FGCC

Multipurpose Land Information Systems
THE GUIDEBOOK

prepared by
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MULTIPURPOSE LAND INFORMATION SYSTEMS:

THE GUIDEBOOK

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SECTION ONE

Section One contains background material on land information systems, mapping, and geodesy.

1 INTRODUCTION TO MULTIPURPOSE LAND INFORMATION SYSTEMS

Earl F. Epstein and Patricia M. Brown

A great deal of the work of local government—some say as much as 90 percent—relates to land, to its location, characteristics, value; to restrictions on its use, and claims on its resources. Local government agencies of all kinds have developed systems and procedures to help them do this work. For a long time, these have been manual systems, with records on paper, index card, and mylar. They included reports and maps, cross-indexing catalogs, log books, and chronological files. Formal and ad hoc numbering schemes and standard procedures were set up to maintain these systems. The records, numbering schemes, procedures, and people all make up the land information system.

The agencies that maintain these systems, as well as their users both in government and outside, recognize many shortcomings. Cross-referencing is inadequate; retrieval is inconvenient; the records are old, deteriorating, voluminous, outstripping storage space and getting in the way. On their own initiative or under pressure from users, many agencies with land information systems have introduced improvements ranging from new numbering schemes, mechanized storage and retrieval, microfilm, and microfiche to new maps, aerial photography and computer systems. But some of the most difficult problems for local governments to solve—problems that cause great inconvenience to users and cost to the taxpayers—are rooted in the separation of historical functions and their assignment to different divisions of government. Each governmental entity attends first to its specific mission. Coordination takes time, energy, and money, and many managers see it as detracting from their primary objectives. Coordination also takes conviction and a willingness to depend on someone else to do something necessary. As a result, most land information systems—old, new, improved, or otherwise—serve a single purpose and support the objectives of a single governmental entity.

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The central theme of this *Guidebook* is the *multipurpose* land information system. While the technical information may be useful to readers who will plan, design, implement or use LISs of all kinds, the vision for improving the Nation's land information emanates from a belief in the benefits of an information system designed to meet the many requirements of government and the private sector.

In 1980, the National Research Council published its report, *Need for a Multipurpose Cadastre*, which declared the "critical need for a better land-information system in the United States," and publicized the concept of the multipurpose cadastre—"a framework that supports continuous, readily available, and comprehensive land-related information at the parcel level" (NRC 1980, p. 1). The land records reform movement in North American already had a substantial history when this document was published.

The 1966 Comprehensive Unified Land Data (CULDATA) Conference culminated a 2-year effort by the U.S. Department of Agriculture and the American Bar Foundation "to develop a model system for a multipurpose land data system. In addition to a review of the model itself, the conference devoted considerable attention to the status of computer technology used to implement various functions of the CULDATA model, including mapping, surveying, and indexing" (Moyer 1980). Although dated, the proceedings from this conference document an important part of MPLIS history. (See *References and Additional Readings.*) The Mackinac Conference in 1969 focused on two issues related to land title records: legal requirements for the transfer of property rights, and the relationship between land title data and functions that use them. The American Bar Foundation sponsored the CLIPPP Conference (Compatible Land Identifiers—Problems, Prospects, and Payoffs) in 1973 to bring together representatives of the various disciplines that are involved in land records for workshop sessions (Moyer 1980). The development of a single, uniform method for identifying land parcels and related records was the major recommendation to come out of this conference. In 1974, a nonprofit organization of governmental agencies and professional organizations was incorporated as the North American Institute for Modernization of Land Data Systems (MOLDS) "to assist in the land records reform issue" (Moyer 1980). MOLDS sponsored two conferences and has published the results of research, including an annotated bibliography. This organization continues now as the Institute for Land Information (ILI). Conference activities in support of the land records movement continued through the 1970s and 1980s with the

Land Records Symposium in 1976, the Symposium on Land Registration and Data Banks in 1978, and an increasing level of activity among professional organizations.

These activities demonstrate the diversity of skills and professions interested in the various aspects of land information systems. The American Bar Association, the American Bar Foundation, the American Congress on Surveying and Mapping, the American Society of Photogrammetry and Remote Sensing, the International Association of Assessing Officers, the National Association of County Recorders and Clerks (an affiliate of the National Association of Counties), and the Urban and Regional Information Systems Association (URISA) have shown continuing and growing interest in land information systems.

Many prototype and demonstration projects, some successful, some not, have added to our understanding of how to implement land information systems (Moyer 1980). A review of the project histories, documented in reports and conference proceedings, shows the diversity of scope, intent, method, cost, and organization of multipurpose land information systems. And while each project, like each jurisdiction is unique, there are common problems and issues.

The 1980 *Need for a Multipurpose Cadastre* report has become a *de facto* standard for many looking for guidance, but while it identifies needs and requirements, and describes the roles of the various levels of government, it is not specific enough to guide implementation. To help meet this need, NRC published *Procedures and Standards for a Multipurpose Cadastre* in 1983. This report reiterates the most important findings and recommendations of the *Need for a Multipurpose Cadastre,* and goes on to make more specific recommendations regarding the many aspects of multipurpose cadastre implementation. Subjects range from the technical (geodetic reference frameworks and base mapping) to the organizational (institutional context, roles, and budget). This *Guidebook* is built on the foundation laid by these two publications. It shares with them a commitment to the vision of compatible, accurate land information available throughout the United States at all levels of government and supporting a wide range of uses.

For the people working in the hundreds and thousands of agencies that house this country's land information, this vision has not always been clear. Tremendous advances in computer technology are making many of the goals of a multipurpose land information system achievable. At the same time, the concept itself has been confused with the tools, techniques, and end products of its implementation. Down in the trenches, surrounded by daily pressures and problems, with limited access to other professionals, organizations and the literature, local government employees are trying get the picture through a haze of acronyms and vendor pitches: MPC, LIS, GIS, CAD/CAM, AM/FM . . ..

Although they are used interchangeably in some settings, each acronym was invented to convey a meaning slightly different from its predecessors. Many of the terms were invented to describe computer applications, software, and hardware, and they tend to be used in different fields of expertise and to carry slightly different connotations. AM/FM (Automated Mapping and Facilities Management), for example, is used among public works and utilities managers, while CAD/CAM (Computer Aided Design/Computer Aided Mapping) is more common among designers and mappers. (In the design world, CAD/CAM sometimes refers to Computer Aided Design/Computer Aided Manufacturing.) AM/FM implies functionality to support inventory management, work order processing and network analysis; CAD/CAM offers support for engineering design and mapping. The boundaries between various packages are becoming blurred as vendors extend their capabilities, but the origins of a package are reflected in its structure, and continue to affect its capabilities, strengths, and weaknesses. As important as hardware and software have become to the implementation of multipurpose land information systems, experienced users come to see them as only one part of the system of procedures, programs, people, and organization, as well as software, hardware, applications, and data. Nonetheless, the acronyms have generally retained an aura of automation, and for those just entering the field they often mean simply products.

The first person in a local government to become interested in multipurpose land information system or geographic information system is generally from a department that has as its focus land, its uses, and value, and that relies heavily on maps, such as public works, planning, property assessment, or title recording. The first step may be a visit to the Data Processing Department to discuss the possibility of computerizing some land information or a related function. Most Data Processing Departments have dealt almost exclusively with nonspatial information systems. Although many computer applications may have important spatial references, such as street address in 911 and building permit systems, the spatial reference is not a primary key to the system. Usually there is no way to relate data from different systems based on the spatial reference, nor any way to analyze the data based on location. These shortcomings reflect the origin and history of data processing in local government and can present a significant obstacle to automating a multipurpose land information system in this setting.

For the purposes of discussion, consider spatial information systems in three categories: GISs, LISs, and other spatial systems, such as CAD/CAM. The identification of various branches of spatial systems and the distinctions among them are less important than the range of information encompassed by the terms. In this *Guidebook*, we will be looking at *land information systems*, which are the data, products, services, the operating procedures, equipment, software, people—the sum of all the elements that systematically make information about land available to users.

Historically, the term geographic information system (GIS) has referred to spatial information whose detail, accuracy, and precision generally corresponded to maps at scales of 1:20,000 or smaller. The products and analyses available from these systems are designed for policy decisions and planning. The information system was often built to support specific projects so that it was not necessarily tied to the day-to-day transactions of the institution.

Although there is no clear or widely accepted distinction between them, the term *land information system (LIS)* conveys a stronger orientation toward land records and a larger scale than the term *GIS* does. Much of the data and many of the sources are the same. In local government, an LIS could include the property appraiser's maps, maps on which approved subdivisions are compiled, utility maps, right-of-way maps, and zoning maps. It could also include all of the tabular records associated with the maps: the property assessment files, deeds, subdivision review applications and approved plans, inventories of pipes, manhole details, maintenance records, building permits, zoning applications, zoning violations and other code enforcement records. At the planning level, an LIS might incorporate road networks—existing, planned, funded—and related data on capacity and volume. It could include land use, land cover, projected or planned land uses, soils, environmentally sensitive areas, socio-economic data, redevelopment areas. For upper level management and elected officials, the LIS might provide information on projects, permit applications or taxes by election district, capital improvement programs and distributions of crime, school populations, complaints. In short, "a land information system is what a government or unit wants it to be and/or do and become what . . . [they] want it to become" (McLaughlin 1988 from Hodgkinson 1985).

In this *Guidebook*, we will use the term *multipurpose land information system* to refer to a system in which "the fundamental means of organizing data is the *cadastral parcel or proprietary land unit*," whose main objective is "the provision of institutional data concerning *land ownership, value, and use*" (McLaughlin 1988, p. 11, emphasis added). It is built to support a wide variety of applications. The underlying data should be *accurate* enough to support the envisioned applications, *compatible* so that data sets can be used in combination with one another, and *comprehensive* so that current and appropriate data are available when they are needed. A fully implemented multipurpose land information system should be incorporated into an environment that provides:

1. The fundamental land base
2. Data features on or near the Earth's surface
3. The means to interpret and manage these data—increasingly computer software
4. The media upon which data and management techniques reside, increasingly computer hardware
5. The means to represent and disseminate data and information
6. People organized to oversee the system operations
7. Procedures for using and maintaining the system.

Such a system would permit data to be used conveniently and accurately through spatial analyses, such as polygon overlay, area and distance calculations. It would also use interrelationships among data sets for tying maps to a common spatial reference system and for linking records through common identifiers.

In too many local governments, this list of land-related information and the associated governmental functions is matched by an equally long list of information systems, single purpose applications built to meet a single need, such as tracking building permits, monitoring subdivision applications, or appraising land for taxation. As a result, opportunities for cost savings, better service, better information, and better decisions are being lost every day at a substantial cost to society.

Growth and resource management decisions have high stakes. They are always uncertain and often the subject of controversy. Mistakes and poor decisions can be very costly and hard to correct. Current, accurate information about land should be readily available, at a reasonable cost, for the decision-making process. As a society, we seem to be willing to invest in better information. Continuing growth and increasing demand for shrinking resources will make current, accurate information even more valuable. Land is one of the most fundamental of resources. In the past, records of land resources have been poor, but as we recognize the value of these resources, and the limits to their availability and resilience, we will demand better information for our decisions.

The projected investment in automated LIS/GIS reflects our need to make that information available for record-keeping, public inquiries, analysis, and decision-making. Our existing land information systems do not meet these needs—a well-implemented multipurpose land information system can.

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NRC, *see National Research Council.*

National Academy of Sciences, *see National Research Council.*

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SECTION TWO

Chapters in Section Two of the MPLIS Guidebook will continue to introduce technical material. These chapters also begin to explore in greater detail how the various functions of local and state government interact, and show how the information data base for the MPLIS can be linked and used to better serve these functions. Section Two thus provides the framework needed in Section Three, which deals with specifics of how one builds and maintains an MPLIS.

2 INTRODUCTION TO MAPPING CONCEPTS

Samuel T. Bardelson

Maps are abstractions of reality, an attempt to fit the world into a reduced or simplified view. They are primarily designed to answer two questions: where something is located relative to other things, and what is at a particular location. The job of the cartographer is to make a full-sized, three-dimensional world fit onto a two-dimensional map in such a way that these two questions are answered. Obviously, it would take an extra large map to portray all the features in the world accurately, and even then the job might be impossible. The cartographer must select and generalize features, representing them symbolically at a reduced scale, and identify them by name and type. This chapter introduces the mathematical and graphic design concepts that are important in understanding how to make and use maps.

PROJECTIONS

Map projections are a systematic representation of all or part of the surface of a sphere onto a plane. In other words, projections are a method of putting information from the Earth's surface onto the flat surface of a map. It is impossible to transfer Earth data to a plane surface without distorting either the measurable area or the shapes of Earth features. Many projections have been devised that minimize one or the other of these problems, but no single projection gives an absolutely true picture of the surface of the Earth.

There are two general categories of map projections: conformal projections and equal-area projections. On conformal maps, scale varies across the map in order to preserve the shape of any small area. The relative local angles about every point on the map are shown correctly and meridians intersect parallels at right angles. For this reason, nearly all large-scale maps produced by government agencies have conformal projections. An example of a conformal map is the Mercator map of the world. The magnification of the area of continents as they approach the poles is a vivid example of

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the area distortion that conformal maps can contain. Equal-area maps are such that a coin placed on one part of a map covers exactly the same area of the actual Earth as the same coin placed on any other part of the map. Shapes, angles, and scale must be distorted on most parts of an equal-area map. A map projection cannot be both conformal and equal-area, but many map projections are combinations that compromise between the two.

In the *Lambert conformal conic projection* (Figure 2-1) mapping is done on the surface of a cone which intersects the Earth along two latitude lines, or *standard parallels.* Along the intersecting lines, distances on the Earth correspond to distances on the cone. Beyond the parallels, the cone is outside the Earth and distances are longer than corresponding Earth distances. Inside the parallels, the cone is inside the Earth and distances are shorter than corresponding Earth distances. North-south lines have a changing scale; east-west lines have a constant scale. The *transverse Mercator projection* (Figure 2-1) uses a cylinder that intersects the Earth along two ellipses equidistant from a central meridian. Along the two ellipses, distances on the Earth correspond to distances on the cylinder. North-south lines have a constant scale; east-west lines have a changing scale.

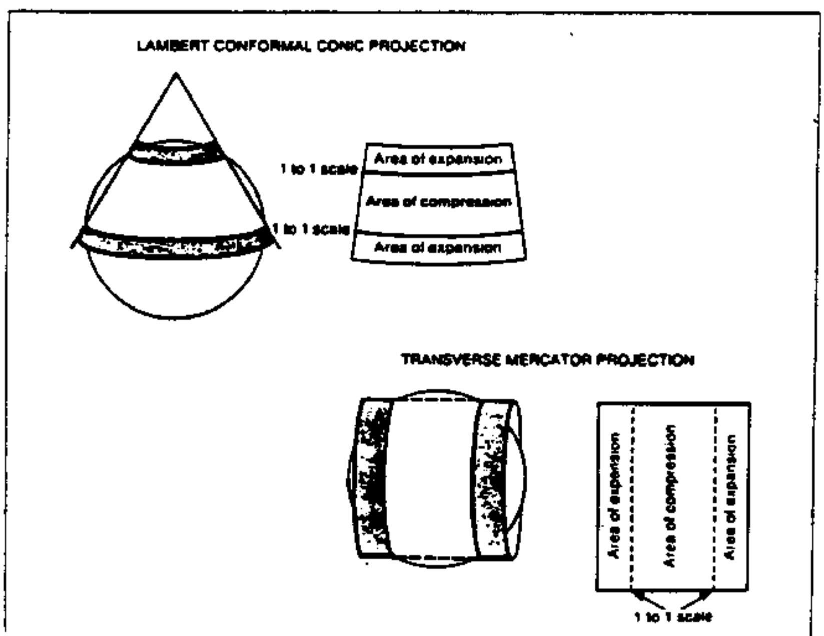

Figure 2-1: Construction of map projections.

COORDINATE SYSTEMS

Positions on the ground may be described in relative or in absolute terms. In Figure 2-2, we may know precisely where each stake is relative to the tree on the same side of the stream. But without a *tie* between the two trees or a coordinate system to which the trees or the stakes are tied, we do not know the absolute position of the stakes on the coordinate scheme, or their position relative to each other. In a land information system or map series, a land parcel is defined by the *parcel boundary*, generally four or more property corners and the lines connecting them. Each property corner has a position *relative* to the other corners of the parcel and to the corners of adjoining cadastral parcels. If a parcel corner is located with respect to a coordinate system, the position is also an *absolute* position. Of course, the absolute position is subject to the degree of accuracy of the survey that determined it. The idea of relative and absolute positions is important in a multipurpose land information system (multipurpose LIS or MPLIS) because one of the central objectives of the system is to tie all of the various features, including parcels, to a geodetic network so that both their absolute positions and their relative positions are known even though each feature is not tied to all other features.

Figure 2-2: Absolute and relative position.

LATITUDE AND LONGITUDE

The most common method of specifying location on the Earth's surface is by latitude and longitude. A *latitude line*, sometimes called a *parallel* (Figure 2-3), is a circle parallel to the equator. It describes location north or south of the equator. Values range from 0° at the equator to 90° at the poles. A *longitude line*, sometimes called a *meridian* (Figure 2-3), follows the shortest distance from pole to pole. It describes location east or west of the prime meridian. Values range from 0° at the prime meridian (which passes through Greenwich, England) to 180° east or west.

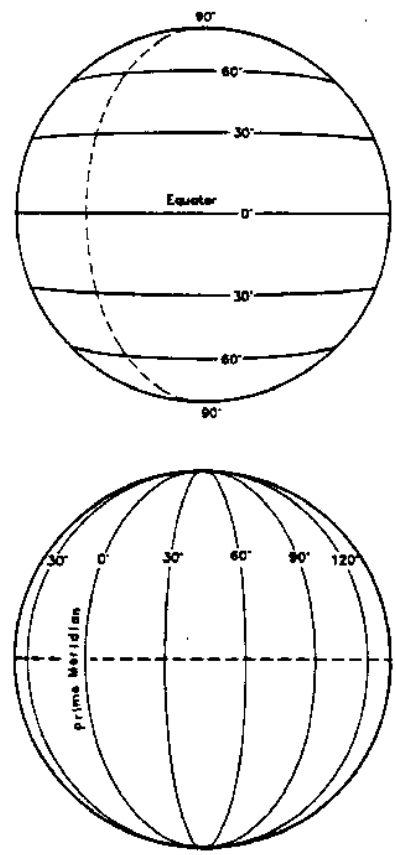

Figure 2-3: Parallels and meridians.

Figure 2-4 shows more precisely how latitude and longitude are defined. Imagine three planes cutting through the Earth like sheets of paper: the equatorial plane at the equator; the prime meridian plane; and the meridian plane of P, which cuts through point P and contains the meridian (longitude line) on which it lies. The intersection of two planes is a line. The intersection of the equatorial plane with P's meridian plane and the prime meridian plane defines two lines. The angle between those lines, measured from the prime meridian on the equatorial plane, is the longitude of P.

Latitude is more difficult to describe. Imagine a line drawn on P's meridian plane and perpendicular to the meridian at P. That line will intersect the equatorial plane close to the center of the Earth. P's latitude is the angle between that line and the equatorial plane, measured from the equatorial plane to the line in P's meridian plane.

