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Understanding the spatial database of the multipurpose GIS

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UNDERSTANDING THE SPATIAL DATABASE OF THE MULTIPURPOSE GIS

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Executive Order 12906 implied that access to reliable geographic information is needed at the local level to ensure the well being of communities. Increasingly, local governments are adopting GIS technology in order to implement this vision. However, the existing academic GIS paradigm is inadequate in meeting the day-to-day needs of local government activities. What is needed is a multipurpose system in which a spatial database is constructed and stored such that all users may quickly access the most current and reliable information possible.

To explore the methods by which the spatial database for a multipurpose land information system (MPLIS) is developed, a pilot study project was conducted for a portion of Ravalli County, Montana. Before conducting the pilot study, various government guidelines were consulted, GIS professionals were interviewed, and an information needs assessment was conducted.

Data quality is of considerable importance to GIS users. Speediness of implementation is important to managers and policy makers. A successful MPLIS requires the development of quality data within a reasonable amount of time and within a meager budget.

Spatial data useable by a local government MPLIS must be detailed, current, and reliable. At present, free data from outside sources meets none of these requirements. To fulfill the needs of a typical local government, spatial data collection methods must be as efficient possible without sacrificing an acceptable standard of quality. Metadata is the means by which to assess the quality of any given data set.

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To the memory of my father, Benjamin Eugene Miller, who taught me to appreciate the outdoors, offer more questions than answers, and look at everything with a critical eye.

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LIST OF ABBREVIATIONS

ASPRS	American Society of Photogrammetry and Remote Sensing
BLM	Bureau of Land Management
CAMA	Computer Assisted Mass Appraisal
CFF	Cartographic Feature File
COGO	Coordinate Geometry
COS	Certificate of Survey
DBMS	Database Management System
DEM	Digital Elevation Model
DoD	Department of Defense
DOQQ	Digital Ortho Quarter Quad
E-911	Enhanced-911
EO 12906	Executive Order #12906
EPA	Environmental Protection Agency
ESRI	Environmental Systems Research Institute
ESZ	Emergency Service Zone
FGCC	Federal Geodetic Control Committee
FGDC	Federal Geographic Data Committee
GCDB	Geographic Coordinate Database
GIS	Geographic Information System
GLO	General Land Office
GMM	Geographic Measurement Management
GPS	Global Positioning System
HARN	High Accuracy Reference Network
INA	Information Needs Assessment
ISO	International Organization for Standardization
LIS	Land Information System
MCP	Montana Cadastral Project
MPLIS	Multipurpose Land Information System
MSAG	Master Street Address Guide
NAD83	North American Datum of 1983

NAPP	National Aerial Photography Program
NCEES	National Council of Examiners for Engineering and Surveying
NMAS	National Map Accuracy Standards
NRC	National Research Council
NRIS	Natural Resources Information System
NSDI	National Spatial Data Infrastructure
NSSDA	National Standards for Spatial Data Accuracy
OMB	Office of Management and Budget
PBS	Primary Base Series
PDOP	Position Dilution of Precision
PLSS	Public Land Survey System
PSAP	Public Safety Answering Point
RMSE	Root-Mean-Square Error
SA	Selective Availability
SDTS	Spatial Data Transfer Standard
SPCS	State Plane Coordinate System
TIN	Triangular Irregular Network
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

I. INTRODUCTION

> Geographic information is critical to promote economic development, improve our stewardship of natural resources, and protect the environment. Modern technology now permits improved acquisition, distribution, and utilization of geographic (or geospatial) data and mapping. The National Performance Review has recommended that the executive branch develop, in cooperation with State, local, and tribal governments, and the private sector, a coordinated National Spatial Data Infrastructure to support public and private sector applications of geospatial data in such areas as transportation, community development, agriculture, emergency response, environmental management, and information technology.[1]

Executive Order 12906 (EO 12906) was issued in April 1994 under the premise that "responsible stewardship of our natural resources for sustainable development depends on making sound scientific information available to local decision makers."[2] The implication is that access to reliable geographic information is needed at the local level to ensure the well being of communities. Geographic information, therefore, is a key element by which people identify and solve environmental problems.

Quite often, local governments find themselves at the battlefront of land-use conflicts. Whether a skirmish ensues between angry neighbors over the location of a fence or the Sierra Club files a lawsuit against a logging company, all associated legal land-tenure documents will be sought. Fortunately, legal systems throughout history

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[1] President. Executive Order, "Coordinating Geographic Data Acquisition and Access the National Spatial Data Infrastructure, Executive Order 12906." *Federal Register* 59, no. 71 (13 April 1994): 17671.

[2] Federal Geographic Data Committee, *A Strategy for the National Spatial Data Infrastructure* (Washington, DC, 1997), 4.

have placed emphasis in maintaining the necessary records to determine the ownership of a parcel of ground and the rights (and responsibilities) of those individuals or parties.

Most of the information needed to operate a local government is referenced to a specific geographic location.[3] Planners and tax assessors need detailed information about the distribution of land and resources; civil engineers need topographic information to plan roads; and police departments need to know the spatial distribution of crimes and accidents. Interestingly, geography seems to be the common reference that links the functions and duties of nearly every department within a local government. Geographic Information Systems (GIS) technology is now hailed as the premier tool by which this information is collected, stored, maintained, and analyzed in order to make better decisions regarding the use of the land and its resources.

THE PROBLEM

Huxhold writes, "The trouble with geography is that there are so many different kinds in local government."[4] He expands on the statement by discussing the varying geographical reference requirements of the diverse entities within a local government jurisdiction. However, not only do the reference requirements differ among departments within the same organization, but the accuracy requirements differ as well.

In the United States there are over 3,100 counties containing more than 19,000 municipalities—each having some method of managing their complicated geography.

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[3] Stan Aronoff, *Geographic Information Systems: A Management Perspective* (Ottawa: WDL publications, 1995), 16.

[4] William E. Huxhold, *An Introduction to Urban Geographic Information Systems* (New York: Oxford University Press, 1991), 147.

Some use sophisticated, mature GISs while others continue to manage with filing cabinets and road maps. As these organizations begin to invest the necessary resources to adopt GIS technology, unexpected problems often arise for various reasons.

Obviously, one expects the implementation of a GIS to bring about various benefits, which in turn ultimately bring about a more efficient and effective operation. For instance, a GIS can automate the map production and maintenance process, provide easier access to and maintenance of data, and facilitate the analysis and understanding of spatial phenomena. The "corporate database" concept of GIS eventually introduces a fundamental change in the way in which local governments conduct business by promoting more effective sharing of the most current information.[5] The hope of many GIS advocates within local government is that the redundancy and local control associated with prior methods of individual data collection will eventually be replaced with inter-departmental cooperation and data sharing. The result of these benefits is a government that costs less to run, makes better decisions, and involves its constituency more thoroughly in the democratic process.

Benefits, however, do not come without at least some initial cost. Normally, the adoption of any new technology requires substantial initial purchases, the hiring and training of personnel, and the allocation of new office space. GIS implementation requires not only this, but also the construction of a large spatial database. These initial

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[5] New York State Archives and Records Administration, "Manager's Overview," *Geographic Information Development Guides* [on-line] (13 October 2000); available from http://www.archives.nysed.gov/pubs/gis/manager.htm; Internet.

procedures are quite time consuming, and the costs are substantial—both are often met with objections and skepticism.

GIS technology came about in direct response to the types of demands associated with land-use planning, environmental assessment, and policy issues. Individual systems were designed to support specific projects without necessarily addressing the day-to-day transactions of the institution. Moreover, the spatial extent of the projects was such that large areas became the subject of study without regard to individual parcels of land.[6] Local governments, on the other hand, are very much concerned with the meticulous individual details of those land parcels—in addition to large areas of interest.

Regarding any new technology, local governments face a unique challenge. A typical rural county for instance, constitutes a domain of substantial geographical area, which is populated by relatively few taxpayers. More often than not, local officials must work with a limited fiscal budget, vintage personnel, and a constituency that resists technological change. When faced with the reality of the cost of designing and constructing an expensive database for an already expensive GIS, city and county officials understandably become apprehensive about making the required investment.

The major problem cited for the failure of a GIS program is that the system does not perform to the expectations of management.[7] Often, the expectations consist of a vision that does not coincide with the capabilities of the GIS staff. In other words, the

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[6] Earl F. Epstein and Patricia M. Brown, "Introduction to Multipurpose Land Information Systems, Chapter 1," in *Multipurpose Land Information Systems: The Guidebook,* (Silver Springs, MD: FGCC, 1992), 1—5.

[7] Aronoff, 249.

customary paradigm of GIS might be guiding the developers while the officials wait in vain for the system to efficiently integrate with the existing technology and improve the day-to-day transactions of the organization. Another source of disappointment might be that only a select few are able to interact with the GIS thus creating a mysterious void in the minds of those on the outside. More than likely, a GIS program fails to delight the upper echelon because of a combination of these and other issues.

The Topic

No longer is the power and utility of GIS in question—much has been written concerning the subject, and the vast amount of literature regarding GIS success stories has more than demonstrated its worth. What is in question, however, is the fit of GIS with local government operations. Can those within a typical local government truly expect GIS to integrate with their existing technology and business practices in order to provide a more efficient, effective, and equitable operation? Can GIS developers break from the traditional mold and present a true automated, multiuse, organization-wide system worthy of being considered a multipurpose land information system?

EO 12906 established the National Spatial Data Infrastructure (NSDI) based upon the needs of and information from State, local, and tribal governments. This implies a focus on the details and issues at the individual parcel level. The topic of this research concerns the practical aspect of collecting and managing the geographical data necessary to support the functions of a local government, which in turn induces the evolution of the traditional GIS into a Multipurpose Land Information System (MPLIS).

Statement of Purpose

The purpose of this research is to discover the optimal methodologies by which a local government might efficiently construct the fundamental spatial database themes necessary to implement a Multipurpose Land Information System.

Objectives

The objectives of this research are:

- To understand the requirements of local government regarding the spatial database component of a Multipurpose Land Information System (MPLIS)
- To catalog the existing spatial data sets available, and address the issues of making them useable in the county government setting
- To define and compile the established methods of spatial data collection
- To assess the utility and accuracy of spatial data that is collected by established methods in relation to the effort involved
- To discover and address the common problems that arise during the spatial database design and construction process

Scope of This Study

The scope of this research was confined to certain specific base data layers. The layers included in this research were geodetic control, orthoimagery, transportation, cadastral, and hydrography. Data collection and experimentation was confined to an area of one 36 square mile township of the PLSS. It is located in Ravalli County, Montana, and is described as Township 10 North, Range 20 West, Principal Meridian, Montana (T10N, R20W, PM, M).

II. BACKGROUND AND PURPOSE

This chapter addresses the background issues related to this research topic and communicates the purpose of the study. The first part defines the fundamental cartography- and GIS-related terms and concepts that are necessary for the reader to follow the specifics of this discussion. The second part will review the important and relevant literature. Finally, the purpose and significance of this particular project will be articulated.

TERMS AND CONCEPTS

It has been observed by many that GIS technology is responsible for the creation of a host of esoteric jargon and acronyms. The terms and concepts that follow are intended to be logical in order—to follow a path from the fundamental mapping and land tenure concepts, to the specific activities related to gathering geographic information, and finally, to the more technical terms and concepts associated with GIS and MPLIS.

MAPPING AND DIVVYING THE EARTH

Although disputed by some, the earth is shaped like a sphere. More precisely, the earth is an oblate spheroid, whereby its width is larger than its height. For the part of man's history when the earth was assumed flat, representing geographical features and places along with their relationships was a relatively simple task. However, the discovery of the true shape of the earth has spawned the need to represent things in space by abstract methods. Furthermore, the dividing of the earth into discrete portions—to provide inhabitants with a sense of ownership—has prompted the development of sophisticated instruments that can report the near exact location of any point on the earth.

MAPS, MAP PROJECTIONS, AND COORDINATE SYSTEMS

Map. Muehrcke defines a map as a spatial representation of the environment.[1] Robinson, et al, agrees with this definition but expands the concept to include "...a carefully designed instrument for recording, calculating, displaying, analyzing, and understanding the interrelation of things."[2] For the purpose of this research, a map is defined as a carefully designed graphic representation of the environment, which is used for recording and displaying spatial information for the purpose of making spatial calculations, analyzing spatial phenomena, and understanding the spatial relationships of things. A map is planimetric insomuch as it shows horizontal spatial relationships. With regards to a GIS, a map may take the form of graphics on paper, or graphic images on a computer monitor.

Base Map. A base map is the graphic representation at a specified scale of selected fundamental map information, used as a framework upon which additional data of a specialized nature may be compiled.[3] In a GIS, base map data forms the foundation upon which all other map data is overlaid.

Map Projection. A painful fact for cartographers and the like is that a spherical object such as the earth cannot be flattened without stretching and tearing portions of the original surface. Such is the dilemma of depicting large geographical areas on a two-

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[1] Phillip C. Muehrcke and Juliana O. Muehrcke. *Map Use: Reading, Analysis, and Interpretation, 3rd Edition* (Madison, WI: JP Publications, 1992), 2.

[2] Arthur H. Robinson, Joel L. Morrison, Phillip C. Muehrcke, A. Jon Kimerling, and Stephen C. Guptill. *Elements of Cartography, 6th Edition* (New York: John Wiley and Sons, Inc., 1995), 10.

[3] American Society of Photogrammetry and Remote Sensing, *Manual of Photogrammetry, 4th Edition* (Falls Church, VA: ASPRS, 1980), 76.

dimensional map. A map projection is a mathematical means of transferring information from the spherical earth to a flat map while keeping distortions to a minimum.

Map Scale. The scale of a map refers to the relation of the distance and size of objects found on the map to the actual distance and size of those same objects on the earth. Scale is often described as a ratio between map and earth such as "1:24,000" or "one inch equals two thousand feet."

Coordinate System. A coordinate system is simply a grid of horizontal and vertical values that allows one to define a specific location. The most common geographic coordinate system uses spherical latitude and longitude values to define locations worldwide. Planar coordinate systems such as Universal Transverse Mercator (UTM) and State Plane are used in localized areas to facilitate easier measuring of distance and area. In this case, the planar coordinate system is a Cartesian grid of X and Y values, which is superimposed upon a projected map.

Datum. Strictly speaking, a datum is some fact, proposition, quantity, or condition granted or known, especially when it is to be used for further research or reasoning.[4] In regards to GIS, a datum is a mathematical approximation of the ellipsoidal shape of the earth, which is necessary to develop a coordinate system. A *global datum* approximates the entire earth whereas a *local datum* most closely defines the surface in a particular region such as North America or Europe.[5]

[4] *The Lexicon Webster Dictionary,* 1971 ed., s.v. "datum."

[5] Huxhold, 321.

<u>Geodetic Reference.</u> A geodetic reference consists of a mathematical function that spatially relates the coordinates of features in the database to their true location on the earth. The reference acts as a means to control or tie the placement of each feature to a chosen coordinate system and datum. In practice, an accurate geodetic reference aids in assigning reliable coordinate values to each point in the database.

Land Interests and Surveys

It must be clearly stated that this research project is in no way an expository in surveying. However, practitioners in MPLIS will encounter situations that directly relate to the functions of a surveyor. Therefore, it is necessary to understand certain terms and concepts that professional surveyors regard as fundamental knowledge.

Some of the most essential information of concern to a local government is the nature and extent of land interests. The *nature* of an interest in land refers to the rights and restrictions of the landowner. The *extent* of a land interest refers to the geographical boundaries at a given point in time.[6]

<u>Cadastre.</u> The cadastre is the physical collection of land record information within a government jurisdiction. It is the official register or survey of the worth, amount, and proprietorship of an area's real estate, used in assessing taxes.[7] Cadastral records consist of the documentation (including maps) of property boundaries, subdivision lines, buildings, and related details.[8]

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[6] Earl F. Epstein and Patricia M. Brown, "Land Interests, Chapter 4," in *Multipurpose Land Information Systems: The Guidebook,* (Silver Springs, MD: FGCC, 1992), 4—1.

[7] *The Lexicon Webster Dictionary,* 1971 ed., s.v. "cadastre."

[8] *Webster 7th New Collegiate Dictionary,* 1971 ed., s.v. "cadastral."

Property Description. A property description is the written evidence of the spatial extent of land parcels and their common associated surface interests such as easements and rights-of-way. Property descriptions are also referred to as land descriptions, land boundary descriptions, and legal descriptions.

Surveying. Surveying is the process of recording observations, making measurements, and marking the boundaries of tracts of land. A survey is the plat and the field notes that record and describe these activities.[9]

Metes and Bounds. Metes and Bounds refers to a type of property description whereby a parcel is legally described by beginning at a specified point of beginning and describing the boundary as a series of directions and distances around the area until the point of beginning is reached. Location monuments marking property corners are often established and relocated by means of Metes and Bounds surveys.

Certificate of Survey. A Certificate of Survey (COS) is a document containing a statement dated and signed by a surveyor that a survey has been executed according to specific instructions. A COS is the verbal and geometric record of the steps of the surveyor, which ultimately describes the boundaries of a parcel of land.

Deed. A deed is the written legal document that conveys ownership or interest in real property. A major component of a deed is a legal description, such as a Metes and Bounds, that accurately and definitively locates the property without oral testimony.[10]

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[9] Bureau of Land Management, *Glossaries of BLM Surveying and Mapping Terms*, (Washington, DC: BLM, 1980), 17.

[10] Huxhold, 317.

Monument. With respect to land surveying, a monument is a physical object such as an iron post or marked stone, which is set in the ground to mark the specific location of a corner established by a survey.

Public Land Survey System. Initiated by the Land Ordinance of 1785, the Public Land Survey System (PLSS) was devised as a means of efficiently and systematically dispensing the lands of the public domain—lands held by the Federal Government. The PLSS is a rectangular network of established survey monuments spaced at intervals of one mile in the early areas and one-half mile in others. The area defined by the monuments (either 640 acres or 160 acres) was then available from the Federal Government.

Geographic Coordinate Database. The Geographic Coordinate Database (GCDB) is the digital representation of the geometry of parcels contained within the PLSS. Developed and maintained by the Bureau of Land Management (BLM), it provides interested parties with the most accurate digital portrayal of the locations of PLSS corners, thus serving as the foundation for cadastral mapping projects. The GCDB is assembled by gathering the information from all pertinent surveys, and allowing computer algorithms to determine the geographic coordinates of each survey corner.

It is important to draw the distinction between digital PLSS data and the GCDB. Digital PLSS data is derived from digitizing PLSS section corners from paper maps such as those produced by the U. S. Geological Survey (USGS). The GCDB is produced from the original surveyors' field notes and plats. The idea behind creating the GCDB is that, upon receiving new survey information, the data can be made better by allowing the necessary computer algorithms to statistically adjust the location of the PLSS corners.

Gathering Earthly Information

Creating a map consists of drawing features that can be found on the earth. Until recently, mapping things on the earth was a long, arduous process. Technological advances in the 20th Century such as aerial photography, satellite imagery, electronic distance measuring devices, and Global Positioning Systems have drastically reduced the time and effort involved in gathering information about the earth.

Airborne Imagery

The process of photographing the earth from above has a number of cartographic advantages over direct ground observations. These include: 1) a bird's-eye view of large areas to provide a spatial context; 2) the capability to stop the action to create a permanent record of existing dynamic phenomena; 3) the ability to record more spatial data than can be seen from the ground; and 4) an economical means of data collection.[11]

Aerial Photograph. As the name implies, an aerial photograph is a photograph of the ground surface taken from the air. In a vertical aerial photograph, the axis of the line of site from the camera to the ground is less than three degrees from perpendicular. It is important to note that aerial photographs inherently contain a sizeable degree of geometric distortion.

In 1980, the USGS began the National High Altitude Photography program to acquire aerial photography of the 48 coterminous states on a five-year cycle. In 1987, the program was changed to the National Aerial Photography Program (NAPP) to respond to

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[11] Thomas M. Lillesand and Ralph W. Kiefer, *Remote Sensing and Image Interpretation, 3rd Edition* (New York: John Wiley and Sons, 1994), 49.

new user requirements and more stringent flight specifications. NAPP photography is acquired at 20,000 feet above the average terrain height, which produces hard-copy photographs at a scale of approximately 1:40,000.[12]

Orthophotograph. An orthophotograph is a geometrically correct aerial photograph in which the various forms of geometric distortions and displacement are removed. The photograph is spatially accurate because ground features are represented in their true planimetric positions in the same manner as the features shown on a topographic map. The advantage of an orthophotograph is that it combines the image characteristics of a photograph with the geometric qualities of a map.

Digital Orthophoto Quadrangle. A digital orthophoto quadrangle is the digital version of an orthophotograph. In many portions of the United States, the USGS has constructed DOQs from the 1:40,000 scale NAPP photography. The area covered by a single digital photograph is that area equal to one-fourth of a USGS topographic map ("quad"). Thus, a digital image of this nature is called a Digital Ortho Quarter Quad (DOQQ). The spatial resolution (relation of image pixel size to ground distance) is approximately one meter.

Satellite Image. A satellite image is the pictorial representation of the earth, which has been electronically recorded from a special sensor aboard a satellite and transmitted to receiver stations on the earth. Note that satellite images are digitally produced whereas photographs record information on film.

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[12] United States Geological Survey, *National High Altitude Photography and National Aerial Photography Program* [on-line] (July, 2000); available from http://edc.usgs.gov/Webglis/glisbin/guide.pl/glis/hyper/guide/napp; Internet.

GLOBAL POSITIONING SYSTEMS

The Global Positioning System (GPS) is a satellite-based navigation system, which is controlled by the U. S. Department of Defense (DoD). It consists of satellites, monitoring stations, receivers, and computer software used for locating positions on the earth. The set of satellites and monitoring stations are operated by the DoD, and the receivers and associated software are available for civilian use from GPS receiver manufacturers. Understanding the information provided by the system (and using it for mapping) requires a basic knowledge of the concepts previously discussed as well as certain geodesy-related terms and principles.

The Ellipsoid. The ellipsoid is the mathematical model that describes the general, elliptical shape of the earth. It is defined by the length of the semimajor axis (the distance from the center of the earth to a point on the equator) and the semiminor axis (the distance from the center of the earth and the north or south pole).

The Geoid. The geoid is the three-dimensional shape that is approximated by mean sea level across the oceans and hypothetically across the land surfaces if canals were to crisscross the continents. More technically, the geoid is a sea level equipotential surface, which is the surface on which gravity is everywhere equal to its strength at mean sea level. Variations in rock density and topography cause the geoid surface to deviate from the ellipsoid surface by as much as 100 meters.

Selective Availability. Selective Availability (SA) is a program by the DoD to intentionally degrade GPS satellite signals in order to limit the accuracy of position fixes by civilian receivers. The error in position can be as much as 100 meters. SA was turned off on May 1, 2000. However, the DoD has the prerogative to turn it on for any reason pertaining to national security.

Dilution of Precision. Dilution of Precision is an indication of the expected accuracy of a GPS position. Position Dilution of Precision (PDOP) is the indicator most commonly applied by GPS users. It is a number that expresses the relationship between the error of the receiver and satellite positions by calculating the volume of the pyramid formed by lines running from the receiver to the four satellites observed. PDOP values less than three are good whereas values greater than seven are poor.

Differential Correction. Differential correction is the process of correcting the error-prone GPS positions of an occupied location by correlating the data with that simultaneously collected from a receiver at a base station of exact known location. GPS data can be corrected in real-time with a radio signal from the base station or post-processed at any time after collection by downloading the base files.

Geographic and Land Information Systems

Geographic Information System. Burrough defines a GIS as, "a powerful set of tools for storing and retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes."[13] For all practical purposes, and for the purpose of this discussion, a GIS is a database management system for geographical information. It consists of computer hardware and software, geographic information, and the people who operate the system according to a defined set of procedures.

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[13] Peter A. Burrough, *Principles of Geographical Information Systems for Land Resources Assessment* (Oxford: Clarendon Press, 1986), 6.

An Enterprise-wide GIS broadens the implementation strategy from focusing on a system for one or two departments to an interrelated geographic database management system that includes the needs of the entire organization. It is characterized by a corporate database, which stores data on a central server for use by all departments.

Land Information System. A Land Information System (LIS) is regarded as a GIS that is designed to handle detailed land ownership information. It is characterized by large-scale map output, large volumes of land-related information, and many separate data layers.[14]

Multipurpose Cadastre. A multipurpose cadastre is a parcel-based land information system consisting of a geodetic reference framework, a base map, and a cadastral overlay. The cadastral overlay incorporates unique parcel identifiers, which facilitate the linking of the spatial entities with their associated attribute information.[15] A multipurpose cadastre can consist of paper and Mylar maps that display references to tabular records in a database.

Multipurpose Land Information System. A Multipurpose Land Information System (MPLIS) combines the elements of the Enterprise-wide GIS, the LIS, and the Multipurpose Cadastre to efficiently and effectively make information about land available to users.

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[14] Aronoff, 41.

[15] Panel on a Multipurpose Cadastre, Committee on Geodesy, Commission on Physical Sciences, Mathematics, and Resources, National Research Council, *Procedures and Standards for a Multipurpose Cadastre* (Washington, DC: National Academy Press, 1983), 7.

Information and Data

When reading a map, one intuitively interprets two types of information: spatial information (points, lines, and areas) and descriptive information that conveys the attributes of those features by means of standardized symbols and text. Unfortunately, a computer does not possess this level of perception. The transformation of map information into the digital realm (then back to a map) involves the creation of a conceptual model of the geographic information, inputting and storing the information as data within the computer system according to the model, maintaining and manipulating the data, and offering the information to interested parties in the form of output and display.

Spatial Data. Spatial data is the computerized equivalent of the geographic features that can be seen on a map. It assumes the form of pixels, points, lines, or polygons, which are generated when information is scanned or digitized from a map and stored in digital form.[16] This portion of a GIS is the spatial database. Spatial data within the GIS database is stored in a proprietary format specific to the software vendor.

Attribute Data. An attribute is a descriptive characteristic of a feature. Attribute data, then, is the information that describes a spatial feature such as name, address, length, area, elevation, or appraised value. In order for a GIS to achieve its full potential, each spatial entity must be linked to a record of attribute information.

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[16] William E. Huxhold, *GIS County User Guide* (New York: Oxford University Press, 1997), 41.

Database. Deitel, et al, defines a database as an integrated collection of data that is stored in such a manner that it may be queried and accessed conveniently.[17] A relational database is composed of multiple tables, each containing numerous rows and columns of data. The tables are related to one another by common fields of data. A geo-relational database enhances the relational database by providing a spatial identifier that provides the link between each tabular record and corresponding entity in the digital map.

Data Model. A model is an abstraction of reality. It can take the form of a table in a database, a mathematical equation to predict the expected atmospheric pressure at a given altitude, or a drawing to visualize the shape of a real-world object. To model a geographic feature is to define the method by which to describe its location and understand its situation. A map is perhaps the simplest form of a geographic model.

A data model is the conceptual organization of a database.[18] A GIS employs various data models for both the spatial and attribute portions of the database. Spatial features are stored by means of the vector data model, the raster data model, the Digital Elevation Model (DEM), or the Triangular Irregular Network (TIN) model. The most common are the vector and raster models.

The three classic methods of organizing attribute data are by the hierarchical, the network, and the relational models. Nowadays, the most common of these is the relational model. The geo-relational and object-oriented data models define the relation of the spatial features with their particular characteristics and behavior.

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[17] Harvey M. Deitel, Paul J. Deitel, and Tem R. Nieto. *Visual Basic 6: How to Program* (Upper Saddle River, NJ: Prentice-Hall, 1999), 768.

[18] Aronoff, 155.

DATA QUALITY

Accuracy. Accuracy is the level to which a measurement of information matches the actual value. Accuracy is synonymous with correctness. Positional accuracy is the expected deviance of the location of an object in a database or a map from its true ground position, and the likelihood that the position of a point as determined from a map will be the same as its true position on the earth.[19]

Precision. Precision refers to the fineness of a measurement scale and the exactness of the assignment of the numerals.[20] An example of a precise measurement is a number with three decimal places, which is more exact than an integer although not necessarily more accurate.

Logical Consistency. Logical consistency refers to how well relationships between data layers are maintained. For instance, if a portion of a school district boundary follows the eastern channel of a river, then a logically consistent database would maintain the portions of the boundary and river channel as coincident lines.

Resolution. Resolution defines the smallest discernable or represented unit in a data set.[21] Resolution can refer to spatial (space), temporal (time), or spectral (light wavelength) characteristics of the elements in a data set.

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[19] Ibid., 144.

[20] Robert H. Stoddard, *Field Techniques and Research Methods in Geography* (Fairfax, VA: TechBooks, 1982), 51.

[21] Aronoff, 137.

Metadata. Metadata is information regarding the source, derivation, construction, changes, and characteristics about spatial features in a GIS database.[22] Metadata is often referred to as data about the data.

BASIC GIS FUNCTIONS AND PRINCIPLES

Function. A function is an activity that one does to fulfill a duty. For instance, a floodplain administrator performs the function of determining if a proposed building site is located within the floodplain. By viewing parcel data overlaid upon river and floodplain data, the administrator might conclude that the building sight is very close to the flood zone and call for a more extensive survey of the area.

Functions of local government that are enhanced by GIS technology fall into several broad categories: browsing information, custom display, data query, data maintenance, and analysis and modeling. Each of these broad functions incorporates some form of a procedure or algorithm that can be part of a GIS software package.

Information Needs Assessment. An Information Needs Assessment (INA) is the systematic look at and documentation of the functional and spatial data needs of each department within an organization. The final report of the INA serves as a blueprint for developing the database and implementing the GIS.[23]

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[22] Bureau of Land Management, *NILS: National Integrated Land System, Appendix A, Glossary of Use Case Terms,* [on-line] (July, 2000); available from http://www.blm.gov/nils/bus-req/Reqs-pdf-docs/app-a.pdf; Internet.

[23] New York State Archives and Records Administration, "Needs Assessment," *Geographic Information Development Guides* [on-line] (13 October 2000); available from http://www.archives.nysed.gov/pubs/gis/needs.htm; Internet.

Digitize. To digitize something is to convert its real-world representation into a digital, computerized representation. Digitizing is the process of converting manually created source materials into digital computer codes.

Topology. With regard to GIS activities, topology is the method used to explicitly define spatial relationships between objects such as adjacency and connectivity. Topology describes how points, lines, and polygons connect and relate to each other.

Coordinate Geometry. Coordinate geometry (COGO) is a form of data input whereby bearings, angles, distances, and various curve parameters are used to determine the locations of property corners and boundaries within the GIS. COGO relies on explicit verbal descriptions such as Metes and Bounds surveying.

Geocode. A geocode is a unique geographic identifier that is assigned to both a map feature and its related attribute data record. With respect to GIS software, geocoding is the process of identifying the coordinates of a location by inputting its street address.

Georeference. To georeference is to establish the relationship between the coordinates of an object in a spatial database and its real-world coordinates. When performed on independent spatial data layers, georeferencing allows the disparate layers to be overlaid according to their true relative positions.

Rectification. Rectification is the process of converting the coordinates of each pixel in an image to their real-world coordinates. During the process of rectification, the computer will resample the original image and create a new image with a different orientation and scale.

Rubber Sheeting. Rubber sheeting is a GIS procedure that adjusts (stretches and compresses) features in one data set to approximately match same or coincident features in another. The process works in a non-uniform manner by causing features in one area to shift in a certain direction while features in other areas shift differently, hence, the term, 'rubber.'

LITERATURE REVIEW

Background information relating to this research consists of various articles and documents such as peer-reviewed literature, trade magazines, documents from government and private agencies, and texts. It has been categorized into three general areas: 1) issues of competency and data quality, 2) standards and recommendations, and 3) issues regarding GIS data management, functions, and applications.

COMPETENCY AND DATA QUALITY

The role of local government is to make decisions in the public interest. As a local government begins to rely on information gained from a GIS, a number of these decisions will no doubt be altered. It is expected that the foundation of such decisions is sound, accurate data, and that the effect will be toward the positive. Technology, however, has seemed to make possible accurate and cost-effective geographic measurements by almost anyone capable of reading a user's manual. However, it should be rather obvious that merely obtaining a measurement from some sophisticated machine does not necessarily produce reliable information.

