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Metrics of Success for Enterprise Geographic Information Systems (EGIS)

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ABSTRACT: An enterprise geographic information system (EGIS) addresses the institutional challenge of providing common infrastructure to share geospatial data and associated services. We propose a comprehensive definition and conceptual framework for EGIS, and we apply this framework to analyze and assess the success of a prototype EGIS implementation. We define EGIS as institutional GIS capability with three attributes: 1) integrated components (common infrastructure); 2) services (shared data, analysis, modeling, and visualization capabilities); and 3) institutional management (administration and leadership). Further distillation yields nine specific implementation requirements: 1) common networked infrastructure; 2) high reliability and availability; 3) spatial data warehouse; 4) documentation of data and services; 5) coordination of dataflow and workflow; 6) coordination of personnel roles and responsibilities; 7) formalized management; 8) institutional financing; and 9) institutional leadership. We tested the hypothesis that a project-based GIS could be used as a prototype EGIS for a large institution. Evaluation of the Cerro Grande Rehabilitation Project GIS (CGRP-GIS), study system, yielded a comprehensive taxonomy of direct metrics (e.g., server downtime) and indirect metrics (e.g., increases in productivity) for evaluating EGIS. Some elements of the CGRP-GIS did not scale well to EGIS (e.g., management, financing, and leadership), since projects allocate resources primarily to achieve project goals, whereas EGIS allocates resources to long-term infrastructure. An EGIS, constructed on a solid conceptual framework, holds tremendous potential to advance sharing of geospatial data and associated services; to better allocate institutional and project resources; and to aid in problem solving, communication, and decision making.

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KEYWORDS: Enterprise GIS, EGIS, management.

INTRODUCTION

The use of geospatial data and analyses is growing beyond the traditional project-based, desktop driven geographic information system (GIS), challenging institutions to provide common infrastructure for more effective sharing of geospatial data and associated services (Keating et al. 2002, 2003). Ensuring availability of high quality geospatial data and elimination of redundant project-based GIS infrastructure (hardware, software, networks, etc.) are foremost among the incentives. In the past, numerous technological roadblocks hampered an institution's ability to design and implement a solution. With the advance of high-speed networks, increasingly fast computers, and intelligent geospatial-data serving technologies, the newest challenge involves integration of the various technological and institutional components from project-based GIS to an enterprise GIS (EGIS). This migration can be viewed as an inevitable stage in the evolution of GIS.

Three fundamental questions arise as GIS practitioners face the problem of migrating existing GIS capabilities from a traditional project-based GIS to an institutional or enterprise solution. First, what is EGIS, in terms of a definition that serves as the basis for a rigorous EGIS conceptual framework? Second, how can EGIS be implemented, in terms of methodology, design, and metrics of success? Third, is EGIS a better solution, in terms of the key differences in scale and structure between project-based GIS and EGIS?

EGIS has been defined as providing access to shared geospatial information and analysis resources for a large number of concurrent users located in different parts of an organization (Rich et al. 2001; Somers 2002, 2005; Maguire and Longley 2005). EGIS has also been defined by the components that comprise it (hardware, software, shared geospatial data), and distinct roles of participants (Oppmann 1999). However, describing EGIS by what it provides or the components it contains does not fully define EGIS or its necessary requirements. An additional three elements are critical for EGIS: 1) integration of data flow with a set of necessary work processes (a "complete geospatial data cycle") (Figure 1); 2) consideration of diverse stakeholder needs (data managers, GIS users, and customers); and 3) application of existing information management techniques, such as those developed for data warehousing (Keating et al. 2003; Witkowski et al. 2002, 2003). EGIS is more a complete approach to geospatial resource management than simply the collection of technologies that enable it (Somers 2005).

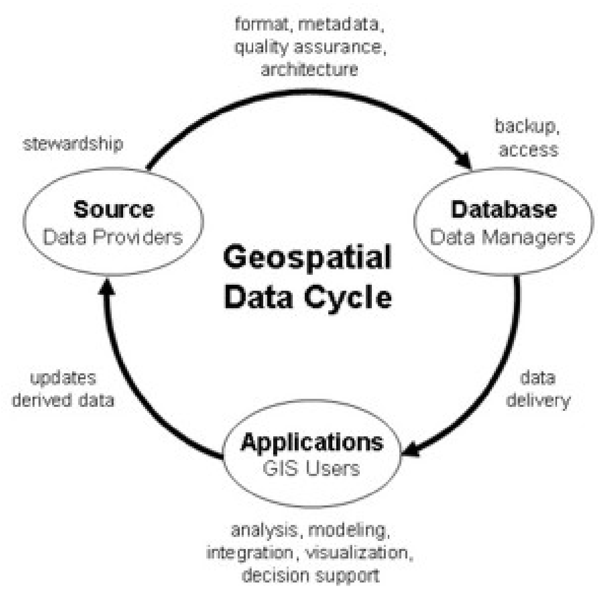

Figure 1. A complete geospatial data cycle ensures that data are complete, secure, documented, and accessible to GIS users.

Although there are a number of management approaches and institutional models that have been developed to describe a particular EGIS implementation from a management perspective (e.g., Oppmann 1999; Fletcher 1999; Lembo 1999), a comprehensive definition and complete conceptual framework for the technical design of EGIS is lacking. Case studies describing attempts to migrate from project-based GIS to EGIS emphasize the need for in-depth needs assessment; development of consistent policies, standards, and procedures; identification of core data sets; training; and participation of both users and management (Coiner 1997; Lloyd 2000; Somers 2002, 2005). A conceptual framework is required to distill the salient and distinguishable concepts of EGIS and to ensure completeness of both design and implementation.

The value of sharing integrated data and computation resources (cyberinfrastructure) is increasingly being recognized at the level of corporations and national agencies (Bonham-Carter 1994; Atkins et al. 2003; Estrin et al. 2003; Barnes and Sietzen 2004; Maguire and Longley 2005; Goodchild et al. 2007; Carr and Rich 2007). Practitioners cite problems in migrating large institutional GIS (government, corporate, etc.) to the enterprise model, including redundancies in departmental hardware, software, and databases ("stovepiping"); lack of standards; low levels of data and other resource sharing ("poor institutional behavior"); limited participation of GIS stakeholders; and financial limitations for individual GIS projects (Coiner 1997; Fletcher 1999; Lloyd 2000; Somers 2002, 2005; Keating et al. 2002, 2003; Rich et al. 2007). In addition, reports of successful implementations may conflict with unofficial evaluations of the performance or appropriateness of the new system (Caron and Bedard 2002; Somers 2005).

