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Perspective on Department of Energy Geospatial Science: Past, Present, and Future

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ABSTRACT: For many decades, the Department of Energy (DOE) has been an international leader in basic scientific and engineering research that utilizes geospatial science to advance the state of knowledge in disciplines impacting national security, energy sustainability, environmental stewardship, and associated basic research. However, the realized benefits from cross-cutting geospatial science contributions have fallen short of what they could have been with greater collaboration across the DOE complex, stronger emphasis on core geographic information science (GIScience) research and development to support advanced applications, increased strategic institutional support (e.g., for management of legacy data), and additional education and outreach concerning how geospatial science can benefit DOE programs and operations. We propose a vision for DOE's geospatial science based on expanded collaboration to address major national problems, additional advanced GIScience research and development, and a long-term strategy to better manage DOE's geospatial science resources (personnel, facilities, shared data, etc.).

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KEYWORDS: U.S. Department of Energy, geospatial sciences, GIS, energy, environmental stewardship, outreach, national security

INTRODUCTION: Toward an Understanding of the Importance of Geospatial Science for DOE

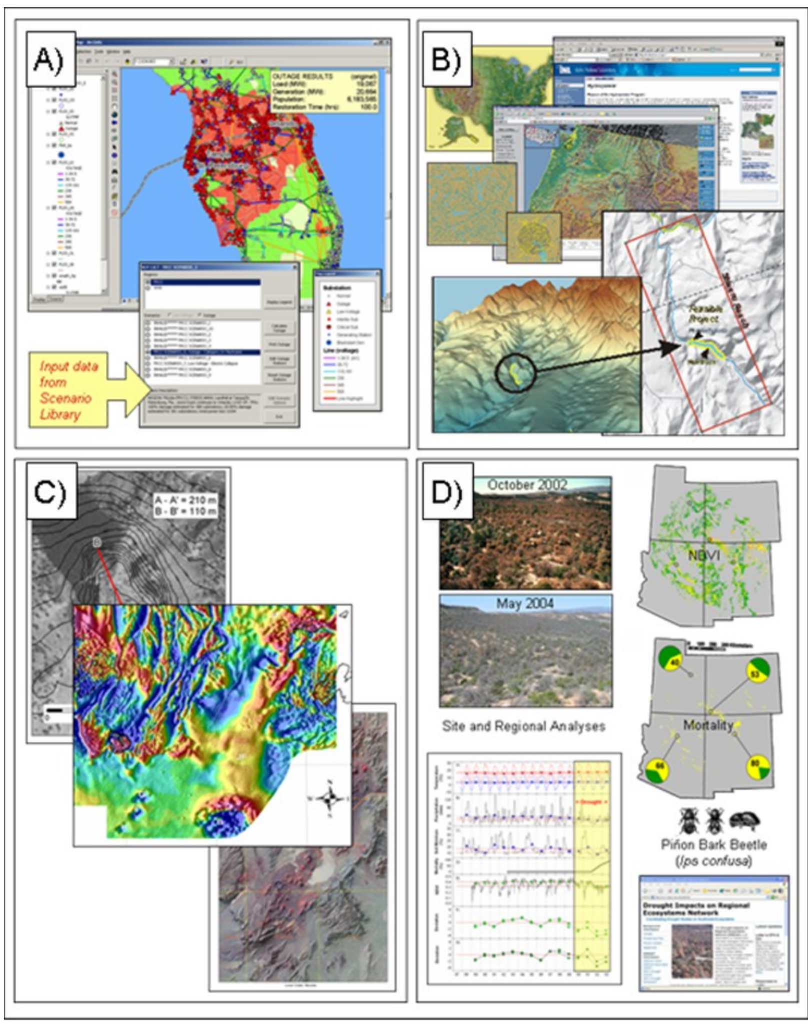
Geographic information represents characteristics of places on Earth's surface, essentially a collection of data consisting of where—geographic position expressed as space-time coordinates—and what—attributes associated with the particular location (Goodchild et al. 1999, 2006). In recent years, the academic community has distinguished geographic information science (GIScience) as the study of such spatially-referenced information, encompassing geographic theory, technological design, and analytical algorithms; versus geographic information system (GIS) as a special kind of "information system" that is used to manage, manipulate, query, edit, visualize, and, generally, to work with geographic information stored in computer databases (Goodchild and Kemp 1992; Kemp and Goodchild 1992). Herein, we use the term geospatial science in the broadest sense as encompassing both GIScience and GIS, ranging from basic theory concerning algorithms for spatial analysis and modeling, to practical implementations designed to solve particular problems—using technologies such as GIS, remote sensing, and global positioning systems (GPS).

Geospatial science has become an important and embedded part of the U.S. Department of Energy (DOE) (Bollinger et al. 2007). DOE's contributions to advancing geospatial science arise from addressing both basic and applied problems, and entail sustained "pushing the envelope" in terms of producing novel theoretical and technological contributions. Growing recognition of the importance of geospatial science for DOE's mission—including mission areas of national security, energy sustainability, environmental stewardship, and basic science—led to the recent establishment of a DOE Geospatial Science Program to coordinate and foster DOE's geospatial science activities (DOE 2005). The success of this program will depend upon a solid understanding of the challenges facing DOE's geospatial science community, a well articulated vision, and a carefully formulated and well executed implementation plan. The goal of this paper is to stimulate and inspire deeper thinking about the potential of geospatial science to enhance science and technology across the DOE complex.

In this paper we provide perspective on the past, present, and future of DOE's geospatial science activities. First, we provide an overview of current geospatial science activities within DOE. Then, based on history and collective experience, we examine the current challenges facing DOE's geospatial science community and discuss the need for 1) developing a vision for the future of DOE's geospatial science, 2) addressing the challenges of collaboration across the DOE complex, 3) enhancing support for basic GIScience research and development (R&D) in conjunction with project support, 4) ensuring strategic institutional support for key activities (e.g., legacy geospatial data management), and 5) providing better education and outreach to build an understanding of the potential for geospatial science. Next, we introduce the new DOE Geospatial Science Program and consider the prospects for coordination and enterprise GIS cyberinfrastructure (shared data and computational capabilities). Finally we conclude by proposing a vision for DOE's geospatial science, with the goal of stimulating discussion within the geospatial science community.

Current DOE Geospatial Science Activities

Geospatial science is used across the DOE complex to address a broad range of problems in support of both basic and applied scientific research, as well as site operations, including emergency response, homeland security, environmental restoration, weapons stewardship, facilities management, transportation routing (nuclear materials, weapons, and hazardous waste), and infrastructure analysis. These activities correspond directly to DOE's mission areas concerning national security, energy sustainability, environmental stewardship, and basic science (Figure 1).