The influx of GIS practitioners into the field of land information has caused much alarm within the surveying community. The concern stems from the belief that only those licensed to practice land surveying are qualified to construct and modify GIS base map data. The main issue is the competency of the individual to provide accurate information.

WHO WILL CONTROL THE GIS?

On July 31, 1998, the California Board for Professional Engineers and Land Surveyors passed Policy Resolution: #98-03 (Resolution 98-03) regarding the practices of Land Surveying and Civil Engineering related to GIS and LIS. The Resolution proposed changes to California State Law that would restrict the creation and update of subdivision data in a GIS to only licensed land surveyors or registered civil engineers authorized to practice land surveying. The verbiage of the Resolution is contained in the article, "Who Will Control the GIS?" in which Henstridge describes the basic procedures involved in "geobase" (spatial database) development and asserts the critical nature of the process. In short, he defines the spatial database construction procedure as "work done by a professional land surveyor."[24]

Two articles in particular provide interesting responses to the debate regarding the authoritative control of spatial database construction. Both articles make the distinction between creating cadastral or survey data and using the data to make illustrations. In the first, "Fuzzy Data or Split Hairs? Exploring the Need for Surveyors in Developing GIS Base Maps," Joffee and Johnson perpetuate the debate for the purpose of an amicable solution.[25] The authors pose questions regarding such issues as appropriate GIS accuracy, the responsibilities of GIS professionals, and the legal responsibilities of land

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[24] Fred Henstridge, "Who Will Control the GIS?" *Professional Surveyor* 19, no. 10 (1999): 46.

[25] Bruce Joffee and David Paul Johnson, "Fuzzy Data or Split Hairs? Exploring the Need for Surveyors in Developing GIS Base Maps," *Geo Info Systems* 9, no. 1 (1999): 39-45.

surveyors. In the process, they propose a separation of responsibilities between GIS professionals and surveyors as a logical and reasonable resolution.

In the second article, "Is the Sky Really Falling?" Zimmer responds to the proposed changes to the National Council of Examiners for Engineering and Surveying (NCEES) Model Law.[26] The Model Law is a document prepared by the NCEES, which is intended to be a reference for the states to amend existing laws and prepare proposed laws regarding surveying activities and licensure.[27] Zimmer's response is to a document titled, "GIS/LIS Addendum to the Report of the Task Force on the NCEES Model Law for Surveying," in which the authors define more clearly those activities that fall under the practice of surveying and those that do not.[28]

Zimmer, a local government GIS Coordinator and licensed land surveyor, recognizes the concern within the GIS community that a strict interpretation of the preamble of the Model Law would require that GIS/LIS activities be performed under the direction of a licensed land surveyor. He does not however support any changes to the existing verbiage of the Model Law.

Recently, various professional organizations have begun to seriously discuss the issue of GIS certification. The goal of certification is to insure that individuals involved in public-related GIS activities are qualified to do so without endangering the health,

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[26] Rj Zimmer, "Is the Sky Really Falling?" *Professional Surveyor* 21, no. 5 (2001): 38-39.

[27] National Council of Examiners for Engineering and Surveying, *NCEES Model Law* [on-line] (1999); available from http://www.asprs.org/NCEES_Model_Law.html; Internet.

[28] National Council of Examiners for Engineering and Surveying, *GIS LIS Addendum to the Report of the Task Force on the NCEES Model Law for Surveying* [on-line], (October 20, 2000); available from http://www.acsm.net/gislisreport.pdf; Internet.

safety, or welfare of those who rely on their services. "GIS Certification, Professional Cultures, and the ISO" discusses this development and the role played by the major professional groups involved.[29] (ISO stands for International Organization for Standardization.) Obermeyer recognizes that the marked increase of GIS users in the 1990s has "increased the need for a systematic means to assess the qualifications of GIS practitioners."[30]

One might interpret the debate over Resolution 98-03 and GIS certification in a number of ways. On one hand, the concern might simply be a matter of power, job security, and intellectual pomposity. On the other hand, the dispute could stem from a genuine concern for quality of work. Proponents of the Resolution express their concern for the safety and welfare of individuals whose lives may be affected by the misplacement of an entity on a map or in a database. Opponents argue that maps and entities within a spatial database are merely depictions to provide geographical references, and are not to be construed as the final word regarding policy and law.

Zimmer implies that the rift between GIS professionals and surveyors is the result of a lack of understanding "about each other's roles in information gathering and mapping."[31] An article written by James Donahue in 1988, "Land Base Accuracy: Is it Worth the Cost?" perhaps illustrates how this came to be. Donahue begins his article by stating that, for GIS, accuracy determines the extent of possible applications, and that the

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[29] Nancy Obermeyer, "GIS Certification, Professional Cultures, and the ISO?" *ACSM Bulletin*, no. 185 (May/June 2000), 21.

[30] Ibid., 24.

[31] Zimmer, 39.

problems arising from inaccuracy "have largely gone ignored or have been denied by the GIS community."[32] He continues by pointing out the difference between the coordinate systems of maps and cadastral surveys, and that reconciling the two is a difficult and sometimes impossible endeavor. According to Donahue, many professionals with backgrounds other than surveying and mapping do not understand the fundamentals of coordinate systems enough to make this happen.

An important lesson here is that the conversion process between map and real-world information into digital data is no simple task. There are many issues to resolve—some expected, and many unexpected. Indeed, if lives and interests are affected by government decisions that are based upon knowledge derived from a GIS, it behooves those individuals involved to become competent at their craft.

DATA QUALITY

Because of the ability of a GIS to enlarge spatial data output beyond the scale of the original map and the probability that someone will use the data for purposes not intended by the developer, reporting and understanding the quality of data has become a necessity. In his text, *Geographic Information Systems: a Management Perspective,* Aronoff devotes an entire chapter to the discussion of data quality. He groups the components of data quality into three categories: micro level components, macro level components, and usage components.[33]

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[32] James G. Donahue, "Land Base Accuracy: Is it Worth the Cost?" in *ACSM Bulletin*, no. 117 (July 1988), 25.

[33] Aronoff, 135-141.

Micro level components pertain to the quality of individually collected data elements. These components are generally evaluated by statistical testing against independent data sets of higher quality. Micro level components consist of:

- Positional accuracy
- Attribute accuracy
- Logical consistency
- Resolution

Macro level components pertain to an entire data set. They are evaluated by subjective judgment and by metadata reporting. Macro level components consist of:

- Completeness
- Time
- Lineage

Usage components are factors that are specific to the resources of the organization such as accessibility to and the cost of obtaining the data. Usage components of data quality allow one to evaluate whether or not a data set is worth the cost of obtaining.

The State of Minnesota has published on the Internet the *Positional Accuracy Handbook, Using the National Standard for Spatial Data Accuracy to Measure and Report Geographic Data Quality.*[34] The *Handbook* explains the national standard for data quality according to the National Standard for Spatial Data Accuracy (NSSDA).

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[34] Minnesota Planning, Land Management Information Center, *Positional Accuracy Handbook, Using the National Standard for Spatial Data Accuracy to Measure and Report Geographic Data Quality,* [on-line] (October, 1999); available from http://www.mnplan.state.mn.us/pdf/1999/lmic/nssda_o.pdf; Internet.

The NSSDA describes a method by which to measure and report the positional accuracy of features in a spatial data set. The components of data quality according to the *Handbook* are inline with those of Aronoff. Specifically, data quality consists of positional accuracy, attribute accuracy, logical consistency, completeness, and lineage.

In *Principles of Geographical Information Systems*, Burrough and McDonnell devote a chapter to the discussion of errors and quality control. In their context, the term 'error' is broadly defined to include faulty information as well as statistical uncertainty and spatial variation. With that in mind, they discuss the various factors affecting the quality and reliability of spatial data, and examine the blunders that occur from assumptions regarding spatial exactness.[35]

The notions of data quality and data reliability can be somewhat confusing. It appears that the authors' perception of data quality is in accordance with Aronoff's categorization of micro level and macro level data quality components, and that data reliability roughly coincides with Aronoff's usage components. According to Burrough and McDonnell, the factors affecting spatial data quality are:

- Currency (Is the data up to date?)
- Completeness (Is the coverage area partial or complete?)
- Consistency (Are the data layers consistent with one another?)
- Accessibility
- Accuracy and Precision

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[35] Peter A. Burrough and Rachael A. McDonnell, *Principles of Geographical Information Systems* (New York: Oxford University Press, 1998), 222-239.

- Sources of errors

The factors affecting spatial data reliability are:

- Age of data
- Areal coverage
- Map scale and resolution
- Density of observations
- Data format, data exchange, and interoperability
- Costs and copyrighting

Other articles address the specific issues (or a combination thereof) listed above. "Cadastral Overlay: Ontological Accuracy," by David W. Clark delves into the land tenure system unique to the United States, and suggests that surveyed cadastral boundaries are 'fuzzy' until legally determined by the Courts.[36] (Ontology is the study of the nature of existence.) Clark identifies the legal document as the basic unit of the cadastral layer, and stresses the importance of accurately relating the social information from the cadastre to environmental data.

Onsrud and Hintz warn about giving the false impression of accuracy when hand-drawn tax maps only are used as the basis for the cadastral layer. The authors assert that the database must be "legally supportive" insomuch that "the land ownership database

[36] David W. Clark, "Cadastral Overlay: Ontological Accuracy," in *Geographic and Land Information Systems for Practicing Surveyors: A Compendium*, ed. Harland J. Onsrud and David W. Cook (Bethesda, MD: ACSM, 1990), 99-110.

should be based upon the documents the legal profession will resort to in the event that conflicts between adjoining parcels arise."[37]

Goodchild writes about the uncertainty of the database that uses binary digits to create an approximation of real-world phenomena. Uncertainty, according to Goodchild, "has emerged as the preferred term for all that the database does not capture about the real world, or the difference between what the database indicates and what actually exists out there."[38] He describes some of the forms of uncertainty such as positional inaccuracy and errors, and stresses the importance of related metadata.

The quality of data within a GIS is easy to overlook—especially in areas unfamiliar to the developer of the data set. Often, it is only when individuals subjectively examine a GIS product (such as a map) that poor data quality is discovered. At best, these situations can be grouped into life's most embarrassing moments. At worst, undocumented errors and poor data quality can result in disastrous consequences.

Standards and Recommendations

In 1953, the U. S. Bureau of Budget issued Circular A-16 for the purposes of directing surveying and mapping activities toward meeting the needs of Federal and State governments and the general public and ensuring that these activities will be performed

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[37] Harlan J. Onsrud and Raymond J. Hintz, "Upgrading Boundary Information in a GIS Automated Survey measurement management System," in *Geographic and Land Information Systems for Practicing Surveyors: A Compendium*, ed. Harland J. Onsrud and David W. Cook (Bethesda, MD: ACSM, 1990), 129.

[38] Michael F. Goodchild, "Uncertainty: The Achilles heel of GIS?" *Geo Info Systems* 8, no. 11 (1998): 50.

expeditiously and without duplication of effort.[39] (In 1967, the Bureau of Budget was changed to the Office of Management and Budget (OMB), and became a member of the Cabinet of the President.) The theme of efficiency and data sharing has pervaded the various revisions of Circular A-16 as well as newly created standards documents in the years since. The second revision of the Circular, in October 1990, expanded the applicable mapping activities to include those related to digital spatial data. Beginning in the 1990s, the facilitation of data sharing provided by the Internet has made the importance of standards self-evident.

THE COMMITTEE ON GEODESY

In 1980, the Committee on Geodesy of the National Research Council (NRC) determined that, "there is a critical need for a better land-information system in the United States to improve land-conveyance procedures, furnish a basis for equitable taxation, and provide much-needed information for resource management and environmental planning."[40] The Committee identified land resource-related problems faced by local organizations, and outlined the nature of a multipurpose cadastre as a means of remedy. In so doing, they emphasized the establishment of local governments as the primary access points of local land information to be disseminated to higher levels

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[39] Federal Geographic Data Committee, *Revised OMB Circular A-16: Appendix C. History and Background of Circular A-16* [on-line], (July 3, 2001); available from http://www.fgdc.gov/publications/a16final.html#appendixc; Internet.

[40] Panel on a Multipurpose Cadastre, Committee on Geodesy, Commission on Physical Sciences, Mathematics, and Resources, National Research Council, *Need for a Multipurpose Cadastre* (Washington, DC: National Academy Press, 1980), 1.

of government when needed.[41] The resulting publication, *Need for a Multipurpose Cadastre*, outlined the various needs and requirements of local governments with regard to reforming their land records procedures.

To guide the reformation process, the NRC published *Procedures and Standards for a Multipurpose Cadastre* in 1983. First, the authors defined the basic components of a cadastre, which are:

- A spatial reference framework consisting of geodetic control points
- A series of current, accurate, large-scale base maps
- A cadastral overlay that delineates all cadastral parcels and displays a unique identifying number for each
- A series of compatible registers of interests in land parcels keyed to the parcel identifier numbers

Second, they stressed the importance of maintaining these components in such a manner that multiple layers of data may be accurately overlaid and their records linked.[42] The report covers such topics as geodetic survey networks, base mapping, and land parcel records.

Revised Circular A-16 and the Federal Geographic Data Committee

The ideas set forth in *Procedures and Standards* led to the 1990 revision of *Circular A-16: Coordination of Surveying, Mapping, and Related Spatial Data Activities* by the OMB. A major objective of the revision was to develop a national digital spatial

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[41] Panel on a Multipurpose Cadastre, Committee on Geodesy, Commission on Physical Sciences, Mathematics, and Resources, National Research Council, *Procedures and Standards for a Multipurpose Cadastre* (Washington, DC: National Academy Press, 1983), 7.

[42] Ibid., 1.

information resource (with the involvement of Federal, State, and local governments) to enable sharing of spatial data between producers and users. The 1990 Circular also called for the creation of the Federal Geographic Data Committee (FGDC) to head the process of developing the necessary standards.[43]

The FGDC is an interagency committee composed of representatives from 17 Cabinet level and independent Federal agencies. As previously mentioned, it was organized for the specific purpose of promoting the coordinated use, sharing, and dissemination of geospatial data on a national basis. Various subcommittees have been organized to specifically address and develop the standards for such issues as base cartographic data, cadastral data, geodetic control, transportation, and demographics.[44] The FGDC is generally headed by the current Secretary of the Interior.

Executive Order 12906 and the NSDI

The result of the above publications was the issuance of Executive Order 12906, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure."[45] EO 12906 directed the FGDC to implement the National Spatial Data Infrastructure (NSDI) to "support public and private sector applications of geospatial data in such areas as transportation, community development, agriculture emergency response, environmental management and information technology." The NSDI was defined by EO

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[43] Office of Management and Budget, *Circular A-16: Coordination of Surveying, Mapping, and Related Spatial Data Activities* [on-line], (October 19, 1990), available from http://www.whitehouse.gov/omb/circulars/a016/a016.html; Internet.

[44] Federal Geographic Data Committee, *FGDC Organization* [on-line], (June 21, 2002), available from http://www.fgdc.gov/fgdc/fgdc.html; Internet.

[45] Executive Order 12906 may be viewed at http://www.fgdc.gov/publications/documents/geninfo/execord.html

12906 as the set of policies, standards, and human and technological resources designed to foster data sharing within and among various organizations.[46] The implementation of the NSDI directed the FGDC to develop the following:

- A National Digital Geospatial Framework (Framework) consisting of essential GIS base data—geodetic control, orthoimagery, transportation, cadastral, hydrography, elevation, and governmental units.
- Spatial data accuracy and content standards (Standards) to facilitate the sharing of data between all public and private agencies, and across State and local boundaries.
- A Geospatial Data Clearinghouse (Clearinghouse) to disseminate data to users.
- Standardized documentation of spatial data sets (Metadata) to help users determine the usefulness of available data.

THE GUIDEBOOK

In response to the flood of local governments adopting GIS technology, the Federal Geodetic Control Committee (FGCC) published *Multipurpose Land Information Systems: the Guidebook*. *MPLIS: the Guidebook* was designed to acquaint the reader with the various issues involved in developing an MPLIS at the local level. It presents the various subjects involved in MPLIS implementation, segregated by chapter, which are written by respected specialists in each field. With respect to topics in information technology, some of the writings are somewhat dated, however, the FGCC offers free updates as they occur.

Increasingly, State GIS committees are publishing their own local government GIS guidelines and recommendations. Some are tailored versions of *MPLIS: the*

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[46] President, 17671.

Guidebook, whereas others are compilations from other sources. Each reflects the specific laws and bureaucratic nature of the individual State government and are generally available on the Internet. Hard copy versions can also be obtained by contacting the appropriate source.

Notable examples of the States that have adopted specific GIS guidelines are New York, Nebraska, and Minnesota. Following is a list of these State documents and their associated Internet addresses:

- "New York State Archives Local GIS Development Guides," available from http://www.archives.nysed.gov/pubs/gis/gisindex.htm
- "Nebraska Guidebook for a Local Government Multipurpose Land Information System," available from http://www.calmit.unl.edu/gis/LIS_Stds_Intro.html
- "Implementation Guide for Parcel-Based GIS in Minnesota Local Government," available from http://www.gis.state.mn.us/iisac/gisindex.html

GIS Data Management, Functions, and Applications

GIS Data Management

The implementation process of a MPLIS is much akin to the Federal Government's vision of implementing the NSDI whereby each of the four elements of the NSDI is equally necessary for a successful MPLIS. For example:

- NSDI Framework: A MPLIS spatial database requires a solid foundation of the most commonly used base map layers.
- NSDI Standards: Collecting, maintaining, and displaying information must be done according to some predefined set of standards.
- NSDI Clearinghouse: Data must be logically and efficiently stored, and easily disseminated to all users.
- NSDI Metadata: Users need to know the quality and applicability of all information made available to them.

The GIS data management issues that pertain to this research include data collection, database construction, data maintenance, and documentation. There are certainly more issues than these to consider when one implements an enterprise-wide information system—such as analysis, modeling, and output. However, the concern here is the construction of the foundation by which better analysis and output may be achieved.

GIS versus MPLIS. It is necessary at this time to reinforce the difference between GIS and Multipurpose Land Information Systems. For the most part, traditional GISs have historically been built upon spatial data taken from map information at scales of 1:24,000 or smaller, covering relatively large areas of interest. (These include USGS topographic maps, USDA Forest Service forest visitor maps, and BLM land status maps.) The focus of the systems was specific projects and related analyses dealing with a particular snapshot or limited period in time.

Many maps used by local governments, however, are of considerably large scale, and are continually modified and updated. This is because local governments are required to meticulously track the day-to-day land transactions that occur within their jurisdiction. As Epstein and Brown put it, "the term *land information system (LIS)* conveys a stronger orientation toward land records and a larger scale than the term *GIS* does."[47] The authors regard a MPLIS as a system in which the cadastral parcel becomes the fundamental, proprietary land unit, and the main objective is to provide detailed

[47] Earl F. Epstein and Patricia M. Brown, "Introduction to Multipurpose Land Information Systems, Chapter 1," in *Multipurpose Land Information Systems: the Guidebook*, (Silver Springs, MD: FGCC, 1992), 1—5.

information concerning land ownership, land value, and land use.[48] Furthermore, the authors assert that an automated MPLIS "reflects our need to make that information available for record-keeping, public inquiries, analysis, and decision-making.[49]

A final note to reinforce the point: Meltz states, "a LIS has the capability of serving as a GIS. But a system that is designed to function as a GIS may not have the capability to serve as a LIS." He lists three conditions that must be present if an information system is to be classified a LIS. These conditions are:

- The text/graphic output is primarily related to an aspect of a cadastral map base.
- The lowest common cartographic unit is the cadastre land parcel.
- The cadastral attributes are used to define the database architecture.[50]

Once again, the topic of this research concerns the practical aspect of collecting and managing the geographical data necessary to support the functions of a local government MPLIS. The discussion that follows is a brief introduction to some of the spatial data management issues that apply to this endeavor.

Spatial Database Design and Construction. It is important to draw the distinction between assembling a spatial database and merely storing spatial data in a computer. The organization of a database should be such that sophisticated queries and analyses can be performed on the data. This, of course, is next to impossible without a logically and

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[48] Ibid., 1—6.

[49] Ibid., 1—7.

[50] Samuel J. Meltz, "Georgia's Future Land Information System," in *Geographic and Land Information Systems for Practicing Surveyors: A Compendium*, ed. Harland J. Onsrud and David W. Cook (Bethesda, MD: ACSM, 1990), 51.

efficiently designed database. Because of individual institutional requirements and such, the ideal spatial database might be difficult to identify. However, a poorly designed database is readily apparent. More often than not, it takes the form of ambiguously named files scattered throughout the various storage media of the organization—the relations of which are known only to the creator.

The GIS guidelines and recommendations mentioned earlier devote a substantial portion to database design. In the *MPLIS, the Guidebook*, for instance, Von Meyer writes about the necessary elements of designing a database for a MPLIS, and specifically discusses the individual phases of the design process: the conceptual, the logical, and the physical.[51] (These phases will be discussed in Chapter IV, Developing the Database.) New York's *GIS Development Guide* contains two chapters that address the planning, design, and construction of the database. Of special note in *GIS Development Guide* is that database planning and design involves defining how the spatial and attribute files are to be structured, how files and directories will be named, how the geographic area will be subdivided, and how the GIS products will be presented.[52]

Environmental Systems Research Institute, Inc. (ESRI) publishes a number of books regarding GIS issues specifically related to their software products. (ESRI is the maker of the popular GIS applications, ARC/INFO, ArcView, and MapObjects.) *Modeling Our World, the ESRI Guide to Geodatabase Design* presents the GIS database

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[51] Nancy von Meyer, "Database Design, Chapter 25," in *Multipurpose Land Information Systems: the Guidebook,* (Silver Springs, MD: FGCC, 1992), 25—3.

[52] New York State Archives and Records Administration, "Database Planning and Design," in *Geographic Information Development Guides, Volume III,* (Albany, NY: NARA, 1996), 24.

concepts used in developing and using their new object-oriented "Geodatabase." In particular, the publication delves into the various geographic computer models that have been developed to depict the world's complicated geography. The Geodatabase is ESRI's attempt to combine spatial data models with the many tables present in commercial relational database systems. More importantly, it is intended to provide the ability to endow geographic features with natural behaviors such as the flow of a stream or the nature of a highway overpass.[53]

Spatial Data Collection. Collecting spatial data involves translating geographic information into computer form. This process is referred to as data input—the procedure of encoding data into a computer-readable form and writing the data to the GIS database.[54] Nowadays, spatial data input consists of manual digitizing, scanning, automated digitizing (vectorization), coordinate geometry (COGO), GPS methods, and converting existing data. None of these procedures is necessarily superior, although certain situations will dictate which one is more appropriate. For example, car-mounted antennae and fast-moving vehicles facilitate collecting road data with a GPS receiver whereas slippery rocks, cold water, and thick brush make collecting stream data by GPS an expensive proposition. Factors to consider when choosing a collection method include the type of feature being collected, the source material of the information (maps, deeds, etc.), budget and time constraints, and accuracy requirements.

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[53] Michael Zeiler, *Modeling Our World, the ESRI Guide to Geodatabase Design*, (Redlands, CA: ESRI Press, 1999), 5.

[54] Aronoff, 103.

Of the collection methods previously listed, converting existing data is often regarded as the most economical. In "Looking for the Best Data Sources," Robert Hoch discusses some of the sources of digital spatial data. According to Hoch, the data comes in two varieties: free and not free. He urges the reader to think carefully about what is needed before purchasing data, and to realize that the cost of data is in proportion to the level of effort required to produce it.[55]

Spatial Data Maintenance. Maintaining spatial data involves making corrections or updates to the database as changes in the real world occur, or when information that is more accurate is obtained. The State of New York has found that, "usually, the effort required to maintain the database is as much as, or more than that required to create it."[56]

An important characteristic that distinguishes a MPLIS from a project-oriented GIS is that, with a MPLIS, data maintenance is required on almost a daily basis. With that in mind, it is essential to stress the concept of data integrity. According to Von Meyer, data integrity means that if an attribute value is changed in one place, such as in a table of values, then all other occurrences of that attribute value for that record must also change.[57] This, of course, highlights the importance of the centralized corporate-wide database.

Important to this discussion is the concept of data integrity applied to the actual spatial features in the database. *ARC/INFO Data Management* discusses the notions of

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[55] Robert Hoch, "Looking for the Best Data Sources?" *GEOWorld* 13, no. 4 (2000): 45.

[56] New York State Archives and Records Administration, 35.

[57] Von Meyer, 25—12.

spatial relationships and topology.[58] A spatial relationship is merely the relationship between geographic features based on their location—something that we humans are able to implicitly interpret from reading a map. For instance, from looking at a map, one can instinctively determine which features are connected to, adjacent to, and near others.

Computers, however, do not possess the intelligence of humans, and need to be unambiguously told about the spatial relationships between points, lines, and polygons. Topology is the means by which these spatial relationships are explicitly defined. The importance of a topological association is equal to that of tabular data integrity inasmuch that when the boundary of a particular parcel is updated in the database, all other features that coincide with that parcel boundary should automatically update as well.

Documentation. Recall that metadata is the information that describes the characteristics of features in a GIS database—the data about the data. The FGDC has published the *Content Standard for Digital Geospatial Metadata* to help users find and evaluate data. According to the FGDC, the objectives of the standard are to "provide a common set of terminology and definitions for the documentation of digital geospatial data."[59] As well, the FGDC offers tools and applications to help one develop metadata according to the accepted standards.

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[58] ESRI, *ARC/INFO Data Management, Concepts, Data Models, Database Design, and Storage* (Redlands, CA: ESRI Press, 1994), 1-1 - 1-48.

[59] FGDC, *Content Standard for Digital Geospatial Metadata* [on-line], (June 26, 2002), available from http://www.fgdc.gov/metadata/contstan.html; Internet.

GIS APPLICATIONS

As mentioned earlier, the broad categories of functions that are enhanced by GIS are: browsing information, custom display, data query, data maintenance, and analysis and modeling. Performing specific functions within these categories constitutes an application of GIS. Huxhold defines an application as "a use of a computerized information system that can be repeated more than once, with different data."[60] In a typical organization, this can be as simple as browsing information from a map hanging on a wall or as complex as modeling traffic flow with a specialized computer program. Following are brief descriptions of several common applications of GIS.

Thematic Classification. A thematic map is designed to display one or two themes of information. The objective is to present the overall distribution and relationship of a chosen feature. An example is a map of land use. One wishing to analyze the distribution of land usage would symbolize each land parcel according to a land-use code as determined by the Tax Assessor. Roads, streams and certain administrative boundaries may be included in the map to give the reader a frame of reference.

Robinson, et al, devote a substantial section of *Elements of Cartography* to the subject of cartographic abstraction, which addresses such topics as map selection and generalization, thematic classification, symbolization, and statistical surface portrayal.[61] Understanding and incorporating these issues are necessary to avoid confusing the map-

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[60] Huxhold, 313.

[61] Robinson, et al, 447 – 566.

reader with too many details and complexity. To ensure the ability to display geographic features according to some thematic classification, the associated database records might be assigned one or more classification codes. For instance, ownership parcels would contain fields of information that would signify land-use, owner type, and assessed value. Roads would include attribute values for surface type, surface condition, easement width, or even speed limit.

Reapportionment. After each decennial census, State and local governments are required by law to redefine the boundaries of the political districts in their jurisdiction. These districts include Commissioner and State House and Senate districts, which are to be delineated according to population. In *Introduction to Urban Geographic Information Systems*, Huxhold describes how GIS was used to efficiently and accurately determine new alderman district boundaries in Milwaukee, Wisconsin.[62] In short, a manual task that cost the city approximately $60,000 in 1970 was replaced in 1980 by a GIS process that was completed in less than half the time, with fewer people, and at a cost of $24,000. After the 2000 Census, ESRI released a custom extension for ArcView 3.2 designed specifically for reapportionment.

Enhanced-911. Local telephone companies are the providers of 911 emergency telephone services. In an area with basic 911 services, an emergency call is routed to the local dispatch center—now called the Public Safety Answering Point (PSAP)—where an individual answers the call and responds by contacting the appropriate emergency response team. Other than perhaps the telephone number of the caller (provided by a

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[62] Huxhold, 79 – 83.

special Caller-ID module), the dispatcher is given no further information regarding the source of the call beyond that provided by the caller.

Enhanced-911 (E-911) is a service that provides not only the telephone number of the caller, but also the name of the owner, the address location of the telephone service, and the appropriate emergency response agency. The telephone number of the caller is first displayed then, within a few seconds, the owner and location information is displayed. Because this information is made immediately available to the dispatcher, response time and the confusion that normally accompanies emergencies is significantly reduced.

The technology that makes the E-911 marvel possible consists of a Computer Aided Dispatch System and a Master Street Address Guide (MSAG) database. Of special importance is the MSAG database, which is merely a tabular record of all road names within a jurisdiction and their associated attributes such as address range, community, and Emergency Service Zone (ESZ). An ESZ is that area defined by the unique combination of ambulance, law, and fire districts. ESZ information is critical to an E-911 system because it indicates which agency is to respond to which type of emergency at any given address.

Literature pertaining to E-911 is becoming increasingly prevalent with the spread of "on-line systems" throughout the country. Often, when a government agency is finally able to implement a successful system, the major individuals involved in the project will publish a paper describing the process. The authors will not only tout the successes and benefits of the system, but will also describe the painful processes of coordinating the efforts and of converting and gathering the necessary data as well. These reports are of considerable value.

In 1992, officials from Orange County, New York authorized the development of a GIS-based E-911 system and began the project in October 1993.[63] The account of this project describes how the necessary maps were developed, how the MSAG was developed, and the coordination efforts involved in presenting the final product.

In 1996, another E-911 project was begun in Garrard County, Kentucky. In this project, the participants were determined to integrate their common needs such as tax assessment, emergency response, and miscellaneous mapping.[64] Although Garrard County was relatively small (7,500 parcels), the project demonstrated that multiple departments and agencies could benefit from data generated primarily for E-911 mapping purposes.

A thorough presentation relating GIS, emergency response, E-911, and associated database issues was given by Marc Berryman at the ESRI User's Conference in July 2001.[65] Referred to as the Houston Public Safety GIS Project, a number of agencies came together to produce a single spatial database to be used for E-911 and various other

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[63] David P. Washburn, James Beaumont, and Simon L. Gruber, "Orange County, New York's Enhanced-911 System Helps Residents Breathe Easier," *Geo Info Systems* 8, no. 11 (1998): 28 – 34.

[64] Ron Householder and Nick Kearney, "Garrard County, Kentucky-Integrated Solutions: The Tax Assessor, E911, GPS, and GIS," *URISA 1999 Annual Conference Proceedings*, (Chicago)1999.

[65] Marc E. Berryman, "Using GIS in Public Safety – Reducing Emergency Response Time," *ESRI's User's Conference*, [on-line], (July 2001), available from http://www.esri.com/library/userconf/proc01/professional/papers/pap308/p308.htm; Internet.

public safety needs. Berryman's presentation provided specific details regarding the necessary standards, the development of spatial data, and the development of the MSAG.

A missing dimension in the GIS-related literature is the connection between the actual functions of local government, the uses of GIS, and the issues of MPLIS implementation. If a local government is to partake of the benefits afforded by GIS, then the system must adapt and integrate with existing technology, staff, and operations. This discussion is intended to help fill this gap by focusing on the construction of the spatial database of a multipurpose, enterprise-wide land information system.

III. METHODOLOGY

The culmination of this research was the construction, evaluation, and discussion of a realistic pilot study project for a local government MPLIS. The procedures involved were intended to logically achieve the completion of the pilot study. Specifically, the methods of this research consisted of the following:

- A review and summary of available Federal and State guidelines regarding the implementation of a MPLIS
- Personal interviews of specialists involved with local government GIS programs
- A partial Information Needs Assessment of Ravalli County, Montana
- A limited pilot study of the PLSS Township T10N, R20W, P. M. M.

