A Brief History of Geospatial Science in the Department of Energy

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ABSTRACT: The U.S. Department of Energy (DOE) has a rich history of significant contributions to geospatial science spanning the past four decades. In the early years, work focused on basic research, such as development of algorithms for processing geographic data and early use of LANDSAT imagery. The emphasis shifted in the mid-1970s to development of geographic information system (GIS) applications to support programs such as the National Uranium Resource Evaluation (NURE), and later to issue-oriented GIS applications supporting programs such as environmental restoration and management (mid-1980s through present). Throughout this period, the DOE national laboratories represented a strong chorus of voices advocating the importance of geospatial science and technology in the decades to come. The establishment of a Geospatial Science Program by the DOE Office of the Chief Information Officer in 2005 reflects the continued potential of geospatial science to enhance DOE's science, projects, and operations, as is well demonstrated by historical analysis.

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Introduction: A Historical Approach to Understanding Geospatial Science in DOE

The roots of geospatial science in the Department of Energy (DOE) extend back to the days of the Manhattan Project, and, in keeping with DOE’s mission, this science has been used to address such diverse issues as monitoring effects of nuclear testing, survey of nationwide energy reserves, environmental restoration, and response to national emergencies. Geospatial science has become an important and embedded part of the department. Understanding historical underpinnings of DOE’s geospatial science is of value in an instructional and inspirational sense, in that future progress is best guided by the lessons of the past. We may find the most appropriate path by examining and learning from the successes and failures of our predecessors—and it is just these successes and failures that may well inspire our greatest steps forward.

Herein we provide a brief history of significant developments in DOE geospatial science from the late-1960’s, with emphasis on the early years and on events leading to the recent formation of a DOE Geospatial Science Program (Bollinger et al. 2005; DOE 2005; Rich et al. 2007). Our historical treatment is not intended as a definitive or complete history of geospatial science within DOE. Rather, it is promulgated as a first step to chronicle some of the important events that have framed geospatial science at DOE, to encourage more comprehensive historical treatments, and to garner a set of historical lessons of value to current and future geospatial science efforts. We ponder three important questions: (1) What role has DOE played in the broader development of geospatial science and technology? (2) What significant events guided and impacted development in geospatial science? and (3) What lessons can we garner to direct future efforts in further development of geospatial science and technology?

Historical Underpinnings of DOE’s Geospatial Science

Basic Science Applications in the Early Years (through mid-1970s): Prior to the days when GIS was a recognized acronym, various DOE laboratories were making pivotal contributions that would shape the future of this burgeoning science and technology. These early years can be characterized as focusing on using geospatial science to address basic science questions, generally pushing the limits of existing hardware and software technology for graphics display and spatial analysis, sometimes adapting early commercial graphics and mapping programs (e.g., Hypermap and Supermap), and more commonly developing custom software to meet particular project needs (Cole 2006). Noteworthy were the geospatial science activities at Oak Ridge National Laboratory (ORNL) in Oak Ridge, TN, the Pacific Northwest National Laboratory (PNNL) in Richland, WA, Los Alamos National Laboratory (LANL) in Los Alamos, NM, and the Remote Sensing Laboratory in Las Vegas, NV.