DOE's national security mission area is focused on ensuring the integrity and safety of the country's nuclear weapons stockpile, while promoting international nuclear safety and non-proliferation. DOE's energy sustainability mission area is focused on providing diverse and abundant sources of energy and thereby contributing to the nation's economic viability. DOE's environmental stewardship mission area is focused primarily on cleanup of contaminated sites and disposal of radioactive waste left behind as a byproduct of nuclear weapons production, nuclear powered naval vessels, and commercial nuclear energy production—a legacy for which tens of billions of dollars have been invested in environmental remediation and management. DOE's basic science mission area is focused on diverse scientific problems relating to the other mission areas and includes study of climate change, physics, life sciences, fossil and nuclear energy, and the environmental sciences. Appendix A summarizes a comprehensive listing of DOE's geospatial activities, based on a DOE-wide portfolio prepared for the DOE Geospatial Science Expo (held January 30 to February 10, 2006, at DOE Headquarters, Washington, DC).

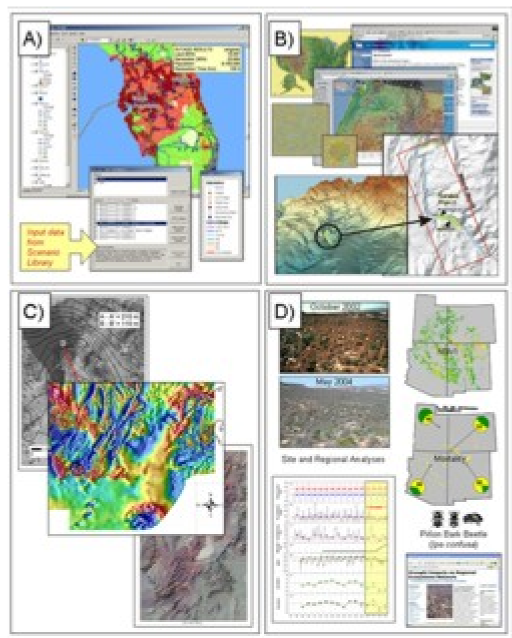


Figure 1. Examples of geospatial science applications in the four main DOE mission areas: national security, energy sustainability, environmental stewardship, and basic science. A) The Scenario Library Visualizer (SLV) enables rapid evaluation of regional electric and gas outage scenarios, such as those that occur during hurricanes and other natural and human-induced emergencies (upper left). B) The Virtual Hydropower Prospector assists in locating and assessing hydropower potential and feasibility (upper right). C) GIS-based analysis and visualization are used to assess long-term risks of high-level waste storage at Yucca Mountain (lower left). D) GIS and remote sensing are used to evaluate local and regional patterns of tree die-off due to drought, in the context of understanding cross-scale consequences of extreme weather events (lower right).

Most current geospatial scientific activities entail GIS support for projects, with cartography, spatial analysis (e.g., measurements of areas, delineation of watersheds, and calculation of data contours), and geoprocessing (e.g., georectification to place data in the same coordinate system and overlay of multiple data layers) featured prominently, and with increasing focus on advanced services such as network-based data and map services, 3- (volume) and 4-D (space/time) visualization, and custom tool development (Table 1).

Table 1. Typical GIS services provided in support of projects and operations.

Service Provided	Description
Cartography	Map production, management of map library, etc.
Spatial Analysis and Geoprocessing	Georectification, watershed analysis, area calculations, line-of sight, data contouring, etc.
Custom GIS Tools	User interfaces and specialized analysis/visualization tools

Data Service	Network based access to key institutional and project data
Digitizing and Data Conversion	Heads-up and tablet digitizing, data import/export, etc.
Enterprise GIS Design / Cyberinfra-structure	Institutional GIS logical and physical architecture customized by project
Expert GIS Consultation	Technical information, methodologies, system evaluation, hard-ware/software recommendations; data structures, etc.
Geospatial Information Management	Geospatial data archive, documentation, quality control, management, delivery, and update
GIS Training	Basic and advanced GIS and geospatial data management courses
GPS Services	Field mapping and differential correction
Internet GIS	Web-based mapping services
Remote Sensing Process-ing/Analysis	Image processing, fusion with GIS, classification, spatial analysis
Spatial Decision Support Systems	Data/model integration, decision tools, custom interfaces
Three-Dimensional GIS	Surface generation, tomography, volume analyses, spatial relations
Modeling in a Geospatial Framework	Physics, engineering, system dynamics, transport, and other mod-els
Visualization	2-D, 3-D, time series (4-D), animations, etc.

Despite widespread recognition that GIS-cience R&D is crucial to provide the basic science underpinning future technology and application needs (Bollinger et al. 2007). typically R&D currently is typically conducted only insofar as it is in keeping with project deliverables, and is only rarely leveraged across other diverse projects (Table 2).

Although the number of geospatial science professionals in DOE is relatively small, recently many of the national laboratories have experienced a proliferation of geospatial science capabilities, sometimes distinguished by a main focus on GIS, but also commonly embedding GIS capabilities within projects or operations units. For example, throughout Los Alamos National Laboratory (LANL) there has been an expansion of project and operations applications requiring GIS, which has been met in part by turning to existing capabilities, but more commonly by establishing local GIS capabilities within organizational units or programs (Table 3). This proliferation of GIS and other geospatial science capabilities, with a mix of distinct roles, semi-autonomous management, and competition for limited funding, is currently typical throughout the DOE complex.

Table 2. Some major GIScience research and development areas

R & D Area	Description
Enterprise GIS (EGIS)	Institutional level computational architecture and data structure for efficient geospatial data analysis and visualization
Geospatial Data Management	Design of efficient geospatial data and flow processes, including archive, documentation (metadata), stewardship, data/model inte-gration, and delivery
Cyberinfrastructure (CI)	Integrated computing environments that provide access to science information, models, problem solving capabilities, and communica-tion
Spatial Decision Support Systems (SDSS)	Knowledge-based approach to data/model integration, data and scenario library implementation, and decision tools for data man-

	agement, analysis, and visualization
Advanced Visualization	Two, three, and four-dimensional visualization of complex data
Data/Model Coupling	Linkages and analytical interfaces between models and diverse distributed data sources
Model Development in Geospatial Framework	Physics, engineering, system dynamics and other model development to solve complex spatial/temporal problems.

Table 3. Summary of known GIS capabilities throughout LANL in April 2006.