The GIS hardware and software products used in this research include a Trimble GeoExplorer II GPS receiver, a Trimble ProXR GPS receiver, and ESRI software products.

A Review of the Guidelines

Previously discussed was the recognition by the NRC of the need for a better system of land recording in the United States, which was voiced in *Need for a Multipurpose Cadastre*. Shortly thereafter, *Procedures and Standards* was published to guide the implementation process of such a system. These initial recommendations eventually disseminated through the chain of governmental bureaucracy and became adopted and modified by various State and local institutions. The applicable published standards and guidelines that were discovered during the course of this research included:

- Standards documents published by the FGDC

- *Procedures and Standards for a Multipurpose Cadastre*, published by the NRC
- *Multipurpose Land Information Systems: the Guidebook*, published by the FGCC
- *Local Government GIS Development Guides*, published by the New York State Archives and Records Administration
- *Nebraska Guidebook for a Local Government Multipurpose Land Information System*, published by the Nebraska Advisory Committee on Standards for Multipurpose Land Information Systems

THE INTERVIEWS

Many local governments throughout the United States have established GIS programs with varying degrees of success. Some GIS departments have fully integrated their data and applications with other departments, and others consist of one or two mapping technicians creating products for ad-hoc requests. Managers from selected nearby local governments with mature GIS programs were interviewed in order to discover their unique perspective and advice concerning data collection and the associated caveats. The interviewees included:

- Rj Zimmer (GIS Manager, City of Helena and Lewis and Clark County, Montana)
- Allen Armstrong (GIS Coordinator, Gallatin County, Montana)
- Tom Tully (GIS Manager, Butte-Silver Bow County, Montana)
- Rick Breckenridge (GIS Manager, Flathead County, Montana)

The interview process was an effort to foster an in-depth discussion, and the basic questions were intended to lead the discussion. The following questions were asked:

- Approximately how much of your GIS budget was spent building your database?
- What were some of the major problems encountered as you constructed your database?

- What were the most difficult, costly, and time-consuming procedures of your database construction process?
- What do you consider the most important, or fundamental, base map layers (and why)?
- Which departments require most of your services?
- What measures do you take to ensure the best possible quality and flexibility of data?

THE INFORMATION NEEDS ASSESSMENT

An Information Needs Assessment (INA) is the systematic look at and documentation of the spatial data needs of each department within an organization. An INA was conducted for selected departments of Ravalli County, Montana. The purpose was to systematically document their needs with regards to geographic information and associated applications. The department supervisor was asked to designate the necessary individuals to interview. Individuals from the following departments were interviewed:

- Clerk and Recorder
- Disaster and Emergency Services
- Environmental Health
- Planning Office
- Sheriff
- Volunteer Fire Chiefs

The INA process for each department began with a presentation highlighting the uses and benefits of a GIS, and concluded with personal interviews of selected members from each county department. The data requirements of each departmental function were documented and summarized. The findings of this process were used as a guideline for constructing the pilot study database.

The GIS Presentation

A handout providing an overview of the fundamental uses and benefits of GIS was given to the participating members of each county department. Various examples of basic GIS functions and applications were discussed to demonstrate how each department might benefit from an established system. This was followed by a preparatory discussion of the interview process for the INA. Again, examples were used to inform the participants of the special forms required to document their data and application needs. Each meeting was concluded with a question and answer session.

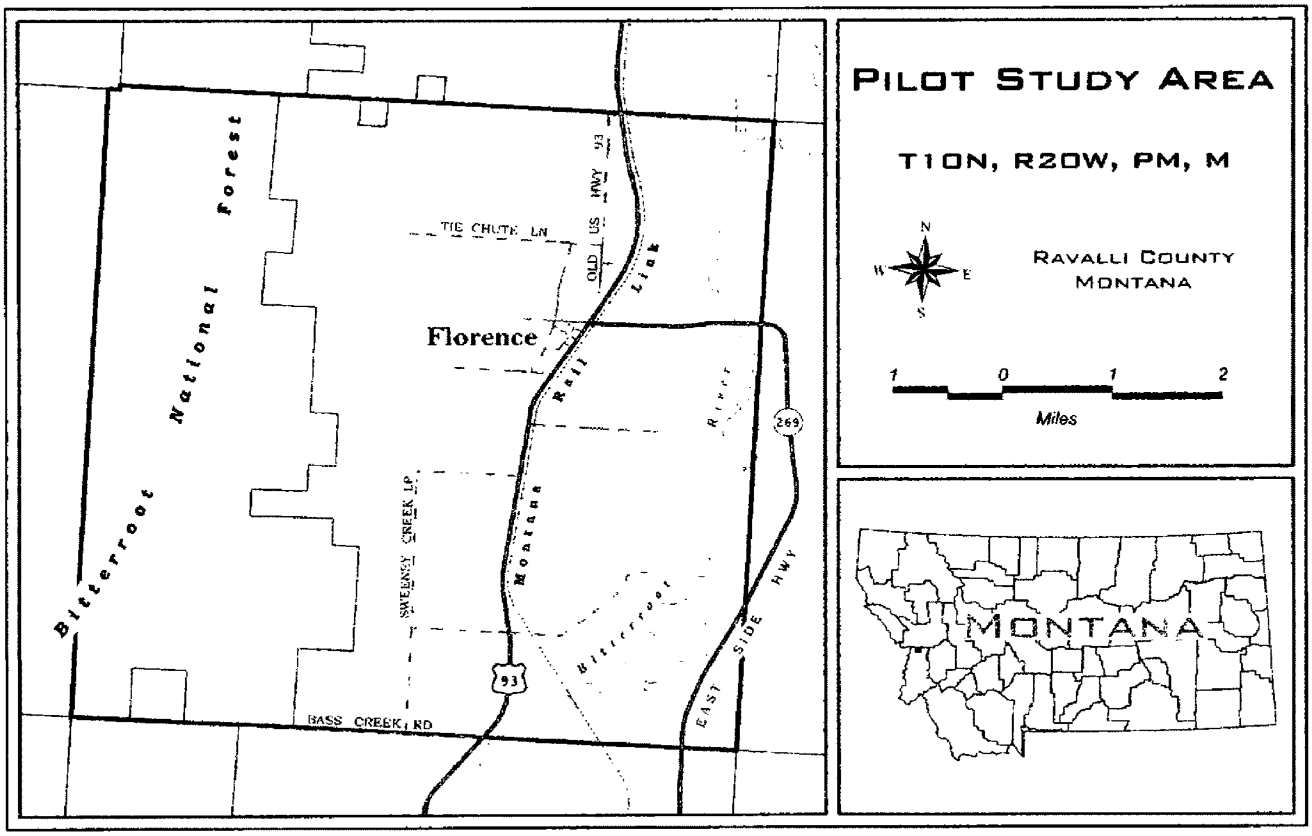
The INA Interviews

After the initial meeting, ample time was allowed for the members to consider the specific applications of their respective departmental functions. A second meeting was scheduled to document their needs using the INA forms. After collecting the INA forms from each member, the information was entered into a master document and summarized. From the summary of all interviews, a data list was generated in which all of the required geographic features and associated attributes were compiled.

The Pilot Study

Normally, a pilot study project is the short-term use of a GIS for a small geographic area to test the planned applications and demonstrate the capabilities of the system to key people in the organization. The scope of this research was such that a complete evaluation of GIS applications and feasibility was not in order. Therefore, a limited pilot study was conducted for the study area. The objectives were confined to creating a sample database, testing the quality of available data sets, and testing the quality of source document conversion. The sample database was limited to the NSDI Framework layer data themes. The area chosen for study was T10N, R20W, PM, M, which is located in the northern portion of Ravalli County in western Montana.

Figure 1 - Map of Pilot Study Area



Spatial data sets were compiled from existing sources and collected by digitizing from existing maps and DOQQs, COGO of Deeds and COSs, and GPS methods. GPS field measurements were made to assess the accuracy of the existing data sets such as the GCDB, the DOQQs, and the various other data layers. All data sets were assembled in the project database and manipulated with ESRI ARC/INFO 8.2 and ArcView 3.2 GIS software. Accuracy assessments are discussed in Chapter IV, Developing the Database.

Existing data was obtained from the U. S. Census Bureau, the BLM, the USDA Forest Service, the Montana Natural Resource Information System (NRIS), and the Montana Department of Administration. All data sets were converted from their native map projection into the Montana State Plane Coordinate System, North American Datum of 1983 (NAD83) before being assembled in the project database.

New data was generated from the methods previously mentioned. All manual, on-screen digitizing was performed with backdrops consisting of DOQQs and rectified aerial photographs. COGO was also used to input cadastral data, which was compared with the same information manually digitized by technicians for the Montana Cadastral Project. Data digitized from the aerial photographs was compared with the same data taken from the DOQQs. GPS point and road data was compared with that contained in the GCDB, the various existing vector data, and the new data digitized from the DOQQs.

All GPS data collected for this project was differentially corrected according to base data obtained from the GPS base station operated by the USDA Forest Service, in Missoula, Montana. The corrected GPS files were then exported as ESRI Shapefiles and stored in the project database. GPS Road data was collected at a one-second logging interval and with an external antenna mounted on the driver's side of the vehicle. Point data was collected with an external antenna mounted on a tripod. Each point feature was measured three times for periods of no less than one minute each. The location of each feature was regarded as the average of the multiple coordinate values.

Compiling Existing Data

What follows are the details of collecting existing data from various sources.

The GCDB

Recall from the Terms and Concepts portion of Chapter II that the GCDB is the digital representation of the geometry of parcels contained within the PLSS. It is assembled and maintained by the BLM using information from all pertinent surveys, field notes, and plats—which distinguishes it from digitized versions of the PLSS. Each data set is constructed, updated, and stored according to township.

GCDB data is available in two formats: raw text files and ESRI Shapefiles. Raw GCDB text files are for use with the BLM's Geographic Measurement Management (GMM) software, which is used to build the GCDB product and adjust the geographic coordinates of the survey corners. GMM is also able to export the raw GCDB data into a format useable with commercial GIS software. ESRI Shapefiles are provided as a service by the BLM to save users the effort of building the GCDB themes. Both data formats were downloaded from the BLM's national GCDB Website.[1]

Orthoimagery

The Montana NRIS was established in 1985 by the Montana Legislature in order to facilitate the sharing of natural resource information. In addition to other information and services, NRIS offers a GIS data clearinghouse for commonly used data, digital maps, and DOQQs covering much of Montana. DOQQs that were produced from 1995 NAPP aerial photography were obtained from the NRIS Website.[2]

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[1] http://www.blm.gov/gcdb/

[2] http://nris.state.mt.us/nsdi/doq.asp

TIGER/LINE FILES

TIGER/Line files are digital vector representations of various geographic features such as roads, streams, and political boundaries. They are produced by the U. S. Census Bureau for census-related mapping activities, and much of the source material for the data comes from the USGS 1:100,000-scale topographic maps. Transportation, hydrography, and PLSS data sets were downloaded from their Website.[3] In order to be brought into the project database, the data was converted from the Census Bureau's format into an ESRI shapefile format.

CARTOGRAPHIC FEATURE FILES

As are TIGER/Line files, Cartographic Feature Files (CFFs) are digital vector representations of geographic features. CFFs however, depict the features that are shown on USDA Forest Service Primary Base Series (PBS) maps. PBS maps are 1:24,000-scale maps constructed from the USGS topographic maps and maintained by the Forest Service's Geospatial Service Center in Salt Lake City, Utah. In addition to that carried on USGS maps, PBS maps contain additional Forest Service information such as general ownership, Forest Service route numbers, and various governmental administrative boundaries and facilities. CFF transportation, hydrography, and PLSS data was obtained from the USDA Forest Service Regional Office in Missoula, Montana.

CADASTRAL

Cadastral data for Ravalli County was produced during the period from 1999 to 2001 under the auspices of the Montana Cadastral Project. During the course of the

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[3] http://www.census.gov/geo/www/tiger/tiger2k/mt/.

project, the data was created by GIS contractors and various State and county GIS technicians. Existing cadastral data for the study area was obtained from the Montana Cadastral Project Website.[4]

Collecting New Data

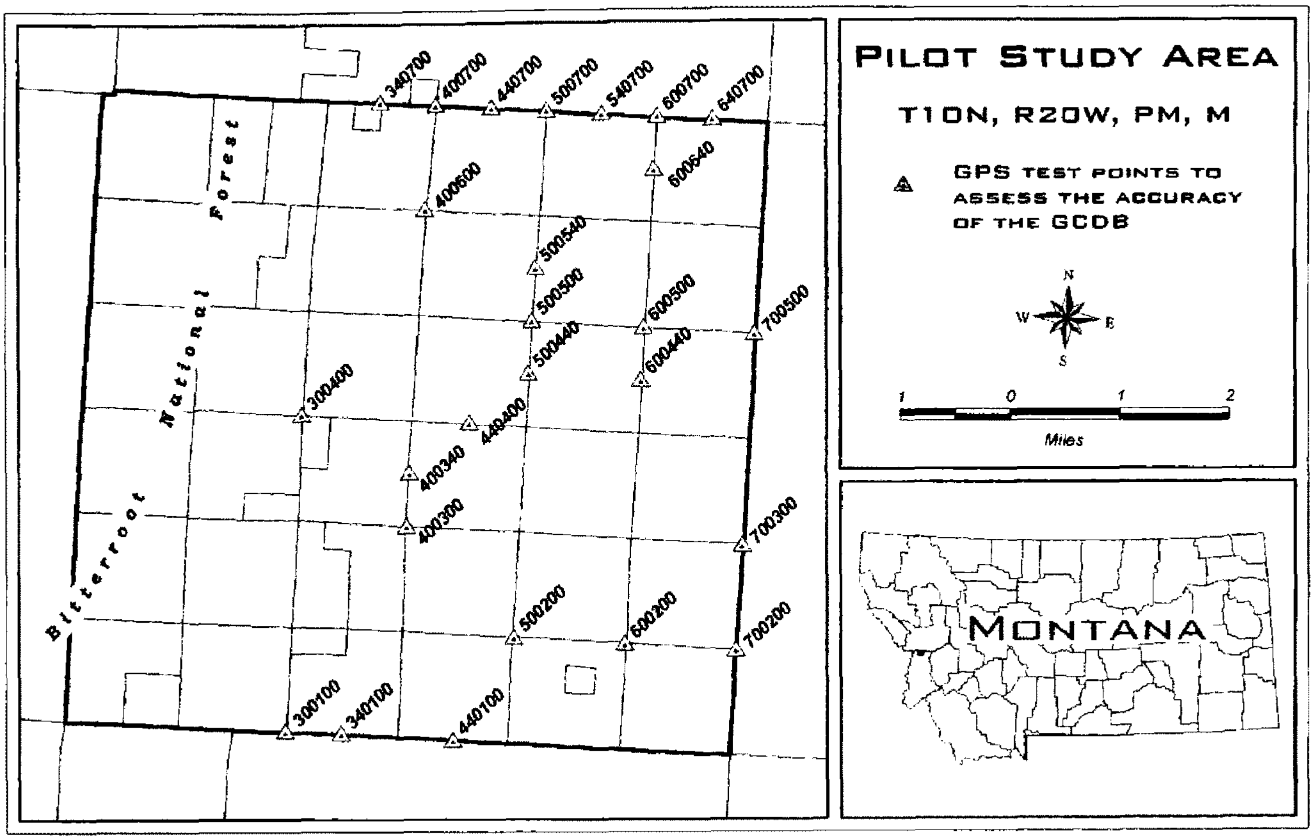
In the cases of cadastral, transportation, and hydrography, new data was generated for this research. In the cases of geodetic control and orthoimagery, only existing data was obtained. However, GPS measurements were made to assess the spatial accuracy of the data, and therefore, point features were collected to relate to the existing data.

Geodetic Reference

To test the accuracy of the GCDB, the appropriate corner recordation forms (official documents that describe and diagram the location of PLSS monuments) were obtained from the Clerk and Recorder's office at the Ravalli County courthouse. A sample of the section and quarter section corners in the study area were located, on the ground, and their coordinates were measured with the GPS receiver. Figure 2 shows a map of the tested PLSS corners.

[4] http://gis.doa.state.mt.us/index.html

Figure 2 - Map of Found PLSS Corners



It was expected that the GPS coordinate values for every PLSS corner would disagree with that in the GCDB. What was in question was the amount of disagreement. A data table was constructed listing each tested PLSS corner, its GCDB coordinates, its GPS coordinates, and the error distance. An evaluation of the expected error within the township was then made. A discussion of this accuracy assessment is contained in Chapter IV, Developing and Testing the Database.

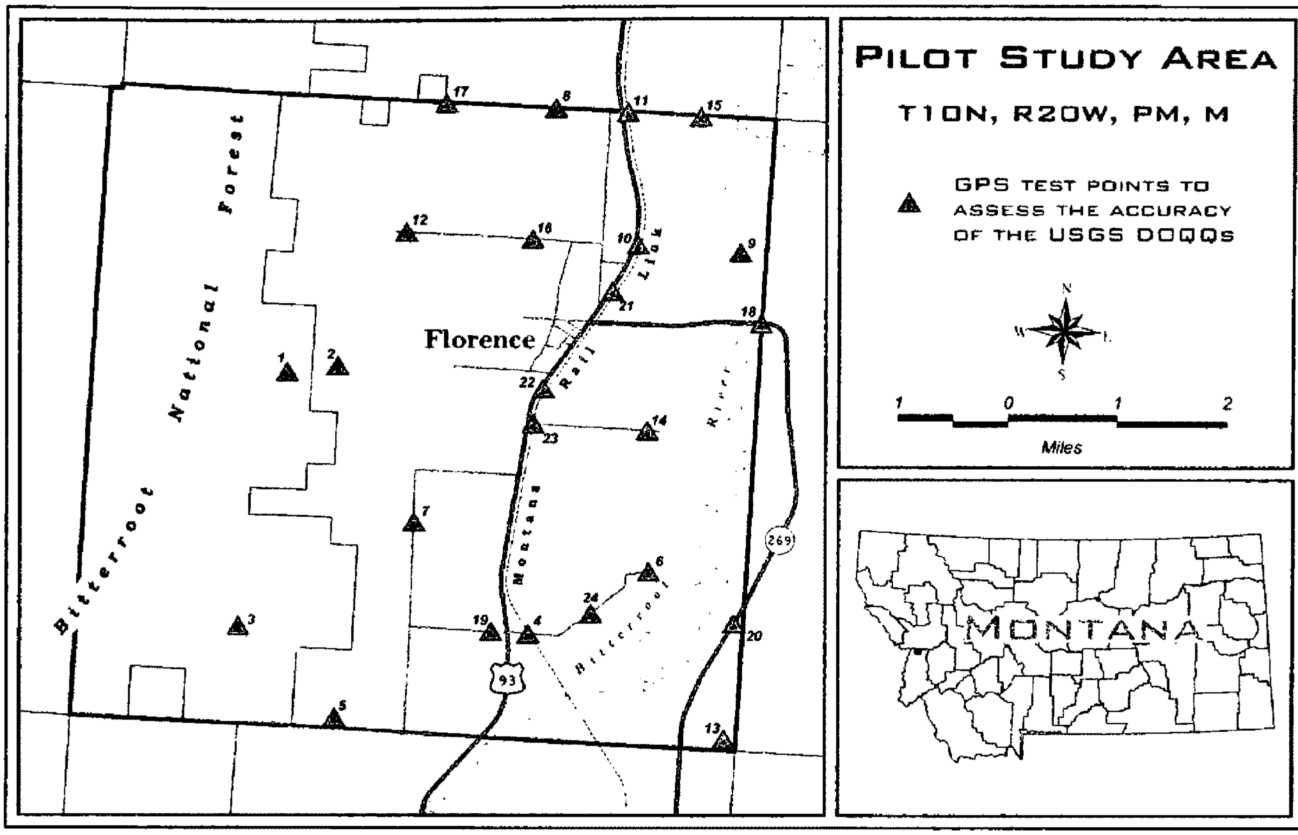
The GCDB was adjusted using the BLM's Geographic Measurement Management (GMM) software. To make this adjustment, recent survey information reporting the distances and bearings between the section and quarter section corners was used to replace the imprecise information from the original surveyors. This survey information was obtained from COSs and subdivision plats. Additionally, the previously mentioned GPS coordinates of the PLSS corners were input to further correct the geometry of the lines. By overlaying the adjusted data set upon the original, the results of the GCDB adjustment were made evident.

ORTHOIMAGERY

From the DOQQs, 24 identifiable and easily accessible point features such as bridge centers, road intersections, and fence corners were chosen in and around the study area. An ArcView point theme was created to mark, as closely as possible, the locations of these features. Each feature identified in the DOQQs was located on the ground and measured with the GPS receiver.

A data table was created to list each test point, its image coordinate values, its average GPS coordinate values, and its positional error. The positional error of the orthoimagery at the chosen locations was considered as the horizontal distance between the points created from the image and their associated, averaged GPS points. The accuracy of the orthoimagery will be discussed in Chapter IV, Developing the Database. Figure 3 shows a map of the selected points.

Figure 3 - Map of DOQQ Test Points



TRANSPORTATION

New transportation data was digitized by GPS methods and again manually digitized from the DOQQs. Normally, this data includes roads, trails, and railroads. Trails and railroads, however, were not collected for this project. The data sets created by the two methods were overlaid to reveal any discrepancies.

GPS Digitizing. All Federal, State, and County roads in the pilot study area were digitized with a Trimble GPS receiver. Driveways, alleyways, and other approaches were excluded. Existing maps of the area were used to construct a preliminary inventory of existing roads and to determine the most efficient work plan.

At the time of digitizing, each road segment was logged into the GPS receiver along with the associated name and surface type. Names were gotten from available road signs, and the surface type of each segment was assigned by personal evaluation. This attribute information was input into the GPS receiver prior to driving each segment. To minimize the amount of time spent idle on the roadway, short codes (acronyms for names and surface types) were used. A unique identifier was generated for each individual road segment in the data table by concatenating the GPS file name, road name code, and surface type code.

A hand written log sheet was used to record the lengthy descriptions of each segment. The title of each log sheet was the particular GPS file name used for the day. Each entry in the log sheet included the name code, full road name, surface type code, full surface type, start/stop odometer reading, start/stop time, and estimated offset distance from the GPS antenna to the road centerline. Upon return from each field session, the information from the log sheet was immediately entered into a Microsoft Excel spreadsheet. Mileage and time for the session were calculated and stored in additional columns and used to determine the amount of time and cost involved in the process. Again, the unique identifier for each record in this table consisted of the GPS file name, road name code, and surface type code.

The result of the above procedure consisted of an ArcView shapefile with an attached attribute table and a separate table containing the actual names of the road segments. The two tables were joined by means of their common unique identifiers. This allowed the full road names to be attached to the appropriate road segment in the spatial file. The final product was a GIS data theme consisting of arcs depicting the road features in the study area and an attached table defining the name, surface type, length, and various other attributes of each road segment.

<u>On-Screen Digitizing</u>. The second method of creating the transportation theme consisted of digitizing, from the DOQQs, the road segments directly into the database. This was accomplished by first loading the appropriate DOQQs into an ArcView project, drawing the arcs directly over the roads in the digital imagery, and then saving the arcs as a spatial file. The zoom level, or scale of the image in the view was varied as deemed appropriate. Because the spatial resolution of the DOQQs was approximately one meter, linear ground features of at least two meters in width were easily discernable. Effort was taken to place each arc directly along the centers of the visible roads.

No attribute information was obtainable directly from the DOQQs. Therefore, the road layer from the TIGER/Line files with the appropriate attribute information was brought into the same project view. By labeling the TIGER/Line data, it was a rather simple task to choose the corresponding arc of the digitized layer and transfer the appropriate tabular information. This provided for the naming of most of the road segments in the digitized layer at the time of data entry. However, because the TIGER/Line files were not without fault, all roads were verified with the official county records and corrected as needed.

CADASTRAL

There are approximately 1,250 individual ownership parcels within the study area. Therefore, because of time constraints, new cadastral data was created for selected portions of the study area only. The data was entered by COGO methods from COSs obtained from the Ravalli County Courthouse. The framework used to enter the cadastral information was the adjusted GCDB described earlier. This allowed for the comparison of the new data and collection methods with the existing data and earlier methods.

HYDROGRAPHY

New hydrographic data was digitized from the DOQQs. The specific features digitized were the Bitterroot River, major streams, and visible ponds. Existing data sets and topographic maps were used to ensure that all applicable water features were digitized and that the correct names were attached to each feature.

This chapter described the methods by which various spatial data sets were collected. After assessing their accuracy and utility, the appropriate data was assembled into a database for the pilot study area. Collecting, assessing, and assembling the data was a lengthy endeavor—perhaps because of the 'trial-and-error' nature of the research process.

The methods described herein were designed to be a logical progression such as that normal to any major undertaking. The first step was to discover and understand all established standards, procedures, and recommendations regarding the subject. The second step was to seek advice from experienced professionals who had gone before. Step three was to take into account the needs and wishes of those individuals expected to benefit from the system. The final step involved assembling the final product using the knowledge previously gained.

IV. DEVELOPING AN MPLIS DATABASE

Planning and designing the spatial database for a MPLIS involves such activities as defining the names and structures of files, how the project area will be subdivided, how graphics will be symbolized, and how GIS products will be presented. Developing the database involves collecting the data and assembling it in such a manner that it will be used according to the definitions devised during the planning and design phases. Collecting the data for the database consists of creating the digital files from source documents, aerial photography, tabular information, and existing maps. As the digital files are assembled, a geography-related database begins to take shape.

Mentioned earlier were the three database design phases described by Nancy von Meyer in the *Guidebook*: the conceptual, logical, and physical. She likens the construction of a database to that of a building for which architectural designs, engineering drawings, and construction drawings are necessary. Each phase represents a distinct point when the design process is to move from the broad, general view to detailed system specifications.[1]

The purpose of the conceptual design phase is to identify, in general terms, the functionality of the system without attempting to define the technology or system requirements for the data. This is the time to discover what geographic data is needed to support the goals and objectives of the organization.

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[1] von Meyer, 25—3.

The logical design phase details the specific data relationships and definitions. During this phase of development, the appropriate GIS data model is matched with the specific data. For instance, the determination is made during this phase to model roads with lines, wells with points, and so on.

The physical design phase is to specifically describe how data is stored, and to indicate which applications are necessary to retrieve, link, and use the various tables in the database. This is the time for the actual implementation and tuning of the database.

When choosing a GIS package, it is necessary to have a clear vision of the logical design of the database. In other words, by the time the necessary hardware and software are purchased, the system developers should possess comprehensive lists of potential data sources, data requirements and definitions, and functional application requirements. Obviously, the actual physical design and development of the database cannot be completed before the hardware and software are purchased. The design and testing of the database is therefore generally conducted concurrently with the hardware and software evaluation.

THE ARC/INFO VECTOR DATA MODEL

It must be stressed that this discussion is not intended to endorse any particular software or hardware company. All of the major GIS hardware and software manufactures can offer products and services capable of developing an adequate system. Solely because of availability, ESRI software products were used as the primary means of data editing and presentation for this project, and therefore, a data model devised by ESRI was adopted.

The general structuring of a spatial database is common to all major software packages. For example, topology is required to define the spatial relationships of features, entities are related to tabular records by means of unique identifiers, and individual data layers are overlaid to produce the final product. The intricate workings, however, vary considerably among software developers. For this reason, organizations are encouraged to evaluate numerous types of GIS software before committing to a purchase. If done properly, this will ensure the best possible match between the capabilities of the software and the circumstances and budget of the organization.

The ARC/INFO Coverage

In 1981, ESRI released its first commercial GIS software package, ARC/INFO, which employed a 'geo-relational' data model called the Coverage. This method of modeling geographic features relied on the combining of the spatial and attribute data tables by joining the associated records of each feature according to an internally maintained common identifier called a sequence number.

The ARC/INFO Coverage consists of vector data, which is well suited for storing and processing point, line, and area features. The basic building blocks or data entities (also called feature classes) used to depict these features are nodes, arcs, and polygons. The respective feature attribute tables attached to these entities are the node attribute table, the arc attribute table and the polygon attribute table.

Arc-Node Topology

Recall that topology is the method used to explicitly define spatial relationships such as connectivity, adjacency, and area definition. An important aspect of the Coverage data model is that topological relationships between features are recorded and preserved by the software. For example, the spatial record for a line segment contains information about which nodes delimit that line, which lines connect to that line, and which polygons are on each side. Polygons are defined by listing all arcs that form a closed area. Topology is necessary for the efficient storage and processing of the data.

Regions and Routes

Nodes, arcs, and polygons are limited in their ability to depict complex geography. For instance, a county might contain two ambulance districts with overlapping jurisdictions. By drawing the boundaries around each district, an area of overlap is created. With normal arc-node topology, the software creates a third polygon from the area of overlap, and then interprets it as a separate area. Although we humans can easily recognize the area as simply two overlapping districts, the computer sees it as three discrete entities unless it is explicitly instructed to do otherwise. In another case, a farmer might own a large cornfield, which is dissected by a narrow strip of land maintained by a ditch company. To the Tax Assessor, the cornfield is one parcel of land with a ditch easement running through it. To the computer, these are three polygons, which must somehow relate to one and only one tax record.

To allow users to address such issues as overlapping areas, areas made from multiple polygons, and linear features made from multiple line segments, the Coverage data model incorporates additional feature classes. These include Regions and Routes. A Region is simply some area, which is defined by a number of discrete polygons. These polygons can be either contiguous or noncontiguous. An example is the State of Hawaii, in which one governmental unit (Hawaii) consists of a number of separate islands.

A Route is a linear geographic feature that can be defined by one or more arcs or portions of arcs. Examples include school bus routes and sections of highways described according to such attributes as surface type, maintenance jurisdiction, or address range. By incorporating Region and Route feature classes into the spatial database, a MPLIS can begin to effectively depict the complicated matters of the real world.

The database for the pilot study area was constructed according to the ARC/INFO Coverage data model and extensively incorporated Region and Route feature classes. The intent was to use the software to logically model the goings on in the study area with respect to the necessary applications of a MPLIS such that a user of the available GIS tools might intuitively access the information. The specific physical design of each data theme will be addressed under the Pilot Study portion of this section. Before this, however, the results from researching the guidelines, conducting the interviews, and the INA process will be discussed.

The Guidelines

The historical development of the various governmental guidelines should be of particular interest to anyone developing a MPLIS. From the first OMB Circular A-16 in 1953 to the various guidelines published today, there have been noticeable reoccurring themes. For instance, all stress the importance of accurate base maps referenced to accurate geodetic grids, encourage the reduction of duplicate work, and urge developers to share ideas, information, and data. Although this material was briefly mentioned in the literature review, the following will be an in depth discussion of the useful information gleaned from studying the major, well-known guidelines pertaining to mapping and the spatial database.

CIRCULAR A-16

The purpose of the first Circular A-16 was to "insure that surveying and mapping activities may be directed toward meeting the needs of Federal and State agencies and the general public, and will be performed expeditiously, without duplication of effort."[2] The 1967 revision of the Circular was made to add the section, 'Responsibility for Coordination,' which outlined the responsibilities of the Departments of Interior, Commerce, and State. The second revision of the Circular, in October 1990, included activities related to digital spatial data.

Finally, the latest revision was issued in July 2002 to address specific issues regarding the sharing of spatial data between Federal, State, local, and Tribal government agencies. In particular, the purpose of the revision was to "reflect changes in technology, further describe the components of the NSDI, and assign agency roles and responsibilities for development of the NSDI."[3]

Circular A-16 contains directives toward the various Federal agencies charged with developing and maintaining spatial data. In that regard, very little is of direct consequence to local governments. However, the presence of the document and its various revisions has led to the coordinated development of certain standards that allow data from one organization to be shared with another. This, of course, is of considerable

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[2] U. S. Bureau of the Budget, *Circular A-16: Programming and Coordination of Surveying and Mapping* [on-line], (January 16, 1953), available from http://www.fgdc.gov/publications/a16/1953/a16_1953.pdf; Internet.

