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Kurt B. Wurm

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**THE INTEGRATION OF CADASTRAL BASE MAPPING
WITH CADASTRAL PARCEL ATTRIBUTION**

By

Kurt B. Wurm

B.S. Ferris State College, 1986

M.S. University of Maine, 1998

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

(in Spatial Information Science and Engineering)

The Graduate School

The University of Maine

May, 2003

Advisory Committee:

Raymond J. Hintz, Associate Professor of Spatial Information Science and Engineering,
Advisor

Steven Frank, Associate Professor of Surveying Engineering, New Mexico State
University

Charles Ghilani, Professor of Surveying Engineering, Pennsylvania State University

Knud Hermansen, Professor of Construction Management Technology


Alfred Leick, Professor of Spatial Information Science and Engineering

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THE INTEGRATION OF CADASTRAL BASE MAPPING WITH CADASTRAL PARCEL ATTRIBUTION

By Kurt B. Wurm

Thesis Advisor: Dr. Raymond J. Hintz

An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy
(in Spatial Information Science and Engineering)
May, 2003

A cadastre is a parcel-based, up-to-date land information system containing a record of interests in land. Creation and maintenance of a cadastre usually involves coordination between different public and private organizations that are responsible for the various data. The U.S. Bureau of Land Management (BLM) has built a Geographic Coordinate Data Base (GCDB) that currently provides cadastral base map data for more than 38,000 townships across the country, with many of the western states nearly complete. The GCDB strategy is that the coordinates can and do change as more recent and accurate information becomes available. The locational reliability of the GCDB as a digital representation of the Public Lands Survey System is widely recognized.

This thesis examines issues in building upon this framework for the depiction of the local parcels as a core component of the national cadastre, maintainable at the local government level, such as a municipality or county. As new data in the federal base

framework are provided, the local parcel fabric may need to be updated without creating gaps and overlaps. The measurement management methodology has been expanded to provide this maintenance capability. This ultimately leads to the desired political outcome of a consistent, reliable, spatial representation of legal land objects.

The legal land descriptions encoded in the GCDB framework can be extracted and utilized to provide consistent parcel attribution of aliquot part parcels. As most states have external databases that maintain an index of real property parcels. Experimentation identifies that integration with these external databases is an extremely accurate, expedient, and cost-effective method of cadastral parcel attribution at the state or local government level, depicted on a uniform parcel-based map. The methodology presented yields great success in automatic identification and interpretation of encoded legal land descriptions of aliquot part parcels. Building upon the FGDC Cadastral Data Content Standard, expansion of this can lead to automatic parcel identification and attribution as high as 96% in some areas.

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Over many years this research has been sponsored by the Cadastral Survey organization within the U.S. Department of the Interior, Bureau of Land Management; my gratitude extends to the many talented professionals who have been a part of the effort. To the scores of individuals who utilize the computer software on a daily basis, I thank you for your untiring diligence and patience and

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CHAPTER 1 CADASTRAL PARCELS AND BASE MAPS

1.1 Introduction

Historically, cadastral base mapping and parcel attribution have been two distinct operations, often performed by separate entities. The surveying profession has ordinarily been called upon for the demarcation and delineation of the boundaries of parcels as well as the mapping and recording of cadastral surveys. Other entities, such as Geographic Information System (GIS) technicians, legal experts, and other non-surveying personnel have routinely been utilized for the assignment of Parcel Identification Numbers (PIN) and management activities of the cadastre. This thesis examines the issues involved in creating a parcel-based map, identification of parcels, and the benefits of having source record identification included as part of parcel identification. A portion of this research has resulted in the development of techniques and tools to integrate these functions through enhancements to the Windows Geographic Measurement Management (WinGMM) software. As will be readily seen through examination of examples, this represents a dramatically different approach for land information data collection and maintenance. In numerous examples, recommendations are made that personnel tasked with this duty have a strong background in survey concepts. The benefit of this integration is that land surveying personnel tasked with the creation of cadastral base map products have the knowledge and experience to interpret the legal land descriptions as well as to identify the resultant parcels.

Much of this work is being sponsored by the United States Department of the Interior (USDI), Bureau of Land Management (BLM) in support of the Geographic Coordinate Data Base (GCDB). A related development is also underway known as the National Integrated Lands System, (NILS) which has GCDB at its core. In essence, NILS forms the base parcel data that will be utilized, and perhaps densified for local government use. Generally the local government is responsible for management of the cadastre in the United States. Thus, this technology has potential for widespread use among all land related organizations for maintenance of their specific parcel base.

This research encompasses several areas of study, including a detailed review of the federal system as implemented by the United States Department of the Interior, Bureau of Land Management, and the U.S. Forest Service (USFS). Combined with state and local operations, this becomes the NILS (ESRI, 1999), based upon measurement management concepts which form the basis of WinGMM (Hintz, et al., 1993). This research builds upon this framework. Linkages to state and local government operations will be investigated with emphasis on data sharing and development of reliable parcel base maps for use at all levels of government.

Specific details will be provided regarding the computational aspects of the parcel base map through the use of measurement management technology within the WinGMM software system. Abstraction of records, weighting of survey data, coordinate generation, and derived parcel boundaries via the United States Public Land Survey System (USPLSS) aliquot parcel descriptions will all be examined and documented.

Moving beyond the computational components to the issue of parcel identification is the key focus of this research. The computational components enhance the success of

parcel identification. The automation of the parcel identification process begins during the data abstraction and computational phase of the collection process where key elements of the WinGMM approach provide for parcel topology that leads to a locational-based identification scheme. Integration of measurement management technologies to external parcel indices is a major emphasis of this thesis.

1.2 Relationship between Land Management, Land Information Systems, and the Cadastre

Land Management is the process of managing the use and development of land resources. Land management has many social and environmental objectives, including the following:

- ❖ Improving the efficiency of land resource use;
- ❖ Land development, including infrastructure and housing;
- ❖ Protection of the natural environment from degradation;
- ❖ Supporting government services through taxation and fees related to land and improvements.

When the information about rights in land is included in a Land Information System, the basic requirements of a cadastre are met. This information includes ownership information about interests in parcels of land; the nature and duration of rights, restrictions, and responsibilities; and information about the parcels such as the location,

size, improvements, and value. Indeed, as the value of land rights increases, the accuracy of data utilized for policy formulation and decision-making becomes critical.

A cadastre is a parcel based, up-to-date land information system containing a record of interests in land (e.g. rights, restrictions and responsibilities). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements. It may be established for fiscal purposes (e.g. valuation and equitable taxation), legal purposes (conveyance), to assist in the management of land and land use (e.g. for planning and other administrative purposes), and to enable sustainable development and environmental protection. (International Federation of Surveyors [FIG], 1998)

The use of modern computer technology has made geographical databases and digital land information systems widespread. Digital geospatial data is widely available in a variety of formats and systems. The greatest benefits of the cadastral system can be realized when it is coordinated with other types of land information. This usually involves coordination between different public and private organizations that are responsible for the various data. To be successful, this coordination needs leadership, communication, and commitment. It can be best facilitated through legislation, establishment of standards, and establishment of advisory groups.

1.3 The Role of the Professional Land Surveyor

The two basic aspects of the surveying profession — the ability to locate objects in the physical and legal worlds and the ability to represent these objects on a map — are influenced to a considerable extent by developments in the fields of electronics and information technology. Most GIS-parcel-delineation-type work has been assigned to non-surveyors, yet surveyors can make a significant contribution and should take on a greater role in this endeavor to benefit society's changing needs. Kaufmann & Steudler (1998) predict the land surveyor will play a much greater role by the year 2014. The Cadastre 2014 is a vision of future land information systems highlighting the role of the cadastre that will include all legal land objects. Legal land objects are pieces of land where laws define the outlines, or rights or restrictions. Examples of legal land objects are the following: (1) private property parcels, (2) areas where traditional rights exist, (3) administrative units such as countries, states, districts, and municipalities, (4) zones for the protection of the water and nature from noise and pollution, (5) land use zones, and (6) areas where the exploitation of natural resources is allowed (FIG, 1998). Land surveyors understand the processes involved in the determination and definition of legal land objects. They must know the adjudication processes and must understand the principles of land valuation. They must be able to manage the land administration system. This includes documenting land with all its physical and legal aspects, and providing land information for citizens, enterprises, authorities, and political decision-makers (FIG, 1998). Producing individual maps with specialized content and representations, or simply

delivering spatially-related data to interested people, will be an important part of the surveyor's work.

1.4 Measurement-Based Land Information Systems

The Geographic Measurement Management software was initially designed for the data input, coordinate production, and subdivision process for GCDB. As the development of the GCDB has continued, so has research to facilitate this ambitious project. Growing from research of the early 1990s, which included Cadastral Electronic Data Collection and geodetic land survey computations (Blanchard, 1990) (Parker, 1992) (MacDonald, 1992), WinGMM became the official software tool utilized in the collection of GCDB. The BLM's GCDB currently provides cadastral base map data for more than 38,000 townships across the country, with many of the western states nearly complete. The strategy employed for the creation of the GCDB utilized Public Land Survey Records and available control for the creation of the coordinate base. The most important feature of the GCDB strategy is that the coordinates can and do change as more recent and accurate information becomes available (Hintz, et al., 1993). A seamless coordinate framework and built-in facilities for maintenance of the system are its greatest assets.

A regional approach to least squares coordinate generation resolved earlier difficulties with creating seamless data. The regional approach produces seamless coordinates efficiently and can resolve reliabilities independent of coordinate production. This process lends itself to maintenance operations, where newer survey data is added to

GCDB and results in better coordinates (Hintz, et al., 1995). Updated bearings and distances, or controlling corner coordinates, are utilized with appropriate error estimates to rebuild the database.

After coordinate generation is complete in the regional analysis, these coordinates serve as control for all further proportioning and subdivision to the quarter-quarter section level (Hintz, et al., 1996). All special rules for unique section subdivision are stored so that re-generating these new coordinates occurs with minimal user interaction. Parcel topology is built simultaneously with the coordinate generation process. Each proportioning and intersection process is built upon the raw (section line & special survey) data. The topology can be expanded. For example, creating a 1/16th corner between a section corner and a quarter corner redefines the section line between the quarter corner and the section corner into two segments connecting the section corner to the 1/16th corner to the quarter corner. In other cases new line segments are created. In computation of the center of the section, or the center of the quarter section, four new line segments are created connecting the controlling corners to the center position. This technique is known as boundary by computation and is a key feature of automatic parcel identification (Hintz, et al, 1995).

1.5 Parcel Management

Vast bodies of articles exist that describe procedures, standards, and the benefits of a multi-purpose cadastre (NRC, 1983). Several published articles describe creating boundary data from data such as the GCDB (Breckenridge, 1994), (Hintz, et al. 1993), (MT GIS Services Section, 1998). However, a void exists concerning the management of the core component, the cadastral parcel. Previous work has focused on the computational aspect of creating the GCDB through the development of the Geographic Measurement Management (WinGMM) software.

WinGMM technology is officially a core component of the NILS. The WinGMM system is in widespread use among Federal land management agencies as well as many State and local governments (Breckenridge, 1994), (MT GIS Services Section, 1998). WinGMM was originally a computational tool for input and manipulation of survey records, horizontal control, and the subdivision of sections into aliquot parcels. Becoming an operational measurement-based Land Information System requires additional tools to identify and manage the most important feature, the cadastral parcel.

As previously discussed, the parcel topology in GCDB is completed under land survey personnel control. For convenience, a coordinate pair located inside the parcel is used to serve as a spatial reference for the parcel attribute. A discussion of various parcel identification systems will appear elsewhere; in this introduction the BLM system serves as a good base. Within the BLM, additional databases containing legal land descriptions (LLD) are also available which identify parcels to the 1/16 aliquot part level,

but the LLD contains no spatial correlation. The US Public Land Survey System, which provides simplified legal descriptions through the use of aliquot parts, also introduces some complexity to the management of cadastral parcels described through the LLD. As the configuration of surveys within a township becomes more complex through the inclusion of (perhaps numerous) non-aliquot special surveys, unique lotting configurations, meanders, etc., the aliquot parts system, at minimum, provides a nominal location index for the identification of the special land descriptions. A simple example of this is in Section 6, shown in Figure 1, where the northern and western tier of parcels abut closing lines described legally as Government Lots 1-7 rather than as aliquot parts (quarter-quarter sections). The LLD database identifies these by their nominal location and identifies the proper lot numbering as well as the legal area of the parcel. The nominal location is simply a one-character code of A-P, where each letter corresponds to one of the 16 nominal aliquot part locations. WinGMM identifies components along the closing line that were originally thought of as aliquot, and automatically assigns the lot numbers from the LLD data. Additionally, WinGMM computes acreage based on the coordinates and compares this with the legal area to assist in the assignment of parcel identifiers.

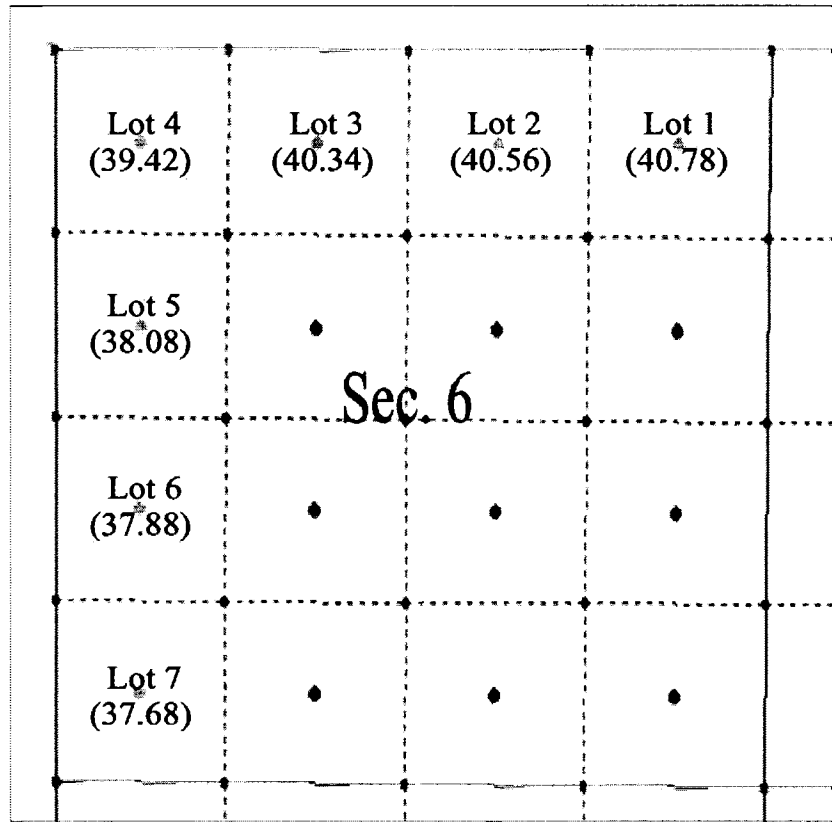


Figure 1. Ordinary Lotting of a Typical Section 6.

Further complexities arise when multiple special surveys exist within a common nominal location. Figure 2 illustrates the type of identification difficulties encountered in USPLSS records. Often part of the area covered by the nominal aliquot part is inside the special survey, or the nominal part is bounded by at least one side of the aliquot part. Coding for these minimal sub-parcels is handled in the raw polygon attribution stage. Notice the term “polygon” is used here to identify the differences between “raw” and “final” — the final areas (after subdivision) are termed parcels in this thesis.

Yet further complexities arise in unsurveyed areas. In these areas, the US BLM issues protraction diagrams. These protraction diagrams are essentially a plan of survey,

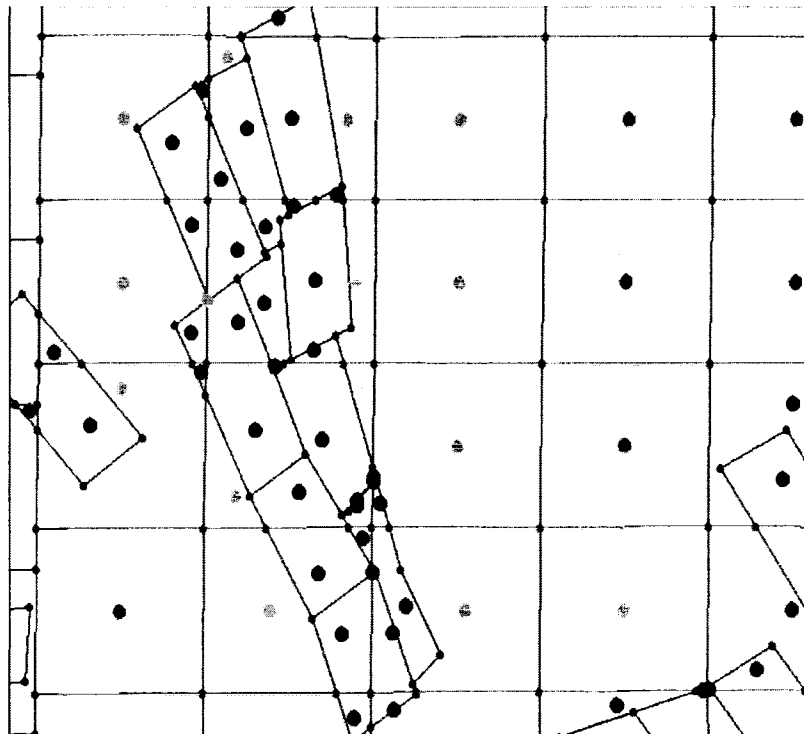


Figure 2. Complexities of Parcel Attribution.

should the survey ever be completed. Protraction diagrams give government land managers the ability to legally describe parcels for land management operations such as leasing for timber, mineral exploration, and other development. In these cases, areas ranging from an unsurveyed section to multiple townships can exist, legally described and able to be located, yet without the benefit of ground survey and monuments. To attribute these parcels, an understanding of the protraction process is essential and is covered in this study, as documented in Appendix C.

GCDB and LLD were independently collected sources of USPLSS information. While a variety of checks existed in their creation, blunders or misinterpretations are found that the land survey personnel tasked with merging these two databases must resolve. WinGMM parcel management provides a graphical visualization of parcel boundaries, the LLD database, and several assigned parcel identifiers. This specialized attribution component of WinGMM provides many utilities to assist in quality control and the correction of automatically generated initial estimates of the parcel identifiers. Tools have been built within WinGMM that provide for inspection, editing, and matching of parcels graphically.

1.6 Beyond the Federal Sector of Land Management

The BLM provides cadastral map products for townships. A typical local implementation requires multiple townships to complete coverage for a county or state.

This cadastral base map provides a framework from which local government may further densify the parcel base through inclusion of the parcel level (often metes-and-bounds descriptions) detail needed for local government functions. Local governments routinely record survey maps, subdivision plats, deeds, and other records of survey. These documents may be used to spatially locate these additional parcels within their appropriate township, section, and nominal location, as is routinely done as part of the land survey. These additional records may also be abstracted into raw data, and included in the analysis. The missing piece is the attribution of these polygons, which makes the spatial representation of parcels complete.

Additional complexities arise in this system because there are little or no standards for parcel attribution, even those based on USPLSS rules. Special considerations must be made to accommodate the parcel identification systems in use, and provide suggestions for those states, counties, or other land management entities where no standard has been employed.

This research builds on this concept and provides new tools to assist in spatial location and management of parcels for all levels of government. Additionally, private sector organizations that manage land information as a part of their business will benefit from the streamlined access of parcel information by linking to a standard identification system.

The Cadastral Data Content Standard provides common definitions and structures for cadastral information found in public records (FGDC, 1996). This facilitates the effective use, understanding, and automation of land records. The standard also provides

guidance and direction for land records and land surveying professionals on standardized attribute values and definitions. Use of the standard results in improved land records creation, management, and use.

One of the greatest benefits of standardized descriptions and attribute values is that it enhances data sharing. It also resolves discrepancies related to the use of homonyms and synonyms in federal land record systems, which minimizes duplication among those systems. The cadastral standard will mesh with the data model for the cadastral data theme of the framework. To provide a standard for the definition and structure for cadastral data will facilitate data sharing at all levels of government and the private sector and will protect and enhance the investments in cadastral data at all levels of government and the private sector (FGDC, 1999).

In order to illustrate the unique concept of this research, it is important to include a discussion of related efforts. There are literally thousands of local land information systems in place in the US and around the world. The technical details of the implementation of these systems generally identify three methods for assembling a cadastral parcel base map. These methods include 1) digitizing source maps, 2) scanning and vectorizing existing source documents and 3) computing parcel positions through coordinate geometry. This third method is the process of entering bearings and distances for the computation of parcel corner coordinates. It is generally accepted that computation of parcel boundaries results in the most accurate depiction. Yet this method is the most time-consuming and expensive method of data collection. This thesis expands measurement management technology to provide a design that can minimize this

cost. This is accomplished by storing the abstracted bearings and distances used in the computations for later reuse when updates to the system are required.

The following examples are provided to serve as a sample of the various methodologies being employed in the U.S. and abroad in the creation and maintenance of the most important land survey feature of the land information system, the cadastral parcel.

Case Study 1 Minnesota

In 1997 a needs assessment and implementation study for parcel-based GIS in Minnesota local governments was performed to document the current status of local GIS's and to provide guidance for the successful implementation of a parcel-based GIS. The aim of this project was to understand the spatial data needs, implementation means, and realized benefits of GIS.

The study found that coordinate-controlled, parcel-based GIS is fundamental to realizing most of the benefits of this technology in Minnesota local government. The demands on Minnesota local government are increasing while available resources continue to decrease. It was found that the wise implementation of GIS technology could make a significant contribution to service delivery and overall efficient and effective local government operations. Financial investment and technical guidance is key to the realization of this technology's potential in local government. Coordinate controlled parcel-based GIS will eventually come to Minnesota local government statewide because

the needs of these organizations will force it. The real questions are how soon the benefits can be realized and how efficiently the investment can be managed. The findings of the study conclude that a coordinated, multi-jurisdictional approach to funding and standards establishment will provide the most benefits for the least cost in the shortest time (Minnesota Governors Council on Geographic Information, 1997). At the time of the assessment, only the more urban, fast growing local government units were engaged in parcel-based GIS activities, yet a growing interest was readily seen by all of the counties.

While the recommendations provided are very sound and represent an excellent primer for local government interested in developing GIS technology, specific focus will be given to the project's development of base map parcel themes. Beginning with a call for geodetic network control in the area, the base map compilation builds on the geodetic framework. As the U.S. Public Land Survey System (USPLSS) subdivided all lands in Minnesota, it is recognized as logical that this subdivision be a primary component of the base map because it provides the framework for all parcel boundaries in the state. As most of Minnesota has original surveys from the second half of the 19th century, the perpetuation of the USPLSS is an important task charged to local government through state law. As a part of any parcel-based GIS, the sectional framework component is considered a primary requirement. Parcel-based GIS creation should include recovery, verification, and restoration of all PLSS corners in the location where they were originally set. This is a major undertaking that requires establishing geodetic coordinates for at least each PLSS section corner in rural areas and each quarter-section corner in

developed areas. It is quite obvious that these recommendations have been brought forward from the early NRC procedures and standards for a multipurpose cadastre (NRC, 1983) and that coordinated positions of the USPLSS in Minnesota are not readily available from other sources (such as the BLM in the western states).

The parcel boundaries are drawn once the required geodetic control and PLSS corners have been included in the GIS base map. There are three principal ways to do this: board digitizing of existing maps, scanning and vectorization of existing maps, or reconstruction of the lines based on the legal descriptions or survey notes using coordinate geometry. The choice between these three methods depends on the nature of the most pressing needs, available resources, involvement of needed professionals in the GIS effort, and so forth. It is also recognized that a relatively inexpensive parcel base can be created through digitizing on an adequate control network to show the value of parcel-based GIS. This would help build support and show the need for more expensive COGO created parcels.

Each parcel of land has a unique legal description whether it is a lengthy metes-and-bounds description or a simple lot-and-block description. Reconstructing the parcel lines from legal descriptions is considered most suitable for engineering purposes. Positional accuracies in the range of ± 1 ft or better can be achieved in many cases (IISAC, 1997). Successful use of the COGO approach requires a higher frequency and level of accuracy in geodetic control, more time, skill, and money, and can entail a major effort in land records cleanup and improvement. Legal descriptions of land records have been written by a great many individuals of varying abilities over the generations. They

are based on both old and new survey technology derived from dramatically differing field circumstances. Each one was written individually for a particular transaction, referencing little more than the nearest monuments, property lines, and physical features. Chances are, until a parcel base mapping effort these descriptions have never been tied together into a single cohesive network. Likewise, discrepancies between adjoining parcels cannot be resolved until a networked system exists. The parcel base map built from these legal descriptions will usually contain gaps and overlaps, and a policy to address these discrepancies is essential.

Of serious consideration is that although a good description of these issues is provided, no guidance is given to employ the services from the surveying profession. The Minnesota study provides only minimal guidance in the interpretation of problems. To let technicians affix the lines results in a pretty picture, but may not strictly interpret legal descriptions, resulting in a potential source of error in the location of a land parcel line. The second approach is to simply provide a faithful representation as given in the legal descriptions and submit all of the discrepancies to the proper authorities for resolution. The Minnesota needs assessment states that this method may wake sleeping dogs that have slumbered for generations.

Building a parcel map from the legal descriptions using COGO techniques produces high positional accuracy, but it is not without problems. The correct handling of the issues involves a multi-faceted interpretation by a land surveying professional. How accurate were the original measurements? Were they recorded correctly? How carefully were the landmarks and monuments used in the creation of the legal

descriptions? Have any of these landmarks changed? How precisely was the surveying done? Are there errors in the descriptions? Obviously the answers to these questions are not an easy one-size-fits-all solution. In the case of parcel-base map compilation, the surveying profession could employ adjustment techniques to obtain the best possible map, and allow for improvement over time. The state of Minnesota project is mute on the issue of maintenance of the parcel base to improve over time. They recognize the benefit of the computational method, yet the methodology utilized does not provide for future updates.

Parcel Identification Numbers (PINS) are basically assigned in one of two ways: A numbering system which makes use of meaningful numbers that contain useful information about the parcel, or an arbitrary numbering system that containing no useful information but serves as a tag. PINS with meaningful numbers often contain some combination of county, township, range, section, and quarter section designations, together with plat and lot numbers or other sub-quarter section identifiers. To get around problems in assigning meaningful PINS many Minnesota counties have adopted an arbitrary numbering system that is linked to database tables. However, looking at the number itself tells nothing. Most jurisdictions in Minnesota prefer the meaningful numbering system. Potential shortfalls of existing numbering systems are also examined. For example, the assessor may have one PIN for parcels of land that are taxed as a single unit. However this will often apply to more than one platted parcel. Thus this PIN does not provide a unique numbering system for pieces of land at the lowest level in the parcel base map (Minnesota Governors Council on Geographic Information, 1997).

To address these potential problems, the Minnesota Governor's Council on Geographic Information issued a report on parcel identifier issues and recommendations on a conservative approach to the management of PINS. It also recognizes the need to support data sharing with other organizations.

Case Study 2 - Florida

In this example, it becomes apparent that the issues surrounding building a local cadastre are complex, expensive, and require specialized personnel. The Florida Department of Revenue has recommendations for the county property appraisers of all jurisdictions to try to develop a multipurpose cadastre to furnish a framework to record, store, and provide comprehensive land information at the parcel level and to make it possible to share parcel data among all users of the data.

Florida Statute (Chapter 193.085 FS) is supported by the Cadastral Mapping Guidelines and Standards. These standards discuss base mapping of boundaries, roads, and water features. The general theme of boundaries is divided into three classes: 1) public land survey boundaries, 2) parcel boundaries, and 3) political boundaries. The guidelines dictate that a needs assessment that includes accuracy requirements is essential, along with quality control measures. The conversion from paper to the digital environment can be accomplished by several alternatives: scanning, digitizing, or coordinate geometry. The guidelines recognize that a combination of methods may affect the optimum strategy for an individual project. The report states the option of utilizing

coordinate geometry is best to ensure consistency between recorded instruments and the base map, and generally considers this approach as the most accurate method of base map construction. Integration of computed boundaries with other reliable digital sources provides accuracy and consistency while also minimizing the expense and efforts of the data collection process. (Florida Geographic Information Advisory Council, 1998)

Florida Administrative Code (Rule 12D-8.008, (1), (a)) requires all descriptions and parcel maps to be based upon reference to the government grid survey system (USPLSS). Therefore, this system is a logical choice upon which to build a parcel identification strategy.

Base map compilation involves six major tasks, including:

- 1) Assembling and weighting source data. The recommendation is that highly weighted information that is the most precise and accurate data available should be plotted first and held fixed, while lower-weighted information is fitted to it. This process involves classifying mapping data by personnel with extensive cadastral mapping experience and knowledge of surveying principles and practices.
- 2) Constructing a framework for the parcel maps. The framework establishes a link to a ground control system common in all maps in the digital system. The linkage includes direct ties by ground survey between the National Geodetic Reference System (NGRS) and the legal referencing system for parcels (USPLSS).
- 3) Compiling the boundaries of parcels. All parcels must be accounted for. Specific guidance is provided for parcels crossing section lines. In this case, a new parcel should

be created. The remaining tasks of 4) adding notation as needed, 5) maintenance, and 6) quality control are self-explanatory.

Beyond this description of the base map compilation, the Florida guidelines provide specific criteria for parcel numbering. A parcel identification system provides a method of referencing land parcels and data associated with the parcels using a number or code instead of a complete legal description. All parcel files are indexed using a uniform parcel identifier for the jurisdiction. Three forms are in common use: location identifiers, name-related identifiers, and alphanumeric identifiers. The primary identifier for assessment purposes is a location identifier. Examples include map based identifier systems, geographic coordinate identifier systems, or identifiers related to the USPLSS.

The standard recommends, in the digital environment, that a centroid, with state plane coordinates, be established as a secondary method of identification. This is termed a label point, not a parcel identifier, as it provides a means for the parcel identifier that tends to contain more descriptive information (Florida Geographic Information Advisory Council, 1998).

Case Study 3 - Montana

In 1997 Montana Governor Marc Racicot recognized the impact that GIS technology and spatial data has on many state agencies as well as local, federal, and private interests within the state. The Montana Geographic Information Council (MGIC) was created by executive order to provide policy level direction and to promote efficient and effective

use of resources for matters related to geographic information. The MGIC is comprised of representatives from four state and three federal agencies, three local governments, two private sector businesses, and one tribal government delegate. (Racicot, 1997) The council has several stated objectives:

- 1) Promote a spirit of cooperation among state, federal, and local agencies and the private sector in addressing geographic data and information needs and services.
- 2) Review and establish priorities for statewide geographic information needs and assist in the development of implementation plans.
- 3) Simplify cost sharing and collaborative arrangements to develop and maintain high-priority GIS databases and applications.
- 4) Promote coordination of programs, policies, technologies, and resources to maximize opportunities and reduce duplication of effort, and to facilitate the documentation, distribution and exchange of geographic information.
- 5) Ensure the development of consistent policies, standards and guidelines for geographic information.

The council has several standing committees, including the land records modernization committee, which is primarily responsible for oversight of the Montana cadastral database project and standards in general. Other committees include coordination and infrastructure, legal and legislative issues, cost benefit and economic analysis, and technology. (MGIC, 1998)

Montana is a state where the GCDB coverage is nearly complete and thus the GCDB has become an integral part of the statewide project. A brief description of the Montana GIS cadastral project follows.

Cadastral data is a framework of property boundaries along with associated land ownership information. The goals of the project are to produce, and maintain, cadastral information in a consistent, digital format for the entire State of Montana. In the interest of efficiency, the project is using existing resources (data, personnel, funding) whenever available. (MGIC, Land Records Modernization Group, 1998)

Montana is largely a rural state with a small percentage of its lands being subdivided, leaving a large percentage of land in aliquot parts. Because aliquot parts are a mathematical subdivision of larger parcels into equally sized smaller parcels, it is possible to create ownership parcels in an automated manner if the supporting data exists. Two pieces of information are required to create aliquot part parcels: 1) legal land descriptions defining the aliquot parts to plot; and 2) a framework of coordinates defining the public land survey. Both pieces of information exist for most of the State of Montana in a digital format. These existing databases are 1) the Montana Department of Revenue Computer Assisted Mass Appraisal System (CAMA), and 2) the U.S. Bureau of Land Management Geographic Coordinate Data Base (GCDB).

CAMA is a database of all taxable (and some tax-exempt) lands in the State of Montana. It has four 30-character text fields for legal land descriptions of property. The GCDB holds locational information (xy coordinates) of all section, quarter section, and quarter-quarter section corners in a township indexed system. The GCDB covers

essentially the entire State of Montana with just a few isolated townships nearing completion.

The Montana Cadastral project has developed applications in the Perl programming language and in ArcInfo Macro Language (AML) that assist local implementations to fit the existing parcel coverage to the available GCDB townships. This methodology makes use of all existing data in a systematically defined fashion, while providing upgraded spatial location information. Under this process, specifications are given to adjust the existing parcel coverages to the GCDB (Montana GIS Services Section, 1999). This process is known as rubbersheeting. In this case, existing parcel coverages exist in many separate jurisdictional units, collected more or less along the lines of the collection procedures discussed in the Minnesota and Florida cases. The newly available GCDB was used to ensure the consistency in parcel representation. Additionally, both of the previous two cases identify the process of computing parcel boundaries as a costly endeavor, yet each is considered complete when a set of coordinate positions is obtained. The GCDB is measurement based. As newer, more accurate information becomes available, the entire network can be regenerated resulting in better coordinate positions. In cases where local government operations have included the use of WinGMM technology for their own parcel boundaries, another analysis results in updated positions for all parcels, as well as providing capabilities for registration of new land records.

Case Study 4 - Western Australia

An international perspective is worthy of comparison. The Spatial Cadastral Database (SCDB) of Western Australia follows a similar approach to the Montana system.

Western Australia is one of that country's fastest developing regions. The boundaries on the SCDB were originally captured from various scale map series (1:1000 to 1:500,000). The accuracy of the digital data is therefore dependent on the scale of the map from which it was digitized. Resulting coordinate accuracy is no better than 1 mm at map scale. This translates to two meters at 1:2000 and 250 meters at 1:250,000. In order to improve the relative and absolute accuracy of this data, Western Australia is undertaking a program of spatial upgrade to surveyed cadastral boundaries and coastal hydrographic features utilizing surveyed cadastral boundaries. In this spatial upgrade procedure, an approach of entering in surveyed data is followed by an adjustment. The parcel identification links are then updated to reflect the higher accuracy. The new data is then made available in the system. While much of the area in the state has been upgraded, this practice is done on a project-by-project basis.