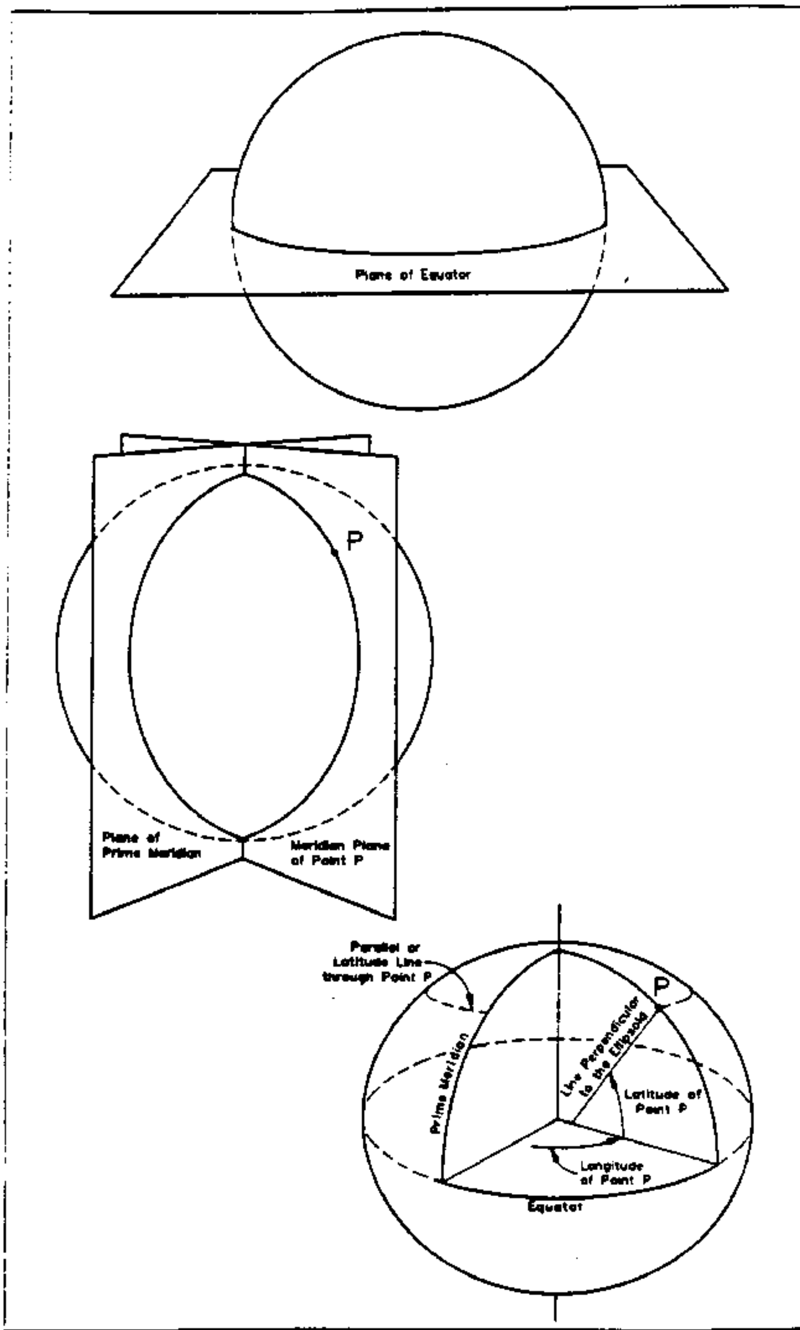

Figure 2-4: Definition of latitude and longitude.

Much work has been done over the years to develop an accurate mathematical description of the Earth's surface. The Earth's surface most closely resembles an oblate ellipsoid, bulging at the equator and flattened at the poles (Figure 2-5). As a result, the length of one degree of latitude increases very slightly as you approach the poles. The length of one degree of longitude decreases to zero as the meridians converge at the poles. Figure 2-5 illustrates these concepts where D equals the length of 30 degrees of latitude near the equator and E+ equals the length of 30 degrees of longitude at the equator.

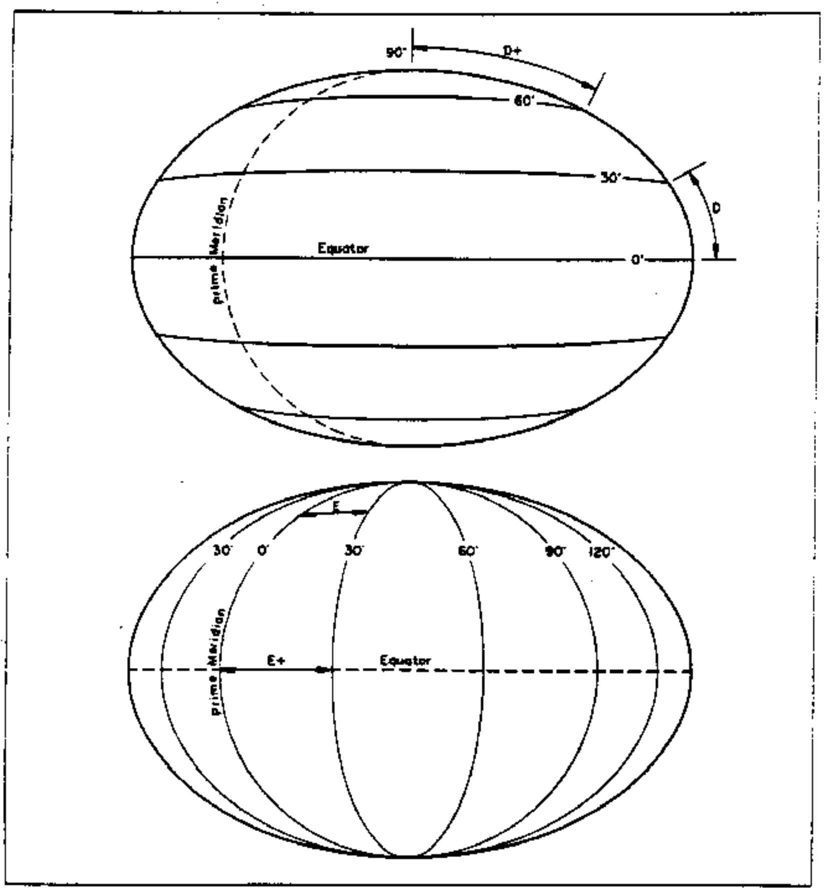

Figure 2-5: The Earth resembles an oblate ellipsoid.

PLANE COORDINATE SYSTEMS

Two plane coordinate systems are also commonly used to express position: the State Plane Coordinate System and the Universal Transverse Mercator grid system. *Universal Transverse Mercator (UTM)* coordinates (northings and eastings) are derived from a rectangular grid based on a transverse Mercator projection. The UTM system consists of 60 north-south zones, each 6° wide in longitude. The zones are numbered consecutively, starting with zone 1 between 180° and 174° W. longitude and increasing eastward to zone 60 between 174° and 180° E. longitude. The UTM system is designed to be used for latitudes between 80° S. and 84° N. and does not include the polar regions. Unlike state plane coordinates, UTM coordinates are available for the whole world (minus the poles). UTM coordinate values are given in meters.

The *State Plane Coordinate System (SPCS)* is a system of rectangular (X and Y) grid coordinates derived from one of two projections over a state or part of a state (zone). A Lambert conformal conic projection with two standard parallels is used for states having a large east-west extent. A transverse Mercator projection is used for states having a large north-south extent. Most states have more than one zone to minimize the distortions inherent in the projections, and the zone boundaries follow county lines. Computed state plane coordinates are available for horizontal geodetic stations established by Federal agencies. The State Plane Coordinate System is the system most commonly used by state and local governments and by private surveyors in the United States.

SCALE

Virtually all maps show features on the surface of the Earth at a much smaller size than the actual features. The scale of a map is the ratio of the length of a feature as measured on the map to the true length of the feature on the surface of the Earth, expressed as a representative fraction. For example, on a map at 1:2,400 scale, 1 inch on the map would represent 2,400 inches (200 feet) on the ground. Sometimes such a map is referred to as a 200 foot map or a 1"=200' map. Maps are said to be larger in scale as the denominator of the proportion gets smaller, and a larger scale map shows features larger than a smaller scale map. For example, 1:2,400-scale maps are larger scale than 1:10,000-scale maps. Larger scale maps would generally show more detail than a smaller scale map of the same area. On maps covering very large areas or the whole world, the scale varies over the map, and only a globe would be a true-scale replica. Table 2-1 lists some equivalencies and area covered for various scales.

Table 2-1: Scale equivalencies

Inch-Pound System

Scale	1 inch represents	At this scale, a 20" by 20" map covers:
1:1,200	100 feet	0.38 by 0.38 miles = 0.14 sq. miles *(2,000' by 2,000')*
1:2,400	200 feet	0.76 by 0.76 miles = 0.57 sq. miles *(4,000' by 4,000')*
1:4,800	400 feet	1.52 by 1.52 miles = 2.30 sq. miles *(8,000' by 8,000')*
1:12,000	1,000 feet	3.79 by 3.79 miles = 14.35 sq. miles *(20,000' by 20,000')*
1:24,000	2,000 feet	7.58 by 7.58 miles = 57.39 sq. miles *(40,000' by 40,000')*
1:63,360	5,280 feet	20 by 20 miles = 400 sq. miles *(105,600' by 105,600')*

Metric System

Scale	1 cm represents	At this scale, a 50 cm by 50 cm (19.7" by 19.7") map covers:
1:1,000	10 meters	0.5 by 0.5 km = 0.25 sq. km (0.1 sq. miles)
1:2,000	20 meters	1 by 1 km = 1 sq. km (0.4 sq. miles)
1:5,000	50 meters	2.5 by 2.5 km = 6.25 sq. km (2.4 sq. miles)
1:10,000	100 meters	5 by 5 km = 25 sq. km (9.7 sq. miles)
1:25,000	250 meters	12.5 by 12.5 km = 156.25 sq. km (60 sq. miles)
1:50,000	500 meters	25 by 25 km = 625 sq. km (241 sq. miles)
1:100,000	1,000 meters	50 by 50 km = 2,500 sq. km (965 sq. miles)

ACCURACY

Some maps, such as road maps, are designed to show only relative positions. Other maps have been designed and constructed to meet more stringent accuracy standards. A multipurpose land information system that includes a graphic depiction of the relationships between property parcels depends on a set of highly accurate large-scale maps.

Several systems of determining and expressing map accuracy have been devised, the most well-known of which is the National Map Accuracy Standards (Appendix 2-1). These standards cover both vertical and horizontal accuracy. Map accuracy is determined by checking the mapped position of a location, either horizontal or vertical, against its true ground position. National Map Accuracy Standards describe a method for determining the accuracy of map products: "on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch." For a map at 1:2,400 (1"=200'), that means no more than 10 percent of the points tested would be more than 6.67 feet from the position determined by a field check. For vertical accuracy, "not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval." No governmental or legislative requirement exists that a map meet National Map Accuracy Standards, except as required by the agency producing or contracting for the map.

The American Society for Photogrammetry and Remote Sensing (ASPRS) has recently developed another standard for classifying map accuracy for large-scale maps. The *ASPRS Interim Accuracy Standards for Large-Scale Maps* indicate accuracy at ground-scale and allow digital cartographic data of known ground-scale accuracy to be related to the appropriate map scale for graphic presentation at a recognized standard. Horizontal map accuracy is defined as the ***root mean square (RMS) error*** in terms of the project's planimetric survey coordinates (X, Y) for checked points as determined at full (ground) scale of the map. Based on the accuracy level achieved, maps are designated as Class 1, 2, or 3. These standards, and the limiting RMS errors (maximum permissible RMS errors) for Class 1 maps are included in Appendix 2-2 along with typical map scales associated with the limiting errors. These levels of accuracy apply to tests made on well-defined points only. For vertical accuracy on Class 1 maps, the limiting RMS error for well-defined points is set at one-third of the contour interval, and for spot elevations, one-sixth of the contour interval.

Map accuracy must be defined in the initial planning. For a typical photogrammetric mapping project, the required accuracy will affect the flying height of the aerial photography, the density of ground control and the stereocompilation instruments used. Once these parameters have been defined and the project started, greater accuracy would be difficult to achieve.

Table 2-2: Map accuracy standards

Horizontal accuracy examples

Scale	NMAS[1]
1:1,200	± 3.33 feet
1:2,400	± 6.67 feet
1:4,800	± 13.33 feet
1:9,600	± 26.67 feet
1:10,000	± 27.78 feet
1:12,000	± 33.33 feet
1:24,000	± 40.00 feet
1:63,360	± 105.60 feet
1:100,000	± 166.67 feet

[1] National Map Accuracy Standards define the requirements for meeting horizontal accuracy as 90 percent of all measurable points must be within 1/30th of an inch for maps at a scale of 1:20,000 or larger, and 1/50th of an inch for maps at scales smaller than 1:20,000.

Maps should be tested to determine whether or not they meet desired accuracy standards. Generally, the horizontal accuracy of a map is tested by comparing the planimetric (X,Y) coordinates of well-defined ground points on the map to the coordinates of the same points as determined by an accurate field survey. Well-defined points would include such features as road intersections, road-railroad crossings, or building corners. For testing vertical accuracy, spot elevations and elevations determined by contour interpolation are compared with elevations determined by an accurate field survey.

> Map accuracy determination is by no means an exact science. Map accuracy specifications and testing procedures cannot be so clear and mathematically incontrovertible that they will give the exact and only answer to the problem of evaluating the accuracy of a given map. There is an area of interpretation whose existence must be recognized to avoid rigidly applying narrow rules in a way that does not reflect the spirit or intent of the specifications.
>
> In a sense, accuracy specifications are akin to laws in a civil community. A law can be clearly written and apparently unmistakable in meaning, yet a case involving the application of that law may go through court after court with many variations in its interpretation. In the same way, a map may pass or fail, according to how the accuracy specifications are applied or interpreted.
>
> *(Thompson 1987, p. 105)*

Ideally, an agency contracting for large-scale mapping would have the coordinates for a number of check points that are not available to the contractor and a means for checking them against the compiled or digitized mapping. Usually an instrument such as a coordinatograph connected to a digital readout device is used for accuracy checking. Software is relatively simple and must perform a linear transformation between the actual coordinates of the check points and the sheet coordinates of the points as portrayed on a stable-base copy of the map. At the time of accuracy checking, the neatline of the quadrangle, or the values of the quadrangle corners can also be checked.

HORIZONTAL AND VERTICAL GEODETIC DATUMS

Latitudes, longitudes and heights are based on assumptions about the size and shape of the Earth. These assumptions are expressed in the *geodetic datum*, or *datum* which is defined as "a set of constants specifying the coordinate system used for . . . calculating the coordinates of points on the Earth" (NGS 1986). There are two kinds of datums: horizontal and vertical.

The *horizontal geodetic datum* used in the United States is being redefined. Currently, most of the existing maps in this country use the *North American Datum of 1927 (NAD 27)*. However, the National Geodetic Survey (NGS) has recently changed the datum of the country on the basis of additional horizontal observations and a new definition of the ellipsoid, GRS80. This new definition is called the *North American Datum of 1983 (NAD 83)*. The most commonly used *vertical geodetic datum* is the *National Geodetic Vertical Datum of 1929 (NGVD 29)*, but the National Geodetic Survey is developing a new vertical datum as well, the *North American Vertical Datum of 1988 (NAVD 88)*. The elevation values of most vertical control marks in the country will be adjusted with NAVD 88. The reference datums are discussed more thoroughly in Chapter 3, "Introduction to Geodetic Reference Frameworks," in this *Guidebook*.

The cartographer or the person contracting for mapping must be aware of which datum is being used. *Positions from one datum cannot be used on the same map with positions determined on another datum, without converting one data set.* For horizontal positions, this problem will be apparent immediately, but for vertical control the problem will become apparent in the 1990s with the redefinition of the vertical datum. *Global Positioning Satellite* technology gives positions based on NAD 83, and the increasing use of this technology will intensify the problem.

THE BASE MAP

A base map for a multipurpose land information system can take one of many forms. Several factors influence the form of the base map, including cost, intended use, and the type of existing maps. The most common forms of base maps are *line maps, photomaps* and *orthophotomaps,* and *digital maps.*

Line maps are typically scribed or inked and can be multi-color or black and white. A line map usually includes roads, buildings, fences, vegetation, control and other monumented points, railroads, trails, transmission lines, and pipelines. A topographic line map also contains information representing the ground surface, typically through the use of contours. A planimetric line map would not contain relief information.

Photomaps and orthophotomaps are other frequently used forms of base map. The advantages of a photographic base include lower cost and abundant detail. All of the information on the ground is included on the photograph, although some ground information can be partially obscured or too small to be visible. Important features such as jurisdictional boundaries or land parcels are generally not visible. Conversely, a photographic base map may have such an abundance of detail that relevant information may be difficult to interpret. Skilled photo-interpreters may be needed to use the photographic base map to its full potential.

A photographic base map can be either an enlarged photograph, a rectified photograph, or an orthophotograph. Aerial photographs are subject to several types of distortion, as shown in Figure 2-6. A photograph can be enlarged to a nominal scale, but displacements from tilt and relief prevent the photograph from having a uniform scale. An unrectified enlargement of an aerial photograph would not meet National Map Accuracy Standards, and would be a very poor base for a multipurpose land information system. A rectified photograph is one that has been corrected for tilt, but not for relief displacement. In extremely flat areas, such as California's Central Valley, a rectified photograph may meet National Map Accuracy Standards, depending upon the scale and other factors. An orthophotograph is a photograph whose image has been photogrammetrically manipulated so that features on the photograph are in true *orthographic* position. A properly made orthophotograph with sufficient horizontal and vertical control will meet accuracy standards appropriate to the scale.

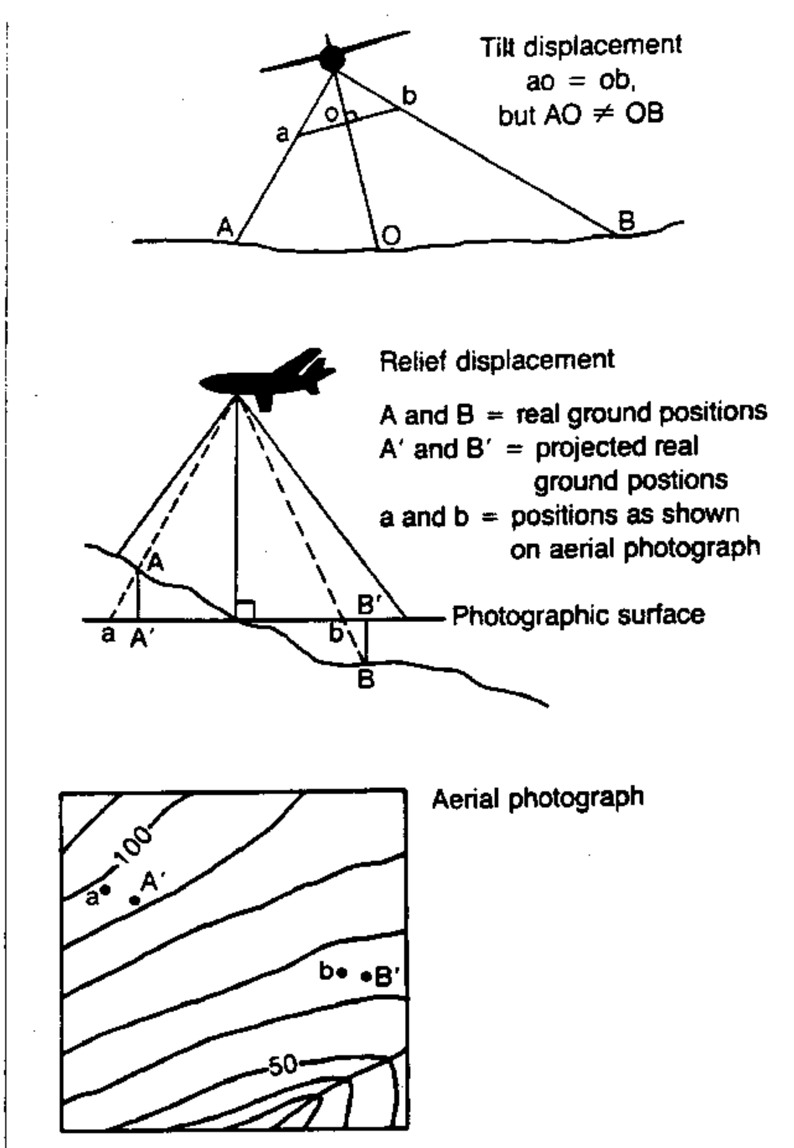

Figure 2-6: Causes of displacements on aerial photographs.