In addition to GIS, DOE has a rich history in remote sensing that goes all the way back to the Manhattan project (van Etten 2006). In fact, this history is extensive to the point that it easily could be the topic of a stand alone book. From the Manhattan project forward, remote sensing was used extensively to measure the physics of nuclear detonations and assess the resulting detonation impact on the ground surface—both in Pacific weapons testing and at the Nevada Test Site for atmospheric and underground tests (van Etten 2006). Remote sensing data also has historically been used by DOE for efforts in international nuclear non-proliferation. Much of the history regarding DOE remote sensing is now unavailable due to the time that has passed since the development of the nation’s nuclear weapons program.
ORNL established itself as one of the leading national institutions in the development of GIS and geospatial science in 1969—a tradition that started with regional modeling and later the analysis of the very first LANDSAT satellite (then referred to as ERTS) imagery (Dobson and Durfee 1988) (Figure 1). During the period extending from 1969 through 1976, ORNL focused its efforts on research and development in GIS with funding provided primarily from the National Science Foundation (NSF). At that time, software for processing remotely sensed or geographic data was very limited. Therefore, ORNL developed its own software to process raster and cell-based data. This software included the Oak Ridge Regional Modeling Information System, which focused on land use planning and economic analysis of the Eastern Tennessee region (Durfee 1984; Durfee 1988). This capability was further extended to process vector data in the mid-1970’s similar to the Polygon Input Output System (PIOS)—an early and primitive forerunner of modern day GIS software (Edwards 1977; Durfee 2006). GIS software development at ORNL during this time period incorporated capabilities for perspective and isometric drawing of cartographic surfaces, map projection transformations, integration of remote sensing and statistics in GIS, viewshed calculation, polygon intersection, and raster/vector transformation (Dobson 2001). ORNL would continue on to develop software for transportation routing and analysis in 1982, true 3-D imaging in 1983, and eventually geospatial analyses of 3-D information such as air traffic over the U.S. (Dobson 2001) (Figure 1; Figure 2).
In 1977, ORNL geospatial scientists were invited to make presentations at the Advanced Study Symposium on Topological Data Strategies for Geographic Information Systems sponsored by the Laboratory for Computer Graphics and Spatial Analysis at Harvard. At this meeting, ORNL presented an overview of the geographic data structures and software techniques that had been developed to support polygon processing and mapping (Coleman 1977; Edwards 1977; Coleman 2006). Participation in early meetings such as this underscores the importance of the contributions ORNL historically made to the development of GIS technology and geospatial science.

Similar to ORNL, PNNL initiated its GIS and remote sensing program in the early 1970’s by performing analysis of early LANDSAT satellite imagery (Foote 2006). PNNL needed to display geographic data such as roads, topography, political boundaries, and other data overlaid on the LANDSAT imagery. As was the case with ORNL, PNNL was forced to develop its own GIS software to handle vector and raster data processing. Software applications were developed to handle polygon processing, projections, and spatial data visualization and analysis, both in 2-D and 3-D (Foote 2006).

The software capabilities developed at ORNL and PNNL, as well as similar capabilities developed at LANL and other DOE laboratories, are remarkable given the state of computing and software development in the 1970s and early 1980s, when hardware consisted of slow, clunky mainframe systems and small mini-computers with either paper tape or card input and paper output and when the dominant programming language was FORTRAN.

An early application for the PNNL GIS capabilities involved the analysis of 3-D seismic data with earthquake hypocenters plotted at depth and with color coding representing either the earthquake time or the magnitude. Viewed graphically as stereopairs, large plate tectonic earthquakes along subduction zones readily stood out. Following the Mt. St. Helens eruption in 1980, PNNL plotted 3-D seismic data for the region (earthquake hypocenters and depth) along with a transparent digital elevation model as a geographic reference. Earthquake hypocenters were color coded by time and clearly showed the movement of magma toward the surface. This PNNL-developed software technology was subsequently used in a collaborative project with LANL in the mid-1980’s to study the Jemez caldera above the town of Los Alamos, NM. LANDSAT imagery, digital elevation data, magnetic and gravity survey data, and geologic data were all used to construct a 3-D model of the caldera plotted as a function of gravitational potential that could be viewed as stereopairs (Foote 2006).

In the late 1960’s, PNNL built thermal infrared (IR) scanners with a sensitivity of 1/10th of a degree Kelvin to image the thermal footprint of power plants along the California coastline. Overflights were made of these power plants to determine the geographic extent of thermal plumes along the coastal Pacific with the temperature differential above a specified threshold to gauge the ecological impact of waste heat discharged from these plants. In addition, dyes were released along the discharge canals of these plants and were allowed to disperse into the surrounding waters. Both IR and visible wavelengths were recorded during the overflights. Filtering was used on the visible wavelength at the emission wavelength of the dye to determine the fluid velocity. Combined with the thermal IR to determine temperature and the measured fluid velocity, 3-D hydrodynamic simulations were performed to better understand the thermal plume behavior at parametrically varied discharge power levels (Foote 2006).
**Applied Science Applications (mid-1970s through mid-1980s):** The period from the mid-1970s through the mid-1980s was characterized by GIS application development. Among various efforts, the National Uranium Resource Evaluation (NURE) program (1973-1984) (Bolivar 1980) is notable because it involved coordination across major national laboratories (Smith 2006), and because it led to many other applications such as LANL’s geochemical surveys of New Mexico, St. Lucia, and Costa Rica (Cole 2006, LANL 1984, 1985, 1987). The main goal of NURE was to identify domestic uranium resources for the purpose of developing nuclear energy. The early years of NURE involved independent development of different sampling and analysis techniques by each laboratory, typically involving geostatistical sampling using krigging and multi-variate regression. As NURE proceeded, there was increased coordination to build a complete and seamless nationwide coverage. While never completed because funding ended, the NURE databases were subsequently made accessible through the U.S. Geologic Survey.