A software product known as the Cadastral Package is utilized for the computation of parcel boundaries in a WinGMM-like fashion. The entry of bearings and distances for each parcel allows a survey-accurate parcel network to be assembled. The cadastral parcel network is strengthened through the inclusion of control points and then the collected parcel measurements are simultaneously adjusted with the geodetic control. Like the U.S. system, because the bearings and distances are stored, the values can be updated based on more recent measurements and the network can be readjusted to

achieve better accuracy. The network adjustment process automatically weights the data according to the date of the survey record; however, it is limited to handling 200-300 parcels at a time. All of the resultant files contain data elements in ASCII files for easy import to other software packages in a fashion similar to the WinGMM approach. This system was originally developed by the University of Newcastle about five years ago as part of a research project which was funded and supported by the Land Information Council and the Computer Users Group of the Consulting Surveyors Association. The computer software has been progressively refined over the last five years by MIMAKA, Ltd. and has been used to process more than 15,000 parcels of land. This is the equivalent of approximately 26 townships subdivided to quarter-quarter section level where no special surveys exist; thus the magnitude of its use is minimal when compared with the American system. This system has been utilized in most Australian states as well as parts of Malaysia, the Philippines, and New Zealand (Eflick, Fryer, 1996).

The key difference between the WinGMM approach and the Cadastral Package is clear. No automated proportioning and subdivision is performed in the Cadastral Package. Therefore, there is no automated parcel identification strategy employed. In the Cadastral Package, all parcel identification is done manually at the time of data entry with each survey building on previous work. Although the resultant database is equivalent, the methodology is significantly different. The parcel identification is comprised of a plan number, date of survey, parcel number, parcel type, legal area, and centroid point.

1.7 Summary and Thesis Organization

Based on the examination of the above systems, it seems that all of these systems are moving toward a common data definition. Yet each struggles with data collection issues and cost. Issues of maintenance of the parcel databases are largely unresolved. The parcel identification schemes are all manual with a noted exception in Montana, which still utilizes a manual method of matching the parcel identification to the spatial representation. The goal of this research is to develop procedures and technology to enhance not only the collection, but the maintenance of the parcel base map as well.

The collection issues will be facilitated through automated processes as much as possible. An intuitive user interface will provide an efficient means for user editing to resolve parcel identification that could not be automatically captured. The interface will also provide tools for inspection and quality control. The integration of cadastral parcel base mapping with cadastral parcel attribution will support partnerships for data sharing between various levels of governmental jurisdiction.

In Chapter 2, we examine the federal system; the procedures used in its creation give understanding to the GCDB data model. Exploration of these procedures provides an understanding of the extensions developed. Chapter 3 begins with a discussion of the political support for continued development of the GCDB in partnership with State and local governments. The recommendation from the Western Governors Association is based in part upon published success with the Montana Cadastral Project, which utilizes the GCDB and augments the parcel database to depict local parcels through its GIS. An examination of the State's parcel appraisal database is performed and compared with data

content of the GCDB. This comparison identifies significant similarity to warrant a detailed study to exploit these similarities and provide recommendations to resolve the differences. The solution proposed utilizes a set of enhancements to the measurement management technology.

In Chapter 4, the computational components of the WinGMM software system are examined. Building on this, a set of design enhancements to support this endeavor is discussed. A new concept is introduced, termed a multiple parcel fabric. This is essentially an additional parcel database that can be derived repeatedly to reflect changes introduced through inclusion of new records or changes in the federal network. Chapter 5 applies the research technology. A local parcel fabric is created for sample areas in Montana. An integration of data from the state and the federal government is made to build a representative secondary parcel fabric. A research product to read and interpret legal descriptions is applied to attempt automated identification of parcels. This technology is applied to a representative sample of townships and the results are tabulated. This sample was chosen to cover large and small counties, encompassing rural and urban areas. The methodology is fully discussed, exposing both the strengths and weaknesses. The successes and failures are examined, and in some instances systematic refinements are applied and suggestions made for further study.

The results of this research present many unique contributions to the evolving development of the national cadastre. These contributions include extensions to the previous work of measurement-based information systems and entirely new developments unique to this research, listed below.

- ❖ Creation of parcel attribution system as part of the cadastral base mapping computational product. This integration provides for a high degree of automated matching and facilitates cadastral parcel maintenance.
- ❖ Implementation of a modern interface for defining and storing coordinate geometry commands which can be used to create or recreate parcel topology at any time. Extensions to the geometry functions result in the ability to maintain multiple cadastral parcel fabrics to satisfy the needs of all levels of government and promote cooperative maintenance of the cadastre.
- ❖ Resolution of the issues in maintaining an up-to-date representation of the parcels. It is an ongoing task to incorporate new surveys creating parcels without disruption or creating gaps or overlaps.
- ❖ Refining the process of regional analysis. The regional analysis provides seamless coverage of the PLSS network and meaningful coordinate reliabilities. The process will be refined through creation of a modern interface to facilitate merging of data sets and a batch update feature for automatic final computations.
- ❖ Linking the national GCDB with an external database of cadastral data. Previous work has made use of the GCDB as the base map product, yet little has been done to fully integrate it with local systems. A method is presented to fully integrate the national databases with a state database in support of creation and maintenance of the national cadastre, as implemented at both levels of government.

- ❖ Creation of a methodology to accommodate unsurveyed areas and protracted parcels to support national priorities such as mapping and land management activities in these areas.

The combination of these contributions addresses both political and technical needs in the development of a uniform depiction of the USPLSS and extends this framework for the depiction of local cadastral parcels. The methodology resolves the issue of long-term maintenance of the system, providing significant economic incentive.

CHAPTER 2 THE FEDERAL APPROACH TO A NATIONAL CADASTRE

2.1 Overview

The Bureau of Land Management (BLM) and the U.S. Forest Service (USFS) employ identical procedures for the creation of parcel base maps; manual records are coded according to the published rules for the GMM software system. One of the products of this applied research has been the development of graphical user interface to GMM titled WinGMM. Two excellent volumes were published in 2001 to describe procedures and operation of WinGMM, namely the Technical Reference Manual and the Software User Guide (BLM, 2001). This discussion will not focus on actual operation of the software, but rather will document specific portions of the applicable data at various points in the process. The purpose of documenting the process will achieve a common understanding of the data model employed in the GCDB that allows this research to proceed. The reader is referred to the software documentation for instruction in the actual operation of the software, yet numerous examples of specific issues are explored and presented in this thesis.

The initial step in building the parcel-based map is to collect all appropriate source documents. Due to previous records modernization projects within the BLM, all of these documents are indexed and exist on microfiche. This greatly simplifies the task of collecting the recorded plats and locating information within the official field notes of the surveys. The set of records is analyzed to locate the latest official record for each course,

identifying each plat with a survey identifier (SID). Mixtures of various plats are used to create the mosaic intended to most closely represent actual locations rather than legal locations. Horizontal control ordinarily exists in external databases that are queried to retrieve appropriate data one township at a time. The data is then imported directly to the adjustment set. Source identifiers and general properties for the data set are set up. These properties include project-wide variables such as datum, state plane zone, and various options to control the analysis.

With all source documents gathered, the data is interpreted by land surveyor personnel, carefully broken down to individual courses, coded, and input to the computer. Perhaps the most tedious, yet critical, operation is the assignment of point identifiers. During data input the handling of point identifiers is facilitated by pre-computing default values based upon a rule-based understanding of the data. A familiarity with the basic scheme is essential.

2.2 The Point Identification System

The GCDB point identifiers are six-digit-long integers. Very specific rules exist for coding the corners of the PLSS lands and special surveys. Special surveys are defined as all of the survey records that do not directly make up the sections, section subdivisions, and townships. These special surveys have an impact on the sections, and in many cases the PLSS records are incomplete without the special surveys. One example of this is a fixed boundary with mileposts. The fixed boundary is ordinarily monumented with mile and half-mile posts rather than with section corners and quarter corners. In this

case the sections adjacent to the fixed boundary have closing lines that terminate at the actual intersection with the fixed boundary line. Other examples of special surveys include mineral surveys, homestead entry surveys, various types of land grants, and tracts.

As shown in Figure 3, the GCDB point number has two components, a three-digit prefix and a three-digit suffix. For the rectangular lands, the prefix corresponds to the “X” direction, beginning on the west boundary that is designated at the “100” line. Each mile increments 100 units; thus the East boundary of the township is the “700” line. The suffix component of the point identifier corresponds to the “Y” direction in the township where “100” represents the southern boundary. Similarly, the “Y” direction values increments by 100 to the north boundary of the township which is designated as the “700” line. Thus 100100 is the southwest corner of the full township and 700700 is the Northeast corner of the township.

The point identification scheme then provides for the subdivision of section corners by implying a nominal distance from the section corners. A quarter corner located at midpoint between two section corners is located nominally at a forty-chain increment. Note that the actual measurement may be greater or lesser than the 40 chains but, for purposes of identifying the point’s function, the nominal “40” is used, exercising care to assign the forty to the proper segment of the point identifier; 140100 is not the same corner as 100140. The quarter section corner on the South boundary is 140100 where the other (100140) is the quarter section corner on the West boundary.

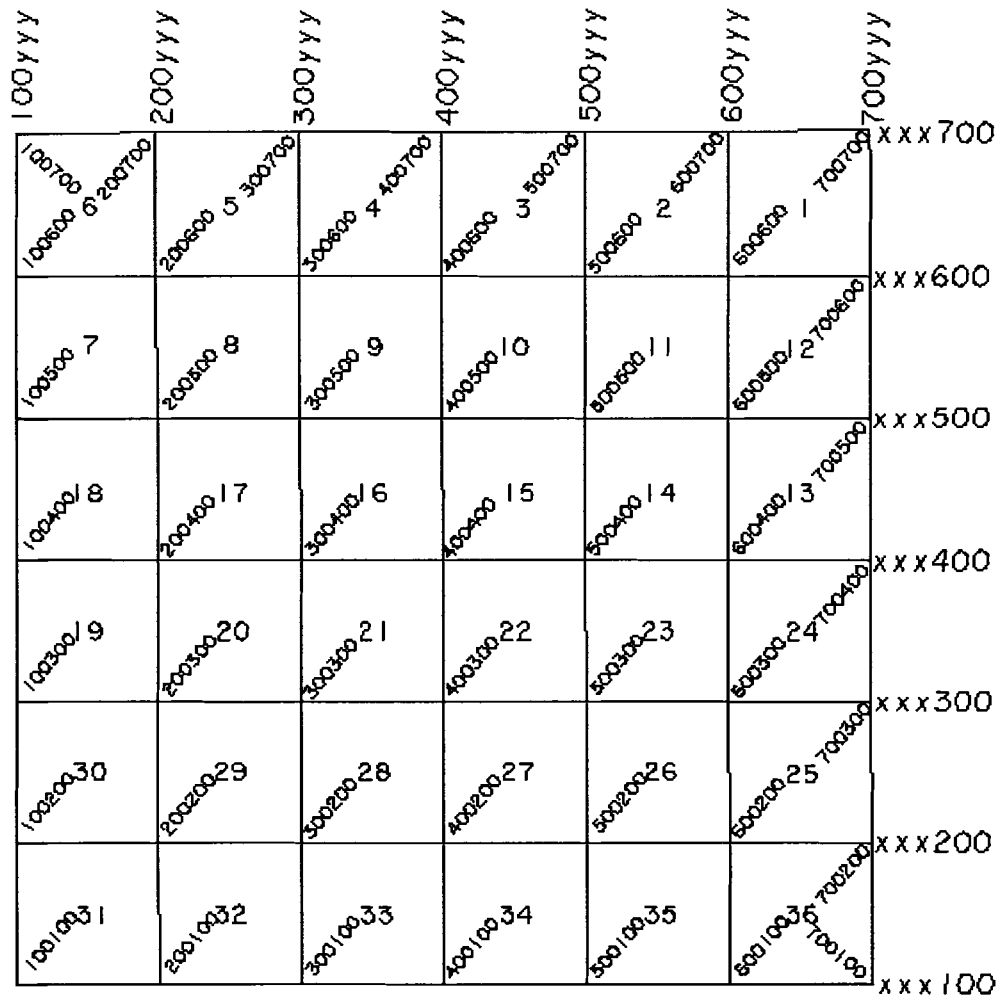


Figure 3. Point Identification Scheme of Ordinary Township.

A simple extension of this logic accommodates sixteenth corners, located at nominal intervals of twenty chains, 1/64th corners at ten-chain intervals, and 1/256 corners at five-chain intervals. Note that the system breaks down at the 1/1024 level of legal aliquot part subdivision that is located nominally at 2.5 chains. In these cases, the nearest even numbering is used without negative effect. Figure 4 illustrates the point identification scheme for the subdivision of sections.

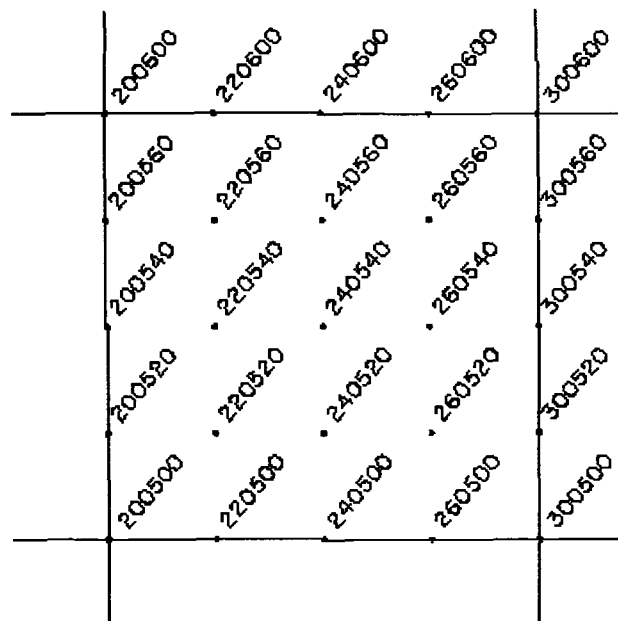


Figure 4. Point Identification for Subdivision of Sections.

Many complexities within the USPLSS give cause for departure from the ordinary point identification scheme. The fact that townships close onto the exterior boundary with closing corners creates a situation with two corners along the same line. As GCDB data collection intends to collect identical boundaries, a naming scheme has been developed to “offset” one of the point identifiers by plus or minus three. The first

illustration, in Figure 5 below, shows the proper coding for the township to the south and then the township to the north in the following illustration. The last two illustrations in Figure 5 show similar scenarios on the range lines of townships.

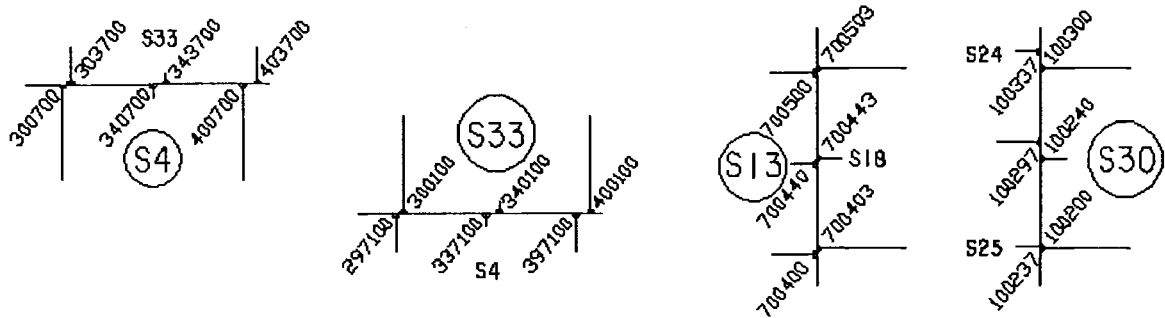


Figure 5. Point Identification for Double Corners.

Instances such as closing lines inside a township create a special situation because two corners exist for what appears to be one point identifier (Hintz and Wahl, 1994). Perhaps the most common of these irregularities are created during completion surveys of partially surveyed townships, often resulting in double or triple corners in the same nominal location, each controlling only a portion of the parcels.

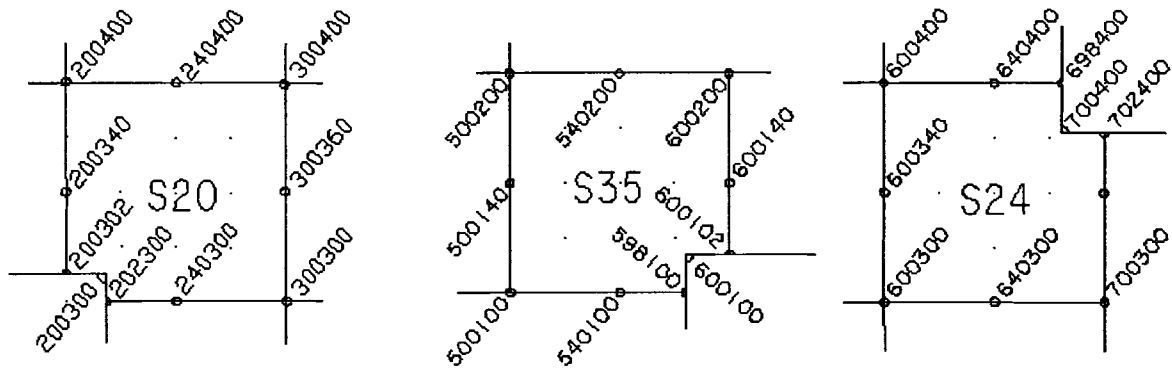


Figure 6. Point Identification Scheme for Sections Invaded by Senior Survey.

The next concept for point identifier assignment is the scheme used for the non-rectangular survey records. In these cases, the prefix portion of the point identifier is assigned according to a set of rules that assign segment identifiers for specific types of survey records. The suffix portion is ordinarily assigned in sequential order, incrementing by ten. Table 1 below lists segment identifiers to illustrate the modeling of these data types.

Prefix Range	Data Type
711-799	Boundaries with mileposts
800-836	Meander Lines
837 – 899	Tracts
900 – 999	Mineral Surveys

Table 1. Segment identifiers.

The last concept in this point identification scheme involves integrating these non-rectangular surveys with the rectangular grid, appearing in Figure 7(a). Tract 38 is abstracted using the 838 prefix, from 838060, southerly to intersection with the section line 117300, continuing southerly to the Tract corner 838070, easterly to 838080, southerly to 838090, easterly to the intersection with the section line at 200226. Figure 7(b) represents the out boundary of several mineral surveys grouped together, using a 933 prefix. Figure 7(c) shows a meandered body of water where the prefix 831 has been used for the left bank of the river and 832 for the right bank of the river.

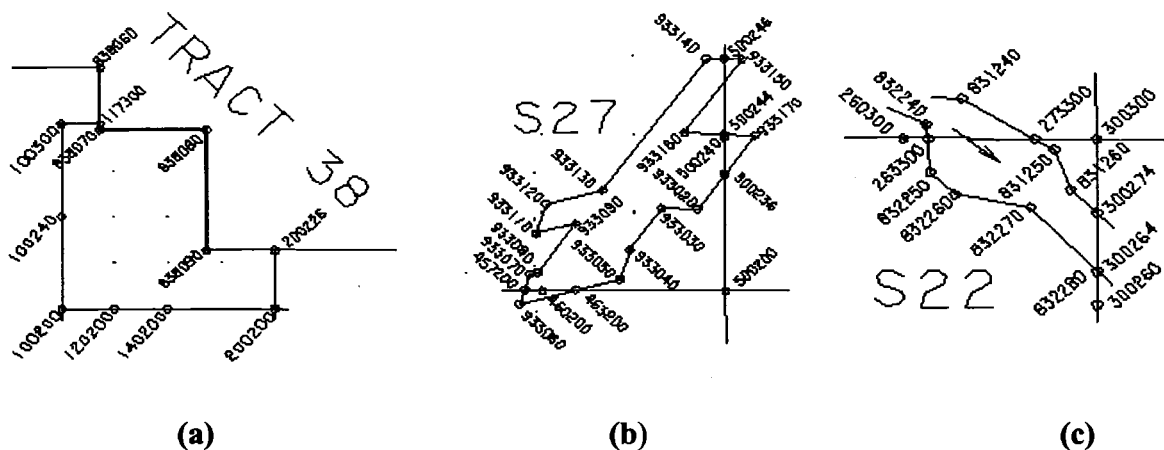


Figure 7. Integrating Non-Rectangular with Rectangular PLSS Records.

2.3 Raw Data Abstraction, Entry and Adjustment

Ordinarily, rectangular survey records are abstracted from section corner to section corner with sectional subdivision corners computed post-adjustment to preserve the geometry of the sections. Exceptions exist. For example, abstraction through

subdivision corners is often performed when surveys identifying such subdivision exist. Closing lines also include subdivision corners and are typically abstracted from section corner to quarter corner, and then from quarter corner to lot corner, and the final course from the lot corner to closing corner reflects the parenthetical distance used in lotting.

The township data ordinarily begins with the South to North lines, from the West boundary of the township. The East to West lines normally follow. Lastly, the meanders and any special surveys are included. Each record of the survey information is tagged with a source document or survey identifier (SID). All of this data is simultaneously being set up for least squares analysis. Any unit conversion necessary is performed, reduction to the State Plane projection grid is performed, and data files for the analysis (measurements and weights) are set up. Weights are computed using error estimates assigned to the survey identifier. Initial coordinates for all points are automatically computed after leaving the data input module. A graphical depiction of the data is available at this time. The lines are displayed with point identification, using unadjusted, approximate positions. This graphical depiction is an aid to data entry, as any large blunders are easily identified. Additionally, color-coding lines according to the SID facilitates inspection of the survey identifiers. The survey identifier properties may be edited. Specific lines of data can be selected for editing as necessary to correct data entry error, for SID reassignment, or for re-weighting. The survey identifier properties provide for systematic error corrections to be applied to support various types of measurement data. Distances may be grid, ground, or ellipsoidal. Bearings may be magnetic, mean geodetic, forward geodetic, or assumed. Details of the use of these methods are included in Appendix A.

A least squares analysis of the network follows. Knowledge and skills using least squares analysis techniques are essential as one must evaluate the results of an analysis, find and correct blunders, modify error estimates, and rerun the analysis until acceptable results are achieved. Utilizing robust error estimation to reassign weights, experienced users can effectively find and eliminate manual entry blunders. Once the data is determined to be free of blunders, a re-computation is performed with realistic weights to obtain usable coordinate values. The analysis provides adjusted coordinates and standard errors of the coordinates stored in the .PGC coordinate file. Full error ellipses may be included in the adjustment report and can be optionally exported to the drawing interchange format (.DXF). WinGMM runs the least squares module synchronously, allowing for an automatic reload of updated project data and a graphical update to the adjusted coordinated positions immediately upon completion of the analysis.

2.4 Post Adjustment Computations

Following the final adjustment, post-adjustment computations are performed to produce coordinates and create topology for all remaining positions. These computations can be placed into three groups: “Subdivision of sections,” “Additional computations,” and “Not functions”.

2.4.1 Subdivision of Sections

“Subdivision of sections” includes all the regular rules for section subdivision as described in the Manual of Surveying Instructions (BLM, 1973) and also provides for a

custom definition for specific sections known as irregular definitions or (.IRR). The rule-based computations proceed by placing quarter corners at the geodetic midpoint between section corners and then placing the exterior 1/16th corners at their midpoints. The center of section is computed at straight-line intersections of lines connecting opposite quarter corners, interior 1/16th corners are placed at midpoints along these lines and finally centers of quarter sections are placed at the intersections of the appropriate 1/16th lines. As each computation is performed, the parcel topology is built. Each computation represents either a break in an existing line, a traversed or proportioned new line, the extension of an existing line, or an intersection creating four new line segments connecting the intersection point. The automatic subdivision of sections is dependent upon the point identifier scheme. When conditions exist that depart from the ordinary identifier scheme, the section is defined to record the irregular definition. Irregular definition varies from a simple point identifier substitution to fully describing the computations for proportions and intersections necessary for highly irregular or fractional sections.

2.4.2 Additional Computations

Additional computations are used for a variety of purposes, most commonly in extremely irregular sections. In these cases, certain portions of automatic subdivision are turned off then defined explicitly using additional computations. Other common uses of additional computations are to complete the subdivision of elongated sections and to define sections requiring subdivision below the 1/16th aliquot part level. Other calculations are performed post-adjustment when determined inappropriate for the adjustment set. This

research creates a major expansion of these capabilities and proposes several additional uses of the additional computations.

Another use of additional computations is for creation of additional topology. The logic described above creates topology by computation and is proven very efficient. However, occasionally parcels are bounded through some coordinated positions not reflected by the computation itself. For example, the expedient subdivision method known as the “Three-Mile Method” created 1/16th corners along E-W lines within the section interiors. Automatically generated topology would show the computation of these positions as points along the E-W lines only. In cases such as this, the lines necessary, yet not defined by computation, may be drawn between any two coordinated points. The term “coordinated point” is used to identify any point having stored measurement information sufficient to compute the coordinates of the point. In this example, the 1/16th corners computed along the E-W lines are coordinated points missing needed topology. The N-S lines connecting these coordinated points, for depiction of the parcels, are included using the add-a-line feature.

2.4.3 Not Functions

Similar computation types known as “not functions” are used for the creation of topology. Often, a point must be calculated simply to provide connectivity for subsequent computations and not to be actually a corner of a parcel. This type of point is referred to as a “not point.” “Not points” are omitted from the topology, as are the lines used to create the point. A similar function is provided for line segments, where individual line segments from computations may be tagged as “Not lines” to be omitted

from creation of parcel line segments. Under normal circumstances, the computations provide the necessary topology. Thus, interaction is only necessary to identify specific anomalies where computations are provided for construction purposes rather than for parcel topology. The final task in the post adjustment computation is the identification and computation of points at the intersection of parcel boundary lines from the defined topology (Hintz, et al., 1996). This is an automatic operation.

2.5 Regional Analysis

Once a neighboring group of townships have been completed as stand-alone entities, they are joined for a regional analysis. This provides for a seamless edge match by ensuring that common record data are used on the common township lines and it provides one unique set of coordinates for each of the points on the common lines. A regional analysis also provides for more meaningful reliabilities based upon the post-adjustment error analysis of the larger data set. However, joining these individual townships presents a problem. The point identification scheme is designed to be unique within a township. A corner common to four townships will have four distinct point identifiers associated with it. To resolve this issue, a merge process was developed which was not dependent on the point identifiers. (Hintz, et al., 1996)

When joining the townships, a file containing the names of the townships to be joined is built, optionally using two keywords in the file, FIXED and NOREL. Research has shown that if the exterior of a region is held FIXED, meaning that each point on the exterior is artificially held as fixed control, bias is introduced which has adverse effects

on proper computation of error ellipses. By utilizing a buffer, this additional data is used for the computation of coordinates and reliabilities for the region, but the coordinates of the buffer strip itself are not saved. A further refinement allows for the outside edge of the buffer to be fixed, again, all leading toward seamless coordinates and minimization of the effect of the fixed pseudo-control (fixed edge) on reliabilities. Ordinarily, very little refinement of adjustment parameters is necessary at this step, as computation of the townships as stand alone entities has provided most of the error detection, correction, and proper weighting. When complete, the townships from the regional analysis are parsed back to their individual township data sets with updated coordinates for the points in the network.

At this point, all post-adjustment computations are once again performed, driven by a batch process in WinGMM known as the “Post-regional analysis update”. A batch process is possible because of the measurement management concept where all further calculations are stored for subsequent regeneration. A series of checkboxes control the command elements to be performed on the individual townships following the regional analysis. The command element APROPW recalculates all post-adjustment computations. The final topology is rebuilt, creating automatic intersections as necessary. Other procedures that may be included in this batch process produce optional desired output, such as the computation of UTM coordinates or the creation of export files.

2.6 Attributing Polygons to Create Parcels

Sometimes, parcels are attributed prior to the regional analysis when the townships exist as stand-alone entities. At other times, the attribution process doesn't occur until final coordinates are obtained. In the first case, the regional analysis could possibly adjust a parcel's coordinates so its previous centroid (area point) coordinate is no longer inside the parcel. As the area point is used to spatially locate the parcel attribute inside of the parcel, this would be undesirable. A utility module verifies the position of all parcel area points, computing new positions as necessary. A second use of the verification module is to perform one final re-formatting of the parcel attribute information and area points into a predefined data file format (the .AN file) used in the conversion to GIS coverages. This file format is essentially just a report, as much of the information maintained by WinGMM itself is omitted from the .AN file format. All manual parcel editing/attributing capabilities are performed graphically on the full (township) database. Appendix B is included to fully document the parcel attribution details as implemented in the software.

CHAPTER 3 STATE AND LOCAL GOVERNMENT OPERATIONS

3.1 Political Support for GCDB

With the PLSS being the basis for nearly all land descriptions in 31 states, the inclusion of a PLSS layer in the local cadastre is essential for building the parcel land base. The BLM's GCDB providing PLSS coverage for most of the western US has gained support from the Western Governors Association (WGA). On June 13, 2000, the Geographic Information Council of the WGA passed policy resolution 00 - 005, "Public Lands Survey System and Ownership Database." The resolution points out several very important points in its background section:

1. The Public Land Survey System (PLSS) defines land ownership and boundaries in the Western states and can be traced to the early development of the nation. Different representations of the PLSS on the ground, on maps, and now in computer databases have evolved. These representations significantly vary in content and accuracy. Digital data is being used increasingly in state, federal, tribal, and local Geographic Information Systems and as such, it is imperative to reconcile these various representations.
2. The National Spatial Data Infrastructure (NSDI) is a broad-based effort to create a framework of data and communication links that will facilitate public and private participation in decision making processes. State, local, tribal, and federal

entities are in the process of modernizing land record data used in the western states. The Cadastral (or landownership layer) is one of the framework layers for the NSDI.

3. The Western Governors Geographic Information Council, the National States Geographic Information Council, the National Association of Counties, the Intertribal GIS Council, the Federal Geographic Data Committee (FGDC) Cadastral Subcommittee and many other organizations recognize that the NSDI, land record modernization, and cadastral data are critical for maintaining livable communities, encouraging economic development, and developing the tools that give community leaders the ability to manage both.

4. The Bureau of Land Management (BLM) is developing a digital representation of the PLSS in Western states called the Geographic Coordinate Database (GCDB). GCDB is the best hope of standardizing the PLSS in Western states and its use is strongly endorsed by the WGA-sponsored Western Cadastral Data and Policy Forum and the Western Governors Geographic Information Council.

5. As was discussed at the Western Cadastral Data and Policy Forum, GCDB implementation varies widely from state to state, depending upon the priorities and resources of each BLM state office. To best utilize GCDB, the WGA member states need a consistent implementation of GCDB across the West, and state BLM offices need to develop and coordinate with state partners. (WGA, 2000)

Zimmer accurately summarizes the reasoning behind the GCDB and a portion of the procedures utilized. The spatial integrity of GCDB is given high regard. Reference is made to the software created by Craig Bacino, whereby GCDB is downloaded and extracted and the coordinate data and reliabilities are imported to the GIS. The software discussed is essentially a series of programs that extend the functionality of the GIS software to accommodate the GCDB data sets. These programs, collectively known as the Montana Automated Parcel Program (MAPP), provide the ability to load GCDB coordinate data into GIS coverages. The parcel attributes are loaded from the Computer Assisted Mass Appraisal (CAMA) system. The MAPP programs read each legal description found in the CAMA file and attempt to map the parcel by finding its corresponding parcel corners by point identifier. MAPP also includes coordinate geometry routines to calculate additional boundaries from records such as certificates of survey (MGIC, 1998).

A macro is run in the GIS software, creating new topology of the GCDB and a new coverage. A second program reassigns GCDB point identifiers to the new coverage; then a GIS command rubber-sheets the existing parcel coverage to the GCDB. Finally, an attempt is made through the use of point identifier logic to link (attribute) aliquot parts. Zimmer points out that continued maintenance of the GCDB is essential to the long-term success of the program and assumes that this responsibility will remain with the BLM. The WGA resolution includes the following two items related to continued GCDB operations and maintenance in the Governors' policy statement:

Western Governors recommend the BLM, in conjunction with the Western Governors Geographic Information Council, develop a comprehensive,

unified plan for GCDB implementation across the West. This plan needs to address technical issues (e.g. data content), policy issues (e.g. data sources), and resource issues (e.g. funding).

Western Governors urge BLM to complete, enhance, and maintain the GCDB in coordination and partnership with states. Western Governors call on Congress to provide the necessary funding for BLM to undertake this important effort. (Zimmer, 2000)

The responsibility for maintenance of GCDB has been charged to the BLM. In light of current political situations favoring partnerships with other public entities and contracting with private entities, it is probable that a shared maintenance program will be employed. For example, the techniques in the Montana Cadastral Project may need modification to provide for value-added enhancement back to the BLM as data stewards of the PLSS. The BLM would then inspect, verify, and adopt the updated information to the “official coverage.” Maintenance operations likely will include selectively replacing data and thinning the network through exclusion of various surveys. Readjustments and updates to the databases will be performed as necessary. “The BLM and the GIS community expect that the GCDB will continuously improve over time as new surveys are performed and incorporated into the GCDB. Any adjustments to the GCDB will also require adjustments of those data sets based on the GCDB” (Zimmer, 2000).

Using the current methodology, what is described will represent quite an intensive process, essentially recreating yet again the topology during the update of the cadastral layer. By moving to the measurement management approach, the accepted and stored measurements will be reused to generate updated parcel topology. The process facilitates

the anticipated workload of the future. The two-way partnership is facilitated in much the same way. The local GIS community will begin with the readjusted GCDB and selectively include additional parcel measurement data in compatible formats. The appropriate measurement management methods shall then be performed to compute the positions and update the topology. This process will be largely automated, requiring minimal interaction. One of the reasons behind the development of NILS is to provide this technology in a widely used commercial GIS. Adoption of the measurement management technology will ensure data compatibility and begin the management of the maintenance of the GCDB and datasets based on the GCDB.

One of the items identified in the resolution is content enhancement. Currently, only a fraction of the GCDB content is used. In addition to the coordinate framework, GCDB also includes record survey data, survey identifiers, raw polygons, dependent coordinated positions, topology of all section subdivision, and a fully attributed parcel base. To describe the GCDB as a simple coordinate framework for the PLSS is a disservice. The GCDB topology, data structures, and software contain much more useful information.

This research seeks to change the current data collection and sharing for several reasons. First, GCDB is utilized to minimize the cost of data collection through partial elimination of redundant effort in data collection, and secondly, to further minimize cost through shared maintenance of the data. Thirdly, reliability of the data is known, and is able to be improved by inclusion of more accurate measurement data.