A map in digital form is more flexible than other forms of maps. Selective features can be viewed and displayed as desired, and data from different sources and scales can be merged. However, with this flexibility come additional problems. Mixing data at different scales can degrade the accuracy of the map. For example, data that meet the accuracy standards for 1:4,800-scale cannot be merged with data at 1:2,400-scale and be assured to meet 1:2,400-scale standards.

Ultimately, the mixture of data from several sources at different scales and accuracies can lead to a cartographic nightmare. Another problem with a digital map is the production expense. Digital maps can be produced by digitizing existing maps, by digitizing aerial imagery during stereocompilation, or by direct entry of coordinate data into the database. Substantial costs are involved in either acquiring digital mapping hardware and software and developing an in-house capability or in contracting for digitizing services. Additionally, the cost of database maintenance is often overlooked. Digital mapping systems are designed to be easily revised. If the data are not kept current, one of the main advantages to a digital system is negated. Still, the many advantages of a digital map seem to outweigh the disadvantages, and current state-of-the-art mapping systems are all digital.

The selection of the form of the base map for a multipurpose land information system depends upon the intended use of the maps, the funds available for developing the system, and other factors such as the extent and content of current maps. One form of map is not inherently superior to the others, and it is possible to move from one form to another. For example, a city or county developing a multipurpose land information system might use a set of orthophotographs at 1:2,400-scale initially. Cadastral parcels could then be delineated on the orthophotographs and unique identifying numbers generated for or associated with each parcel. The parcels and selected information from the orthophotographs could be digitized at a later time. MPLIS developers should keep in mind, however, that it is easy to build a less accurate map on a more accurate base, but virtually impossible to build a more accurate map on a less accurate base.

MAP DESIGN CONSIDERATIONS

Map design considerations determine whether a map is legible and easily interpreted. *Scale* is one of the first decisions made in map design. The selection of scale is based on the sources of information and the intended use of the map, as well as the *accuracy* and *content* requirements of the map. Other factors, such as sheet size, past practice, and the scale of auxiliary maps may also influence the selection of scale.

Maps are *selective in content*, consistently representing the features that are important for the intended use of the map and omitting others. Through selection and the choice and placement of symbols and annotations, maps also emphasize some features and de-emphasize others. In contrast, aerial photographs are not deliberately selective and may lend emphasis to large or distinctive yet irrelevant features while more relevant features may be missing or obscured.

Maps represent features using *symbols*, which should be standard at least for that map or map series. Many conventional uses of symbols, lettering, and color have evolved. Generally, adherence to these conventions will make a map easier to read. A map legend should define any unusual symbols used, but the more self-evident the symbology is, the better. In addition to pictorial symbols, line type and line weight are symbols, as are color and fill pattern. The style, size, and weight of *lettering* and its placement on the map can enhance or detract from a map's readability. The use of too many styles, too much variety in weights (boldness) or sizes, or careless use of capitalization will confuse the map reader and clutter the map. Convention guides the placement of names, their spacing, rotation, and direction, and whether they are on a straight line or curved along a feature. Map series that are maintained constantly by local government personnel are the products of many years and many hands. It is not uncommon to see a great deal of variation in symbology, lettering, and other cartographic decisions, particularly in the absence of written standards. Development of a multipurpose LIS provides an ideal time to develop, review, or implement such standards.

Most maps have a *title block* or *legend* showing the title of the map, its scale, projection, datum, information on its date of production and accuracy, and the source or producer of the map. If the map is one of a series, there will often be a grid reference, such as a U.S. Geological Survey quadrangle name, or section, township, range, and perhaps a context map or other indication of neighboring map sheets. Many maps also include coordinate system references or tick marks.

Every map is a *generalization* of features to some degree, representing a whole city by its boundaries or even by a symbol. The intricacies of coastlines and the twists and turns of rivers and roads are simplified for the sake of legibility and appearance. The difference in the degree of generalization can be an important limitation in creating map products at various scales by enlarging or reducing the same original.

The information required for a single map sheet may be represented on several sheets or *separates*. A *registration system*, is essential to ensure that the separates overlay properly during reproduction. Separates are required for multicolor maps, but they also enable the map maker to create essentially new maps through recombination, reduction, or enlargement. A carefully planned and produced set of map separates can support several map series and greatly reduce the amount of time required to keep maps up-to-date. Scale, content, symbolization, lettering, generalization, and layout must be considered carefully to guarantee flexibility and legibility of the maps.

In its guidelines for large-scale mapping (USGS 1986), the U.S. Geological Survey suggests six separates for large-scale community maps for display at scales between 1:1,200 and 1:4,800.

1. Streets, drainage, boundaries, rights-of-way, and names data.
2. Hypsographic information in the form of contour lines and vegetative information.
3. Buildings.
4. Surface and underground service and utility lines.
5. Property lines and lot and block data.
6. Property data and street addresses.

These separates could be used individually or combined in a number of different ways. For example, separate 1 could be the base for the official community map; separates 1, 2, and 3 could be the base for conventional topographic maps; and separates 1, 5, and 6 could serve as an assessment map.

The idea of separating different kinds of information is also important in digital mapping. The computer is not limited by the physical constraints imposed by reproduction, therefore, the number of separates, or *layers*, in a computer mapping system can be much larger. While the concept of explicitly distinguishing features is common in most computer systems that support mapping, the implementation methods and terminology vary.

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APPENDIX 2-1
UNITED STATES NATIONAL MAP ACCURACY STANDARDS

With a view to the utmost economy and expedition in producing maps which fulfill not only the broad needs for standard or principal maps, but also the reasonable particular needs of individual agencies, standards of accuracy for published maps are defined as follows:

1. Horizontal Accuracy. For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch. These limits of accuracy shall apply in all cases to positions of well-defined points only. Well-defined points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as bench marks, property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings); etc. In general what is well defined will also be determined by what is plottable on the scale of the map within 1/100 inch. Thus while the intersection of two road or property lines meeting at right angles would come within a sensible interpretation, identification of the intersection of such lines meeting at an acute angle would obviously not be practicable within 1/100 inch. Similarly, features not identifiable upon the ground within close limits are not to be considered as test points within the limits quoted, even though their positions may be scaled closely upon the map. In this class would come timber lines, soil boundaries, etc.

2. Vertical accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.

3. The accuracy of any map may be tested by comparing the positions of points whose locations or elevations are shown upon it with corresponding positions as determined by surveys of a higher accuracy. Tests shall be made by the producing agency, which shall also determine which of its maps are to be tested, and the extent of such testing.

4. Published maps meeting these accuracy requirements shall note this fact on their legends, as follows: "This map complies with National Map Accuracy Standards."

5. Published maps whose errors exceed those aforestated shall omit from their legends all mention of standard accuracy.

6. When a published map is a considerable enlargement of a map drawing (manuscript) or of a published map, that fact shall be stated in the legend. For example, "This map is an enlargement of a 1:20,000-scale map drawing," or "This map is an enlargement of a 1:24,000-scale published map."

7. To facilitate ready interchange and use of basic information for map construction among all Federal mapmaking agencies, manuscript maps and published maps, wherever economically feasible and consistent with the uses to which the map is to be put, shall conform to latitude and longitude boundaries, being 15 minutes of latitude and longitude, or 7.5 minutes, or 3-3/4 minutes in size.

U.S. BUREAU OF THE BUDGET

Issued June 10, 1941
Revised April 26, 1943
Revised June 17, 1947

APPENDIX 2-2
ASPRS Interim Accuracy Standards for Large-Scale Maps

Horizontal map accuracy is defined as the rms error in terms of the project's planimetric survey coordinates (X, Y) for checked points as determined at full (ground) scale of the map. The rms error is the cumulative result of all errors including those introduced by the processes of ground control surveys, map compilation, and final extraction of ground dimensions from the map. The limiting rms errors are the maximum permissible rms errors established by this standard. The limiting rms errors for Class 1 maps are listed below. These limits of accuracy apply to tests made on well-defined points only.

Planimetric (X or Y) Accuracy (limiting rms error, *feet*)	Typical Map Scale
0.05	1:60
0.1	1:120
0.2	1:240
- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - - - - -[1]
0.3	1:360
0.4	1:480
0.5	1:600
1.0	1:1,200
2.0	1:2,400
4.0	1:4,800
5.0	1:6,000
8.0	1:9,600
10.0	1:12,000
16.7	1:20,000

Planimetric (X or Y) Accuracy (limiting rms error, *meters*)	Typical Map Scale
0.0125	1:50
0.025	1:100
0.050	1:200
- - - - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - - - - - - -[1]
0.125	1:500
0.25	1:1,000
0.50	1:2,000
1.00	1:4,000
1.25	1:5,000
2.50	1:10,000
5.00	1:20,000

[1] Indicates the practical limit for aerial methods; for scales above this line, ground methods are normally used.

Vertical map accuracy is defined as the rms error in elevation in terms of the project's elevation datum for well-defined points only. For Class 1 maps the limiting rms error in elevation is set by the standard at *one-third* the indicated contour interval for well-defined points only. Spot heights shall be shown on the map within a limiting rms error of *one-sixth* of the contour interval.

Lower Accuracy Maps

Map accuracies can also be defined at lower spatial accuracy standards. Maps compiled with limiting rms errors of twice or three times those allowed for a Class 1 map shall be designated Class 2 or Class 3 maps respectively. A map may be compiled that complies with one class of accuracy in elevation and another in planimetry.

Root Mean Square Error

The root mean square (rms) error is defined to be the square root of the average of the squared discrepancies. In this case, the discrepancies are the differences in coordinate or elevation values as derived from the map and as determined by an independent survey of higher accuracy (check survey). For example, the rms error in the X coordinate direction can be computed as:

$$rms_x = \sqrt{(D^2/n)}$$

where: $D^2 = d_1^2 + d_2^2 + \ldots + d_n^2$

$d =$ discrepancy in the X coordinate direction

$d = X_{map} - X_{check}$

$n =$ total number of points checked on the map in the X coordinate direction

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3 INTRODUCTION TO GEODETIC REFERENCE FRAMEWORKS

James E. Stem and Gary M. Young

The need for accurate national surveys was recognized, in concept, by the founding fathers of the United States. Land transportation in the colonies was difficult, and commerce between the states was mainly by coastal shipping. Similarly, foreign trade, which was critical to the new Republic, was entirely by sea. The commercial shipping lanes were, for the most part, uncharted or inadequately charted, and shipwrecks were common. The responsibility of the central government was spelled out in the so-called commerce clause of the Constitution which provided that Congress shall have the power "to regulate commerce with foreign nations, and among the several states, and with the Indian Tribes." As part of this obligation, Congress, acting on a recommendation by President Thomas Jefferson, adopted a resolution on February 10, 1807, for a "Survey of the Coast." This act authorized President Jefferson "to cause a survey to be taken of the coasts of the United States, in which shall be designated the islands and shoals, with the roads or places of anchorage, within twenty leagues of any part of the shores of the United States; and also the respective courses and distances between the principal capes or head lands, together with such other matters as he deem proper for completing an accurate chart of every part of the coasts within the extent aforesaid."

By this act was created the first United States civilian scientific agency, the Survey of the Coast. Later the responsibility for surveys of the interior was added to its original mission to chart coastal waterways to assist waterborne commerce. The authorizing legislation for this new task was passed on March 3, 1871, calling for "a geodetic connection between the Atlantic and Pacific coasts" (Shalowitz 1964). It was this added responsibility to provide geodetic control for the interior of the country that led to the Act of June 20, 1878, which changed the name of the agency to *Coast and Geodetic Survey*. In 1970 the Coast and Geodetic Survey

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became a component of the National Oceanic and Atmospheric Administration (NOAA) and is presently named the National Ocean Service (NOS). To acknowledge the geodetic aspect of its mission, the portion of NOS responsible for geodetic activities was named the *National Geodetic Survey (NGS).*

Today NGS is responsible for establishing, developing, and maintaining the *National Geodetic Reference System (NGRS)*. The NGRS comprises more than 800,000 accurately located survey points called *geodetic stations* and serves as the common surveying and mapping base of reference for latitude, longitude, height, scale, and orientation throughout the United States.

The Federal Geodetic Control Committee (FGCC) was organized to assist the Department of Commerce in meeting the requirements of the Office of Management and Budget (OMB) Circular A-16, dated May 6, 1967. FGCC consists of representatives from 11 departments and independent agencies that have geodetic and related survey activities and interests. Geodetic survey activities of these departments are coordinated by FGCC. FGCC also develops and publishes standards and specifications, and performs instrument testing for compliance to manufacturers specifications.

THE USES OF GEODETIC REFERENCE FRAMEWORKS

A *geodetic reference framework (GRF)* consists of permanently monumented stations whose locations are accurately measured and mathematically described relative to a common datum. (Chapter 2, "Introduction to Mapping Concepts," contains an introduction to the concept of datums.) In engineering, a geodetic reference framework provides the structure to support surveys, mapping, and construction. For a multipurpose LIS, the framework provides an accurate and efficient means to describe the location of land features and their relationship to one another, and makes it possible to interpret, analyze, and disseminate compatible land information. By *compatible* we mean related, or *tied*, to the same geodetic reference framework. The exact spatial relationship among the points in the framework is known, so the relationship between features that are related to these points is known. An adequate geodetic reference framework ensures sufficient spatial accuracy for linking the different types of data that comprise a multipurpose LIS.

Surveyors, mappers, and engineers routinely rely on a reference framework of some type to provide spatial control. For small projects, isolated field surveys may be performed to establish a temporary reference framework for that project. Larger projects often use the NGRS or a *local geodetic reference framework* consisting of the NGRS stations, plus other stations tied to the NGRS by less accurate surveys for spatial control.

THE LOCAL GEODETIC REFERENCE FRAMEWORK

Surveying activities performed by state, local, and private agencies often originate at the NGRS geodetic stations. When Federal standards and specifications are used to perform and connect surveys of other agencies to the NGRS, the surveys all become part of a single spatial reference system. *A local geodetic reference framework consists of the NGRS geodetic stations plus all properly connected stations of other agencies, whether they are included in the NGRS database or not.* NGS encourages private and public sector users to use and improve both the NGRS and local geodetic reference frameworks for the development of multipurpose LIS and for traditional engineering, surveying, and mapping.

FGCC specifications for traditional survey methods call for at least two ties to known positions to provide horizontal spatial control for a project. Specifications for vertical control call for four or more ties to known positions. Requirements for satellite methods differ. The positions can be expressed in the NGRS or geodetic reference framework coordinate system or their derivatives, or in an arbitrary coordinate system established for the project. The latter method of establishing single-purpose control in the form of a project-specific control system is often uneconomical in the long run, as it will not be consistent with other project-specific control systems in the future. Either way, the principle of spatial control is the same, that is, the geodetic survey points provide position, scale, and orientation for the project. When the spatial relationship between two projects is needed, however, a project-specific reference framework is not enough. The position, scale and orientation of each project to the other can be established by tying the two project reference frameworks together. Distance or field conditions may make this tie difficult, but even when it has been made, no relationship has been established between these two projects and any other projects or features. Tying projects to a geodetic reference framework that is, in turn, tied to the NGRS ensures that the relationship between projects is known, regardless of distance or field conditions.

Given at least two *horizontal geodetic stations* in a project, the computed distance between these points provides the scale of the project and the computed azimuth or bearing between these points provides orientation for the project. A common geodetic reference framework also creates a link between disparate types of data. For example, USGS 7-½ minute quadrangles refer to the NGRS and the 1927 datum (NAD 27). Any other map referring to the same datum, to the NGRS, or to a geodetic reference framework property tied to the NGRS, would be *compatible* with the USGS 7-½ minute series.

CHARACTERISTICS OF A GEODETIC REFERENCE FRAMEWORK

A geodetic reference framework has five characteristics:

- monumentation and field descriptions
- field measurements and methods
- survey accuracy
- density
- datum

MONUMENTATION AND FIELD DESCRIPTIONS

The physical evidence of a geodetic reference framework on, or near, the Earth's surface is provided by *geodetic stations*. Such stations are typically well defined points in manmade monuments, landmarks, or natural features. Most stations are metal survey disks set in concrete posts or bedrock outcrops. Some points are marked by steel rods. They usually extend far underground for stability and may have a metal survey disk or logo cap attached to the top. Usually stamped into the disk or logo cap are station-identification and establishing-agency information, plus an indicator of the precise point of the station for which a geodetic position is available. Monuments for survey stations other than *geodetic stations* also exist in the field, but until information for the station is obtained from the establishing agency, the station's utility or function is often unknown.

Geodetic stations must be very stable in order to provide an effective, multipurpose framework over time. All station monuments are subject to the effects of local soil activity, but by careful site selection and monument construction, such movement can be minimized. Vertical bench marks are particularly vulnerable to movement because displacement results in relatively larger vertical motion than horizontal motion. Consequently, monumentation for vertical stations differs from that used for horizontal stations. Monumentation designed for combined horizontal and vertical stations (i.e., *three-dimensional, or 3D, stations*) must be stable both horizontally and vertically. In addition to natural disturbances, construction and vandalism can damage, displace, or entirely remove stations. These create problems in maintaining monumentation.

Monument stability refers to the ability of a monument to maintain a fixed physical position over time. It is characterized by the degree and duration of stability. To a local surveyor running a topographic survey on a small construction site, a stable point can be the top of a prominent boulder or a spike driven into a gravel road surface. These objects could move 1 to 10 centimeters or more in a year's time, but still be adequate for this surveyor's needs. Another surveyor might be concerned with laying out a major highway that could take years to complete. The monumentation for this project must be more stable and longer lasting. In this case, a concrete post extending to a depth of 1 meter or so, or a spike in the side of a large utility pole, might be considered stable points. Required stability depends on the accuracy of the survey and the duration of the project for which accurate positions are needed.

In order to maintain the NGRS for all its intended purposes, NGS establishes monuments of very high stability, to minimize their movement due to local ground effects. Floyd (1978) and *Coast and Geodetic Survey Technical Manual 4* (1968) describe the establishment of the primary station for which the position or height is determined. Other, less stable peripheral monuments called *reference marks*, are often established near primary horizontal stations to aid in locating or relocating the primary station. Another peripheral monument, an *azimuth mark*, provides a point to which an accurate azimuth or bearing can be determined.

A vital part of geodetic information is the *field description* of the primary and peripheral station monuments, together with "to reach" instructions that describe the drive (sometimes the hike) to the stations, starting from a well-known landmark, such as a road intersection (FGCC 1989).

FIELD MEASUREMENTS AND METHODS

Geodetic surveyors use both terrestrial and satellite survey methods to locate positions of geodetic stations. Positions of horizontal geodetic stations are expressed in geodetic coordinates of latitude and longitude. (These are also called *horizontal control stations, triangulation stations*, or *traverse stations.)* Latitude and longitude are often mathematically converted, or *projected*, to the State Plane Coordinate System (SPCS) of X, Y coordinates (or northings and eastings), or some other map projection system. For *vertical geodetic sta-*

tions, also called *vertical control stations*, a very accurate height or elevation of the station has been determined. Of the various height systems, *orthometric height* is most commonly used. For the NGRS stations, orthometric height is defined as the distance between the vertical reference surface and the vertical geodetic station on the surface of the Earth, measured along the plumb line between the two. Orthometric height is positive upward from the datum surface. (See Horizontal and Vertical Datums, below, for a discussion.) The NGRS stations for which highly accurate orthometric heights have been determined from geodetic leveling are commonly called *bench marks*. In this *Guidebook*, the terms *bench mark* and *vertical geodetic station* are used interchangeably.