[3] Office of Management and Budget, *Circular A-16 Revised: Coordination of Geographic Information and Related Spatial Data Activities* [on-line], (August 19, 2002), available from http://www.whitehouse.gov/omb/circulars/a016/a016_rev.html; Internet.

benefit to local governments insomuch as data developed by other agencies can be obtained free of charge or for a nominal fee and that the end users have available the information necessary to determine the applicability and quality of the data.

RECOMMENDATIONS BY THE NRC

The recommendations by the Committee on Geodesy of the NRC in *Procedures and Standards for a Multipurpose Cadastre* stressed the importance of maintaining detailed and accurate land ownership information that is collected almost entirely at the local government level. As implied by the name, a multipurpose cadastre is specifically designed to serve the informational needs of more than one set of users.[4] The concept of a multipurpose cadastre is the synergy of four components that allows the most current parcel level land information to be made readily available. These components are:

- A spatial reference framework consisting of geodetic control points
- A series of current, accurate, large-scale base maps
- A cadastral overlay that delineates all cadastral parcels and displays a unique identifying number for each of them
- A series of compatible registers of interests in land parcels keyed to the parcel identifier numbers[5]

Procedures and Standards was published in 1983, prior to the popularity of desktop computers and centralized databases. Although the authors foresaw the role that computers would play in implementing their ideas, they probably did not foresee the incredible processing power of our inexpensive 21st Century computers and the relative

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[4] NRC, *Procedures and Standards for a Multipurpose Cadastre*, 66.

[5] Ibid., 1.

ease by which the components of a multipurpose cadastre can be integrated and implemented. Because of the technological mindset in 1983, the authors' wording of the four components might seem somewhat confusing to those of us who take these advances for granted. Therefore, a translation from the original verbiage to modern day lingo is in order before attempting to relay the recommendations of the Committee.

THE SPATIAL REFERENCE FRAMEWORK

In 1983, the spatial reference framework of geodetic control points consisted of approximately 750,000 horizontal and vertical survey monuments, which has facilitated the development of various coordinate systems to define the locations of geographic features. Of these monuments, approximately 250,000 contained the horizontal value of the position. Although this might appear to be a considerably large number of monuments, it equates to approximately one horizontal survey monument for every 14.2 square miles of land surface. Because of this inadequate spacing and other factors such as imprecise geographic coordinates and the outright loss of the original monuments themselves, these points have traditionally not been adequate to be used to locate and reference individual property corners.[6]

Monumentation and the PLSS. The Committee observed that any accurate mapping project requires the establishment of a system of survey control. If the project is to be an effective planning and management tool for a multipurpose cadastre, the survey control system must meet two criteria. First, it must permit the correlation of cadastral boundary data with topographic, earth science, and other land data. Second, the control

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[6] Ibid., 20.

points must be permanently monumented on the ground so that the lines on the map may be reproduced in the field.[7] The Committee also recommended that the spacing of these monuments range from 0.2 to 0.5 mile in urban areas and 1 to 2 miles in rural areas, and that the density be uniform throughout the entire area.[8]

Since its creation in 1785, the PLSS has provided the geometric land-tenure framework for all lands that were originally part of the public domain and owned by the Federal Government. The responsibility of surveying these lands was placed on the General Land Office (GLO), which became the BLM in 1946. Today, the PLSS exists in 30 states that contain approximately 80 percent of the land of the nation. These states are often referred to as the 'PLSS states.' The other 20 are sometimes referred to as the 'Colonial states' or the 'Metes and Bounds states.' The map in Figure 4 shows the states surveyed under the PLSS.

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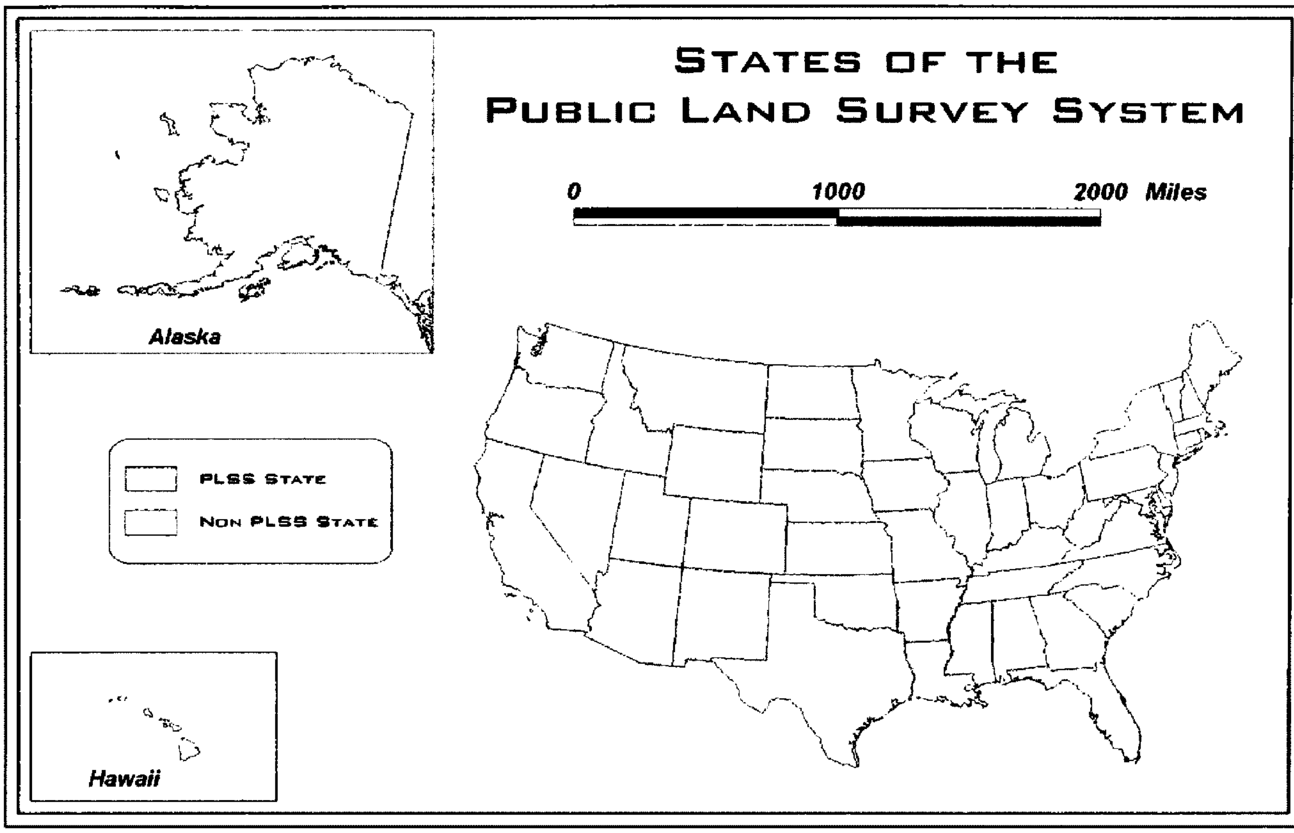
[7] Ibid., 23.

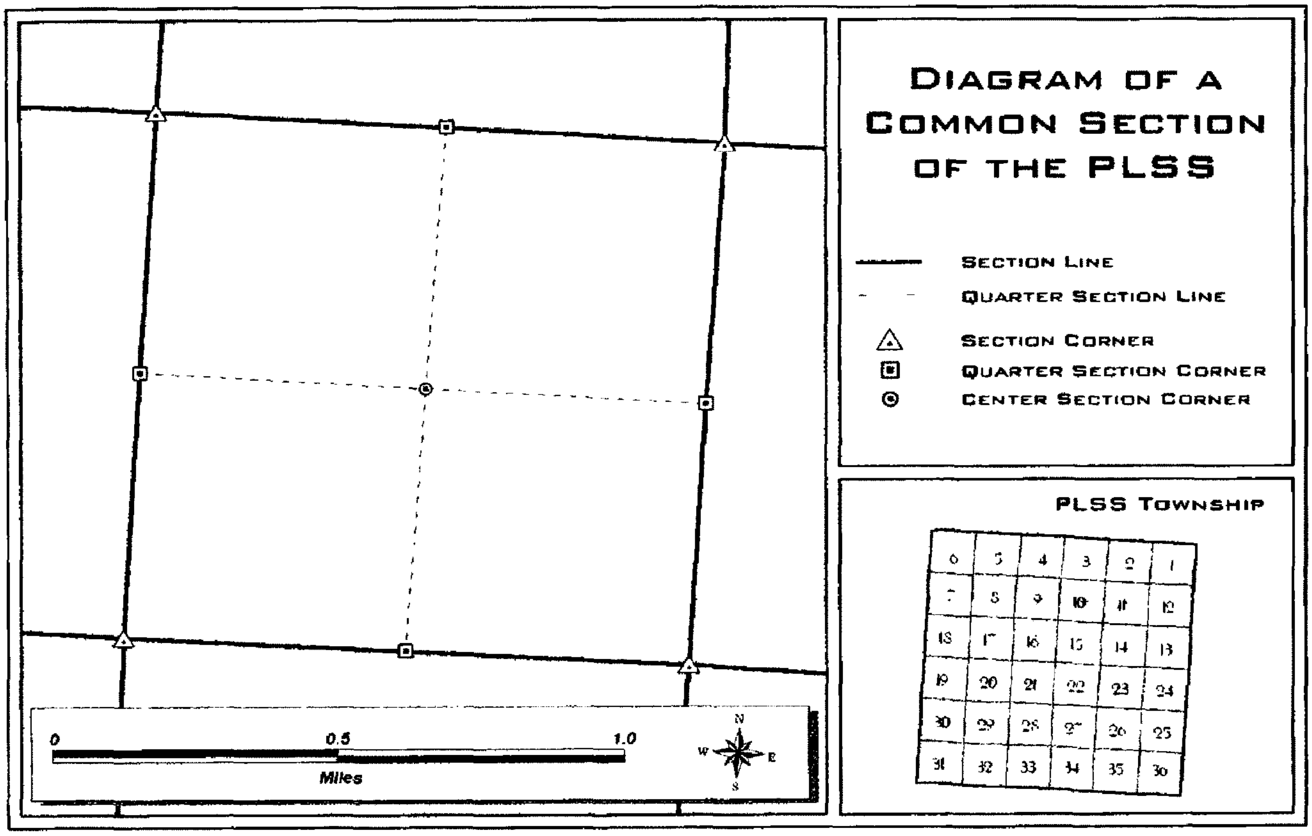
[8] Ibid., 24.

Figure 4 - Map of PLSS States



In the areas of the United States covered by the PLSS, the monuments established at the section and quarter section corners and at the section centers would meet the design requirements for survey control stations. Figure 5 shows the relative location and spacing of these designated control points for one section in a typical township. (Note that the original GLO surveyors were not required to set a monument at the center of a section. Therefore, any monumentation of these corners was performed by those engaged in subsequent surveys.) In the areas not covered by the PLSS, the Committee recommended that an even distribution of selected property corners and right-of-way monuments serve as control stations. Regardless of the survey system, the principle of density and uniformity remains the same.[9]

Figure 5 - PLSS Section Diagram



Coordinate Systems. The National Geodetic Survey (NGS) has developed the various State Plane Coordinate Systems (SPCS) as a practical means to coordinate surveying and large-scale mapping efforts. These localized coordinates can be easily transformed into other coordinate systems within known accuracy limitations. By choosing a limited area and a conformal map projection (to preserve shape), SPCS grids fit the curved shape of the earth to a plane surface with a minimum amount of distortion. Thus, any data within each state system can be easily correlated and used with data from

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[9] Ibid., 25 – 26.

regional, state, national, and other local institutions. Therefore, the Committee recommended that developers of a local government LIS use the SPCS and their associated map projections as the basis for recording and mapping the positions of geographic features.[10]

Large-Scale Base Maps

Throughout *Procedures and Standards*, the importance of thorough and accurate base maps was emphasized. The Committee asserted that the base map of a multipurpose cadastre must provide the level of planimetric detail necessary to locate ownership boundaries referenced to natural and man-made features such as streams, lakes, fences, highways, and railroads.[11] Compiled according to a spatial reference framework, a base map represents certain fundamental map information upon which other specialized geographic data is drawn. In so doing, natural and cultural features can be related to the spatial reference framework and to each other.

In 1983, most base maps were large paper maps such as USDA Forest Service visitor maps, BLM land status maps, or USGS topographic quadrangle maps. The specialized information was generally drawn on clear film and physically overlaid on the base maps. The composite information was then presented and used to make land-related decisions. Therefore, the scale of any mapping project was limited to the scale of the paper base map. Today, base maps within a GIS take the form of raster images or vector

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[10] Ibid., 24.

[11] Ibid., 42.

lines within the computer. Because of this, it is tempting for the mapping technician to enlarge the view of the project beyond the intended scale of the base map information.

Accuracy. The accuracy of the horizontal and vertical position information on the base map was acknowledged by the Committee as a function of the scale of the map and contour interval.[12] In other words, the larger the map scale (the larger the features appear on the map), the closer the features must be in reference to their true position; and the more frequent the contour interval on the map, the closer the elevation information of the features must be to their true elevation.

The Committee referenced two standards for controlling the accuracy of plotted map information: the National Map Accuracy Standards (NMAS) and the specifications for large-scale mapping by the American Society of Photogrammetry—now called the American Society of Photogrammetry and Remote Sensing (ASPRS). According to the NMAS, for map scales larger than 1:20,000, 90 percent of all points tested shall be plotted on the map within 1/30 inch of their true horizontal position. The standards for vertical accuracy allow a maximum tolerance of one-half the published contour interval.[13] The large-scale mapping standard by the American Society of Photogrammetry is essentially a more stringent accuracy requirement. Rather than the 1/30-inch tolerance of the NMAS, the ASPRS standard requires that 90 percent of the points tested shall be within 1/40 inch. Regardless of which accuracy standard is used, the Committee

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[12] Ibid., 43.

[13] U. S. Bureau of the Budget, *National Map Accuracy Standards* [on-line], (Revised June 17, 1947), available from http://rockyweb.cr.usgs.gov/nmpstds/nmas647.html; Internet.

emphasized the need for a rigorous form of quality control within the base-mapping project to assure the accurate placement of mapped features.

Base Map Content. The Committee visualized the base map as a coordinated series of different levels and overlays. The goal was to provide the data content and structure that would allow a variety of users to relate cadastral information to specific types of base data.[14] Ideally, the base map begins with orthophotography, which is rectified to either geographic, UTM, or State Plane coordinates. As previously mentioned, the Committee recommended that local governments use the SPCS.

Natural and cultural features that can be related to a cadastral parcel form the next series of levels of the base map. In order of importance, this series includes the following themes:

- All streets, roads, railroads, and airports and their associated names
- All permanent buildings greater than a specified size
- All water features including perennial and intermittent streams, canals, aqueducts, lakes, ponds, and reservoirs and their associated names
- All boundaries of governmental jurisdictions at all levels: state, county, municipal, and township[15]

Other secondary levels of features may be selectively included in the base map as well. These include contours, floodplains, wetlands, vegetation, and utility information. Of course, digital mapping and GIS provide the tools necessary to assemble and maintain these individual themes and to overlay them in any combination.

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[14] NRC, *Procedures and Standards for a Multipurpose Cadastre*, 41.

[15] Ibid., 41.

THE CADASTRAL OVERLAY AND REGISTERS OF LAND INTERESTS

The fundamental element of the multipurpose cadastre (or MPLIS) is the cadastral data theme in which the individual building block is the cadastral parcel. The notion of the cadastral overlay implies the same procedure as previously described whereby the graphic representation of ownership parcels is overlaid upon a large-scale base map. Although the Committee stated that cadastral maps should be viewed as overlays to large-scale base maps, they clarified that cadastral boundaries are lines connecting points that can be located on the ground by means of their unique identities and records.[16] In particular, one must be able to locate a property corner in the cadastral overlay and use any attached information to find the actual corner on the ground.

Within the computer, topology is the most efficient means to relate the countless legal references to cadastral parcels, boundaries, and corners. Recall that, in a spatial database, topology describes how points, lines, and polygons connect and relate to each other. The Committee stated, "It is essential that the cadastral parcel layer of a digital map system contain complete topological references."[17] In other words, each cadastral parcel polygon must explicitly indicate which arcs define it, and each cadastral boundary arc must explicitly indicate which nodes define its beginning and end. The nodes, of course, represent the physical property corners. Each of these entities within the cadastral theme—the nodes, arcs, and polygons—must therefore have some unique identifier, which can be used to relate it to information recorded elsewhere. Then, as the

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[16] Ibid., 55.

[17] Ibid., 51.

Committee stated, the cadastral overlay can be a 'living map' that can be easily updated as conditions change.[18]

Creation and Maintenance. The Committee defined certain prerequisites to beginning a cadastral mapping program. Additionally, they recommended that, once the cadastral overlay is in place, updating procedures should be scheduled such that any new or changed land parcels can be accounted for within two weeks.[19] The prerequisites to the cadastral mapping process are:

- Establishment of the geodetic reference framework
- Completion of the base map
- A budget for continuing maintenance of the maps

The Committee's observation was that, "land-tenure information initially obtained for the development of the cadastral mapping program will undoubtedly be of mixed quality."[20] For instance, some areas are described by recorded subdivision plats, some are described by hand written COSs, and many others are merely described by simple (and often ambiguous) deed descriptions. Therefore, the Committee strongly recommended that the implementation of the cadastral overlay should be done in an iterative manner. In this situation, the overlay is based initially on existing information but improved over time as more and better information becomes available.[21] Above all, it is important that:

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[18] Ibid.

[19] Ibid., 56.

[20] Ibid., 57.

[21] Ibid.

- All cadastral parcels within the jurisdiction have been accounted for
- The best information has been used to determine the approximate size, shape, and location of each parcel
- The correct parcel identifier has been assigned to each parcel
- Indices are available to facilitate access to all documents necessary to locate and describe property corners and monuments shown on the maps

The Committee defined the 'parcel identifier' as a code for recognizing, selecting, identifying, and arranging information to facilitate organized storage and retrieval of parcel records.[22] The parcel identifier provides the means by which attribute information regarding specific cadastral parcels is retrieved. Within a GIS, the parcel identifier can be used to link a cadastral parcel polygon to its attribute information stored in a separate Database Management System (DBMS). This unique identifier, according to the Committee, should be assigned to the cadastral parcels during the initial phase of the cadastral mapping program; and should be unique, simple, and economical to maintain. To ensure and facilitate its use, the Committee recommended that one parcel identifier in the land-parcel register should become the official legal reference to all title documents affecting that parcel. They also suggested that this identifier would be sufficient for legal descriptions of parcels.[23]

Of special importance to various local governments was the recognition by the Committee that, "any parcel-identifier system can only work if one agency has the sole authority for assigning identifiers. This preferably should be that agency responsible for

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[22] Ibid., 63.

[23] Ibid., 64.

land registration."[24] Personal experience has shown that, in the case of Montana for instance, two unique identifiers exist for land parcels. Whereas the county governments assign a unique, numeric parcel number to be used as a tax identification number, the state government assigns a unique, location-related, alphanumeric identifier to essentially the same parcel. The primary reason for this often-confusing situation is that Montana is one of two only states in which the State Department of Administration retains full responsibility for assessing real property.

In *Procedures and Standards*, the Committee included a number of case studies that demonstrated some of the concepts for a MPLIS. In addition, the Committee provided examples regarding estimated implementation costs, recommendations concerning funding, and instructions for determining user requirements. Although they have not been included in this discussion, these sections of the publication are valuable for providing a general overview to MPLIS issues beyond the construction of the database.

THE FGCC GUIDEBOOK

The Federal Geodetic Control Committee (FGCC) comprises 11 Federal departments and independent agencies involved in geodetic surveying. As directed by Circular A-16, the FGCC coordinates the planning and execution of geodetic control and related survey activities of Federal agencies.[25] *Multipurpose Land Information Systems: the Guidebook* (*Guidebook*) was published by the FGCC to aid those involved in

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[24] Ibid., 65.

[25] FGCC, *Multipurpose Land Information Systems: the Guidebook,* (Silver Springs, MD: FGCC, 1992), 2.

implementing a MPLIS. As such, it was built on the foundation laid by *Need for a Multipurpose Cadastre* and *Procedures and Standards for a Multipurpose Cadastre*.[26]

The *Guidebook* consists of two volumes containing 24 chapters. Topics include mapping, land interests, basic data and database concepts, analysis and planning, and organizational issues. The chapters were written by various authors during the period between 1988 and 1993.

Chapter One of the *Guidebook* introduces the background information and concepts regarding a LIS and its evolution from a standard GIS. It also specifically defines a MPLIS as, "a system in which the fundamental means of organizing data is the cadastral parcel or 'proprietary land unit,' whose main objective is the provision of institutional data concerning land ownership, value, and use."[27] The FGCC contends that the data of the MPLIS "...should be accurate enough to support the envisioned applications, compatible so that data sets can be used in combination with one another, and comprehensive so that current and appropriate data are available when they are needed."[28]

The specific chapters of the *Guidebook* most applicable to this research project were:

- Chapter 3, Introduction to Geodetic Reference Frameworks
- Chapter 4, Land Interests
- Chapter 5, Property Boundaries

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[26] Ibid., 1—3.

[27] Ibid., 1—6.

[28] Ibid.

- Chapter 6, The Public Land Survey System
- Chapter 9, Land Data: Types and Requirements
- Chapter 10, Data Linkages in an MPLIS
- Chapter 12, The Base Map
- Chapter 13, The Parcel Map
- Chapter 16, Needs Assessment
- Chapter 19, Mapping: Methods and Procedures
- Chapter 25, Database Design

Of the chapters listed above, the information contained in chapters 3, 6, 10, 12, and 19 were essentially reiterations of the recommendations by the NRC. Hence, they will not be addressed here. Chapter 16 regarding the needs assessment will be discussed under the Revelations from the INA portion of this section. Much of the benefit gained from the *Guidebook* dealt with the topics of land interests, property boundaries, parcel mapping, and database design.

LAND INTERESTS

Chapter four of the *Guidebook* defined and described the nature of land interests. Examples of land interests include ownership, zoning, rights-of-way and easements, political jurisdictions, and taxation. All of the interests regarding a parcel of land fall within two categories: nature and extent. The nature of an interest refers to the rights and restrictions affecting the use of the land and its resources. The extent of an interest refers to its boundaries in space and time.[29] Interest in the land is perhaps the most fundamental information to local government, and constitutes much of what is required in a MPLIS.

Authors Epstein and Brown made the following observation:

> Most of us think of the land parcel in terms of ownership, or as the unit of land described in property surveys and subdivision plats. However, many interests in land fracture this parcel or extend to many parcels... Information about the nature of the interest cannot always be ascribed to a particular parcel. The information is at the parcel level, but it is not necessarily parcel-based. The ideal MPLIS would record the nature and extent of all public and private land interests and would provide the capability to retrieve information about these interests for any land area.[30]

From this observation, one can begin to realize the complexity facing those involved in constructing the cadastral layer. Perhaps because of limited resources, builders of the cadastral layer often push aside most of the applicable land interests in order to quickly present a map showing the delineation of parcel boundaries. However, as Epstein and Brown stated, parcel delineation as described in surveys and plats is only a small portion of the cadastre.

Another important observation of Epstein and Brown was that public records are for the most part functionally inaccessible. What this means is that public records that are used as evidence in an examination of land interests are scattered among a number of agencies and levels of government.[31] Because of this, they are often redundant with no standard method of retrieval. Although this system is convenient for storage, it is not

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[29] Earl F. Epstein and Patricia M. Brown, "Land Interests, Chapter 4," in *Multipurpose Land Information Systems: the Guidebook,* (Silver Springs, MD: FGCC, 1992), 4—1.

[30] Ibid., 4—6.

[31] Ibid., 4—9.

convenient for those who must access and use the records. A functional MPLIS must facilitate access to those records.

PROPERTY BOUNDARIES

Property boundaries are defined by property descriptions, which describe the spatial, two-dimensional extent of the common types of land interests such as fee simple ownership, easements, and rights-of-way. Unfortunately, as Brown observed, accurately compiling property descriptions in a MPLIS can be a difficult task because descriptions for any area contain contradictions, inconsistencies, errors, and omissions. Resolving these issues is an expensive, time-consuming task and is solely the responsibility of the owners and courts.[32]

If it does not conflict with the descriptions of neighboring parcels, the original property description sets the boundaries of all subsequent divisions of the land. In many areas, the original property description of a given parcel can be hundreds of years old. This in and of itself can lead to conflicts because of the original surveying equipment and methods by which land was surveyed. However, our legal system gives greater weight to the physical evidence of a boundary, such as monuments, than to the legal description itself.[33]

Much of Brown's discourse regarding property boundaries dealt more with defining various terms and concepts than with dispensing advice. What was especially

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[32] Patricia M. Brown, "Property Boundaries, Chapter 5," in *Multipurpose Land Information Systems: the Guidebook,* (Silver Springs, MD: FGCC, 1992), 5—1.

[33] Ibid., 5—12.

important was Brown's observation regarding discrepancies in property descriptions. She summarized her chapter with the following:

> A number of factors have resulted in an accumulation of discrepancies, errors, uncertainties, and inconsistencies in this country's land boundary descriptions. The responsibility for these problems—and for their resolution—does not lie with a single profession, level of government, or agency. Under our system of law, the responsibility for final resolution almost always lies with property owners and the courts.... The compilation of land boundary descriptions onto a single map often brings many inconsistencies to light. No amount of mapping accuracy or geodetic control will erase years of change, error, and inconsistency.[34]

THE PARCEL MAP

Chapter 13 of the *Guidebook* dealt with the parcel map, and specifically discussed the purposes for creating and maintaining parcel maps. In addition, the chapter covered the basic approaches to constructing parcel maps and the factors important to the implementation of a parcel-mapping program.

Fundamentally, a parcel map depicts the boundaries of parcels, which are considered as defined units of land within which a bundle of rights and interests are legally recognized in a community.[35] The parcel is a concept associated with rights and relations between people in regard to land and its product.[36] Parcel maps are used for a number of purposes by nearly every department within a local government. They are often referred to by a variety of names such as plats, assessor maps, tax maps, and cadastral maps. Epstein and Moyer list four of many uses of parcel maps:

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[34] Ibid., 5—18.

[35] Earl F. Epstein and D. David Moyer, "The Parcel Map, Chapter 13," in *Multipurpose Land Information Systems: the Guidebook,* (Silver Springs, MD: FGCC, 1992), 13—3.

[36] Ibid., 13—22.

- Property assessment
- Planning and engineering activities
- Management of title records
- Management of public utility and service systems[37]

In addition to the known uses of parcel maps, there are public and private individuals who use parcel maps in ways not intended by those who construct them. Thus, the cartographer must somehow anticipate as many uses as possible in order to create maps that can fulfill unexpected needs.

When compiling, updating, and using parcel maps, problems are often encountered for which certain decisions must be made. Examples include:

- Separate parcels that are sometimes treated as a single parcel for other purposes
- How to treat various easements
- Inconsistent legal descriptions
- Condominiums and multiple interests
- Publicly owned land
- Moveable boundaries such as those defined by bodies of water[38]

Efforts to resolve these issues often result in a long, expensive process. Furthermore, many of these problems are not evident until the compilation process is underway, and their resolution will often rely on the judgment of the cartographer.

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[37] Ibid., 13—7.

[38] Ibid., 13—5.

Epstein and Moyer stress that the geodetic framework and base map should be in place before developing or revising the parcel map layer.[39]

A checklist of factors to consider is necessary when designing a parcel-mapping program. The factors should be discussed and agreed upon by as many MPLIS users as possible. The factors are as follows:

- The scale, format, accuracy, content, and timeliness of each parcel map
- Which types of boundaries, parcel definitions, and specific features that must be included
- The needs of each individual who will use the parcel maps
- Which processes will be used to supply the specific records and their attributes that will contribute to the parcel maps
- Who has responsibility for the design and execution of the parcel mapping plan
- How the parcel map will be related to the base map and the associated set of land records
- How gaps and overlaps among parcels will be resolved
- How the final map product will be represented and characterized for the users[40]

Many problems can be avoided by resolving the issues listed above before the parcel mapping process begins. It is important to keep in mind that there will already be those with the responsibility of maintaining the parcel information, and that their input and judgment is most critical. Epstein and Moyer included certain recommendations regarding these factors. Because specific land laws vary among State governments, they

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[39] Ibid., 13—6.

[40] Ibid., 13—6 – 7.

reflect only a general rule. The exceptions, however, will be minor and infrequent. What follows is the upshot of their recommendations.

Scale. Parcel size and density of necessary descriptive information are the most important factors in selecting a scale for the parcel maps. It should be the smallest scale that legibly shows all of the boundary and associated textual information. Parcel map scales will generally vary from 1:600 (1" = 50') to 1:9,600 (1" = 800').[41] Obviously, the larger scale maps will be used in the urban areas where the parcel density is high, and the smaller scale maps will be used in the rural areas.

Content. Parcel maps should contain the following basic information:

- Boundaries of all parcels
- Parcel dimensions or area
- Names, boundaries, and block and lot numbers of all subdivisions and COSs
- Boundaries of PLSS subdivisions and other such divisions
- Location and names of transportation and hydrographic features
- Parcel identifiers
- Basic title and legend information[42]

Supplemental parcel information allows access to other data without changing the original maps. This information should be recorded as an overlay to the basic information. Common supplemental parcel information includes the following:

- Right-of-way and easement boundaries

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[41] Ibid., 13—8.

[42] Ibid., 13—10.

- Names and addresses of parcel owners
- Assessed values and sales information
- Location of improvements
- Street address numbers
- Zoning and special districts
- City and county infrastructure information
- Topographic information
- Deed and survey reference information[43]

Map Compilation. To make a judgment of the status of parcel boundaries, the written and physical evidence regarding their locations must be gathered, evaluated, and arranged. Sources for this information include title and assessment records, infrastructure records, land use and zoning records, court records, and survey records. In order of importance, the written and physical evidence of parcel boundaries are:

- Rights of possession (The long-term use of a property carries more weight irrespective of any written intentions.)
- Senior rights (Older parcels retain their boundaries in the areas where newer adjoining parcel descriptions indicate an overlap.)
- Conflicting elements (Boundary locations are tentative until conflicting descriptions are resolved by a resurvey or a court decision.)

Proper compilation of the parcel maps must first consist of arranging the various legal records according to the above levels of importance.[44] Furthermore, it is unsafe to assume that a recent description with measurements by the most modern and precise

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[43] Ibid.

[44] Ibid., 13—15.

instruments determines the boundary. It is essential that the cartographer indicate the material used to compile the data for the parcel map.[45]

The Parcel Framework. Epstein and Moyer confirm that the geodetic reference system is the basic layer upon which all of the MPLIS data rests, and the base map provides further orientation for parcel map information. If the corner locations are known to a proper level of accuracy, section and quarter section corners of the PLSS are sufficient to establish the parcel map framework.[46] However, it must be emphasized that parcel boundary information cannot be compiled under the assumption that PLSS sections are perfectly square. Therefore, some procedure must be in place to assemble, as accurately as possible, the geodetic framework as it exists on the ground.

Maintenance. The parcel map (or data layer) becomes an integral part of a MPLIS only when it remains timely and accurate. Therefore, a plan for maintaining the accuracy and timeliness of parcel data is critical.[47] In addition, the cadastral layer must provide the basis for unique parcel identifiers that are attached to all parcel-related documents. Epstein and Moyer concurred with the NRC that, "...the updating of the cadastral overlays (parcel maps) be scheduled so as to assure that they will reliably show any new or changed land parcels that have been in existence for two weeks or more."[48]

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[45] Ibid., 13—17.

[46] Ibid.

[47] Ibid., 13—19.

[48] Ibid., 13—21.

Database Design

In Chapter 25 of the *Guidebook*, von Meyer presented an overview of GIS and LIS database design by incorporating principles of information engineering. Information engineering systematically shows how information is created, used, and flows by describing the various technologies, processes, data, and organizational structures involved.[49] She also described the three distinct, progressive design phases of a database: the conceptual, the logical, and the physical. These phases will be discussed here.