Currently problems exist in utilizing the data, due in part to a misunderstanding of the process and the product. The common use simply takes the base township data to

produce the GIS coverage. The GIS software is utilized to manipulate any additional information. The additional information includes additional record information as well as new parcel attributes. Sometimes, the coordinate geometry routines of the GIS software are used to create additional points and lines. This procedure is deficient in that this information has not been integrated to the core of the GCDB. Thus, as future regeneration of coordinates becomes necessary, this new data is not adding to the data analysis. If this were changed, the data would be maintained and used to strengthen the solution, increasing the reliability of the coordinates and the parcels. Without changing, the GIS computations needed to re-compute the additional positions would require significant extra effort to update the parcels.

This study charges that this high profile, successful project still has inefficiencies. Elimination or reduction of these inefficiencies could significantly further the success through two-way partnership of data maintenance and simplified attribution. Ordinarily, data is obtained from the BLM, quickly transformed, and completed for the purpose of posting high levels of coverage. Implementation of the methods identified in this research will facilitate the local GIS operation and improve the likelihood of maintaining the cadastre.

3.2 Utilizing GCDB for State-Level Parcel Mapping

The work thus far has focused on initial data collection and GIS solutions for specific projects. The work required to perform the COGO solution to supplement the GCDB with other survey records is lost, as these solutions yield coordinate positions alone. This

is an unfortunate fact when considering future maintenance issues that often require complete rework to update the parcel spatially. The shared maintenance of the cadastral data envisioned by the WGA can be obtained through application of this research.

All of the data used in the generation of the GCDB product is stored for later reuse. Record survey measurement information, control, and supplemental computational details are stored in an ASCII file of fixed format. The local GIS's need to further densify the parcel base to accommodate parcels beyond the federal management interest. This is currently accomplished by using COGO for coordinates, without storing computations, to populate the GIS only. If new and existing lines of record were input and stored, the network analysis could be performed again. Very simple processing would generate new topology, creating parcels ready for validation or attribution. These new records and new parcels may not be needed or wanted by the BLM; thus if data sharing is to proceed in reverse, the BLM could exclude the portions deemed unnecessary. However, if these surveys further strengthen the network, and are of acceptable quality to the BLM, they could continue to be a part of the network, despite the fact that BLM may not be concerned with the actual parcels that they create. In this case, the data is essentially only used by BLM to strengthen the data product, not necessarily for the densified parcel base. The functions to separate this data already exist; though modifications for the sake of efficiency could be incorporated in future research efforts.

This additional data to be maintained locally comes in three forms: geodetic control, adjustable, and dependent. Geodetic control is essential for BLM's maintenance of GCDB. Adjustable data includes surveys having ties to the existing PLSS grid. This

data could be selectively used by BLM to add redundancy to the network and to strengthen coordinate positions. Dependent data is parcel data whose location is based upon other calculated positions. The local certificate of survey whose starting location is a 1/16th section corner is an example of dependent data. If the section breakdown is not included by measurement, this data is dependent upon the proportioning of the section. Note that this data may also create many valid parcels, yet it would seldom be desirable in the BLM's record of the township. Encoding the measurement information from this record along with the survey identifier will greatly simplify future maintenance issues for the local system.

3.3 State-level Parcel Attribute Elements

Returning to the initial data collection issue for local government, we will next discuss the parcel attribution process. As discussed in the previous chapter, the BLM makes use of a database known as the Legal Land Description (LLD). The LLD contains rule-based codes to provide the full legal description of the parcels. The LLD database alone has limited spatial ability. The codes are limited to locating to a nominal 1/16th aliquot part. GCDB attribution addresses this shortcoming and makes assignment to the individual parcels and their sub-parcels. For purpose of this discussion, a sub-parcel can be described as that portion of a particular parcel lying within a 1/16th aliquot part. Thus, if a mineral survey is physically located in portions of two 1/16th aliquot parts, or spans

across a section or township line, each of the smaller pieces is a sub-parcel, and each will have elements in its parcel attribute to identify it.

In the case of the Montana Cadastral Project, the parcel attribute information provided by the BLM is not used. The custom software simply makes use of the point identification system to derive simple identification of section corners, quarter corners, quarter-quarter corners, and special survey corners. No effort is given to utilize line topology, parcel topology, or BLM parcel attributes in the assignment of the new parcel labels. This seems to be a serious weakness in a very successful project, which once rectified could result in even greater success.

The method of linking BLM parcel attributes to the State parcel attributes will begin with an examination of the database used for parcel descriptions by the State. Montana uses a database known as the Computer Assisted Mass Appraisal (CAMA). From CAMA, a unique geocode is assigned to each parcel. This geocode is the attribute to be assigned to the parcel, and is used as a primary key in the spatial database to link with full details of the parcel. An example geocode is: 24455301303010000. The geocode is a concatenated set of several database fields. This combination uniquely identifies each parcel. The geocode is 17 characters in length. It contains the database fields shown in Table 2.

FIELD	STARTING POSITION	LENGTH OF FIELD
COUNTY	1	2
TWNSHP	3	4
SECTION	7	2
QTR-SECT	9	1
QTR-SECT-B	10	2
QTR-SECT-L	12	2
UNIT-NO	14	4

Table 2. Elements of CAMA Geocode.

The elements are further described as shown in Table 3; provided by the Montana Property Administration Library.

Field	Field description
COUNTY	Each county number is identified by the number currently used on automobile license plates
TWNSHP	Township number as defined by the federal rectangular survey system
SECTION	Section number is the unique identifier for each of the 36 square miles in a township
QTR-SECT	Number assigned to the quarter section: NE = 1; NW = 2; SW = 3; SE = 4
QTR-SECT-B	Number identifying the block within the quarter section
QTR-SECT-L	Lot or parcel number within the quarter section block
UNIT-NO	Unit number identifies the property rights associated with each parcel

Table 3. CAMA Field Descriptions for Elements of the Geocode.

The descriptions provided are misleading; for example, the TWNSHP field description would imply that a PLSS designation is used. In the example geocode used above, 4553 corresponds to this field. However the PLSS numbering of this township is T33NR18E of the Principal Meridian, signifying that an internal numbering scheme was used.

A full CAMA record is 2678 characters in length, and contains many fields unrelated to the spatial location or extent of the parcels. They exist for parcel management functions of government. Examples of these fields include owner's name, address, property improvements, etc. The CAMA record also includes information similar to the content of the BLM's LLD. Exploring further into the record, fields relevant to the linking exist, including a PLSS descriptor of the township, range, and section shown in Table 4.

FIELD NAME	STARTING POSITION	LENGTH OF FIELD
SECT-NO	200	2
TWP-NO	202	2
TWP-HLF-NO	204	1
TWP-SUFFIX	205	1
RANGE-NO	206	2
RNG-HLF-NO	208	1
RANGE-SUFFIX	209	1

Table 4. PLSS Identification in CAMA

As with the BLM's LLD database, the CAMA was collected prior to implementation of the Montana Cadastral Project. CAMA was originally a text-based database application for managing appraisals of the parcels. It was not until the spatial component became available that this data was incorporated to the GIS. When originally collected, the CAMA included certain fields having defined data formats and content. Other fields, including the legal land description, were left in a free format as keyed in by the specialist rather than conforming to a rigid standard.

3.4 Exploration of the GCDB and CAMA Relationships

While both systems contain equivalent data content for parcel location and identification, differences do exist. Sufficient correlation exists to attempt rule-based translation and attempt automated linking at some level. By evaluating the section, township, and range fields, a relationship could be derived. A minimal difference exists in that township and range numbers in the BLM data model accommodate all principal meridians in all states. In several cases, the township or range numbers are four-digit fields. Furthermore, the BLM data model utilizes a 3-digit code for the section number since this may be necessary for the extremely rare circumstance of a "Section 100." In Montana, all PLSS land descriptions relating to the Principal meridian, township, range, and section numbering do not exceed two digits. The codes require only minimal translation. For example, a Montana township T8S R45E would be coded in the BLM's LLD as 0080S 0450E. The same township in the state CAMA is 080S450E. In each case, the trailing

zero between township or range number and the direction is reserved for use with partial townships given a fraction designator (1/2 or 1/4 townships or ranges).

A rule-based relationship could easily be modeled for this level of the description. Beyond this relationship, the next most important components of the CAMA are fields related to the legal description of the parcels. The legal description is a concatenated set of four, thirty-character fields. As transcribed from the actual deeds, abbreviations were often used. It is highly variable in coding; just as the English verbiage in the legal descriptions on the deeds vary significantly.

Consider an ordinary quarter-quarter section such as the Southeast quarter of the Southeast quarter. This may be shown in the CAMA data coded in one of two ways. The most common form would be a code of SESE, yet different data entry personnel may have coded this as SE4SE4, still rule-based and understandable, but not consistent. In the GCDB LLD attribute definition, this is defined as nominal location P. If only one parcel exists in this quarter-quarter section, a simple match of the BLM parcel to the CAMA parcel can be performed, and the CAMA geocode assigned to the parcel at its area point.

Going one step further in complexity, consider the South Half of the Southeast quarter. In BLM descriptions, this is two separate sub-parcels, one for the nominal location O and one for the nominal location P. This description appears in the CAMA as S2SE4 or S2SE, and again both of these methods are modeled in this research.

Relationships must also be modeled. A CAMA record, which is by section, may contain several sub-parcels: for example, NE, N2SE. This coding makes reference to the Northeast Quarter and the North Half of the Southeast Quarter. In CAMA, this is one record containing two sub-parcels. In GCDB this is represented as six nominal location

sub-parcels (A, B, C, D, M, and N) within the same section. The simplest form of an aliquot part description is ALL. This designation is used to identify a full section.

The next step involves going beyond aliquot parts to identify and use government lots and other numbered survey records. The GCDB has information included to identify these types of parcels. Mineral surveys, homestead entry surveys and other special surveys are included and are fully attributed. What was quickly discovered in the CAMA descriptions is that the land clerks responsible for the recording and entry of these descriptions were not necessarily experts in land survey terminology. The interpretation and coding of the descriptions varies significantly. In some cases the CAMA records a description for Section 1, Government Lot 1 as the NENE of Section 1. On occasion it was found that reference to the government lot was made, yet even greater coding irregularities exist. A few examples of this irregularity include “LOT 1”, “GOV LOT 1”, and “LOTS 1-4”.

In most cases, the source of the lot number could not be differentiated from a local certificate of survey or a GLO plat. Matching of government lots is performed on the basis of the nominal aliquot part it represents since this is found to achieve the greatest success. Numbered survey descriptions such as mineral surveys and homestead entries could be identified automatically due to consistent naming across the two systems.

Much effort of this research focused on exploring and modeling the various techniques used to encode an aliquot part description. A review of the federal attribution schema is included in Appendix B, which could be useful to understand details of the research technology.

3.5 Maintaining Multiple Parcel Fabrics

Maintenance of the PLSS database is of critical importance. The Western Governors Association is well aware of this fact. This inspired their policy to support the federal program in a unified manner. The western states all believe that the BLM-defined locations provide the most reliable content for the PLSS layer.

Building on this framework to compute positions depicting the local parcels is also recognized as providing the most reliable parcel base. The maintenance of the local parcel base is recognized as an immense issue that is largely unresolved. A readjustment of the PLSS network would introduce mismatches, creating unacceptable overlaps and gaps. The elimination of these mismatches would involve tedious and expensive re-computations, yet this is necessary to maintain seamless parcel-based mapping.

Local government also has the need to maintain an up-to-date representation of the parcels. It is an ongoing task to incorporate new surveys creating parcels and ideally not disrupt or create additional gaps or overlaps. Resolution of this issue is the primary benefit of this research.

There are three kinds of coordinated position provided through the measurement management technology.

- Horizontal control
- Adjusted positions computed from horizontal control and record
- Positions of points dependent upon the position of other computed points

The GCDB includes the data necessary for regeneration of all coordinated positions. The Montana Cadastral Project coordinates additional positions using a coordinate geometry solution that only results in new coordinates. Thus, if the BLM maintenance program should perform a re-adjustment of the network, these COGO positions must be recomputed. Without storing the necessary computation parameters for reuse, this is a very expensive, tedious, and error-prone procedure.

Extending the GCDB concept where each record used in the adjustment set is assigned a source identifier, a new functionality to the post-adjustment computations was created. This new extension allows all of these computed positions to be assigned a source (or survey) identifier. This technique allows for the computations to be selectively included or excluded from the batch process. This creates the ability to create and maintain multiple parcel-based maps or overlays using the same network as a coordinate framework. By applying this research, a local government can utilize WinGMM to store parameters and perform the necessary computations to depict the local parcels. This secondary parcel map is termed a parcel fabric. Implementation provides three key benefits listed below.

- 1) Facilitating maintenance of the network managed by the federal agencies.

Data may be provided from the local partner organizations to the BLM for maintenance of the network. For example, additional control positions, updated PLSS measurements, and so forth are desirable for strengthening the network. The additional measurement data used to create the local parcel fabric aren't necessarily important or useful to the BLM. The ability to

identify these records by survey identifier is beneficial to BLM in providing the ability to selectively include or exclude portions of the data.

- 2) The second key benefit facilitates rebuilding the local parcel fabric. As the federal government updates the network, the local parcel fabric may be regenerated. This is further illustrated in the next chapter. WinGMM has been designed and expanded to include the capability to generate or regenerate the parcel fabric without disrupting the network at any time.
- 3) The local government has the task of keeping the parcel-based map up to date. Additional records need to be incorporated as they are received and filed. The digital representation should accommodate this function with no adverse effects. A re-generation of the overall parcel base will not create problems such as gaps and overlaps, and can be performed anytime. The improvements to the measurement management solution defined by this research yield the desired outcome for today as well as preserving the work for future maintenance.

CHAPTER 4 WINGMM COMPUTATIONAL ASPECTS OF THE PARCEL BASE MAP

4.1 Source Records to Digital Record Components

This chapter will document the files and interfaces created as part of this research along with their relationships to the previously published components created over many years. The purpose of this documentation is to provide a foundation and understanding for future development cycles of this body of research and this software tool.

To fully understand the computation of the parcel base map, one must evaluate the entire data structure that allows for the automatic regeneration of parcels. This automatic regeneration of parcels is key to maintenance of the base map (Hintz, et al, 1995). All of the examples used in Chapter 1 have a very clear distinction between creating the map and the attribution of parcels. Each leaves the question of maintenance unresolved. The GCDB solution does not have such a clear distinction between map creation, attribution, and maintenance. Instead it blends these integral components throughout the process. Individuals with a land records background often perform the final completion and maintenance of the parcel attributes. Surveying personnel are responsible for the completion of the parcel base map.

Parcels are polygons with attributes. Parcels are dependent upon a set of lines that define their boundaries. Boundaries, in the simplest definition, are geometric lines with attributes that define magnitude, direction, and the end points. In turn, corners are

geometric points with attributes that define their location. Thus points, lines, and polygons, combined with their attributes, create corners, boundaries, and parcels. The data structures are normalized for efficient computer processing and storage. The implied relationships are best described through defining the data structures. For organizational clarity, the following information discusses the data structures in the order that they are created.

4.2 Raw Data

The first file created in a township documents several items of global importance to completion of the township. This is known as the project definition file .def, referred to in GMM as the projects properties. Figure 8 illustrates a specific township as an example.

PROJECT IS	T11NR55E	
(1) T11NR55E		<TOWNSHIP AND RANGE>
(2) 20		<PRINCIPAL MERIDIAN>
(3) MT		<STATE OR LOCAL
DESIGNATION>		
(4) 84 MONTANA CENTRAL LAMBERT		<STATE PLANE ZONE>
(5) PROJECT ELEVATION IS	2600.00 FT.	

DEFAULT STANDARD ERROR ESTIMATES

(6) DISTANCES	.1 FT. PLUS 1000. PPM (1/ 1000. OR	5.4 FT./ MILE)
(7) ANGLES	0- 0- 4.0 (D-M-S)	
(8) BEARINGS	0- 2- .0 (D-M-S)	
(9) CONTROL NORTHING (Y)	30.000 FT.	
(10) CONTROL EASTING (X)	30.000 FT.	
(11) PRINT OUT ALL RESIDUALS		
(12) ELEVATIONS READ FROM .LEV FILE ?	-- NO	
(13) ERROR ESTIMATES READ FROM .SD FILE ?	-- YES	
(14) ERROR ELLIPSES COMPUTED ?	-- YES	
(15) READJUST WITH ROBUSTED ERROR ESTIMATES ?	-- NO	
(16) UTM ZONE = # 13		

Figure 8. Project Properties.

The evaluation and abstraction of a township begins with assembling all items pertaining to the official cadastral survey record and control (Owen, 1994). This data includes bearings and distances derived from field surveys of land boundaries that are specific to the PLSS (Hintz, et al., 1993). Among these are township and section lines, subdivision of section lines, meander lines, mineral surveys, land grant boundaries, land claim boundaries, and various other forms of non-rectangular (metes-and-bounds) surveys. Other “measurement” information includes control coordinates derived from the digitizing of maps (primarily U.S.G.S. quadrangle maps), coordinates of corners from a field survey, or a bearing-distance tie to a corner from a control station. The control

coordinates and bearing-distance information is synthesized via least squares analysis in production of coordinates for all corners in the measurement information (Hintz, et al., 1996). Source documents create equivalent content data files.

As pointed out in Chapter 2, the abstraction process involves determination of the most recent record for individual boundaries. This information often comes from a variety of sources. The assembly of these various sources into data files must also maintain keys to the source documents. Thus, the abstraction and data entry phase yield three critical files for the generation of coordinates. The original records are combined into one set of files. These are easily distinguished by recognizing the database keys. The first such key is the SID file. It contains identifying information for each source document. Figure 9 is an example SID file; line numbering is shown to aid readability.

Line #	Contents of SID file
1:	S16545 .100 1000.0 300.0 30.000 30.000
2:	C GLO 29-DEC-1903 O SCOTT,R
3:	C SOUTH BT FROM T10NR55E
4:	S16547 .100 500.0 120.0 30.000 30.000
5:	C BLM 14-DEC-1981 D LARUE,J
6:	C SOUTH BT FROM T10NR55E
7:	S17711 .100 1500.0 420.0 30.000 30.000
8:	C GLO 29-DEC-1903 O SCOTT,R
9:	C WEST BT FROM T11NR54E
10:	S17715 .100 500.0 120.0 30.000 30.000
11:	C BLM 14-DEC-1981 D LARUE,J
12:	C WEST BT FROM T11NR54E
13:	S17717 .100 1500.0 420.0 30.000 30.000
14:	C GLO 29-DEC-1903 O SCOTT,R
15:	C SUBDIVISION
16:	S17721 .100 600.0 150.0 30.000 30.000
17:	C BLM 14-DEC-1981 D LARUE,J

Figure 9. SID file contents for T11NR55E.

Beginning at line one, the survey identifier number appears first, prefixed with the letter S, in this case, S16545. The remaining items on line one are weighting values used later during analysis and computation of points. In Figure 9, .100 is a distance constant. The proportional value in parts per million (PPM) to be applied to each distance segment is 1000.0. The bearing error estimate, expressed in seconds of arc is 300.0. The final two items are currently unused, but may someday be used for control error estimates in Easting and Northing. The second line is the first line of description and defines the source document. GLO refers to the agency that produced the record, in this instance, the U.S. General Land Office. The date of acceptance shown on the plat is listed as 29-DEC-1903. The letter O infers that this was the original survey of these lands. SCOTT, R is the name of the surveyor who performed the survey. During the assembly of these records, the surveying personnel may include as many comments as necessary to document their process or the use of the plat. Line 3 of Figure 9 shows that this particular boundary was transferred from the township immediately to the boundary's south.

Survey identifier S16547 appears on line 4. This survey is a dependent resurvey ("D") of (at least) a portion of the south boundary, performed by the BLM Cadastral Surveyor, LARUE, J, and accepted on 14-DEC-1981. Each plat may actually have several SID numbers associated with it, as is shown in Figure 9. The 1903 survey has three separate SID entries. The 1981 survey also has three, even though only two are physically mentioned. This type of segregation is made by the survey personnel analyzing the data and may involve separate weighting parameters for separate

components of the survey. A clear example of this is shown using the LARUE survey. In yet other cases, the accuracy requirements of components of a survey vary greatly. As an example, the rectangular lines of a survey are usually surveyed more precisely than returned meanders of a water boundary. The SID file is also used to encode other special information relating to a particular survey or part of a survey. Appendix A.4 fully documents this special information.

The second component of raw data is the abstracted record of the surveyed lines themselves. A clipped portion of the raw file, showing the south boundary of the township appears in Figure 10.

Line #	Content of RAW file					
1:	700100	640100	39.910	3	900000.0	16547
2:	640100	600100	40.090	3	894400.0	16547
3:	600100	540100	40.030	3	895100.0	16547
4:	540100	500100	40.060	3	894800.0	16547
5:	500100	440100	40.040	3	895100.0	16547
6:	440100	400100	40.070	3	894200.0	16547
7:	400100	340100	40.040	4	895100.0	16547
8:	340100	300100	40.040	4	895100.0	16547
9:	300100	240100	40.040	4	895100.0	16547
10:	240100	200100	40.080	3	895400.0	16547
11:	200100	140100	40.000	3	895400.0	16545
12:	140100	120100	20.000	3	895400.0	16545
13:	120100	100100	17.680	3	895400.0	16545
14:	700200	640200	39.925	3	894700.0	17721
15:	640200	600200	39.925	3	894700.0	17721

Figure 10. A portion of the RAW data file for T11NR55E.

Line one begins with From and To station identifiers. This data in this line represents beginning at the SE corner of the township “700100” and proceeding westerly

to “640100,” the south quarter-corner of Section 36, a distance of 39.910 chains, on a bearing of due west (Quadrant 3, 90-00-00). The survey identifier of the record is “16547”, which is identified as the LARUE survey of 1981 in the SID file of Figure 9. This survey was used across the south boundary up to Station “200100,” shown in lines 2-10. This is the southwest corner of Section 32. Continuing westerly across the south boundary of Section 31, the original 1903 GLO survey performed by SCOTT is associated with 16545 survey identifier. Examining this final mile of the south boundary, three segments are coded. Line 11 records from the section corner (200100) to the quarter corner (140100) for a distance of 40.000 chains. Line 12 records from the quarter corner (140100) to the W 1/16 corner (120100) for a distance of 20.000 chains. The final course on this line begins at the W 1/16 corner (120100) to the township boundary (100100), a distance of 17.680 chains. This type of coding is later used to define the section subdivision. In this case, 17.680 chains would be shown on the plat as a parenthetical distance. It is used for computation of the closing line parcels that are ordinarily described as government lots.

The remaining example lines (14-16) show the abstraction continuing, by first returning to the east boundary of the township at the northeast section corner of section 36, “700200,” and proceeding westerly as before. These records use the 17721 SID, referring to the LARUE subdivision. Use of the word subdivision in this case implies the subdivision of the basic unit of survey, the township. This is noted only for clarification, as later use of the word subdivision relates to the subdivision of sections.

The final component required for generating coordinate positions is the horizontal control used for the township, as illustrated in Figure 11.

Line #	Contents of .CON File									
1:	02/28/95 0110N 0550E 20 MT CONTROL									
2:	ORIGIN									
3:	100100	463922.0347	1045129.8124	2600.000	30	30	27			
4:	100200	464013.7880	1045129.9318	2600.000	30	30	27			
5:	100500	464250.3308	1045129.7233	2600.000	30	30	27			
6:	200100	463922.2920	1045016.7150	2600.000	30	30	27			
7:	200200	464014.0128	1045016.7204	2600.000	30	30	27			
8:	200300	464105.9940	1045016.7543	2600.000	30	30	27			
9:	200400	464158.2618	1045016.8830	2600.000	30	30	27			
10:	200500	464250.5685	1045016.7088	2600.000	30	30	27			
11:	200600	464342.5167	1045017.0269	2600.000	30	30	27			
12:	200700	464434.6210	1045017.4589	2600.000	30	30	27			
13:	300200	464014.3223	1044900.4713	2600.000	30	30	27			

Figure 11. The computed coordinate positions in a .CON file for T11NR55E.

Line 1 of Figure 11 is the header line of the .CON file. The line identifies the date the control was assembled and an abbreviated PLSS description of the township, range, principle meridian, and State. The word CONTROL is added to avoid possible confusion with a later file of similar structure. The lines following in the .CON file contain individual coordinate records for each location. These data elements are the point identifier, latitude, longitude, elevation, error estimates of the position coordinates, and reference datum. The error estimates of the control coordinate positions are critical to the analysis, as the source and accuracy of the control varies considerably including digitized USGS Quadrangles, field survey ties, inertial positioning, and GPS (Owen, 1994), (Hintz, et al., 1996). For instance, Line 3 contains the control record information for Station 100100. This station has a latitude of 46°39'22.0347", a longitude of 104°51'29.8124", and has been assigned the average elevation of the township, 2600.000

ft., with error estimates in both the X and Y directions of 30 feet. All horizontal control information referenced in this file is referenced to the NAD27 datum.

The three files discussed above (raw data, survey identifiers, and control) are used to generate a pair of files for input to the least squares analysis. These files have extensions of .LSA and .SD. These two files are not described here since they are not considered part of the official GCDB record for a township, and can be rebuilt from the record files as needed. The least squares adjustment output, including residuals, snoop numbers, root mean square errors, standard error of unit weight, etc., are used during the initial data collection to indicate the appropriateness of error estimates assigned to SID's (Hintz, et al., 1996). This information is maintained to insure a high quality, accurate duplicate of the source records. Often at this stage of the collection process, computations are repeated several times as errors are discovered and corrected. This eventually leads to the results of the adjustment being a stand-alone entity. The adjustment reports are well documented in the WinGMM software manuals and are not repeated here.

Completion of the adjustment is a key step since it results in coordinated positions for all points surveyed. These results are stored in a variety of files whose extensions and contents are as follows: (1) the .COR file, which contains the state plane coordinates for the positions, (2) the .GEO file, which contains geographic latitudes and longitudes for the positions, and (3) the .PGC file, which is one of the official record files. It has the same format as the .CON file shown in Figure 11. It contains all points calculated rather than simply the control as contained in the .CON file.

4.3 Subdivision of Sections

The next set of files stored as official records to the township includes any irregular section subdivisions contained in the .IRR file. This file contains encoded information for deriving the rules to be used in the subdivision. The exact contents of these files vary greatly. Generally, the type of information encoded includes point identifier substitutions, special techniques to be used, and any other information necessary to identify a departure from the normal rules for section subdivision. It is important to note here that the regular parenthetical distances used for computing government lots are not considered irregular; rather this information is inferred through the actual structure of the .RAW data file construction.

The township used in the previous example does not contain any irregular information. The subdivision of this township is considered normal, and the appropriate aliquot parts and government lots are generated with no further information. This is true for a large percentage of the total GCDB. The computer software WinGMM was designed for the handling the exceptions by allowing normal subdivision to occur automatically (Hintz, et al., 1994). For illustration purposes, a new township will be used. This township, T08SR48E, contains 18 sections with irregular subdivision. A portion of the township is shown in Figure 12.

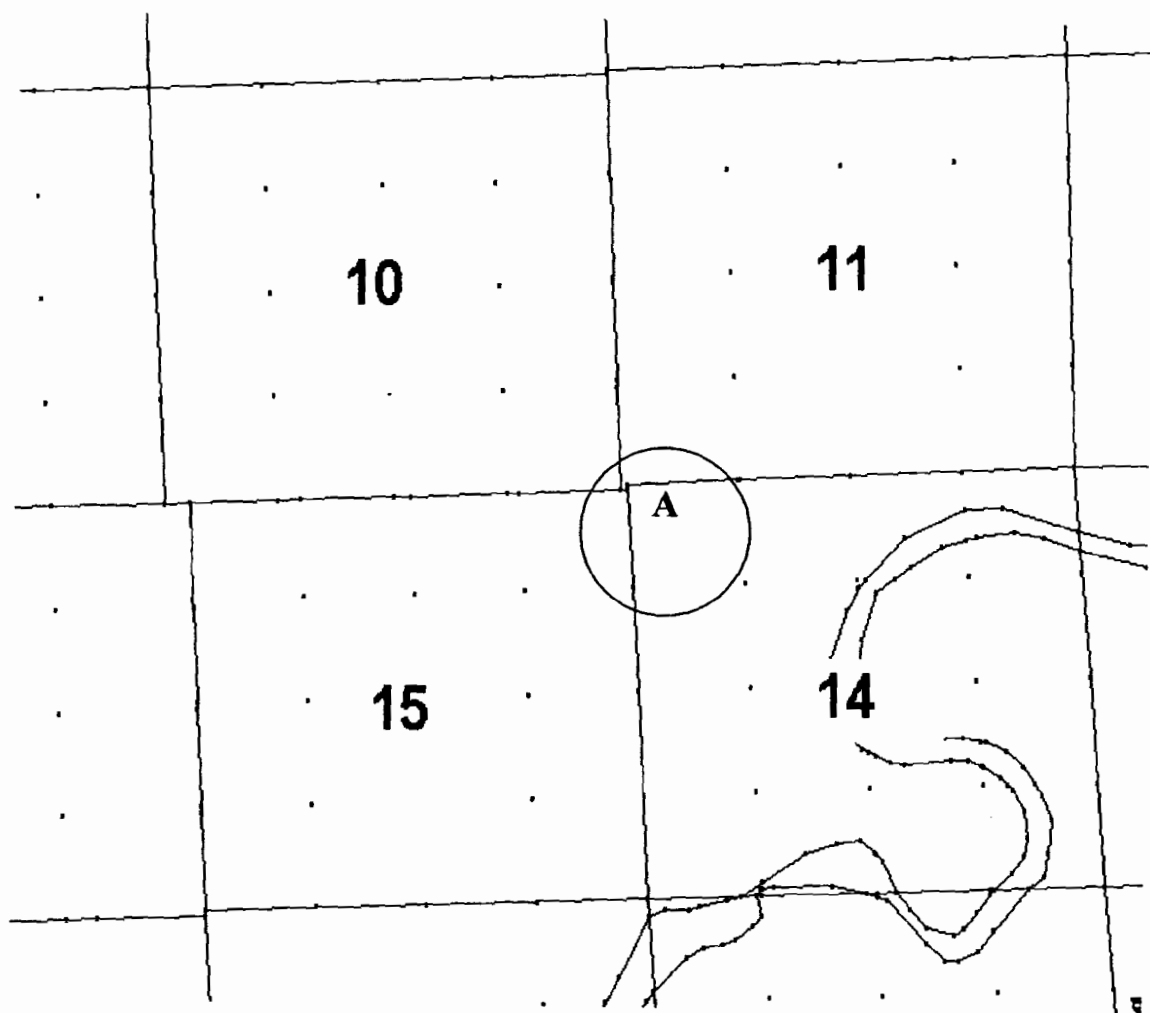


Figure 12. Example of Irregular Section Subdivision.

Sections 10, 11, 14, and 15 in Figure 12 have each been defined with irregular section subdivision. In the circle labeled A in Figure 12, it can be seen that double and triple section corners exist. Each corner controls the subdivision of one or two sections only. In these cases, the substituted point identifiers are coded into the .IRR file that is organized into parts, each part relating to a specific Section. The first line below in Figure 13 begins with “440440,” referring to the center of section identifier in Section 15.

```

440440
400500 402500
420500 422500
440500 442500
460500 462500
500500 502500
  0  0
  0  0  0
  0
  0
  0
440460 18.730 38.730
  0 .000 .000
  0
  ^

```

Figure 13. Irregular section subdivision definition of Section 15.

The lines following the center of section number are used to identify the substitute point identifiers. Each of these lines begins with the normal point identifier to be replaced; the second identifier is the substitute. Interpreting line two, the normal section corner “400500” will be substituted with “402500.” If a section is partially irregular, the subdivision rules must be explicitly identified for the entire section. Also shown in this example is a 1/16th corner (440460) to be proportioned according to the distances

shown, creating a lot rather than an ordinary aliquot part. The remaining values that are shown as zeros represent other portions of the section subdivision irregularities not used in this particular case. Software isolates the user from the rigid structure of this file.

4.4 Post Adjustment Computations

First introduced in Chapter 2, the final computations performed on the township consist of calculations dependent upon previously derived points. These calculations are known as post-adjustment computations. The post adjustment computations are used in three ways: to (1) store the necessary information to perform section subdivision, (2) perform additional calculations to depict survey information that is dependent upon the adjusted positions of the network, and (3) build or rebuild line and parcel topology. The additional calculations are stored in the .ADD file. They were originally designed to accommodate the very unusual calculations occasionally found in the subdivision of sections. In these cases, the common practice is to set portions of the section subdivision to “non-computable” using the irregular definition. One would define the computations of these points using COGO procedures. Unlike other COGO packages, the parameters used in the computations are coded and stored in the additional calculations file.

This research has expanded the core functionality of post-adjustment computations to handle creation of the local parcel fabric. The expanded functionality of the post-adjustment calculations is also driven by a graphical interface that complements its functionality. As with the irregular subdivision, the rigidly coded data file is managed through an interface that allows the definition, inspection, and editing of all calculations.

The highlighted record in Figure 14 illustrates one such computation, a bearing-bearing intersection to create “460220.” Several other definitions are shown in this illustration; each line begins with an integer code signifying the computation type. Type two computations are intersections. Type one calculations are traverse or proportioning. Type three definitions refine the final topology.

Line	ID1	ID2	ID3	Bearing	Type	Distance	Angle
2	460220	460200	462240	.00000	1	.000	.000
2	0	440220	500220	.00000	1	.000	.000
2	460260	458240	460300	.00000	1	.000	.000
2	0	440260	500260	.00000	1	.000	.000
1	440260	440240	440294	.00000	1	17.455	.000
3	440260	420260	0	.00000	0	.000	.000
3	300220	296220	0	.00000	0	.000	.000
3	440294	440300	0	.00000	0	.000	.000

Intersection definition for: 460220
Line 1 From ID is 460200. Bearing is defined to ID 462240 (Straight).
Line 2 From ID is 440220. Bearing is defined to ID 500220 (Straight).

New Find Delete Edit Status Compute Test Close

Figure 14. The post-adjustment computations graphical interface in WinGMM.

In the cases of elongated sections, the post-adjustment computation definitions are used extensively for minor aliquot part subdivision. The uses of this functionality are seemingly endless. It has full coordinate geometry calculations and provides the essence of measurement management where the rules are coded, rather than performing the calculation only for a coordinate pair. Options within intersections are numerous,

including functionality to define bearings as geodetic or straight lines, as parallel to other lines, and as weighted mean bearings for specific purposes.