ORNL entered a second major developmental period (1977-1985) when NSF funding became virtually unavailable to DOE national laboratories due to a shift in policy. This precipitated a change in emphasis at ORNL from basic research and development to applications-oriented research. Applications during this time focused on solving problems in environmental management, nuclear power plant siting, impacts of national energy programs, and evaluation of U.S. natural resources. As an example of environmental management, ORNL developed a 3-D perspective of coal strip mines with streams superimposed on the terrain to determine those streams most likely to receive acid drainage from the mines (Dobson and Durfee 1988) (Figure 3).

ORNL was heavily involved in NURE, with responsibilities for analyzing and archiving NURE data related to potential uranium resources for the U.S. commercial nuclear power plant industry. Aerial radiometric, geomagnetic, and hydrogeologic data was collected on a quadrangle by quadrangle basis across the country and analyzed at ORNL to determine potential uranium resources. ORNL developed spatial filtering, interpolation, and contouring techniques to convert one-dimensional flight line data into usable contour data indicating the presence of uranium resources (Durfee 2006). Other projects completed during this time period included an evaluation of water resources required across the country for energy production (Figure 4), a compilation of abandoned mine locations and aerial extents to prioritize reclamation, and the derivation of population demographic information across the U.S. at a fine resolution to support siting analyses for future nuclear power plants (Durfee 1983, 1984, 1988). Work during this time period was accomplished as hardware platforms of that day were in the process of migrating from mainframe to minicomputer systems and eventually to PC systems (Figure 5).
In 1983, Richard Durfee and Jerry Dobson noted that few institutions had the capability to use GIS technology due to the high cost of establishing and maintaining GIS facilities. As an example of this cost, SRNL purchased its first copy of ArcInfo™ in 1986 at a cost of over $100,000 for a single license (Hayes 2006). ORNL thus promulgated the establishment of a national geographic information and analysis center to provide a focal point for advancing research and education. This led to the creation of the National Center for Geographic Information and Analysis (NCGEA) and the subsequent University Consortium for Geographic Information Science, of which ORNL was a founding member (Dobson 2001).

Coincident with this second developmental period at ORNL (1977-1986), work at PNNL continued to focus on GIS and remote sensing applications. PNNL worked closely with the National Aeronautics and Space Administration (NASA) to calibrate the thermal bands of the LANDSAT satellite thermal imagery system at 60-m resolution. As a result of its collaboration with NASA, PNNL was asked to investigate the nature of the fire resulting from the Chernobyl accident in 1986 based on LANDSAT thermal IR imagery. This fire burned at about 2000° C, corresponding approximately to the 2-micron thermal IR band of LANDSAT (30-m resolution) (Foote 2006). PNNL hypothesized that even at a 30-m resolution in the thermal IR bands, the temperature and energy of much smaller fires could be resolved by examining the radiance from both the LANDSAT 1.5- and 2-micron wavelengths. To test this hypothesis, PNNL set up a test fire in a small barrel coincident with a LANDSAT pass and had NASA image the fire. The image surface area of the barrel fire was approximately 0.28 m² (3 ft²). The barrel fire was instrumented with a thermocouple to determine the actual fire temperature for comparison against the corresponding remotely sensed value. Using the radiance at the 1.5- and 2-micron wavelength bands in conjunction with the black body radiation spectra curves, PNNL successfully devised techniques for observing small fires using the 30-m LANDSAT thermal IR imagery capabilities (Foote 2006).