The goal of this manuscript is to provide a conceptual framework for EGIS and apply the implementation requirements to a study system in an effort to test the hypothesis that a project- based GIS could be used as a prototype EGIS for a large institution.

STUDY SYSTEM

The Cerro Grande Rehabilitation Project GIS (CGRP-GIS) was launched at Los Alamos National Laboratory (LANL) shortly after a wildfire burned over 17,000 ha in and around the town of Los Alamos, New Mexico, May 5^{th} – May 22^{nd}, 2000 (Mynard et al. 2003, 2005, 2007). A GIS component of the CGRP was charged with capturing and managing geospatial data, providing rapid access to and sharing of the data, and integrating the data into predictive models and risk assessment systems. The needs of the stakeholders were assessed collectively via stakeholder meetings and individually via a web-based consensus-building and conflict-clarification tool (Keating et al. 2001). Existing LANL spatial databases and infrastructure, along with legacy spatial data resources were thoroughly evaluated for incorporation into the CGRP-GIS.

CGRP-GIS was deemed an adequate study system because it differed from typical project-based GIS in three ways: 1) the effort transcended many organizational divides and required participation from diverse GIS stakeholders throughout a large and complex institution; 2) hardware, software, and other required common infrastructure were designed to address the data sharing needs of all GIS stakeholders; and 3) a major goal was to develop the CGRP-GIS into a sustainable EGIS that would serve the institution (Keating et al. 2003; Witkowski et al. 2003).

METHODS

EGIS Conceptual Framework: First, we develop a conceptual framework for EGIS based on a comprehensive definition and practical requirements for implementation. Our approach emphasizes *completeness*, in terms necessary elements, relations, and processes; *generality*, in terms of applicability to any EGIS, and *simplicity*, in terms of a minimal but sufficient formulation. Next, we define EGIS and seek to be both comprehensive and general, in terms of components, services provided, and management essential to EGIS. This abstraction is made practical by enumerating and defining the requirements for implementation of EGIS. Next, we expand upon and incorporate the three foundational concepts originally put forward by Keating et al. (2003) -- 1) the "complete geospatial data cycle" (Figure 1), 2) stakeholder needs, and 3) application of data warehousing methodology -- into our requirements for EGIS. The EGIS definition, implementation requirements, and these three foundational concepts constitute the conceptual framework that we apply to assess a prototype EGIS, and then use to formulate generalizations of theoretical and practical importance.

EGIS Requirements and Metrics Analysis: We apply and compare the requirements for EGIS to a comprehensive set of EGIS metrics collected and observed from the CGRP-GIS effort. For each metrics element we identify specific metrics of success and provide examples of actual measures from the CGRP-GIS. Major elements of this metrics taxonomy include both the physical system (implementation, performance, and utility) and institutional benefits (increased efficiency, decreased redundancy, and cost saving). Then, we discuss design features of the CGRP-GIS and evaluate the success or failure of implementation.

Scaling from Project-Based GIS to EGIS: We identify key differences between project-based GIS and EGIS, with consideration of what is needed to make the transition to an EGIS based on the EGIS definition and implementation requirements. Then, we compare financial differences between project-based GIS and EGIS with two models of investment: one that involves a project-based GIS conducted with no initial investment in common infrastructure (cyberinfrastructure), and another with initial investment in EGIS, followed by the same series of projects. We evaluate differences in overall investment in infrastructure, long-term stability as measured by oscillation in investment, and ability to meet project goals.

RESULTS

Conceptual Framework for EGIS:

Definition and Requirements for EGIS: We build on the definition of EGIS as *an effort to design integrated geospatial management techniques to serve a complex institution* (Peng et al. 1998). More specifically, we define EGIS as an institutional GIS capability with three sets of attributes: 1) integrated components that provide a common infrastructure (hardware, software, networks); 2) services that facilitate access to shared geospatial data and associated capabilities (spatial analysis, modeling, visualization); and 3) institutional management that ensures that stakeholder needs are met (operational, research, and administrative).

Further distillation of these three attributes yields nine specific implementation requirements for EGIS (Table 1).

Table 1. EGIS attributes and implementation requirements (continued on next page).

Element	Description
1) Common Networked Infrastructure	Includes hardware (servers able to process numerous concurrent data or services requests), software (GIS, database, etc.), storage (efficient redundant storage devices necessary to store the typically large quantity of data used in an EGIS); and network (local area networks = LAN, and wide area networks =WAN), with cables or wireless to connect all infrastructure components.
2) High Reliability and Availability	Ensures maximum availability and minimum downtime. Depends on combined performance of all system components, typically eight hours (or less) of server downtime per year (Brady 2000), and less than 40 hours downtime per year from all failures (including server, network, and software). Each institution must develop its own criteria for high availability and consider all potential causes of failure, impact to data access, and a response plan to minimize system downtime.
3) Spatial Data Warehouse	Provides a clean institutional structure for the logical organization, storage, management, and delivery of the databases and file architecture that contain institutional geospatial data and metadata as well as associated GIServices. Geospatial data can be organized either in a series of related or spatially indexed tables within a database management system (DBMS) or as flat files (individual files within a hierarchical directory structure). All geospatial data necessary to perform the day-to-day operations and research and development (R&D) activities, is accessed through an institutional spatial data warehouse, providing centralized storage for decentralized use (e.g., Somers 2005). GIServices (e.g., re-projection of data, conversion of data from original to new formats, etc.) can also be requested from the warehouse through client server architecture.
4) Documentation of Data and Services	Provides the means to locate, use, and manage data and services, by the use of metadata. Metadata are data that describe the content, quality, condition, and other characteristics of data or services. Geospatial metadata enable stakeholders to determine data availability, fitness for use, access, and source (FGDC 1998, OMB 2002). Although a national standard to document GIServices is lacking, documentation of the GIServices is also key.
5) Coordination of Dataflow and Workflow	Guide how data are received, stored, and distributed. A complete, or unbroken, geospatial data cycle guides the dataflows from data source to database, from database to applications, and, if modifications have been made, from applications back to the database, with necessary steps to ensure that data are complete, secure, documented, and accessible (Figure 8). These steps include a suite of necessary data operations: formatting, quality assurance, documentation (metadata), cataloguing, tracking, backup, delivery, and updating. Peer review of data is essential and can ensure quality and broad utility. Three steps define data flow within the context of the work performed: 1) Staging involves receipt and preparation of data for placement in the spatial data warehouse; 2) Storage involves the actual housing of data in the warehouse; and 3) Delivery involves distribution of warehoused data to GIS users.