Hintz (1996) developed routines to automatically detect, record, and compute intersections of all crossing lines for use in development of the parcel topology. These calculations always generate a point identifier prefix of 950, and are numbered sequentially thereafter. These calculations are also stored in the .ADD file, and are accessible via the PAC interface, as occasionally need arises to modify or delete the definition of these intersections from the automatic identification.

PAC functionality was greatly expanded as a part of this research to accommodate the smaller parcels introduced by the state and local records as described in Chapter 3. The expansion involves the ability for each of these calculations to be assigned a survey identifier. This survey identifier is crucial to the selective inclusion or exclusion of records that form the multiple parcel fabric concepts from the previous chapter. Due to the need to integrate with the existing GCDB data, the use of survey identifiers for post-adjustment computations is optional. The BLM does not use a survey identifier for the post-adjustment items, but rather the source is implied from the record or records used to define the section. In many cases, it cannot be readily determined and the source is actually a mixture of records defining the section. When used, the survey identifiers are set up as others described in Section 4.2. When defining the post-adjustment computations, the identifier is selected from the drop down list on the definition screen. Computational capabilities provide for test computations as well as final computation of coordinates. The typical procedure involves a series of computations to refine the full set of positions, testing and evaluating to insure data quality and appropriate methodology.

When satisfied with the results, the final computation is made to update the database. In addition to the coordinate computations, this final processing also creates positions for the intersections of lines, refines the line topology, and creates the parcel boundaries.

The sequence of this final processing performed is important to understanding the creation of the line topology and parcel boundaries. The sequence of operations is:

- 1) The .ADD file is searched for calculations dependent on the framework alone.
- 2) The sections having defined irregular subdivision are computed.
- 3) All remaining normal sections are subdivided.
- 4) The .ADD file is again searched for possible calculations to perform. This process repeats until the entire list of calculations is complete.

The topology for each new calculation is built based upon the calculation itself. A new traverse or proportion calculation results in either a new line, or a break in an existing line. An intersection creates three or four new line segments. While this rule is generally true for building parcel topology, it can become convoluted when calculations are necessary for construction purposes, rather than defining a boundary. In these instances, it will be necessary to refine the topology. Topology refinements include identifying which points are not to be included as well as which lines should not be included in creating the lines and polygons. These topology refinements are stored as post-adjustment computations and occur automatically.

It is critical to note that the word “final” in the measurement management sense, is not a terminal operation; these computations may be processed again and again without disruption to the underlying network. In this manner, the local parcel fabric may be maintained independently of the federal network, and regenerated as necessary to reflect

changes. This is the most time-consuming and tedious task of the creation of the local parcel-based map, yet the benefits far outweigh the cost.

4.5 Regional Analysis

Early in the design and collection of the GCDB it was felt that each township, as the standard unit of survey, would define the limits of the data analysis. To ensure a seamless connection with the adjacent townships, a set of fixed coordinate positions along the common border was used. This approach illustrated the build-up of systematic error due to the fixed township boundary assumption. As more townships were collected and pieced together, this systematic error grew to unacceptable levels, forcing residual error into the record measurements and control coordinates (Hintz, et al., 1995). The alternative was to adjust each township as a single entity, which obviously does not allow the systematic error buildup as it is a distinct entity, yet this alternative produced equally unacceptable results where a common boundary did not have the same coordinates in each township data set. Furthermore, the fixed boundary scenario creates overly optimistic coordinate standard deviations of corners near the boundary. As an example, a quarter corner located 40 ch from a fixed boundary would have unrealistically small standard deviations due to its proximity to the fixed positions (Hintz, et al., 1996).

To rectify the systematic error buildup due to fixed township boundaries, a multi-township least squares analysis was required. The design of a system to merge the individual data sets for a regional analysis was complicated by the fact that the point identification scheme is township based. A township corner common to four townships

has four distinct point identifiers in the corresponding individual data sets (Hintz, et al., 1993). Further complexities arise with the point identification system where the standard corners are given standard identifiers while the closing corners of the adjacent township are given identifiers to imply the offset direction from the nearby standard corners. The problem was compounded by the fact that townships are offset, sometimes by several miles along the standard parallels and guide meridians. Finally, the non-standard lines (meanders, mineral claims, and so forth) cross township boundaries, yet their intersection with the township boundary is not always identified in the record information itself (Hintz, et al., 1995).

The township merge was finally resolved by not basing it upon the point identifiers, but rather utilizing the coordinates from the individual township data sets. At the beginning of the merge process, an appropriate coordinate match for the region is input by the user. The first township is read and the township name is suffixed to the point identifiers. When a subsequent township is read, the record bearing and distance is compared to existing bearings and distances in the region. If a match is found, coordinate comparisons are made to see if they are within the user-defined tolerance. If no match is found, the record data does not exist in the building region, and region point identifications are assigned based on its township. When a unique match is found, the line already exists in the building region and the points belonging to more than one township are identified. If more than one match results, the user is instructed to refine the tolerance level (Hintz, et al., 1995), (Hintz, et al., 1996). Once the region has successfully merged, the least squares analysis is run on the entire dataset. A later batch process updates the individual township coordinates.

This initial phase of regional analysis seemed to correct the problem, yet a similar problem had arisen when joining regions together. Due to the large size of the region datasets, the problems are not as significant as at the township level. As the process evolved, further refinements of the regional adjustment process were implemented.

These refinements introduce the buffer concept that is employed in two ways for coordinate generation of regions. The first procedure is used where the user is confident that creating a fixed boundary will not cause adverse problems. When forming the region, inclusion of additional townships frame the region with a buffer. The measurement information of the buffer townships is not part of the region analysis. Instead, the common bearing-distance information is identified as before, but only the existing adjusted coordinates from the buffer township are brought in as fixed control. These buffer township coordinate files are not used to update the individual township data sets, as they were part of a previous region adjustment. This procedure does not fully address the issue of the effects of fixed coordinates. The second procedure addresses this issue. This can be thought of as a double buffer. The first buffer consists of townships where all measurement information is included for the least squares adjustment, but their coordinates will not be imported back to their respective townships.

The second buffer is the fixed layer of coordinates as used in the first procedure. This procedure produces a seamless GCDB as coordinates of boundary points to the first buffer retain their coordinates and are not influenced by the new regional analysis. The assumption is that these boundary coordinates have insignificant shifts due to the double buffer. Thus, it does not matter which coordinates are assigned to the point (Hintz, et al.,

1995). The double buffer concept requires regions to have overlap, and the overlap provides a measurement buffer between data being used for coordinate production and an outer buffer being held fixed, ensuring regions are seamless (Hintz, et al, 1996).

The buffering concept provides seamless GCDB as far as the coordinates are concerned; yet the remaining requirement of coordinate reliabilities derived from generating coordinate standard deviations still exist. A new procedure was developed by Hintz to address the coordinate reliabilities issue. The new procedure is an offshoot of concepts in survey network design. In this design process, one defines approximate coordinates for control and unknown stations and defines the measurements that are to be made in the survey. Error estimates are included for the simulated measurements. From this information the variance-covariance matrix can be derived, which produces coordinate standard deviations. The actual values of the measured quantities are not required, and as final coordinates are not computed, the solution is not iterative. Reliabilities can be generated as a separate process from the least squares analysis for coordinate production (Hintz, et al. 1995).

When measurements are not in close proximity to a station, they do not significantly affect the reliability of that station. Furthermore, improving measurements five miles from and indirectly connected to a station, does not appreciably improve the reliability of that station's coordinates. It also is important to not include any artificially fixed coordinates, as this does produce artificially small reliabilities in that general area. Thus, the process forms a region similar to the method used for coordinate production, without the fixed boundary, and much smaller than the region used for coordinate production. This is desirable, as it significantly reduces the processing time. When

generating the reliabilities for a given township, a series of buffer townships are used which encircle the target township. The size of the buffer is user-definable. The most common buffer employed is six miles; thus, for generating reliabilities on a single township, the eight surrounding townships are included. This process selectively applies the update to the center township only. The algorithm then moves on to the next township and repeats the process (Hintz, et al., 1996).

In this research, a third phase of refinement for the production of regionally adjusted coordinates and reliability generation has been implemented through an enhanced user interface. The interface addresses the many intricacies of managing multiple data sets and building the region. In essence, the user begins by defining a project that will contain the region measurement information. Townships may be added singly or several at a time; a preliminary test is performed to identify any potential problems that would prevent a successful merge of the region. The suspect mismatched lines are graphically depicted as a problem area requiring attention. The interface allows the user to switch to one of the individual township projects to make necessary modifications and return to the region building process. The test procedure can be reactivated as additional townships are added to the region. The type of error that would cause the unsuccessful merge includes mismatched measurement information on a common boundary or coordinate tolerance irregularity as discussed above.

As the use of the initial regional analysis procedures were utilized, it became apparent that occasionally a mismatch could occur when record measurement data was incorrectly coded in one township and then compared to the adjacent township. In simple terms, if an intervening point was omitted in one township, yet included in the adjacent

township, an error could occur where the join did not identify the common lines because they did not exist in the coding. The regional interface facilitates discovery of this error by providing the test procedure discussed above. It has therefore been a significant quality assurance procedure when handling these immense data sets.

The processing power and disk storage of desktop personal computers has dramatically increased over the past 10 years. This has allowed a “reasonable” size of regional adjustment to now encompass several hundred individual townships. In addition to the resolution of the common boundary/fixed boundary issues, this interface and the regional analysis process has the latent benefit of ensuring consistent application of abstraction rules and assignment of source identifiers.

In Figure 15, an example region has been created, and the test has been invoked, illustrating the potential mismatch. The merged region is displayed and the test performed identifies three areas requiring attention in this eight-township region. The software identifies these mismatches by highlighting the suspect lines and displaying the endpoints. One such mismatch is circled, and is on the common line between T29S13E and T30S13E. T29S13E has this mile encoded in two segments as follows.

```
300100 240100 40.000 4 900000.0 1
```

```
240100 200100 40.000 4 900000.0 1
```

These two lines from the RAW data file are referenced to SID 1. The matching SID record is as follows:

```
S1          .030 17444.0 3600.0  .000  .000
```

```
C 0  BLM 22-SEP-1871 01 PENGRA, ,M
```

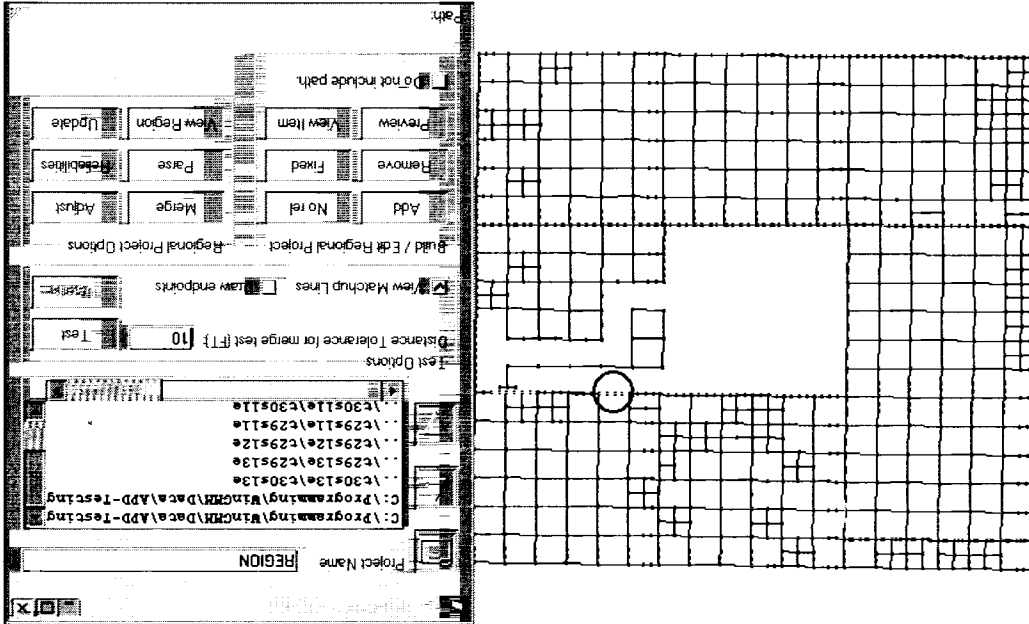


Figure 15. Regional Analysis Interface.

Further investigation shows a coding error in the same mile of the adjacent township, T30S13E. The RAW data identifies the common mile coded into four segments.

300700	260700	20.000	4	9000000.0	1
260700	240700	20.000	4	9000000.0	1
240700	220700	20.000	4	9000000.0	1
220700	200700	20.000	4	9000000.0	1

These four segments refer to SID 1. In this case it is defined as

S1 .030 14314.0 1208.8 .000 .000

C 0 BLM 22-SEP-1871 01 MC CLUNG & P

The problem in the coding is that one file used two line segments to define the common mile, whereas the second used four line segments. This was discovered when performing the pre-merge test of the region; further, the coordinate differences at the section corners were discovered to exceed the test tolerance, flagging the mismatch for user interaction. The merge process would not find the common segments and would have loaded both. The solution to the situation in this case is to revisit one or the other township and make the required changes to ensure consistent coding prior to performing the regional merge. Similar situations occur in two other locations in this eight-township region.

By varying the test distance value and performing the test prior to the merge, a significant savings may be realized as these errors may be identified and corrected prior to a major adjustment. The test procedure can be used in similar ways after the adjustment as a quality control check. The regional analysis provides for update of the coordinates and the associated reliabilities for the coordinates. This adjustment process does not include the subdivision of sections or other post-adjustment computations based upon the updated controlling positions. Thus, in addition to facilitating the design, merge, and adjustment of a region of townships, the interface provides for the post regional update of the individual township data sets. Using a macro like batch process, these remaining final steps are performed without user interaction.

Local government may find that maintenance of the entire jurisdictional area is facilitated by the region dialog. Viewing the entire region, the spatial query tool may be utilized. Navigation through the area is facilitated by the graphical display that interacts with the text listing. Once an area of interest is selected, the individual item can be updated. This process updates the entire database to reflect the changes.

The post regional update dialog seen in Figure 16 performs a series of user-defined operations to completely finish the task of updating all included township information. The primary function is to perform an automated update of dependent positions to reflect changes made to the core network. Upon completion of the changes, the subdivision of sections is rebuilt along with post-adjustment computations and parcel topology. Additionally, the interface can batch several other utilities to produce required output files and run parcel validation procedures.

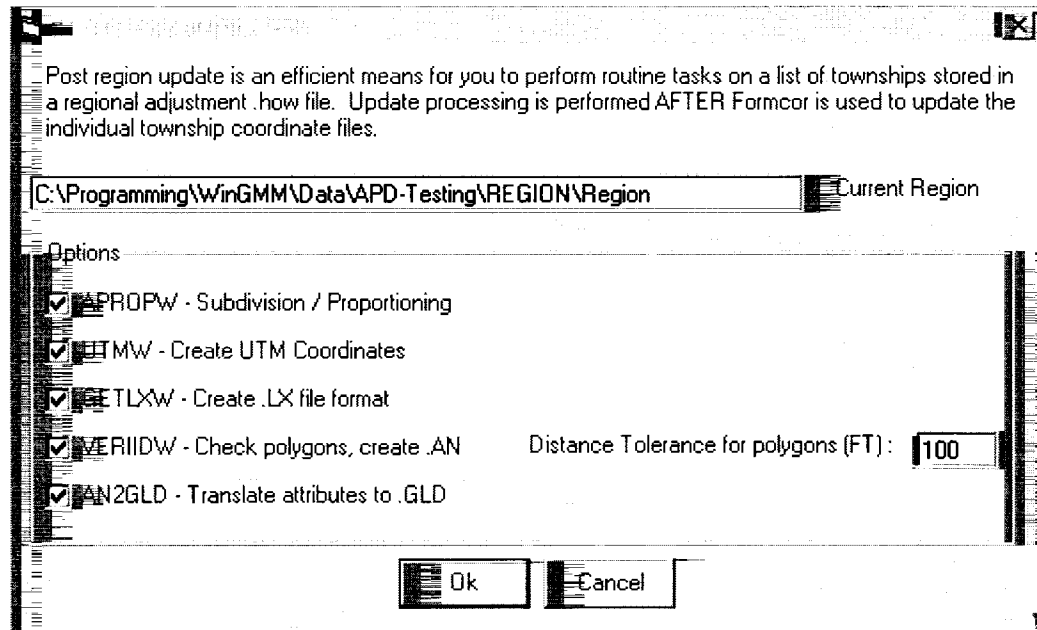


Figure 16. Post regional update interface.

It is imperative to recognize that regional analysis is performed first during initial data collection, and also when performing maintenance to the database. In these maintenance procedures, the inclusion of new survey measurement information could result in the intersections changing and cause parcel topology to be significantly different from the initial data collection. For example, the new adjustment could cause a displacement of lines such that some of the previous intersections are no longer valid. Although remote, these situations require the validation of the previous intersections followed by validation of the parcel boundaries in the reprocessed township. New intersections, invalid intersections, and new parcel boundaries due to new intersections, and possibly new lines, create the rare need for user verification that the new parcels have been automatically assigned their proper legal description (Hintz, et al., 1996).

The post regional update feature supports the multiple parcel fabric regeneration by providing for automatic update of all dependent positions within the region. This is the ongoing task of the local government to maintain the local parcel base. Future research activities could focus on parcel validation procedures custom to the secondary parcel fabric. This was not included in this research.

4.6 Notes Concerning GCDB Maintenance

As local surveys are incorporated in the cadastre, it is important to remember that the BLM has a somewhat ubiquitous responsibility for maintenance of the PLSS. It is recognized that a local survey may use a section subdivision corner as the point of beginning for a survey that creates two or more new parcels. In cases like these, a decision must be made to determine whether the local survey should be included in the network analysis, or whether it should be re-computed in its correct relational location to the network. Indeed if the section subdivision is recorded and follows the procedures set forth in the Manual of Surveying Instructions, it may well represent the best locations for the parcels. This is also true if the new survey also includes additional horizontal control that would further strengthen the network.

Some individuals within the BLM cadastral survey organization believe that all of the new survey records belong in the adjustment set. Variations exist between state authority surveys and the federal survey authority. Evaluation of local surveys for acceptability is a major effort of the cadastral survey program within the federal government. Cadastral surveyors become experts in the evaluation of these records and

field retracement of these surveys. These surveys are handled on a case-by-case basis to determine acceptability. By extension, it is felt that a similar technique will likely be employed for the maintenance of the core PLSS network.

Considering the extent of the BLM's responsibility for the maintenance of the cadastre, it becomes extremely important for all local records to be backed up with required metadata. This should include, at minimum, the source identifier for the origin of the record being used. By simply including the source identifiers for all of these computations, any readjustment performed by the BLM will not result in a catastrophe for the local GIS. The local GIS may simply regenerate the local parcel fabric dependent upon the updated framework as needed. The decision making concerning the acceptability of particular records to the core PLSS network remains with the proper authority. Local records shall continue to create local parcels, maintaining harmony. Implementation of this technology provides resolution of a significant problem previously recognized but unresolved. An example of implementation follows.

4.7 Implementation of a Secondary Parcel Fabric

A secondary parcel fabric is implemented and shown below in Figures 17 and 18, beginning with the primary parcel fabric, shown in Figure 17. Section 8 is shown subdivided to the quarter-quarter level with associated parcel attributes. The parcels shown in the graphic in bold are individually attributed with the codes displayed in the window labeled "Selected Parcel Ids". In this illustration, 16 aliquot parts have been

created, each containing the record area of 40 acres. This can be considered the primary parcel fabric.

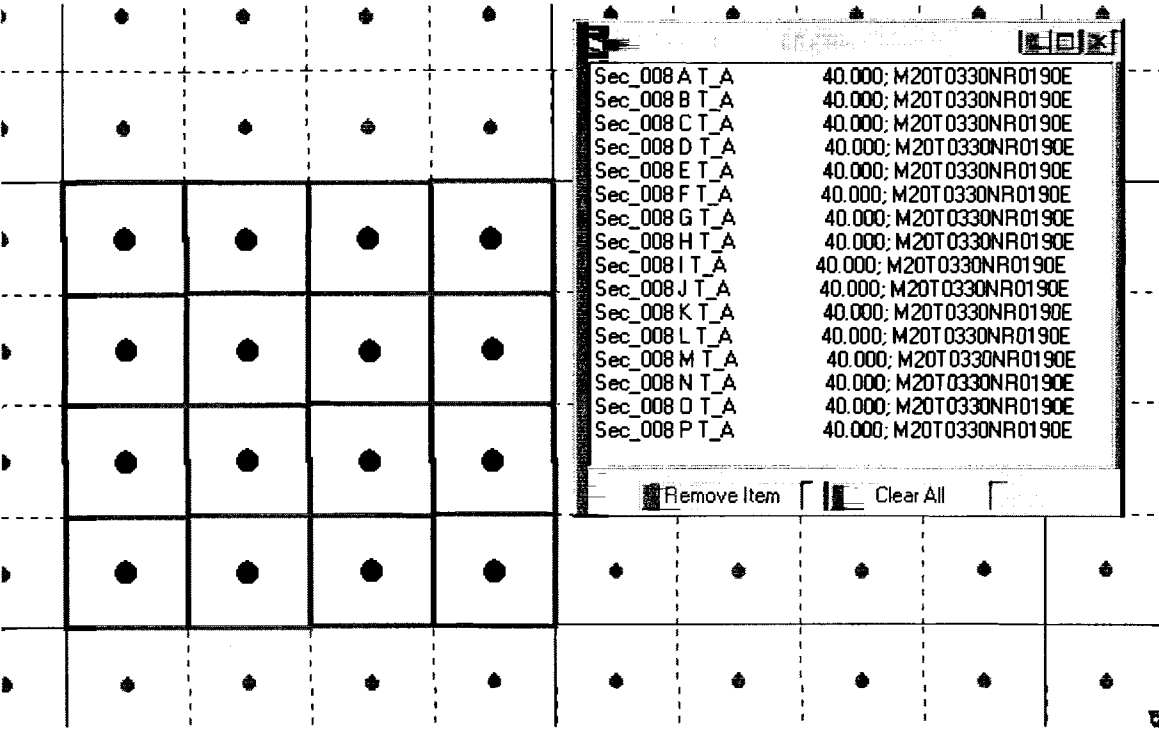


Figure 17 BLM Depiction of Parcels. Section 8, T33NR19E, Montana.

The secondary parcel fabric of the same area is seen in Figure 18. In this illustration, additional aliquot part subdivision has been performed to depict the local parcels. The parcel locator window has selected one geocode, representing one ownership record. The graphical depiction of the section has highlighted all individual sub-parcels in bold lines. The legal description of these components by aliquot part defines the individual sub-parcels. In this example, the smallest components represent

five-acre aliquot sub parcels. The legal descriptions and owner's name are seen in the "Cama Parcel" window.

The concept of multiple parcel fabrics is essential to the efficient partnership of cadastral database development and maintenance. In Figure 18, the local parcel fabric is created through a set of post-adjustment calculations to create the minor aliquot subdivision. The local parcel fabric can be updated and regenerated at any time to support the local needs. The local government maintains the computations necessary for this depiction, adding or modifying as necessary to support their requirements. In this example, the required computations are simply for smaller subdivision of aliquot parts, and performed for illustration purposes. Figure 19 illustrates the interface used for dividing aliquot parts, a streamlined process for quartering and halving the aliquot parts.

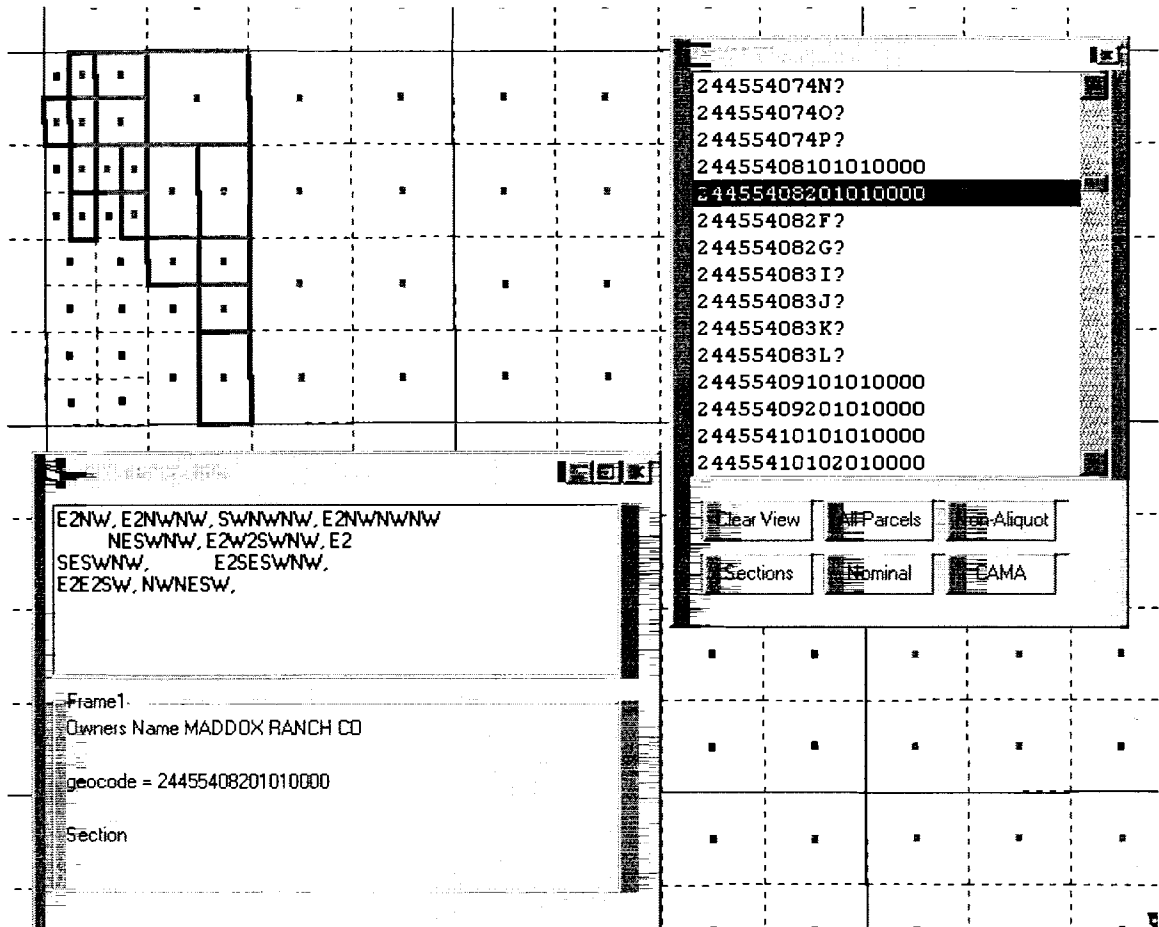


Figure 18. Depiction of Local Parcel Fabric.

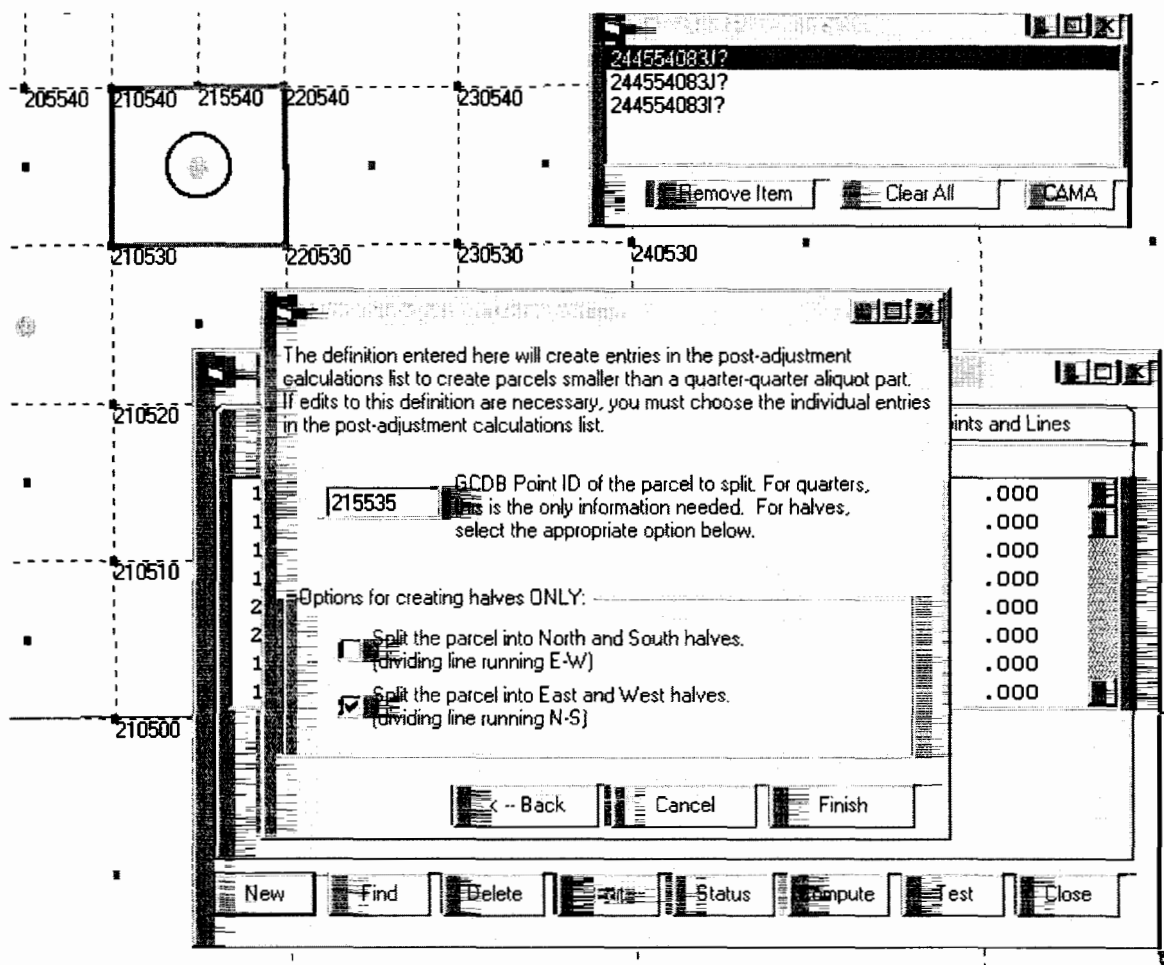


Figure 19. Utilizing PAC interface to subdivide aliquot parts.

The computations necessary for full implementation of the local parcel fabric may become quite complex for other record types. Entire urban subdivisions may be included as post-adjustment computations. Certificates of survey and subdivisions require careful analysis and abstraction to derive individual record components.

These local certificates of survey and subdivisions that create parcels often include retracement of the PLSS lines and may provide additional horizontal control. Thus, some of the data may be desirable for the BLM to include in future readjustment of the township. Efficient handling of this transfer is also accommodated. The remaining portions of the local certificates of survey or subdivisions are often considered dependent on the PLSS grid and can be treated as post-adjustment computations.

The measurement management approach provides for rebuilding the parcel fabric again and again, without causing the gaps, overlaps, and unreliable positions created by digitizing or from the simple COGO approach. Coordinates are simply a capture in time of location based on available information. Recognition of the fact that coordinates can and will change as additional measurements are included represents a major shift in geographic information management.

4.8 Simplified Parcel Fabric

As has been previously pointed out, a rural area will have higher percentage of parcels with aliquot part descriptions compared to urban areas. In these situations, the automatic linking can eliminate almost any need for manual intervention. However, the skilled abstraction and inclusion of additional post-adjustment computations may still be cost-

prohibitive in many rural counties. This could result in a long delay in implementation of a solid cadastral framework. In some situations, the actual calculation of the additional parcels may not be necessary. A simplified spatial arrangement of the parcel attributes in appropriate quarter-quarter sections could provide a minimal level of a functional cadastre.

In these cases, expected to be temporary solutions, the local parcel database can be densified without the necessary lines that define the parcels. Assigning multiple parcel attributes to a single parcel location creates the simplified parcel fabric. Again, it is important to understand the ramifications of making this choice — maintenance is not facilitated for providing data back to the originator (BLM), and the complete seamless parcel coverage is not created. The spatial representation of the parcels does not include the bounding lines. Instead, the bounding lines are approximated through the use of the parcel label points. This method provides for a quick solution, albeit temporary, as the completion of the required computations implies significant effort performed by highly skilled personnel.

The long-term benefits of a measurement-based land information system are numerous. The paramount benefit goes beyond the simple spatial depiction of parcels; more importantly, it encompasses the issue of long-term maintenance. The full implementation begins with an inventory of records and assignment of survey identifiers. This physical handling of the source documents has an additional benefit by providing a modern indexing of the records. In many cases this will improve the management of source documents. Application of other technologies such as document imaging may be incorporated if time and funding allow. Again, this must be facilitated through a modern

database and indexing system. Improvements in the methods of record access, filing, and storage all represent significant benefits to the general public.

CHAPTER 5 APPLICATION OF THE RESEARCH TECHNOLOGY

5.1 Parcel Attribution Extensions for CAMA

Chapter 3 introduced the Montana Computer Assisted Mass Appraisal (CAMA) database. This research has resulted in a series of enhancements to the WinGMM software to illustrate the concept of integrating an external database to complete the local parcel fabric. The computer software enhancements have been designed and implemented to function similar to the attribution process employed by the BLM in the GCDB. These enhancements provide opportunity for implementation with minimal effort. The attribution process has been designed to function similarly to the method used by the BLM, which is fully discussed in Appendix B. Future research is expected to expand these concepts to provide integration with a wide variety of external parcel databases. The following discussion focuses on the integration with the Montana CAMA for proof of the concept.

5.2 Creating the Local Parcel Fabric

The process begins with assembling all of the digital data necessary for the parcel densification project. In this example, this process includes the GCDB townships and the appropriate CAMA digital records. The CAMA files are stored and distributed on a

county basis. In addition to the digital records, the local source documents required to depict the local parcel fabric are necessary. These documents are indexed and assigned source identifiers. A flowchart documenting an overview of the procedure is shown in Figure 20.