As is the case with the GIS capabilities that were developed at ORNL and PNNL, early software was developed at the LANL in the 1970s to handle simple vector processing and to provide vector data overlay on remote sensed imagery. Such software included the
DISPPLAY system for visualizing geographic data on a simple Cartesian plane in both 2- and 3-D views. The MAPPER application was developed to provide a simple scripting language allowing users to make use of the functionality of DISPPLAY without having to modify the original FORTRAN source coding (van Etten 2006). These applications allowed the overlay of vector data, such as isopleths of radiation dose, roads, and other surface features, on top of aerial imagery and were used at LANL for environmental management and emergency response. In the late 1970s, the capability to make 16mm movies of temporal spatial information was developed. One application of this capability included the spatial and temporal modelling of elk migration over a two year period (van Etten 2006).

At the DOE Remote Sensing Laboratory (RSL) in Las Vegas, NV, remotely sensed data has been generated for many decades to serve the DOE complex. This data has included thermal, visible, and radiation surveys of DOE facilities and test sites. As an example, RSL has provided aerial imagery of DOE facilities for many decades and this imagery is now a key source of historical data. The RSL multispectral collection capability was developed in 1978 by Dr. Bill Ginsburg (Brewster 2006). This capability, along with thermal imagery, was utilized in the 1978-81 time period to image the city of Las Vegas, NV so that citizens could locate their homes in a map book at RSL to determine the structure thermal signature. Such information was useful in determining whether additional insulation or energy conservation efforts were in order. This program was very popular with the local population.

In 1978, RSL participated in an operation to image remote areas in Canada to find a Soviet satellite that had unexpectedly entered the atmosphere and crashed. This was an early example of a large-area radiation survey to locate an unknown source (Brewster 2006). RSL flew Mt. St. Helens and collected multispectral and thermal imagery the Friday prior to the 1980 eruption for the USGS. Subsequent analysis of the thermal imagery indicated clearly the progression of the magma dome to the surface. It was historically unfortunate that this analysis had not been concluded prior to the eruption as the thermal imagery most certainly would have provided a definitive early warning of the impending eruption. RSL again flew the area six months following the eruption to assess the overall damage and geological change (Brewster 2006). In 1981, RSL flew multispectral and thermal imagery to support the efforts to fight a major fire at the DOE Strategic Petroleum Reserve (SPR) and an underground fire at the oil shale processing facility at Anvil Point, CO. In the case of the SPR fire, near IR imagery was used to determine the extent of the petroleum spill and fire in the Gulf of Mexico. At the Anvil Point fire, thermal imagery helped to locate and determine the extent of the fire in the subsurface (Brewster 2006). In the early 1990s, RSL developed a landmark first-of-a-kind processing system for geocorrecting imagery using laser-based gyroscopes and inertial measurements to determine acceleration. This work was performed in collaboration with the Canadian Center for Remote Sensing and is now a standard feature on most image collection platforms (Brewster 2006).

**Issue-Oriented Applications (mid-1980s through present):** The final period of ORNL development (1986-1995) discussed by Dobson and Durfee (1988), was characterized by issue-oriented research and analysis. During this timeframe, sophisticated GIS capabilities flourished across the DOE complex. As an example, at the Savannah River National Laboratory (SRNL), the first GIS was used to display and analyze predictions from atmospheric dispersion models to support emergency response in 1986 (Hayes 2006). At ORNL, GIS was utilized to analyze diverse
problems including lake acidification and acid rain, environmental restoration at the ORNL complex as well as Air Force facilities, and transportation modeling and analysis (Dobson and Durfee 1988) (Figure 6). In 1988, commercially available GIS software had reached a point in its development that ORNL made a change from its internally developed software to commercially vended GIS software (Durfee 2006). Interestingly, PNNL made a similar transition from internally developed GIS and remote sensing software to commercially vended software the same year (Foote 2006).

Figure 6. 1977 Strip Mining Impact in Eastern Tennessee (ORNL).

As personal computers and UNIX workstations became more prolific in the late 1980s into the 1990s, sophisticated GIS capabilities sprang up across the DOE complex. Most of these early systems were UNIX based with emulator software used to serve GIS applications across a local area network. As an example, at SRNL, the first sitewide GIS was established in 1995 and was comprised of a DEC Alpha 2100 UNIX server running ArcInfo™ and ArcView 2.1™. Hummingbird Exceed™ emulator software was used to serve ArcView 2.1™ as an application across the network (Koffman 2006).

