthy ecosystems, economic prosperity, and emergency response.

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The USGS promotes the Nation's health and prosperity by producing and communicating the best available science describing the complex, dynamic Earth system as it responds to natural forces and human activities. The USGS exploits the ever-increasing body of science and technology to observe, understand, and predict processes occurring upon and beneath the earth's surface to inform decisions concerning protection from natural hazards and use of natural resources.

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My vision for the future is a USGS that actively evaluates societal issues relating to natural resources and natural hazards across the physical, biological, and socioeconomic sciences. The USGS of the future builds on status and trends assessments to model and explore the response of natural systems to natural and human-induced drivers of change, and to explore the resulting human and societal impacts. The USGS will develop forecasts of future natural resource or hazard outcomes for alternative scenarios. The USGS will have an integrated delivery system that facilitates dissemination of data and analytical results across different groups of stakeholders ranging from citizens to government decision makers. Data and information are gathered through nontraditional sources including citizen science, crowd sourcing, and indigenous knowledge. The USGS will create a research office focusing on developing new science applications and delivery systems with the intent of increasing the use and societal value of science.

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The Nation adapts and prospers as oceans and coasts change. The USGS provides the scientific information, knowledge, and tools required to ensure that decisions about land and resource use, management practices, and future development in the coastal zone and adjacent watersheds can be evaluated with a complete understanding of the probable effects on coastal ecosystems and communities—and a full assessment of their vulnerability to natural and human-driven changes—so that the consequences of coastal change are anticipated and effective actions are taken to reduce risk and preserve and enhance the benefits of coastal landscapes and resources.

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Develop and operationally deliver standardized Earth science products and services generated from Earth observing data to be used in monitoring, modeling, and forecasting climate change and its impacts; water availability and quality; natural hazards risk and resilience; national and international energy and mineral resources; and landscape-scale ecosystem changes. (Note: the USGS produces a plethora of Earth observation data and products used not only by the USGS but also by a host of Federal agencies, universities, and the private sector, providing a science and application multiplier effect across the Nation.)

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Produce Earth science that crosses seamlessly between global, national, and local scales, translating global-scale probabilities into local cause and effect relationships, and linking space-based Earth science and field science.

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Bring USGS science capabilities into coherent alignment with Earth science activities of other Federal Earth science agencies like the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), U.S. Environmental Protection Agency (EPA) and others. (U.S. Group on Earth Observations has 13 U.S. agencies) and with international Earth science agencies to efficiently and effectively identify, analyze, and produce solutions to Earth science problems impacting society.

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The USGS will foster opportunities to address scientific problems at national and global scales and encourage integrating data and perspectives across disciplines in a manner that uses new data sources, systems approaches, and ambitious collaborations.

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The USGS serves our Nation by providing an integrated understanding of Earth system science that allows for information and tools to enhance our economy, natural resources, environments, and the quality of our lives. The USGS performs innovative science to inform transformational solutions to our Nation's energy, water, and environmental challenges. The USGS employs the power of scientific discovery and integrative collaboration to create advanced knowledge and tools in support of our Nation's most critical economic, energy, and environmental challenges.

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The USGS is uniquely positioned to provide science and decision support to inform natural resource policy for the Nation. Building upon long-term data and expertise concerning the physical environment and biotic response (critical zone systems), the USGS should build tools and capacity to forecast hydrology, geomorphology, land-cover, and ecosystems to inform wise use and management of natural resources with near-term and long-term forecasting.

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The USGS is the trusted source for the science of changes on the Earth. The USGS detects and explains mechanisms of change (trends and fluctuations), and projects and explains change into the near and far futures. Many types of audiences/stakeholders can easily navigate, interact with, and experience change information in various spaces and times. They can explore what it means for them and use decision support to connect to other relevant information to explore solutions to problems and be prepared for a changing world.

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The USGS of the (near) future seamlessly integrates multidisciplinary science and disruptive technologies to translate unprecedented volumes of data and disparate information into unique insights and actionable knowledge that proactively identifies, anticipates, and addresses some of the most complex and pressing global issues facing current and future generations.

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The natural systems that we rely upon for our livelihood, security, and well-being are changing. Understanding these changes well enough to provide guidance and solutions requires an integrated scientific framework that cuts across traditional scientific boundaries and disciplines. The knowledge base within the USGS is broad at the agency level, yet specialized at the individual level.

It is well known that limits to disciplinary integration are often caused by a lack of sufficient contact across disciplinary boundaries. The USGS has recognized the need to promote interdisciplinary research and has undertaken several successful but relatively small-scale steps to address this need. These include the Powell Center for Analysis and Synthesis, and the former National Research Program within the Water Mission Area. These models should be replicated and built upon with a new effort to integrate science across the agency.

Ideally, scientific researchers from across the agency would come together to address topical issues within a framework that promotes contact and integration across disciplines. Scientists would form teams to work on a specific topic and to be largely freed of other duties. The teams would have clear aims, management structure, deadlines, and end-points. Sufficient funding would be provided to cover portions of salaries, conduct regular in-person meetings, conduct the actual research, and hire postdocs or other junior scientists who bring energy, new skills, and fresh perspectives to the crosscutting issues facing society in a changing world.