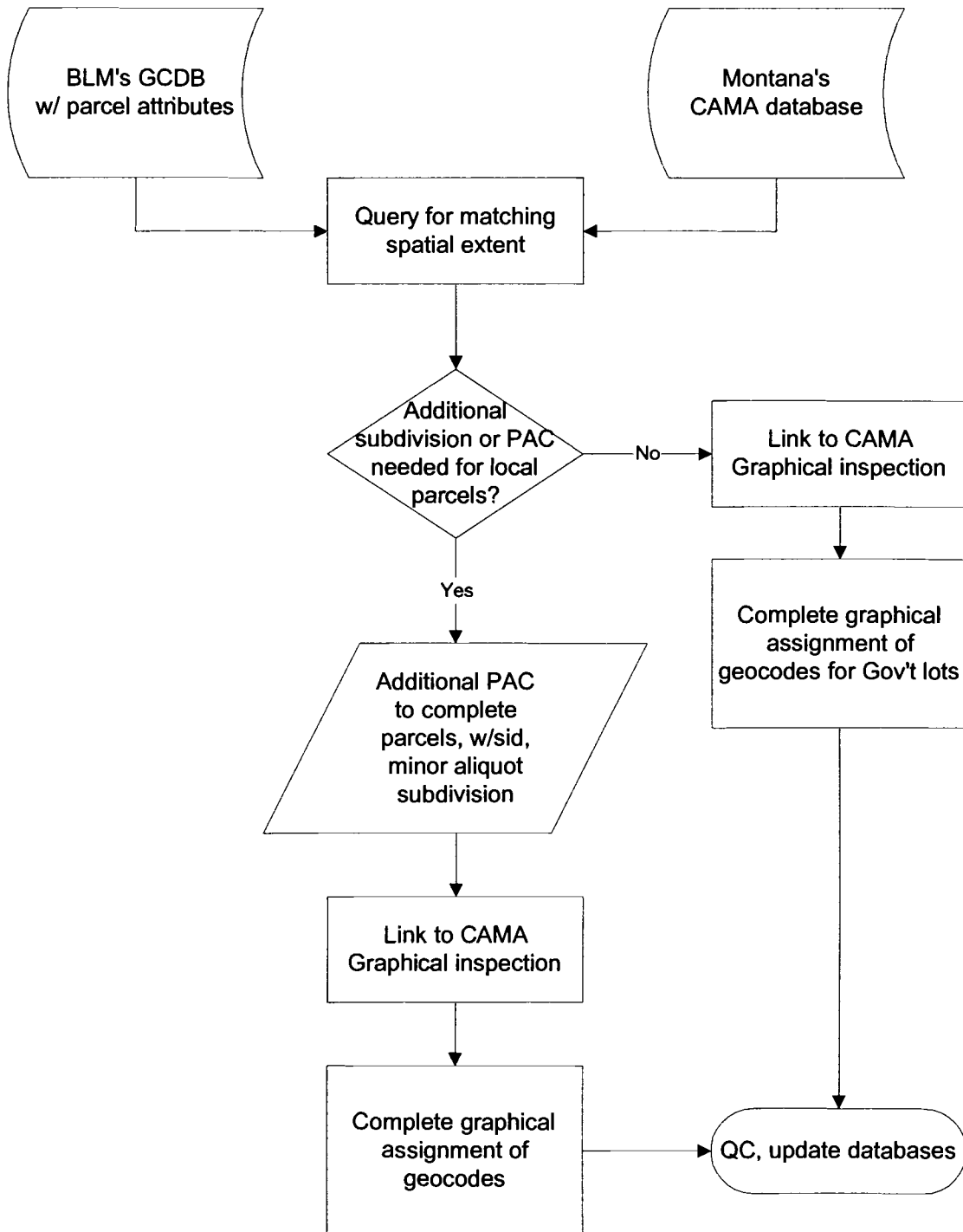


Figure 20. Flowchart of operations to complete local parcel fabric.

Notice the decision box in the Figure 20 flowchart labeled, “Additional Subdivision or PAC needed for local parcels?” The subdivision or other post-adjustment computations identified here are the calculations necessary to complete the local parcel fabric. The goal is to provide all local records necessary for depiction of the local parcels. Inclusion of all local records is crucial to the long-term maintenance as previously discussed. In most cases this will be the most time-consuming task. It should be noted that this research has considered the impact of this task and has provided the software capability to accomplish 100% coverage.

Rural areas often contain a large number of aliquot part legal descriptions. If the aliquot part descriptions depict parcels to the 1/16 section level, the automatic linking achieves very high levels of success with no additional effort. This is the level of detail ordinarily included by the BLM in the GCDB data product. In order to proceed with the discussion of automated linking, it shall be assumed that the GCDB contains sufficient detail to depict the local parcel fabric, or that the necessary supplemental computations have been added to the data set.

5.3 Automated Linking of GCDB with CAMA

The following discussion details the second major benefit of this research. Namely, linking the GCDB with an external database of legal descriptions. This linking experiment is to attempt to automatically read, interpret and spatially identify a database of parcel legal descriptions. Custom computer software modules were created to perform an automated linking of the GCDB with the Montana CAMA database. The logic used in

these modules will be discussed along with an explanation of the operation to perform the automated linking.

With a GCDB township open and displayed in the software, the user begins by selecting “Import CAMA file” from the Attributes menu. A dialog box appears with the default translation of the township and range fields. The user is given the opportunity to override these values to rectify any ambiguities in labeling township and range fields in the CAMA. The CAMA file for an entire county is queried, returning all records for the township, and stored in a file for this township.

The automated procedure begins by invoking the linking process, “Link to CAMA,” from the attributes menu. This function launches a series of subroutines that perform the automated parcel match. The first process examines the CAMA data to identify all sections containing parcels. Next, the existing BLM attributes are examined. For each section identified in CAMA, all existing parcel centroid coordinates are captured. This information is stored temporarily in a file. Next WinGMM begins building the CAMA geocode for each of the centroids.

One experiment relating to the capture of the parcel centroids attempted to limit the capture to the quarter section identified in the CAMA – matching each quarter section to the 4 nominal location codes used by the BLM to identify the nominal quarter-quarter sections. Due to the coding structure of the CAMA, if several sub-parcels exist, they may occur in multiple quarter sections, yet the database ties only to the quarter section of the first sub-parcel. The coding structure of CAMA will only present an additional record when a sub-parcel is located in another section. The quarter section approach was abandoned because of this fact and the method implemented utilizes the full section,

capturing all centroids in the section. Future research or implementation involving linking to other parcel databases may reveal the quarter section approach as applicable.

With the centroids captured, the first two sub-elements of the CAMA geocode, county and township, are taken as-is from the CAMA file and used to begin developing a temporary geocode. This action is possible because the full township and range fields were utilized in the initial query importing the CAMA file. The section number field is translated from the three-digit to the two-digit field. The BLM nominal location field containing a one-character code of A-P representing the aliquot part is converted into the one-digit quarter section designation of CAMA geocode. The BLM nominal locations of “A, B, C, and D” are translated to the CAMA quarter section “1.” Likewise, “E, F, G, and H” translate to quarter section “2.” Nominal locations “I, J, K, and L” translate to quarter section “3.” Nominal locations “M, N, O, and P” translate to quarter section “4.” The quarter section designations are suffixed to the temporary geocode of each centroid.

Next, the BLM attributes are searched for the numbered surveys. Survey types “M,” which are Mineral Surveys and “H,” which are Homestead Entry Surveys, are processed, capturing both the survey type and survey number fields. When matches are found, the geocode is completed with the remaining sub-elements from the CAMA record.

As mentioned in Chapter 3, the numbered Government Lots were attempted for similar automatic linking, yet this action was abandoned due to the inconsistent coding of these parcels in the CAMA database. In further applications of this research technology, it is strongly encouraged for local coding of lots to conform to a standard method. Details

of this limitation are shown later in this chapter as part of the documentation of the success of automated linking for the chosen samples.

The process continues by searching the CAMA record section-by-section for the keyword “ALL” and not including the keyword “LESS” in the legal description fields. As a match is found, the remaining portion of the geocode is assigned to the sub-parcels. With numbered mineral surveys, homestead entry surveys, and full sections matched, the procedure continues to address the remaining parcel descriptions. All parcels not linked at this point are assigned a question mark character as part of the temporary geocode for identification purposes. This phase of the automated linking is where the legal description field is translated.

To read and interpret the legal description, a specialized software function was created that scans a string and returns sub-strings of varying length based upon a delimiter value. This specialized function scans the full 120-character field containing the legal description of the parcel utilizing a comma delimiter. The comma delimiter is found most often in the CAMA files investigated; yet this is not an exclusive delimiter. In some areas, irregular coding was discovered and systematic corrections could be performed. The delimiters are used to identify sub-parcels within a specific CAMA record. For each of the sub-parcels within a single record, the translation looks first at the length of the sub-string, disregarding any spaces. Next, the sub-strings are processed through a “Select Case” statement that evaluates each sub-string based on its length. The logic of these cases is discussed next.

If the length of the sub-string is found to be two characters, the sub-parcel is a full quarter section or half section. For this situation the following codes are modeled: NE,

NW, SW, SE, E2, W2, N2, and S2. The possible matches are searched for each of the quarter sections or the combination of quarter sections making up a half section. As matching records are found, the geocode of the CAMA record is copied and applied to the appropriate centroid(s). Matching a full quarter section will update four centroids; a full half section will update eight.

If the length of the sub-string is three characters, the description refers to a full quarter section and includes a trailing “4”, and the following codes are modeled: NE4, SE4, SW4, and NW4.

If the length of the sub-string equals four, sixteen quarter-quarter sections are modeled: NENE, NESE, NESW, NENW, SENE, SESE, SESW, SENW, SWNE, SWSE, SWSW, SWNW, NWNE, NWSE, NWSW, and NWNW. Half quarter sections match the length criteria, allowing an additional sixteen half quarter sections to be modeled: N2NE, S2NE, E2NE, W2NE, N2SE, S2SE, E2SE, W2SE, N2SW, S2SW, E2SW, W2SW, N2NW, S2NW, E2NW, and W2NW. Half - half sections match the length criteria, allowing eight half-half sections to be modeled: N2N2, S2N2, N2S2, S2S2, E2E2, W2E2, E2W2, and W2W2.

If the length of the sub-string equals five, half-quarter sections are modeled as above, accounting for the sometimes present trailing 4: N2NE4, S2NE4, E2NE4, W2NE4, N2SE4, S2SE4, E2SE4, W2SE4, N2SW4, S2SW4, E2SW4, W2SW4, N2NW4, S2NW4, E2NW4, and W2NW4.

If the length of the sub-string equals six, sixteen quarter-quarter sections with trailing “4’s” are modeled: NE4NE4, NE4SE4, NE4SW4, NE4NW4, SE4NE4, SE4SE4, SE4SW4, SE4NW4, SW4NE4, SW4SE4, SW4SW4, SW4NW4, NW4NE4, NW4SE4,

NW4SW4, and NW4NW4. In all of the above named aliquot part descriptions, the appropriate components are updated and written to an output file that contains all of the CAMA parcels assigned.

The FGDC Cadastral Data Content Standard also attempts to model these relationships. The standard aims to provide a consistent coding of these descriptions. The FGDC Cadastral Data Content Standard documents a data element named "PLSS Township Second Division". The intent is to specify consistent coding of these aliquot part descriptions. Public Land Survey System Township Second Divisions are normally PLSS aliquot Parts or PLSS government lots. This entity extends to the quarter or quarter-quarter division of a section. The domain of the second division designator is the following: N, S, E, W, N2, S2, E2, W2, NE, NW, SE, SW, NE, NW, SE, SW, NENE, NENW, NESE, NESW, NWNE, NWNW, NWSE, NWSW, SENE, SENW, SESE, SESW, SWNE, SWNW, SWSE, SWSW, N2NE, E2NE, W2NE, S2NE, N2NW, E2NW, W2NW, S2NW, N2SE, E2SE, W2SE, S2SE, N2SW, E2SW, W2SW and S2SW (FGDC, 1999).

These domains have been modeled as recommended by the standard, but fall short in the ability to adequately model coding used in the actual CAMA. It can be noticed above that the nominal quarter sections are listed twice, which is undoubtedly an error, but nevertheless this is the exact wording of the standard. The remaining 32 elements are limited when compared with the domain modeled in this research, consisting of 84 combinations of aliquot part description abbreviations. The irregularity encountered in CAMA that was coded prior to the creation of the FGDC standard illustrates the typical variation existing in actual records.

The domain of the FGDC standard intends to model quarters, sixteenths, half sections, half quarters of sections, and coding of government lots, yet numerous further combinations are necessary as illustrated. It is unfortunate that the standard, as published, does not address the coding of government lots; perhaps future revisions of the standard shall address this. Subdivisions below the sixteenth (quarter-quarter) are described in the Cadastral Data Content standard as the “PLSS Township Third Division.” The data element “PLSS Township Third Division” lists the domain as “free text” that unfortunately does not standardize this coding.

After the automated linking has been completed, the graphical depiction of the township is displayed and interactive processing to complete the parcel attribution is performed. Parcel centroids are displayed and may be selected for editing similar to the method described for GCDB parcel attribution. This is discussed fully in Appendix B. Since multiple parcel fabrics are enabled, parcel selection is directed by the parcel overlay currently displayed. In the following illustration shown in Figure 21, the CAMA parcels are displayed and several centroids have been selected representing parcels not attributed. Brief descriptions of BLM attributes are displayed in the graphic to aid the software user in identification of the Government Lots.

The spatial component of the temporary geocode facilitates this portion of linking process that requires user interaction. Examining the selected parcel identifier in Figure 21, the temporary geocode can be read by applying the following rules: (1) the first six digits represent the county and township; (2) the section number begins in the seventh column, in this example section number “07”; (3) the quarter section designator “2”

appears next, followed by the BLM nominal location code "G"; and (4) the question mark character at the end of the code identifies this centroid as unassigned.

The valid legal descriptions are queried and displayed for a selected sub-parcel in the window captioned "CAMA parcels for Section 07," presenting a multiple-choice format of legal descriptions to the software user. Looking closely at the lotting shown in the graphic of Section 07, the irregular Government lot numbering displayed from the BLM attribute is an aid to deciding which of these two ownerships to assign. This type of manual interaction continues to complete the attribution of all components.

The township displayed in Figure 21 achieved 96% automatic linking of parcels. Thus, the remaining 4% require user interaction and obviously this level of manual process represents a major savings in the data collection effort. This is an example of the outstanding success of automated linking for townships where the parcels are aliquot parts of quarter-quarter size or larger. In this case, the remaining 4% includes parcels having government lot descriptions, as shown in the Figure 21. The user interaction required in this situation is minimal. Completion of the attribution in Section 7 involves graphical matching of the parcels with the appropriate description. This is simplified by the fact that only two choices are available.

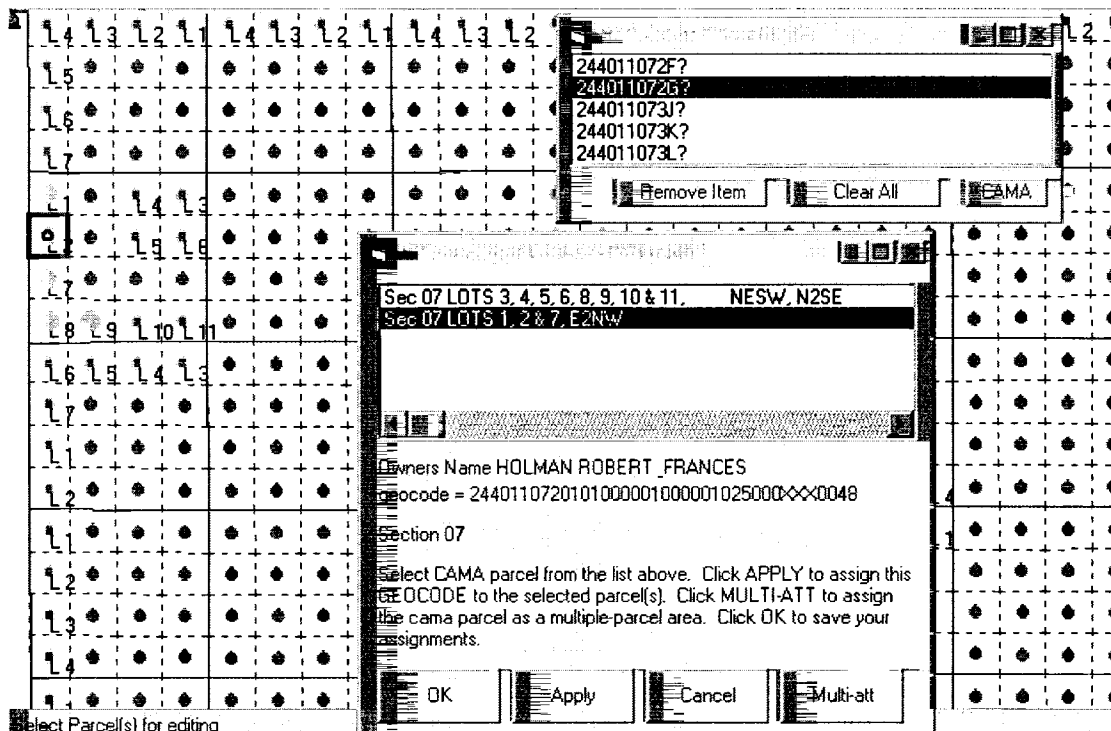


Figure 21. CAMA Parcel Editing.

Hintz (et al., 1995) points out that mismatches of GCDB to LLD indicate that problems exist in one or both of the systems. This needs to be resolved before validity of the two systems is truly achieved, which is also true of mismatches of GCDB with CAMA. Irregularities discovered in the BLM parcel attribution process discussed by Hintz spawned a procedure for corrections to be made to the legal land database as they were discovered. A similar procedure could be employed to provide corrections to the CAMA database as irregularities are encountered.

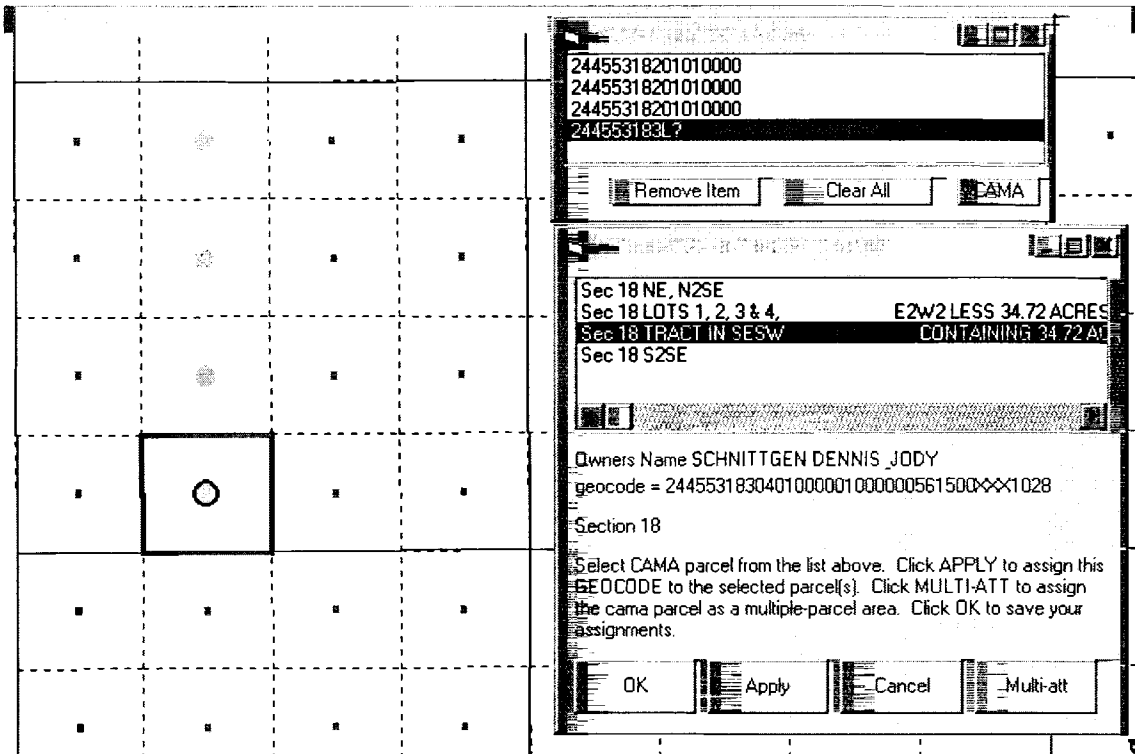


Figure 22. CAMA record identifying a missing record in SESW of Section 18.

The largest obstacle to automated matching of CAMA descriptions is the creation of additional parcels needed to fully account for the parcels of the local cadastre. Figure 22 illustrates the effect of omitting local records to densify the parcel fabric. In this example, the SESW of Section 18 is selected. The CAMA record identifies a tract in the SESW containing 34.72 acres, even though this parcel is not shown in the graphic. Also notice the CAMA record preceding the selected record identifies a parcel to be the remainder “E2W2 LESS 34.72 ACRES.” The record of the tract is not included and must be added to create the parcel topology. When situations such as this are encountered, the process of attribution must halt until completion of the parcel fabric is performed or, optionally, to utilize the simplified parcel fabric.

5.4 Quality Assurance of Parcel Attribution

Quality assurance procedures developed for the CAMA attribution process include an extension to the “parcel locator” for graphical inspection of the parcels. The parcel locator is a data validation tool further described in Appendix B. The enhanced parcel locator is displayed in Figure 23. One particular geocode (CAMA parcel) is selected in the parcel locator and the adjacent window displays the legal description of the selected record. Reading the legal description in the CAMA Parcel window illustrates the success of the legal land description interpreter. The geocode 24455333202010000 refers to a legal description containing 4 sub-parcels: N2NW, SENW, NESW, and N2SE. The graphical depiction shows a full match of these aliquot parts indicated by the bold line outlining these sub-parcel components on the map. The legal description of four sub-parcels have been automatically linked to six nominal quarter-quarter sections.

A second tool for quality control provides a listing of unresolved CAMA entries. This tool is used to ensure full coverage of the CAMA record. In this township, 89 parcels remain unassigned due to missing local records creating parcels or unresolved legal descriptions. Figure 24 illustrates the missing record issue and the ambiguous use of the word “LOT,” described above. In this case, a Lot and Block description is included even though no reference is included to the subdivision plat creating the lots. This omission results in 29 unassigned parcels in this section. The word LOT is used interchangeably in the CAMA database with meanings varying from Government lot to local subdivisions

description by lot and block. This is not an error, but rather an illustration of the issues for the state or local government responsible for collection of records.

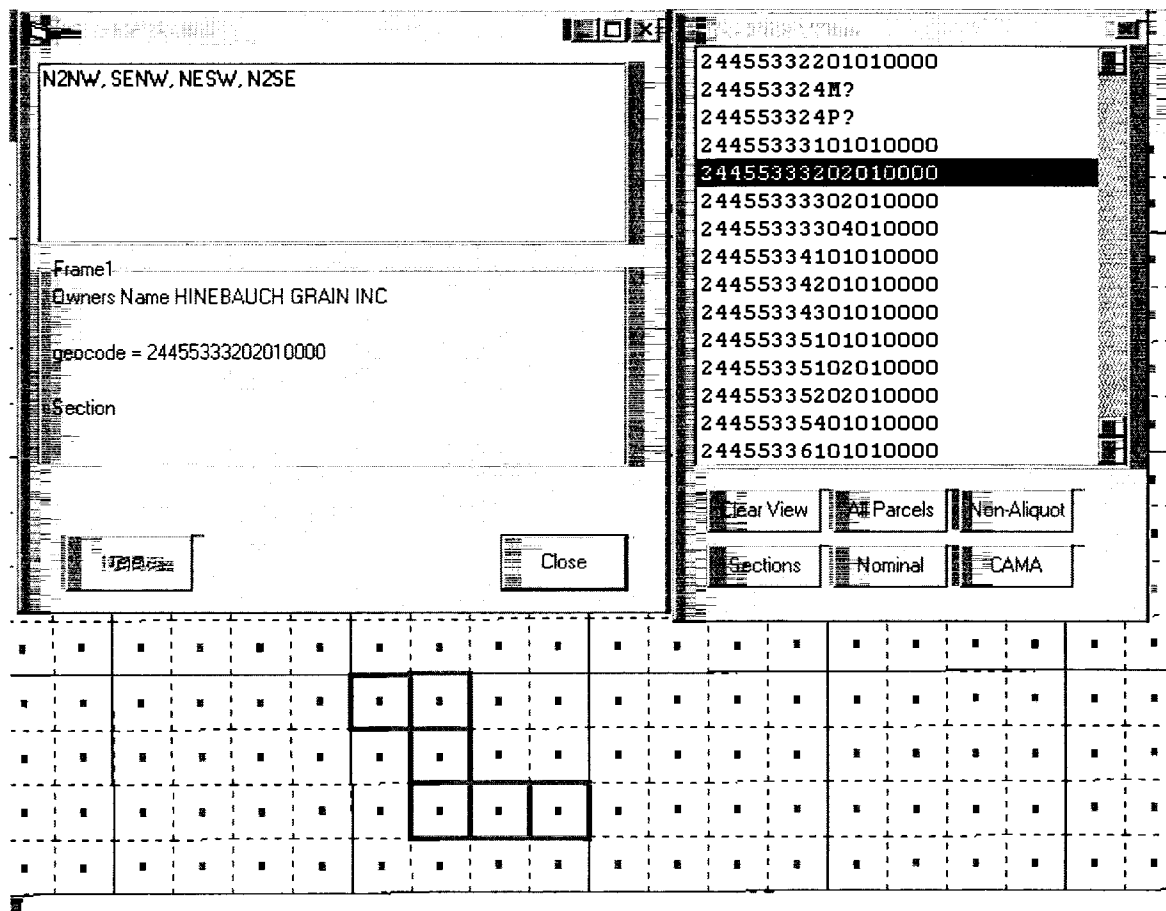


Figure 23. Parcel Locator Displaying a CAMA parcel.

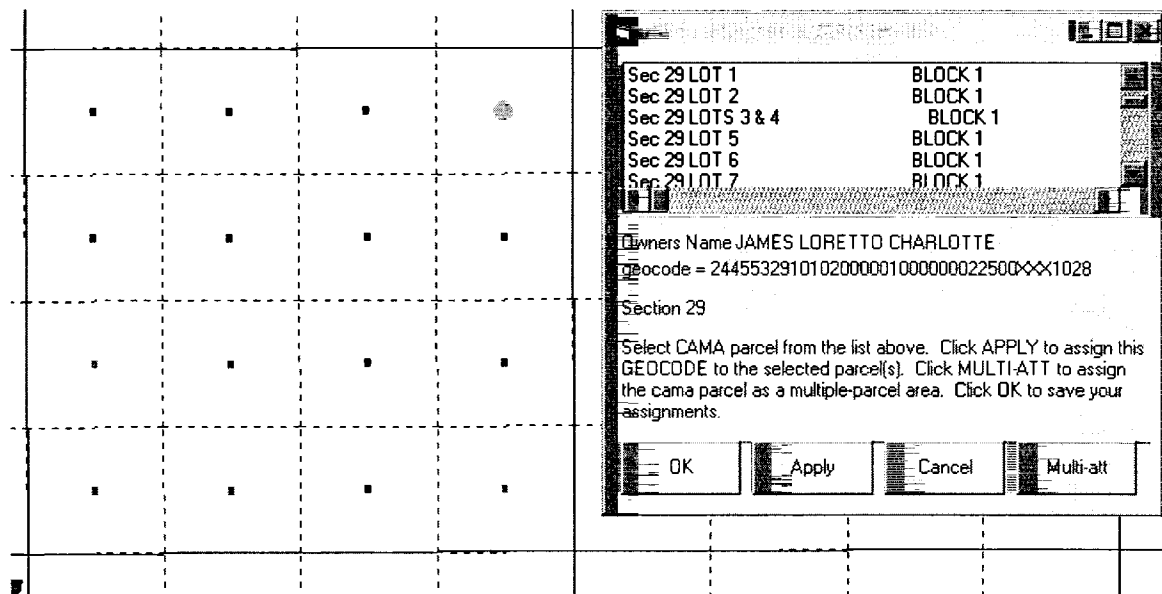


Figure 24. Lot and Block Descriptions Referencing a Missing Plat.

A great deal of attention has been given to the accuracy of the interpretation of the legal land descriptions. When ambiguous descriptions of any type are detected, the parcel is not attributed. These parcels are flagged with the question mark character indicating that user interaction is necessary to resolve the parcel attribute.

Sections 5.5 through 5.11 of this Chapter discuss the application of the automated linking technology. A representative sample of townships has been chosen from a mixture of urban and rural areas. The result of the evaluation, arranged by County, follows. To properly interpret these results, it must be noted that the figures reflect only the automated parcel linking. Inclusion of the local records and use of the interactive tools would provide 100% attribution, yet this is beyond the scope of this experiment. The goal of this experiment is to identify the success of the automated linking and

interpretation of the legal descriptions. Discussion is provided to clarify reasons for unsuccessful matching in the experiment.

5.5 Beaverhead County

The results of automated linking are shown for eight townships in a summary table below. A similar table appears for each of the seven counties chosen to apply the automated linking experiment.

Township	Sub-parcels	Linked	Percent	Total CAMA	Percent Linked
T14SR08W	496	304	61%	362	16%
T14SR09W	224	116	52%	39	85%
T14SR10W	164	37	23%	21	81%
T14SR11W	384	134	35%	38	68%
T15SR08W	16	2	13%	2	50%
T15SR09W	123	39	32%	15	47%
T15SR10W	256	106	41%	25	84%
T15SR11W*	384	208	54%	57	84%

Table 5. Beaverhead County linking summary.

Tables 5 through 11 share the same format. The first column identifies the township. Column two, “Sub-parcels,” identifies the total number of parcels from the BLM depiction of the township when matched with Section numbers from the CAMA

database. Note that if any local parcels are identified for a particular section, all sub-parcels in the BLM depiction are counted. Column three, "Linked," is a count of the total sub-parcels that have been automatically identified. Column four, "Percent," summarizes columns two and three and expresses the result as a percentage. This percentage loosely approximates the total land area of the township automatically linked. Column five, "Total CAMA," is a count of the total CAMA database records for this township. It is important to note that CAMA does not have a one-to-one relationship with ownership. Duplicates exist, yet the duplicates generally have the same geocode. Often, two or more CAMA entries exist for one owner; one record usually describes the property, the other(s) relate to the improvements. Column six, "Percent Linked," expresses the percentage of the total CAMA records for the township that were properly assigned to one or more centroids.

Examining the first township in Table 5, T14SR08W, it is shown that 61% of the land area within this township has the appropriate CAMA geocode applied. Yet in this township, a total of 362 CAMA records exist. Only sixteen percent of those were automatically matched. An examination of the record reveals that 114 of the unassigned CAMA records are located in Section 5. Further examination of these legal descriptions reveals parcels described as lots and blocks of the original townsite survey of Lima, MT. The townsite survey is not included in the parcel fabric. Also in Section 5, two additional certificates of survey are referenced in the records and not included in the parcel fabric. Section 4 identifies 59 additional local parcels related to the "LIMA GARLAND ADDITION." This represents another urban subdivision that has not been included. Beyond this, it is also observed that five of the sections do not have any CAMA records.

Investigation reveals that when government ownership for the entire section is encountered, the records are often (but not always) omitted. This is a significant fact because these five sections represent 14% of the total area of the township. If included, the 61% linked would likely be 75%. Thus, the proper evaluation of the result of this automated linking is that 14% of the total parcels were automatically identified, covering approximately 61% of the township land area.

The second township in Table 5, T14SR09W, shows a different relationship. In this example, 85% of the total legal parcels were automatically identified even though these parcels make up only approximately 52% of the total land area of the township. Twenty-two of the thirty-six Sections do not have any CAMA records. Irregularities in coding of the legal descriptions were encountered throughout this portion of the research. Many of these irregularities are simply punctuation errors that hinder the automated process. These errors can only be resolved through the human interaction process. For example, Section 3 of this township contains a legal description that reads, “Sec 03 LOTS 1, 2 SWNE”. This description is missing a comma after the numeral 2 that separates the sub-parcel components “Lot 2” from “SWNE.”

Focusing the township T15NR11W, shown with an asterisk in Table 5, several important observations can be made from the parcels that did not automatically link.

- Irregular coding of Government Lots was encountered throughout this township.
- Incomplete CAMA for Sections 2, 4, 6, 7,8, 9, 11, 12, 13, 15, 21, 25, 28, 33, 34
- CAMA Error in punctuation in Section 24
- Local Survey Record creating parcel omitted in Sections 26 and 35

The incomplete CAMA for the sections identified occurs due to the county boundary passing through the subdivision of sections in this township. The capability to merge multiple county CAMA data files has been added to the software to accommodate these situations, but was not applied in this experiment. In actual practice, crossing these jurisdictional boundaries may not warrant its use. It has also been observed in this county that most of the land under Government management has not been included in the CAMA. Local records needed to complete the parcel fabric are missing in Section 26 and Section 35. Most of the manual editing required involves deletion of centroids carried forward from the original GCDB due to the crossing of the geopolitical boundary.

Keeping these data observations in mind, townships chosen in the next six counties display a variety of results summarized into similar tables.

5.6 Blaine County

Nine townships in Blaine County, MT were chosen to apply the automated linking. A summary of the results is presented in Table 6.

Township	Sub-parcels	Linked	Percent	Total CAMA	Percent linked
T25NR17E	256	127	50%	31	77%
T25NR18E	576	430	75%	95	84%
T25NR19E	576	470	82%	109	91%
T28NR20E	576	524	91%	70	96%
T32NR18E	576	500	87%	149	85%
T32NR19E	576	493	86%	169	71%
T32NR22E	671	271	40%	169	62%
T33NR18E	576	433	75%	218	59%
T33NR19E	576	196	66%	1113	14%

Table 6. Blaine County linking summary.

Significant success is achieved in most areas. For example, T28NR20E, containing 70 total CAMA records, achieved 96% automatic linking to the BLM township depiction without any additional survey records to depict the local parcel fabric. The remaining 4%, requiring user interaction, simply involves assigning the Government Lot descriptions from the CAMA record. The last township listed in Table 6 identifies that 66% of the township area was linked, yet due to extensive local records not included to identify the 1,113 parcels, only 14% of the CAMA parcels were identified. The missing records spatially represent many individual parcels. In this case, these parcels

are located within a small municipality. Identification of this issue could further support the completion, as the municipality may share in the cost of the additional effort.

The Blaine County example identifies similar issues to those previously identified in Beaverhead County, including the following:

- Irregular coding of Government Lots throughout
- Incomplete CAMA, including omission of government lands
- Local Survey Record creating parcel(s) not included in the experiment.