In conjunction with the advances in technology, many of the current DOE capabilities evolved in the face of changing funding priorities to serve needs for environmental management in compliance with national environmental legislation and to bring together GIS, modeling, and information management. For example, at LANL, the Facility for Information Management, Analysis, and Display (FIMAD), was formed in 1991, bringing together both existing and new staff, with original funding primarily to support the LANL Environmental Restoration Program. Expert advisors, in particular Michael Goodchild (University of California at Santa Barbara), were brought in to advise on the design for FIMAD; among other recommendations, Goodchild suggested that Environmental Systems Research Institute (ESRI) software was the best choice as the emerging standard. After a decade of environmental management work, in 2001, as part of the Cerro Grande Fire Recovery Program (Mynard et al. 2003, 2005, 2007), new staff were hired within FIMAD, including team leader Paul Rich, and the name of the team was changed to GISLab, to better reflect the emphasis on GIS, to encourage enhanced GIS-related research and development, and to encourage diversification into a broader set of cross-cutting projects. Attention turned first to enterprise GIS design (Keating et al. 2003, Witkowski et al. 2003, 2007), developing capabilities for organization-wide data sharing; and later attention turned increasingly to integration of GIS and modeling, and GIS for decision support based on common needs for disparate projects (Rich et al. 2005). This example emphasizes how recent human caused and natural disasters have prompted shifts in the focus of geospatial science across the complex to address issues of growing national
importance. Some of these events include the impact of climate change on regional ecology and energy production, economic impacts of large scale events such as the 9/11 World Trade Center attacks, Hurricane Katrina, and the fires of 2001 that occurred at LANL, the DOE Hanford reservation, and the Idaho National Laboratory (INL), northeastern U.S. power blackout in 2003, and the electrical power shortages recently experienced in the western U.S.

In the early-to-mid 1990s, ORNL, like other DOE facilities, began developing integrated geo-information systems to provide organization-wide access to analytical tools and commonly-shared databases. In support of the environmental restoration program, the Oak Ridge Environmental Information System (OREIS) was developed by integrating GIS, modeling and analysis tools, relational database management software, and shared databases. OREIS combined ESRI GIS software with ORACLE, SAS (Statistical Analysis System), a user friendly interface, and a suite of geospatial and environmental data for community-wide use throughout the Oak Ridge facilities. These capabilities functioned within a strong data management framework to ensure the integrity and legal defensibility of environmental and geographic data (Dobson and Durfee 1995).

Although the availability of adequate hardware and GIS software was critical to the implementation of GIS capabilities across the DOE complex, the availability of GIS data was equally important. During the early years, the GIS users in these programs created the spatial data they used for analysis. Commercially available data to support GIS applications did not become widely available until the mid-1990s. At SRNL, GIS data was organized for the first time in 1995 on the central GIS server in a flat-file data structure that could be easily navigated by the average GIS user. The system was organized by coordinate system at the highest level (UTM, Lat-Long, Savannah River Site (SRS) local coordinates) and then by geographic scale at the next level (SRS local, SRS site, and regional). Significant amounts of spatial data were contributed to the SRNL system by the U.S. Geological Survey (USGS) and by the U.S. Department of Agriculture Forest Service (USFS). This intuitive system for organizing geographic data served SRS well for many years (Koffman 2006).

The guiding philosophy behind the SRNL system, referred to as Falcon, was that GIS software and data should be made freely available to all professionals on their desktops to enable them to effectively use spatial information. These users (including engineers, geoscientists, ecologists, seismologists, oceanographers, meteorologists, and others) had much more familiarity and experience with their own data; thus providing an additional efficiency to the distributed system approach. Users with particularly challenging problems had ready access to the GIS professional staff. In addition, the GIS staff developed a myriad of specialized applications (projection algorithms, database applications, utilities, etc.) for use by site GIS users. Introductory and advanced training was provided to all users at no cost to encourage development of skills so that users could effectively solve their own spatial problems (Koffman 2006). The SRNL GIS system was introduced to the SRS Emergency Operations Center (EOC) in 1997—demonstrating the value of maintaining spatial data as a site resource that could be readily used in diverse applications.