Conceptual Design. Von Meyer wrote, "The conceptual database design identifies the scope, purpose, scale, and functionality of the system in general terms. It identifies which data should be grouped into which databases, the relationships among these databases, and the relationships of databases to functions and processes of the organization."[50] The conceptual design phase begins with an enterprise data model, which describes the departments and structure of the organization, the functions and processes of each of the departments, and the necessary data to support each function and process.[51] The product of modeling the data flow of an organization is a diagram that shows each function performed by each department, the information that is needed, the steps used to process the information, and the data that results from the function. A

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[49] Nancy von Meyer, "Database Design, Chapter 25," in *Multipurpose Land Information Systems: the Guidebook,* (Silver Springs, MD: FGCC, 1992), 25—2.

[50] Ibid., 25—5.

[51] Ibid.

benefit from this design phase is that it educates those in the organization about information and its flow.[52]

Logical Design. The logical database design phase details the data relationships and definitions. During this phase, each required piece of information is explicitly defined and related to other information, thus clarifying the data definitions.

The logical design phase produces an entity-relationship diagram that shows the many data entities in the system and their relationships. A data entity is any object about which someone in the organization chooses to collect data. All entities have various attributes that are defined in a data dictionary.[53]

The associations between entities will take the form of one-to-one, one-to-many, or many-to-many. A one-to-one association means that a given value of one characteristic has one and only one value of another. For instance, one person has one social security number, and one social security number is assigned to only one person.

A one-to-many association means that a value of a characteristic might have more than one value of another. An example of this is Parcel Number 16503, which has three owners: James Walker, William Dixon, and Riley King. The only value of 'Parcel Number' in this record is 16503 but it contains three values for 'Owner.' However, each partner has only a partial interest in that parcel. The parcel has a one-to-many relationship with its landowners.

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[52] Ibid., 25—7.

[53] Ibid., 25—9.

A many-to-many association means that a value of a characteristic has more than one value for another and visa-versa. Again, Parcel Number16503 is located within many administrative districts such as fire, ambulance, police, and school while any one of the districts containing Parcel Number 16503 contains many other parcels. One value of 'Parcel Number' is associated with many values of 'Administrative District' and one value of 'Administrative District' is associated with many values of 'Parcel Number.'

It should be obvious that these relationships can quickly become quite complicated. The purpose of the entity-relationship diagram is to organize and describe all of the data that an organization collects and uses whereby each individual data entity is listed once in the diagram. The effort in the logical design phase should be to eliminate duplicate data definitions.[54]

Physical Design. The physical design phase describes in detail how the data is input into the system and identifies the specific programs necessary to link and join the separate tabular information. During this phase, the data is restructured to conform to the requirements of the chosen hardware and software. This phase is critical in order to assure the integrity of the organization's data such that if an attribute value is changed in one place, all other occurrences of that attribute value for that record are also changed.[55] In addition, the data redundancy that was eliminated during the logical design phase is somewhat reintroduced to enhance the performance of the specific software.

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[54] Ibid., 25—10.

[55] Ibid., 25—12.

Each of the three design phases discussed here are necessary to construct a useable and efficient MPLIS database. The temptation for some is to skip to the physical design without regard to the flow of data and entity relationships. In this case, the database developers will quickly lose control of the construction process and forego the valuable experience necessary to deliver a complete system.

A complete discussion regarding database design is far beyond the scope of this project. There are manuals and texts that deal in great depth with this issue. Individuals with the expertise in relational database design are rarely found within a typical local government. Therefore, much consideration must be given to outside consultation.

As mentioned earlier, all chapters within the *Guidebook* are of considerable value to those tasked with implementing a MPLIS. Only the chapters directly relating to this research topic are covered here. Perhaps in the years to come, the FGCC will refine the publication to serve as the de facto standard for local government MPLIS operations.

STANDARDS OF THE FGDC

The FGDC was organized in 1990 under OMB Circular A-16, and is now composed of representatives from 17 Cabinet level and independent federal agencies. The purpose of the FGDC is to promote the coordinated use, sharing, and dissemination of geospatial data on a national basis. To carry out this plan, the FGDC is organized into several subcommittees based upon certain geographic data themes. Some of these data themes include base cartographic data, cadastral data, transportation data, cultural and demographic data, and federal geodetic control.[56] Through these subcommittees, the FGDC develops geospatial data standards for implementing the NSDI. They do so in consultation and cooperation with State, local and tribal governments, the private sector and academic community.[57]

Recall that the NSDI is the linkage of technology, policies, standards and resources that are necessary to improve the way geographic data is acquired, stored, processed, disseminated, and used.[58] To understand what this really means, one must read the article by Nancy Tosta titled, "Data Data—A View from Here." In it, Tosta explained her involvement with the FGDC, the history of the NSDI, and the processes that led to EO 12906. She reduced the concept of the NSDI to the following:

> The NSDI vision basically called for an attitude of cooperation in the creation, management, and use of geospatial data.... To me, the NSDI was very much an attitude—it was a way of thinking about doing business differently based on networks, shared knowledge, integrated resources, and evolution. The NSDI was never a 'thing'—it was always a state of mind. It would never be built—it would be experienced. It was a web of interactions.... The fundamental purpose of the NSDI was to encourage data sharing. Data sharing would help reduce duplication, make more data more accessible, and would contribute to building communities to address common problems.[59]

To describe how differing data sets would integrate in the NSDI, Tosta stated:

> Many of us recognize that the most realistic version of a national coverage might resemble a patchwork quilt of data, where higher resolution data are

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[56] Federal Geographic Data Committee, *FGDC Organization Subcommittees* [on-line], (October 23, 2002), available from http://www.fgdc.gov/fgdc/fgdcsc_org.html; Internet.

[57] Federal Geographic Data Committee, *FGDC Standards* [on-line], (October 23, 2002), available from http://www.fgdc.gov/standards/standards.html; Internet.

[58] NSDI. *Community/Federal Information Partners,* Reston, VA. March, 2000.

[59] Nancy Tosta, "Data Data—The View from Here" *Geo Info Systems* 7, no. 11 (1997): 38-39.

> available over certain geographies. The worst data—that is, data with the lowest resolution—would be 1:100,000 digital data, as they already exist everywhere.... Major urban areas and counties with sophisticated GIS efforts are developing much more detailed data, at scales ranging from 1:10,000 to 1:100. The rest of the country might be filled in by state agency, federal land management agency, and USGS mapping efforts, probably at 1:24,000 scale. Standards would allow 'seamless' integration across these varying scales.[60]

As of December 2002, the FGDC had published 19 standards governing GIS database construction as it relates to the NSDI. They are intended to guide the process of developing and disseminating spatial data and associated attributes. The FGDC standards regarded to be at the final stage and applicable to this research are:

- *Content Standard for Digital Geospatial Metadata (version 2.0)*, FGDC-STD-001-1998
- *Spatial Data Transfer Standard (SDTS)*, FGDC-STD-002
- *Cadastral Data Content Standard*, FGDC-STD-003
- *Geospatial Positioning Accuracy Standard, Part 1, Reporting Methodology*, FGDC-STD-007.1-1998
- *Geospatial Positioning Accuracy Standard, Part 2, Geodetic Control Networks*, FGDC-STD-007.2-1998
- *Geospatial Positioning Accuracy Standard, Part 3, National Standard for Spatial Data Accuracy*, FGDC-STD-007.3-1998
- *Content Standard for Digital Orthoimagery*, FGDC-STD-008-1999[61]

In addition to those above, there are various other standards in either the review stage, draft stage, or proposal stage. Only the endorsed standards will be discussed here.

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[60] Ibid., 39.

[61] Federal Geographic Data Committee, *Status of FGDC Standards* [on-line], (August 13, 2002), available from http://www.fgdc.gov/standards/status/textstatus.html; Internet.

The topics, then, will be metadata, spatial data transfer, cadastral data, geospatial positioning accuracy, and orthoimagery.

Metadata. The purpose of the Metadata Standard is to provide a common set of terminology and definitions for the documentation of spatial data. According to the standard, documenting a spatial data set requires the following elements:

- Identification information – basic information about the data set such as title, geographic area, currentness, and rules for acquiring or using the data
- Data quality information – an assessment of the quality of the data set such as positional and attribute accuracy, completeness, consistency, and sources of information
- Spatial data organization information – the mechanism used to represent spatial information in the data set such as raster or vector representations and street addresses or geographic coordinates
- Spatial reference information – the description of the reference frame for coordinates in the data set such as name of and parameters for map projections and grid coordinate systems, horizontal and vertical datums, and the coordinate system resolution
- Entity and attribute information – information about the content of the data set such as the names and definitions of features, attributes, and attribute values
- Distribution information – information about obtaining the data set such as a contact for the distributor, available formats, how to obtain data sets online, and fees for the data
- Metadata reference information – information on the currentness of the metadata information and the responsible party[62]

To help data producers develop accurate and consistent metadata, the FGDC has offered various tools that can be downloaded from their Website.[63] These tools include

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[62] http://www.fgdc.gov/publications/documents/metadata/metafact.pdf

[63] http://www.fgdc.org/metadata/metadatool.html

computer applications for creating metadata, an exercise tutorial, and instructions for implementing a metadata program.

Spatial Data Transfer. The Spatial Data Transfer Standard (SDTS) was developed to promote and facilitate the transfer of digital spatial data between different computer systems while preserving all relevant, associated information. The supplemental information includes attribute data, georeferencing information, data quality reports, data dictionaries, and other supporting metadata. The USGS is the lead agency in developing the SDTS.[64]

The need for the SDTS is because the various GIS software manufacturers each use their own proprietary data structures. This means that, for instance, spatial data created by AutoCad cannot be directly used by ARC/INFO without first making a conversion. Other reasons for the SDTS involve the attribute data for each spatial record and metadata for the entire data set. The SDTS is designed to encode and exchange spatial data without losing or corrupting any of the pertinent associated information.

Most SDTS interaction by local government personnel will involve translating data from the SDTS to the format required by their specific GIS software. In rare cases, data might need to be converted to the SDTS. All major GIS software manufacturers include extensions to perform this conversion. However, because much of the data available from the Federal Government is stored in the SDTS format, it is necessary to become familiar with the Standard in order to perform the necessary data conversion.

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[64] United States Geological Survey, *What is SDTS?* [on-line] (February, 2000); available from http://mcmcweb.er.usgs.gov/sdts/whatsdts.html; Internet.

Cadastral Data. The Cadastral Data Content Standard provides semantic definitions of objects related to land surveying, land records, and land ownership information. According to the FGDC, cadastral data includes the spatial information necessary to describe the geographic extent of the past, current, and future rights and interests in real property. These rights and interests are recorded in land record documents. The spatial information necessary to describe them includes surveys and legal description frameworks such as the PLSS, as well as parcel-by-parcel surveys and descriptions.[65] The major goals of the Standard are to:

- Provide common definitions for cadastral information found in public records
- Standardize attribute values
- Resolve discrepancies related to the use of homonyms and synonyms in federal land record systems
- Provide guidance and direction for land records and land surveying professionals on standardized attribute values and definitions

Most of the material contained in the Standard consists of cadastral data entities and their associated database definitions. The entities are those regarded by the FGDC as necessary to fully account for all possible cadastral records. Also included in the Standard are definitions of many cadastral-related terms and concepts.

Geospatial Positioning Accuracy. To date, the FGDC has issued the Geospatial Positioning Accuracy Standards in five parts. They are as follows:

- Part 1: Reporting Methodology
- Part 2: Standards for Geodetic Networks

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[65] FGDC, *Cadastral Data Content Standard for the NSDI*, 2.

- Part 3: National Standard for Spatial Data Accuracy
- Part 4: Standards for Architecture, Engineering, Construction, and Facilities Management
- Part 5: Standards for Navigation Charts and Hydrographic Surveys

The purpose of Part 1: Reporting Methodology was essentially to introduce the Standard. It describes the objective, which is to provide a standardized methodology for assessing and reporting the accuracy of horizontal and vertical coordinate values for clearly defined features where the location is represented by a single point.[66] The FGDC recommends that all spatial data activities develop their classification scheme for reporting positional accuracy. The FGDC recommendations are as follows:

- Report horizontal accuracy such that the true or theoretical location of a point falls within the radius of a circle of uncertainty 95-percent of the time
- Report vertical accuracy such that the true or theoretical elevation of a point falls within plus-or-minus a linear uncertainty value 95-percent of the time
- Describe the method used to evaluate accuracy
- Reference horizontal coordinate values to the North American Datum of 1983
- Reference elevation values to the North American Vertical Datum of 1988[67]

Of major concern to developers of a MPLIS in the publications listed above is Part 3: National Standard for Spatial Data Accuracy (NSSDA). The objective of the NSSDA is "to implement a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to

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[66] FGDC, *Geospatial Positioning Accuracy Standards, Part 1: Reporting Methodology*, 1.

[67] Ibid., 1.

georeferenced ground positions of higher accuracy."[68] It was developed by the Base Cartographic Data Subcommittee of the FGDC in order to update the NMAS and the ASPRS Accuracy Standards for Large-Scale Maps.

The FGDC recognized that the NMAS of 1947 was not adequate for reporting the accuracy of digital spatial data, which can be easily manipulated and output to any scale. In addition, whereas the NMAS dealt with map units such as 1/30 inch, accuracy reporting under the NSSDA is stated in ground distances. This allows users to compare spatial data sets of differing scales or resolutions.

The NSSDA relies on a minimum of 20 sample points, randomly selected and evenly distributed throughout the area of interest. These test points must be from some independent source and of higher accuracy than the particular data set tested. Root-mean-square error (RMSE) is used to estimate the positional accuracy of the points. RMSE is the square root of the average of the set of squared differences between the coordinate values in the data set and the coordinated values for their corresponding points of higher accuracy.

Again, accuracy is reported in ground distances at the 95-percent confidence level. This means that 95-percent of the positions in the original data set will have an error equal to or smaller than the reported NSSDA accuracy value. When 20 points are tested, this confidence level allows one point to fail the published threshold of the product.

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[68] FGDC, *Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy*, 2.

Orthoimagery. The Content Standards for Digital Orthoimagery are applicable to those involved in creating and disseminating digital orthophotography products. Although it will be rare that local government personnel be tasked with this activity, using digital orthophotographs to extract planimetric information will, in time, no doubt become commonplace. At present, the most available form of orthoimagery for most local government jurisdictions is the DOQQs constructed by and for the USGS. These products are often available free of charge over the Internet or for a nominal fee from the USGS. Therefore, it behooves one to understand the procedures involved in constructing the images as well as their limitations for use.

The Standard was intended to set a common baseline for producing and documenting digital orthoimagery that will allow users to get the most use from the product. It applies to NSDI Framework digital orthoimagery produced or disseminated by or for the Federal Government.[69] The draft version was developed by the Base Cartographic Data Subcommittee of the FGDC.

The Standard states that, "By definition, orthoimagery exhibits geometric qualities, which distinguish it from unrectified imagery, hence accurate measurements can be made from digital orthoimagery and features on orthoimagery will be correctly positioned."[70] Therefore, it is mandatory that producers of the product report the positional accuracy of the data. The NSSDA shall be used for the accuracy report.

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[69] FGDC, *Content Standards for Digital Orthoimagery*, 1.

[70] Ibid., 11.

As mentioned, the Standard applies to those constructing orthoimagery. It sets various limitations with regard to the following:

- Formats for transferring the data
- Accuracy of the necessary digital elevation data and geodetic control
- Aerial extent of each image
- Spatial and radiometric resolution
- Spatial accuracy reporting
- Image smear (portions of the original image that were hidden from view)
- Cloud cover
- Image mosaicking procedures
- Metadata

Again, understanding the procedures involved in constructing an orthoimage allows one to more accurately extract information from it. As described in the metadata, the USGS DOQQs have been produced according to this Standard. Therefore, one can read the metadata entries to discern whether the product is acceptable for a particular application. For most local governments, DOQQs should become a valuable asset.

State Guidelines

As mentioned earlier, various state GIS programs have adopted certain Federal guidelines regarding MPLISs for state and local government. Many are attempting to develop spatial data according to the recommendations of the FGDC, and to comply with the standards of the NSDI. With regard to specific MPLIS guidelines, the material discovered during this project was found to be reiterations and variations of the major recommendations in *Procedures and Standards for a Multipurpose Cadastre*, *MPLIS: the Guidebook*, and the various standards of the FGDC.

New York, Nebraska, and Minnesota are noteworthy examples of states that have issued MPLIS guidelines and recommendations. In 1996, the New York State Archives and Records Administration sponsored the publication of *Local Government GIS Development Guides*, which includes chapters that address the major aspects of implementing a local government GIS program. A copy of the publication is available free of charge by contacting the Administration.

Although it is not yet finished, the Nebraska GIS Steering Committee has published a set of recommendations for GIS/LIS implementation. It relies heavily on the Federal publications, but reduces the information down to short sections that are more easily readable.[71] Of special note: the Committee placed strong emphasis on building a solid network of geodetic control stations for referencing the PLSS. In fact, Nebraska has established an impressive array of control stations within the High Accuracy Reference Network (HARN). HARN stations are high-order survey control points, which have been surveyed by both conventional methods and GPS. Their coordinates are known to a centimeter level of accuracy.

The Intergovernmental Information Systems Advisory Council of Minnesota has published on the Internet the *Implementation Guide for Parcel-Based GIS in Minnesota Local Government*.[72] This publication much resembles a generalized version of that by

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[71] http://www.calmit.unl.edu/gis/LIS_Stds_Intro.html.

[72] http://www.gis.state.mn.us/iisac/gisindex.html

the State of New York. However, it might provide one with a checklist of the various tasks involved in implementing a GIS program.

A very useful offering from the State of Minnesota is the *Positional Accuracy Handbook*.[73] This publication instructs one in using the NSSDA to measure and report the quality of spatial data. It also presents case studies in which different groups applied the NSSDA to assess the accuracy of important data sets.

A Short Summary

The above discourse was not intended to completely summarize the investigated publications. It was intended to inform the reader of an assortment of information available regarding this topic and present what information is considered important. Therefore, it is recommended that the reader obtain this information to ascertain its utility and value.

From the publications reviewed, certain issues of considerable importance to the MPLIS spatial database became evident. First, and most important, the foundation of the spatial database should be a dense network of geodetic control. This does not mean to merely obtain a data set containing the PLSS. It means determining, as closely as practical, the actual coordinates of as many control points as possible. The geodetic control establishes the framework for the other data themes to follow.

Second, thoroughly describing the necessary details of each data set is essential. Many resources are devoted to developing digital data. If its quality is to be assessed,

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[73] http://www.mnplan.state.mn.us/pdf/1999/lmic/nssda_o.pdf

there must be some method of determining its accuracy, lineage, and limits of use. Every publication reviewed stressed the importance of metadata.

Third, there are standards. Standards provide consistency and reliability. Consistency and reliability means that less money is spent searching through data files, fixing errors, and reprinting maps with better, more appropriate data.

PEARLS FROM THE INTERVIEWEES

Of the four GIS managers interviewed, two (Rj Zimmer from Lewis and Clark County; Rick Breckenridge from Flathead County) were licensed land surveyors. The other two (Allan Armstrong from Gallatin County; Tom Tully from Butte – Silver Bow County) had no formal surveying experience although each had considerable experience with cadastral mapping, and both were conversant of surveying issues. The contrast in backgrounds between all of the individuals provided an interesting, multifaceted perspective of the issues that are important to this discussion.

LEWIS AND CLARK COUNTY

Rj Zimmer is the GIS manager for Lewis and Clark County and the City of Helena, Montana. He is also a contributing editor for *Professional Surveyor*, a trade publication for the surveying community. At the time of the interview, Mr. Zimmer had 25 years experience in land surveying including 13 years experience in GIS. He had been in his present position for approximately five years.

CURRENT ACTIVITIES

As of October 2001, Zimmer's group was involved in an orthophoto project covering the City of Helena and a portion of Lewis and Clark County. Their major purpose for the imagery was to obtain planimetric information such as hydrography, buildings, road edges, utilities, fence lines, building footprints, and contour lines. In the urban area, the scale of the photography was 1:1,200 (one inch equals 100 feet). In the rural area, the scale was 1:2,400 (one inch equals 200 feet).

Zimmer was also in charge of the base mapping for both the city and county. Because of budget constraints, two separate procedures were involved. For the city, the process was to first obtain the necessary orthophotography. Once the imagery was in place, the planimetric information was extracted. Next, the ownership parcels were built. The expectation was that all other data layers would properly overlay on the newly created base map information.

Orthophotography was too expensive for the county. Therefore, the emphasis was placed on building an accurate parcel map, which began with a solid survey control network and the necessary adjustments to the GCDB. Upon completion of the adjustment, the parcel information was built upon the GCDB. In the areas where data layers did not overlay correctly, Zimmer expected to obtain additional survey control. In urban areas, he expected positional accuracy between two and five feet whereas in certain rural areas, the accuracy may be off by as much as 100 feet. According to Zimmer, this positional tolerance was acceptable as long as the areas with the best accuracy coincide with denser population and critical land interests.

PHILOSOPHIES AND ADVICE

Positional accuracy was an important topic during the discussion. Zimmer described accuracy as "how well our stuff fits with other stuff." In other words, spatial accuracy is relative—as opposed to absolute. While emphasizing that all things are scale-dependent, Zimmer expressed that his primary interest was in the accuracy of the overlay.

He stated, "When people do geographic analysis, they will often overlay data upon aerial photography." Therefore, relative accuracy between the data layers and the photography is necessary.

Zimmer observed that the state of the GCDB and the process of parcel mapping are evolutionary—they should get better and better over time. As a surveyor, he understood well the problems in the original GLO survey notes, and as a result, the GCDB will be equally problematic. However, he added that the location of a survey monument takes precedence. In other words, "the corner is where it is," and GPS measurements define where a corner actually is regardless of the original surveyor notes.

To Zimmer, map disclaimers and statements of application constraints are mandatory. He stressed the need to provide adequate metadata. The GIS community has a responsibility to let users know what was done, how it was done, the purpose of the products, and information about the accuracy of the data sets. Regarding the liability issue of the parcel database, he does not perceive a problem, "provided that whoever made the map does not claim it as an authority in terms of placement." Maps are merely references to the actual legal documents.

People, survey control, and data maintenance were cited as the major challenges within the organization. People and data maintenance problems are related insomuch that individuals in other departments must be willing to be trained to maintain their own data sets. As Zimmer stated, "the GIS staff can't do it all." The issue of survey control relates to the problem of the GCDB and parcel map accuracy discussed earlier. To date, Zimmer's GIS department had spent approximately $200,000 on parcel mapping and

$65,000 on survey control. (This is in addition to $400,000 spent on the orthophoto project.)

GALLATIN COUNTY

Allen Armstrong is the GIS coordinator for Gallatin County, Montana. He is responsible for management and development of the department to create and maintain the GIS database. Prior to coming to Gallatin County, Mr. Armstrong was manager of GPS/GIS services at GeoResearch, Inc. in Billings, Montana. In that organization, he was responsible for project planning and system implementation consulting, data conversion activities, and database designs. Armstrong's experience spanned 15 years, in which he has authored many papers and conducted seminars on GIS-related issues.

CURRENT ACTIVITIES

Gallatin County was part of the NSDI Community Demonstration Project. The mission of the project was to demonstrate the effectiveness of a particular GIS project, and to pass the gained knowledge on to other local governments. A desired goal was to show the benefits of sharing information and data between agencies.

Considerable effort in Gallatin County's GIS Department was spent making data and information available to end-users. Armstrong had recently finished the publication of a county atlas. The atlas was an effort to "get the database into paper form." The printing cost of 600 copies was $30,000, and each copy was sold for $60. Additionally, the county's common base layer data is made available free of charge via the Internet. The software currently being used to serve the data is ArcIMS (Internet Map Server), which is produced by ESRI.

The departments that require the most GIS services are 911 Dispatch, Planning, and Environmental Health. Of special note: the GIS Department is continuously involved in crime mapping in which they map and analyze the calls to 911 Dispatch. By extracting the physical address from the county's telephone record database, the location of each person making a call to 911 Dispatch can be determined. From this, crime analysts can determine where to place more officers.

The county has recognized that personnel from other departments will not become full GIS users and developers; therefore, the mapping, analysis, and maintenance will remain a responsibility of the GIS staff.

In addition to GIS Coordinator, Armstrong was the MSAG Administrator for the county's E-911 project. His major activity, at the time of the interview, was GPS road and address collection, which was constantly required to maintain the databases that link incoming emergency calls to geographic locations.

The most costly procedure for the GIS Department was the collection of road and structure data. All road, access point, and structure locations were collected by GPS—in a mountainous county of more than 2,500 square miles. The longest running project, of course, was cadastral collection and maintenance. Maintaining the cadastral layer required periodic updating of parcel splits and combinations.

Philosophies and Advice

It was obvious throughout the discussion that Armstrong was very much service oriented. He recognized the amount of time spent by county personnel interacting with the public (mostly answering simple questions), and he strove for ways to make their efforts more effective. He regarded public safety as the first priority of any local government.

Armstrong expressed his frustration with the GCDB. When faced with the spatial inaccuracy of the product in Gallatin County, he decided to use the digital version of the PLSS and road intersections as the base reference for his parcel-mapping project.

An equally frustrating situation was the condition of addresses throughout the county. Many resident address numbers were blatantly out of sequence along various road segments, and the county contained a number of duplicate road names. Armstrong's belief was that no two roads within a jurisdiction should have the same name.

BUTTE-SILVER BOW COUNTY

Tom Tully is the GIS manager for Butte – Silver Bow County, Montana. Mr. Tully graduated from the University of Montana in 1977 with a degree in Geography and an emphasis in Cartography. Tully had worked as a GIS specialist for the county for seven years before becoming the program manager. His background included GPS, cadastral mapping, and data conversion projects.

CURRENT ACTIVITIES

The Butte – Silver Bow GIS Department was the oldest of the four visited. It was begun in the late 1980s, during the time when the area was deemed a Super Fund site by the Environmental Protection Agency. Because of the intense environmental assessment and analyses required by the Super Fund project, the department was provided with data layers extracted from orthophotography at a scale of 1:2,400. The resolution of the photography was such that the edges of roads, sidewalks, and buildings were clearly visible. The department was able to obtain this information as well as hydrography, power poles, fences, trees and wooded areas, and contour lines.

Most of the activities in the GIS Department involve producing custom paper maps. These include land-use maps, which are symbolized according to the land-use codes in the State's Computer Assisted Mass Appraisal (CAMA) database. On occasion, requests are fulfilled to supply GIS users with data. According to Tully, their data does not reside in a single database. Instead, they "have a lot of little databases sitting on individual computers." The department is considered to be in the maintenance phase whereby little expenditure is required to develop new data layers.

PHILOSOPHIES AND ADVICE

Tully observed that there are many who underemphasize data quality while others (mostly surveyors and engineers) tend to overemphasize data quality by expecting spatial accuracy to within one-tenth foot. He regards most data in a GIS, especially cadastral, as 'reference grade.' It should never be construed as 'survey grade.' Consequently, "care must be taken to document the data, whether it be in the form of metadata or a simple 'readme' file attached to the data set.... [Data developers] need to document the known errors and problems, and specify the useable scale of the data."

Tully had much praise for the accuracy of the data taken from the USGS 7.5-minute topographic maps while expressing considerable discontent for the 1:100,000-scale TIGER/Line data. When asked how much benefit he might gain from spatially accurate data beyond that from the 1:24,000-scale maps, he replied, "Probably not much." A reoccurring theme during the interview was the issue of scale and the problems that arise when data of varying scales are overlaid.

For Butte – Silver Bow County, the most important data themes are the cadastral layer and environmental data related to the Super Fund activities. The 1:24,000-scale digital PLSS was the fundamental base layer for the cadastral mapping project because of problems with the GCDB. In addition to the usual spatial inaccuracies, a complete GCDB coverage for the county did not exist when the cadastral mapping project began—nor did it exist at the time of the interview. The incompleteness was because of the large number of old mining claims in the area that must be taken into account when constructing a GCDB township. Tully was fully aware of the inaccuracies in the digital PLSS but asserted that they were inconsequential at normal mapping scales.

Tully recognized the value of a pilot study project in order to discover which methodologies provide the most reliable data. However, he cautioned that a realistic area must be chosen, and that an acceptable level of accuracy must first be determined before setting out to construct the database. He also noted the rewards of simply "getting the GIS program running" and "not letting the details bog you down."

FLATHEAD COUNTY

Rick Breckenridge had been the GIS project manager for Flathead County, Montana since 1993. Before coming to Flathead County, Mr. Breckenridge spent 18 years in the Army as an Infantry Officer and eight years as a Cadastral and Control Surveyor with the BLM. He also worked as a GCDB developer, and eventually became a GMM software instructor for various GIS workshops. In addition to being Flathead County's GIS project manager, Breckenridge maintains his own businesses in which he is a Professional Land Surveyor and mapping consultant. He contracts his services to various government agencies.

CURRENT ACTIVITIES

At the time of the interview, two members of the Flathead County GIS Department were dedicated to maintaining the cadastral, transportation, and address database. Parcel splits were captured from new deeds and COSs, new addresses were entered into the database soon after they were issued, and road data was collected by GPS as soon as a new road was drivable.

In addition, temporary employees were hired to assist with the PLSS adjustment process. Here, the staff researches COSs and subdivision plats for recent survey descriptions that references PLSS corners. In areas of relatively easy access, the coordinates of available PLSS monuments are measured by GPS. From this data, Breckenridge adjusts the GCDB data provided by the BLM. This process will provide an extremely accurate representation of the PLSS in Flathead County.

Breckenridge had constructed the spatial database portion of the GIS with older releases of AutoCad drafting software. To link the map data to the county's tabular database records, he used an inexpensive software product called Geo-SQL.

The office of Clerk and Recorder was the impetus for the GIS Department, which was begun in 1993. Hence, the department that most utilized GIS services and products was Clerk and Recorder. In addition, the Planning Department, Road Department, real estate offices, and real estate appraisers were frequent users of GIS data and services.

PHILOSOPHIES AND ADVICE

Breckenridge asserted that his approach to building his GIS was "different from the canned, out-of-the-box approach." He stressed that the geodetic control, the PLSS, and the cadastral data should be one and the same. Because survey descriptions begin at some point within a reference framework such as the PLSS, "those three data themes cannot be separated." It was interesting to note that Breckenridge used for his guide a publication sought for this research project: *Need for a Multipurpose Cadastre*. He believed that the cadastre must truly be multipurpose in order to capture the complexity of land interests, and simply to justify the expense of the GIS Department.

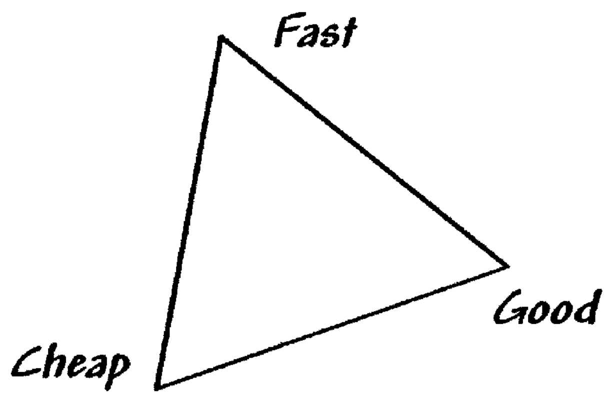
Breckenridge had much to say regarding the accuracy of the cadastre. To him, if new line work from a recent survey description did not fall to within 10 feet of the existing parcel boundaries, then investigation must be done to determine why. He pointed out that the width of a property line drawn on a 1:400-scale map is equal in width to approximately 10 feet on the ground. According to his reasoning, the location of the line is the best it can be.

Breckenridge was asked how much confidence he put in the state plane coordinates reported by a survey-grade GPS receiver. He had absolute confidence provided two conditions were met: the person operating the GPS receiver must be qualified, and the measurements must be repeated to within a few centimeters variance. He felt that resource-grade GPS receivers are readily capable of reporting coordinates to one-meter accuracy.