The inclusion of the omitted records represents a significant workload. However, the initial processing of the automated linking facilitates the data collection issue by identifying these areas requiring additional effort. This leverage allows local government to prioritize the long-term effort while enjoying the benefits of streamlined, parcel-based mapping in other areas. This partial completion is beneficial since it provides an incentive to local policy makers to support the continuation of the project to fully realize the long-term benefits.

5.7 Gallatin County

Gallatin County, MT includes several urban areas. In these areas, extensive local records are necessary to complete the parcel fabric. This requirement is largely responsible for lower figures in the “Percent linked” column. However, the automated parcel linking continues to achieve significant identification of the total land area (62 – 80%).

Township	Sub-parcels	Linked	Percent	Total CAMA	Percent linked
T04NR05E*	624	448	72%	55	58%
T04NR05E*	624	474	76%	55	58%
T04NR06E	572	460	80%	41	59%
T04NR07E	617	449	73%	41	78%
T05NR05E	459	285	62%	30	73%
T05NR06E	363	275	76%	22	77%
T05NR07E	352	224	64%	26	62%

Table 7. Gallatin County linking summary.

In Gallatin County, a systematic anomaly in the coding of legal description was encountered. Examination of the CAMA records in this county identifies a systematic use of an unnecessary “1/” in the coding of aliquot parts. For example, NW1/4NE1/4 is used to identify parcels that should be coded as NWNE or NW4NE4. A systematic correction was applied to eliminate the “1/” from each of these records. T04NR05E appears twice

in Table 7 to identify the partial success of the systematic correction. The first occurrence is without the systematic correction, the second is with the correction applied. The systematic correction results in successful matching of 26 additional parcels.

An additional anomaly was encountered in the Gallatin county records. Individual sub-parcels are inconsistently punctuated. In many cases, a comma is correctly used for several sub-parcels and the final sub-parcel is coded using an ampersand. In this case, the ampersand has not been systematically corrected. In other cases, the comma is not used at all to distinguish sub-parcels. Human interaction is required to correct these coding errors.

The entire T04N tier of townships in Gallatin County are elongated, and significant variability in the CAMA coding exists. This is reflected in the match statistics. In many cases, the entire section has one owner. Thus, the description “ALL” offers success in these areas. Other sections achieve much less automatic matching due in part to the large number of Government Lot descriptions and the variance in coding these in the CAMA. Section 4 of T04NR5E provides an excellent example. In this section, two CAMA parcels exist. One of the records contains the following description, “Sec 04 LOTS 1 & 2 4 4N5E 31.18AC”. In this abbreviated description, a duplicate and unnecessary identification of Section 4, T 4 N, R 5 E is included, as well as an area “31.18AC,” not ordinarily considered part of these database fields. Beyond this fact, “LOTS 1 & 2” could better be described and separated with a comma rather than the ampersand. The second CAMA parcel in this section reads “Sec 04 LOTS3-16 & S2 4 4N 5E 839.08.” It can safely be assumed the extraneous information is once again the unnecessary duplication of Section number, township, range, and the area contained. The

coding of the description, “LOTS3-16 & S2,” could not be interpreted by the automated linking procedure.

5.8 Madison County

In Madison County, the CAMA records appear very uniform in coding. Most of the unsuccessful matching is due to the omission of public domain lands from the records. In areas where the public domain lands are omitted, many centroids exist on the map, identifying lands not included in the local parcel fabric. Manual interaction in these cases would delete centroids not needed for the local parcel fabric. Madison County is located in the southwestern portion of Montana, and contains a significant amount of federal government-managed lands. These omitted descriptions are responsible for the sub-parcels not linked. Of the total valid CAMA entries, significant automated linking was achieved (72-97%) as shown in Table 8.

Township	Sub-parcels	Linked	Percent	Total CAMA	Percent Linked
T07SR05W	468	301	64%	51	73%
T08SR05W	448	320	71%	48	83%
T08SR06W	544	478	88%	69	72%
T09SR05W	336	226	67%	29	97%
T09SR06W	208	128	62%	21	81%
T10SR05W	176	112	64%	24	83%

Table 8. Madison County linking summary.

5.9 Powder River County

Powder River County is in southeastern Montana. It is highly rural and contains a very high percentage of public domain land. Powder River County CAMA records include the public domain lands, ordinarily described by aliquot parts and uniform in coding.

Examining Table 9, we see that the two percentage fields are nearly equal. This shows that few local records are needed to depict the local parcel fabric. The human interaction necessary for completion is minimal, mostly to assign the Government Lot numbered descriptions.

Township	Sub-parcels	Linked	Percent	Total CAMA	Percent Linked
T08SR45E	624	502	80%	89	80%
T08SR46E	627	519	83%	106	87%
T08SR47E	624	532	85%	87	86%
T08SR48E*	690	417	60%	75	71%
T09SR45E	624	556	89%	62	84%
T09SR46E	627	470	75%	86	77%
T09SR47E*	656	496	76%	89	88%
T09SR48E*	644	451	70%	72	71%

Table 9. Powder River County linking summary.

A systematic anomaly was encountered in the three townships identified with an asterisk.

T08SR48E contains 55 sub-parcels located in the bed of the Powder River that are not included in the CAMA. With these accounted for, the match percentage increases to 66%. T09SR47E contains 24 sub-parcels of riverbed. Accounting for these gives a match percentage of 78%. T09SR48E contains 38 sub-parcels of riverbed. Accounting for these sub-parcels gives a match of 74%. Even without the systematic correction to identify the riverbed sub-parcels, the level of manual interaction is minimal.

5.10 Prairie County

Prairie County is adjacent to Powder River County in southeastern Montana. Although similar in location, they are not similar in the local coding of CAMA parcels. Prairie County CAMA records include a systematic error in punctuation in the legal description field. A colon was utilized as a delimiter of sub-parcels rather than a comma. A systematic correction was applied, which is why T10NR53E, shown with an asterisk, appears in Table 10 twice. The first entry documents the matching prior to the systematic correction. In this example, 496 sub-parcels matched prior to the systematic correction (86%), and 540 sub-parcels matched after the correction (94%). Upon discovery of this error, the correction was applied to all other townships in the sample.

Township	Sub-parcels	Linked	Percent	Total CAMA	Percent Linked
T10NR53E*	576	496	86%	57	82%
T10NR53E	576	540	94%	57	82%
T10NR54E	576	509	88%	50	90%
T10NR55E	288	268	93%	19	95%
T11NR53E	576	551	96%	65	88%
T11NR54E	588	531	90%	122	38%
T11NR55E	576	539	94%	44	95%
T12NR54E	600	465	78%	68	74%
T12NR55E	600	524	87%	55	85%

Table 10. Prairie County linking summary.

T10NR54E, Section 3, contains an aliquot part description “S2N2S2,” requiring further subdivision of several quarter-quarter sections. In this case, no further local survey records are necessary to depict the sub-parcel, but additional subdivision must be performed. T12NR54E, Section 6, yet another irregularity in the coding of Government lots, appears in the legal description field as “LTS 1 THRU 8,” further illustrating the inconsistent coding of lots. A second CAMA parcel in this Section 6 is completely missing the legal description, an error that is unexplainable without further investigation of the records.

5.11 Sweet Grass County

Sweet Grass County CAMA also contains a systematic error in coding of legal descriptions. The individual sub-parcels in the listing of aliquot parts have a single space delimiter. This systematic error was particularly troublesome in that the software algorithm was specifically designed to ignore spaces in the description field. A systematic correction was applied to the Sweet Grass County records. T02SR15E appears twice in Table 10 to illustrate the benefit of this correction. An increase in total area from 59% to 92% was achieved after the correction. Additionally, the CAMA parcel match increased from 49% to 86%.

Township	Sub-parcels	Linked	Percent	Total CAMA	Percent Linked
T02SR13E	615	423	69%	165	50%
T02SR14E	584	558	96%	52	96%
T02SR15E*	723	426	59%	95	49%
T02SR15E	723	666	92%	95	86%
T02SR16E	576	494	86%	122	89%
T03SR12E	199	165	83%	38	74%
T03SR13E	468	339	72%	139	60%
T03SR16E	288	279	97%	53	87%

Table 11. Sweet Grass County linking summary.

Moving beyond the automated linking, a continuation of the experiment was performed on one township, T02SR14E. This experiment was to fully complete the attribution by utilizing the “manual methods” previously discussed. Upon completion of this and several other townships, it was discovered that one additional tool was necessary for purposes of quality assurance. This new software tool would provide a database check of the CAMA records unassigned to any parcel centroid. For example, in T02SR14E, two CAMA entries were found in Section 6 not assigned to any parcel centroids. These two items do not represent any legal description of real property, but rather are entries for appraisal and taxation purposes. The legal descriptions in this case call out improvements on the property, and are listed under the same ownership as the valid geocodes that have already been correctly assigned in the section. It is beyond the scope of this research to validate these entries, yet it is critical to this research to provide for the listing of unassigned CAMA records. In this case, these remaining geocodes are assigned to the exact same area through the use of multiple attributes to the parcel(s).

The new software tool is used in conjunction with the parcel locator for insurance that each centroid is assigned one or several geocodes, and to ensure that each CAMA geocode is assigned to one or several centroids.

5.12 Summary of Parcel Attribution Process

There are many variables responsible for less than perfect matching. Certificates of survey and local subdivisions not collected by BLM are indeed the largest factor. Local jurisdictions responsible for the local parcel fabric must include the additional data necessary for depiction of the parcel fabric. This is best accomplished utilizing the measurement management methodology discussed in Chapter 4 to create the repeatable topology in the alternate parcel base. It is recognized that much of this additional parcel topology may exist digitally, yet most of this has been digitized. Digitized data is subject to scale limitations and lacks maintainability due to not storing the record measurement values. Including simple coordinates or line topology not tied to the network could result in erroneous location and quite possibly result in gaps or overlaps. As time, funding, and needs are realized, the data required to define these parcels should be considered for abstraction, entry, and analysis. A typical local subdivision may contain retracement information for the section(s) that the subdivision occupies and additional geodetic control in addition to the parcels created within the subdivision itself. These data are candidates for submission to the BLM for inclusion to the GCDB. Submitting the information in some compatible file format could facilitate the likelihood of these data actually being accommodated in future revisions to the base map. Additional lines of the subdivision and other parcels created simultaneously on the plat are best left for proportioning and intersection computations performed in PAC. These calculations would be omitted from the BLM database, yet re-computable for the local needs.

A second major limitation is the degree of variability used in the collection of the legal land descriptions from their paper records. For example, numbered government lots would seem easy to identify, yet the actual coding varies greatly. The nominal government Lot 1 description may be coded as “GOVT LOT 1”, “LOT 1”, or “GOVT LOTS 1-4”. Analysis of the CAMA records in the experiment shows significant variability in the punctuation used. For example, the apostrophe may or may not appear in the word “GOV’T” or the word may not appear at all. In the design and implementation of the automated tools, a decision was made to not match items unless the match is highly reliable. The software design was expanded to include graphical tools to facilitate user interaction necessary to “manually” assign these attributes through a simple multiple-choice listing to one or many centroids representing individual sub-parcels. These graphical tools provide unique spatial database queries based on a thorough understanding of the data sets used in the GCDB.

Significant success has been obtained when dealing with other types of “numbered” parcels, such as mineral surveys and homestead-entry surveys. An attempt to match the [BLM] survey type “L” with numerical designation was abandoned due to the inconsistent use of the Government Lot designation of legal descriptions in the CAMA. Further examples of this include incorrectly coding the nominal aliquot designation for the lot, coding NENE instead of coding GOVT LOT 1. The nominal location of a LOT 1 may well be within the NENE, yet the use of aliquot part description incorrectly implies method of subdivision for future conveyances. The special meaning of LOT 1 is lost.

Table 12 is a summary comparing the accuracy achieved in the automated linking process experiments presented above. The table includes a data element from the US Census bureau labeled “Housing units per sq. mile.” This study does not intend to conclude that the effectiveness of the automated linking is dependent upon low population. However, the automated linking achieves its greatest success in the rural areas that typically contain fewer parcels and a high percentage of aliquot part descriptions. These general characteristics are reflected in the “housing units per sq. mile” statistic from the Census. As the number of housing units per square mile increases, the automated linking success drops.

County Name	Housing units per sq. mile	Average linking success
Powder River	0.31	80.5%
Prairie	0.41	81%
Blaine	0.70	71%
Beaverhead *	0.82	71%
Sweetgrass	1.0	78.5%
Madison	1.30	81.5%
Gallatin	11.32	66%

Table 12. Comparison of automated linking success.

The type of cadastral base mapping presented in this thesis is very affordable. The counties with largely rural populations are often the same counties with very limited

financial resources. Limited financial resources impede implementation of a digital local cadastre. A paradox arises, as the success of the automated linking portion of this research is greatest in these rural areas. Thus implementation may lower the cost of data collection to an affordable level for even the most financially restricted counties.

Typically, sparsely populated counties include small municipalities and both of the government entities may have limited financial resources. Cooperative efforts to accomplish the task could be facilitated by identifying the scope of work necessary to create the local parcel fabric. A joint venture of the local governments to address the data collection and maintenance responsibilities would further minimize the cost and eliminate duplication of effort. Deployment of the measurement management approach could result in a greater ability of the surveying profession to participate in the creation, maintenance and operation of the local cadastre. Involvement of the surveying profession should result in improved integrity of the spatial locations and could provide a tremendous amount of work for surveying practitioners. In turn, greater involvement by the surveying profession would foster greater concern and appreciation, resulting in improved relationships of all interested parties.

5.13 Recommendations for Future Research

The use of this research for storing the parcel base is but one solution for the issues of initial data collection and maintenance of the cadastre. Its use requires specialized knowledge typically found in land surveying personnel. This may be a limiting factor for some local jurisdictions but is a tremendous opportunity for the land surveying profession. The issue of maintenance is a weakness of most GIS solutions. The systems typically do not consider long-term strengthening of the parcel fabric and ordinarily only produce coordinate positions of newly added records.

Enhancements to the linking process could be explored where the source document survey identifiers (SID) used for generating the local parcel base are incorporated into the automated linking process. Extensions to the standardized extensions in the survey identifiers data file could be incorporated to facilitate storage of local records in the native units of the source documents. The existing support of native units is limited to raw data file creation and the network analysis as documented in C.4.

Additional research could be applied to further strengthen the FGDC Cadastral Data Content Standard. Specifically, research could address areas of standardized coding of the smaller aliquot part descriptions and coding of Government lot descriptions.

This research has presented a method to digitally read and interpret aliquot part descriptions for identification purposes. A logical advancement of this technology could develop logic and algorithms to automatically populate the database that stores the additional calculations needed to further subdivide the sections. Reading and interpreting standardized legal land description of smaller aliquot parts could logically compute and

store the necessary calculations for depiction of the parcels smaller than 1/16 section level.

Appendix B and Appendix C document many specialized functions developed to maximize efficiency for the BLM parcel maintenance needs. The software extensions developed in this research have not been refined to the same degree; the software is not ready for widespread deployment. Software development is not research, yet application of this research to develop and refine the software will significantly increase the acceptance and use of the technology.

The data structures are presented in Appendix A, as documentation of these is crucial to support future research or development. The WinGMM approach to measurement management is the first graphical implementation; indeed many future enhancements are anticipated.

REFERENCES

Blanchard, B.M. (1990). *Utility Program Development: A Digitally Integrated Measurement Management System for the U.S. Public Land Survey System*. M.S. thesis, University of Maine, Orono, ME.

Breckenridge, R. (1994). "Building a county GIS through inter-governmental cooperation." *Montana Policy Review* 4(1):19-23.

Bureau of Land Management, (1992). *GMM Users Manual*. US Department of the Interior, Bureau of Land Management. Vol. 3:1-73.

Bureau of Land Management, (1998). *Instruction Memorandum, IM98-152*, Bureau of Land Management; Washington.

Bureau of Land Management, (1998). *Guidelines for Developing Amended Protraction Diagrams, IM98-152, Attachment 4*, Bureau of Land Management; Washington.

Bureau of Land Management, (1998). *General Rules on Surveying Amended Protraction Diagrams, IM98-152, Attachment 5*, Bureau of Land Management; Washington.

Bureau of Land Management, (2001). *WinGMM V. 1.0 Technical Reference Manual*.

Bureau of Land Management; Land & Resources Project Office, Denver.

Bureau of Land Management, (2001). *WinGMM V. 1.0 Software User Guide*. Bureau of Land Management; Land & Resources Project Office, Denver.

Eflick, M. (1996). "*Cadastral coordination*." University of Newcastle.

Environmental Systems Research Institute, (1999). "*National integrated lands system, parcel consortium, and ESRI form partnership*." *ARC News* 21(2):38 Redlands, CA.

Federal Geographic Data Committee, (1999). *Cadastral Data Content Standard for the National Spatial Data Infrastructure, Version 1.1*, Subcommittee on Cadastral Data, Reston, Virginia: FGDC.

Federal Land Policy and Management Act of 1976 (43 U.S.C.), Washington: US Government Printing Office.

Federal Register: September 12, 2000 (Volume 65, Number 177), Washington: US Government Printing Office.

Florida Geographic Information Advisory Council, (October, 1998). *Cadastral Mapping Guidelines and Standards*. Tallahassee: FL Department of Revenue.

Hintz, R., J. Wahl, K. Wurm, and D. McKay. (1996). “*Geographic measurement management: an operational measurement-based land information system.*”

ASPRS/ACSM Annual Convention and Exhibition Technical Papers 3:141-149.

Bethesda: ASPRS/ACSM.

Hintz, R., J. Wahl, K. Wurm, and D. McKay. (1995). “*Strategies for automated parcel identification from digital record data in the U.S. public land survey.*” ACSM/ASPRS

Annual Convention and Exposition Technical Papers 1:320-326. Bethesda:

ACSM/ASPRS.

Hintz, R., K. Wurm, J. Wahl, and D. McKay. (1995). “*A regional approach to adjustment and coordinate reliability from digital record data in the U.S. public land survey.*” ACSM/ASPRS Annual Convention and Exposition Technical Papers 1:74-82.

Bethesda: ACSM/ASPRS.

Hintz, R.J. and J.L. Wahl. (1994). “*Automation of the computation of survey quality parcels in the public lands survey environment.*” ACSM/ASPRS Annual Convention and Exposition. 1:335-344. Bethesda: ACSM/ASPRS.

Hintz, R.J. and J.L. Wahl. (1994). "*Specialized Automated Functions for Subdivision and Parcel Recognition within the U.S.P.L.S.*" ACSM/ASPRS 94 annual meeting proceedings. 1:123-134. Bethesda: ACSM/ASPRS.

Hintz, R.J., J. Wahl, K. Wurm, and D. McKay. (1993). "*The Use of Public Land Survey Records in Establishment of a Geodetic Framework for Land Information.*" ACSM/ASPRS Annual Convention Technical Papers. 1:233-242. Bethesda: ACSM/ASPRS.

Intergovernmental Information Systems Advisory Council (IISAC), (1997). "*Implementation guide for parcel-based GIS in Minnesota local government.*" [Online brochure] <<http://www.admin.state.mn.us/iisac/gis/gisindex.html>> St. Paul

International Federation of Surveyors, (1995). "*Statement on the cadastre.*" FIG Bureau, Canberra, Australia.

Kaufmann, J. and D. Steudler. (1998). "*Cadastre 2014: A vision for a future cadastral system.*" Report of FIG Workgroup 7.1. Bern, Switzerland.

Land Withdrawals, 43 CFR 2300 (2001). Washington: US Government Printing Office.

Leasing of Solid Minerals other than Oil and Shale, 43 CFR 3500 (2001). Washington: US Government Printing Office.

MacDonald, Scot A. (1992). *“Implementation of Automated Field Notes in the Cadastral Electronic Field Book System.”* M.S. thesis, University of Maine, Orono, ME.

Minnesota Governors Council on Geographic Information. (1997). *Identifying land parcels: is a statewide format needed?* [Brochure] St. Paul: Land Management Information Center.

Montana Geographic Information Council (MGIC), (1998). MGIC charter. Information Services Division, State of Montana.

Montana Geographic Information Council (MGIC), (1998). *Montana GIS cadastral project methodology*. Helena: Information Services Division (ISD).

Montana GIS Services Section, (1999). *Rubbersheeting parcel coverages using adjusted GCDB*. Helena: Montana Information Services Division (ISD).

National Research Council (U.S.). Panel on a Multipurpose Cadastre. (1983). *Procedures and standards for a multipurpose cadastre*. Washington: National Academy Press.

Owen, D. (1994). "*Building the National Cadastral Layer: The BLM's Geographic Coordinate Data Base (GCDB) Project.*" Urban and Regional Information Association (URISA) Proceedings. 1:455-463 Washington: URISA.

Parker, B. C. (1992). *Numerical and Operational Aspects of the Cadastral Electronic Field Book.*, M.S. thesis, University of Maine, Orono, ME.

Racicot, M. (1997). *Executive order forming MGIC*. Montana Executive Order 17-97, Helena.

U.S. Department of the Interior, Bureau of Land Management (1973). Manual of Instructions for the Survey of the Public Lands of the United States 1973. Washington: U.S. Government Printing Office.

Western Governors Association. (2000). *Public Lands Survey System and Ownership Database*. Policy Resolution 00-005. Denver: WGA.

Zimmer, R.J. (2000). "*The GCDB and GIS.*" Professional Surveyor. 20(7):60-61,
Frederick, MD: Professional Surveyors Publishing Co., Inc.

APPENDIX A EXAMPLE FILES AND FORMATS

Sample file contents and file formats utilized in the WinGMM software system and GCDB are presented to facilitate future research. For each file listed, a table is presented to formalize the format and to provide additional descriptive information. Following the format is an example file for clarity. Each of the files share the name of the project; each has a unique filename extension used for identification. The files presented are those used for data input and data storage; other files are derived from these core data elements. For detailed explanation of derived files, refer to the WinGMM v 1.0 Technical Reference Manual.

A.1 .DEF File

Row	Field Description	Start	Length	Type
1	Program Prompt	1	1	Character
2	State Plane Zone	2	40	Character
3	Datum; 1=NAD27, 2=NAD83	1	1	Integer
4	Horizontal Units; 1=Meters, 2=US survey ft, 3=Int'l ft.	1	1	Integer
5	Project Elevation	2	10	Real .3
6	Elevation from .lev?	1	1	Boolean
7	Error Estimates from .sd ?	1	1	Boolean
8	Default dist error estimate; constant	2	10	Real .3
8	Default dist error estimate; ppm	12	10	Real .1
9	Default Angle Error Estimate (seconds)	2	10	Real .1
10	Default Bearing Error Estimate (seconds)	2	10	Real .1
11	Default Control Error Estimate Easting	2	10	Real .3
12	Default Control Error Estimate Northing	2	10	Real .3
13	Bearing type; Mean Geodetic	1	1	Character
14	Distance Residual Print Limit	2	10	Real .3
15	Angle Residual Print Limit	2	10	Real .1
16	Azimuth Residual Print Limit	2	10	Real .1
17	Error Ellipses Computed?	1	1	Boolean
18	Readjust with robusting?	1	1	Boolean
19	Print adjusted bearings & distances?	1	1	Boolean
20	Print coordinate file?	1	1	Boolean
21	Township and Range	1	30	Character
22	Principal Meridian	1	30	Character
23	State or local designator	1	30	Character
24	UTM Zone	1	3	Integer

Table A1 . DEF File Format.

```

Y      83 MONTANA NORTH LAMBERT
2
1
      762.002
N
Y
      .100      1000.0
      4.0
      120.0
      30.000
      30.000
Y
      .000
      .0
      .0
Y
N
N
Y
T32NR22E
20
MT
12

```

Figure A1 .DEF File Example

A.2 .CON File

Row	Field Description	Start	Length	Type
1	File Header	1	Var.	Character
2	Origin (not used, relic of earlier software format)	2	6	Character
2	Latitude (origin – may not be populated)	12	11	Real .4
2	Longitude (origin – may not be populated)	24	12	Real .4
2	Elevation (origin – may not be populated)	36	9	Real .3
2	“0” (may not be populated)	48	1	Character
2	“0” (may not be populated)	53	1	Character
2	“2000.0000” (may not be populated)	56	9	Real .4
2	“5000.0000” (may not be populated)	66	9	Real .4
3 ...	Control Available/Used (“*” indicates control available but not used)	1	1	Character
3 ...	Control Station Point Identifier	2	6	Long
3 ...	Latitude (DDMMSS.ssss)	12	11	Real .4
3 ...	Longitude (DDDMMSS.ssss)	24	12	Real .4
3 ...	Station/Project Elevation	36	9	Real .3
3 ...	Northing Error Estimate (ft.)	45	4	Integer
3 ...	Easting Error Estimate (ft.)	50	4	Integer
3 ...	X-Coordinate (may not be populated)			
3 ...	Y-Coordinate (may not be populated)			
3 ...	Datum (27=NAD27, 83 = NAD83, HP = HPGN)	56	2	Integer

Table A2 .CON File Format.

```

02/28/95  0320N 0220E 20 MT CONTROL
ORIGIN
305200    482940.3853 1085316.4880 2500.000  30    30    27
305200    482940.3741 1085319.0697 2500.000  30    30    83
300300    483036.7777 1085322.1546 2500.000  30    30    27
300300    483036.7677 1085324.7358 2500.000  30    30    83
500100    482848.0727 1085037.5261 2500.000  30    30    27
500100    482848.0607 1085040.1026 2500.000  30    30    83
500200    482940.1609 1085037.8128 2500.000  30    30    27
500200    482940.1497 1085040.3889 2500.000  30    30    83
600100    482848.0019 1084919.1427 2500.000  30    30    27
600100    482847.9899 1084921.7164 2500.000  30    30    83
600200    482940.0706 1084919.6521 2500.000  30    30    27
600200    482940.0593 1084922.2254 2500.000  30    30    83
700100    482848.0661 1084800.7692 2500.000  30    30    27
700100    482848.0541 1084803.3401 2500.000  30    30    83
711060    483119.5063 1085316.5856 2500.000  30    30    27
711060    483119.4972 1085319.1660 2500.000  30    30    83
711040    483027.3332 1085316.7737 2500.000  30    30    27
711040    483027.3229 1085319.3549 2500.000  30    30    83
305100    482848.1733 1085316.6760 2500.000  30    30    27
305100    482848.1613 1085319.2581 2500.000  30    30    83

```

Figure A2 .CON File Example.

A.3 .RAW File

Row	Field Description	Start	Length	Type
1	File Header	1	Var.	Character
2	(Optional control line) may not be populated			
3	"999999"	1	6	Long
4 ...	Point Identifier – FROM Station	1	6	Long
4 ...	Point Identifier – TO Station	10	6	Long
4 ...	Distance (default unit Chains, native unit if defined in SID)	17	8	Real .3
4 ...	Bearing Quadrant (1=NE, 2=SE, 3=SW, 4=NW)	27	1	Integer
4 ...	Bearing (DDMMSS.s)	31	8	Real .1
4 ...	Source Identifier (SID)	40	18	Character
5	"999998" (end of file marker)	1	6	Long

Table A3 .RAW File Format.

T32NR22E		20		MT		
11111	0.000		0.000	2500.000	1	1
999999						
100100	100140	40.000	4	.0 35867		
100140	100200	40.000	4	.0 35867		
100200	100240	40.000	4	.0 35867		
100240	100300	40.000	4	.0 35867		
(...)						
800200	360534	2.200	1	870000.0	35876/MC	
360534	800210	3.300	2	874500.0	35876/MC	
999998						

Figure A3 .RAW File Example.

A.4 .SID File

Row	Field Description	Start	Length	Type
1 ...	"S" (SID record)	1	1	Character
1 ...	Source Identifier (SID)	2	18	Character
1 ...	Distance Error Estimate, Constant	20	7	Real .3
1 ...	Distance Error Estimate, PPM	27	8	Real .1
1 ...	Bearing Error Estimate (seconds)	35	8	Real .1
1 ...	Control Easting Error Estimate (not used)	43	9	Real .3
1 ...	Control Northing Error Estimate (not used)	52	9	Real .3
2 ...	"C" (Comment record)	1	1	Character
2 ...	Descriptive comments (see notes following example)	2	40	Character
2 ...	Native Units Identifier(s) or Index Correction (see notes following example)	2	40	Character

Table A4 .SID File Format.

S35867	.030	2000.0	450.0	.000	.000
C GLO 18-MAR-1891 O PAGE,R					
C WEST-EAST BDYS.					
C BC: -3.01000 (BEARING ROTATION CORRECTION (DD.MMSS))					
S35873	.030	1500.0	310.0	9.144	9.144
C GLO 15-JAN-1917 O HARRINGTON,E					
C EAST BDY.					
S35873/MC	.030	1500.0	310.0	9.144	9.144
C GLO 15-JAN-1917 O HARRINGTON,E					
C MEANDERS					
S35876	.030	1500.0	310.0	9.144	9.144
C GLO 15-JAN-1917 O STINSON,A					
C SUBDIVISION					
S35876/MC	.030	5000.0	1070.0	9.144	9.144
C GLO 15-JAN-1917 O STINSON,A					
C R. BANK MEANDERS, MILK RIVER					
S37845	.100	1500.0	120.0	.1	.1
C GLO 15-JAN-1917 O HARRINGTON,E					
C DU:F <DISTANCE UNITS ARE US SURVEY FEET>					
C DT:G <GROUND DISTANCES>					
C BT:M <MEAN GEODETIC BEARINGS>					

Figure A4 .SID File Example.

Notes concerning SID file:

In its original definition, the comment fields used in the .SID file were free from text entries of descriptive information concerning the survey. In practical use, the SID comments have evolved to a more complex definition. The WinGMM software enforces portions of the complex definition, yet others do not. The first comment line of a SID typically includes metadata describing the survey. In Table 20 above it will be noted that the first comment line includes: Source Agency, Date of Survey, Survey Type (Original, Resurvey), and Surveyor's Name. Local GCDB offices have adopted other field definitions for this particular record, unique to their jurisdiction. For detailed explanation of such coding within a local area, one should consult the Cadastral Survey or GCDB staff at the appropriate BLM State Office.

Further advances in the standardization of SID comments include specific coding to support storage of measurement data in the .RAW file in units native to the source document, for the conversion of bearings to angular measurements, to support index corrections including bearing rotation, and for systematic distance corrections. Although these elements are all optional, a record of the domain of reserved keywords is necessary.

DU: Distance Units. Domain: C (Chains - default); F (U.S. Survey Foot); M (Meters); I (International Foot). Example: DU:F

DT: Distance Type. Domain: G (Ground); E (Ellipsoidal); P (Plane)

Example: DT:G

DC: Distance Correction, when used, must supply Constant + PPM correction.

Example:

```
C DC:          .100          1500.0    <DISTANCE CORR
CONST+PPM>
```

BC: Bearing Correction, when used, must supply rotation.

Example:

```
C BC:   1.02000    <BEARING ROTATION CORRECTION (DD.MMSS) >
```

BT: Bearing Type. Domain: M (Mean Geodetic); F (Forward Geodetic); G (Grid – State Plane); C (Compass – magnetic); L (Local – assumed)

Additionally, in very rare circumstances the input bearings may be treated as angles to preserve alignment. When used, the error estimate to use for angles must be supplied as shown in the following example.

```
C BT:MA      .01000 <MEAN BRGS., CONVERT TO ANGLES (ERR. EST
DD.MMSS) >
```

As this research created expanded functionality of the survey identifiers use to include post adjustment computations, it is imperative to point out that the above-mentioned use of native units is not supported in the .ADD file. When SID's are used to segregate post-adjustment calculations, the computation must express distances in chains. The bearing type is defined within the calculation definition itself.

Additionally, standard coding techniques have evolved for the SID naming to facilitate topology generated for the creation of parcels. If a particular SID is a

connecting line of a mineral survey or other special survey and not intended to represent a boundary line, the use of a special SID suffix may be employed. The reserved SID suffix of “/TIE” is used to indicate that a particular segment should be automatically excluded from .LXN and parcel topology.

A.5 .NOT File

Row	Field Description	Start	Length	Type
1 ...	Count of points not included	1	6	Integer
2 ...	Point identifier of unwanted point	1	6	Long
3	Count of lines to omit from final topology	1	6	Integer
4 ...	Point identifier of endpoint 1 (point from)	1	6	Long
4 ...	Point identifier of endpoint 2 (point to)	8	6	Long

Table A5 .NOT File Format.

1 440440 1 711090 711110
Figure A5 .NOT File Example.

A.6 .ADD File

Row	Field Description	Start	Length	Type
1 ...	Computation type (1=Trav/Prop, 2=Inter, 3=add line)	2	1	Integer
1 ...	Point ID of computed point	4	6	Long
1 ...	Point ID of known starting point	11	6	Long
1 ...	End point ID of bearing, or Quadrant (zero if not applicable)	18	6	Long
1 ...	Bearing (zero if not applicable)	25	8	Real .5
1 ...	Line Type (1=geodetic, 2=plane) (zero if not applicable)	36	1	Integer
1 ...	Record distance to new corner (zero if not applicable) (Point ID's if bearing is weighted mean)	38	9	Real .3
1 ...	Record distance to endpoint (if non-zero, used with above for proportion) (Point ID's if bearing is weighted mean)	48	9	Real .3
2 ...	Second line used for intersections (type 2 calculations)	2	1	Integer
2 ...	Zero identifies 2 nd line of intersection definition	9	1	Integer
2 ...	Remaining fields defined as above – refer to line 2 of intersection computation type.	11	Various	Various, as above

Table A6 .ADD File Format.

1	370360	360360	400360	.000000	1	.000	.000
1	350400	340400	360400	.000000	1	.000	.000
1	370400	360400	400400	.000000	1	.000	.000
1	500210	500200	500220	.000000	1	.000	.000
2	803285	803280	803290	.000000	2	.000	.000
2	0	320520	340520	.000000	1	.000	.000
2	803215	803210	803220	.000000	1	.000	.000
2	0	440520	420520	.000000	1	.000	.000
3	320400	320420	0	.000000	0	.000	.000
3	320420	320440	0	.000000	0	.000	.000
3	320440	320460	0	.000000	0	.000	.000
3	340400	340420	0	.000000	0	.000	.000

Figure A6 .ADD File Example

Notes concerning .ADD file:

Type 1 calculations always exist on one record; type 2 calculations always include a second record defining line 2 of intersection. Contents of distance fields may contain point ID's for various bearing types (parallel, weighted mean). Type 3 calculations only contain data in field 2 and field 3, the point ID's of start and end points for additional line segment to connect.