Table 1 (continued). EGIS attributes and implementation requirements.

Element	Description
6) Coordination of Personnel Roles and Responsibilities	Integrates and differentiates necessary leadership and technical roles (Table 4). In addition to the roles of EGIS personnel, complete enterprise design also considers the diverse and integral roles that participants, or stakeholders, play in the process (Dueker and Butler 2000). Data providers need consistent standards and effective tools to prepare, organize, and document their data, as well as to ensure that the data will be responsibly managed. Data managers need consistent workflow procedures that ensure efficient, standardized means to manage and deliver data. GIS users need consistent mechanisms to locate and access well-documented and reliable data. Customers benefit from timely and reliable service, based on sound technical and business design. Successful EGIS design depends on facilitating each of these participants in the context of the geospatial data cycle (Keating et al. 2003) and (Witkowski et al. 2002, 2003).
7) Formalized Management	Provides necessary policies, standards, and procedures for governance and efficient operation. Policies govern, in general terms, how data will be documented, managed, and made accessible. Standards provide specific requirements concerning content, structure, and format; these requirements help ensure that the integrated data management system does not break down and revert to multiple independent, “stovepipe” GIS within the institution (Somers 2002). Procedures define work processes and detail the steps applied to meet the requirements of policies and standards, for example to assign names for data layers, to provide for access control when required by data providers, and to ensure sufficiently complete and consistent metadata.
8) Institutional Financing	Provides direct allocation of funds from the institution to operate and maintain EGIS, thus avoiding the financial limitations of individual project-based GIS (Keating et. al 2003).
9) Institutional Leadership	Provides vision, leadership, and management authority. First, institutional management must be clearly defined, either by strong consensus among the teams involved or by management fiat. Second, it is essential during the transition to EGIS that the technical capabilities be understood and served by management. The challenge is to avoid confusion in which management does not sufficiently understand why EGIS is important to the institution. Third, the institution must build a "team of two" — technical expertise and management support (Dangermond personal communication 2002, Keating et al. 2002, 2003) — to move EGIS forward. Finally, there must be an institutional champion for EGIS (Oppmann 1999, Somers 2005), for example a Geographic Information Officer (GIO). This office or individual ensures a common vision during and after the transition and provides leadership and authority.

CGRP-GIS Design: At the beginning of the development of CGRP-GIS a web-based survey was conducted to identify areas of conflict and agreement and to provide documentation for GIS design (Keating et al. 2001). The survey was administered and analysed using a web-based consensus tool, which utilized mind-maps as a means to illustrate the connections and distinctions among the views of different stakeholders. The consensus tool highlighted a need for a central institutional data repository, which was most strongly correlated with the need for storing topographic data, predictive model results, remotely sensed data, and infrastructure data (roads, utilities, and buildings) (Figure 2).

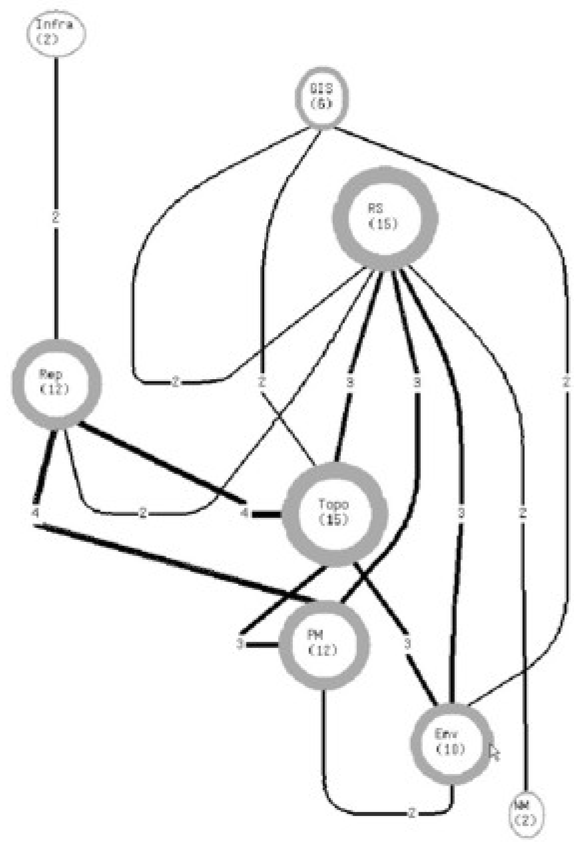

Figure 2. Mindmap of main data needs from CGRP-GIS based on the responses to a web-based survey in which multiple answers were possible for each question (from Keating et al. 2001). Mindmaps demonstrate not only the distribution of survey answers per category (represented by the thickness of a node's rim), but also the interconnectivity of answer categories (represented by the thickness of the tie lines between nodes). This filtered mindmap displays only those nodes with more than one connection. Topo = topographic data; Rep = data repository, downloads, information management; RS = remote sensing; NM = numerical model input; PM = predictive model results; Vis = data visualization; Infra = infrastructure data; GIS = GIS services; and ENV = post-fire environmental changes.

Stakeholders voiced concerns about potential problems with data access, ownership, and maintenance; costs; and redundancy of spatial data management efforts. It was also determined from the results of the consensus tool that spatial data would need to be accessed in several ways, including direct GIS client software connections to the database, network transfers of files stored hierarchically in a directory structure, and the Internet through an Internet Map Service (IMS) (Figure 3). In an effort to address stakeholder concerns and institutional data management needs, a five-step methodology was adopted to implement the CGRP-GIS (Table 2).