With regards to the dispute between surveyors and GIS professionals, Breckenridge did not ascribe to the notion that GPS activity constitutes surveying. In his opinion, "You are out there collecting information and it just happens to be on a survey monument. Big deal. They're free. You're not surveying. However, you shouldn't use your coordinates from GIS or GPS as a legal description. GPS is not that accurate." He observed that the quarrel between surveyors and GIS professionals is subsiding, which, in his opinion, is as it should be.

During the interview, Breckenridge drew his "fast-good-cheap triangle" diagram to illustrate what local government officials and managers can expect regarding GIS implementation. The concept was profound, and the diagram is shown in Figure 6.

Figure 6 - Rick Breckenridge's "Fast-Good-Cheap" Triangle



As described by Breckenridge, the situation is that officials and managers wish to know how quickly a GIS can be implemented as well as the cost. Most often, an actual cost and accurate time line is near impossible to predict. However, Breckenridge suggests drawing and labeling the triangle in Figure 6. While gesturing to his drawing, he stated, "Tell them that they can have any two of the three. They can have it fast and cheap, but it won't be good. They can have it cheap and good, but they won't get it fast. They can have it fast and good, but it ain't gonna be cheap."

REVELATIONS FROM THE INA

During the 1990s, Ravalli County experienced a 44-percent rate in population growth. This has resulted in increased workload in nearly every department. Those especially affected were the offices of Planning, Environmental Health, and Clerk and

Recorder. Individuals from these departments as well as those from the Sheriff's Department were interviewed.

All of the individuals interviewed expressed an interest in GIS. Most recognized that an implemented system would provide improved service to the public and other agencies. All voiced the impression that certain GIS tools would indeed make their jobs somewhat more efficient and effective. Certain individuals expressed interest in having GIS capabilities within their own offices and were eager to see current data stored on a central server.

DEPARTMENTAL SUMMARIES

Following are summaries of sample application and data requirements determined for selected departments within Ravalli County.

PLANNING DEPARTMENT

The major activities of the Planning Department pertain to managing the growth and development of Ravalli County. The department works with the Commissioner-appointed Planning Board to implement and administer land use ordinances and review subdivisions. The primary responsibilities of the department include:

- Community planning projects
- Processing Special Zoning District applications
- Administration and enforcement of subdivision regulations
- Rural addressing and road naming
- Development of a Ravalli County Growth Policy

Because of the information kept by the department, it is frequently visited by individuals from mortgage title insurance companies, land developers, and the public. In addition to reviewing subdivision applications, much of the time here is spent assigning and maintaining rural addresses and road data.

To assist the staff with the duties mentioned above, a number of GIS applications were identified. Examples included address-geocode maps, subdivision review maps, and an automated method of assigning new addresses. Following is a brief description of these applications.

Address-Geocode Maps. An address-geocode map is a large-scale map showing the ownership parcels and roads within one PLSS section. In densely populated areas, either two or four maps are required to adequately display the information. Hand-written on these maps are each parcel's unique identifier (geocode), road names, address numbers, and a small hatch mark indicating the approximate location of access. These maps are intensely used by the staff for addressing, and by individuals from title insurance companies to confirm the existence of parcels and associated addresses. Consequently, the maps are quickly becoming difficult to read beyond the wrinkles, erasure smudges, poor handwriting, and White-Out.

The staff requested a new address-geocode map series to replace the old. The new maps would be much easier to read, and the automated method of producing them would ensure that new ownership parcels would be accounted for. In addition, the new maps would be offered for sale, which would generate income for the department as well as reduce the amount of interruptions.

Subdivision Review Maps. After the planning staff has reviewed a subdivision application, a public hearing is called to present the request to the Planning Board, which will give a recommendation regarding approval. This hearing provides interested individuals the opportunity to speak either for or against the proposed subdivision. Many issues are discussed with regard to water quality and quantity, environmental quality, parcel density, and access. Discussions at these meetings are often polarized and heated.

To enhance the review process, the planning technicians requested a custom map to display at the subdivision review meetings. This map would show the subdivision, all surrounding parcels, and all roads in the area. This data would be overlaid on the 1995 USGS DOQQs. The second map would show the same data, but overlaid on rectified aerial imagery taken in 2002.

The purpose of the subdivision review map would be to demonstrate to the attendees the changes in the landscape over the last seven years. In most cases, the changes are dramatic. This new information is hoped to help the Planning Board members and the commissioners make better decisions regarding the subdivision approval or special requirements.

Rural Address Application. Physical addresses in the rural areas are assigned by the staff of the county Planning Department. (Addresses within incorporated city limits are the responsibility of the city planners.) Unfortunately, rural roads are often configured such that determining an appropriate address is difficult. Rural addressing standards dictate that 1,000 address numbers are possible for one mile of road. This means that, if the beginning address number of a road segment is 400, then the following numbers must increment by one for every 5.28 feet along the road with odd numbers on one side and even numbers on the other. Thus, the address number for a house built 53 feet from the intersection would be 410. This situation, of course, exists only in a perfect world.

In Ravalli County, a significant number of addresses are out of sequence, in reverse sequence, or referenced to the wrong road entirely. Much of this problem has been because of inadequate source information and improper judgment by those in years past. To reduce the opportunities for future error, and to speed the process, the staff requested an automated addressing method.

Automating the addressing process can be provided by means of a custom GIS application that would report an address number simply by clicking a mouse on a digital map of the road data theme. The application could be written such that, by clicking in a view of an active road layer, a request would be sent to find the nearest arc to the click. The name, address range, and address direction associated with that arc would be processed to determine the closest address to the mouse click. If the address number is in use, the algorithm would choose a different number. This procedure, of course, would require a spatially accurate road theme with accurate and current attributes as well as a current address database. The data themes and associated attributes necessary to develop the above applications are shown in Table 1. The attribute, 'Location' means that the spatial location of the feature is required.

Table 1 - Data Required by Planning Department Applications

FEATURE	TYPE	ATTRIBUTES
Ownership Parcel	Polygon	Geocode; Location
Structure	Point	Address_Number; Location
Road	Line	Name; Low_Address; High_Address; Direction; Location
Postal Area	Polygon	Name; Zip_Code; Location
Emergency District	Polygon	Name; Type (Ambulance, Fire, Law); Location
Proposed Subdivision	Polygon	Name; Location
DOQQ	Image	Location
2002 Aerial Image	Image	Location

ENVIRONMENTAL HEALTH DEPARTMENT

The Environmental Health Department is the enforcement branch of the board of health. The director is the Sanitarian, who is appointed by the County Commissioners and licensed by the State of Montana. The department is responsible for:

- Food service, public accommodation, RV campground, and trailer court inspection
- Subdivision review under Department of Environmental Quality contract
- Issuing well and sewage disposal permits
- Administering the Floodplain Management Program
- Administering the Community Decay Ordinance and Junk Vehicle Program
- Public drinking water and air quality monitoring

The Environmental Health Department is frequently visited by land developers and the public wishing to obtain septic system and well permits. Issuing these permits requires that designated members of the staff visit proposed building sites and make certain determinations. A member of the staff is dedicated to administering the Floodplain Management Program, which requires determination of the whereabouts of a building site in relation to the river floodplain.

The GIS applications to assist with the functions of the department included GPS inventory of septic tank locations, GPS inventory of well locations, and an application to determine the location of land parcels with respect to river flood stages. These applications will be briefly described.

GPS Inventory of Septic Tanks. State law requires that a permit be issued to install a septic tank. To issue the permit, certain criteria must be met such as a minimum distance from a well, a minimum capacity of the tank and depth below ground, and a minimum length and configuration of the associated drain field. The department staff wishes to maintain an inventory of all septic tanks within the county. This inventory would include accurate coordinates of the location of each tank, as well as all applicable attributes. The coordinates would be provided by GPS, aerial photographs, or survey plats and the attribute information would be provided by department records.

GPS Inventory of Wells. Permits are required for the installation of water wells. The criteria for installing a new well include its purpose in relation to surrounding wells, its assessed impact on the surrounding aquifer, and its distance from an existing septic system. In the same manner as septic tanks, the staff wishes to inventory all wells within the county. Again, the data collection method would be consistent with that of the septic tank data.

Floodplain Application. When a home is built, its location with respect to the flood stages of a river or stream will determine its insurance premium rate or even its legality. For instance, the county recognized three flood stages of a river: an annual flood stage, a 100-year flood cycle, and a 500-year flood cycle. Homes are not to be built within the annual flood stage area. Insurance companies will drastically increase the premiums for homes built within the 100- and 500-year flood areas.

The Floodplain Administrator requested an application to quickly make ad-hoc flood hazard determinations. This would require overlaying a floodplain data layer on the cadastral layer to make a visual judgment. The cadastral layer would be queried by either geocode or tax identification number. If a potential flood hazard exists, the administrator would recommend that a more rigorous survey be performed.

Table 2 shows the data themes and associated attributes required for the above example applications.

Table 2 - Data Required by Environmental Health Applications

FEATURE	TYPE	ATTRIBUTES
Ownership Parcel	Polygon	Geocode; Owner; Acres; Location
Structure	Point	Address_Number; Number_Of_Bedrooms; Location
Road	Line	Name; Location
Stream	Line	Name; Type (Ditch, Perrenial, Intermittent); Location
Septic Tank	Point	Unique_ID; Type; Size; Location
Drainfield	Line	Unique_ID; Conduit_Type; Location
Well	Point	Unique_ID; Owner; Parcel_Number; Status; Depth; Type; Driller_Name
DOQQ	Image	Location
2002 Aerial Image	Image	Location

As seen in the above table, the attribute, 'Unique_ID' is associated with Septic System, Drain Field, and Well. This identifier will be used to relate the spatial records in the GIS with other record information maintained separately. The attribute, 'Geocode' is also a unique identifier, but will only be used to query the spatial database and locate a parcel.

CLERK AND RECORDER

Individuals in the office of Clerk and Recorder are responsible for storing and maintaining records related to land ownership, births and deaths, and elections. These records include deeds, COSs, maps, birth and death certificates, and voter registration records. In addition to warehousing these instruments, the office is responsible for maintaining the electronic database in which much of the information is also recorded.

The office of Clerk and Recorder is visited by information seekers more often than other departments. This is where title insurance companies search for the chain of title for real estate transactions. Developers and surveyors also come here to search for historic COSs and subdivision plats pertaining to their areas of interest. When lawsuits erupt from feuding neighbors, the records kept by the Clerk and Recorder will be used to settle the dispute.

Examples of GIS applications to assist those in the office of Clerk and Recorder include geocode maps, levy district maps, and an application to accurately determine and define the boundaries of administrative districts.

Geocode Maps. As well as the Planning Department, the office of Clerk and Recorder must maintain a set of maps showing ownership parcels and their associated geocode numbers. These are known as geocode maps. Unlike those kept in the Planning Department, the Clerk and Recorder geocode maps do not show physical address numbers nor points of access. Other than this, the two map sets are identical.

The same maps produced for the Planning Department could serve the needs of this application. Address numbers would be easily removed from this map set. This automation process would free up the valuable time of those who must update the maps by hand. Furthermore, it is possible to increase the geometric accuracy of the maps by entering the data with COGO methods.

Levy District Maps. Property taxes are assessed according to a number of criteria such as the size of the parcel, the number and type of improvements, and the levy district in which the parcel resides. Essentially, levy districts are segregated according to school district and fire protection district. For instance, Levy District 13-3 contains all of Lone Rock Elementary School District, a portion of Stevensville Elementary School District, all of Stevensville High School District, and all of Three Mile Volunteer Fire District.

From this example, it is evident that determining which parcel belongs to which district can become quite complicated. In addition, because much of this information is processed by an antiquated, unconventional DBMS, it is cumbersome to determine if a property is properly taxed according to its levy district.

The person responsible for updating the database requested maps to show all parcels within the county according to their levy district values in the database. Because of certain conditions in the past, many of the records have been assigned incorrect values. A thematic map of the parcels based on these values would quickly reveal the errors. When the errors are eliminated, the new thematic map would serve to define the exact boundaries of school and fire districts at the individual parcel level.

Redistricting. After every decennial census, local governments are required to redefine certain administrative districts, which must be delineated into areas of equal population. This is often called redistricting or reapportionment. The population figures used are those provided by the Census Bureau. The administrative districts in question include voting precincts and wards, Commissioner Districts, and State House and Senate Districts.

The person in charge of election matters requested a better method of determining new districts than those previously used. In the past, adjusting boundaries required many days of trial and error. A custom GIS application would reduce these tasks to a matter of hours. The data required for the application would be a digital file of the county's census blocks available from the Census Bureau.

Table 3 shows the necessary data themes and attributes to develop the above applications.

Table 3 - Data Required by Clerk and Recorder Applications

FEATURE	TYPE	ATTRIBUTES
Ownership Parcel	Polygon	Geocode; Parcel_Number; Owner; Levy_District; Location
Census Block	Polygon	Population; Location
Administrative District	Polygon	Type; Name; Location
Emergency District	Polygon	Type; Name; Location
School District	Polygon	Name; Location
Levy District	Polygon	District_Number; Location
PLSS	Line	Type (Township, Section, Quarter-Section, 16th-Section); Location
Road	Line	Name; Location
Stream	Line	Name; Location

Again, the attributes shown in the table above are those attached to the spatial features. Relations will be made to the existing database via the attributes 'Geocode' and Levy 'District Number.' Other relations will be performed by overlaying the various data layers and relating them to one another by means of a spatial join. A GIS can join tables according to the coincidence of their spatial location in the same manner as primary and foreign keys are used to join tabular files.

EMERGENCY SERVICES

An emergency service can involve a response to a fire, a crime, an accident, or some natural disaster. Agencies involved in emergency response include the Sheriff, various fire departments, and ambulance services. With regards to information needs for emergency services, Enhanced 911 (E-911) procedures have been in place for a number of years. Hence, the data and associated attributes and definitions necessary for E-911 service have been defined by the various agencies responsible for its implementation and maintenance. A critical component of an E-911 system is the MSAG database. As described earlier the MSAG database consists of a tabular file containing specific attributes. Table 4 shows these data requirements.

Table 4 - Required Attributes of the MSAG Database

Attribute	Data Type	Description
PREDIR	C	Prefix direction (N, S, E, W)
STREET_NAME	C	Name of street
SUFFIX	C	Suffix information about street/address
POSTDIR	C	Post direction (N, S, E, W)
LOW	I	Low address of street segment
HIGH	I	High address of street segment
COMMUNITY	C	Community
ST	C	State
O-E	C	Odd/even/both (O; E; B)
ESN	I	Emergency Service Zone number
DATE	C	Date of data input - MMDDYY
ESZ	C	Emergency Service Zone name

Although it is certainly a critical aspect of a MPLIS, the scope of this project does not include a thorough discussion of E-911. Information on this topic can be gotten from a number of sources including the National Emergency Number Association.[74] However, the issues pertaining to the E-911 database are central to this project. The position taken in this discussion is that the database of a MPLIS must be constructed in such a way that any changes made by appropriate personnel in any department will immediately result in the necessary changes to the E-911 system. This topic will be further discussed in the Revelations from the Pilot Study portion of this section.

Other GIS applications required by the Sheriff's deputies and local fire departments include tactical maps of criminal activity and large-scale fire district maps.

[74] http://www.nena.org.

Tactical Maps. The Sheriff's investigators requested tactical maps for raids on places of criminal activity. Most often, investigators are given a tip regarding the nature and address or location of some criminal activity. They will have only a short time in which to plan and execute the raid, and they consider it critical to have all pertinent information before hand. At times, the only geographic information immediately available is the address of the activity.

The most important component of these maps is recent aerial photography. A typical tactical map would contain an enlarged aerial photograph of the area, an indicator of the exact location of interest, contour lines indicating the nature of the terrain, and roads. The map must also contain an accurate scale bar to determine the best placement of deputies. Here, time is valuable; therefore, the map must be produced immediately.

Fire District Maps. In order to respond to fires in remote areas, fire crews have expressed their need for maps of their districts. Most available maps have been found to be inadequate for locating specific residence locations. Therefore, the crews responding to a fire emergency are often forced to rely on their knowledge of the area. Various fire chiefs have requested adequate maps of their particular district.

The requested format of the fire district maps was book form—somewhat akin to a road atlas whereby specific features would be listed in an index and referenced to a particular page. The requested content of the maps was rather detailed. The fire chiefs wished to see the locations of all roads and driveways, all residences and outbuildings, any hazardous materials such as fuel tanks, streams, bridges, and helicopter landing sites. In addition, each map must be annotated with all feature names including the addresses and names of the residents of each building.

The data themes and attributes requested for the above applications are shown in Table 5. The MSAG requirements are not included.

Table 5 - Data Required by Emergency Service Applications

FEATURE	TYPE	ATTRIBUTES
Ownership Parcel	Polygon	Geocode; Owner; Location
Residence Structure	Point	Address_Number; Occupant; Location
Out-Building	Point	Location
Hazard	Point	Type; Location
Road	Line	Name; Surface_Type; Location
Stream	Line	Name; Location
Bridge	Point	Load_Limit; Width; Status (Public or Private); Location
Tanker Fill Site	Point	Type; Capacity; Location
Helicopter Site	Point	ID; Latitude; Longitude; Location
Emergency District	Polygon	Type; Name; Location
Elevation Contours	Line	Elevation; Location
2002 Aerial Imagery	Image	Location

A Final Note

A beneficial result of the INA was determining which data layers and associated attribute information were most needed. Whereas some departments wished to see certain attributes of a particular feature, other departments requested others. By collating the individual lists of data requirements, a master data list was created. The list contained an entry for each data theme and all of the associated attribute definitions. From this, it was possible to build the feature data tables that were normally intrinsically part of the spatial records, and to decide which information was best kept in separate related tables.

The INA procedure described above is only an example. It lists sample applications for a chosen few departments. It should be understood that the proper procedure is to carry out the INA for every individual, in each department, who will interact with the MPLIS. As well, individuals from other institutions should be included if they are found to be frequent users of county records and information. Examples include those employed by title insurance companies, law firms specializing in land law, and land surveyors.

Revelations From the Pilot Study

The result of a pilot study project should be the culmination of test results, ideas, and recommendations. Throughout the course of this project, it became evident that the only realistic method by which to test and refine ideas was by building the sample database, discarding it, and building it again until sensible data models emerged.

Data Layers

It is difficult to find a definition of GIS that fails to describe its capabilities of layering data. Associated with the definition, one often finds a three-dimensional drawing of data layers stacked one upon the other. Usually, the drawing will display the transportation, cadastral, hydrography and PLSS layers. However, it is rare to see such a diagram that shows the various layers within each layer. For instance, the cadastral layer itself is composed of many themes of information, all of which are of equal importance. By definition, the cadastre consists of varying interests, rights, and responsibilities. These are often manifested as easements, restrictions, zoning, and administrative districts among others. As well, depicting the transportation layer is not limited to merely showing roads and their associated names. There are bus routes, surface conditions, address ranges, easement widths, and many other aspects to consider.

The geography of the earth is complicated. It becomes more complicated when one attempts to catalog and describe it with a computer. While developing the database for this project, various 'sub layers' were developed to cope with the geographic complexity facing those in local government departments. What follows is a discussion of each data layer chosen for inclusion in the pilot project.

GEODETIC CONTROL

As described earlier, the geodetic reference framework for a MPLIS consists of a network of monumented corners within which cadastral surveys are conducted. For the surveyors, each monument in the network serves as a control point to tie or connect their subsequent surveys. Consequently, any legal description prepared by a competent land surveyor can be accurately relocated, retraced, and mapped. The cadastral portion of a MPLIS relies heavily on the same geodetic reference framework used by the surveyor.

The GCDB is the product of the efforts of the BLM to make the geographic coordinates of the PLSS corners accurate enough to serve as the framework for cadastral mapping. Although the accuracy of a typical GCDB township in its first stage is suspect, the value of the product is such that it can be adjusted—and therefore made better—when recent survey information and GPS measurements are obtained. The recent survey information replaces that from the older GLO records and the GPS measurements provide control points for the framework. In turn, each adjusted corner of the PLSS will serve as geodetic control for the parcels within the cadastral theme.

Recall that the NRC recommended that the spacing of geodetic control points be on the order of one-half-mile spacing in densely populated areas and one- to two-mile spacing in rural areas, and that the corners of the PLSS are sufficient in such a scheme.[75] Reliance on the PLSS is largely because of two factors. First, the function of the PLSS

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[75] NRC, *Procedures and Standards for a Multipurpose Cadastre*, 24.

was initially to define the corners of and provide legal descriptions for the tracts of land deeded to the original homesteaders. Second, state laws require surveyors to reference the monumented corners of the PLSS or to subdivision corners derived from them. Hence, a typical township in the GCDB provides at least 169 possible control points for a 36 square mile area.

Collecting Geodetic Control. Collecting geodetic control involves determining the coordinates of all reference monuments within the project area. By using survey-grade GPS instruments and the proper procedures, professional land surveyors can measure the location of these monuments accurately to within 0.1 foot. Those without surveying expertise are generally limited to approximately one-meter accuracy, which is generally considered acceptable for most cadastral mapping.

Although GPS technology has made the collection of geodetic control relatively inexpensive compared to normal surveying methods, finding and measuring every PLSS monument within even a small jurisdiction is cost prohibitive—if every monument can be found. Unfortunately, this is not the case; only a portion of the original corner monuments in any given PLSS township can be found. For this reason, some acceptable number of the monuments must be chosen for field measurement, and the remaining monuments estimated from the survey records.

Figure 2 (Chapter III, page 52) shows the PLSS section lines for the study area and the section and quarter section corner monuments that were found during the course of this project. The labels of the corners are the GCDB point identification numbers, which allow one to determine the relative location of a particular corner within the township. The found corners were measured to assess the accuracy of the initial GCDB and used to perform the GMM adjustment on the township as well.

The coordinates of the found monuments were measured according to the method described in Chapter III. The error of each point was considered as the distance between its coordinates in the GCDB and respective GPS coordinates. Table 9 in Appendix B lists the corners, their GCDB coordinates, their GPS coordinates, the error distance, and the NSSDA statistic for the data set. Again, the NSSDA statistic is a margin of error distance in which a data set is reported to be within at a 95-percent confidence level.

From the data, one can see that the errors in the GCDB are considerable. The average of the errors is 23.181 meters (76.05 feet) and the RMSE of the data set is 24.388 meters (80.01 feet). According to the NSSDA, the data tested 42.211 meters (138.49 feet) horizontal accuracy at the 95-percent confidence level. A PLSS township with this level of accuracy is quite unacceptable for use as a geodetic framework for a MPLIS cadastral layer where map scales are as large as 1:600 (1" = 50'). Furthermore, because many survey lots have dimensions less than this error, there is the potential that a parcel will be mapped in an area entirely outside its true location.

Adjusting the GCDB. Considering the factors involved, the amount of error in the GCDB is not surprising. The information used to build this particular township data set consisted of GLO surveyor notes as much as 130 years old and four control points taken from the USGS 1:24,000-scale topographic maps. The fact is that, in 1873, surveyors were physically unable to precisely measure distances and determine bearings. Furthermore, four control points taken from a paper map with an acceptable error of 40 feet does not constitute solid geodetic control. However, in order to build a GCDB township, the BLM cadastral technicians must start somewhere. At the time of initial construction, the only available information was that described above. Recent survey information and accurate GPS measurements must be used to adjust the coordinates in the GCDB to more closely represent the truth on the ground.

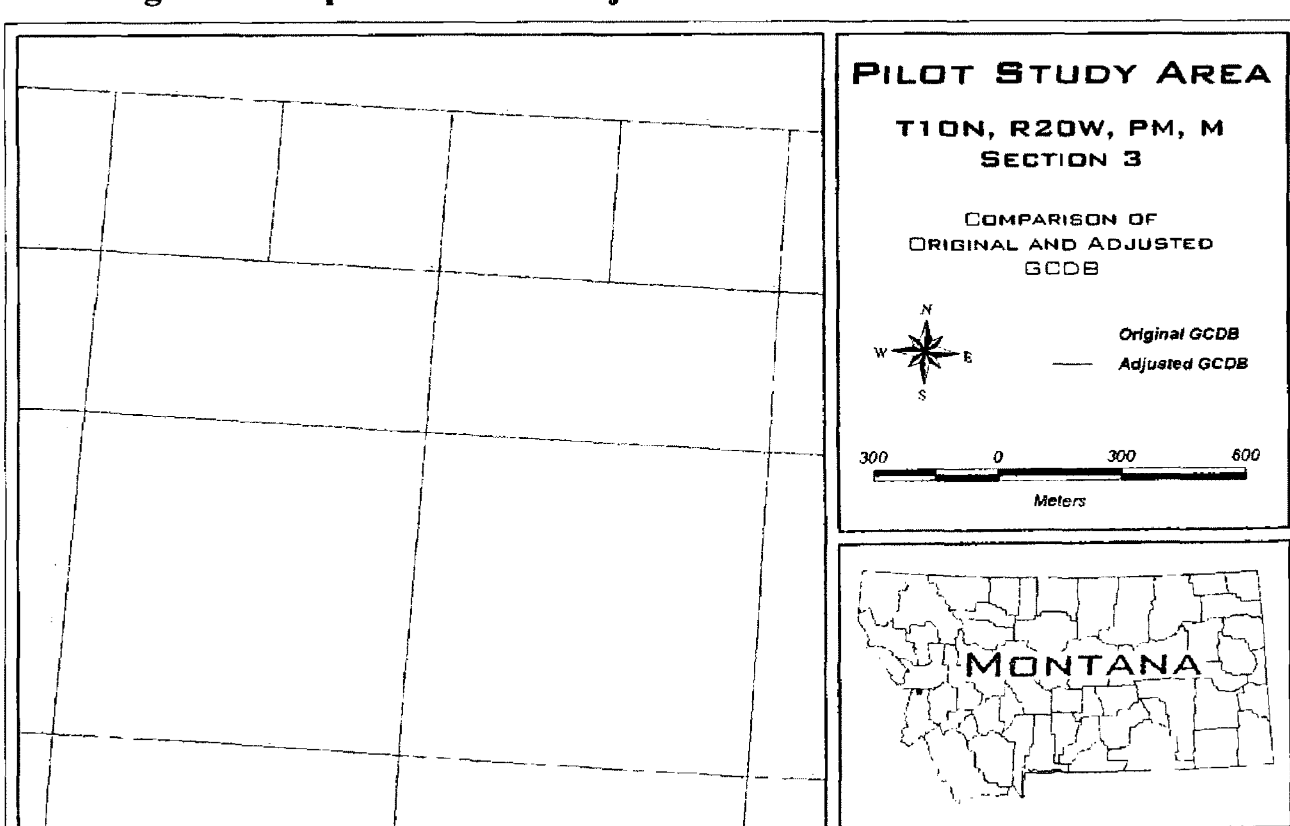
GMM was developed through a cooperative effort between the University of Maine, Department of Spatial Information Science and Engineering and the BLM. Dr. Raymond J. Hintz, of the University of Maine, was the primary developer of the application. The Windows version was developed by Kurt B. Wurm. GMM was developed to construct each GCDB township and to adjust it as well.

Recent survey information was obtained for the pilot study area and input into the appropriate GCDB records. This survey information consisted of modern survey measurements of the distances and bearings between each PLSS section and quarter section corner within the township. In many cases, the distance reported by an original GLO surveyor (and thus recorded in the GCDB) and the distance recorded on the modern survey plat differed dramatically. Some differences were found to be in excess of 100 feet. Distance measurements performed by licensed land surveyors with modern electronic measuring devices can be considered accurate to well within 0.1 foot. Because of various conditions, bearing calculations are considered accurate to within approximately 45-minutes of arc.

The final information needed to adjust the GCDB was a better assortment of control points. These consisted of the GPS measurements of the section and quarter section corners used to assess the accuracy of the original data set. It must be noted that the GPS measurements were of mixed quality and not considered appropriate for survey descriptions. Some measurements were perhaps very accurate (within one foot); some were perhaps up to three feet in error. (A safe assumption was that all measurements were better than the four original control points.) Technically, the quality of any given measurement cannot be accurately reported without a generous amount of redundant measurements. Only a qualified surveyor can determine the quality of a measurement with an appropriate level of accuracy. However, it was assumed that the GPS measurements were accurate to within one meter (3.28 feet).

The accuracy assumptions described above were used when entering data into GMM. Although recent survey information was not available for the entire township, enough was obtained to perform a reasonable adjustment. In some of the areas without survey information, GPS control was available to partially offset the deficiency.

Figure 7 - Map of the GCDB Adjustment Results



The map in Figure 7 shows the effects of the GMM adjustment for Section 3. The approximate XY shift in this section was 20 meters (65.6 feet) to the east and 9 meters (29.5 feet) to the south. Some corners in other portions of the township moved as much as 40 meters (131.2 feet).

An interesting observation is illustrated in Figures 12, 13, and 14 in Appendix A. COS and subdivision descriptions were entered with COGO methods and tied to the adjusted GCDB. The digital layer containing the survey lines was then overlaid on the 1995 USGS DOQQs. From the overlay, it appears that features visible in the imagery and survey lines (based on the adjusted GCDB) coincide well.

ORTHOIMAGERY

An important use of aerial imagery is to extract information about geographic features that can be seen from the air. Such features include roads, streams and lakes, buildings, and general vegetation. However, when extracting planimetric information from an orthoimage, a reasonable assumption must be made regarding the accuracy of the resulting data.

Metadata pertaining to the orthoimagery, which describes the source, purpose, and quality of the data is available from the USGS.[76] The survey control used to rectify the original images is reported to conform to the NMAS for 1:12,000-scale products.[77] This means that 90-percent of the chosen, well-defined points in the photo will fall within 10.16 meters (33.3 feet) of their true ground positions.

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[76] http://edc.usgs.gov/fgdc/doq_qquad.html

[77] http://rockyweb.cr.usgs.gov/nmpstds/nmas647.html

To test this claim, 24 well-defined points were tested according to the methods described in Chapter III, Methodology. Table 10 in Appendix B shows each point, its image coordinates, its GPS coordinates, the error, and the NSSDA statistic for the data set. Again, considerable effort was spent on this procedure to ensure that a reasonable accuracy assessment was possible.

The 24 GPS field measurements indicated that the accuracy of the DOQQs was well within the allowable NMAS error of 10.16 meters (33.3 feet). The minimum error distance was approximately 0.15 meter (0.49 foot) and the maximum error was approximately 3.62 meters (11.88 feet). With the exception of one, all of the test points in the study area were found to have a positional error of less than 2.60 meters (8.53 feet). From the data, one may state that the RMSE for this orthoimagery is 1.379 meters (4.52 feet). According to the procedures of the NSSDA, the data tested 2.387 meters (7.83 feet) horizontal accuracy at the 95-percent confidence level. The level of accuracy of the DOQQs is quite impressive. This means that the imagery will have many uses beyond serving as merely a backdrop for vector data sets. Further testing by comparing GPS transportation data to the roads shown in the DOQQs will confirm their usefulness.