SRNL and RSL have shared a special relationship over the past few decades and there are many examples of collaborative work in remote sensing that significantly benefited the Savannah River Site (SRS). SRS operated production nuclear reactors for almost 40-years from the early 1950s through the mid
In the 1980s, fuel fabrication, laboratory, nuclear reprocessing, high level nuclear waste, and tritium processing facilities were operated over this time period. The ecological impact of these operations has been an ongoing concern at SRS and the surrounding region. Remotely sensed data provided by RSL and the USFS has been used for several decades to quantify and address the ecological impact of these operations. Several examples are described below.

In 1983, a study was conducted at SRNL of the Pen Branch Creek Delta expansion, created by increased Pen Branch stream flow from reactor cooling water. Aerial imagery taken from 1951 to 1983 was used to determine the rate of annual delta expansion—an important indicator of ecological impacts to wetlands exposed to elevated temperature and flow conditions (Nelson et al. 1983). A follow on study of the Pen Branch delta expansion was conducted by RSL in 1995 to determine the impact of the shut down of SRS K-Reactor in 1988 (Blohm 1995). Christel-Rose and Mackey (1993) used aerial imagery to assess wetlands changes over time at SRS. RSL remotely sensed data was used extensively in a study to determine the ecological impact of drawing down L-Lake—an artificially maintained lake used as a thermal sink for L-Reactor while the reactor was in operation (Bollinger and Dunn 1998; Bollinger and Dunn 1999; Christel 1997; Christel 1996; Jobst 1988) Other RSL surveys were used to determine the ground dose of gamma-emitting radionuclides at SRS (Feimster 1988). Extensive RSL thermal imagery has been used to assess the ecological impact of heated water discharged from operating reactors at SRS and to benchmark 3-D hydrodynamic numerical models (Garrett 2005). A more extensive bibliography of work in GIS and remote sensing performed at SRNL can be found in Mackey (1998).

GIS capabilities at RSL were developed in the mid-1980s to complement its already comprehensive remote sensing program. Much of the early RSL GIS work focused on studies conducted of the SRS ecology (Guber 2006). Work progressed to studies for the Yucca Mountain radioactive waste repository evaluation, environmental and facilities management, and then to DOE and Nuclear Regulatory (NRC) emergency response in the early 1990s (Guber 2006).

History of the DOE Geospatial Science Program

Impetus for Integration of DOE's Geospatial Science Community: Geospatial science provides a framework for managing operations, performing sophisticated analyses of spatial data, and conducting research. These applied geospatial science activities have evolved independently across the DOE complex with limited collaboration and sharing of data and knowledge among the DOE national laboratories and facilities located at geographically disparate locations across the country. In addition, geospatial science related work has typically been funded in a tactical sense as part of other overarching scientific and technical mission requirements.

There have been several historical attempts to bridge the geographic distance separating DOE’s national laboratories and facilities to develop an integrated approach to GIS and geospatial science across the complex. In the late 1970s, the DOE Interlaboratory Working Group on Data Exchange was created to develop GIS standards for DOE (Durfee 2006). In addition, a symposium was held in this timeframe to showcase the GIS capabilities of the DOE national laboratories. Then, in the early 1990’s, ORNL’s Center for Risk Management hosted the first of several GIS Information Exchange (GISIE) meetings. These
meetings focused on the use of GIS for DOE’s growing Environmental Restoration and Environmental Management programs. The GISIE meetings were designed to encourage collaboration across the department and to foster a shared approach to GIS. Topics of discussion at these meetings included geospatial data quality assurance, integrating GIS with other tools, graphical user interfaces, site GIS coordination, and user requirements. GISIE1 was held in November 1991 at Oak Ridge, TN; GISIE2 was held in May 1992 and was hosted by Sandia National Laboratory (SNL) and LANL in Santa Fe, NM; GISIE3 was held in November 1992 and hosted by the ORNL Center for Risk Management; GISIE4 was held June 1994 and was hosted by Pacific Northwest Laboratory and the Westinghouse Hanford Company Environmental Restoration Program. By the end of 1994, the GISIE meetings resulted in the formation of an informal network of 75 people within the DOE complex who shared a vision for working together to promote the use of GIS across the DOE complex by using the success experienced through the Environmental Restoration Programs.