When *terrestrial survey methods* are used, a survey usually establishes horizontal stations or vertical stations, but not both. Consequently, only occasionally is a horizontal geodetic position determined for a bench mark, or a geodetic-quality height determined for a horizontal station. With *satellite surveying methods*, it is common to establish a *three-dimensional (3D) position* of latitude, longitude, and height, although satellite-derived orthometric heights are usually less accurate than those determined by terrestrial vertical control surveys. When discussing characteristics of the NGRS or geodetic reference frameworks, horizontal and vertical stations are addressed separately, while the properties of 3D stations attempt to satisfy both horizontal and vertical requirements. So while a horizontal station monument is constructed to resist horizontal movement and a vertical station monument is constructed to resist vertical movement, a 3D monument must resist both horizontal and vertical movement.

The quantities measured in a field survey—the *observations*—are used to compute geodetic latitudes, longitudes, and heights. In a terrestrial horizontal survey, the primary observables are angles, distances, and azimuths (bearings). In a terrestrial vertical survey, the primary observables are height differences. In a 3D satellite survey, the observables are radio signals transmitted by satellites.

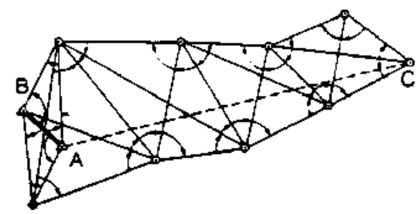
Terrestrial Methods

Coordinates for horizontal stations determined by terrestrial methods are established using one or a combination of three basic surveying methods: *triangulation*, *trilateration*, and *traverse*. A *triangulation* system consists of a series of connected or overlapping triangles in which the lengths of some of the sides are measured and the remaining side lengths are calculated from angles measured at the vertices of the triangles. *Trilateration* is similar in that a network is also formed by a series of triangles, but differs in that all the sides of the triangles are measured and only the angles required to establish orientation are observed. Figure 3-1 illustrates chaining of triangles to form an *arc of triangulation.* This was the primary means of extending horizontal control and establishing new geodetic horizontal stations within the NGRS until the early 1980s. Most of the horizontal portion of the NGRS was surveyed using this technique. In urban areas, triangles were chained together to form area networks. With the advent of precise electronic distance measurement instruments in the 1960s, the accuracy of the NGRS was gradually increased as an increased number of measured distances, which can be measured more accurately than angles, were incorporated gradually. At the same time, the practical differences between triangulation and trilateration have become less distinct.

Coördinates can be calculated sequentially from a *traverse,* which is a series of measured angles and distances. Figure 3-2 depicts a simple traverse between points A and C, which have previously established positions. The measured angle at station A between stations B and 1 is added to the known azimuth of line AB to give the azimuth of line A1. The distance between A and 1 is measured, processed, and combined with the azimuth to calculate the coordinates of station 1. This process is repeated until the position of station C is computed. The computed position of C is compared to the previously established position of station C, and the discrepancy is prorated over all traverse stations by an appropriate data distribution technique such as a least squares adjustment.

Geodetic leveling techniques are the terrestrial methods of establishing vertical stations. The fundamental observation in leveling is the height difference between two nearby points on the ground. Figure 3-3 illustrates how a leveling instrument is set up midway between two points so its horizontal line of sight intersects graduations on the two leveling rods set vertically on the points (Fig. 3-3). From the readings on the leveling rods, observed height differences are determined. When leveling between two widely separated points, it is necessary to set the leveling rods on intermediate temporary points, called *turning points,* and accumulate a series of height differences until the overall height difference between permanently monumented bench marks is determined. If proper equipment, observing procedures, and data reduction techniques are followed, the accuracy of these height differences can be sufficient to establish heights of geodetic quality.

A SIMPLE TRIANGULATION NET



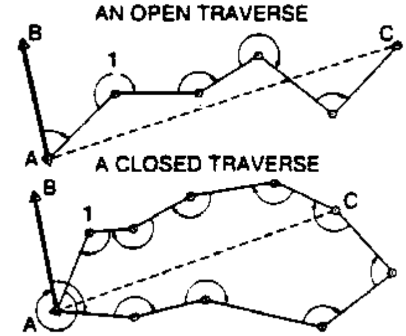
KNOWN DATA:
Length of base line AB.
Latitude and longitude of points A and B.
Azimuth of line AB.

MEASURED DATA:
Angles to new control points.

COMPUTED DATA:
Latitude and longitude of point C, and other new points.
Length and azimuth of AC.
Length and azimuth of all other lines.

Figure 3-1: Triangulation (from DOD 1983, p. 15).

AN OPEN TRAVERSE



KNOWN DATA:
Latitude and longitude of points A.
Azimuth of line AB.

MEASURED DATA:
Length of traverse sides.
Angles between traverse sides.

COMPUTED DATA:
Latitude and longitude of point C, and other new points.
Length and azimuth of AC.
Length and azimuth of line between any other two points.

Figure 3-2: A traverse (from DOD 1983, p. 25).

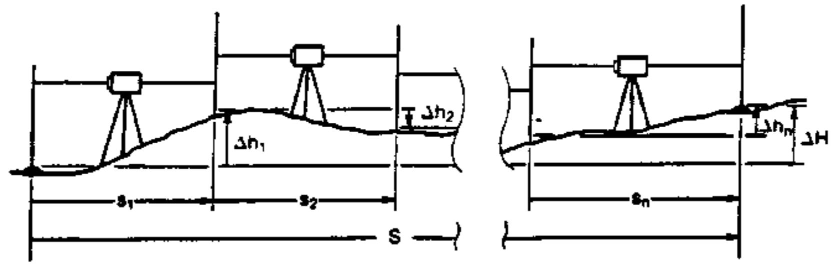


Figure 3-3: Geodetic leveling (from Schomaker 1981)

$\Delta H = \Delta h_1 + \Delta h_2 + \ldots + \Delta h_n$ *and* $S = s_1 + s_2 + \ldots + s_n$.

The observed height differences between bench marks are corrected for significant systematic errors and processed through least squares adjustments using heights of previous NGRS bench marks to determine new heights referred to the vertical datum. This process creates an interrelated network of benchmarks through which height values and differences can be compared for locations that are not directly tied by lines of geodetic leveling. Other methods are available, but geodetic leveling still provides the most accurate determinations of height differences for surveys of limited extent.

Satellite Methods

The *Global Positioning System (GPS)*, incorporating U.S. Department of Defense NAVSTAR satellites, is revolutionizing geodetic surveying. GPS is a very new technology compared to traditional horizontal and vertical geodetic surveys, which have a United States tradition dating back more than 175 years. Department of Defense development began in 1978 with the intention of designing a real-time navigation system, and practical geodetic receivers became available for civilian use in the early 1980s. NGS conducted its first GPS field tests in 1983. By the early 1990s, the GPS constellation of 21 satellites will be complete. This will provide 24-hour simultaneous visibility of at least four satellites almost anywhere on the Earth's surface. As GPS ground receivers become less expensive and more reliable, the advantages of GPS over traditional terrestrial surveying will become even more pronounced. GPS surveys are now used routinely to determine coordinates of new geodetic survey points. In many situations, GPS provides both economic and accuracy advantages over terrestrial surveying, although station height measurements may be less accurate.

GPS offers a number of practical advantages over terrestrial methods. GPS receivers can be operated in almost all types of weather, both day and night. Intervisibility of stations is no longer required. Longer distances between stations can be accommodated by the simultaneous occupation of more than one station, and less skill is usually required of the field observer. A disadvantage is that GPS receivers are sometimes unable to receive sufficient satellite signals when skyward obstructions exist, such as in urban and forested areas.

The position of a GPS receiver placed on ground control stations can be determined by processing specific radio signals transmitted by the GPS satellites. For geodetic applications, simultaneous observations are usually made at three or more stations, where the NGRS positions of at least two stations are known. This method of observation, called *relative positioning* or *differential mode,* provides a *base line vector* (direction and distance) between new geodetic stations and existing NGRS stations. Base lines accurate to 1 to 5 centimeters over distances of as much as 100 kilometers between stations can be routinely measured. Careful post-processing of sufficient GPS data provides geodetic-quality horizontal coordinates of the new stations relative to the previously determined coordinates of the NGRS stations. Using appropriate techniques and procedures, relative GPS-derived heights can be estimated with accuracies that are sufficient to meet many engineering needs (Zilkoski and Hothem 1989).

SURVEY ACCURACY

In any large surveying or mapping project, it is first necessary to establish a framework of geodetic stations to provide a common basis for operation and a coherent product. All positions are then determined *relative* to the framework. For the surveyor, the term *absolute position* is essentially unmeasurable. (The use of absolute and relative is different from common LIS/GIS usage.) *The reference framework must be more accurate than the most demanding project requirement,* so that within the project the small errors in the framework will not significantly affect subsequent, less accurate measurements. Conceptually, the geodetic reference framework "is the equivalent of the survey control system for a map," and the same principles apply to its design and implementation (NRC 1983, p. 23). *The NGRS provides the only national (and statewide) system of control that can provide spatial correlation of independent data sets.* It is for this reason that the National Research Council cites the NGRS as the foundation by which all land data must be related (NRC 1983).

Horizontal and Vertical Accuracy

It is neither economical nor practical for all points in the NGRS to be of the highest possible accuracy. FGCC, which is responsible for publishing national control classifications, has established a classification of accuracy, defining five orders of horizontal control and three orders of vertical control. Several orders are further broken down according to classes. FGCC publishes specifications for each of the classifications describing a measurement system of instrumentation, calibration procedures, observational techniques, acceptable monumentation, network geometry, and data reduction methods, and stating permissible tolerances for a variety of measurement systems (FGCC 1984). Specifications are designed so that the results are usually 2.5 to 3 times better than the stated accuracy of the particular order and class.

The classification of a horizontal control station by order and class certifies that the coordinates of that station were determined to a specific relative accuracy with respect to the coordinates of adjacent, directly connected NGRS points in the horizontal control network. This relationship is expressed as a *distance accuracy*. Distance accuracy is the ratio of the relative distance error between a pair of control points to the horizontal separation of the two points. These accuracy classifications cover a wide range of surveying requirements, from parcel boundary surveys to super-precise global geodetic surveys for crustal motion determination.

The classification of a vertical control point by order and class certifies that the orthometric height of that station bears a specific accuracy to the heights of all other points in the vertical control portion of the NGRS. That relation is expressed as a height difference accuracy. Height difference accuracy is the relative height error between a pair of vertical control points that is scaled by the square root of their horizontal separation traced along the leveling route between the two points.

The accuracy of horizontal survey points is often expressed as if it were *absolute*, such as "plus or minus 1 foot," but this kind of statement always implies accuracy *relative to the project control framework*. Since the project may not be tied to the NGRS, or to any geodetic control framework, the statement says nothing about how accurately positioned the project is relative to other projects or to the geodetic reference framework. In this case, as in most, the statements are relative, not absolute. Statements about spatial correlation and meaningful positional accuracy of data from independent sources can only be made when all positional accuracy is relative to the same reference framework whose accuracy is known.

People often express map accuracy and survey accuracy in the same shorthand even though the two are distinct. *Map accuracy* is determined by comparing the mapped location of selected well-defined points to their "true" location as determined by a field survey. To meet National Map Accuracy Standards, 90 percent of the sample pairs of measurements—mapped and surveyed—must be within a tolerance specified in terms of inches at the publication scale. Map scale and sample size affect the determination of map accuracy. In contrast, *survey accuracy* is independent of any map scale. The accuracy of a survey is based on the specifications and procedures used. For example, if two surveyors followed the specification and procedures for a second-order, class I survey to conduct independent surveys, their results would be within one part in 50,000 of each other 95 percent of the time.

The accuracy of the geodetic reference framework for a multipurpose LIS must be sufficient to support all of the anticipated applications, the most demanding of which will be those pertaining to the land parcel. The National Research Council addressed this issue in *Procedures and Standards for a Multipurpose Cadastre,* making a distinction between systems based on the method of integrating land data:

> If the positional integrity of the land data is to be accomplished solely by graphic means—the necessary correlation being provided solely by reference to the coordinate grid shown on the maps—only the density of control ordered for the maps is required. If, however, the integration of the positional information is to be accomplished numerically, relatively high-density standards are required. Numeric integration of the data should be an essential feature of any modern land-data system, and the density and accuracy requirements of the horizontal survey control should be determined accordingly.
>
> With respect to accuracy, the determining factor will be the extent to which the control survey stations are to serve multiple purposes. Similar to the above, if the integration of the positional data is to be done graphically, a relatively low order of accuracy will be required for the horizontal control network, such as that attendant to the federal classification of third-order, class I, or second-order, class II, should be met.
>
> *(NRC 1983, pp. 24-25)*

The accuracy of the geodetic reference framework is a function of the accuracy of the points and the quality of the adjustment. Since all other spatial information in the multipurpose LIS will be hung on the geodetic framework, it is important to preserve the integrity of the network by including only points that meet minimum accuracy standards, probably third-order class or better. However, there are many surveyed points that can contribute to the value of an MPLIS even though they cannot meet this accuracy requirement. These tertiary control points may be tied to the geodetic reference framework, and coordinates for them derived from the tie. Or coordinates may be obtained in some other way, such as digitizing. Whatever the case, the multipurpose LIS database should carry sufficient information to identify the source of the survey information, and some indication of its accuracy. If coordinate values are available, the database should record their source, how they were derived, and the datum.

The FGCC classification of survey accuracy stops at third-order, and there is not a standard classification for lower-order surveys. A local classification may be used, but it should use the FGCC classification as far as it goes, and follow a conceptually similar scheme for lower-order surveys.

DENSITY

One of the major determinants of the density of a geodetic reference framework is the accuracy requirement. Until recently, the only way to connect the NGRS horizontal points for coordinate determination was through terrestrial horizontal control measurements of angles and distances, so the points had to be intervisible. A traditional first-order horizontal control network by terrestrial methods requires station spacing of 3 to 8 kilometers. Using the same method, a second-order, class I control network requires spacing of 1 to 3 kilometers. In other words, fewer stations are required for the more accurate network than for the less accurate one. The sources of random error are the reason for this. Two kinds of random error affect surveys: errors that are point specific, such as instrument centering error, and errors that are a function of distance. If highly accurate instruments and methods are used for two surveys, all other things being equal, the survey with more points will be less accurate because it has more possibilities for errors.

Another important consideration in determining the density, and also the distribution, of geodetic reference framework stations is accessibility. The National Research Council (1983) has recommended that communities require parcel and subdivision surveys to be tied to the geodetic reference framework. To require ties to a sparse network would be costly for surveyors and for their customers, so many communities have initiated densification programs and at the same time revised their ordinances to require ties to the network when a geodetic reference framework monument is within a specified distance. *"Typical recommendations range from 0.2 to 0.5 mile (0.3 to 0.8 km) between monuments in urban areas to 1 to 2 miles (1.6 to 3.2 kms) in rural areas* (Ziemann 1976, McLaughlin 1977). *We concur with these recommended densities of monumented points"* (NRC 1983, p. 24).

The geodetic reference framework for a multipurpose LIS generally uses existing the NGRS stations as the primary control points. The network is densified by tying in supplemental control stations using the appropriate FGCC specifications and procedures for terrestrial surveys, typically second-order, class II. Regardless of the methods used to establish the NGRS stations, terrestrial or satellite, actual field observations are made to tie the denser, less accurate points to the sparser, more accurate ones. Only by rigorously connecting the supplemental stations to the primary NGRS stations according to FGCC specifications is it possible to establish the accuracy of the supplemental stations and hence of the geodetic reference framework as a whole.

HORIZONTAL AND VERTICAL DATUMS

In civil engineering, a *datum* is any surface, line, or point used as a reference for subsequent measurements. These control points are identified as the datum for the project, i.e., a *local datum*. The NGRS also includes the datum concept. A *horizontal geodetic datum* provides a regular mathematical surface, called an *ellipsoid of revolution*, as a model of the Earth, upon which computations can be performed. The *vertical geodetic datum* of the NGRS is in some respects more complicated than the horizontal datum, in that the vertical datum is based on the physical concept of mean sea level. In practice, however, height values published by NGS provide the project-specific vertical starting points for a multipurpose LIS. Field survey measurements, observed on the surface of the irregularly shaped Earth, can then be reduced to equivalent values on the geodetic datum for subsequent computations. It is usually enough to see the NGRS datum as a set of numbers assigned to monumented control stations. Along with this set of numbers, the FGCC "rules" provide the instructions to properly incorporate new stations that are to be connected to the NGRS by additional field measurements.

Horizontal Datums and Coordinate Systems

Two horizontal datums are encountered in the NGRS: *the North American Datum of 1927 (NAD 27)* and the *North American Datum of 1983 (NAD 83),* which is gradually replacing NAD 27. The horizontal North American Datum is marked by a network of about 300,000 control stations in the United States, and a large number of connected stations maintained by state and local organizations. NAD 83, which was completed in July 1986, is a new mathematical *adjustment* of the entire North American network. Adjustment in this context is the determination and application of corrections to survey observations for the purpose of removing internal inconsistencies in the derived results. Also, NAD 83 uses a refined figure of the Earth called the Geodetic Reference System of 1980 (GRS80). GRS80 is Earth-centered and approximates the Earth's true size and shape better than the Clarke spheroid of 1866, which was the reference ellipsoid used for NAD 27.

NAD 83 resulted in new geodetic coordinates for all horizontal control points in the NGRS. Coordinates within the conterminous United States have changed as much as 100 meters. The NAD 83 project to make this change was undertaken because NAD 27 values could no longer routinely provide the quality of horizontal control required by surveyors and engineers. Serious distortions in NAD 27 have been corrected by NAD 83. In many areas NAD 83 is twice as accurate as NAD 27. The change to an Earth-centered datum also accommodates the incorporation of GPS-derived coordinates, which are also Earth-centered. All positional information should include a reference to the datum used. Without a correct datum tag, invalid assumptions at a future date could result in inaccurate spatial correlation of LIS data.

NAD 83 will affect everyone who uses coordinates related to the NGRS. Everyone needs to consider the impact of NAD 83, from primary users of the NGRS, such as the geodetic surveyor performing precise surveys, to the secondary users of the NGRS that produce products such as maps that are directly connected to the NGRS, to the tertiary users of the NGRS, including anyone with coordinate-encoded data. Coordinates based on NAD 27 are only consistent with other NAD 27 coordinates. Likewise, NAD 83 coordinates are only consistent with other NAD 83 coordinates. ***With both datums currently in everyday use, coordinate users are presented with the task of transforming from one datum to another***. Ideally, the transformation should not degrade the accuracy of the coordinates, as expressed by the order and class of the station. For example, second-order, class I NAD 27 coordinates and second-order, class I NAD 83 coordinates are each internally consistent to 1:50,000, and the aim of a transformation is to preserve this accuracy.

In 1980 NGS adopted three general approaches for transformation from NAD 27 to NAD 83 (Bossler 1983). The selection of the most appropriate approach depends on the accuracy required of the conversion, the amount of supporting data available, the resources available, and the necessity for conversion.

The relationship between NAD 27 to NAD 83 is non-linear, and transformation methods are approximations; no constant or algorithm can be applied everywhere to make the transformations. This kind of coordinate-to-coordinate transformation results in a fit between the two sets of coordinates, but does not improve accuracy. The best way to avoid degradation of coordinate information is to recompute coordinates using original source documents, including field observations. This may dictate the timing of an agency's adoption of NAD 83. In general, *it is preferable to base a new multipurpose LIS on NAD 83 from the beginning,* thus avoiding some of the possible problems associated with transformations. NGS provides consultation, publications, and one-day workshops to assist in the selection of the appropriate approach to conversion.