TRANSPORTATION

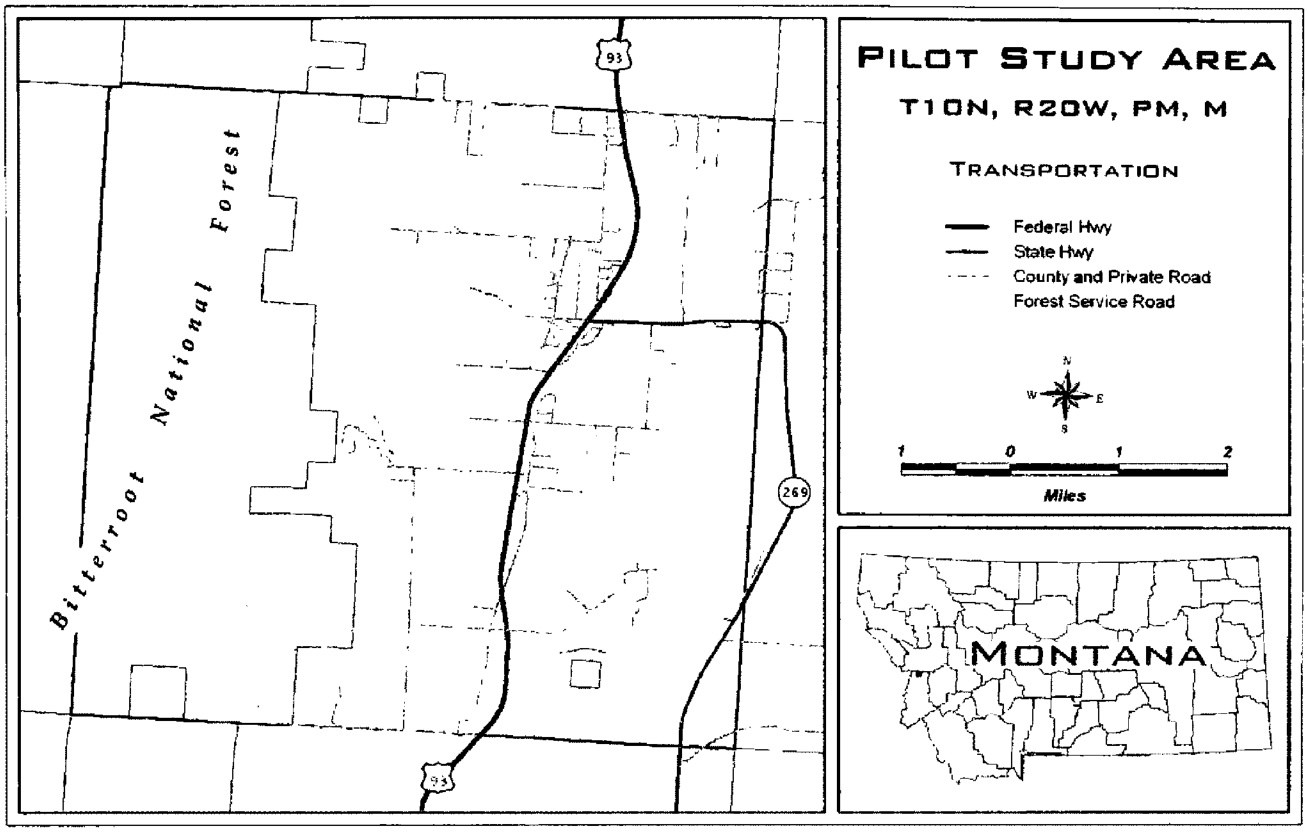
Four independent data sets for the transportation layer were used in this research project: 1) USDA Forest Service CFFs; 2) U. S. Census Bureau TIGER/Line files; 3) GPS data; and 4) data from on-screen digitizing from the DOQQs. Evaluation of the four data sets revealed certain advantages and disadvantages in both utility and data collection effort. For instance, the CFF data set contained the spatial thoroughness and accuracy of a 1:24,000-scale map, but offered very few attributes useable to a local government. The

TIGER/Line files contained many useable and needed attributes; however, the accuracy of the attributes could not be trusted and the positional accuracy of many of the lines was found to be unacceptable. Generating new transportation data facilitated the collection of the necessary attribute information, but required a considerable amount of initial effort. What was interesting was the difference in time and effort involved in the two methods of collecting new transportation data.

GPS Digitizing. During this portion of the project, 276 miles were driven to GPS approximately 76 miles of roads within the study area. The GPS process alone required seven field sessions totaling approximately 17.75 total hours. Field time was measured as the actual time between leaving from and returning to a nearby home base.

Additional time was necessary to differentially correct the GPS data files, export them to ArcView shapefile format, merge each shapefile, fix the errors in the line work, and enter the attribute information for each road segment. The time involved in these tasks was 11.5 hours. The entire GPS road project, including the necessary post-processing activities consumed slightly over 29 hours. Figure 8 shows a map of the transportation data collected for this project.

Figure 8 - Map of the Transportation Data Layer



An assessment of the spatial accuracy was made by overlaying the data on the orthoimagery. Certain spatial inaccuracies appeared to be prevalent in the GPS data. Examples of this observation were arcs that did not connect at intersections, prominent zigzagging, a considerable offset of various road segments, and lengthy periods of time in which no data would log into the GPS receiver. For this reason, extra time was required to make the necessary edits. The advantage of digitizing via GPS was that additional information such as road surface type and the actual road names indicated on the signs could be gathered at the time of data collection.

<u>On-Screen Digitizing.</u> Approximately 75 miles of roads were on-screen digitized from the orthoimagery. The same roads were on-screen digitized as were collected during the GPS session. The total time involved in digitizing the arcs was 3.7 hours. The

additional time that was required to name each road segment was approximately two hours, and another 3.5 hours were spent researching county records to correct inaccurate and unknown road names. The total time spent with this activity was 9.2 hours.

Comparison of the two data sets revealed only minute spatial differences between transportation data generated from GPS and on-screen digitizing—most appeared to be because of the normal, inherent GPS errors such as signal loss and multi-path interference.

There were obvious advantages and disadvantages to each of the previously described methods. On-screen digitizing required much less time to perform and produced "cleaner" results than GPS digitizing. The arcs digitized from the images were more consistent in their placement, extra vertices along straight road segments were eliminated, and intersections were connected immediately. Furthermore, the file size of the on-screen digitized data was roughly 60-percent of the size of the GPS file.

A considerable advantage to on-screen digitizing was that, by digitizing at the computer with the appropriate county records at hand, the arcs could be placed into the database in their proper direction for address matching purposes. An arc's direction is determined by its beginning and ending nodes. For address matching, the beginning of an arc representing a road segment must have the lowest address number assigned to its beginning node and the highest address number to its ending node.

The previously described procedure was merely for the collection of the spatial line work and perhaps a few attributes of the transportation data theme. Unfortunately, the geography of a road system is more complex than this. For instance, the MSAG database required by E-911 services consists of a single table containing certain attributes for each road segment. A road segment is described as a portion of a single road that is contained within a unique combination of all fire, ambulance, and law enforcement districts. These districts are referred to as Emergency Service Zones (ESZ). An MSAG road segment is independent of any intersection unless it demarks the change of addressing directions or the boundary of an ESZ.

Different from the MSAG requirements are those attributes required by each of the various departments within a local government. For instance, some of the required attributes for the transportation theme that were discovered during the INA process included the address ranges on both sides of the road, the surface type of the road, and the agency responsible for maintaining the road. Defining road segments between prominent intersections is better suited for addressing purposes. Therefore, a transportation data scheme suited for the MSAG is not compatible with the needs of the daily activities of say the Planning or Road Departments.

To accommodate the needs of the various applications of the transportation layer, ARC/INFO Region feature classes were used. Table 6 shows the chosen scheme for these feature classes.

Table 6 - Transportation Layer Feature Classes

Feature Class	Description	Type
NODE	NODES	POINT
ARC	ARCS	LINE
ROUTE.MSAG	MSAG RECORDS	LINE
ROUTE.ROADS	DESCRIBED ROAD SEGMENTS	LINE
ROUTE.MAINTAIN	MAINTENANCE ROUTES	LINE
ROUTE.SCHOOL	SCHOOL BUS ROUTES	LINE
EVENT - MILEPOST	MILEPOST MARKERS	EVENT
EVENT - SPEED LIMIT	SPEED LIMIT SIGNS	EVENT
EVENT - SURFACE	SURFACE CONDITION OF ROAD	EVENT

In a GIS, nodes are used to begin and end each arc. Hence, they will occur at the intersections of any number of connecting arcs. Road intersections are modeled using nodes. As such, the type of intersection (overpass, railroad crossing, etc.) and the type of control device (stop sign, yield sign, railroad signal) can be tracked in the node attribute table. This means that the mere geometry of the road network automatically contains a potential record for every intersection. From the node feature class then, one may build an inventory of all traffic control devices.

Events are feature classes used to track occurrences throughout the transportation network. There are both point events and linear events. Point events are placed according to a measurement along a route, and are used to define the locations of accidents, mileposts, and signs. Linear events are placed according to beginning and ending measurements, and can define surface conditions of any portion of the system.

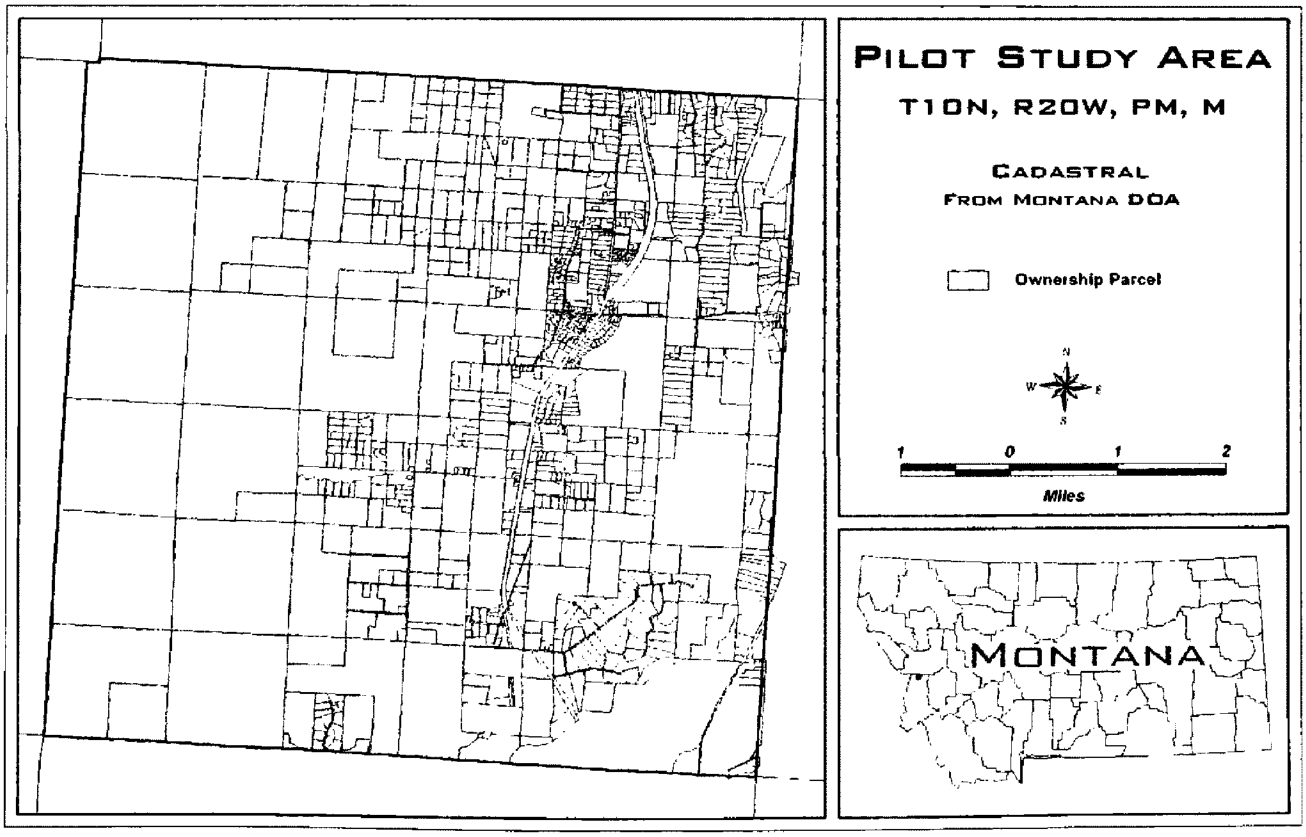
Routes are formed by grouping together a number of arcs. Portions of arcs may also be included in a Route. Because they are delimited by intersections, the Route subclasses for the MSAG and the described road segments will be constructed from full portions of arcs. The described road segments (ROUTE.ROAD) will be used for addressing and road inventory. The Route subclasses for maintenance and school bus routes will incorporate portions of arcs in addition to full sections. This is because the actual route traveled by the equipment may or may not begin or end at road intersections.

CADASTRAL

Two sets of cadastral data were collected for this project. First, data from the Montana Cadastral Project (MCP) was obtained, which had been initially constructed in 1999. Second, a new cadastral theme was constructed, using the adjusted GCDB as the base control layer. Both data sets reflect two methodologies for data collection as well as two methods of modeling the geography of the cadastre.

First, the data set from the MCP was constructed with the Arc, Node, and Polygon feature classes. All attributes pertaining to the land were stored in the polygon attribute table. The arcs were on-screen digitized from rectified, scanned images of the COSs, subdivision plats, and section plats. It appeared that some of the images were rectified to a digital version of the PLSS as seen on USGS topographic maps, and some were rectified to the GCDB, as it existed in 1999. Each parcel boundary was traced by GIS technicians according to their judgment of what constituted a parcel boundary. The only reference to the PLSS network was what was implied from the image rectification process. Figure 9 shows the cadastral theme as constructed for the MCP.

Figure 9 - Map of the Cadastral Data Layer



Second, a new cadastral theme was constructed by COGO methods for an assortment of COSs and subdivision plats for the study area. This involved entering the distances, bearings, and curve parameters of each segment of the entire legal descriptions in the documents. The portions of the legal descriptions that called for a tie to a PLSS corner were tied to the same corner during the COGO process. Constructing the new cadastral theme began after adjusting the township as described earlier.

After entering the cadastral line work from the applicable legal descriptions, the necessary polygon topology was built. The polygons were then used to populate the cadastral data model, which was developed using the subclasses described in Table 7. The ownership feature class (REGION.OWNERSHIP) most resembles the data set created for the MCP.

From the polygons created by the above methods, the various feature classes were populated according to theme. One or more polygons were assembled to form region records within the subclass, REGION.OWNERSHIP; a different set of polygons were assembled as records within REGION.EASEMENT; many polygons were assembled as records within REGION.COS; and so on. This process continued until an appreciable amount of the township was represented for the cadastral data theme.

Table 7 - Cadastral Layer Feature Classes

Feature Class	Description	Type
NODE		POINT
ARC		LINE
POLYGON		POLYGON
ROUTE.PLSS	SECTION AND QTR SECTION LINES	LINE
REGION.AMBULANCE	AMBULANCE DISTRICTS	POLYGON
REGION.COS	CERTIFICATES OF SURVEY	POLYGON
REGION.COUNTY	COUNTY BOUNDARY	POLYGON
REGION.EASEMENT	SPECIAL EASEMENTS	POLYGON
REGION.FIRE	FIRE DISTRICTS	POLYGON
REGION.FS_BDY	FOREST SERVICE BOUNDARIES	POLYGON
REGION.FS_OWN	FOREST SERVICE OWNERSHIP	POLYGON
REGION.FS_RANGER	FOREST SERVICE RANGER DISTRICTS	POLYGON
REGION.FS_RES	FOREST SERVICE RESTRICTIONS	POLYGON
REGION.GEOCODE	GEOCODE PARCELS (MCP)	POLYGON
REGION.LAW	LAW ENFORCEMENT DISTRICTS	POLYGON
REGION.MUNICIPAL	MUNICIPALITIES	POLYGON
REGION.OWNERSHIP	OWNERSHIP	POLYGON
REGION.ROW	COUNTY ROAD RIGHTS-OF-WAY	POLYGON
REGION.SCHOOL	SCHOOL DISTRICTS	POLYGON
REGION.SECTIONS	PLSS SECTIONS	POLYGON
REGION.SP	BLM SURVEY PARCELS	POLYGON
REGION.SUBDIV	LEGAL SUBDIVISIONS	POLYGON
REGION.TOWNSHIPS	PLSS TOWNSHIPS	POLYGON
REGION.WILD	WILDERNESS AREAS	POLYGON
REGION.ZONING	ZONING DISTRICTS	POLYGON

From the table, one can begin to see the complexity of the cadastre. The owner as recorded on a deed is certainly not the only entity with an interest in the land. The most obvious example of this is the notion of an easement. An easement is simply the legal right of an individual or agency to do something to or on another's property. Most easements concern water, roads, or public utilities. An easement has a defined boundary, which is rarely coincident with a property boundary. Easement boundaries are often drawn as hashed lines on plats, and the extents are often described separately in legal descriptions.

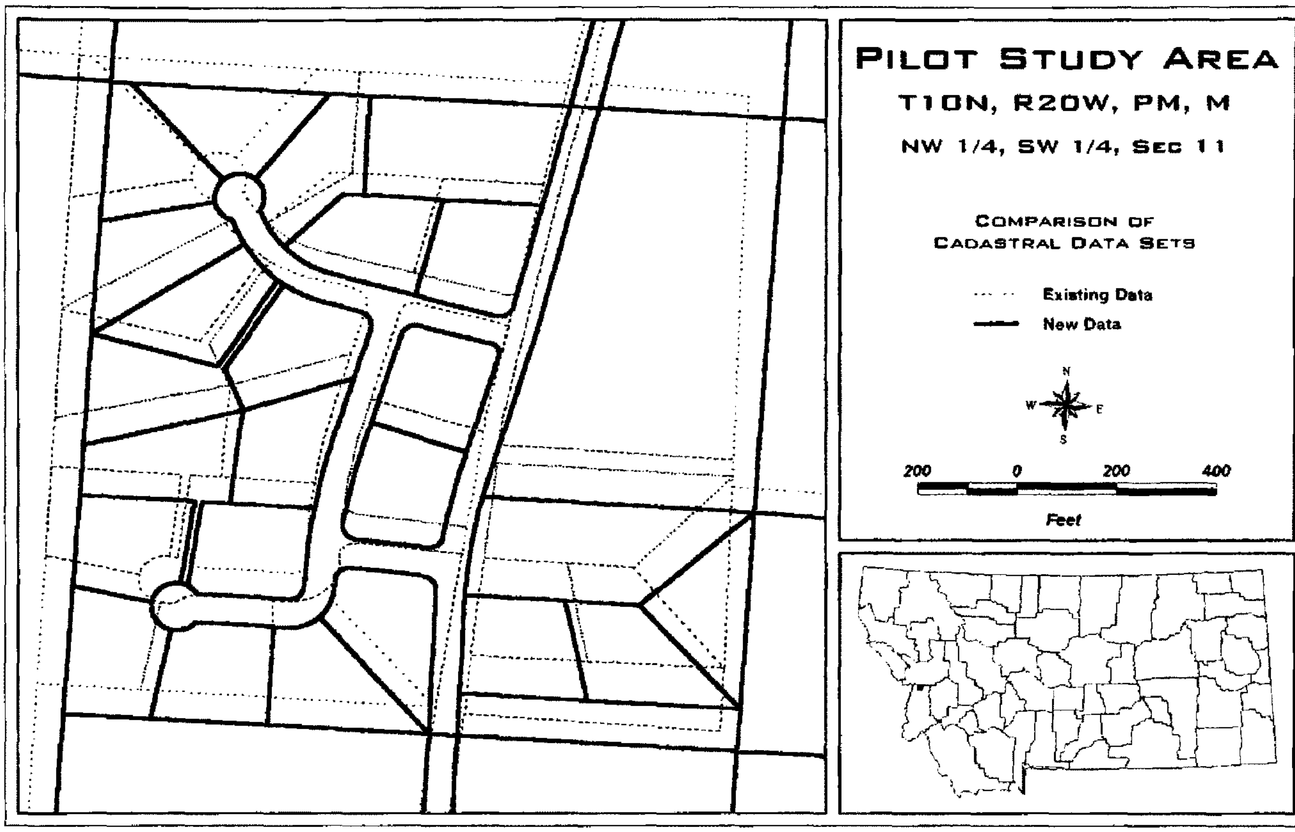
Although the polygon feature class serves as the foundation of the cadastral data model, it should be perhaps the least used. For instance, consider the case of one parcel of land. If one wishes to describe ownership, then the parcel is one polygon. However, if the parcel contains an access easement, then it consists of two polygons: one inside the easement and one outside. If a PLSS section line bisects the parcel and easement, then the property is made of four polygons: two in one PLSS section and two in the other. If the property contains an additional easement for an irrigation ditch, then the complexity increases dramatically. In this case, the polygons, some of which might be only a few square inches in size, lose much of their meaning.

Region feature classes give meaning to the above situation by clustering related polygons into logical categories. The polygons created from the arcs defining each boundary will form the foundation for defining the nature of each interest. Regions may overlap, they may contain voids, and they may stack one upon the other. These are tangible examples of the flexibility of Regions, and the necessity for using them.

Regions require time and thought to build; COGO is a time-consuming process as well. For this reason, many opt for the polygon data model such as that used for the MCP. On-screen digitizing is a relatively fast and simple procedure, and attaching ownership attributes to simple polygons is straightforward. The advantage here is that a cadastral data theme can be implemented in a relatively short period. Unfortunately, the theme is limited to modeling only one aspect of the highly complex cadastre.

Figure 10 shows a small portion of the study area in which the two data sets are overlaid. A part of the spatial differences appears to be correlated to the differences between the original and adjusted GCDB.

Figure 10 - Comparison of Cadastral Data Sets



HYDROGRAPHY

As it exists on the landscape, the notion of hydrography is rather simple: water flows downhill within channels, small streams converge into larger streams and rivers, and depressions capture and store water for some period. Features considered part of the hydrography theme include streams, irrigation ditches, rivers, ponds, and lakes.

Two existing hydrography data sets were obtained for this project: the TIGER/Line files and the CFFs. Their positional accuracy was assessed by overlaying each on the DOQQs. A portion of a third data set was on-screen digitized from the DOQQs.

As in the case of the transportation layer, the Forest Service CFFs provided respectable positional accuracy but little attribute information. CFF codes were available, which indicated the type of stream according to USGS classification schemes. The TIGER/Line files contained many attributes. Again, the attribute information was unreliable, and the positional accuracy was such that the data was useless at scales required by a MPLIS.

Table 8 shows the possible feature classes for a hydrography data theme. The nodes would indicate the confluence of streams, the Route feature classes would model various types of water channels, and the Region feature classes would model the standing or major bodies of water. Especially in this data theme, the polygon feature class would serve only as a foundation to the Regions.

Table 8 - Hydrography Layer Feature Classes

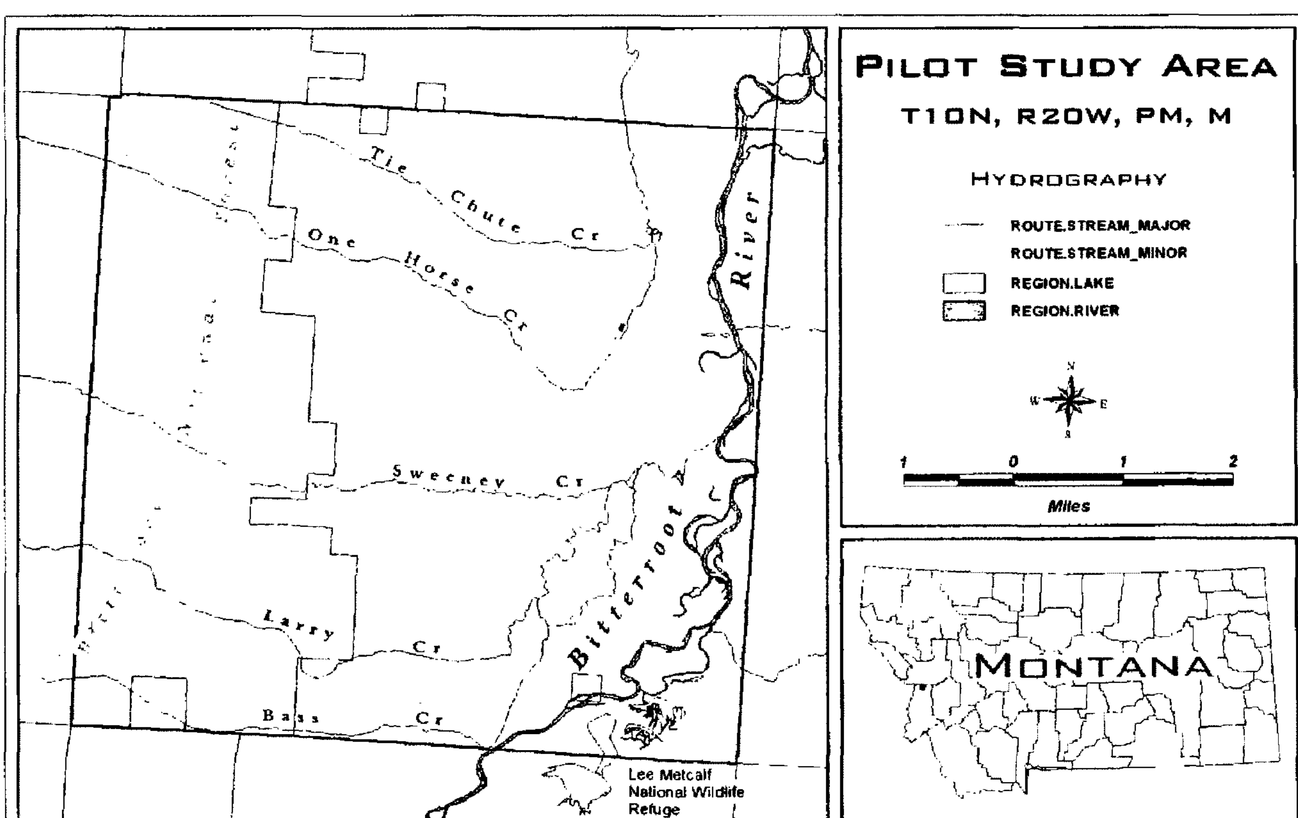
Feature Class	Description	Type
NODE		POINT
ARC		LINE
POLYGON		POLYGON
ROUTE.DITCH	IRRIGATION DITCHES	LINE
ROUTE.STR_MAJOR	MAJOR STREAMS	LINE
ROUTE.STR_MINOR	MINOR STREAMS	LINE
ROUTE.STR_RIVER	MAIN COURSE OF RIVERS	LINE
REGION.POND	MISCELLANEOUS WATER BODIES	POLYGON
REGION.LAKE	NAMED WATER BODIES	POLYGON
REGION.RIVER	MAJOR RIVERS	POLYGON

On-screen digitizing of the outlines of major rivers, lakes, and ponds revealed the utility of the DOQQs. In many cases, these water features were obvious in the imagery. The time involved in digitizing along a shoreline was negligible. For this reason, the DOQQs were excellent sources of information for major water bodies as well as streams that flow through open areas.

Unfortunately, digitizing streams that flowed through canyons and heavily wooded areas from the DOQQs was a difficult process. Unless the stream was clearly visible in the image, marking its actual route was done by guesswork at best. However, the same problem would arise if attempting to capture the stream data with GPS. The same portions of the images that made on-screen digitizing of the streams were also the areas on the ground in which receiving a GPS signal would be next to impossible.

Another circumstance that adds difficulty to building the hydrography data theme is that, over time, the course of many streams and rivers change. This was made dramatically evident by comparing portions of the 1995 DOQQs to the aerial photographs taken in 2002. In seven years time, substantial portions of land were completely removed by the forces of the Bitterroot River. Overlaying the CFF data—from topographic maps drawn in the 1970s—showed a more dramatic change in the course of the river. Figure 11 shows a map of the hydrographic features in the study area.

Figure 11 - Map of the Hydrography Data Layer



The procedures described in this section resulted in the construction of a physical GIS database. Defining the data models and dictionaries were considered part of the logical design phase. In practice, the final database consisted of assorted data folders and files that were easily stored and accessed. Each data theme was kept in a data folder named appropriately. The folders and files of the database were easily browsed with Microsoft Windows Explorer, or ESRI's ArcCatalog. However, any manipulation and maintenance of the data must be performed with the appropriate GIS software package.

Physically building the spatial database involved collecting the appropriate data, determining its suitability, assembling it according to the described data models, and storing it on a computer hard drive. Essentially, there was nothing overly mysterious about the spatial database as it was stored in the computer. Most of the difficulty was in determining how much effort to spend making the data accurate and thorough.

V. DISCUSSION, SUMMARY, AND CONCLUSION

It became evident throughout the course of this project that an extreme amount of time and effort is required to produce accurate spatial data. Although digitizing information from small-scale maps such as those used by many Federal and State agencies is certainly a time-consuming process, the effort required to collect accurate spatial information at the individual parcel level is unequaled. Furthermore, modern surveyors report distances to the nearest hundredth of a foot and bearings to the nearest one second of arc. Can this level of precision and accuracy be captured in the database? Perhaps it cannot. However, in the years to come, individuals will no doubt come to expect GIS output to provide a level of accuracy very close to that available from a surveyor's plat. If a GIS technician calculates the coordinates for a property corner, the expectation will be for that measurement to be well within one meter of error. This is reasonable and achievable. The obstacle, of course, will be funding.

Another example of the need for better spatial accuracy is the case of the road easement. The purpose of an easement is to segregate a portion of land in which to place roads, utility lines, irrigation ditches and the like. However, in certain cases, roads that were once contained within their respective easements have eventually been moved to the point of encroaching on the neighboring land. Landowners generally become displeased when they see this occur concerning their properties.

To avoid potential lawsuits, county officials wish to know the areas where the paths of publicly traveled roads infringe in areas outside their designated easements. Free road data overlaid on hastily digitized cadastral data will not suffice. What is needed is meticulously collected transportation data overlaid on cadastral data accurately referenced to a sufficient geodetic reference framework.

Many agree that the cost of increasing accuracy is not linearly related to the increase in accuracy. This is a logical observation. Today, much small-scale spatial data is available free of charge. Unfortunately, its accuracy is appropriate only for small-scale maps and applications. Consider, then, the initial cost of a typical 'inaccurate' data set, which is zero. Assume that increasing the spatial accuracy of the data by 50-percent will cost $10,000. Increasing the accuracy of the data by 100-percent will not cost $20,000, nor will increasing the accuracy by 75-percent cost $15,000. More than likely, modest and small increases in accuracy will require dramatic increases in time and effort.

While collecting new data for the pilot study area, the reality of this concept became a source of discontent. After discovering the impressive accuracy of the DOQQs, the accuracy of every applicable vector data set was initially assessed simply by overlaying each on the imagery. As expected, the TIGER/Line data sets were the least spatially accurate. In many cases, the CFF data sets were remarkably accurate. However, in a few instances, CFF road segments were no more spatially accurate than TIGER/Line segments. To increase the relative accuracy of the data sets then, the position of the lines must be moved to align with the roads shown in the imagery. In a short time, the cost of the data escalates from free to a considerable amount. This amount depends on the effort one is willing to expend. Figure 15 in Appendix A shows a sample map comparing the two data sets in which each transportation data set was overlaid on the same area of a DOQQ.

The expectation at the onset of this project was that data collected by GPS would indeed be the most spatially accurate. In nearly every case, it was. However, in a number of cases, a GPS line segment for a road would either zigzag far outside the defined right-of-way or simply display as a straight line through curved portions of road. This, of course, was a result of either confused or lost satellite signals. (The official term for a confused satellite signal is 'multi-path.') Figure 16 in Appendix A shows examples of this situation.

To fix the multi-path and signal loss problems, the offending road segments were revisited and measured again. Unfortunately, the problems remained. This was a frustrating example of spending more time and effort with the hopes of making the data better. Perhaps frequent visits and measurements could have provided a means to average the multiple measurements to delineate the road segment. In reality, the cost of such an endeavor would be prohibitive.

TIGER/Line and CFF transportation data have their place in the MPLIS database. CFF road data can alert the data collectors to various roadways that might otherwise be missed. It also aids in determining the amount of roads that exist in a particular area. TIGER/Line data supplies valuable tabular information such as road names, address ranges, and zip codes. Furthermore, transportation and hydrography TIGER/Line files were used to build the blocks and tracks for census activities. If one is charged with building a census population map, using the TIGER/Line roads and streams in conjunction with the census block data theme will ensure coincidence between the roads, streams, and block boundaries. It cannot be stressed enough, however, that the attribute information of transportation and hydrography data sets must be verified for attribute accuracy.

Orthoimagery is a valuable source of visible planimetric information. Individual or multiple photos may be brought into a GIS data view to digitize information, or be used as a backdrop to overlay and assess the accuracy of existing data. In addition to providing road locations, the placement of streams, lakes, and structures can be taken directly from the images at a fraction of the effort involved in field methods.