**Formation of the DOE GIS User Group:**
Following the final meeting of the GISIE in 1994, Denise Bleakly (SNL) held informal meetings of the DOE GIS User Group at major conferences such as the ESRI Annual User Conference, which was held in Palm Springs, CA until 1996 and thereafter was held in San Diego, CA. The User Group also met informally at the DOE sponsored Technical Information Exchange (TIE) Workshop in Santa Fe, NM in April 1996. The TIE workshops focused on technology for environmental restoration and topics regarding the use of GIS to support these activities. During a visit by Denise Bleakly to SRNL in 1999, Bleakly and Bollinger made a decision to reinvigorate the User Group and established it as the ad hoc DOE GIS User Group.

The first meeting of the new user group was hosted by the TIE Workshop held in Augusta, GA in November 2000 (Figure 7). Subsequent meetings were held in conjunction with the ESRI User Conferences biannually in San Diego, CA and Washington, DC, and with the TIE Workshop until its final meeting in Oakland, CA in November 2002. Since 2002, the ad hoc DOE GIS User Group has been co-chaired by Bleakly, Bollinger, and Paul Rich (LANL). The user group currently meets twice annually and produces a newsletter to communicate both technical and other GIS-related news items throughout the DOE complex. During the years 2002-2004, the GIS User Group grew to over 225 members.

**Formation of the Geospatial Science Steering Committee (GSSC):**
In an effort to take a more enterprise driven business approach toward managing its geospatial investment, the GIS Core Team, later renamed the Geospatial Science Steering Committee (GSSC), was established by the Office of the Chief Information Officer (OCIO) in 2001 with representation from the national laboratories, some facilities, and several headquarters program of-
fices to begin to communicate and coordinate geospatial activities across the complex. The GSSC and the applied geospatial science activities across the department have now evolved to a state of maturity where a comprehensive geospatial sciences strategic plan is required to further leverage these collective efforts and investments. A major effort to put forward such a plan was undertaken in 2005 (Bollinger et al. 2005). This strategic plan envisioned a comprehensive DOE Geospatial Science Program to address a full suite of cross-complex GIS needs, including national geospatial initiatives such as the Geospatial One-Stop; homeland security; emergency response; legacy data cleanup and documentation; compliance with Office of Management and Budget (OMB) and Federal Geographic Data Committee (FGDC) requirements; data sharing involving enterprise GIS (EGIS) solutions for data management and access; associated research and development; and cross-complex coordination/collaboration to improve efficiency, eliminate duplication, and achieve economies of scale. In June of 2005, Bollinger was invited to Washington, DC to lead an effort in conjunction with the GSSC to draft a comprehensive financial and strategic plan (referred to as an OMB-300) to initiate a formally funded information technology (IT) program in geospatial science to coordinate DOE’s diverse programmatic efforts. Unfortunately, this effort was not successful because OMB determined that the programmatic plan was not predominately Information Technology. However, these efforts did succeed at keeping geospatial science visible at high levels of DOE.

Establishment of the Geospatial Science Program Management Office (GS-PMO): A positive outcome of developing the DOE geospatial science strategic plan (Bollinger et al. 2005) involved the formation of the DOE Geospatial Science Program Management Office (GS-PMO) in October 2005, cosponsored by the DOE Offices of Science (SC) and Environmental Management (EM) and by the DOE National Nuclear Security Administration (NNSA). Administrative support for the GS-PMO is provided by the DOE Office of the Chief Information Officer (OCIO). The GS-PMO was formed to coordinate and maximize DOE’s investment in geospatial activities as they support the core mission of the department, as is discussed further in Rich et al. (2007). The GS-PMO meets on a regular basis by teleconference with the chair and vice-chair of the GSSC to address issues of importance to DOE in geospatial science. At a joint meeting in January 2006, the GSSC, with sponsorship from the GS-PMO, contributed over 50 posters illustrating many of the diverse aspects of geospatial science to DOE. These posters, displayed in the entrance to DOE headquarters building in Washington (referred to as the Forrestal building), were the focus of the 2006 DOE Geospatial Science Expo, which culminated in a 45-minute presentation to Secretary of Energy Samuel Bodman.