LANL Unit	Description
Center for Homeland Security (CHS)	GIS in support of homeland security applications
Computer and Computational Sciences Division (CCS-3)	GIS in support of generic cities project
Decision Applications Division (D-3, D-4)	GIS-based decision support for critical infrastructure protection and threat reduction
Earth and Environmental Sciences Division (EES-2, EES-6, EES-9)	R&D GIS, comprehensive services and project support, earth and environment applications (main capability centralized in GISLab, EES-9)
Environmental Stewardship Division (ENV)	GIS support for LANL site monitoring, compliance, and environmental restoration
Emergency Management & Response Division (EMR)	GIS support for emergency response, Emergency Operations Center
Engineering, Information Technology Services (ENG-ITS)	LANL site facilities management and mapping
International, Space and Response/Nuclear Nonproliferation Division (ISR/N)	GIS support for non-proliferation, remote sensing
KSL - Utility Mapping	LANL site Facilities and utilities mapping
Space & Site Management Office, Site Planning & Project Initatiation (SSMO-SPPI)	GIS support for LANL site planning
Theoretical Division (T-13)	GIS support for international terrorism models

Challenges Facing DOE's Geospatial Science Community

While the history of DOE geospatial science is one of continual innovation in the face of solving challenging societal, scientific, and technological problems (Bollinger et al. 2007), we explore the tenet that far greater contributions would have been possible with a clearer vision, better coordination and collaboration across the DOE complex, greater support for basic GIScience R&D, more strategic institutional support, and enhanced education and outreach. Historically, the DOE geospatial science community has faced many challenges, some scientific and technological, and some institutional and managerial.

Among scientific and technological challenges, three are particularly relevant to our discussion. First, although it is the policy of DOE to use commercial off-the-shelf software (COTS) where available, existing commercial geospatial technology has typically been inadequate to solve many of the unique problems faced by DOE, such that much of the creative attention of geospatial science experts is focused on developing custom solutions.

Second, geospatial information technology, while increasingly available to novice users for routine tasks, is generally complex and continually changing, requiring considerable training and experience for effective use. And third, because of the relatively small community of geospatial science experts across the DOE complex, there is often not a critical mass to enable the specialization, team work, and intellectual environment that stimulates higher levels of creativity. In all cases, these challenges can best met by a clear vision, collaboration within the greater geospatial science community, basic GIScience to support advanced applications, strategic institutional support, and education and outreach regarding the potential contribution of geospatial science.

Similarly, the institutional and managerial challenges facing the geospatial science community are many, and most involve competition for limited and constantly changing funding, institutional barriers to collaboration across the DOE complex, lack of shared resources (data, facilities, etc.) against which to leverage project efforts, and a general lack of knowledge about geospatial science among scientists and managers in other disciplines, such that many opportunities for geospatial science to contribute have not been fully realized. Again, vision, increased coordination and collaboration, GIScience R&D, strategic institutional support, and education and outreach are key to meeting these challenges.

The arguments for developing a clear vision for DOE's geospatial science are threefold. First, a clear vision provides direction, serving as a sort of pole star, to inspire, guide, and give cohesion to all activities within the greater geospatial science community. Second, development of a vision and subsequent implementation generates a sense of community that is an essential element for the success of collaboration within the DOE geospatial science community. And third, the vision promotes a broader strategic approach to geospatial science, as compared with a narrower tactical approach driven by project-specific goals. In general, geospatial science tends to be performed and funded tactically, with a focus on meeting short-term project requirements, rather than in strategically addressing long-term institutional needs. For example, a tactical approach to data management would find it sufficient to collect and analyze data to answer a specific question, whereas a strategic approach would ensure that data are organized, checked for quality, documented, archived, and made available to satisfy both immediate and diverse future needs.

The arguments for enhanced DOE cross-complex collaboration, as a key part of DOE's broader vision, hinge on realizing tangible benefits of combining the complementary strengths of all of DOE’s national laboratories and facilities. Addressing complex national problems, such as homeland and national security, response to national disasters, and energy sustainability, are best approached by bringing together collective strengths across the complex. For example, only through collaboration could GIS experts provide GIS support for emergency response during the May 2000 Cerro Grande wildfire that threatened LANL (Figure 2) (Mynard et al. 2003, 2005, 2006). While healthy competition can be valuable for promoting innovation, all too often it can lead to wasted efforts and failure to include a full complement of capabilities, and, in the worst case, it can prevent efforts from attaining the critical mass of resources and expertise needed to succeed. By contrast, strategic collaboration can ensure completeness of an effort, a critical mass of resources and expertise, and overall cost savings.

The arguments for GIScience R&D in support of advanced applications depend upon demonstrating tangible benefits, which are numerous. These benefits include directly and indirectly enhancing the quality of the related applications, providing advanced technology and innovation to U.S. industry, leveraging general solutions across many applications, building an environment that fosters creativity and novel solutions, maintaining the interest and cognitive skills of personnel, and enhancing the ability to recruit the best and brightest geospatial science experts. Industry has long recognized that investment in R&D can yield high rates of return, and is an essential part of a successful long-term strategy.

Typically the results of GIScience R&D can be applied to a large number of disparate projects. For example, at LANL, GISLab staff are developing generalized GIScience decision support designs that can be applied to many projects (carbon sequestration, water/energy planning, hurricane response, etc.), based on common needs for a knowledge base (key data and library of model scenarios), gateway tools (links between data sources, process models, system dynamics models, and analysis/visualization), and user interface tools (access to analysis/visualization/etc.) (Figure 3) (Rich et al. 2005). Ultimately, the projects are strong beneficiaries of such cross-cutting approaches, because this ensures that work is based on solid theoretical foundations, that solutions are general and draw on existing designs and tools wherever possible, and that no single project must bear the full burden of developing the underlying GIScience needed for project success

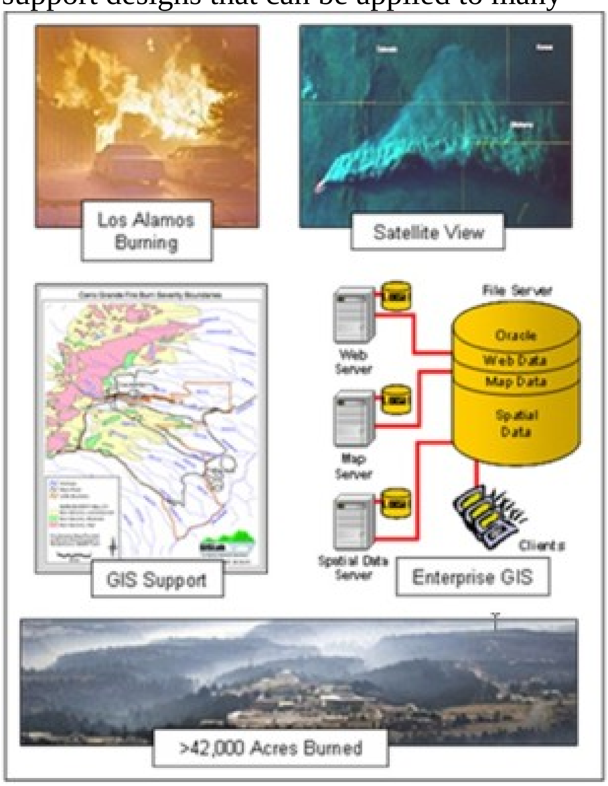


Figure 2. Collaborative GIS efforts played a major role for emergency efforts during and after the Cerro Grande wildfire, which threatened Los Alamos National Laboratory in May 2000. In the aftermath of the fire enterprise GIS capabilities were developed to provide access to key data and tools (Mynard et al. 2003, 2005, 2006).