Latitude and longitude are the primary spatial coordinates for the horizontal portion of the NGRS. From them, a variety of plane coordinate systems can be calculated. Many users prefer plane coordinates to latitude and longitude, which are more complicated to manipulate mathematically. Map projection equations translate geodetic information about the "round" Earth onto a flat map by converting latitude and longitude to plane coordinates. This, of course, leads to some distortion of the data, but the projections are selected to distort the graphical presentation in a controlled, pre-selected manner. On maps prepared using rigorous map projections, the amount of distortion can be mathematically computed.

The national plane coordinate systems currently in use are the State Plane Coordinate System of 1927 (SPCS 27), the State Plane Coordinate System of 1983 (SPCS 83), the Universal Transverse Mercator System of 1927 (UTM 27), and the Universal Transverse Mercator System of 1983 (UTM 83). These predefined map projections are subdivided into zones, each of which is designed to cover a specific geographic region of the country. Figure 3-4 depicts the zones of SPCS 83. The regions are generally bands that are 100 to 150 miles wide and oriented either north-south or east-west. The general principle that applies to any zone is that the distortion is known and is proportional to the width of the area covered by the zone. For the surveyor, the distortions in a map, plat, or engineering drawing that are attributable to the map projection are expressed in terms of corrections to angles and distances between points. Zones are generally limited in width to keep the distortions acceptably small. If the use of a plane coordinate representation only requires conversion between geodetic coordinates (latitude/longitude) and plane coordinates (X, Y or northing, easting), the conversion computation is exact and the zone width is less important. Also, the length of a zone does not cause distortions except in extremely long zones, i.e., pole to pole. While recognizing that "a number of projections have been used as a basis for the preparation of large-scale maps," the National Research Council recommended the use of the State Plane Coordinate System for multipurpose LISs in the United States because of their universality.

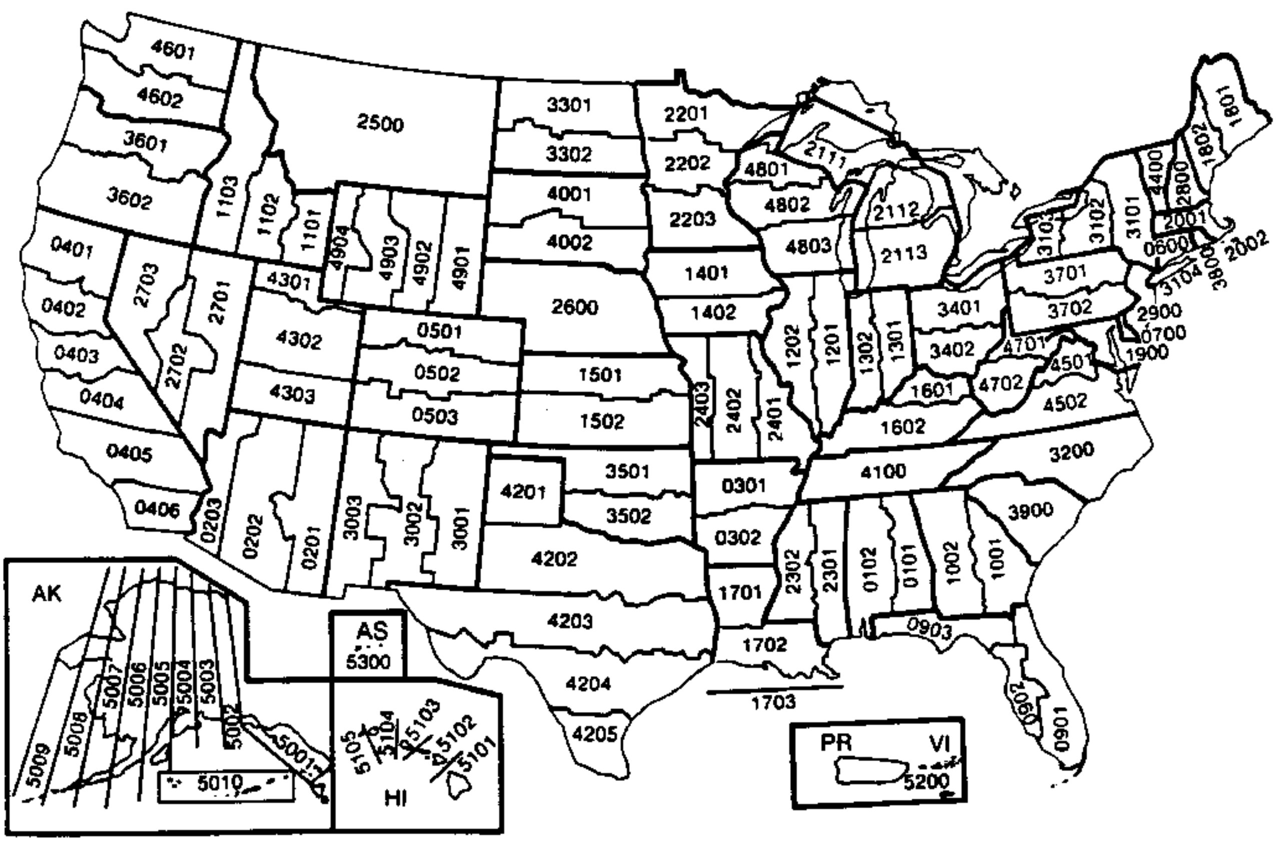


Figure 3-4: Zones of the State Plane Coordinate System.

To date, 26 states have enacted legislature specifying the use of 1983 State Plane Coordinate System. Forty-two states had enacted SPCS 27. In addition to providing the mathematical definitions of SPCS, these state laws define standards to be used in making connections to the NGRS. Mandatory use of SPCS is not the purpose of the laws, but restrictions on the number of coordinate systems commonly used in a state is wise. The laws were generally sponsored or supported by state professional surveying and engineering societies and state agencies (Stem 1989). Regardless of the existence of a state law or its content, SPCS is generally acknowledged to be the "official" plane coordinate system for local maps, and other, mid-scale mapping series, such as the U.S. Geological Survey (USGS) 1:24,000 scale topographic series, also use SPCS.

Vertical Datums of 1929 and 1988

The vertical control portion of the NGRS is based on a national reference surface called the National Geodetic Vertical Datum of 1929 (NGVD 29). Unlike the horizontal datum, which is a purely mathematical surface, the vertical datum (NGVD 29) is based on the *geoid*. The *geoid* is defined as the equipotential surface of the Earth's gravity field which best fits mean sea level (NGS 1986). NGVD 29 contains about 585,000 permanently monumented vertical control bench marks connected by geodetic leveling. These bench marks provide the primary vertical control for United States civilian surveying and mapping operations. Geodetic leveling observations are processed through rigorous adjustments to determine orthometric heights of known accuracy referred to NGVD 29. In this way, all bench mark heights published by NGS can be directly compared to determine differences in height between bench marks.

As was the case for the NGRS horizontal stations, NGS has undertaken a new adjustment of the bench marks in the NGRS. The new adjustment and redefinition of the vertical datum, called the North American Vertical Datum of 1988 (NAVD 88), is scheduled for completion in 1990-91 (Zilkoski and Young 1985). While bench mark heights, in an absolute sense, may change by as much as 2 meters from NGVD 29 to NAVD 88, height differences between nearby bench marks will change by only a few millimeters, which is not significant for the accuracies required by a MPLIS. In crustal motion areas, height differences may change on the order of centimeters to reflect improved, up-to-date height values for surveying, mapping, and other engineering applications. In addition, NAVD 88 will provide an improved basis for better geoid height determinations. These are needed to convert Earth-centered GPS-derived heights to the orthometric heights published by NGS. GPS does not measure orthometric heights directly. This aspect will become more critical in the future as more and more surveyors take advantage of GPS technology.

PRODUCERS OF GEODETIC REFERENCE FRAMEWORK DATA

A geodetic reference framework is a composite of geodetic information provided by many producers. NGS supports the NGRS, a database containing information about control stations with the highest order of accuracy. The NGRS contains information on horizontal and vertical stations established by NGS, as well as stations established by other public and private agencies following rigorous field and documentation procedures. Contributors to the NGRS submit their survey records to NGS according to the prescribed NGS input format known informally as *Blue Book* format (FGCC 1989). If the data are accepted, the stations are mathematically integrated into the NGRS. The composite of all the NGRS-connected data yields the geodetic reference framework foundation for LIS.

The NGRS stations generally constitute the primary control network for a multipurpose LIS. The process of developing a geodetic reference framework of integrated data begins with an inventory of all potential sources of survey records. Surveys by Federal, state, and local government agencies, utilities, and private companies can be a valuable source of supplementary control, but they have not necessarily been integrated into the NGRS. To create a single, integrated geodetic reference framework, the implementing agency should collect these survey records and submit them to NGS, who will analyze them for accuracy, density, distribution, and compatibility and to determine whether or not the stations have been properly connected to the NGRS. Those that meet the requirements are then incorporated into the NGRS. At that point, coordinates can be calculated for the stations.

At the state level, leadership in the establishment and maintenance of geodetic control is often provided by the Department of Transportation or Department of Natural Resources. In some states, the Secretary of State, or the State Surveyor maintains records of geodetic control. Field data from these agencies have not necessarily been sent to NGS for incorporation into the NGRS, but the survey information should be sought and analyzed for inclusion in the geodetic reference framework. FGCC standards and specifications may have been used. If not, additional effort may be required to integrate the data into the NGRS. At the local level, private surveyors, engineers, and utility companies often establish geodetic control in response to project-specific requirements. In some areas, there are public surveying offices. At the local level, a surveyor's office may not be able to provide the data, but may direct the user to the source. Often the local public works or highway department will have a surveying component. In these offices, project-specific coordinates and local control systems will be more prevalent.

Records of the horizontal and vertical portions of geodetic reference frameworks may be maintained separately. Some agencies, particularly those concerned with water resources, emphasize the vertical framework, such as, at the Federal level, the Federal Emergency Management Administration (FEMA), Environmental Protection Agency (EPA), and Coastal Zone Management Agency. Transportation departments may have considerable control data. These valuable sources of survey records should not be ignored in the initial development of a geodetic reference framework. The costs of the surveys have already been paid, and incorporating them into the reference framework extends their utility by making them available to users directly and as the foundation for a multipurpose LIS. Ideally, procedures would be enacted to incorporate new survey data into the geodetic reference framework periodically.

CONCLUSIONS

The geodetic reference framework described in this chapter is the foundation for a multipurpose land information system. By establishing an accurate framework, and then accurately relating land information to it, we create a pool of compatible information on which to base decisions. The accuracy requirements of this framework should be established based on the most stringent requirements of the system. The multipurpose LIS is not only a map; it is a system to "improve land-conveyance procedures, furnish equitable taxation, and provide much-needed information for resource management and environmental planning" (NRC 1980). With its focus on the parcel, the multipurpose LIS should support all of the requirements of land records, and its foundation, the geodetic reference framework, should be designed to meet these requirements, which are more demanding than those of mapping.

Single-purpose control is usually uneconomical in the long run because it is not consistent with other project-specific control systems for future applications. If the spatial relationship between adjacent projects is needed, their position, scale, and orientation must be stated with respect to common, compatible control. The control exists in a geodetic reference framework in the form of permanently monumented stations whose locations are accurately measured and mathematically described, relative to a common datum. Such accurate geodetic reference frameworks provide the most cost-effective spatial foundation for compatible, accurate land data, whether in map or in digital form. While local compatibility may be all that is needed for decisions involving a single, primary activity, users at a higher level, such as planners, investors, developers, and decision-makers in the regulatory process, must be able to relate independent sets of information and find that this type of data cannot be used in its existing form. These activities and decisions require large amounts of diverse types of spatial information, cutting across a large number of primary activities. When spatial data share a geodetic reference framework, they are spatially compatible.

The demand for compatibility among otherwise independent spatial information products makes the use of a single geodetic reference framework a source of economic value in a multipurpose LIS. The use of geodetic reference frameworks as the foundation for a multipurpose LIS ensures that the needs of those operating within a single activity or organization will be met, and more importantly, that the data generated by each activity can be used by others. The user can then use different data sets together to serve as the basis for reasonable decisions without additional data collection or expense.

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APPENDIX 3-1
SURVEY ACCURACY CLASSIFICATIONS

HORIZONTAL SURVEY ACCURACY CLASSIFICATIONS

Distance accuracy, 1:a, is computed using the formula a = d/s, where d = the distance between two points and s = the propagated standard deviation of that distance. The variable s is computed using an error propagation model that takes into account the design of the survey network and the accuracy estimates of the field measurements.

Classifications	Minimum distance accuracy, 1:a
Order A	1:10,000,000
Order B	1:1,000,000
First-order	1:100,000
Second-order, class I	1:50,000
Second-order, class II	1:20,000
Third-order, class I	1:10,000
Third-order, class II	1:5,000

GEODETIC LEVELING ACCURACY CLASSIFICATIONS

Height difference accuracy, b, is the relative height error between the two points, where $b = S/\sqrt{d}$, d = horizontal distance in kilometers between the two points traced along the leveling route and S = propagated standard derivation of height difference in millimeters.

Classifications	Maximum height difference accuracy, b
First-order, class I	0.5
First-order, class II	0.7
Second-order, class I	1.0
Second-order, class II	1.3
Third-order	2.0

(from FGCC 1984, 1988)

APPENDIX 3-2
POTENTIAL SOURCES OF SURVEY DATA

Agencies that have had geodetic surveys incorporated into the NGRS:

U.S. Geological Survey (Department of the Interior)
Bureau of Land Management (Department of the Interior)
Forest Service (Department of Agriculture)
Federal Highway Administration (Department of Transportation)
Soil Conservation Service (Department of Agriculture)
U.S. Army Corps of Engineers (Department of Defense)
U.S. Department of Housing and Urban Development
National Aeronautics and Space Administration
Tennessee Valley Authority
International Boundary Commission
Defense Mapping Agency

Potential sources of geodetic data are:

National Geodetic Survey
Bureau of Land Management
U.S. Geological Survey
Other Federal agencies
State agencies such as Department of Transportation, Department of Natural Resources
County agencies such as Public Works Department, Engineering Department
City agencies
Utilities
Private firms

APPENDIX 3-3
NGRS PRODUCTS AND SERVICES CONTACTS

To order the NGRS data products, contact:

National Geodetic Information Branch
N/CG174, Rockwall Building, Room 24
National Geodetic Survey, NOAA
Rockvillle, Maryland 20852
Telephone: (301) 443-8631

For information on the NGS workshop program, contact:

Mr. Edward J. McKay
N/CG13, Rockwall Building, Room 313
National Geodetic Survey, NOAA
Rockville, Maryland 20852
Telephone: (301) 443-8567

For information on the Federal Geodetic Control Committee, NGS state advisor program, or other NGS programs, contact:

Mr. Gilbert J. Mitchell
N/CG1x10, Rockwall Building, Room 622
National Geodetic Survey, NOAA
Rockville, Maryland 20852
Telephone: (301) 443-8143

4 LAND INTERESTS

Earl F. Epstein and Patricia M. Brown

In Chapter 1 we introduced the central themes of the *Guidebook:* the multipurpose land information system (MPLIS) and the vision for improving the nation's land information. Some of the most basic information about land, and much of what local governments want to include in an MPLIS, concerns *land interests.* Ownership, zoning, rights-of-way and easements, political jurisdictions, taxation—each of these is an example of a particular *interest in land,* defined in terms of *nature* and *extent.* The nature of an interest in land refers to the rights and restrictions affecting the use of the land and its resources. The extent of land interests refers to the boundaries of those interests in space and time. In this chapter, we describe land interests in the United States, how they have evolved over time, and how they have shaped our land records systems. In Chapters 5 and 6 we focus on the extent of land interests, and specifically on parcel boundary descriptions.

CHANGING CONCEPTS OF LAND

Our concepts of land and interests in land have evolved over many centuries. In English feudal society, the relation between people and land was fixed. At all levels of society, services and duties were exchanged for the use of land. The sovereign granted lords of the manor control over the use of land in exchange for military support when needed, and the lords, in turn, allowed others to use the land in return for military service and foodstuffs. No one could sell the land, nor could they easily relocate.

Technological advances brought agricultural surpluses. A class of merchants and entrepreneurs came into being, along with a monetary system. Money began to substitute for prescribed services and duties. Under this new form of *tenure,* individuals gained greater control over land relative to their feudal superiors and demanded freedom in the private defini-

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tion of rights in land. One of the most famous examples of this transition is the Magna Carta, signed in 1215, the second item of which took from the king and gave to the barons the right to determine who would inherit an estate when a baron died.

The post-feudal practice of privately defined and controlled land interests was transported to America. Through the 18th Century and into the 19th, the American concept of land was based upon a stable agrarian society. Thomas Jefferson described, based on the political philosophy of John Locke, a society of small land holders where land was widely distributed in order to widely distribute political power. Land was measured, divided and distributed in family-sized parcels to many private citizens who decided how to use it. Land transfers were infrequent, people had a direct, personal relation with the land, and the value of land was closely linked with its agricultural potential.

With the industrial revolution, the concept of land ownership rights expanded to encompass other uses in addition to agriculture. Land transfers were more frequent, and people began to treat land as a commodity, the value of which was set by the market. Governments derived revenues from a property tax usually based on this *market value.*

This concept of land persists into the 20th Century. However, 20th Century society increasingly recognizes that land has value that derives from aesthetics, ecological function and other characteristics and uses of the land *even when these are not reflected in the market value.* This recognition often comes in the form of legislation that directly or indirectly controls the use of land. Examples at the federal level include the Food Security Act of 1985, the Clean Water Act, and the Clean Air Act. At the state and local levels a wide variety of laws and procedures restrict the uses of land that contains resources ranging from wetlands to farmlands, from vistas to historic areas. These laws are an alternate expression of demand, and the public interest in land they create overrides and limits private interests.

THE BUNDLE OF RIGHTS

The ownership interests associated with land are like the sticks shown in Figure 4-1, with each stick representing a right or an interest in land. In modern society the number and variety of interests in land is considerable. Traditionally, the largest and best recognized collection of privately held rights are those associated with *fee simple absolute ownership,* also called *fee simple,* or just *fee,* referring to what most of us think of as the rights of private land ownership. Alternatively, one person may own rights to use the land surface, another the minerals below the surface, another a lease, and another a mortgage. Overriding these interests are public interests, such as the right to tax, the right to navigate, the right of eminent domain, and the more recently emerging rights to limit the use of land in order to protect the common health, safety, and welfare.