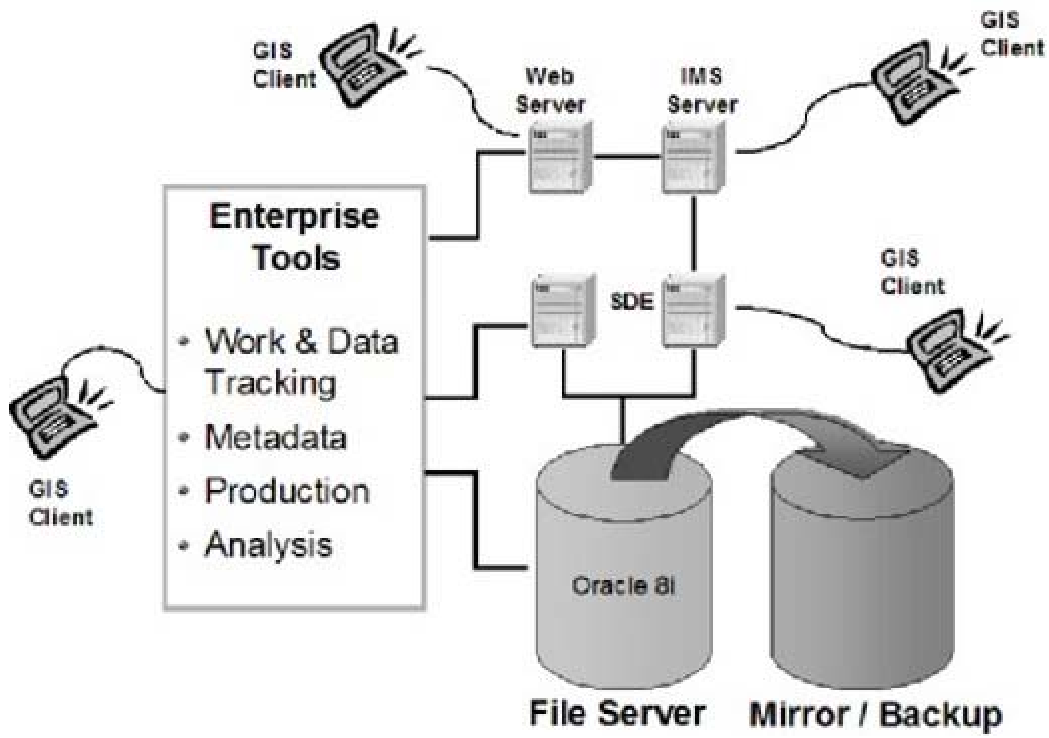

Figure 3. The CGRP-GIS spatial data warehouse physical architecture.

Table 2. Five step process used to implement the CGRP-GIS.

Step	Description
1) Design specification	Needs assessment and definition of strategic goals
2) Resource evaluation	Evaluation of personnel, data, and computational resources, and identification of resource gaps
3) Logical system design	Conceptual plan to stage, store, and deliver data and services
4) Physical system design	Plan of actual common infrastructure (hardware, software, network…)
5) Implementation Plan	Specification of tasks, schedules, funding, and definition of personnel roles

Note: Based on Dangermond personal communication 2002; Keating et al. 2002, 2003.

In an effort to address stakeholders' data and access requirements, the spatial data warehouse was constructed for CGRP-GIS with design considerations for both the logical and physical architecture components. The CGRP-GIS spatial data warehouse logical data architecture focused on the structure of data flow from original source to staging area, where data was reviewed and metadata applied, staging to storage, and storage to data delivery through data files and relational database access through TCP/IP within a client-server architecture (Figure 4). Archives of source data and products (maps, plots, and templates) were stored for future reference. Tools (scripts, source code, and executables) were also stored in a standardized format. A three-tier physical architecture -- consisting of clients, application servers, and a large capacity storage area network (SAN) --- was used to implement the CGRP-GIS spatial data warehouse (Figures 3 and 5). Each tier can be ex-

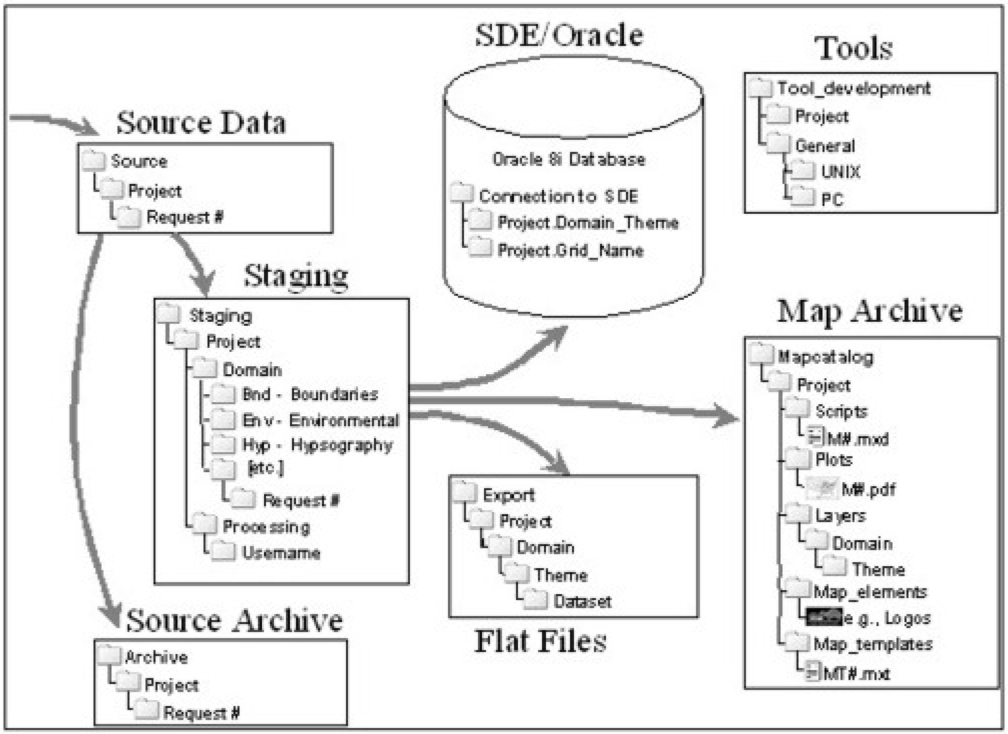

Figure 4. The logical data architecture of the CGRP-GIS.