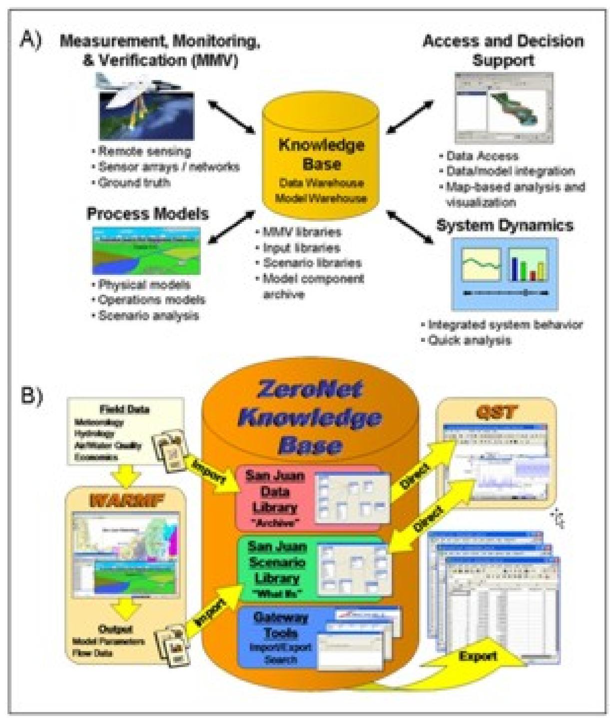


Figure 3. A) A knowledge base approach to decision support links diverse project elements (decision tools, MMV, process models, high-level models) via data libraries. B) The ZeroNet Decision Support System applied this design to build scenario libraries concerning water management as it affects energy production in the San Juan Basin (Rich et al. 2006).

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The arguments for strategic institutional support are three-fold. First, because resources are limited, investment must be viewed in terms of institutional priorities and return on investment. Second, many essential institutional activities can not be funded appropriately from projects, but are essential for the institution, as is the case for geospatial activities associated with site management, common-use facilities and data libraries, and various compliance requirements. And third, strategic support, as opposed to tactical project-oriented support, results in an enduring legacy of continued benefits. For example, the main product from many DOE geospatial science activities is the resulting data, and in many cases these data are neither documented nor preserved after project needs are met. It is estimated from recent surveys that DOE is in danger of losing almost $150M in geospatial data that cannot be replaced—much of which supports closure justification for some of DOE's most environmentally sensitive waste sites—such that strategic institutional investment in documenting and archiving these data is warranted (Bleakly 2002; Bollinger 2005).

The arguments for enhanced geospatial science education and outreach depend on demonstrating benefits from more widespread and deeper knowledge of the subject. Some in the geospatial science community have referred to this education and outreach as "in-reach" in the sense that its audience is generally comprised of scientists and managers in other parts of DOE, and as "marketing" in the sense that it builds a customer base that uses geospatial science to enhance projects. Incorporating geospatial science from the onset of a project, rather than as an add-on later in the project, can yield the greatest benefits. For example, DOE's National Energy Technology Laboratory (NETL) is sponsoring research that includes GIS support to build distributed regional and national data libraries concerning carbon capture and sequestration, that are made available via the NatCarb geoportal—an ambitious effort that has only been possible because of appropriate education and outreach early in the planning process (Figure 4) (Carr et al. 2007).

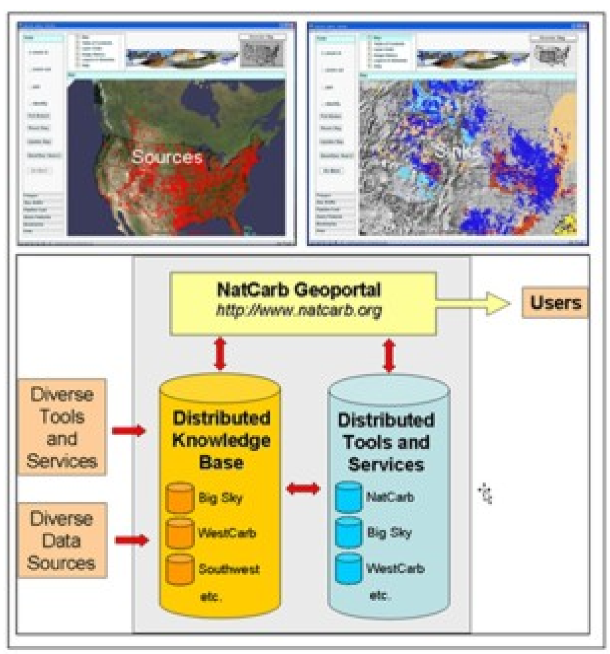

Figure 4. The NatCarb geoportal (http://

www.natcarb.org) provides web-based access to the National Carbon Atlas (CO_2 sources, potential terrestrial and geologic sinks, base maps, etc.), assembled from distributed geospatial resources (data, tools, and services) of the Carbon Sequestration Regional Partnerships (Carr et al. 2007).

A final example emphasizes the benefits of vision, coordination, GIScience R&D, strategic institutional support, and education and outreach to meet the challenges faced by the geospatial science community, and highlights several key activities that require attention. Other federal agencies such as the U.S. Geological Survey, the U.S. Environmental Protection Agency, and the U.S. Department of Agriculture, have recognized geospatial science as a cross-cutting information technology backbone. Most of DOE's current geospatial science efforts are funded on a project specific basis, typically as a subsidiary component of an overarching facilities management or science project. In this context, there is limited ability to build complex-wide capabilities and to leverage generated data and associated geospatial analysis capabilities. Consequently, improved support could be provided for various key institutional activities (Bollinger et al. 2005), in particular 1) cross-complex geospatial science coordination and enterprise data sharing to enhance DOE's science and technology efforts, and to eliminate duplication, inefficiency, and waste (Keating et al. 2003, Witkowski et al. 2003, Witkowski et al. 2007); 2) compliance with mandatory federal geospatial standards, in particular Office of Management and Budget (OMB) Circular A-16 (OMB 2002), Executive Order 12906 (Clinton 1994), and associated Federal Geographic Data Committee (FGDC) geospatial data standards (FGDC 2003); and 3) participation in the Geospatial One-Stop (GOS), a cross-governmental initiative to promote data discovery and sharing as part of the President’s Management Agenda (Goodchild et al. 2006).