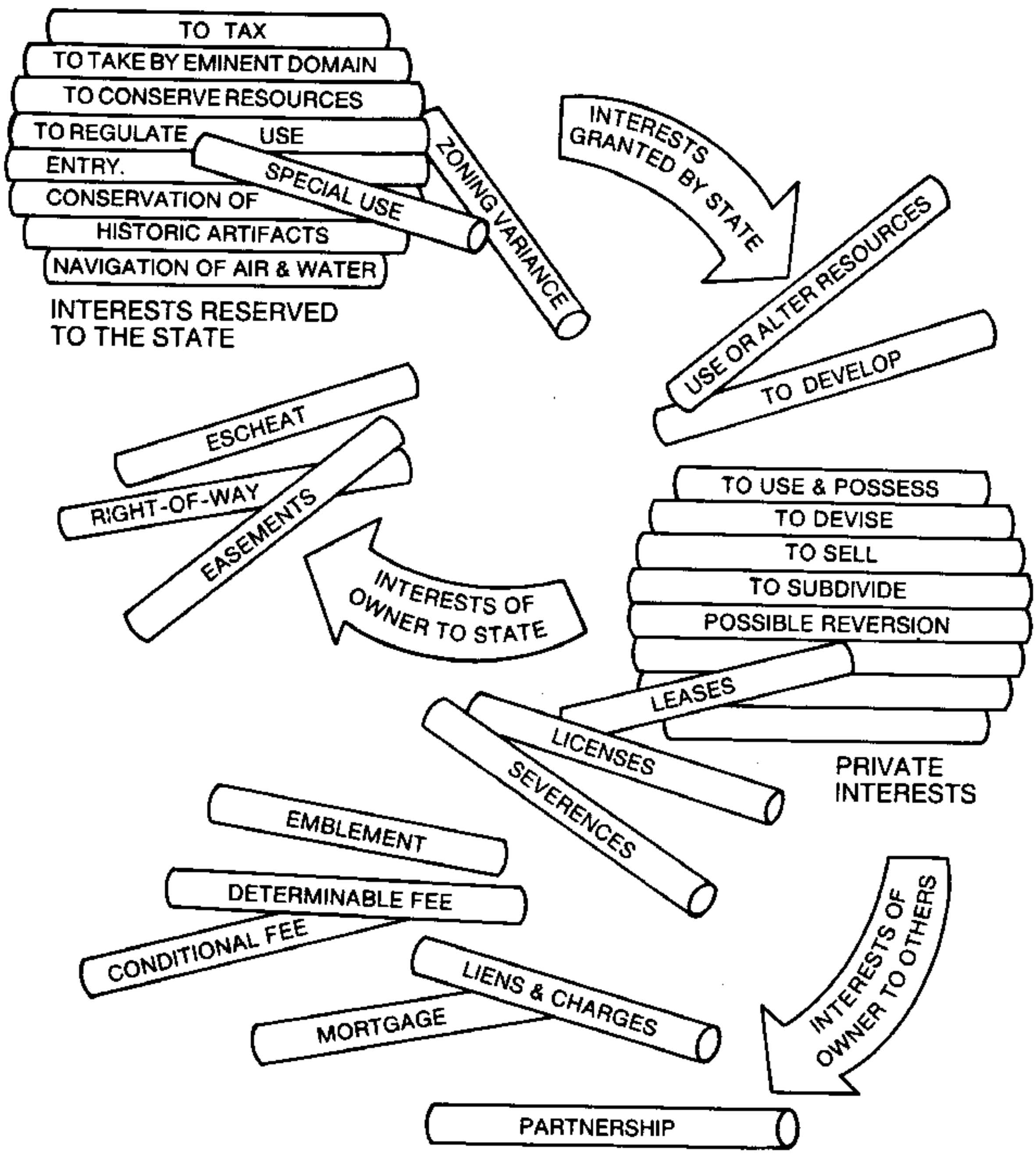

Figure 4-1: The Bundle of rights or interests is dynamic.

The Battle of the Peace River

In 1977, Coastal Petroleum, one of the firms digging West Central Florida's rich phosphate deposits, sued competitor Mobil Mining & Minerals in Polk County Circuit Court. Coastal's claim against Mobil was staggering: $2.5 billion in damages for taking phosphate from state land where Coastal said it held mineral rights.

The suit had its roots a century earlier, when the natural resources of Florida, a swampy, sandy, prickly place that puzzled and frustrated its conquerors, were valued mostly for their income potential. Land was plentiful and cheap, much of it under water much of the year. The state gave away millions of acres of the swamps or sold it for as little as a quarter an acre, to induce the Northern rail and industrial barons to make the boggy peninsula sprout crops and commerce.

Some of the state's inheritance of land was not to be given away. The navigable waters were held as a public trust—a principle drawn from English common law.

So, too, was the land immediately along the rivers, from the channel out to an imaginary line where the highest water during summer floods would ordinarily reach. That, the argument went, was the real extent of a river. Where to draw the ordinary high-water line, which defined the area of state ownership, was pretty much anybody's guess since early Florida surveys are notoriously unreliable—or fraudulent.

By 1941, the state was leasing its land instead of giving it away. Along the Peace and Alafia rivers, two streams in Central Florida, Coastal Petroleum got the rights to mine phosphate within the area the state said it owned. The suit was filed after Coastal discovered that Mobil had been mining the same land.

Mobil came back with its own set of old papers. One was a hand-written deed, signed June 13, 1881 for the same land the state and Coastal later claimed. Mobil had bought the land and mined the phosphate and paid the taxes. For that, they were now being sued for $2.5 billion, and they intended to defend themselves.

In vigorously pursuing that defense, Mobil would inevitably bring up a bothersome little side issue: through the land in Mobil's deed, the Peace River flowed. But Mobil's deed didn't mention it—as if the river itself had been sold with the land.

Mobil said the Peace River did not belong to the people of Florida. It belonged to Mobil Oil Corp.

Mobil's claim on the Peace meant the people of Florida were now a party to the conflict. Florida's grab bag history of land and money was littered with thousands of deeds such as Mobil's. Might the state lose its claim to its lakes and rivers because a century ago, overzealous boosters, relying on erroneous surveys, had unwittingly sold them off? Did the public retain its inheritance, regardless of yesterday's mistakes?

In 1982, Mobil sought to settle the questions. It sued the state to win undisputed title to the Peace River land. Coastal dropped out of the legal tangle in January 1987, but by then the state had jumped in, seeking $60 million from Mobil for mining on state land—the same land Mobil said it owned. Both sides hoped for a precedent that would determine, in this case and others to follow, how much land along rivers the state could claim—or which rivers might actually be private property. Their mission was to seek two fundamental truths: the history of boat traffic on the Peace River, to prove navigability, and the highest point the water would ordinarily reach, to define the extent of state ownership. Those were the narrow issues around which the trial would revolve.

In November 1987, the lawsuit was settled out of court in favor of the State of Florida, based on the State legal team's documentation of the wreck of a barge in the Peace River. One of the stipulations of the settlement was that "the deal could not be cited as a precedent in other state land disputes."

The above is an extract from "Keeping the Peace" written by Randy Loftis and published in the February 26, 1989 issue of Tropic, the Sunday Magazine of the Miami Herald. Randy Loftis is a staff writer with the Miami Herald.

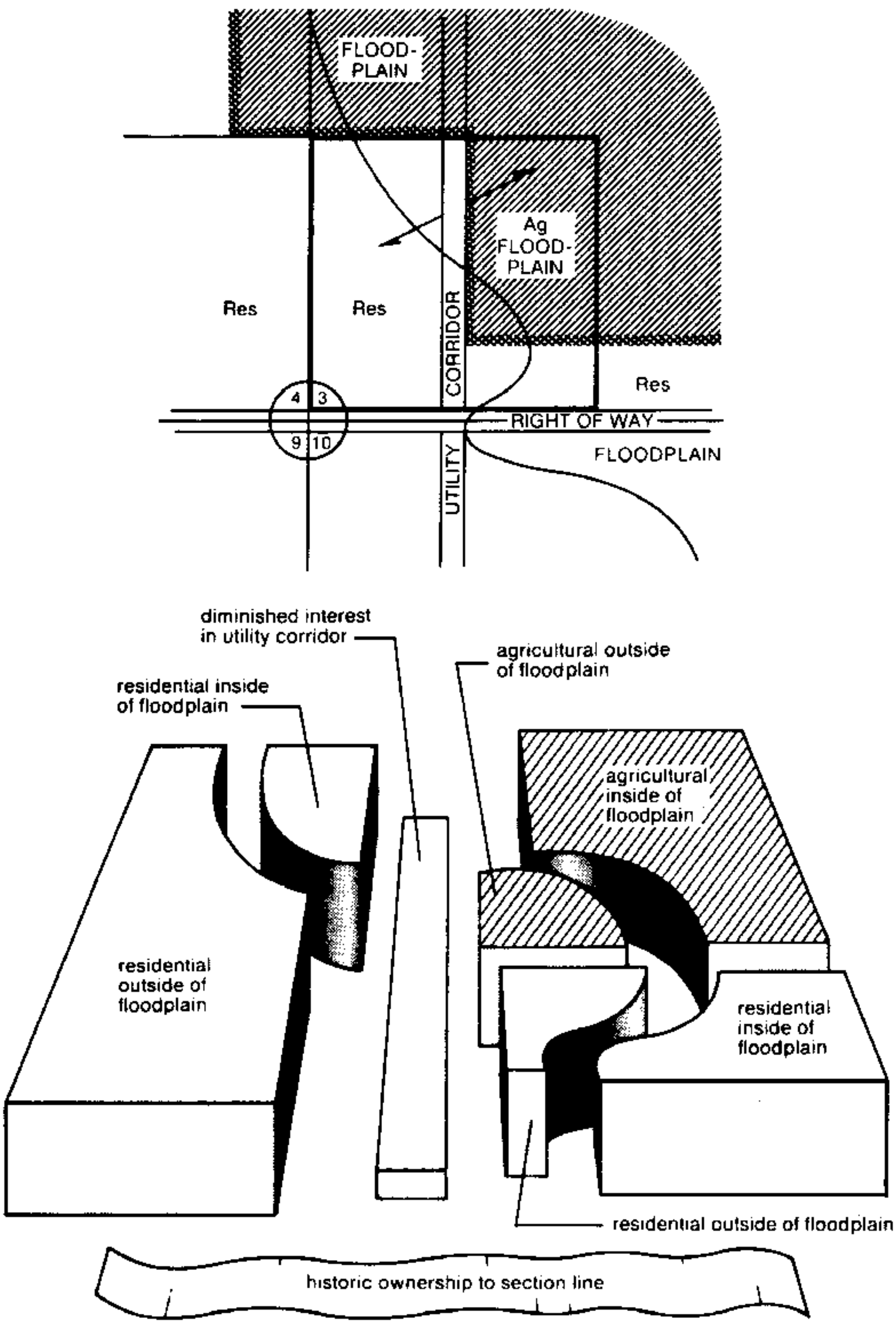

Figure 4-2: Land interests fracture the parcel.

The list of the rights and interests associated with land seems to be unlimited; individuals and society continually create new ones. Air rights, for example, were not made explicit until technology made it possible to use the space above a piece of property separate from its use at ground level. Similarly, the public interests in protecting the ecological function of wetlands and the productivity of farmland have been articulated only during the last thirty years or so.

The bundle of rights paradigm successfully represents the complexity of land interests. This complexity is reflected in records of land interests, which incorporate traditional concepts of the land parcel. Most of us think of the land parcel in terms of ownership, or as the unit of land described in property surveys and subdivision plats. However, many interests in land *fracture* this parcel or extend to many parcels, as shown in Figure 4-2. Information about the nature of the interest cannot always be ascribed to a particular parcel. The information is at the *parcel-level,* but it is not necessarily *parcel-based. The ideal MPLIS would record the nature and extent of all public and private land interests and would provide the capability to retrieve information about these interests for any land area.*

THE DIMENSIONS OF LAND INTERESTS

Property boundary descriptions in commonly held records are usually limited to a narrow subset of interests, such as fee simple and easements. The property description usually specifies only two dimensions of a unit of land; how these are described is the subject of Chapters 5 and 6. There are other dimensions to land interest parcels today however, and improved land information systems must accommodate their description in some way.

AIR AND SUBSURFACE RIGHTS

Air, or *superjacent,* rights are associated with the use of space above a piece of property. *Subsurface,* or *subjacent,* rights are those associated with the use of space below the surface. Originally, the owner of a parcel of land held all the rights to the use of the space, and the resources within it, demarcated by planes from the center of the Earth through the boundaries and upward. In some cases, superjacent or subjacent rights have been sold by their owner, in exercise of the privilege of *free alienation.* In other cases, limitations on the exercise of these rights have been changed through public actions. One example is the modification of air rights to accommodate air traffic. Figure 4-3 illustrates the dimensions of land interests.

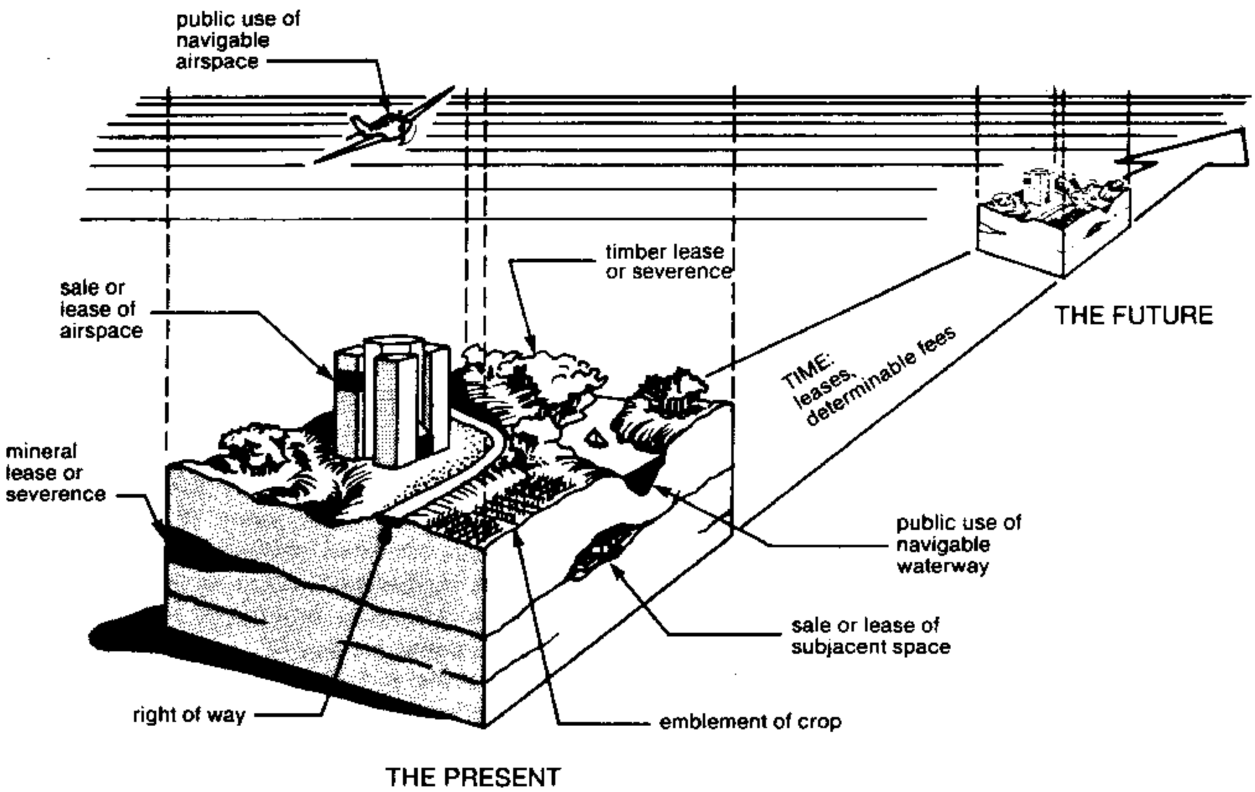

Figure 4-3: The dimensions of land interests.

TIME

Land interests may be limited in time as well as in space. For example, a *life estate* gives use of a land parcel for the life of a particular person. Others are limited to the indefinite period during which a prescribed use exists, and others are limited to a repeating period of time, such as with a time-share unit.

CHARACTERISTICS

Land rights may be granted or restricted according to the presence or absence of specific characteristics, rather than by specific descriptions of location or time. This technique is often used in legislation designed to protect environmental or cultural resources. For example, legislation might limit the uses of wetlands based on the soil or vegetative characteristics. Implementation mechanisms then depend upon the identification of these lands at the parcel level. Similarly, flood plain legislation typically limits the uses of land below the elevation of the 100-year or 50-year flood, but that elevation depends on permeability of soil or land cover, climate and other characteristics of the watershed, and may change if those characteristics are altered. The area affected by the legislation is often poorly identified.

EXISTING LAND RECORDS SYSTEMS

Transfer of land to private ownership was recognized as a basic function of government during the settlement of North America. The institutions for recording land interests in the United States developed at that time (NRC 1980, p. 7). Underlying our recording systems is the *principle of public notice,* i.e., that documents affecting land interests should be recorded in a public place and available for inspection.

> The early North American cadastral arrangements were designed to promote quick, efficient, and secure land settlement. The alienation of public or crown lands, as a means of inducing European emigration, was from the outset recognized as a basic function of government in the English colonies. In support of this policy, three uniquely North American land-record tools were developed, the American recording system, the commercial abstract, and the public-land survey system (albeit, the latter was only developed in the western portion of the continent).
>
> English land-conveyancing practices at the time of the American colonization were dominated by two characteristics:
>
> First, the substantive law has reached its technical worst, and second, the structure of institutions and practices employed were still fluid, relatively undeveloped, and in a state of transition and experimentation (Payne 1961).
>
> As a result, the colonial land-record systems that evolved in the New World were a strange mixture of old English private conveyancing practices and some entirely new institutions. Among the English practices adapted were the concept of a conveyancing profession and the abstract of title. These were blended with two new institutions, the American recording system and the commercial abstract. The form of the American recording system was first described in the early seventeenth century recording statutes of the Plymouth, Massachusetts, Virginia, and Nova Scotia colonies. These statutes had four characteristics that persist today in the deed-recording laws of the United States and the eastern provinces of Canada:
>
> 1. The instrument of transfer, such as deed and mortgage documents, must be acknowledged before a public official before recording;
> 2. The entire instrument must be recorded;
> 3. Legal priority is generally assured the grantee by the act of recording; and

4. The instrument is operative without recording, with the title passing before the instrument is recorded.

NRC 1980, pp. 7-8

In the United States records that describe the transfer of interests are generally maintained at the county level, except in Connecticut, Rhode Island, and Vermont, where the city and town governments perform that function (NRC 1980, p. 17). Most land records systems have remained essentially unchanged since they were established. They were designed simply to record deeds and documents bearing on interests in land:

> . . . the land tenure system presently used in the United States is a rudimentary deed registration system, negative in nature and formulated to fit a rural, agrarian society. As land and building development exploded across America, with its attendant public controls and successive transfers of title, public registries became crowded with those who needed information about the land. Owners, buyers, realtors, investors, conveyancers, conservationists, census takers, utility personnel, among others, literally nudged one another in small areas to absorb and chronicle information about the land.
>
> *NRC 1980, from Fenton 1976*

The public records may be more or less *incomplete* over time, depending on law, historical conditions and events, and the practices in all the various professions involved. The recordation of title documents is voluntary, while recordation is designed to provide protection through public notice, the transfer occurs regardless, and rights may be created with or without records. For example, easements have often been granted privately and informally. Even those held by local government, such as drainage and access easements may be unrecorded. Recorded or not, these are valid land interests. Further, the records may contain *incorrect and mutually contradictory information* that remains undiscovered until a problem is revealed by a search of the record.

Public records that must be considered as evidence in an examination of land interests are administratively and physically scattered among many agencies and levels of government. Because they are scattered, the records are often *redundant,* as similar information is required in various offices. Because of limited and cumbersome indexing and cross-indexing they are *functionally inaccessible.* For example, most local title records systems store documents in chronological order, maintaining one or two indexes, a *grantor/grantee index,* i.e., an index of the names of buyer and seller. The index refers to the location of copies of the document in bound volumes (book-and-page) or other media, such as microfilm. Some systems also maintain a *tract index,* which cross references the location of documents with the location of the land on which they bear. The location of land in a tract index is indicated by large areas, such as section, township and range, subdivision, or tract. These systems are convenient for the storers of records, but not necessarily for their primary users. The records systems serve other potential users even less well because *the records cannot be efficiently gathered, correlated, or aggregated within or between agencies, departments, and levels of governments.* This concept is illustrated in Figure 4-4.

SECURITY OF INTERESTS

A system of assuring *security of interests* has evolved in parallel with our land records systems. The institutions that maintain public records generally do not evaluate the substance of the documents submitted to them. That responsibility lies with the users. When individuals, groups, and institutions acquire a land interest, they generally require assurance that, once the transaction is complete, no *superior claim* exists that would nullify the transaction or reduce the new owner's interest. The most basic form of guarantee is the seller's personal warrant that the interests conveyed to the buyer is the set actually owned by the seller. The seller agrees to indemnify the purchaser for any monetary loss suffered by the purchaser should there be a defect in the ownership of any conveyed interest. The purchaser is not guaranteed against loss of the interest, but he may recover the value of the interest. The seller's warrant was practical at a time when transfers were infrequent, when people knew one another, and knew the land. We are long past such a time, and new methods of securing interests have developed to reflect current conditions.