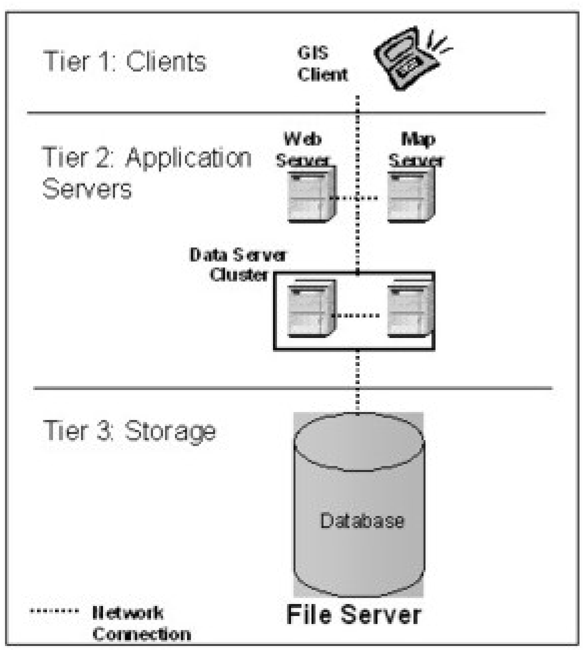

Figure 5. The three-tier architecture of the CGRP-GIS.

panded with more servers and fine-tuned to allow the EGIS to evolve and its capacity to be scaled. The physical architecture included separate web, IMS, and spatial data engine

(SDE) servers for data delivery, a large- capacity file SAN server for data storage, and custom enterprise tools for tasks not provided by commercial GIS software, such as work and data tracking. The SAN provides high availability of GIS data. Should a database be corrupted or otherwise rendered unusable, a previous version of the database could be replicated within minutes from the redundant array of independent disks (RAID), contained as part of the SAN architecture, thereby reducing downtime and increasing reliability.

Metrics of Success for CGRP-GIS: The operational success of CGRP-GIS was measured in terms of tangible criteria such as system performance (e.g., server downtime), number of users, number of data layers loaded, maps and analyses produced, funding stability, and increases in productivity (Table 3). Some met-

Table 3. Metrics for evaluating the success of the CGRP-GIS.

Element	Criteria	Results
Implementation of Physical System	Hardware installed	3.3 Tb file server, web server, and map server
	Software installed	ArcSDE 8.2 ™, ArcIMS 4 ™, ArcGIS 8.3 ™, Oracle 8i ™
	Custom software developed	Request System Rapid Mapping Tool Batch Processing Tool
System Performance	Server down time	< 1 Day/yr
	Data transfer rate	11 Mbps (max)
Utility of Spatial Data Warehouse	Number of data layers loaded and size	1419 SDE & 2304 Folders Total > 85 Gb Served
	Completeness of data and metadata	100% Complete Data with FGDC Compliant Metadata
	Number of users	> 50/yr
Website effectiveness	Number of website visits	> 2000/yr
Workflow standardization	Policies implemented	Data Access, Contracts
	Standards adopted	Metadata
	Procedures implemented	Change Control, Data Processing, Workflow, Cartography, Metadata Preparation, Website Design and Maintenance
Productivity of GIS Services	Number of work requests completed	639/yr
	Number of maps completed	2179/yr
Funding stability	Annual budget	~ $2 million/yr
Institutional Benefits	Enhanced awareness of GIS	5 Training Seminars, 3 invited speakers, bi-weekly tech steering committee meetings, quarterly user group meetings
	Increased internal data sharing	7 LANL divisions use system
	Enhanced data usage by external stakeholders	> 10 Data Usage Agreements Signed and in place.
	Elimination of redundancy	Redundant Personnel Roles, Hardware and Software, and data eliminated.
	Increased productivity	Estimated 35% Decrease in time spent searching for data
	Cost saving to institution	~ $2 million Infrastructure and Staff Labor

Note: Based on calendar year 2002.

rics were readily obtained, such as hardware and software installed, system performance, and number of maps completed. Other metrics were more difficult to obtain, but were key for justifying the investment in EGIS, in particular institutional benefits such as elimination of redundancy, increased productivity, and cost savings. Many metrics were collected automatically, for example monitoring of CGRP-GIS SDE server usage (Figure 6). For most collection of pertinent information as part of the work process. The CGRP-GIS request system tool written in Java, provided ongoing entry of tracking information in the request system database, including such data as customers served, type of service performed, costs, and hours required. Metrics such as maps produced (Table 3) and system usage by discipline (Figure 7A) were readily compiled from the CGRP-GIS request system database. Additional metrics were also compiled to illustrate the diversity of users of the CGRP-GIS, metrics it was necessary to plan ahead, with collection of pertinent information as part of the work process. The CGRP-GIS request system tool written in Java, provided ongoing entry of tracking information in the request system database, including such data as customers served, type of service performed, costs, and hours required. Metrics such as maps produced (Table 3) and system usage by discipline (Figure 7A) were readily compiled from the discipline or educational background of the user (Figure 7A), the LANL organizational membership (Figure 7B), and the GIS users' primary use of the CGRP-GIS (Figure 7C). For example, Figures 7A, 7B, and 7C illustrate that the majority of users of CGRP-GIS are geologists and ecologists who use GIS for field data collection and modeling efforts, ultimately to support the decision making process for projects or tasks related to environmental restoration and the earth sciences.