Orthoimagery is expensive. Recall that the City of Helena spent $400,000 on orthophotography. There are relatively few local governments with the ability to fund this type of project. However, the USGS is near completion of a nation-wide coverage of DOQQs. They make them available for a nominal fee. Furthermore, many states have purchased the images and have made them available for public download.

As noted in Chapter IV, the NRC asserted that the cadastral layer must be such that one is able to locate a property corner on the ground from the information in the MPLIS. This statement carries a number of implications. First, the property corner must be stored as a node in order for it to be represented in the database. (In many cases, cadastral cartographers choose to represent a property corner with a vertex rather than a node.) Second, the location of this node must be within some reasonable spatial accuracy tolerance. Third, the node (as well as the associated arcs and polygons) must be linked to enough information that a ground search can be initiated. For the most part, this link should retrieve all of the pertinent deeds, COSs, and subdivision plats. To do this, every aspect of the cadastre must be interlinked, and each spatial feature must be related to some data table of information.

Building the cadastral portion of an automated MPLIS database is no small task. However, the accumulative amount of time spent by various persons searching county records and maps is neither small nor trivial. If nothing else, one of the greatest benefits of this data layer is simply assisting those who must wade through the countless courthouse records on a daily basis.

Here in the Real World

After all of the articles, textbooks, guidelines, and dissertations have been read, a budding GIS Specialist commencing a local government GIS program is soon faced with certain realities. The most painful reality is that nothing fits into a neat package. Often, commissioners, council members, and department managers will be explicitly informed of the extensive time involved in producing a usable database, yet someone will expect some sort of output almost as soon as the program is begun.

In the real world, GIS personnel must perfect the balancing act between time and money spent towards accuracy and detail and simply getting a product to users. On one hand, policy makers (most of whom know nothing about NMAS and NSSDA) expect magical information to appear soon after a request is made. On the other hand, the information gained from GIS output will be used for decisions that will assuredly affect the well-being and livelihood of one or more individuals. Disclaimers regarding accuracy will protect the mapmaker only to a point.

In *The Three Leading Killers of GIS*, Dave Gallaher asserts that GIS programs often fail because of a lack of utilization. He cites the three reasons for failure as: 1) forgetting that the reason for GIS is to solve problems and get answers, 2) excessive attention to accuracy and precision, and 3) not getting GIS information into the hands of decision makers[1]

A GIS has the marvelous ability to display a digital map and allow the operator to zoom in and out at will. The operator can place a cursor over a point in the display and report its coordinates to a precision of less than a millimeter. A GPS receiver can report the same coordinates of that point with almost equal precision. However, the fact of the matter is that, in practice, the measured coordinates and the true coordinates of any point will never be the same. They might at times be very close, but never the same. The question then becomes: how close is close enough? There is no definite answer.

Regarding the inevitable E-911, consider the following scenario: An emergency occurs in the middle of the night in some remote portion of a heavily wooded, mountainous portion of the county. A dispatcher takes the call then sends a response unit to an address provided by a caller in the midst of panic. The area is cluttered with winding roads leading to houses owned by people who have chosen to live secluded lifestyles. The few-posted street signs are severely out numbered by the 'No Trespassing' signs nailed upon trees at the entrance of driveways that disappear into the darkness. What information will ensure that the ambulance driver will choose the correct driveway? One would hope that the information was not the result of free data. This same scenario can apply to heavily populated urban areas. The best chance for survival in many life-threatening emergencies is a speedy response. This is the purpose for E-911.

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[1] Dave Gallaher, "The Three Leading Killers of GIS," *URISA '99 Annual Conference Proceedings*, [on-line] (June, 2000) available from http://campus/library/ConfProc/urisa/1999/1999-66.pdf; Internet.

The opinion of the author is that the necessary databases for E-911 should be directly integrated into the MPLIS database. The two should not be separate. In the pilot study database, every MSAG record was created by assembling a logical group of road segments into a Route of the feature class, ROUTE.MSAG within the Transportation Coverage. Because of this, the MSAG database would forever be integrated with the transportation data theme in which it belongs. The same principle applies to the digital map portion of the E-911 CAD system. ROUTE.ROADS was constructed as a separate feature class within the Coverage to store all of the information necessary to reliably direct an ambulance, fire crew, or deputy to the scene of an emergency. The actual locations of residences should be tied to the information from the cadastral theme, which is the most appropriate theme for storing owner and resident information.

CONCLUSION

There might be those who scoff at certain methods of collecting spatial data. Most often however, there are those who feel that certain methodologies are too expensive and time consuming to realistically implement. Such is the case for many cadastral projects whereby the initial data collection involves scanning existing maps, rectifying them to the necessary coordinate system, and on-screen digitizing the parcel information. Surveyors in particular point out that this procedure degrades the accuracy of the spatial cadastral information considerably. The observation resulting from this research project is that the surveyors are more often correct than not. As Breckenridge pointed out, a cheap and fast process of building a system will not be good. On the other hand, local governments are not known for their plentiful coffers. A spatial database constructed to the liking of a surveyor or engineer (a good system) will require substantial time, money, and expertise. In other words, it will be neither fast nor cheap. In reality, the balancing act referred to earlier must be performed with Breckenridge's "fast-good-cheap triangle."

The purpose of this research project was to discover and present an efficient methodology for developing the spatial database necessary to implement a MPLIS. This discussion asserts that there is a clear distinction between a traditional, project-oriented GIS and a MPLIS. In simple terms, a GIS is a component of a MPLIS. Although various projects certainly arise, most of the time-consuming activities within local government operations involve day-to-day transactions and information searches. This means that, to be effective, the data must be stored at a centralized location that will facilitate its maintenance and access.

A multipurpose land information system is just that. It is useable by anyone and everyone, it contains the most current information, and it is able to allow one to focus on even the most minor of land-related details. It allows one or multiple users to query a spatial database then view or print a map of a single parcel of land and include any and all geographic information that relates to it. Perhaps there is not yet such a MPLIS in existence. What is certain is this: the more multipurpose a GIS becomes, the more benefit is gained from the system, and the more valuable the information becomes.

Most of the day-to-day requests made by individuals pertain to information about ownership parcels, rights-of-way, and easements. The scale of maps showing this information is considerably large. Furthermore, the information supplied by those in a typical courthouse or city hall will be expected to be accurate, current, and thorough. In all aspects, this is the challenge of local government public servants.

SUGGESTIONS FOR FUTURE STUDY

This discussion deals with a broad overview concerning the development of the spatial base layers for a MPLIS. It is intended to prompt the reader into giving thought to the process of collecting and developing spatial data. The hope is to encourage the evolution of the academic GIS paradigm to a system that is capable of addressing the day-to-day intricacies of local government operations.

As is usually the case, recognizing a need and visualizing a better way is only the beginning of a long process. Regarding MPLIS, there are still many subjects to explore. For instance, developments in technology, such as GPS and satellite imagery, continually reshape our perception of such issues as accuracy, workflows, and access to data. An interesting topic of study would be the tangible monetary relationship between the cost of accurate data supplied by outside sources, the cost of the same data developed by trained in-house personnel, and the benefits gained. Quite possibly, this might put actual dollar figures to Breckenridge's "Fast-Good-Cheap triangle."

Another needed study deals with the issues of authoritative control of the system itself. The rift between the surveying and GIS communities demonstrates the profound misunderstanding between many members of the two professions. No doubt, there are GIS professionals at the local government level who have little concept of and appreciation for the activities and burdens of the land surveyor. This is unacceptable. As well, many surveyors have not been versed in the full workings of GIS and, as such, are limited in their appreciation for those things that GIS professionals do and the burdens placed on them. It follows that the next level of study might be to determine what will be involved in technically bringing these two professions together to work toward the common good of local government operations and the MPLIS.

APPENDIX A (MAPS)

Figure 12 - Overlay Map of Florence South Subdivision

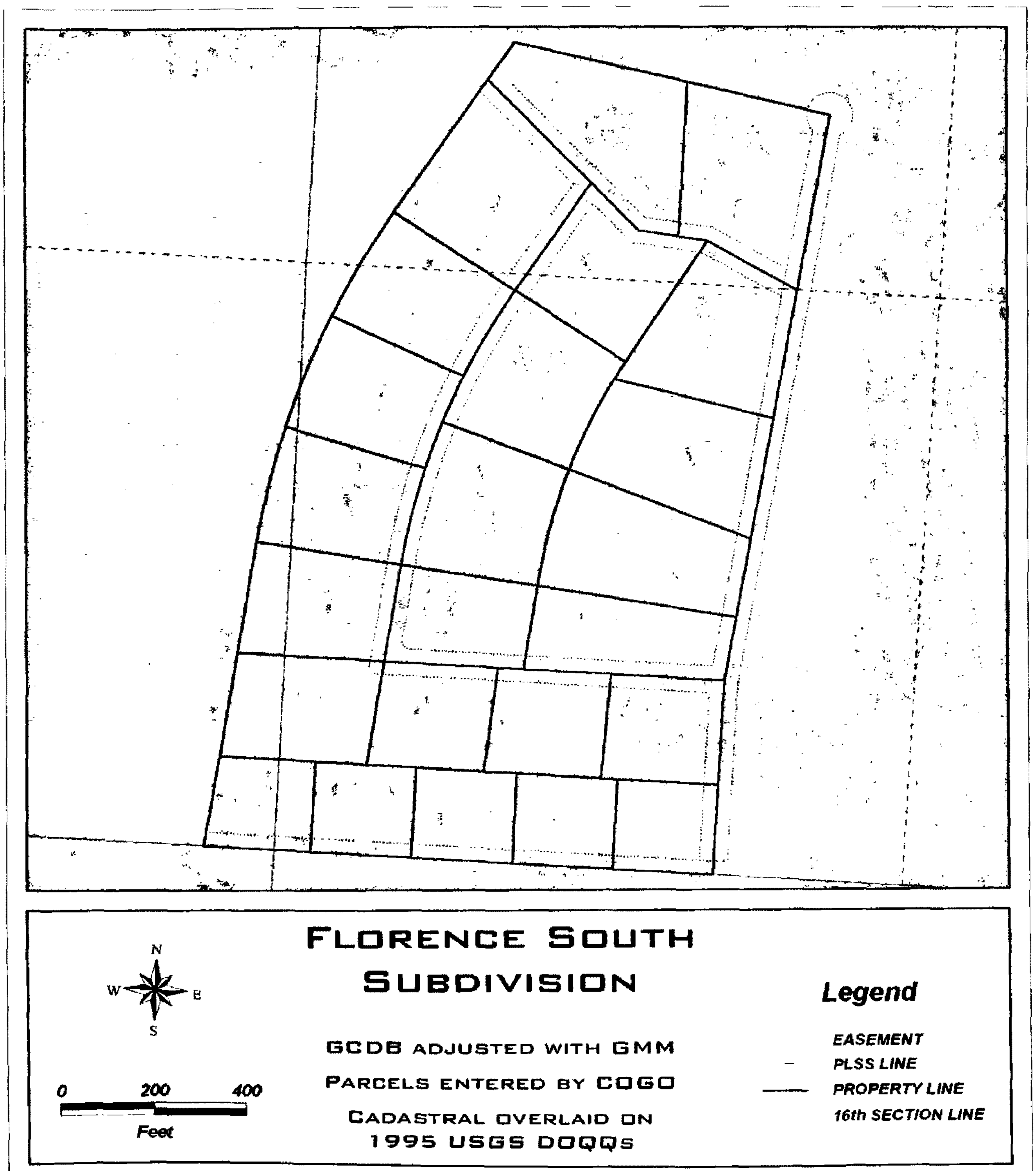


Figure 13 - Overlay Map of Indian Meadows Subdivision

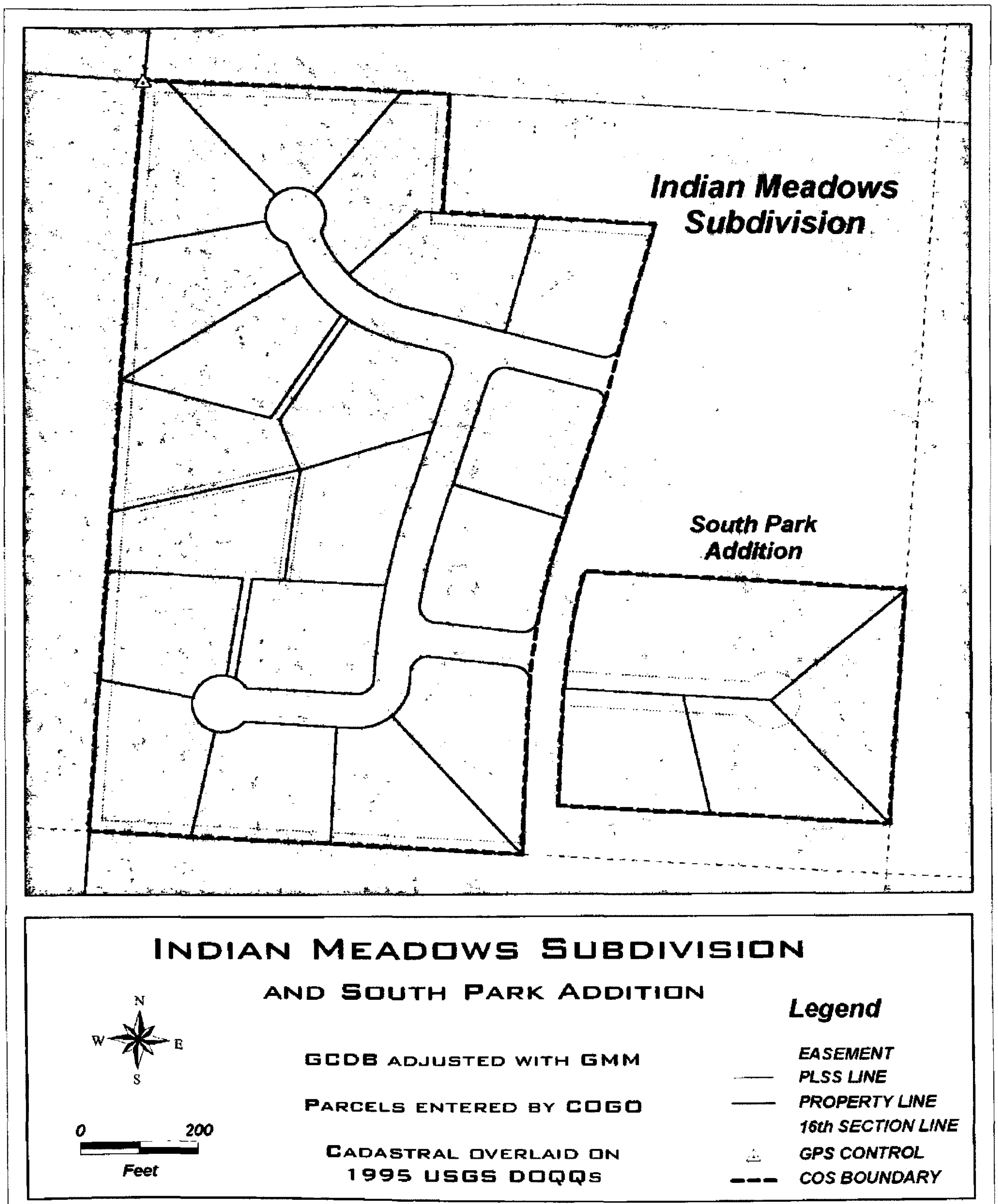


Figure 14 - Overlay Map of Meadow Vista Tracts

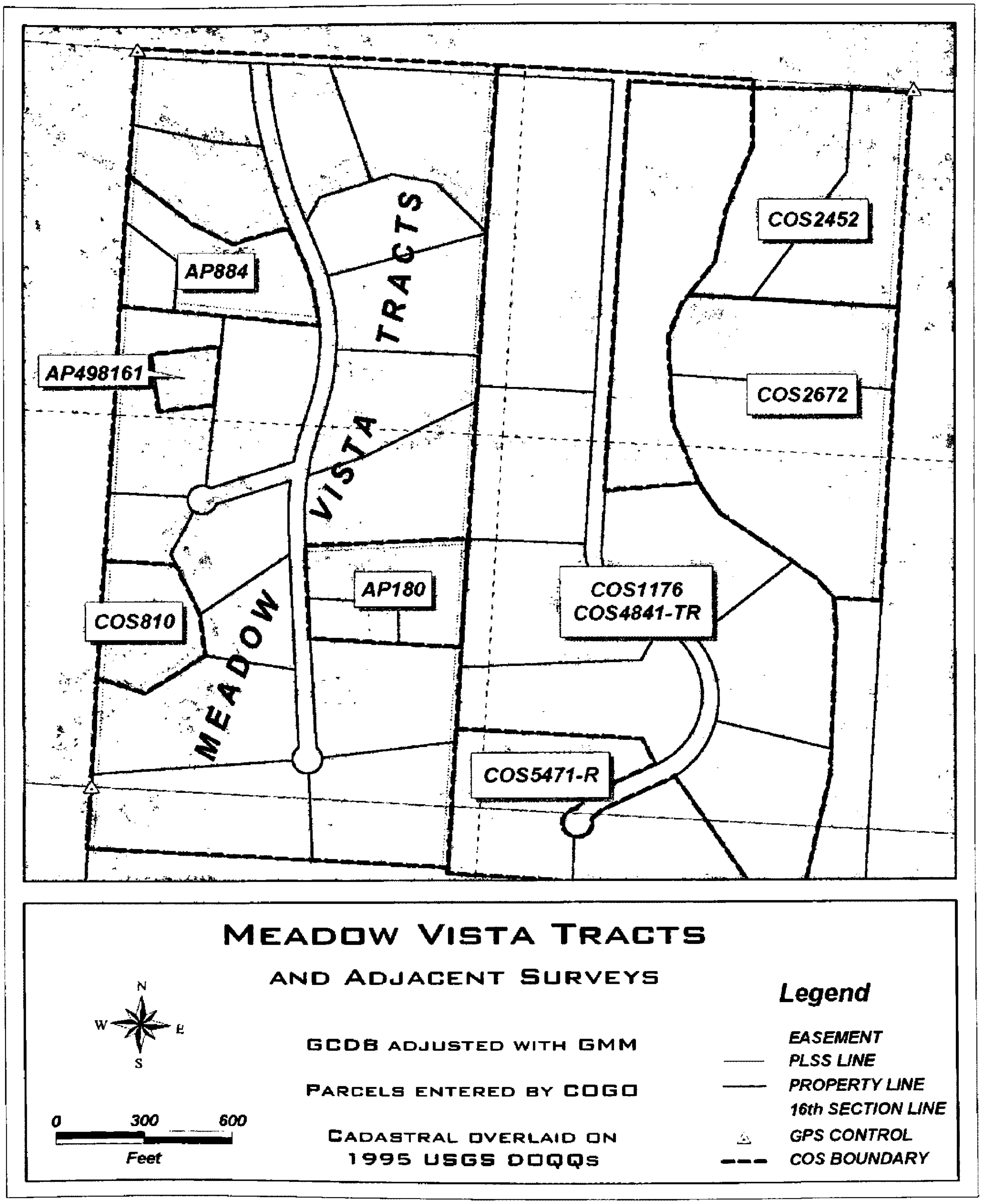


Figure 15 - Visual Comparison of Transportation Data Sets

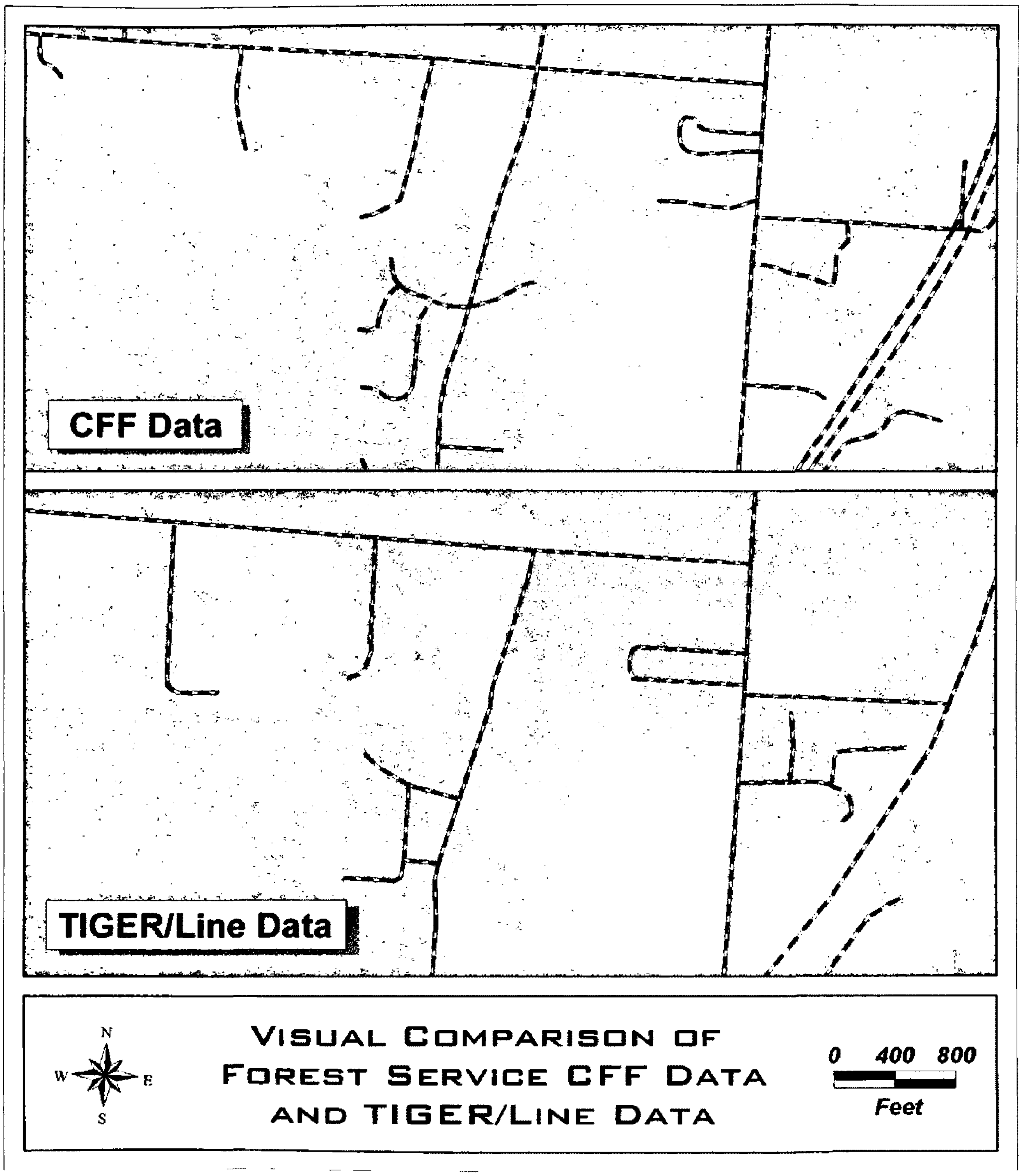
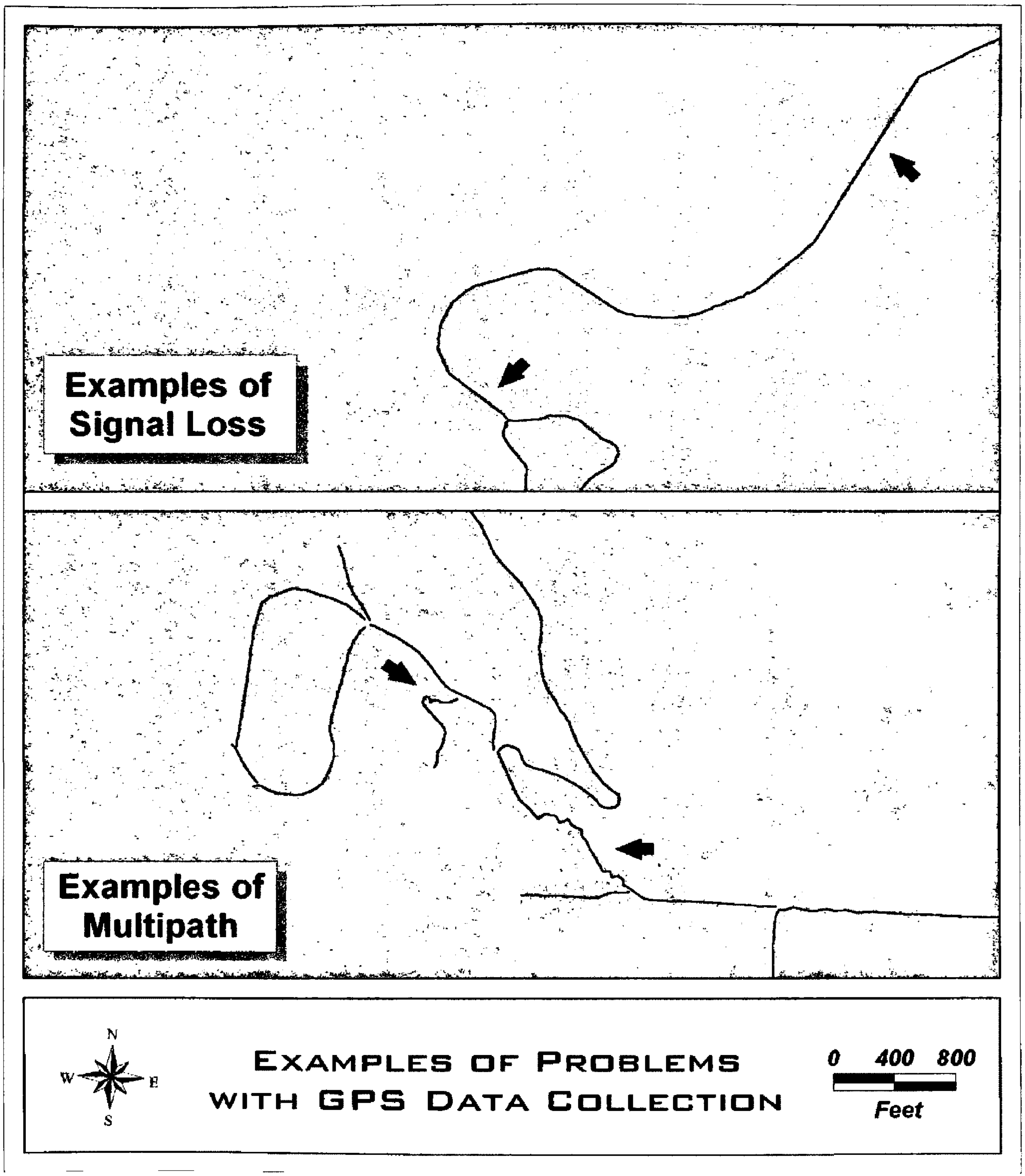


Figure 16 - Examples of GPS Data Problems



APPENDIX B (TABLES)

Table 9 - NSSDA Statistics for the GCDB Test

POINT ID	GCDB X	GPS X	ERROR X	GCDB Y	GPS Y	ERROR Y	SUM OF SQUARED ERROR	RADIAL ERROR
640700	251685.04	251697.14	12.100	278040.22	278015.15	25.070	774.915	27.837
600700	250881.67	250892.41	10.740	278087.98	278061.59	26.390	811.780	28.492
540700	250077.10	250088.92	11.820	278136.18	278114.53	21.650	608.435	24.666
500700	249272.53	249284.58	12.050	278184.49	278172.68	11.810	284.679	16.872
440700	248462.49	248479.88	17.390	278233.11	278220.17	12.940	469.856	21.676
400700	247652.45	247674.80	22.350	278281.85	278271.48	10.370	607.059	24.639
340700	246839.11	246869.54	30.430	278330.87	278319.33	11.540	1059.157	32.545
600640	250830.22	250844.35	14.130	277278.87	277263.40	15.470	438.978	20.952
400600	247495.19	247519.56	24.370	276676.77	276668.92	7.850	655.519	25.603
500540	249101.29	249119.56	18.270	275771.07	275754.45	16.620	610.017	24.699
700500	252292.06	252312.83	20.770	274762.01	274757.61	4.400	450.753	21.231
600500	250676.38	250706.08	29.700	274864.65	274848.98	15.670	1127.639	33.580
500500	249049.72	249062.13	12.410	274966.23	274945.29	20.940	592.492	24.341
600440	250627.26	250657.35	30.090	274058.10	274044.28	13.820	1096.400	33.112
500440	248999.30	249014.44	15.140	274161.06	274142.54	18.520	572.210	23.921
440400	248138.79	248153.81	15.020	273407.00	273389.96	17.040	515.962	22.715
300400	245689.77	245714.93	25.160	273532.51	273522.42	10.090	734.834	27.108
400340	247253.99	247237.74	16.250	272642.92	272630.16	12.760	426.880	20.661
700300	252110.50	252128.71	18.210	271530.26	271543.62	13.360	510.094	22.585
400300	247214.05	247208.52	5.530	271835.54	271827.59	7.950	93.783	9.684
700200	252016.73	252019.16	2.430	269930.73	269930.05	0.680	6.367	2.523
600200	250394.16	250421.30	27.140	270026.22	270036.22	10.000	836.580	28.924
500200	248771.20	248760.69	10.510	270127.14	270135.68	8.540	183.392	13.542
440100	247878.86	247889.32	10.460	268560.10	268558.10	2.000	113.412	10.649
340100	246250.43	246269.49	19.060	268661.04	268646.47	14.570	575.569	23.991
300100	245433.45	245464.89	31.440	268710.05	268692.19	17.860	1307.453	36.159
				Sum			15464.213	
				Average			594.777	
				RMSE			24.388	
				NSSDA Statistic			42.211	

Table 10 - NSSDA Statistics for the DOQQ Test

POINT ID	IMAGE X	GPS X	ERROR X	IMAGE Y	GPS Y	ERROR Y	SUM OF SQUARED ERROR	RADIAL ERROR
1	245352.41	245352.53	0.120	274133.46	274132.42	1.040	1.096	1.047
2	246092.57	246090.57	2.000	274229.45	274229.87	0.420	4.176	2.044
3	244627.53	244626.67	0.860	270244.08	270244.24	0.160	0.765	0.875
4	248884.86	248884.72	0.140	270123.00	270123.46	0.460	0.231	0.481
5	246048.21	246047.04	1.170	268839.11	268837.91	1.200	2.809	1.676
6	250644.03	250643.56	0.470	271068.62	271068.70	0.080	0.227	0.477
7	247212.67	247212.89	0.220	271835.30	271833.43	1.870	3.545	1.883
8	249277.95	249276.85	1.100	278174.46	278173.46	1.000	2.210	1.487
9	251981.70	251981.59	0.110	275962.22	275962.58	0.360	0.142	0.376
10	250480.59	250479.38	1.210	276080.15	276080.44	0.290	1.548	1.244
11	250330.87	250330.23	0.640	278105.37	278105.30	0.070	0.414	0.644
12	247088.66	247086.75	1.910	276282.78	276279.71	3.070	13.073	3.616
13	251746.77	251747.34	0.570	268513.28	268513.02	0.260	0.393	0.626
14	250621.06	250620.13	0.930	273235.41	273234.11	1.300	2.555	1.598
15	251395.73	251395.40	0.330	278031.28	278030.95	0.330	0.218	0.467
16	248942.39	248942.36	0.030	276168.76	276168.34	0.420	0.177	0.421
17	247665.07	247664.43	0.640	278265.22	278265.09	0.130	0.427	0.653
18	252283.11	252283.39	0.280	274874.74	274874.55	0.190	0.115	0.338
19	248341.49	248342.37	0.880	270158.08	270158.40	0.320	0.877	0.936
20	251891.80	251892.70	0.900	270278.96	270277.32	1.640	3.500	1.871
21	250108.98	250108.83	0.150	275366.62	275366.64	0.020	0.023	0.151
22	249095.60	249095.59	0.010	273876.81	273874.30	2.510	6.300	2.510
23	248952.93	248952.78	0.150	273341.30	273341.44	0.140	0.042	0.205
24	249801.22	249801.86	0.640	270431.84	270431.23	0.610	0.782	0.884
				Sum			45.645	
				Average			1.902	
				RMSE			1.379	
				NSSDA Statistic			2.387	

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