Some Lessons from the History of DOE Geospatial Science

Based on consideration of the role of DOE, the broader development of geospatial science and technology, and examination of significant events that guided and impacted this development, we gleaned four general lessons from history:

First, development of DOE’s geospatial science has been strongly influenced by changing priorities. Throughout the four decade period we studied, DOE geospatial science programs have experienced repeated upheaval in the form of changing programmatic and funding priorities. In fact, such dramatic changes appear to occur with approximate ten year periodicity. Some of these dramatic events have included loss of NSF funding, changes in na-
tional environmental policy, and changing priorities due to recent man-made and natural disasters. In spite of this historical upheaval, DOE geospatial scientists have not only successfully adapted, but have continued to push the frontiers of this science and technology. In many instances, this periodic upheaval can be cited as an evolutionary agent that stimulated intense and creative advances in geospatial science and technology within DOE.

Second, DOE’s contributions to the field of geospatial science over the past four decades have been substantial. Early on, the DOE national laboratories played an important role in the development of geospatial algorithms that we take for granted today. These included spatial operations for selecting geographic features based on topology, projections, and image processing techniques. DOE was among the first institutions to utilize the power of satellite imagery in the very early 1970s. Other significant contributions include DOE’s applied geospatial science research, especially in the mid- to late-1970s when DOE utilized geospatial science to address many important issues in regional management, water resource needs for energy production, and regional economic development and planning to name a few. During this time period, DOE employed geospatial science to manage the NURE program—a massive data gathering expedition requiring the very clever use of technology of the period to find geological resources to support the nation’s growing need for nuclear energy. Current DOE work in geospatial science and technology has as its underpinning a very well established tradition and foundation. In addition, DOE developments and innovations have provided an important technology bridge to private industry, as well as solving complex regional, national, and global problems that could not have been addressed without such geospatial research. In many cases, GIS has served as an integrating technology across multiple disciplines so that other branches of science can incorporate spatial logic and geographical analysis alongside their traditional approaches.

Third, institutional efforts to integrate geospatial science across the DOE complex to obtain a more robust, cost-effective, and efficient program have been ongoing since the late 1970s. This process was slow and arduous even for the early pioneers (Durfee 2006). Our current complexwide efforts to encourage such integration are not new. Perseverance and persistence will continue to be critical to this important, evolutionary process. In chronicling this history, it is apparent that the DOE national laboratories have historically functioned more in isolation from each other than in cooperation—in spite of many valiant efforts among early practitioners. One can only imagine what might have been accomplished in the field of geospatial science had more openness and integration been encouraged. In this historical context, it is apparent that the continued struggle to achieve such integration and cooperation is essential to making even greater progress in geospatial science across the DOE national laboratories.

Fourth, efforts to document the history of DOE geospatial science have been inadequate to this point in time. Although we have found many historical treasures, especially from ORNL, which has a well-documented history, these historical treasures are difficult to locate and recognize. Unfortunately, time has already claimed and is in the process of claiming other important historical contributions and perspectives as institutional knowledge vanishes from DOE. The contributions of others will be essential in the future to capture our shared and collective history and the valuable lessons it holds. It is our sincere hope that practitioners of geospatial science across the department will capture and publish the history of their programs before this history is lost to the progression of time. We need to keep in
mind that our greatest steps forward may well be inspired by such lessons from our collective past.

Conclusion

DOE is unique among federal agencies in its contribution to the development of geospatial science. From the early roots of geospatial science in addressing basic scientific problems, to application for an increasing diversity of applied problems, it is clear that there is growing recognition of the importance of geospatial science to DOE. The widespread deployment of the geospatial science and associated GIS, global positioning system (GPS), and remote sensing technology, with increasing sophistication of its applications, suggests that geospatial science has evolved to a point where a coordinated programmatic approach to the management of the investment, such as that advocated by the GS-PMO, will open the way to a new historical period enabling greater coordination and sharing of data and other resources. Historical analysis of DOE's geospatial science activities reveals the importance of progressive change, including upheavals and changing funding, the substantial contributions of earlier workers, the importance of ongoing efforts to promote institutional coordination, and the value of capturing history before it is lost.

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