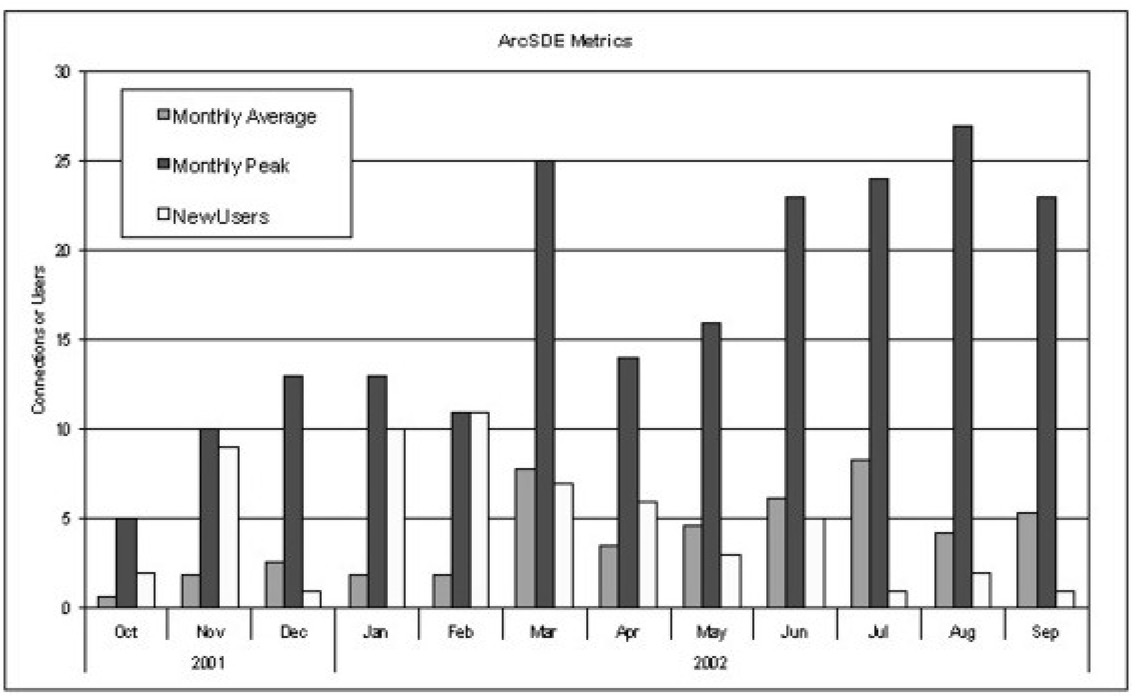

Figure 6. System usage as measured by ArcSDE access over the course of one year.

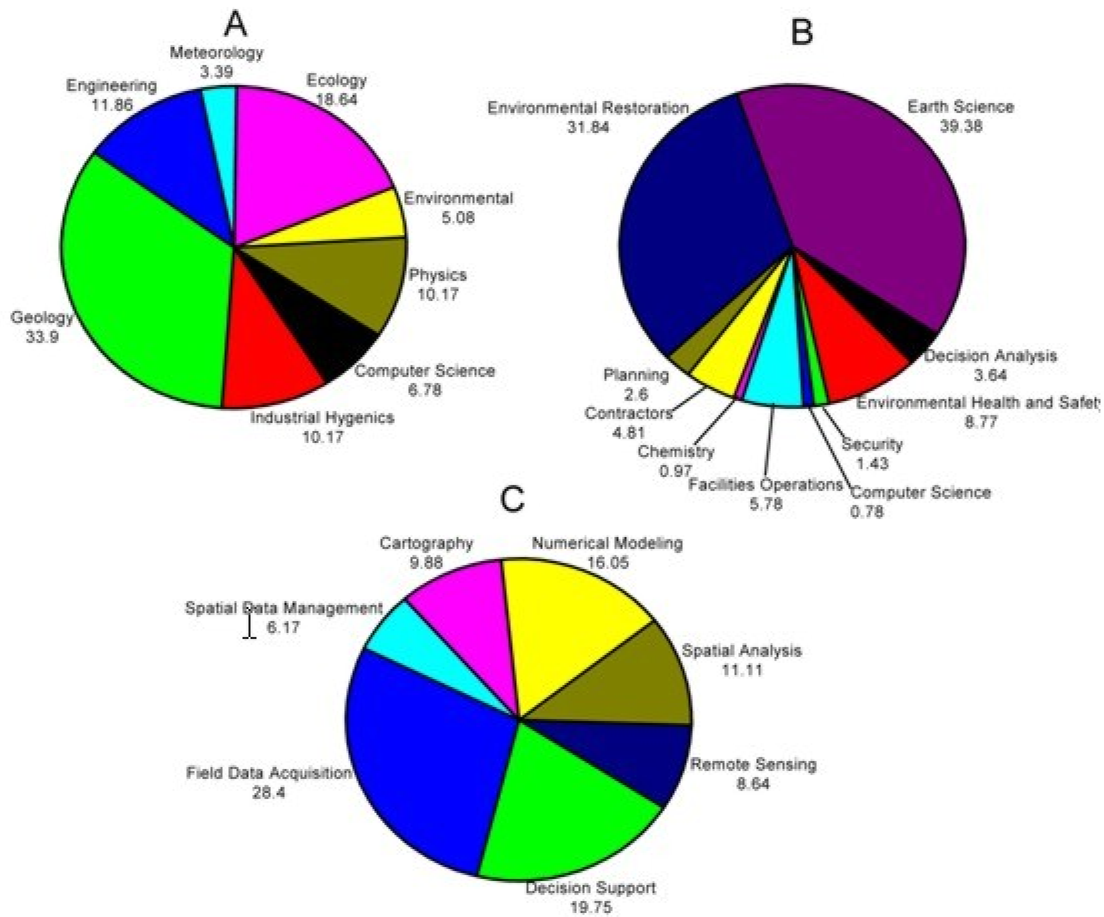

Figure 7. Multi-graph on CGRP-GIS system usage by discipline, requests, and type of GIS task. A) percentage of CGRP-GIS users by professional training; B) percentage of the 639 requests on the CGRP-GIS by different divisions at LANL;C) percentage of CGRP-GIS users by use.

DISCUSSION

The collective technologies that comprise EGIS continue to evolve and develop at a vigorous pace, yet the understanding and acceptance of the EGIS concept has lacked an adequate conceptual framework based on a rigorous and comprehensive definition. Our definition of EGIS and the associated conceptual framework can guide communication among GIS practitioners and is based on a set of measurable requirements (Table 1). We apply these nine requirements, together with the comprehensive set of EGIS metrics collected and observed from CGRP-GIS, to evaluate the success or failure of implementation and to explore scaling rules observed when attempting to migrate a project-based GIS to EGIS.

The metrics used to evaluate the success of the CGRP-GIS were formulated to include a comprehensive set of specific descriptive characteristics and quantifiable measures (Table 3). These metrics serve four important functions: 1) to evaluate the progress of EGIS implementation; 2) to determine ways to improve the EGIS design; 3) to evaluate the value of the EGIS to the institution; and 4) to enable comparison of the EGIS with other project-based GIS and EGIS implementations. By most measures the CGRP-GIS was highly successful. When we compare the metrics collected on CGRP-GIS (Table 3) to the nine requirements (Table 1) we determine that the physical and logical architecture deployed for CGRP-GIS met EGIS requirements 1, 2, and 3 (Table 1). This is exemplified by the fact that the capacity of the CGRP-GIS SAN and related databases (Table 3), at the time CGRP-GIS was operational, could store all existing institutional GIS data, which amounted to less than two terabytes. It was also determined that excess server capacity within the CGRP-GIS would allow for a significant number of users to be provided with simultaneous access to the CGRP-GIS and that all required services could be delivered through the client-server architecture (Figures 3 and 5). As more users were added to CGRP-GIS there was an increase in the amount of data stored. This was in part due to the diversity of users of the CGRP-GIS (Figure 7C) and the changing needs of other project-based GIS utilizing CGRP-GIS.