A.7 .IRR File

Row	Description	Start	Length	Type
1 ...	Point ID of Center of Section for irregular definition.	1	6	Long
2 ...	Standard Point ID to be substituted	1	6	Long
2 ...	Point ID to use in lieu of standard ID. Row 2 repeats for multiple substitutions until " 0 0"	8	6	Long
3 ...	Double Section Corner – First corner	1	6	Long
3 ...	Nominal section corner identifier (NE=1, SE =2, SW = 3, NW=4)	13	1	Integer
3 ...	Controlling direction (1=N, 2=E, 3=S, 4=W) Row 3 repeats for double sec. corners until " 0 0 0"	20	1	Integer
4 ...	Point ID of non-computable quarter corner. Row 4 repeats until " 0"	1	6	Long
5	Center of section definition, if used two or more records follow. N-S centerline & E-W centerline are both defined. Continues until " 0"	1	6	varies
6 ...	Point ID of non-computable exterior 1/16 corners Repeats until " 0"	1	6	Long
7 ...	Interior 1/16 corner proportions. First element is point id, followed by proportion/total distances to utilize. Repeats until "0 .000 .000"	1	26	Integer, 2 real .3
8 ...	Center of quarter section(s). Similar to Center quarter corner definition. May repeat to accommodate multiple definitions, end of type marker is " 0"	1	Varies	Varies
9 ...	Corners requiring offset to line. Repeats until " 0"	1	6	Long
10	"999999" End of paragraph defining irregular section.	1	6	Long

Table A7 .IRR File Format.

340440		
300400	305400	
300420	305420	
300440	305440	
300460	305460	
0	0	
0	0	0
0		
0		
0		
0	.000	.000
0		
0		
999999		
140640		
0	0	
0	0	0
0		
0		
0		
140660	20.158	40.158
120640	17.299	37.299
0	0.000	0.000
0		
0		
999999		

Figure A7 .IRR File Example.

Notes concerning .IRR file:

The .IRR file contents vary extensively. Documentation of each individual option is impossible in this format; thus in this example only a representative sample is included. From Table 24, row 5 and row 8 define the center of section and center of quarter section definitions. The actual data components stored in these records varies according to the methodology employed for the definition of the bearings to utilize for computation. Seven bearing types are accommodated for the following situations: straight line between opposite corners; weighted mean of 2 bearings by point ID's; average of two input

quadrants and bearings; parallel to a line by point ids; parallel to an input quadrant and bearing; input point ID, quadrant and bearing; or non-existent line.

Additionally, these elements may or may not appear exactly in the row number indicated on the format table. The length of each .IRR definition varies based on the amount of irregular information encoded. For specific formatting of these extensive options, one should utilize WinGMM's Irregular Section Subdivision interface, which facilitates reading, creating, and editing of all options included in the irregular section subdivision.

A.8 .ADS File

Row	Description	Start	Length	Type
1 ...	Point identifier of post-adjustment computed point	2	6	Long
1 ...	SID of source document creating point	9	18	Character

Table A8 .ADS File Format

210600 COS123
210560 COS123
200570 COS123
205600 COS123
230520 COS123
230540 COS123
215560 COS123
210520 COS123
200510 COS123
210500 COS123

Figure A8 .ADS File Example

A.9 .IID file

Row	Description	Start	Length	Type
1 ...	Comment lines, always contain "*" as leftmost character if exists	3 or 4	Varies	Character
2 ...	Verbose description of parcel, may extend into several lines.	2	Varies	Character
3 ...	BLM Parcel Attribute (compound, fixed format). If multiple exist, each shall appear on separate row. Active attribute(s) always begin with "Sec_" as first 4 characters	1	52	Character
4 ...	String of point identifiers which describe the parcel	2	Varies	Character
5	Parcel area point. Always begins with "PARCEL N,E" as record identifier	2	10	Character
5	Y-Coordinate of parcel area point	15	12	Real .3
5	X-Coordinate of parcel area point	32	12	Real .3

Table A9 .IID File Format

* * * This file has been edited by WinGMM * * *				
SECTION 31 LOT 4 HAS 34.9 ACRES (COOR.) 34.9 ACRES (PLAT)				
REPLACES SW 1/4 OF THE SW 1/4				
Sec_031 K T_L 4 34.850; M20T0320NR0220E				
100100 100120 120120 120100 100100				
PARCEL N,E 470553.602 642062.692				
SECTION 31 LOT 3 HAS 34.9 ACRES (COOR.) 34.8 ACRES (PLAT)				
REPLACES NW 1/4 OF THE SW 1/4				
Sec_031 J T_L 3 34.840; M20T0320NR0220E				
100140 100120 120120 120140 100140				
1234567890123456789012345678901234567890123456789				
PARCEL N,E 470956.014 642060.477				
Figure A9 .IID File Example				

Notes concerning .IID File:

Obsolete or edited attributes are preserved; each is prefixed with keyword. Active attributes always begin in column 1 with “Sec_” appearing as the first four characters. A paragraph exists for each sub-parcel. Tabular statistics of the township characteristics follow the parcels in the file. Note that the attribute, point identifier string, and area point coordinates are all required elements for each sub-parcel; remaining elements are optional and vary in content. This file is maintained to record history of parcel editing, for movement of area point, and for verbose description of the parcels. Other data files such as the .AN and .GLD are derived from this file.

The existence of this file is required for editing and maintaining attributes using the WinGMM parcel attribute subsystem.

A.10 .MTC File

Row	Description	Start	Length	Type
1	Township (project) name, date, Total parcels linked	1	Varies	Character
2...	"Parcel area point (X,Y) = "	1	22	Character
2 ...	X-Coordinate of area point	35	12	Real .3
2 ...	Y-Coordinate of area point	42	12	Real .3
3...	"Parcel chain ="	1	14	Character
3...	String of point identifiers	17	Varies	Character
4...	"GeoCode = "	1	10	Character
4 ...	CAMA Geocode (parcel identifier)	11	17	Character

Table A10 .MTC File Format.

```

T33NR18E CAMA Linked Parcels 3/29/02 Total linked = 576
12345678901234567890123456789012345678901234567890123456
Parcel area point(X,Y)= 2041869.051 599295.894
Parcel chain = 600600 600620 620620 620600 600600
GeoCode = 24455301303010000

Parcel area point(X,Y)= 2041862.672 601945.025
Parcel chain = 600640 600660 620660 620640 600640
GeoCode = 24455301101010000

Parcel area point(X,Y)= 2041865.413 600621.214
Parcel chain = 600640 620640 620620 600620 600640
GeoCode = 24455301101010000

```

Figure A10 .MTC File Example.

APPENDIX B PARCEL ATTRIBUTION WITH WINGMM

B.1 Parcel Attribution Features of WinGMM

As with many processes, completing the task is somewhat dependent upon where you're starting. This is true with parcel attributing. The tasks to be completed are slightly different if you're creating and attributing a project for the first time or if you're resuming attributing work already performed. Resuming work could include attributing a project that was initially created by another, or performing maintenance & updates to a previously completed project. This distinction is only made to gain an understanding of the process, the data, the files, and the final product. A simple check can be performed by adjusting the viewing screen to display "Parcel Label Points." If colored symbols appear, the project has been linked; thus you are most likely editing or modifying the project. If the colored symbols do not appear, the project has not been linked. An inventory of the relevant files (.RPO, .LOT, .LLD, .AN, .IID) is the best way to determine the status of a parcel attribution project.

Using the Reports menu, choose project reports. Check for the existence of .LOT. This is a GMM .LOT file, which contains information about Government Lots and special surveys. If this file is not present, look for the existence of .LLD. The .LLD file is a flat file containing the data from the BLM LLD database for use in parcel attribution.

At this point, we'll assume that the relevant .LLD file has been obtained, but the project has not been linked. On the attributes menu, choose "Import LLD file." This

action launches a command module named GETLLDW. The purpose of this operation is to read the .LLD file to obtain information about the numbered government lots, special surveys, acreages, and other information useful and/or required to the attributing process. If the project is a township that includes elongated sections, additional information will be required to assist in naming of the government lots. This step is to overcome a shortfall in the existing LLD database, namely that all sections are approximated as having 16 "nominal" aliquot parts. In the case of elongated sections, there will be more than 16 nominal parts, so this information is required. The .LLD file is translated and supplemented as necessary to create a .LOT file. Both of these files aid in assigning parcel identifiers at a later stage of the attributing process. One very important note: the LLD file is not available in all areas. In this situation the .LOT file must be manually created, and future development may facilitate this operation. When data entry to identify elongated sections (if they exist) is complete, we proceed to RAW polygon identification.

B.2 Raw Polygon Identification

Raw polygons are those polygons created only from raw survey information--lines that are part of the network analysis. The intersections of these lines create raw polygons. These are full sections, special surveys, river meanders, etc. The point identification scheme is analyzed to identify all parcels made up entirely of the standard lines. A parcel bounded by corners having special survey point identifiers is also easily identified. Yet in many instances a polygon has both standard point identifiers and special survey point

identifiers. In these instances, the polygon may be either inside of the special survey or it may be the remainder of the rectangular parcel and therefore in most cases is a lot (Hintz, et al., 1995). Hintz implemented a series of rules for the automatic identification of the inside/outside scenario:

1. A parcel consisting primarily of meander corners that contains two distinct lines with section line identifiers is probably "inside." This is typical of a river entering and leaving a section.
2. A parcel consisting of two or more connected components of section lines and one string of special point ids is probably "outside." The special point ids reflect a side of a special survey.
3. Two outside parcels rarely have a common side that is inside a section. That common side should just not exist if both were outside because they would be one parcel with no dividing line. If one parcel has been identified, the connected parcel is of the opposite type.
4. An identified outside connected to an identified parcel by a section line usually indicates the other parcel is outside. The rare exception is when one side of an inside parcel is a section line and is connected across the section line to a lot.
5. Joining inside parcels to identified parcels to create a bigger parcel may result in a parcel with only special point ids. All parcels included in it are inside. This occurs when a series of interconnected mineral surveys crosses a section line (Hintz, et al. 1995).

The WinGMM graphical interface facilitates the creation, display and editing of the raw polygon identification. Choosing "Compute RAW Polygons" from the Attributes menu launches a command module named RPOLYW. Adjust Viewing Options for the

selection of the raw polygon centroids. Choosing "Raw Polygon Centroids" from the View menu turns on a graphical depiction of the raw polygons. Each polygon is represented by a small dot, with an associated tag. The tags are "S" for standard, "I" meaning the polygon is inside a special survey, and "O" meaning the polygon is outside of a special survey.

The correct linking of the project is greatly facilitated by properly identifying any raw polygons that may have been tagged in error. The success of later non-interactive processes is largely dependent on this step.

B.3 Edit Raw Polygon Centroids

When one or more of these raw polygon centroids are found mislabeled, it must be edited to correct the tag assigned to the polygon. On the toolbar, choose the SELECT RAW POLYGONS tool. With the RAW POLYGONS tool, select one or more centroids to edit. It is important to know change is applied to all selected polygons. If a large tract should cover parts of several sections, and the raw polygons are incorrectly identified, one may select all of polygons and perform one change to reassign the label on all. After making the selection(s), a right-button click on the graphic displays the popup menu. "Edit Polygons" is chosen to select the new value on the dialog box as shown in Figure 25. If the wrong polygons have been chosen, CANCEL allows for re-selection. If a raw polygon tag is incorrectly assigned, the process is repeated.

In Figure B1, two polygons are shown incorrectly labeled as “I”, located in a bend of a meandered river, due to the use of the special survey point identifiers along the meandered sides of the polygon. In this case, both of the polygons are selected and the user shall resolve the conflict by assigning these polygons as “O” to identify them outside of the special survey.

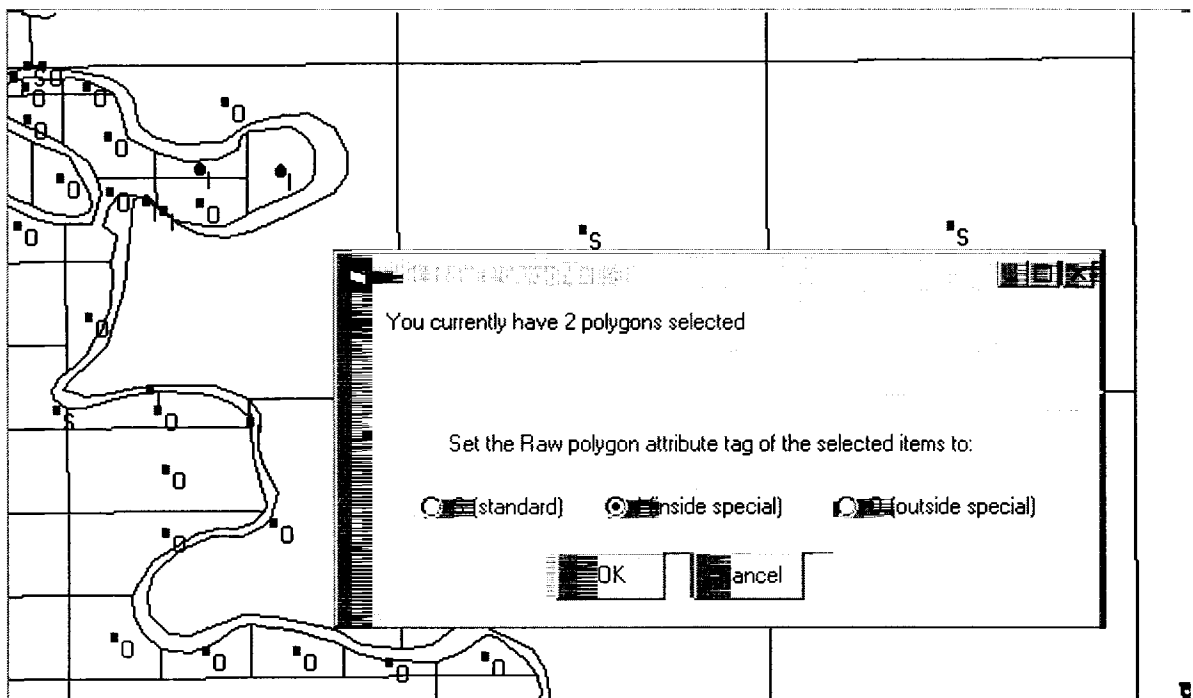


Figure B1. Editing Raw Polygon Labels.

B.4 Linking Parcels with Descriptions

When satisfied with the raw polygon identification, we proceed to link. On the "Attributes" menu, "Link Parcels with Descriptions" is chosen. This launches a command module named LLDW, the workhorse of the attributing process. LLDW attempts to automatically identify all parcels, including those created through subdivision of sections. Each of the subdivision parcels is now identified as being within a special survey, or outside of a special survey (lot) or a standard aliquot part. The parcels are merged with their legal land description; the parcels located outside of the special survey will be assigned a specific lot number. Parcels which otherwise would be considered aliquot, but are terminal ends of closing lines interior or on the exterior of the township are also assigned with government lot numbering. The LLD file contains the platted acreage; LLDW also computes area based upon the coordinates for comparison with the record acreage to assist in the assignment of parcel identifiers.

Hintz points out that GCDB and the LLD databases were two independently created sources of U.S.P.L.S. information. While a variety of checks existed in their creation, unfound blunders and misinterpretations will occur. Mismatches of GCDB to LLD indicate that problems exist in one or both of the systems. These problems need to be resolved before validity of the two systems is truly achieved. The graphical visualization of the parcel and their identifiers, with special graphical effects for mismatches, is the final component of the process (Hintz, et al., 1995).

Adjusting the view again will display the parcels, the .LXN lines are turned on showing all the lines created during the subdivision of sections process, and certain lines

are automatically excluded ("tie-lines" used in mineral surveys are excluded by SID, others by .NOT definition). "Parcel label points" have also been turned on, displaying color-coded. Green indicates the parcel is an ordinary aliquot part; red indicates the parcel could not be identified and will need to be edited; yellow is used for government lots; blue identifies water. Black (or white) is used to identify everything else (Tracts, Minerals, etc.).

The other three viewing options turn on part of the parcel identifier to assist you in identification. For example, if many interconnected mineral surveys confuse the graphical identification on the screen, choosing "Brief" will assist by displaying the survey type and survey number; this option is shown in Figure B2. The second viewing option, "Detailed," also includes the section number, nominal location code, and parcel area. These viewing options are only applied to the non-aliquot parcels. The third viewing option, "Full," displays the full parcel attribute for all parcels, including the aliquot parts. Meaningful attributes, which include spatial components, facilitate the visual representation and identification of the parcel itself. The same general area illustrated previously for raw polygon identification is now shown in Figure B2 with the results of the merge. The brief labeling is also displayed.

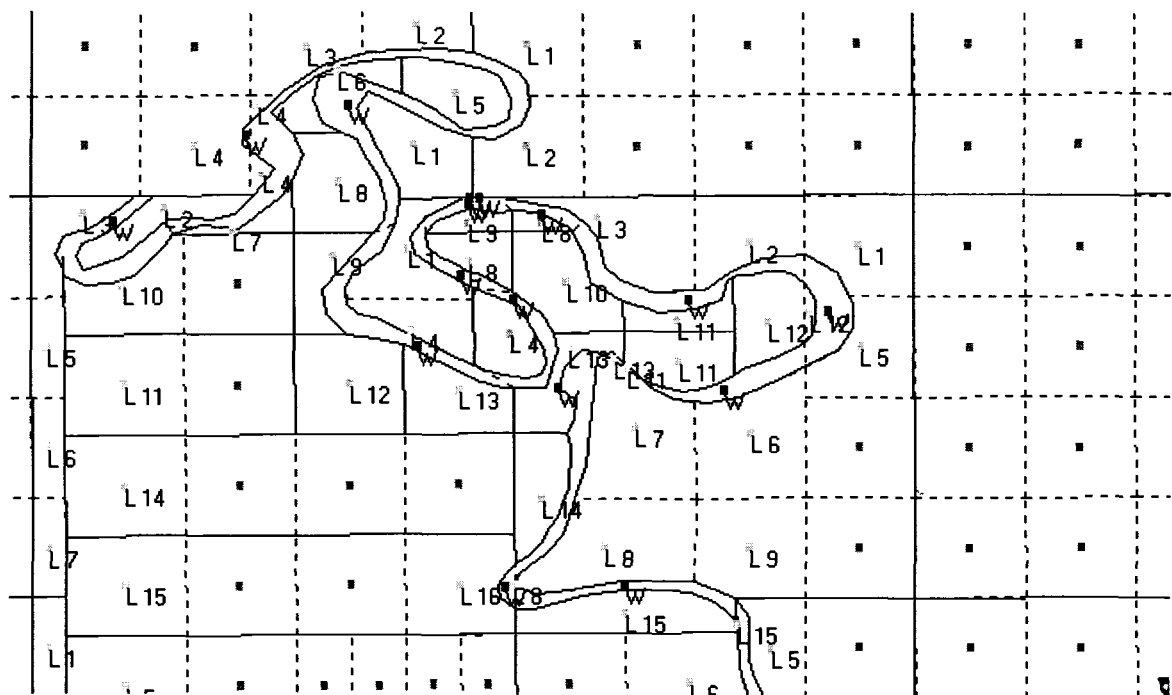


Figure B2. Display of Parcels Following Merge with Legal Land Description.

B.5 Selecting Parcels

Parcels that could not be automatically identified appear in the graphic with a red dot symbolizing its status, indicating user interaction is necessary. Using the "SELECT PARCELS" tool on the toolbar, one of the dots representing the parcel to be edited is selected. The dot is highlighted as selected, and the current identifier is displayed in the window titled "Selected Parcel Id's." Several parcels may be selected for editing at once, but for simplicity of explanation, one is chosen shown in Figure B3.

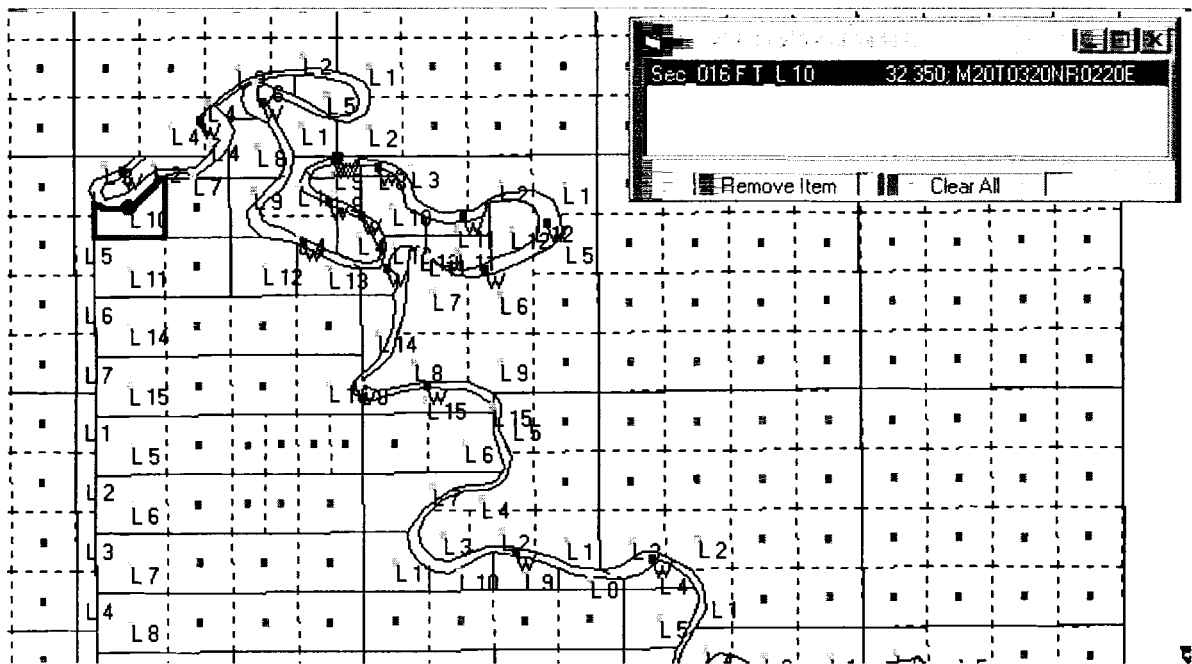


Figure B3. Selecting a Parcel for Edit.

If multiple parcels were selected at once, each would appear in the list box. The parcel to edit is highlighted in the list box; additional feedback is provided by

highlighting the parcel in the graphic. A right-button click displays a popup menu of several choices. “Properties” will be discussed next.

B.6 Parcel Properties

Parcel Properties include individual components of the parcel identification. These components include the following fields: Section Number, Acreage, Nominal Location, Survey Type, Survey Number, Survey Suffix, and Survey Note. The dialog window shown in Figure B4 facilitates editing of these fields through text boxes and drop down lists provided for efficient selection and formatting. The command button "Apply" updates the attribute. If more changes to this parcel are necessary, the update is repeated to rebuild the parcel identifier. When the user is satisfied with the changes made, clicking “OK” commits the changes.

accurately reflects the parcels. Figure B5 illustrates the selection of the parcel description from the .LOT possibilities for assignment.

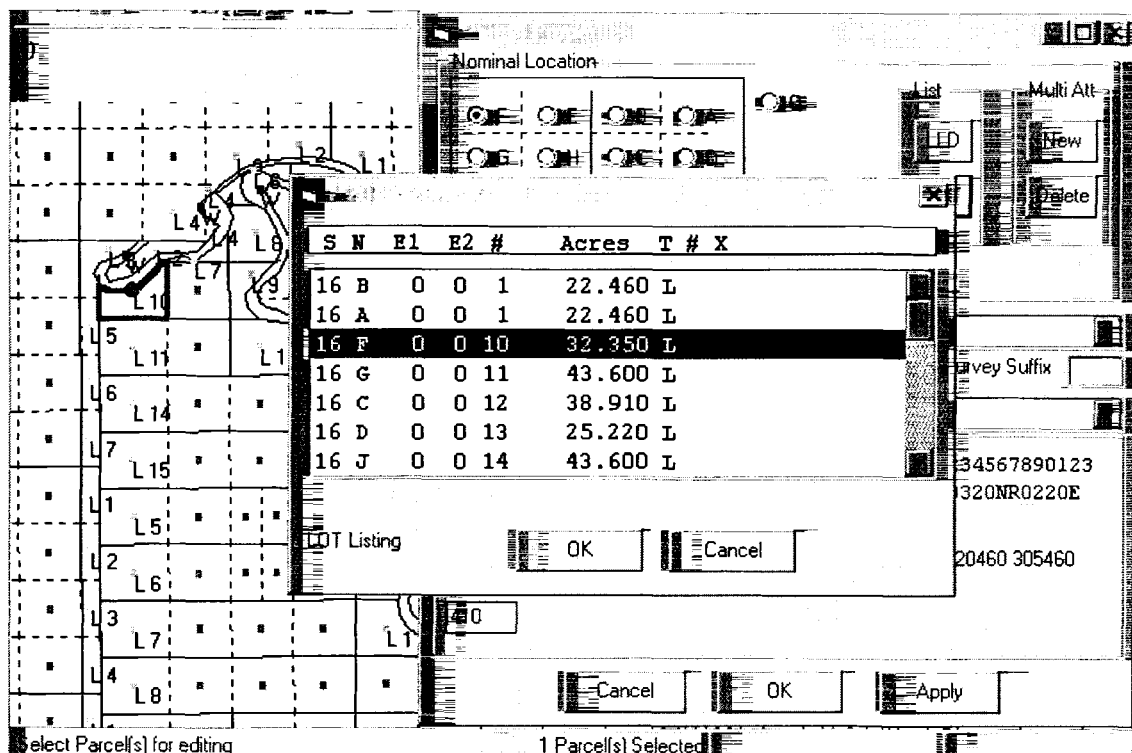


Figure B5. LOT Selection of Parcel Description.

When satisfied with the parcel attribute assignments, one final step is to call the command module VERIIDW. This routine has several uses, including the ability to create the final .AN output file. The user may suspend work at any time by simply exiting the software. Later, work is resumed at the same data assignment level by opening the project and setting the viewing options.

B.7 Advanced Parcel Editing

In addition to the parcel properties window, two advanced features for editing parcel attributes exist, Quick Edit and Multiple. Quick Edit allows selection of one to several parcel area points that require similar edits. As chosen, the selected parcel attribute is added to the listing. Click the right mouse button, then click pop up menu, then choose Quick Edit. A dialog box will be displayed as shown in Figure B6.

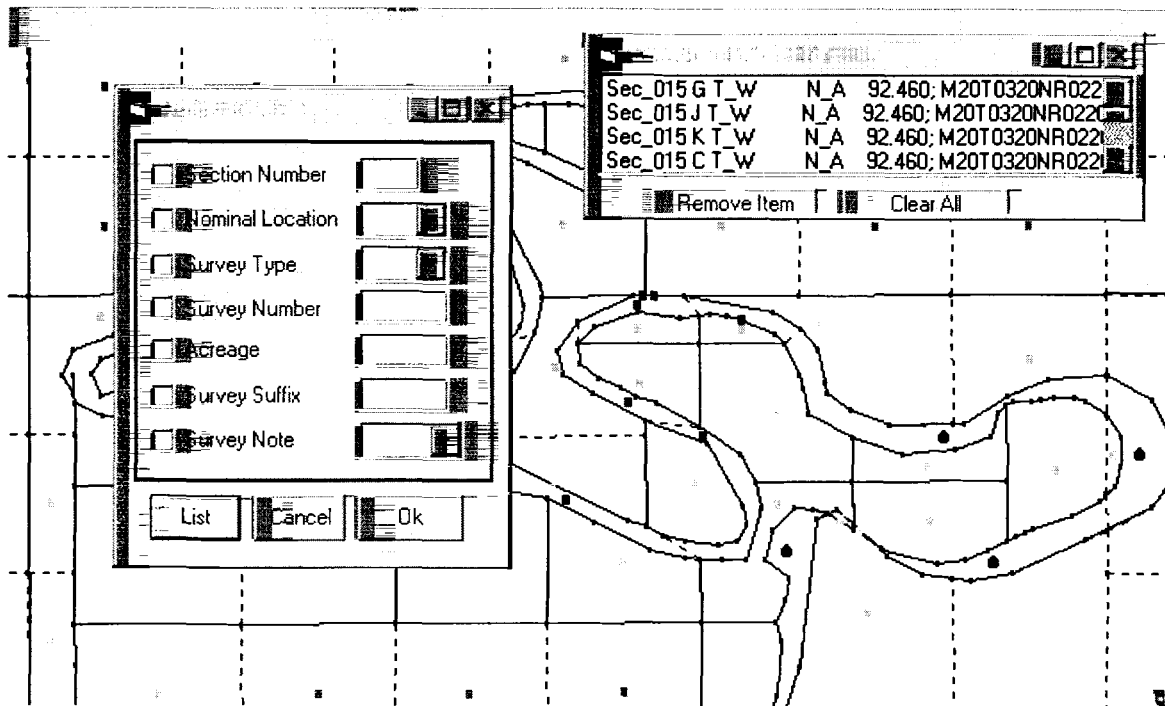


Figure B6. Quick Edit Dialog.

Using this dialog, the user may make changes to any of the attribute components, to be applied to the full selection set. As changes are made to the items, the associated check box command is enabled to signify which components of the parcel attribute will

be updated. Click “OK” to save the changes. Use of the Quick Edit feature performs the same edit on each of the selected parcels. Additionally, a button appears on the quick edit dialog that displays a list of valid LOT file entries, shown in Figure B7.

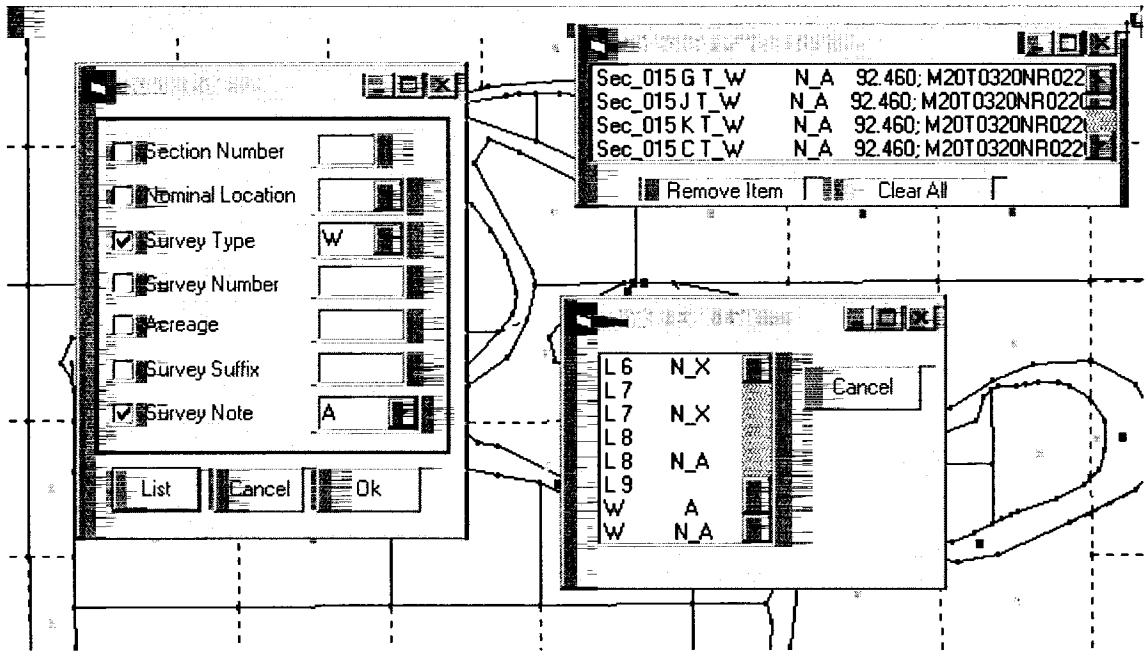


Figure B7. Quick Edit List.

Selecting an item from this pop up listing updates the Quick Edit screen itself, including the check boxes. If the user selects an item, each appropriate component is updated and enabled for update. If a particular component should not be updated, disable it by de-selecting the check box.

The final parcel attribute edit tool is labeled “Multiple,” as its major purpose is assigning multiple attributes to a parcel. This tool is significantly different from the others in that

only one parcel area point may be selected. Choosing the multiple tool displays a listing of the valid .LLD entries for the section. The user then selects several .LLD items to assign to this one parcel, then clicks "OK" to commit the changes. There are several instances where it is necessary to assign two or more attributes to the same parcel. The "Multiple" tool facilitates this just as the quick edit tool facilitates making several changes at once to several parcel area points.

B.8 Quality Assurance and Inspection

The goal of this attribution process is to have 100% of the parcel components assigned to one or more parcel identifications. In complex townships with large numbers of special surveys, significant manual changes may have to be made to the parcel attributes. It is critical that procedures be included to inspect the results of the parcel attribution process. Two tools are introduced for this purpose, namely Banding and the Parcel Locator; each has several options discussed below.

Banding is called from the Attributes menu of WinGMM. It provides for a graphical inspection of the section number and nominal location components of the parcel attributes. When Banding by sections is chosen, a series of colored bands is displayed across a row or column of sections, shown in Figure B8. Using both N-S and E-W banding by sections will perform spatial queries sufficient to identify any parcel area points which have the section number component erroneously attributed.

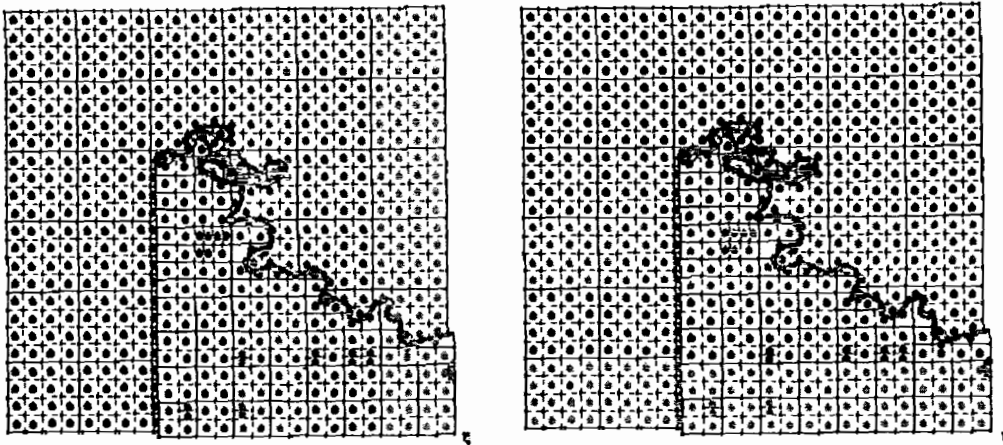


Figure B8. Banding by Section.