The DOE Geospatial Science Program: Promises of a Brighter Future

Experts have long advocated an institutional approach to address challenges facing the DOE geospatial science community (Bollinger et al. 2007), but only recently have grassroots geospatial science efforts gotten attention at the highest levels of DOE. Bollinger et al. (2007) provide a history of the formation of the DOE Geospatial Science Program, wherein bottom-up institutional efforts of the geospatial science community recently have met top-down institutional efforts of DOE's Office of the Chief Information Office (OCIO). Three entities have been important in this development: 1) the DOE GIS User Group, 2) the DOE Geospatial Science Steering Committee (GSSC), and 3) the DOE Geospatial Science Program Management Office (GS-PMO).

The DOE GIS User Group: The primary purpose of the DOE GIS User Group, a grassroots group active since the late 1990s, is to foster effective communication across the DOE complex and to promote technical excellence. The user group meets twice per year, publishes a biannual newsletter, and maintains an e-mail list of personnel active in the geospatial sciences across the DOE complex.

DOE Geospatial Science Steering Committee (GSSC): The DOE GSSC (originally called the DOE GIS Core Team) was formed in 2001, with a mission to promote effective utilization of geospatial science and technology in the DOE complex by fostering technical excellence and communication, identifying and advocating best business practices, and providing sound recommendations on policy and standards. Representatives from major DOE facilities and national laboratories were selected to comprise this team. The GSSC has been active in reviewing the usage of geospatial resources across the complex, evaluating geospatial needs, planning the future of DOE geospatial activities, and advising the new GS-PMO. Goals of the DOE GSSC include the following (Bollinger et al. 2005):

- implement the cross-governmental GOS initiative in DOE;
- increase the visibility of DOE geospatial science programs at DOE Headquarters (HQ) and within the DOE field organizations;
- provide feedback and input to DOE-HQ regarding geospatial issues that are relevant to the entire complex;
- make arrangements for more cost-effective procurement of GIS software and geospatial data by leveraging the purchasing power of the entire DOE complex;
- provide guidance on the implementation of geospatial data standards such as FGDC metadata standard and OMB Circular A-16;
- define geospatial data sharing needs among DOE sites and between DOE and other Federal, State, and local agencies and the public, and then implement a system to meet those needs.

DOE Geospatial Science Program Management Office (GS-PMO): The DOE GS-PMO, established in 2005 to coordinate and optimize DOE's investments in geospatial science and technology activities as they support the core mission of the Department, seeks to provide the framework to assess, coordinate, manage, and implement an integrated geospatial science and technology capability across the complex. The GS-PMO charter established a tri-chair governance structure, with representatives from the Office of Environmental Management (EM), the National Nuclear Security Administration (NNSA), and the Office of Science (SC), and with administrative support from the DOE OCIO (Figure 5).

The charter for the GS-PMO (DOE 2005) calls for a comprehensive and integrated enterprise management solution for leveraging geospatial resources across the DOE complex, along with provision for the governance structure, strategic direction, mission alignment, and communication and resource coordination for the geospatial science activities of the department. Furthermore, the GS-PMO proposes to provide departmental leadership, financial resources, and participation in support of federal geospatial standards, guidance, e-government initiatives, and an overall enter-

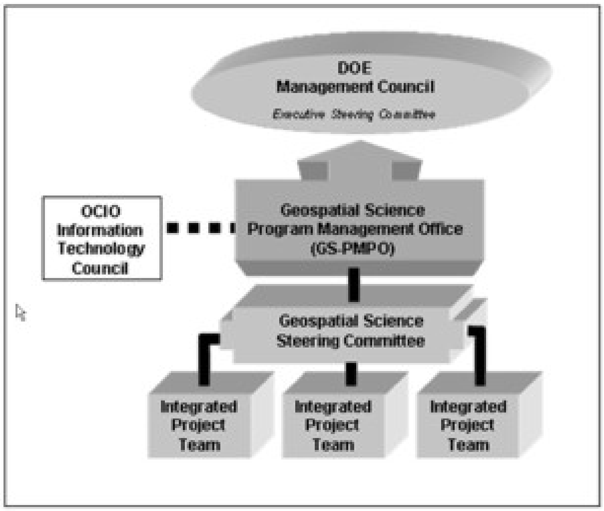

Figure 5. Geospatial Science Program governance structure (DOE 2005).

prise management business approach to geospatial science across DOE. The objectives of the GS-PMO and GSSC will be achieved using Integrated Project Teams (IPTs) comprised of skilled professionals from throughout the DOE complex. These IPTs will report to the GSSC with oversight from the GS-PMO. IPTs have been proposed to focus on geospatial data management, geospatial enterprise architecture and cyberinfrastructure design, enterprise licensing for commercially vended software and data, geospatial data standards and procedures, geospatial science education and outreach, and the GOS.

As compared with geospatial science initiatives in other governmental departments, former Central Intelligence Agency (CIA) CIO John Young observed that the DOE geospatial science program plan is "more firmly grounded in basic science" (Young 2006). This grounding could serve DOE well to enhance both basic and applied science throughout the DOE complex. While the GS-PMO promises to provide the necessary institutional support for DOE's geospatial science, the geospatial science community, as represented by the DOE GIS User Group and the GSSC, is observing development with guarded optimism. To date, the primary benefit has been increased awareness by high level DOE officials, including Secretary Samuel Bodman, of the breadth and importance of geospatial science activities.

Prospects for DOE Enterprise GIS and Cyberinfrastructure: The GS-PMO has proposed to develop enterprise GIS for sharing key data across the DOE complex. Enterprise GIS provides common computational infrastructure to share geospatial data and associated analytical services at an organizational level (Witkowski et al. 2003, 2007). Cyberinfrastructure refers to an integrated computing environment and capabilities that provide access to specific scientific information, models, problem-solving capabilities, and communication (Atkins et al. 2003, Estin et al. 2003, and Berman and Brady 2005). Shared GIS computational infrastructure can decrease the need for each project to build its own infrastructure, enhancing data sharing and computational capacity, thereby increasing productivity (Witkowski et al. 2003, Carr et al. 2007). Many DOE projects have built their own cyberinfrastructure (servers, software, databases, etc.); and similarly cyberinfrastructure has been built to support site operations; however, typically both project and site operations have limited GIS capabilities, and have not shared cyberinfrastructure and data with the greater institutional community of GIS users. Rather, most DOE facilities and national laboratories have been faced with difficulties of coordinating GIS activities and resistance to building shared enterprise-level capabilities (Keating et al. 2003). Most members of the DOE GIS User Group and GSSC advocate DOE enterprise GIS for certain uses, such as emergency response. But there is still not consensus about whether projects and site operations would benefit from DOE-wide EGIS cyberinfrastructure.