Because the public records are scattered and incomplete, and because using them is time consuming, private institutions and professions have evolved to search and examine the evidence of land interests. Title abstracters search the public records and provide a *title abstract* of the chain of title, which lists the recorded documents that apply to a parcel and summarize their contents. The *chain of title* is the series of recorded documents covering the time from the present back to the original government grant or patent or a specified period, such as 40 years. (The abstracter may build his lists to a point where they cover most of the parcels in an area and are probably more readily used than the public records. These abstracter records are private, however.) The abstracter guarantees that the abstract accurately reflects what is in the

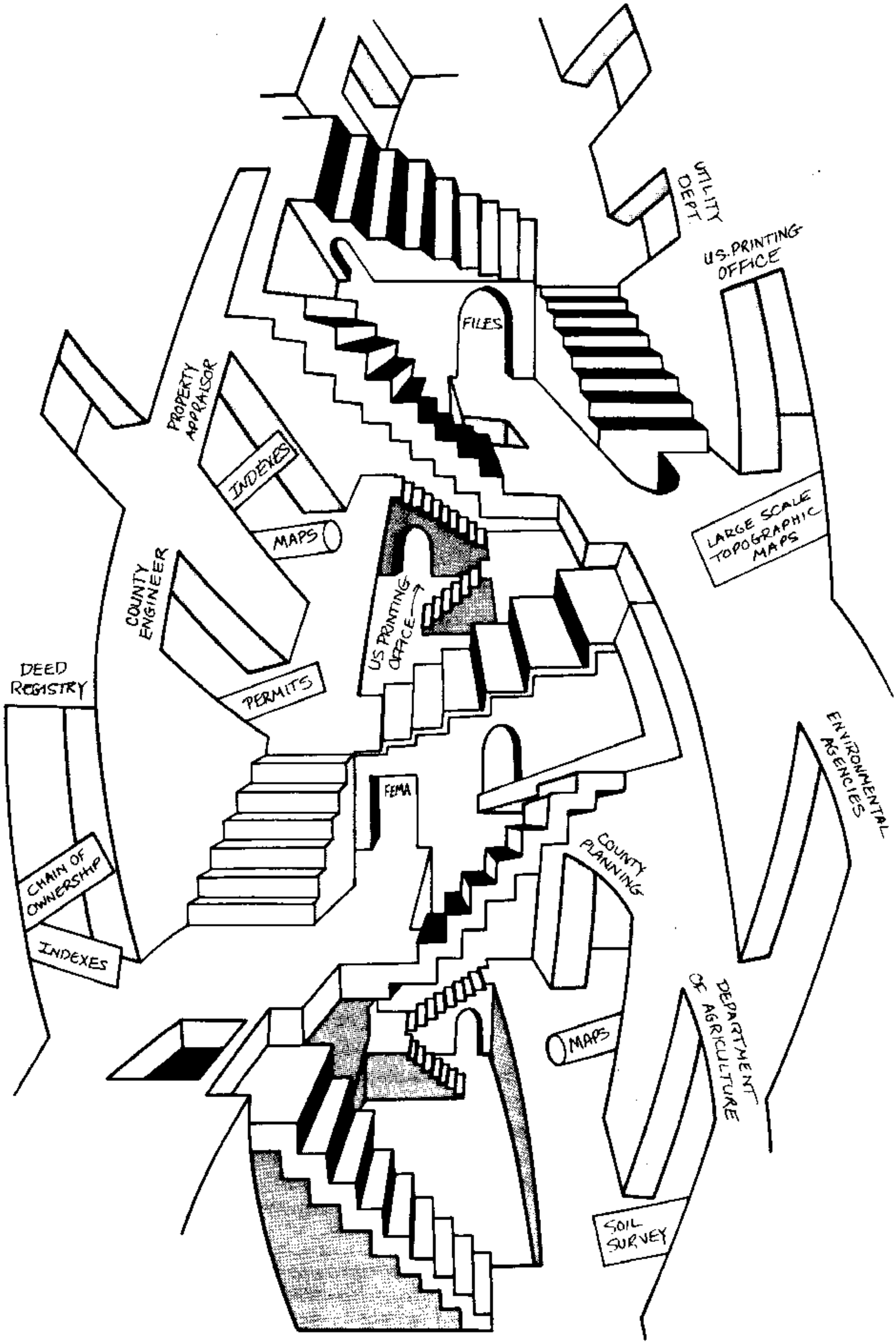

Figure 4-4: Existing records are functionally inaccessible.

public record. The abstracter does not guarantee that the public record is complete, nor does he render an opinion on the meaning of the records and their content.

The records listed in the title abstract are evidence of ownership; whether or not the evidence is sufficient to prove ownership is a matter of judgment. Parties to a land transfer who require greater assurance of ownership may obtain an *attorney's opinion.* A lawyer knowledgeable in land and other pertinent law, such as corporate, probate, bankruptcy, and divorce law, analyzes and interprets the legal significance of the documents in the chain, and offers an opinion about the status of the interest ownership. The attorney's opinion, which is still the principal method of assurance in some places today, guarantees against the negligence of the attorney, but his liability is often limited to the facts presented in the abstract, and excludes "fraud, forgeries, or acts of omission not of record" (Brown 1981, p. 325).

As transfers became more frequent, and as more land purchases were made at distances far from the land and far from the locally knowledgeable title attorney, a system of title insurance was added. Companies have arisen that not only prepare the abstracts and the opinions, but also assume the risks for a broader set of errors than that for which the title attorney is responsible. The mortgage loan business now relies on title insurance companies, which offer protection against a variety of record-based risks and also against risks not disclosed in the public records. The scope of the assurance depends upon the particular assurance policy, and can extend to coverage of boundary errors and conflicts.

These arrangements have all arisen to provide assurance to a buyer regarding the nature of the land interest acquired, its extent, i.e., location, size, shape and duration, and the status of his interest. They do not, however, provide government assurance of ownership. In contrast, in the Torrens system the state issues a government assured statement of ownership, the *registered title* (see Box 4-3). Most Torrens systems and the Massachusetts Land Court are examples of *judicial solutions,* that is the courts examine the evidence and determine the status before registering the title. (The Massachusetts Land Court also guarantees the boundary.) The Wisconsin Assessor's Plat provides *administrative solutions* that do not involve the courts before registering the title.

The Torrens system, developed in Australia and adopted in England, parts of Canada, parts of the United States, and Puerto Rico, requires registration of the title, as opposed to registration of evidence of title. The State, in turn, guarantees the sufficiency of title. Although many states in the United States passed enabling legislation, the Torrens system has not been widely implemented because of the costs of clearing all questions of title before registration, and the need to establish an indemnity fund to back up the guarantee of title. The Massachusetts Land Court, established in 1899, is similar to the Torrens system but guarantees both boundary and titles after 90 years of voluntary registration, and about 15 percent of the land area of the state has been registered.

SUMMARY

Our concepts of land and interests in land have evolved over many years and continue to change to accommodate changes in society. By the 19th Century, the market replaced agricultural potential as the measure of the value of land. In the 20th Century, other sources of value have been recognized, such as aesthetics and ecological function, and are reflected in legislation as a public interest.

The types of land interests are almost unlimited; new ones are added as society needs them. And while the most common collections of land interests, such as fee simple ownership and easements, are generally described in two dimensions, all interests have depth and height and a dimension in time. Also, land interests may be described in terms of characteristics, such as "within the 100 year floodplain" or "wetland," without simultaneously describing its spatial or temporal dimensions.

In the United States records of land interests are maintained primarily at the county level. The systems that house these records have changed little since their inception. As a whole the records are incomplete and often contain incorrect and contradictory information. At the local level they are often redundant and difficult to use, especially for planning and land management.

The public records systems are repositories of information. The status of ownership and the location of boundaries are a matter of judgment. The seller's warrant, the title abstract, the Attorney's opinion, and title insurance are all methods that have been used to provide some assurance of the nature and extent of the land interest being conveyed. Torrens, the Massachusetts Land Court, and the Wisconsin Assessor's Plat are examples of institutional arrangements that provide a government guarantee of title.

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APPENDIX 4-1
LAND INTEREST TERMINOLOGY

Appurtenant easement: an easement that "runs with the land," that is, that continues to encumber the servient estate, and to enhance the dominant estate even in the event of title transfer (SCWRC 1989).

Condemnation: the process by which property of a private owner is taken for public use without his consent, but upon the award and payment of just compensation.

Deed of Trust: similar to a mortgage, a deed of trust by which legal title to real property is placed in one or more trustees (Black 1968, Brown 1986).

Defeasible Title: one that may be annulled or made void, but which is not already void (Black 1968).

Easement: a nonpossessory, irrevocable right to use a particular piece of property generally specific to a particular use. Usually refers to an appertenant easement (SCWRC 1989).

Easement in gross: an easement that attaches to an individual rather than to the estate, such as an easement to fish or hunt on a parcel of land (SCWRC 1989).

Eminent domain: the power to take private property for public use (Black 1968).

Estate: the interest which anyone has in lands or in any subject of property. Often classified by time of enjoyment, e.g., life estate, estate for years, estate at will (which may be terminated at any time). Estate in fee, or estate in fee simple absolute, is the most absolute of land interests and is theoretically infinite in duration (Black 1968, SCWRC 1989).

Fee or fee simple: see *estate* and *fee simple absolute.*

Fee Simple Absolute: ownership of land with unrestricted right of disposition; the most common type of ownership (SCWRC 1989).

Fee Simple Defeasible: ownership of land with same rights as fee simple absolute, except that title may be annulled or lost on the occurrence of a contingent named by the grantor, e.g., grantee may be limited to or prohibited from certain uses (SCWRC 1989).

Incorporeal right: a right which is attached to and belongs with some greater and superior right, which passes as incident to it and is incapable of existence separate from the superior right.

Joint Tenancy: property interest held by two or more persons. Upon the death of a joint tenant, ownership of the share passes to the other joint tenants. Joint tenants share as a group the authority for determining the land and its resources. Each joint tenant has the right of quiet enjoyment of the property (SCWRC 1989). (See *tenancy in common.*)

Land under navigable waterways: under common law, the land under navigable waterways belongs to the public. The definition of the boundaries of the waterway vary: mean high water, high water, ordinary high water (SCWRC 1989). (See also *navigable waterways.*)

Leaseholds: an interest created by a contract for the use and possession of lands, buildings, or other property for a specified period of time and for fixed payments; an estate for a fixed term of years. Leaseholds generally convey only limited authority over the use and disposal of the property and its resources (Black 1968).

Licenses: revocable permission to use a piece of property. Licenses do not "run with the land," but instead terminate with the transfer of the title. They may be revoked within certain limits and are limited to the specified uses of resources. Permission or authority to do a particular act or series of acts on land of another without possessing any estate or interest therein (Black 1968, SCWRC 1989).

Lien: a charge, security, or encumbrance upon property to secure a debt (Brown 1986).

Mortgage: a lien on real property giving the loaning party the right to sue for title and possession of a piece of real property (Brown 1986). An estate created by a conveyance absolute in its form, but intended to secure the performance of some act, such as the payment of money, and the like, by the grantor or some other person, and to become void if the prescribed terms are not met (Black 1968).

Navigable waterways: the interpretation of the term navigable waterway varies. (See also *land under navigable waterways* and *ownership of navigable waterways.*)

Navigable water of the United States: waters are "navigable water of the United States" when they form in their ordinary condition by themselves, or by uniting with other waters, a continued highway over which commerce is or may be carried on with other states or foreign countries in the customary mode in which such commerce is conducted by water (Black 1968).

Navigation rights: the public right of navigation and passage over all water deemed navigable. Therefore, the government has the right to prevent obstruction, appropriation, or alteration that would impede or prevent navigation. (See *navigable waterways.*)

Ownership of navigable waterways: under common law, and sometimes statute law, all navigable waters belong to the public. (See *navigable waterways.*)

Parcel-based information: information that describes individual ownership parcels; attributes of ownership parcels.

Parcel-level information: information that is of sufficient resolution and accuracy to support valid analyses for ownership parcels.

Patent: the title conveyed by the government describing land disposed of by the government (Brown 1986). A grant of some privilege, property, or authority, made by the government or sovereign of a country to one or more individuals. In American law, the instrument by which a state or government grants public lands to an individual (Black 1968).

Police power: the power vested in a state to establish laws and ordinances for regulation and enforcement by its police (Black 1968).

Possibility of reverter: an interest in land whereby ownership passes from the owner of fee simple conditional title to the owner of the possibility of reverter upon failure to meet the condition (SCWRC 1989). This term denotes no estate, but only a possibility to have the estate at a future time (Black 1968).

Profits: the right to take a portion of the products of a piece of property. Profits are treated as easements under the law in that the interest is limited to a particular use or resource (SCWRC 1989).

Public domain: all lands belonging to the Federal government (Brown 1986) and which are subject to sale or other disposal under general laws, and not reserved or held back for any special governmental or public purpose (Black 1968).

Public lands: unoccupied government lands that are subject to sale or other disposal under general land laws (Brown 1986).

Publicly owned land: land belonging to a governmental body (Brown 1986).

Quiet Title, action to: an action at law to establish the plaintiff's title to land by bringing into court an adverse claimant (Black 1968).

Remainder interests: upon his death, ownership of land passes from the owner of a life estate to the owner of the remainder interest. The remainderman has no right to the use of the land or its resources, but may prevent the life tenant from using the property "in a way that would substantially and permanently reduce the market value of the property" (SCWRC 1989).

Restrictive covenant: a promise to refrain from specified uses of the land or its resources. A covenant is enforceable by the original parties and their assignees (SCWRC 1989).

Servitude: a charge or burden resting upon one estate for the benefit or advantage of another. Servitude has relation to the burden or the estate burdened (Black 1968).

Taxation: the process of taking or imposing a tax. Exacts money or services from individuals, as and for their respective shares of contribution to any public burden (Black 1968).

Taxation, right of: the right to impose and to take taxes.

Tenancy in Common: property interest held by two or more persons with no right of survivorship. Tenancy in common is the most common type of joint ownership. Upon the death of one tenant in common, one share of the property passes to the heirs, while the other shares remain with the tenants in common (SCWRC 1989). (See *joint tenancy*.)

5 PROPERTY BOUNDARIES

Patricia M. Brown

As we have said, the record of land interests consists of descriptions of their nature and extent. *Property descriptions,* also called *land boundary descriptions, land descriptions,* and *legal descriptions,* record the spatial extent of certain common types of land interests, such as fee simple, easements, and rights-of-way, and primarily in two dimensions. Developing an MPLIS provides the opportunity, and the challenge, to create a spatially accurate compilation of property descriptions in the public record. Unfortunately, this is not a straightforward task. Typically, the property descriptions for any particular area contain contradictions, inconsistencies, errors, and omissions. At present it is up to the owners and the courts to resolve these problems based on the evidence. The system that has evolved to guarantee security of interest (described in Chapter 4) is a response to the difficulty, delay, and cost associated with this means of resolution.

The compilation of property boundaries brings to light inconsistencies in the evidence. Methods and accuracies for compiling land parcel maps, some of which are presented later in the *Guidebook* are the subject of considerable discussion in the field of geographic and land information systems at this time because they significantly affect the cost and utility of an MPLIS. They also determine the system's contribution to improved land records. The underlying issues are found in how property boundaries are described and monumented, which are the subjects of this chapter and Chapter 6.

PROPERTY DESCRIPTIONS

For any particular parcel, the chain of title leads back through a series of property descriptions to the original conveyance. If it does not conflict with the descriptions of neighboring parcels, the original description sets the boundaries of

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all subsequent divisions of the land. These in turn bound later divisions unless parcels are formally combined, as through a subdivision, for example. In addition to the basic division of the land, there may be legal descriptions for easements, rights-of-way (ROW), land use restrictions, and other public and private land interests associated with a particular parcel. Also, a deed may contain a general description, but refer to a plat or another description, i.e., *a description by reference.* Or it may name a lot shown on a plat and exclude a portion by reference to another deed. Finally, some government offices, often the assessor, maintain in their files an abbreviation of the description found in the deed. While this is not a recorded description and may not be complete, it may be the most accessible and is often used in place of the descriptions found in the legally recorded document. Similarly, the compiled parcel maps represent a summary of the recorded descriptions and are commonly used in place of the legal record. There are cases where these documents have been submitted as evidence of title in boundary disputes.

A property description consists of the caption, the body, and qualifying clauses. The caption sets the stage for the rest of the description, providing background information including a statement of purpose. If any later part of the description is in conflict with the caption, the caption rules. For example, if a description begins with "land lying within the southwest quarter of section 10," then the document is limited to that quarter section even if the detailed description runs outside of it. The body contains the detailed recital of the property description. It should be clear and complete, naming all the necessary facts without contradiction or ambiguity. The qualifying clauses may exclude certain rights or areas or include additional rights or areas. Occasionally, a conclusion will be added, containing less important information.

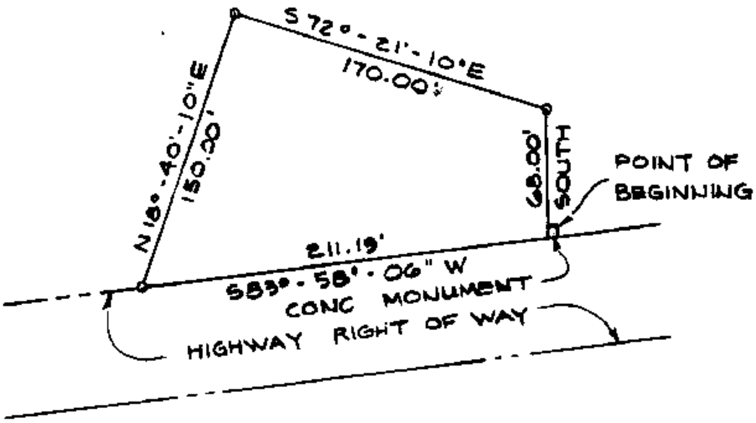
A good property description unambiguously identifies the location of the parcel on the ground and describes the boundaries accurately, briefly, clearly, and completely (McEntyre 1985, p. 29). Most descriptions in the United States use one or more of the following three methods of describing property boundaries: *metes and bounds, the Public Land Survey System* and *aliquot parts,* and *platting* (McEntyre 1985, p. 25). Rights-of-way and easements often use a *strip description.* Other methods include so-called *"of" descriptions* and *coordinates.*

METES AND BOUNDS SURVEYS

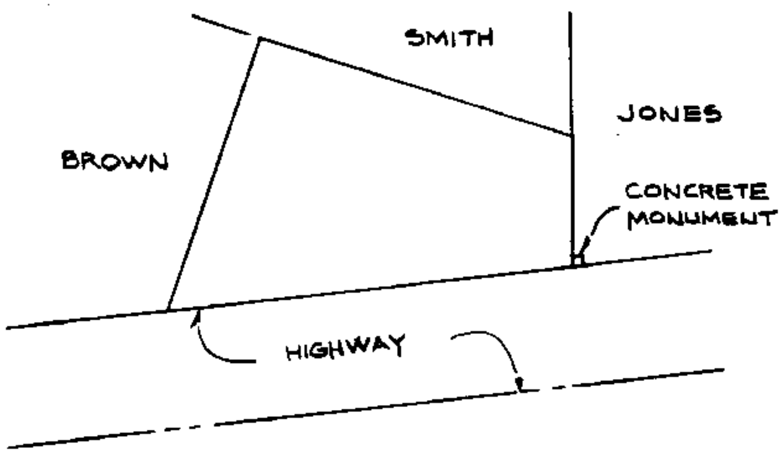
In 18 eastern states, Texas, and Hawaii, legal descriptions usually use the metes and bounds method. (See Figure 5-1.) Metes and bounds are also used to describe subdivision perimeters and irregular parcels in the PLSS states. Typically, metes and bounds describe a parcel of land as though it were an island standing on its own.