When we compare metrics of documentation and metadata, we find that they are not dependent on additional users added to CGRP-GIS. We determine that the standards, procedures, and policies (Table 3), together with tight coupling of dataflow and workflow, along with the documentation of all data and services developed for CGRP-GIS, could easily have been adapted to guide all EGIS users at LANL; and therefore the effort met EGIS requirements four, five, and seven (Table 1).

While informal *ad hoc* personal exchanges are crucial to data sharing and collaboration (Pinto and Onsrud 1995; Nedović-Budić and Pinto 1999a, 1999b, 2000, 2001; Nedović-Budić et al. 2004), formalized processes and procedures for data exchange among users produce a better flow of information because of a better understanding of individual responsibilities and expectations. Effective data sharing within the CGRP-GIS, through the establishment of a complete geospatial data cycle (Figure 1) ensured that all necessary elements and processes of an EGIS were present. For example, meaningful sharing of data is difficult when metadata are lacking or incomplete, when data are not well organized, and when an effective delivery system using common architecture is not in place. Somers (2002) suggested that institutions should view geospatial data as a "corporate asset" and protect it as such. The integrity of the geospatial data cycle is the fundamental means to protect these EGIS assets, and our request system allows for the required tracking of workflow within the EGIS. This tracking provides a conveniently available record of what processes have been completed and whether additional work is required. This method is analogous to "cradle to grave" tracking, is instead "source to archive".

Additional comparison between the CGRP-GIS metrics and EGIS requirements illustrate those metrics that did not meet the EGIS requirements, specifically EGIS requirements eight and nine regarding institutional financing and leadership (Table 1). Although initial project-level investment in CGRP-GIS was substantial (Table 3), the lack of institutional financing after CGRP-GIS funding ceased, hindered the ability of CGRP-GIS to maintain a critical threshold of staff to support the required roles (Table 4) necessary to maintain an EGIS. In particular, Internet GIS, web administration, and database administration lacked adequate funding and could no longer be supported.

Although most of the roles necessary to satisfy EGIS requirement six (Table 1) were adequately staffed for CGRP-GIS, it was observed by CGRP-GIS personnel that a geographic information officer or (GIO) was lacking, such a position would be necessary to provide important institutional management, leadership, and coordination for EGIS stakeholders. The lack of an institutional champion or GIO for the transition to full-fledged EGIS meant that the several, semi-autonomous GIS

Table 4. Example roles for EGIS team personnel.

EGIS Roles Personnel	Description of Roles
Geographic Information Officer (GIO)	Provides institutional management and direction of tasks, schedules, and budget
Technical Coordinator	Provides technical leadership and coordinates all technical EGIS tasks
Data Administrator	Provides data management for staging, storage, and delivery of data
Database Administrator	Provides administration of all database related tasks
Training & Outreach Coordinator	Provides training on how to use EGIS system and coordinates training of EGIS staff
Software Developer	Provides custom software development including scripting and programming required
Internet GIS Developer	Provides and develops internet and intranet GIS based maps and services
Web Administrator	Provides web server administration and other web page development
Customer Support Liaison	Provides a professional interface with institutional users of the EGIS as well as with external clients

teams around the institution had no incentive to accept the CGRP-GIS as an emerging EGIS. The observation is corroborated by results from the consensus building tool, which illustrated that, in the absence of an institutional champion the foundations of CGRP-GIS would only be as strong as the unified coordination, collaboration, and consensus achieved among the various GIS stakeholders within the institution (Keating et al. 2003). A GIO, which needs to be defined at an institutional level rather than at that of an individual project, was never established for CGRP-GIS. It was clear that the CGRP-GIS project manager could not become the GIO without an institutional mandate. We hypothesize that one GIO is required regardless of the number of users or additional capacity added to the system. The GIO provides and promotes the vision for the EGIS, and the presence of multiple GIOs contributes to a lack of coherence in the institutional vision for GIS. The CGRP-GIS supports the idea that EGIS requirements one through seven (Table 1) could develop initially at the bottom team level of management or be mandated from the top, but that EGIS requirements eight and nine (Table 1) could only develop from an institutional mandate at the highest levels of the institution.

The CGRP-GIS metrics represent a starting point toward developing a truly comprehensive taxonomy of EGIS metrics. There is a need to standardize metrics so different EGIS implementations can be meaningfully compared against EGIS requirements. The value of this initial taxonomy of metrics goes beyond EGIS, in that similar metrics could be applied to evaluate the success of any integrated GIS design implementation.

In addition to metrics about users and the tangible elements listed in Table 3, several other less tangible contributions were made at the institutional level in the process of developing CGRP-GIS. Our needs assessment and design efforts raised awareness among users of the importance and interrelationships of GIS at LANL in the areas of facilities and operations, emergency management, environmental monitoring and restoration, and earth science research. At the same time, Federal standards