Conclusion: Toward A Vision for DOE's Geospatial Science

The history of geospatial science in DOE is one of rapid change in response to technological and scientific advances coupled with increasing data availability, departmental and nationwide shifts in emphasis from basic to applied science, the need to respond to changing national priorities and emergencies, and changing funding opportunities (Bollinger et al. 2007). Bollinger et al. (2007) posited four lessons from history: DOE geospatial science has effectively evolved to address continual shifts in funding and programmatic priorities; efforts to form a cohesive institutional geospatial program have been ongoing since 1978; over the past four decades DOE's contributions to geospatial science have been significant; and finally, capturing the history of DOE's geospatial science has been inadequate. Based on this historical analysis, and our experience with the DOE GIS User Group, the GSSC, and the GS-PMO, we suggest that DOE's contributions to geospatial science, while substantial, could have had still more impact, had the Department embraced a strategic vision for geospatial science. For example, during the 1970s, separate prototype GIS software was developed independently at three different national laboratories (LANL, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory), as well as in academia—efforts that could have been combined to produce much stronger products. Such parallel development, still common across all of DOE, could benefit substantially from greater collaboration in which complementary capabilities are brought together in a synergistic interplay. This is particularly relevant because the current societal problems facing DOE and the nation are enormous.

For example, there is a major effort to identify vulnerabilities in the nation's critical infrastructure (transportation, utilities, telecommunication, water and food supply, etc.) as part of current homeland security concerns (Figure 6). Other examples include border and port security; non-proliferation; carbon capture and sequestration; environmental restoration; response to hurricanes, droughts, and other extreme events; environmental and economic impacts of climate change; and development of new sources of energy. Only through collaboration can such enormous problems be addressed.

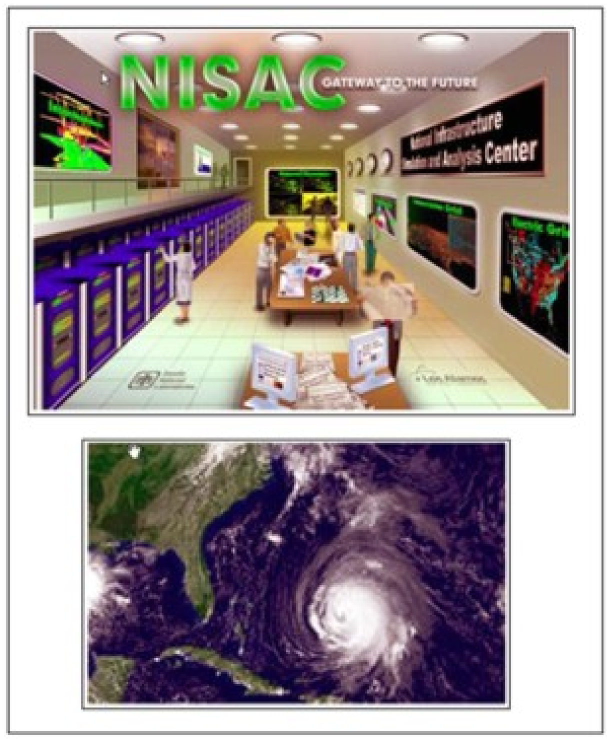

Figure 6. The National Infrastructure Simulation and Analysis Center (NISAC) uses GIS-based tools for modeling, simulation, and analysis of critical infrastructures, their interdependencies, complexities and potential consequences of disruptions (Wimbish and Sterling 2003).

In order to more fully realize the potential of DOE's geospatial science, we reiterate the importance of developing a clear and far-reaching vision, promoting collaboration across the DOE complex, providing enhanced support for core GIScience R&D in support of advanced applications, providing strategic institutional support, and enhancing education and outreach efforts to communicate how geospatial science can benefit projects. In the face of ongoing change and proliferation of geospatial science capabilities, and of growing awareness of the contribution that geospatial science can make, we suggest that the time has come to engage DOE's geospatial science community in critical discussions leading to the development o a solid vision. As such, we conclude by proposing the following vision statement as a starting point for such discussions:

DOE's geospatial science focuses on cross-complex collaboration in three realms: (1) to provide cross-cutting capabilities required to address temporal and spatial aspects of complex basic and applied problems facing DOE and the nation, along with rapid and robust response to emergencies; (2) to ensure ongoing support for the basic geospatial science research and development required to support DOE's advanced geospatial science applications; and (3) to develop a long-term strategy to manage DOE's geospatial sciences resources (personnel, facilities, data, models, and GIServices for geospatial information management, analysis, and visualization).

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APPENDIX A

The DOE Geospatial Science Steering Committee (GSSC) and Geospatial Science Program Management Office (GS-PMO) co-sponsored a DOE Geospatial Science Expo, held January 30 to February 10, 2006, at DOE Headquarters, Washington, DC, to showcase geospatial science activities. Presentations included posters, talks, demonstrations, and a comprehensive portfolio of DOE's geospatial science activities. The portfolio was presented as a continuous-loop slide show that highlighted activities for the following organizations: Argonne National Laboratory (ANL), Brookhaven National Laboratory (BNL), Energy Information Administration (EIA), Hanford Site (HS), Idaho National Laboratory (INL), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), National Renewable Energy Laboratory (NREL), National Energy Technology Laboratory (NETL), Pacific Northwest National Laboratory (PNNL), Remote Sensing Laboratory (RSL), Sandia National Laboratories (SNL), and Savannah River National Laboratory (SRNL). Current DOE geospatial science activities fall in the mission areas of national security (Table A-1), energy sustainability, (Table A-2), environmental stewardship (Table A-3), and basic science (Table A-4). Although this compendium of geospatial science activities represents an excellent sampling across the DOE complex, it is not comprehensive, in that it only includes unclassified activities, and the DOE complex is sufficiently large that it is difficult to identify all geospatial science activities.

Table A-1. Overview of current DOE geospatial science activities concerning National Security.