Banding by nominal location is similar; however, a pattern of colored bands is repeated in each section. Using both N-S and E-W banding by nominal location will perform spatial queries sufficient to identify parcel area points erroneously assigned the nominal location component as shown in Figure B9. Banding options are simple, fast and efficient tools for inspection of the core attribute components of section number and nominal location.

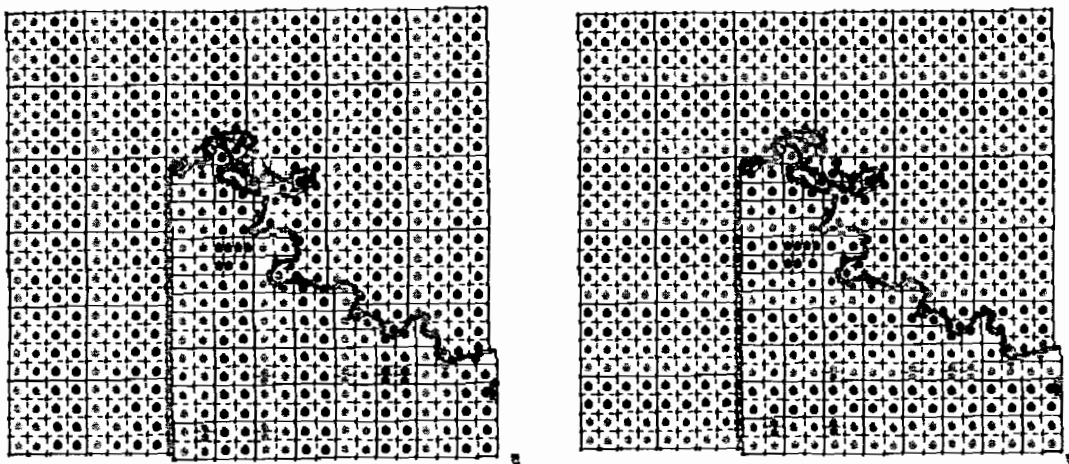


Figure B9. Banding by Nominal Location.

The Parcel Locator is the primary tool for detailed inspection of all parcels. The Parcel Locator dialog shows several command buttons, each performing a unique query for graphical inspection of the parcel attributes for each parcel area point. There is potential for a many to many relationship; thus particular parcel attributes may be assigned to several of the parcels, while several area points typically make up one parcel. The Parcel Locator facilitates inspection by providing graphical feedback for comparison with the source documents.

"All Parcels" lists every parcel in the locator as shown in Figure B10. Parcels are sorted first by section number, then by nominal location code. This provides for fast scrolling to find the desired parcel in the locator. Upon selection in the locator, the parcel is highlighted in the graphical display. Selecting a second parcel erases the first from view, and highlights the second (and so on). Holding the "shift" key allows several parcels to be selected and highlighted together in the spatial display.

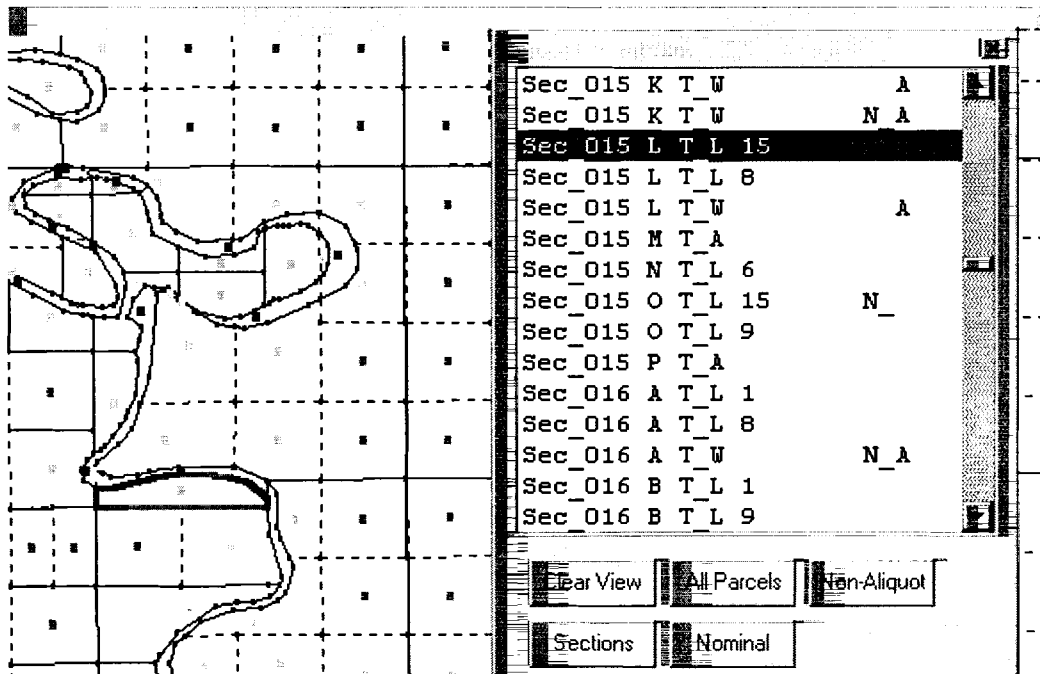


Figure B10. Parcel Locator Dialog.

"Non-Aliquot" lists all Government lots, all special surveys, water, and any other non - aliquot part parcels. If survey type "W" appears in the list, identifying a parcel described as water, when selected all parcels with this attribute are highlighted. This option is illustrated in Figure B11.

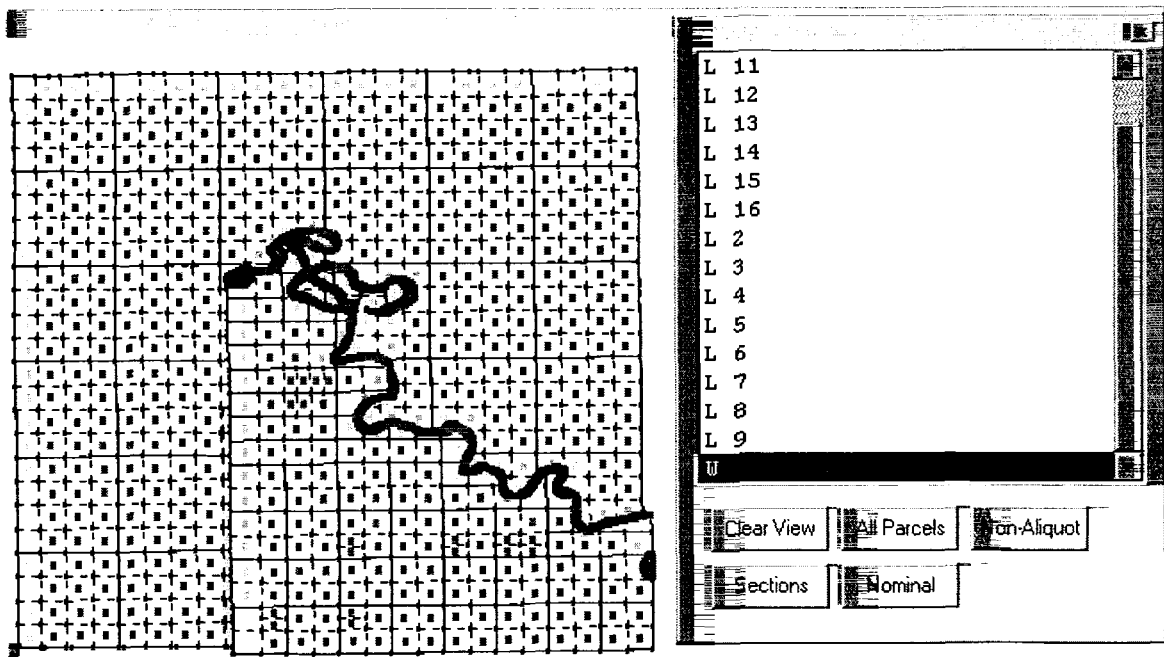


Figure B11. Parcel Locator for Non-Aliquot Parcels.

"Sections" provides a spatial query to all parcels by section number, providing essentially the same functionality as Banding by section number. "Nominal" provides a spatial query to all parcels by nominal location, providing essentially the same functionality as Banding by nominal location.

APPENDIX C SPECIAL DEVELOPMENT TO ACCOMMODATE UNSURVEYED PARCELS

C.1 Unsurveyed Lands and protraction diagrams

Protraction diagrams are essentially a platted plan of survey that is extended across unsurveyed areas as an extension to the Public Land Survey System. This discussion of unsurveyed lands and protraction diagrams is presented because the inclusion of protracted parcels in the cadastre is necessary to achieve full coverage in a parcel-based map. A discussion of the documents creating these parcels follows to explain their interpretation and use in the digital environment.

Extensive areas of the American West and Alaska are unsurveyed, yet legal descriptions of parcels exist. Lines and corners that do not exist bound these parcels on the ground. The protraction diagram gives the ability to describe parcels of land as the basis for land management activities such as leasing (Leasing of Solid Minerals other than Oil and Shale, 2001), withdrawals (Land Withdrawals, 2001), and other administrative boundaries. Most of the original protraction diagrams were produced in the late 1950's and the 1960's based upon rules set forth in the 1947 Manual of Surveying Instruction's Chapter 3. An example is shown in Figure C1.

Chapter Three of the 1947 Manual details the survey of partially surveyed townships and sections. Specific instructions are given to the retracement and rules of acceptance of the existing lines. These rules are applied to determine if the extension survey shall accept the previous lines for continuation of the township exteriors and the subdivision of the township. These so-called completion surveys are described in detail. These discussions in the 1947 Manual indirectly set the procedures used in the creation of these protraction diagrams. A great variation in the quality of the original protraction diagrams exists. Some were built with field ties to closely approximate the field conditions; others are simply based upon a collection of the record surveys about the exterior of the unsurveyed area prior to protracting the plan of survey.

Increasing demand for administrative action in these areas with a more accurate description became apparent in the early 1990s. At this time, a group of BLM and U.S. Forest Service personnel began to devise and implement a new procedure that would result in protraction diagrams. This procedure is intended to minimize the changes in the future locations of the unsurveyed townships and sections.

The new forms of protraction diagrams are known as *Amended Protraction Diagrams* (APD). The PLSS system is extended across the unsurveyed area, and coordinate positions are published as the section corner positions. In the areas where uncertain acreage is contained due to variance in the existing survey and for other reasons, a new form of legal description has been implemented, known as *Protracted Blocks*. The protracted blocks typically appear as a buffer between the coordinate based interior and the previously surveyed lines of the perimeter. The most important feature of the APD is that the protracted corner positions are not subject to change even if latent

facts indicate positional changes of the exterior. Consistent with the Manual of Surveying Instructions, the goal of the APD process is to create the maximum number of regular sections.

Perhaps the greatest benefit is the ability to locate a protraction-based description on the ground to a high degree of reliability utilizing common positioning tools such as global positioning system receivers. Additional benefits include 1) a simplified survey procedure to accomplish the survey for administrative reasons (The method is discussed in greater detail in section C.4.) and 2) the coordinated positions of the APD provide a PLSS framework to support geographic information systems (GIS), including the GCDB. The special development to support GCDB and GIS is the focus of this portion of the research in parcel attribution.

C.2 Policy on APDs

In 1998, the Bureau of Land Management issued an official Instruction Memorandum with five attachments to introduce the new system and specify the methodology. The APD production has continued since 1995. The policy change supports interagency mapping activities where depiction of the protracted land network is involved and includes the Forest Service/U.S. Geological survey, and a possible BLM/USGS “one map” series based on the 1:100,000 map series (BLM, IM98-152). The “one map” designation refers to an agreement for the production of 7.5 minute quadrangle maps between the USFS and the USGS whereby the USFS assumes the responsibility of these maps covering areas of their jurisdiction, providing detailed

content and elimination of duplicate effort. At the time of this policy, the BLM/USGS did not have such an agreement. The reference to a possible “one map” series based on the 1:100,000 scale mapping of the BLM is in anticipation of such an arrangement. The importance of interagency cooperation is emphasized as critical to the construction of the amended protraction diagrams, and their integration into mapping and GIS products. The memorandum further states, “The BLM will work with the Forest Service, US Geological Survey, and other involved agencies to define process and responsibilities to develop effective program management approaches.” It is through this directive that this research became involved in the APD issue, which is addressed in section C.5.

An excellent summary of the APD policy is contained in the caveat statement that appears on the face of the document, replicated here in its entirety for clarification.

“An Amended Protraction Diagram is prepared for the express purpose of describing unsurveyed public land. It does not constitute an official survey but establishes the plan for extending the rectangular survey system over unsurveyed lands and may be used for leasing and administrative purposes only. An Amended Protraction Diagram is an official plat of the PLSS and must be approved by the BLM prior to use for any administrative purpose or incorporation into any mapping product.

It is important to understand that APDs do not absolutely fix corner positions, but are a plan of survey defining corner positions more accurately than existing protraction diagrams. Some flexibility in control, adjustment, and field

procedures could result in slightly different positions when corners are established and monumented on the ground during the official survey.

APDs depict how the area may be surveyed but until that time the area will continue to be unsurveyed lands. BLM has the sole delegated federal authority to conduct official surveys on public lands.” (BLM, Official Amended Protraction Diagrams, 1998)

The North American Datum of 1983 is officially adopted as the coordinate base for the construction and perpetuation of the APDs. The production of APDs has been an ongoing program in the BLM, prepared at the request of the USFS to accommodate Revision of Primary Base Quadrangle Maps for the Geometronics Service Center. As the APDs are completed, public notice is given in the Federal Register of the lands covered. The plats of the amended protraction diagrams are made immediately available for public viewing but are not officially filed until the day after all protests have been accepted or dismissed and become final or appeals from the dismissal affirmed (Federal Register, 2000).

C.3 Construction of APDs

The construction of APDs is essentially a platting process. The goal is to stabilize the interior of the protraction by assigning coordinates to the section corner positions, called the Plan of Survey (POS) coordinates. Lines closing onto previously surveyed

boundaries are fixed in direction and continue until actual intersection. Using 'random and true' lines connects protracted corners with previously surveyed corners.

The APD may be based on the original protraction diagram, or based upon a selected point within the township, or some combination of the two methods. Unlike the original protraction where the corner positions could move each time a different bearing and/or distance is found on the exterior boundaries, the APD protracted corner positions are not dependent on the position of an existing corner or surveyed line, since its POS coordinates have been determined. The protracted blocks are areas of uncertain acreage, and are used to form a buffer between the coordinate-based interior and the previously surveyed lines of the exterior. Therefore, the only variable based upon changes to the surveyed perimeter is the area contained within the protracted blocks. The design of protracted blocks is usually about the size of an ordinary section, but may be larger or smaller based on conditions (BLM, Guidelines for Developing Amended Protraction Diagrams, 1998).

The process begins with the collection and abstraction of survey data and available control for the exterior boundaries of the protraction. Survey data for any existing special surveys that extend into the unsurveyed area and the shoreline of meanderable waters within the protraction must also be collected and abstracted. Coordinates are computed of the exterior boundaries most commonly utilizing WinGMM and the GCDB process. They may also be digitized from maps or utilize mapping data from other sources. Since the initial data collection of the GCDB was based on the North American Datum of 1927, the coordinates of points were converted to the North

American Datum of 1983 using the WinGMM command module GCON. Similar procedures are often utilized for existing maps compiled prior to publishing of NAD83.

It is desirable to have accurate positions for the exterior of the protraction, but it is not essential due to the buffer that will be applied to isolate the POS coordinates from the perimeter (BLM, Guidelines for Developing Amended Protraction Diagrams, 1998).

While protracted blocks are usually approximately the size of a normal section, in areas of extreme uncertainty they may be enlarged as necessary to ensure the plan of survey coordinates do not invade into existing surveyed lines. Coordinates of corners along the boundaries are calculated for construction purposes, these positions are not published on the APD; rather a heavy-weight line is used on the plat to indicate the previously surveyed lines (BLM, Guidelines for Developing Amended Protraction Diagrams, 1998).

The decision of whether to base the new protraction on the original protraction versus creation of a new protraction based upon a chosen initial point is most commonly based on administrative decisions rather than technical preference. If existing administrative boundaries follow the original protraction or where extensive leasing exists based upon the original protraction, the decision is often to follow the existing protraction. Alternatively, new descriptions could be generated and modifications to existing leases could be undertaken. However, the additional workload can often not be economically justified.

When based on the original protraction, the next step involves selecting a position on the previously surveyed boundary and extending a fixed bearing line into the protraction. Coordinates are usually computed at 80.00 chains for computation of the POS of the corner position. However, the final APD will show this line as a closing line

onto the surveyed exterior. All points that are dependent on the exterior are computed first, creating the protraction blocks, followed by the independent positions on the interior.

If the protraction is independent of the original protraction diagram, an initial point is selected near the SE corner of the protraction. From this position all other plan of survey coordinates are computed. In a normal township, the initial point would be the SE corner of section 26. This is placed one mile from the east boundary and one mile from the south boundary. The remaining plan of survey coordinates are then determined, remembering if a protracted line closes on an interior corner or a terminal line, it is designated as a random and true line, rather than as a fixed bearing line (BLM, Guidelines for Developing Amended Protraction Diagrams, 1998). An example of an official Amended Protraction Diagram appears on the next page as Figure C2.

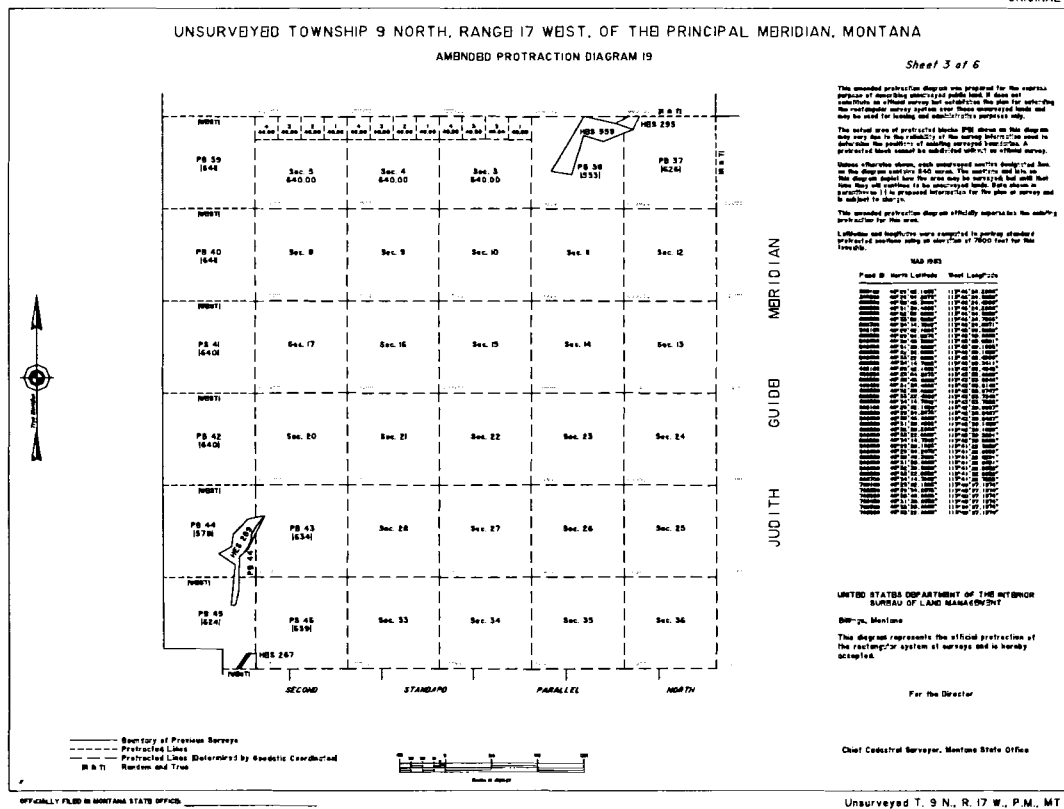


Figure C2. Example Amended Protraction Diagram.

In addition to the plat caption quoted above, tabular data appears on the face of the plat listing the NAD83 latitudes and longitudes of the corners of the protracted sections, identifying each with its GCDB point identifier.

C.4 Surveying Amended Protraction Diagrams

The survey of the original protraction diagrams is dictated by very specific acceptance criteria of the surveyed exterior boundaries of townships and sections. Use of sectional correction lines and sectional guide meridians were employed frequently when the existing surveys were found to be defective in alignment or out of limits of closure. Many townships were completed in this manner with intent to create the maximum number of normal sections. Given that most of the surveys that left townships and sections as partially surveyed were completed many years ago, there is often extensive obliteration that will further require extensive resurveys prior to the completion survey itself. “If defective conditions are encountered in the previously established surveys, the problems concerning the procedure to be adopted multiply rapidly and require the greatest skill on the part of the surveyor” (BLM, 1973).

In contrast to the rigid guidelines for the survey of the original protractions, the rules of survey governing Amended Protraction Diagrams are greatly simplified.

Attachment 5 (BLM, General Rules for the Survey of Amended Protraction Diagrams, 1998) provides eight general rules to govern the survey or partial survey of the APD.

The rules are not rigid. Flexibility exists through special instructions to authorize changes due to technological changes in survey methods, conditions on the ground, and

unforeseen complexities. The general rules for the survey of APDS are a significant departure from previous methods characterized by recognition of technological advances and enhanced by their simplicity.

1. “ Corner points may be established by Global Positioning Systems (GPS), traditional terrestrial survey methods, or a combination of the two.
Federal Geographic Data Committee draft "Standards for Geospatial Positioning Accuracy Standards; Part 2: Standards for Geodetic Networks" should be used as a guideline for establishing corners based on their protracted latitude and longitude, independent of other corners within the protraction. Where several adjacent corners are to be established in a single survey with surveyed lines between corners, it is recommended at least two should be established to meet the FGDC Standards at the 10-centimeter (1-decimeter) accuracy classification level and placed so as to provide control for the other corners. Survey specifications (survey methodology) guidelines will be specified in the Special Instructions, depending on the technology used and the most current specifications generally accepted by the professional survey community.
2. Latitude and longitude are shown for section corners on the Amended Protraction Diagrams; however, the latitude and longitude for any aliquot part corner within the protraction may be computed from the section corner values, lottings, and areas shown on the diagram.

3. Aliquot part corners down to 1/1024th corners may be established at their protracted latitude and longitude without reference to other corners where no areas are to be returned, except under the conditions specified in General Rule 4, herein. Where areas will be returned within a section all four section corners will be established. Where controlling corners have been established and are within Manual limits for rectangularity, corners will be established at proportionate distance or intersection as appropriate, not at the protracted latitude and longitude.
4. Bearing and distance ties to previously established corners of the same section within the protraction are desirable and are required where new aliquot part corners are established along the line surveyed. Ties between section corners are not normally necessary unless corners are required along the line, in which case rectangularity must be ensured and corners will be placed appropriately.
5. Closing lines, random and true lines will normally form the out boundaries of protracted blocks. Once the protracted corner is established (by latitude and longitude) from which the closing line is to be initiated, the line will be surveyed on the protracted bearing to an intersection with the existing surveyed line, random and true line, or water boundary. In like manner, random and true lines will be surveyed from the established protracted corner to the existing corner designated on the amended protraction diagram. Where there is a large misclosure in the exterior boundary of the

protraction, it may be necessary to modify the plan of survey to avoid poorly shaped parcels.

6. When surveyed, a protracted block will normally become a section containing the normal aliquot parts with the excess or deficiency against the previously surveyed boundary.
7. When portions of the unsurveyed protracted areas are surveyed, it may not be necessary to create a new amended protraction diagram for the remaining unsurveyed areas. Since there will normally be no changes in the protracted latitude and longitude of other corners in the protraction, an appropriate notation to this effect on the amended protraction diagram should be sufficient.
8. It is recognized that surveys may be performed within the protracted area, prior to the official survey, to locate and mark lease boundaries, administrative boundaries, or the extent of mineral interests. Positions established by these surveys have no official standing, but at the BLM's discretion may be accepted as corner positions when they are in conformity with the amended protraction diagram. " (BLM, General Rules for the Survey of Amended Protraction Diagrams, 1998)

C.5 Special procedures for Parcel Attribution within Amended Protraction

Diagrams

The GCDB component of amended protraction diagrams is simplified much the same as the survey. Amended protraction diagrams are created using automated systems and involve the computation of geographic coordinates for the section corners within the protracted area. The standard naming convention is employed in the creation and on the face of the document itself. The connecting lines between the corners are drawn in the platting process, and further supported through the use of three standard source identifiers (SIDS) that assist the GCDB surveyor with the eventual task of incorporating the amended protraction diagram into the GCDB land network.

This research explored gaps preventing the full-automated inclusion of APD data into the GCDB. Specific problems existed with point naming and methodology to derive parcels identified as protraction blocks. Conceptually, a fully automated system should work with other automated systems to minimize redundant effort and error. A series of routines were developed in AutoLisp for use within the AutoCad platting environment that provided for the export of a series of files compatible with the WinGMM software. Specifically, a .DEF project definition file, a .RAW data file with absolute bearings and distances to support the plan of survey coordinates, a .CON file containing the published plan of survey coordinates, and a .LOT file to document the lotting and special survey parcels within the amended protraction diagram.

An interface was designed in WinGMM to handle the remaining steps of the conversion process. The first step is to identify lines in the .RAW file assigned with a

special SID of “999999RPB”, which identifies the fixed boundary lines that create the protracted blocks. These lines are stripped from the exported .RAW file. The measurement information stripped is translated and coded as post adjustment calculations stored in the .ADD file. These special lines involve defining a special type of intersection. Line one of the intersection begins at a coordinate pair and extends on a fixed bearing until it intersects line two, defined by a range of point identifiers describing the surveyed exterior. This intersection was created to allow the intersection point to fall as it may on the surveyed exterior while holding the fixed bearing. This is to say that these raw data lines will not become part of the adjustment, but rather will be recomputed to exactly replicate the amended protraction diagram itself.

The next step in the process is to build the adjustment data set based on the remaining lines of the .RAW file, along with the full list of fixed plan of survey coordinates as control. Once the user has selected the amended protraction diagram data, a fully automated procedure results in viewable graphics of the amended protraction diagram. The next step to complete the amended protraction diagram is to import the surveyed exterior boundaries or merge with the existing fractional township GCDB data sets. Once the data set is complete, the least squares adjustment is used to compute a full set of coordinates in preparation for the post adjustment computations. Figure C3 shows a data set at this stage of the process. Inspecting the western tier of sections it is apparent they are not connected to the remaining portion of the township; these are protracted full sections. The area not fully enclosed becomes the protracted blocks. The remaining area showing 23 sections is the surveyed fractional township. In this illustration, the lines not

shown are the lines removed from the .RAW data and re-coded for post-adjustment computation to intersect the boundaries, creating the protracted blocks.

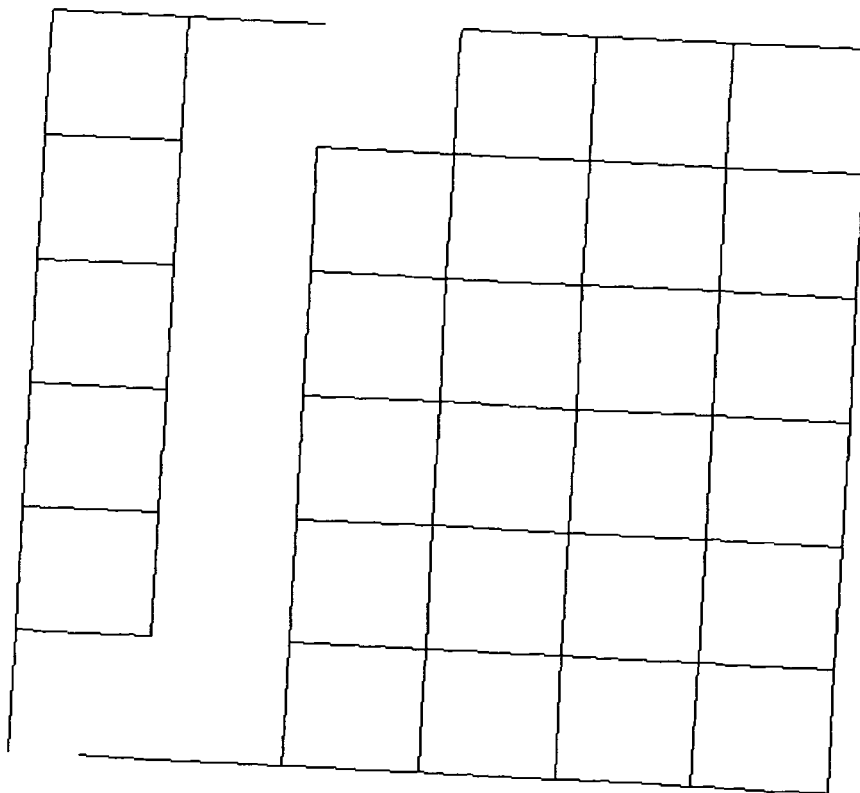


Figure C3. Fractional Township T05NR16W with Protracted Section Lines.

The intersections of protracted block boundaries with the surveyed exterior finally lead to the parcel topology. The protraction blocks are never subdivided, due to their uncertainty in size and location; rather, they are described as a whole unit. The software is instructed to not subdivide these parcels, via the irregular subdivision definition. In some cases, the protracted full sections are subdivided to the nominal 16 aliquot parts, as provided for in the survey rules. The attribution of the parcels is performed, resulting in a complete data set for the township. In Figure C4 the parcel area points for each of the

protracted parcels are selected, showing the attributes and approximate record area of each.

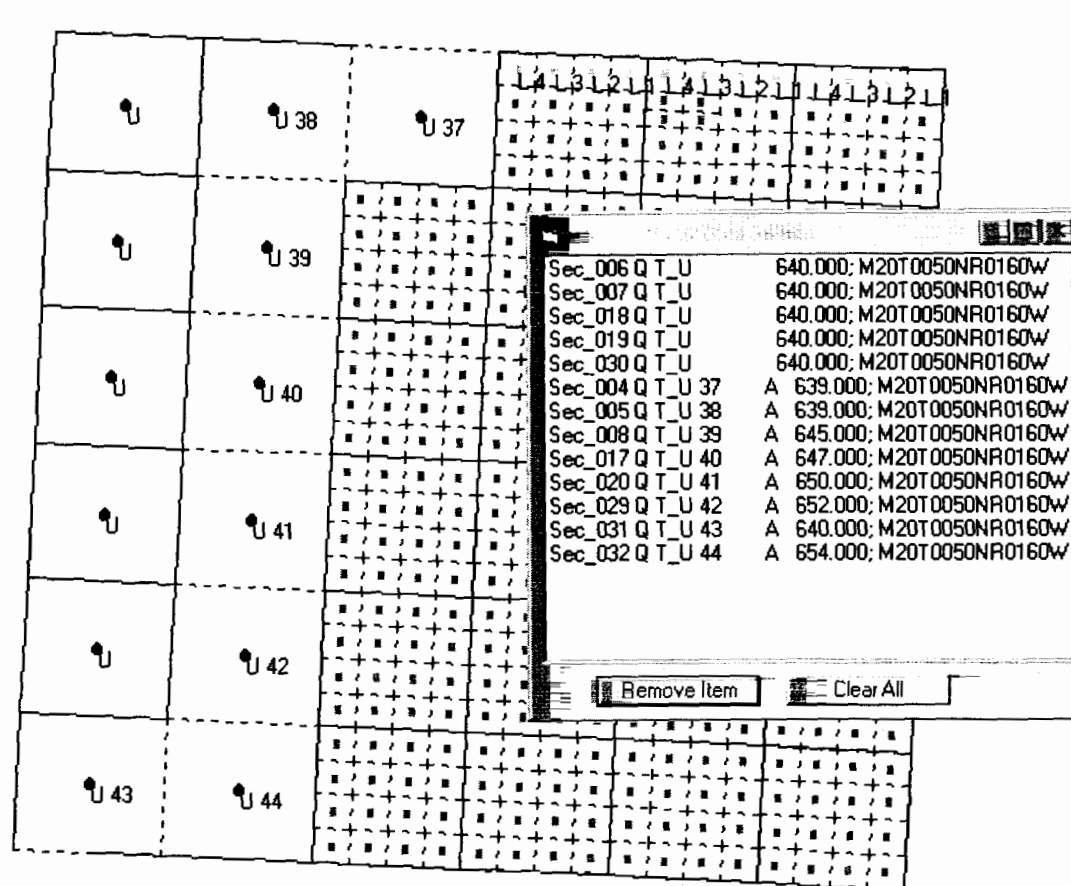


Figure C4. Completed Township Including Protraction.

A protraction block number legally describes protracted blocks. Figure 19 shows several of these, appearing as T_U 37 thru T_U44. The protracted sections are legally described in an ordinary fashion, designating aliquot subdivision or lot, section number, township, range and meridian. A thorough understanding of these parcels is necessary for proper identification and use, yet little has been published to provide this understanding. The material included in this appendix is provided to document the

procedures being used for the creation of amended protraction diagrams, as this information is now widely known or understood. The inclusion of unsurveyed parcels in the cadastre is necessary to achieve full coverage of the parcel base map. A thorough understanding of the intent and method of creation of these special land documents is essential for the proper use and interpretation of these legal land objects. Lastly, inclusion of the special development to accommodate protracted lands in the cadastre serves as an example of a related research effort building on the framework presented in this thesis.

BIOGRAPHY OF THE AUTHOR

Kurt B. Wurm was born and raised in Detroit, Michigan. He graduated from Lutheran High School East in Harper Woods, Michigan in 1980. Upon graduation, the U.S. Army Corps of Engineers in Algonac, Michigan employed him on a hydrographic survey crew. He continued his surveying education at Ferris State College in Big Rapids, Michigan. During breaks from his studies, Kurt worked for the U.S. Bureau of Land Management as a Land Surveyor student trainee in Montana and South Dakota. He earned an Associate's Degree in Civil Engineering Technology and completed a Bachelor's degree in Surveying at Ferris State in 1986.

Kurt continued his employment with the BLM as a Land Surveyor for 14 years. During this time, he became involved with the initial design and implementation of the BLM's Geographic Coordinate Data Base. It is through this experience that he became introduced to Dr. Hintz and the graduate program at the University of Maine. In the fall of 1996, Kurt entered the graduate program of the Department of Spatial Information Science and Engineering at the University of Maine. He earned a Master's degree in Spatial Information Science and Engineering in 1998, and continued his studies in the Ph.D. program. Throughout his graduate studies, Kurt worked as a research assistant to Dr. Hintz in continued support of the Cadastral Survey automation efforts and refinements to the GCDB program.

Kurt is a candidate for the Doctor of Philosophy degree in Spatial Information Science and Engineering from The University of Maine in May, 2003.