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The new integrated USGS improves comprehensive understanding of science processes and impacts on human and natural systems through coordinated and interdisciplinary data collection, synthesis, analysis, and predictions. The USGS will anticipate changes in Earth's natural systems and respond by nimbly aligning all expertise required to generate the best possible information, develop and use cutting edge technologies, and provide useful decision tools that meet societal needs.

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The USGS provides the Nation with foundational and rigorous Earth system science that has the capability to forecast near-term biogeochemical responses, and to anticipate long-term change trajectories in the environment. Its scientists provide both the building blocks necessary to understand a rapidly changing planet, and the expertise to support wise decision making in contexts ranging from well-constrained operations to hyperdimensional wicked problems.

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Science for a changing world!!! The future USGS serves the Nation by empowering citizens and decision makers alike to make informed determinations regarding the use and management of natural resources; the protection of lives and the built environment from natural hazards and threats to environmental health; and the ability to adapt to a rapidly changing environment. The USGS achieves this vision by fusing an Earth systems approach to research and problem solving with a collaborative approach to engaging stakeholders in project design and development. The agency actively seeks opportunities to capitalize on emerging technologies, harness big data, and leverage external partnerships across multiple sectors. The future USGS is recognized as a leader in advancing earth science research and in providing actionable scientific information in forms that are accessible and usable by multiple stakeholders. The agency attracts and retains top talent by nurturing a creative and diverse workforce with access to rich cross-disciplinary interactions spanning the natural and social sciences, engineering, data science, and design.

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Understanding the interaction between people and the surface of the Earth will be increasingly critical to the health of the population and the environment. By focusing on integrated science approaches to future challenges, the USGS will be the national authority on national issues related to loss of productive land (in other words, desertification, acidification, and erosion), smartly addressing population growth, responding and mitigating coastal change, preserving water security, managing critical landscapes (for example, arctic and littoral), and securing mineral and energy resources.

The depth and breadth of the mission of the USGS has grown over the past century to meet the needs of our Nation's utilization of natural resources. Scientific expertise within the

USGS has also grown over this period in incremental fashion as the changes in mission required. Today and in the immediate future, the growing reliance on our Nation's resources for energy, health, and safety is unprecedented. Integration of our science across disciplines within the USGS is required now, more than ever, to meet the complexity of the competing uses of our Nation's natural resources. Application of emerging technologies to address age-old challenges is but one example of our need to maintain and integrate sciences to meet our missions. The USGS has the scientific expertise to address the growing demands on our resources; however, the integration of this expertise in new ways, not fully recognized to date, is going to be required to meet our ever-changing demands.

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The USGS addresses the event-based and rapidly changing needs of society with data-driven and systems-focused science that employs the best available interdisciplinary methods to understand and communicate environmental processes and interactions.

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A diverse, integrated, and technologically advanced USGS workforce will develop solutions for urban and rural, human and natural populations that are clearly communicated to the public. The resulting objective and comprehensive scientific understanding will ensure the health and prosperity of the nation in the face of the oncoming challenges of climate change, globalization, population shifts (and growth), land use change, and economic shifts.

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Ecosystems and the services they provide are changing rapidly, and the USGS is poised to fill an essential role in offering rapid (days to months) information on the spread of diseases from animals to people and animals to other animals; the consequences of different wildlife and fisheries management approaches; rates of change for endangered or invasive species; potential for harmful algal blooms; and consequences of disturbances such as fire, floods, drought, and extreme events on plants, animals, and carbon and nitrogen cycles. This new capability builds off existing strengths in characterizing the status and trends of the environment but adds substantially to it with abilities for model data fusion, state of the art informatics, and new statistical skills for improving predictions and reducing uncertainty.

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Building on the community engagement success of programs such as Earthquake Hazards, the USGS increases its activity and impact within U.S. communities, bringing our scientific expertise to planning activities and response to changing conditions. The Nation's citizens are regularly invited to be part of the co-creation of scientific knowledge.

- The USGS maintains a solid core of continually evolving Earth system characterization products—base observation and measurement data, process and response models, maps and other information products—continually working to improve how these products are delivered through studying and understanding how they are being used.
- All USGS scientific data, information, and knowledge are organized into a cohesive framework, linked openly with the broader scientific community that is a vital part of the research process. This Modular Science Framework is contributed to and drawn from throughout the research lifecycle and serves as the foundation for delivering scientific knowledge to stakeholders in a multimodal way that is able to put just the right information at the right time in the right format to answer important questions quickly and efficiently.

- The USGS strategically manages its workforce for an optimal balance of scientific, engineering, and operational staff and research infrastructure that balances key abilities to pursue and answer fundamental research questions with transdisciplinary syntheses that address pressing societal challenges. We actively recruit for a diverse workforce and build a culture that is responsive and engaged in societal challenges.
- The USGS is committed to the principles of open science and fully reproducible research, making available and accessible the full product of our research process from data and software to annotated scientific workflows to support the integrity of our scientific findings and accelerate the pace of new discovery.

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