Application	Organization(s)	Description
Analysis of Radionuclide Theft and Diversions	ANL	Characterize problem and prioritize program actions to reduce the threat to U.S. national security from radiological materials being used in "dirty bombs."
Critical Infrastructure Protection Decision Support System (CIP-DSS)	ANL, SNL, LANL	Determine critical infrastructure vulnerabilities, protection strategies, and emergency response options during natural disasters or terrorist attacks.
Emergency Planning and Preparedness for Special-Needs Populations	ANL	Enable emergency planners and responders to understand and plan for evacuation orders or other protective actions in emergencies associated with individuals with limited physical or mental capacity.
Emergency Preparedness and Response	ORNL	Support for Office for Electricity Delivery & Energy Reliability, Infrastructure and Energy Restoration Division's Visualization and Modeling Workgroup during natural or technological disasters.
Emergency Response GIS and Wireless Technology	RSL	Real-Time Data Acquisition and Dissemination (RDAD) architecture to allow mobile data acquisition platforms to move data through any IP communication channel to central command and control assets.
Geospatial Data in National Atmospheric Release Advisory Center (NARAC)	LLNL	Provide tools and services that map the spread of hazardous material in the atmosphere for use in planning, preparedness, emergency response, and assessments involving a wide variety of hazards, including nuclear, radiological, chemical, biological or natural emissions.
Hydrologic Transport Assessment System (HYTRAS)	ORNL	Application and integration of watershed modeling to predict transport of nuclear, biological, and chemical agents in surface waters, and downstream exposure risk assessment resulting from incidents.
Image-to-Intelligence Archive (I2IA)	ORNL	Agent-based system architecture that autonomously manages massive but dynamic image data archive that transforms data to intelligence archive to aid national security needs.
Intelligent Consequence Management	ORNL	Integrate sound behavioral assumptions, dynamic traffic assignment, and high-resolution demographic data in GIS framework for evacuation model.
Katrina Response GIS Support	RSL	Deploy B-200 aircraft outfitted with radiological sensors to New Orleans area to survey displaced radiological sources, with data telemetered in real-time for GIS assessment.
Nuclear Emergency Response	RSL	Maintain deployable GIS capability to respond to nuclear emergencies.
Plumes in ArcView for Emergency Response	SRNL	Import calculations from atmospheric transport models into ArcView for emergency response.
Scenario Library Visualizer (SLV)	LANL	Support for data input and visualization of regional electric and gas outage scenarios.
Second Line of Defense (SLD)	LANL	Support for monitoring movement of nuclear materials at customs ports around the world.
SensorNet	ORNL	Promote interoperability and information sharing standards for interfacing autonomous sensor networks for response to radiological, chemical, meteorological, and biological emergencies.
SRS Remote Worker Program	SRNL	Provide centralized tracking and accountability for workers at remote locations.
Support for National Infrastructure Simulation and Analysis Center (NISAC)	SNL, LANL	Provide GIS-based tools for modeling, simulation, and analysis of critical infrastructures, their interdependencies, complexities and potential consequences of disruptions.
Windrose Analysis in a Geospatial Framework	SRNL	Analyze 50 years of wind data over the Southeast for temporal and spatial trends.

Table A-2. Overview of current DOE geospatial science activities concerning Energy Sustainability.

Application	Organization(s)	Description
3D Geologic Modeling	LLNL	Use Earthvision modeling code to build and visualize 3D geologic models.
Automated Oil and Gas Field Mapping	EIA	Produce automated maps based on well data for tens of thousands of oil and gas fields.
Bird's Eye View on California Wind	LLNL	Develop web-based, decision-aid for tracking, evaluating and integrating wind data layers relevant to alternative energy development.
Bus Route Optimization	INL	Develop more efficient bus routes and stops using geospatial technologies.
Calculating Solar Energy Savings	NREL	Provide map-based interface (ArcIMS) to PVWATTS model for evaluating solar energy potential.
Carbon Sequestration Regional Partnerships	NETL, LANL, INL	Build National Carbon Atlas of georeferenced carbon sources and potential sinks (terrestrial and geologic) to assess feasibility to capture and store massive quantities of carbon dioxide.
Coalbed Methane in U.S.	EIA	Summarize key data concerning U.S. coalbed methane resource base and its commercial development history in easily accessed, readily assimilated, geospatially-based graphical form.
Global Energy Technology and Resources Suitability Analysis	ORNL	Geospatially referenced analysis using high resolution physiographic and socioeconomic data that facilitates feasibility for development and market analysis for energy technology solutions on a regional scale.
Finest Railway Network Analysis	ORNL	Build topologically accurate 1:100K rail network for detailed routing and infrastructure analysis.
Geothermal Resource Mapping	INL	Produce geothermal resource maps of the Western U.S. to support DOE's GeoPowering the West activity.
Multimodal Transportation Network	ORNL	Build client/server application to access routable, multimodal network, combining highways, railways, and waterways, for transportation modeling.
NatCarb Geoportal	NETL	Provide web-based access to National Carbon Atlas data and associated tools for assessment of carbon capture and sequestration opportunities.
Perspective on Biomass Resource Availability	NREL	Provide comprehensive up-to-date estimate of biomass resources available in the U.S.
Renewable Energy Prospecting for Brownfields Redevelopment Strategies	NREL	Evaluate opportunities to redevelop brownfields, superfund sites, and abandoned mine lands for renewable energy production.
Transportation Routing Analysis	ORNL	Develop Transportation Routing Analysis Geographic Information System (TRAGIS) model to calculate compliant routes for shipments of radioactive or hazardous materials and other commodities.
Zero Emissions Research and Technology	LANL	Link laboratory, field, monitoring, and modeling for capture and long-term storage of carbon dioxide in geologic formations carbon sequestration at SACROC field site.
Zeronet Water/Energy Decision Support System	LANL, SNL	Develop spatial decision support system to assess water management options GIS-based tools to ensure water availability for power generation in San Juan Basin.

Table A-3. Overview of current DOE geospatial science activities concerning Environmental Stewardship.