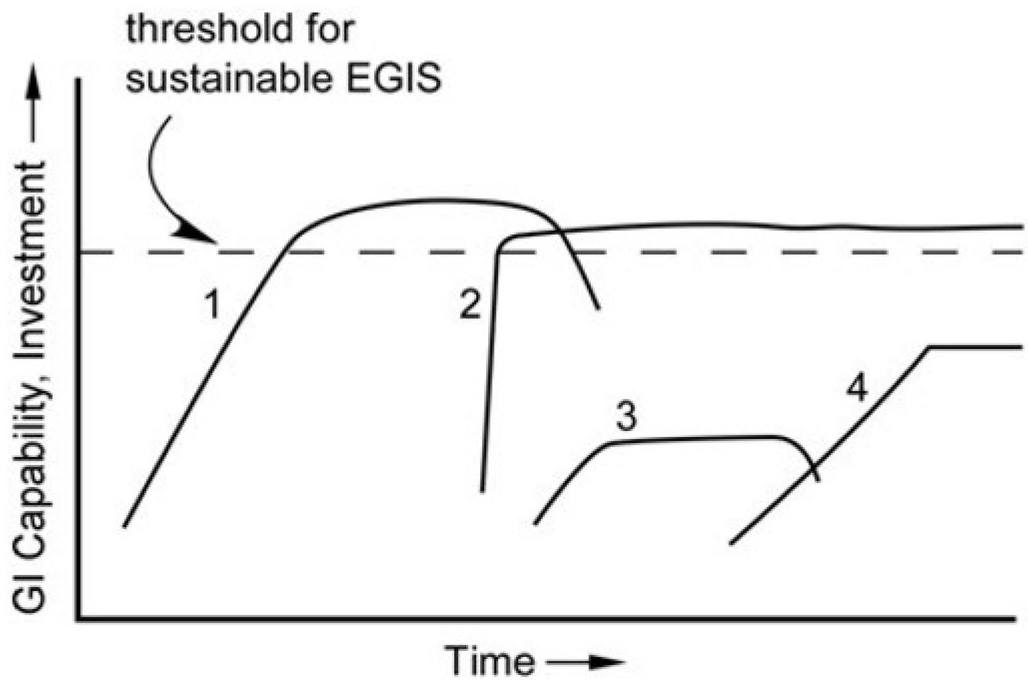

Figure 8. Schematic of project-based GIS funding cycles through time, relative to the threshold for sustainable EGIS at a hypothetical institution (dashed line). Project-based GIS begin at a relatively low level of GIS capability and investment, increase capability and maintain the investment for the life of the project, and then rapidly lose capability at the close of the project (curves 1, 3) if investment is not maintained. Final capability is often greater than initial capability, but new projects do not efficiently build on those that have gone before. Overall institutional investment in multiple project-based GIS does not aggregate through time. Curves 1 and 2 illustrate the hypothetical evolution of two project-based GIS in which each exceeds the threshold, either temporarily (1) or sustainably (2). Curve 2 illustrates the funding profile for the CGRP-GIS project relative to the LANL EGIS threshold of approximately $1.15M. After the close of the CGRP-GIS project, continued funding, integrated from several sources, has allowed this GIS to remain above the EGIS sustainability threshold for the LANL institution. Curve 4 depicts the investment trajectory of a GIS that receives stable investment to support a long-term project but does not have the capacity to serve at the enterprise level

for metadata (FGDC 1998) were being implemented across the DOE complex (e.g., Bleakly and Lee 2001; Rush 2001), and the concepts for a metadata clearinghouse for fire rehabilitation and environmental restoration data, consistent with national standards, were to the institution as a whole. Progress made in establishing efficient spatial information management focused scrutiny on the inefficiency, redundancy, and incompatibility of the independent project-based GIS structure within LANL (Keating et al. 2002, 2003).

Beyond comparing metrics to requirements it is also important to identify the important differences between a project-based GIS and EGIS. One of the most significant differences between project-based GIS and EGIS is that of financial stability. The trajectory of investment and GIS capability for an individual project-based GIS (Figure 8) might typically begin at a low level, rapidly build to a peak, be sustained for some period of time, and then decay when the project ends or is superseded. In the case of CGRP-GIS there was a large investment during a two-year period with no gradual increase in investment (Figure 8, curve 2). While there may be a legacy of GI capability remaining at the end of each project, it may not be entirely available to the next project-based GIS, which then must reinvest during start-up. Remnant capabilities from each GIS persist as a legacy, but they do not aggregate well to serve future project-based GIS within the same institution. Oscillation in funding may be repeated in the absence of an institutional plan, and the repetitious and redundant investment at the project level may exceed the costs necessary to maintain an EGIS. Development of some of the larger project-based GISs, such as CGRP-GIS, may (for a time) exceed the threshold of investment and capability necessary to sustain an EGIS for the institution (Figure 8, curves 1 and 2). In the case of CGRP-GIS the original investments in physical and logical infrastructure have persisted to continue to serve the institution to date, despite the fact that the original CGRP investment has long since faded. In such cases, the resulting window of opportunity in the short run may be leveraged to serve as the seed to develop an EGIS, but only with champions in senior management and sufficient long-term financial investment to sustain it. Nonetheless, CGRP-GIS provided the impetus for the creation of the current GISLab and served as a model for others embarking on EGIS implementations.

The stability of an enterprise GIS, in contrast to the oscillations of project-based GIS, has other benefits as well. Data developed in individual project-based GIS may have institutional value but will be essentially lost in the absence of a central data warehouse and metadata clearinghouse. Future project-based GIS will not realize the benefits of efficient access to centralized data and documentation and will instead depend on *ad hoc* relationships to find and exchange data. Investments in personnel and training may disappear at the conclusion of an individual project rather than persisting as part of an institutional plan for GIS capability. Likewise, in the absence of a comprehensive plan, GI tools and services developed for an isolated GIS project must repeatedly be reproduced by future efforts. In short, project-based GIS can be performed more simply, efficiently, and with more lasting value to the institution if they are executed within the framework of an EGIS. The eventual result will be a new "collective geographic awareness", whereby both GIS specialists and non-specialists can access a wealth of map-based data and analysis capabilities that are continuously available with minimal assistance, for the benefit of day-to-day institutional operations, research, and decision making.

CONCLUSION

Many traditional project-based GIS are now challenged with providing an enterprise GIS solution – an EGIS – in order to realize greater efficiency and cost savings through investment in shared infrastructure. We view EGIS as a phenomenon whose time has arrived. Now that key technological components are widely available – high-speed networks, fast computers, and sophisticated GIS analysis and visualization capabilities – we are ready for the next stage in the evolution of GIS, implementation of GIS at the enterprise level. Our conceptual framework for EGIS, based on a rigorous definition and specific requirements, can help guide the transition and facilitate communication among stakeholders. EGIS design must include by definition integrated components and services, and institutional management. The success of EGIS can be defined by the recognition and successful completion of the nine implementation requirements, and most notably can fail if there is a lack of institutional funds and management support. A standardized set of metrics on EGIS enables meaningful comparison between EGIS requirements and their implementation. Importantly, a project-based GIS completed within an EGIS, as compared to an isolated project-based GIS, can expectantly devote more resources to project goals rather than to infrastructure (cyberinfrastructure), to have greater longevity, and to provide many benefits to the institution itself.

AUTHOR'S NOTE

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