Application	Organization(s)	Description
Aerometric and Hydrometric Monitoring Data Interactive Web Access for Adaptive Decision Management	ANL	Develop interactive web-based mapping site to assess haze and cumulative air quality impacts of existing and proposed power plants in the Four Corners region, with links to live weather and visibility monitoring data along with historical databases.
Argonne Geographic Information System	ANL	Provide site-wide GIS to manage, analyze, visualize, and model geospatial data in support of ANL operations, planning, and environmental activities.
Central Mapping Services for Hanford Site	HS	Provide GIS support for Hanford Site environmental cleanup.
Cerro Grande Rehabilitation Project GIS	LANL	Build Enterprise GIS capability in support of recovery efforts following the Cerro Grande fire to protect LANL site from future disasters.
Critical Habitat Designation for Endangered and Threatened Species	ORNL	Identify "hotspots" of critical habitat for endangered and threatened species and assess potential for protection by establishing biological reserves.
Effects of Hydropower Operations on Endangered Fish Habitats	ANL	Evaluate effects of hydropower operations on the Green River in Colorado.
Environmental Restoration	LANL	Provide GIS support for cleanup of legacy waste sites at LANL.
Facility Asset/Space Tool (FAST)	LLNL	Develop web-based Facility Asset/Space Tool (FAST) for automated tracking, evaluation, and allocation of office and laboratory space.
GIS Based Access Tool for Environmental Data	BNL	Develop web-based interactive map tool for access to well construction, geological, and environmental sampling data in support of BNL Environmental Cleanup Program.
Groundwater Flow Modeling in a Geospatial Framework	SRNL	Develop rapid and precise 2-D groundwater flow modeling capability in a geospatial environment, based on potentiometric contours, groundwater hydraulic properties, and flow trajectories.
Groundwater Monitoring at PNNL	PNNL	Provide GIS support for groundwater monitoring at PNNL.
Groundwater Protection Program	LANL	Model water resources and contaminant transport for aquifer surrounding LANL.
Hanford Map Portal (QMAP)	HS	Develop QMAP tool for web-based access to geospatial and tabular data concerning waste sites and wells.
High-Resolution Social Dynamics	ORNL	Analyze movement of K-12 students from home to school to determine environmental exposure of student population to common pollutants.
Modeling Environmental Effects of Oil and Gas Development	ANL	Integrate GIS, modeling, and visualization tools to advance understanding of complex environmental issues associated with oil and gas development.
Monitoring Natural Resources at BNL	BNL	Provide GIS support for monitoring BNL flora, fauna, and sensitive habitats to ensure their protection in compliance with environmental regulations.
Pesticide Usage and Drinking Water	ORNL	Evaluate water quality impacts of agricultural pesticide application based on transport from upstream contributory watersheds to surface water intake locations.
Selenium Information System	INL	Provides single location where end-users (Federal, State, Tribes, & general public) can access Selenium contamination information associated with southeast Idaho phosphate mining.
SRS Deactivation & Decontamination Program	SRNL	Provide GIS-based analyses for SRS deactivation and decontamination effort.
Stream Flow Forecasting in Snow Dominated Basins	INL	Develop method for measuring snow cover on a daily basis for input into snow run-off models.
Underground Test Area (UGTA) 3D Geologic Model	LANL	Provide GIS support for 3D geologic analysis using well bores at Nevada Test Site, including micro-GIS tool for georeferencing thin-section data and links from micro to site scale.
Virtual Infrastructure and Site Tour System (VISiTS)	INL	Develop a stand-alone GIS application to presents the capabilities of INL Critical Infrastructure Protection Test Range to potential customers.
Volcanic Hazards Assessment (PVHA)	LANL	Provide GIS support for PVHA to assess long-term risks of high-level waste storage at Yucca Mountain.
Watershed Characterization	ORNL	Characterize watersheds based on spatial analysis of surface water intake locations with respect to National Hydrography Data.
Watershed Risk Assessment for SRNL	SRNL	Provide GIS support for contaminant monitoring and watershed risk assessment at SRNL.
Western Energy Corridor Program Environmental Impact Statement.	ANL	Produce Environmental Impact statement for energy transportation networks in the Western US through cooperative interagency effort.

Table A-4. Overview of current DOE geospatial science activities concerning Basic Science.

Application	Organization(s)	Description
Challenges of Coupled Spatial Dynamic Modeling	LLNL	Develop coupled dynamic spatial models concerning the consequences of severe Wildfire Risk and Urbanization.
Cheat Grass Phenology Model	INL	Develop a model of cheat grass phenology (annual pattern of greenup and senescence) based on climate, topography, and satellite imagery.
Data Acquisition and Direct Referencing	INL	Develop methodology for georeferencing of imagery in real-time using unmanned autonomous vehicles, based inertial navigation and GPS.
Developing Techniques for the Statistical Resampling of Geographic Data	LLNL	Develop techniques for incorporating auxiliary data, collected at different spatial scales, in energy models, based on resampling using spatial statistics.
Disaster Utility Metrics and Spatial Correlations for Hi-Res Population	ORNL	Evaluate the use of high resolution population vs. ancillary variables for disaster management, using spatial auto- and cross-correlations and combined variables.
Drought-Induced Tree Mortality	LANL	Evaluate local and regional patterns of tree die-off due to drought, in context of understanding cross-scale consequences of extreme weather events.
Educational and Community Outreach	ORNL	Provide summer and one-year internship appointments for high school and college students to participate in geospatial science projects.
Enterprise GIS Design	LANL	Develop Enterprise GIS capabilities to provide access to shared geospatial data and services.
Geospatial Applications of the System and Decision Sciences Section	LLNL	Produce better estimates of energy and security problems by accounting for spatial and temporal dimensions of data, as well as variance and dominant trends in the process or system.
GIS Education and Technical Outreach for Native Americans	LANL	Provide GIS education opportunities for tribal high schools and technical assistance for tribal GIS facilities for Native Americans of Pueblos adjacent to LANL (San Ildefonso, Santa Clara, Cochiti, Jemez).
GIS Links with Remote Sensing	LANL	Provide GIS support for remote monitoring (reconnaissance, tracking chemical plumes, real-time remote sensing, etc.).
High Performance Computing in Terascale Spatial Data Integration and Visualization	ORNL	Develop high-performance, cluster computing techniques for data processing, using GRASS GIS in a 35 megapixel visualization environment, and involving efficient information extraction, fusion, and query to interpret data.
Immersive Visualization	ORNL	Explore the use of COTS hardware and open source software solutions to provide the user with a wearable, untethered, immersive experience.
Integrating Disparate Spatial Data	ORNL	Provide access to display, analyze, and interact with both locally stored and internet-accessible GIS data to users in multiple locations using a variety of operating systems.
LandScan Global Population	ORNL	Develop LandScan application to provide accurate depictions of global population distribution using multi-variable, dasymetric modeling approach.
LandScan USA	ORNL	Develop LandScan application to provide accurate depictions of U.S. population distribution using multi-variable, dasymetric modeling approach.
Mapping Microbial Diversity	INL	Develop a GIS tool to locate physical characteristics and associated microorganisms of Yellowstone National Park hot springs.
Microclimate Modeling	LANL	Develop GIS-based microclimate and energy balance models to characterize surface climate variability, with applications for land management, agriculture, climatology, ecology, and hydrology.
Multivariate and Multi-scalar Analysis in Space and Time	ORNL	Develop multivariate and multi-scale dependence analysis in space and time, with applications for climate, sensor networks, and national security.
Parallel Visualization for GIS	ORNL	Developed a module for GRASS GIS that can utilize the capabilities of multi-screen display environments driven by Linux-based PC clusters.
Spatial Decision Support System Design	LANL	Develop spatial decision support system conceptual framework applicable for diverse projects, based on a knowledge base approach that links diverse project elements (decision tools, measurement/monitoring/verification, process models, high-level models) via data libraries.
Spatial-Temporal Population Dynamics	ORNL	Develop spatial-temporal models of population dynamics, based on integrating high-resolution population data, socio-economic and behavioral assumptions, and transportation models.
Tera-Scale Data Integration	ORNL	Assist the Tennessee Base Mapping Program (TNBMP) in developing methods of storing, updating, and providing access to large spatial datasets.
Training the Next Generation	BNL	Develop a program of student internships to provide hands-on experiences learning field techniques for collecting baseline ecological data using GIS and GPS systems.