Figure 5-1: PLSS and metes and bounds states.

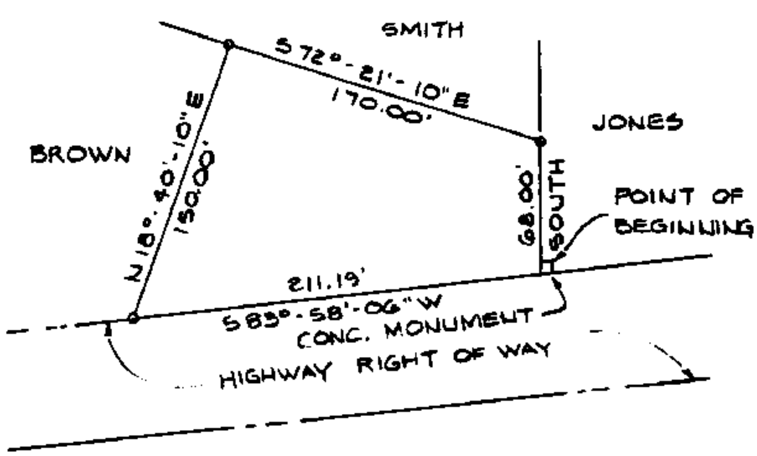
The term *metes and bounds* refers to two kinds of descriptions: *running descriptions* and *bounding descriptions*. Figure 5-2 shows examples of metes and bounds descriptions. In a *running description*, metes, or measures of angles or distance, predominate. The narrator starts at a *point of beginning (POB)*, which may or may not be related to other landmarks in its vicinity. The description then runs either



a. Metes: Beginning at a concrete monument, thence S83°-58′-06″W 211.19 feet; thence N18°-40′-10″E 150.00 feet; thence S72°-21′-10″E 170.00 feet; thence South 68.00 feet to the point of beginning.



b. Bounds: Southwest along the highway, Northeast by land of Brown, Southeast by land of Smith; South by land of Jones to the aforementioned highway.



c. Metes and bounds: Beginning at a concrete right of way monument, thence S83°-58′-06″W 211.19 feet along the North right of way of the highway; thence N18°-40′-10″E 150.00 feet along the East line of Brown; thence S72°-21′-10″E 170.00 feet along the South line of Smith; thence South 68.00 feet along the West line of Jones to the point of beginning.

Figure 5-2: Sample metes and bounds.

clockwise or counter-clockwise around the perimeter boundary, using directions (or bearings) and distances. The line is described as running along or "by" an abutter's property or an abutting street. Each line ends at an angle point or corner, sometimes described by a monument, such as a fence corner, stone mound or iron pipe. The description leads back to the point of beginning and usually gives an area in square feet or acres. A *bounding description* reads as if the narrator were standing within the parcel looking outward, describing each boundary as it is observed from the inside by direction such as northerly, southerly, and a distance. Again, abutting names and features may be cited as well as monuments and acreage.

A legal description may consist of a running description, a bounding description, or a combination of the two. A metes and bounds description often includes reference to a survey plat, which may or may not be recorded with the deed. In case of a conflict, the courts have generally held that the metes and bounds description in the deed prevails over the plat. If the description is vague, then the plat is the controlling feature. A metes and bounds land corner may be any monument that is in one or more descriptions.

THE PUBLIC LAND SURVEY SYSTEM

The Public Land Survey System (PLSS) created the original parcel boundaries for most of the land area in 30 states. (See Figure 5-1.) Authorized in 1785, the PLSS divided land into approximately square parcels. The original *patents*, by which land passed from the public domain into non-Federal ownership, were based on the PLSS. Legal descriptions in the PLSS states still refer to the PLSS either by reference to aliquot parts or to the land corners created and placed under the PLSS. The term *aliquot parts* refers to the approximately square subdivisions of the township and section. PLSS land corners are generally monumented at township and section corners and at quarter section corners, when they are present.

The measurements shown on the PLSS plats filed by the original surveyor do not always correspond with resurveys of the actual monuments. The Bureau of Land Management (BLM), the Federal agency responsible for the PLSS, has published procedures that govern the subdivision of aliquot parts and take this problem into account. Ambiguities and conflicts can arise, however, when metes and bounds are used to describe land within the PLSS, as shown in Figure 5-3. The BLM also has established procedures for restoring or reestablishing PLSS corners which have been *lost* or *obliterated*. The PLSS is described in greater detail in Chapter 6.

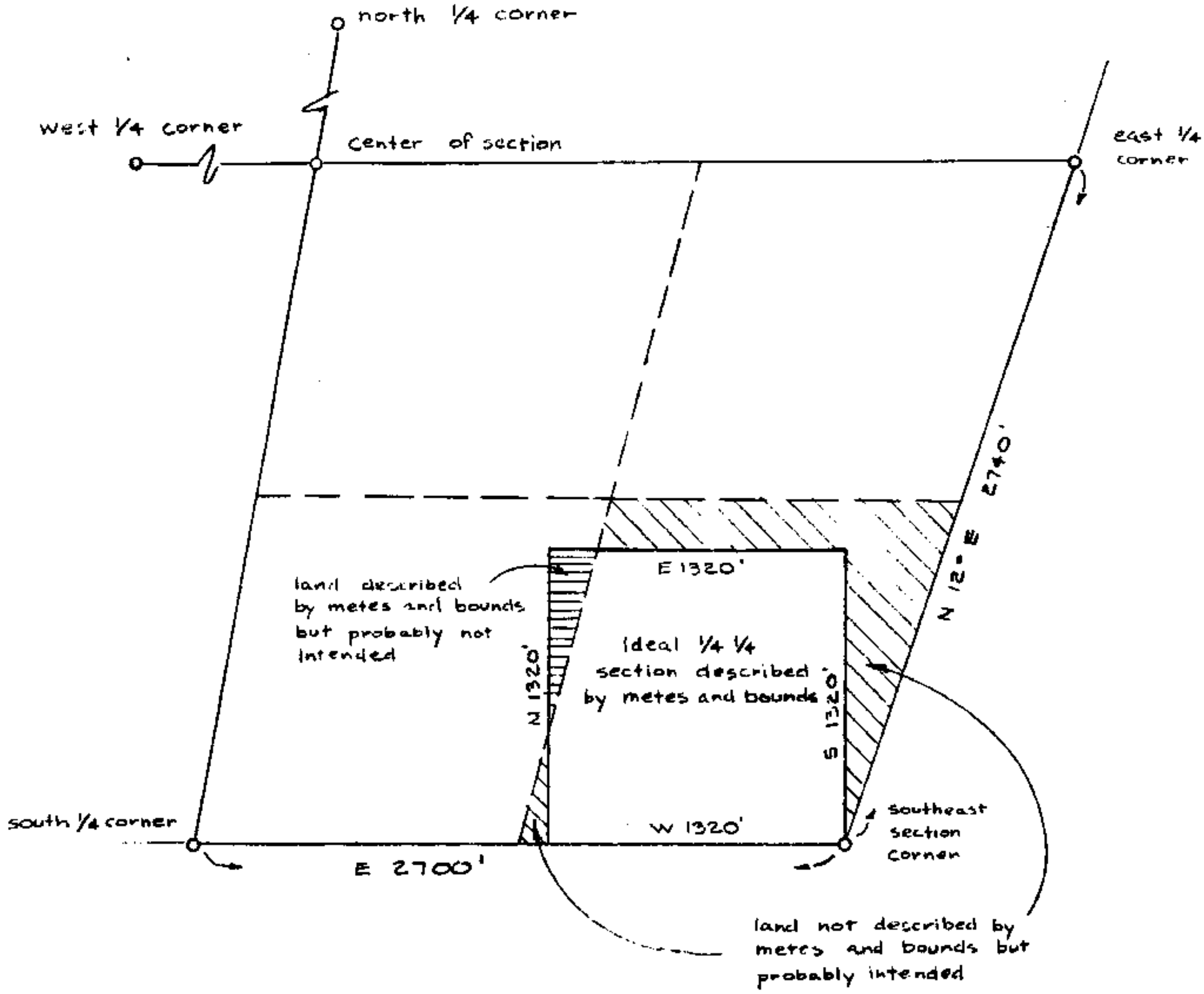


Figure 5-3: Mixing PLSS and metes and bounds descriptions (from Brinker and Minnick 1989, pp. 1071-1072).

PLATTING

The term *plat* is generally used to describe a map or drawing showing property boundaries. The drawings of PLSS surveys are called plats, as are those submitted as part of the subdivision process in most jurisdictions. Most states and many local governments have by now enacted platting laws, often as a part of subdivision regulations. Typically the platting act requires plat surveys to meet certain accuracy and monumentation standards and to be tied to other monuments to establish the relationship between the parcel and its neighbors, as shown in Figure 5-4. The laws usually require the plat to be recorded as well. In developing areas, the boundaries of a large majority of parcels created in the last 30 to 40 years are described on plats governed by these regulations. While subdivision regulations have broader land development objectives, the purpose of the platting act is to improve the quality of land records. Subsequent legal descriptions and references to parcels created by subdivision plat typically refer to lot number, block or part, the subdivision name, the local jurisdiction, and the state.

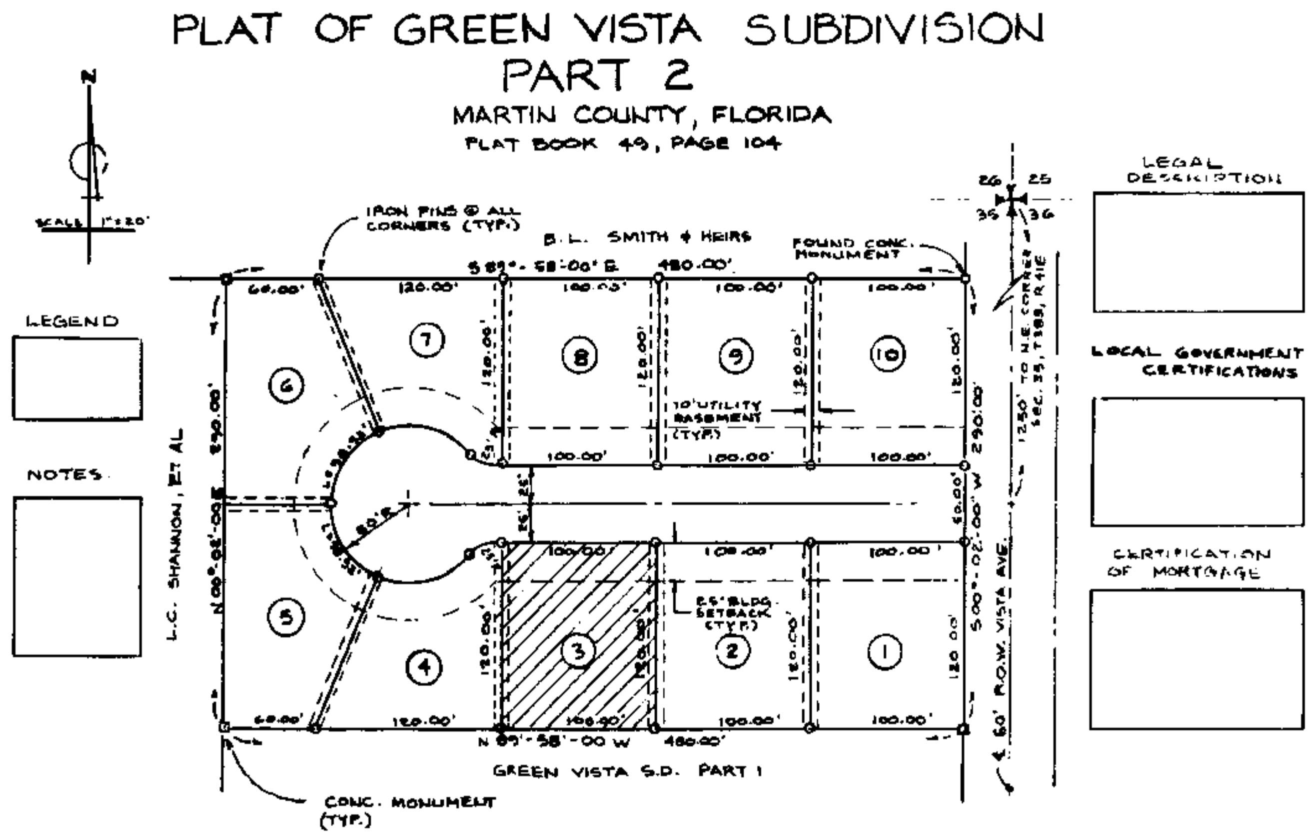
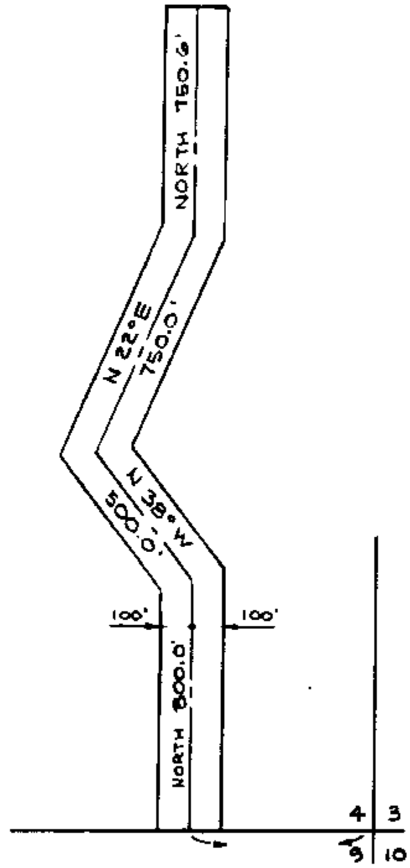


Figure 5-4: A plat.

STRIP DESCRIPTIONS

A *strip description* describes a piece of land by means of a reference line and a width. The reference line is typically a surveyed centerline when the land being described is a right-of-way or easement for travel. For landscape easements, road widenings, and certain other cases, the reference line may be an existing parcel boundary or right-of-way boundary. Figure 5-5 shows an example of a strip description.



A strip of land 200 feet wide, 100 feet on each side of the following described centerline:

Beginning at a point on the South line of section 4, Township 35 North, Range 36 East, being 586.4 feet west of the southeast corner of said section 4; thence North 800.0 feet; thence N38°W-500.00 feet; thence N22°E 750.0 feet; thence North 750.6 feet to the north line of the southeast quarter of said section 4; the side lines of said description being shortened or elongated to meet the property lines of the Grantor.

Figure 5-5: Strip description.

"OF" DESCRIPTIONS

The "of" (or "ly") form of description is often used to specify a portion of an already described parcel, as in "the easterly 35 feet of Lot 12" or "the western half of Section 20." These are useful and often the simplest way of describing the intended portion, but they can easily cause difficulties, particularly when irregular shapes are involved, as shown in Figure 5-6.

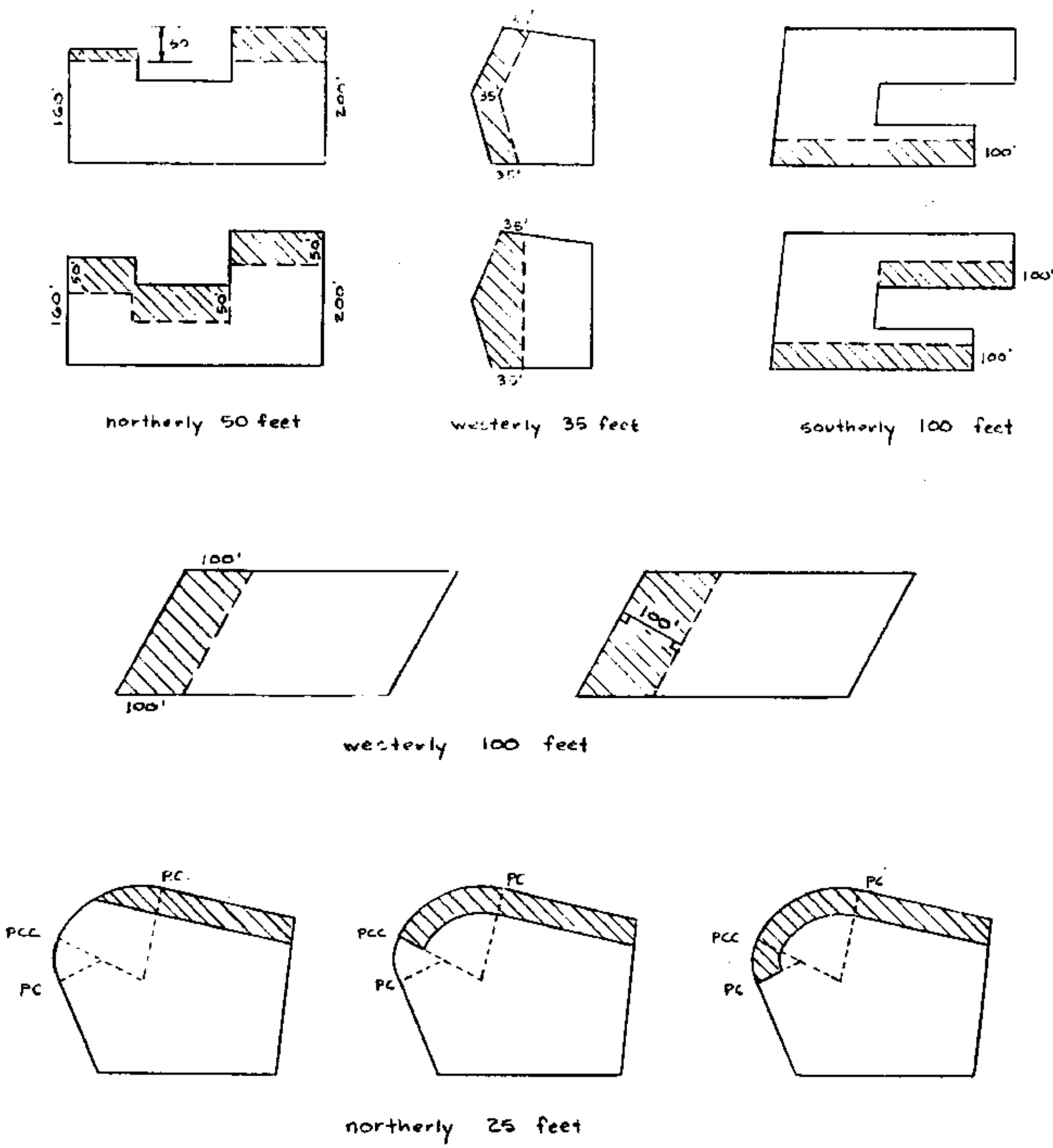


Figure 5-6: Irregular parcels and the "of" description.

GEOGRAPHIC COORDINATES

The use of coordinates such as latitude and longitude or state plane coordinates in property descriptions is still uncommon. Their use in parcel mapping and in describing the general location of monuments is growing quickly.

OTHER METHODS

Many other methods to describe property boundaries can be found in the public record. Some are adequate, many are not. Some are extremely simple, such as "the house owned by Brown in George County." Early grants sometimes referred only to a quantity of land in a general area. Some were longer and more descriptive, but not necessarily more definitive, referring to natural or cultural features that cannot be relocated with assurance. Some included drawings, such as those laying out the first New England towns. These were not necessarily surveyed and monumented, however, and the boundaries on the ground might bear little resemblance to the original plan.

SIMULTANEOUS AND SEQUENTIAL CONVEYANCE

New parcels are created by marking out a portion of an older parcel or of platted land. If two parcels are created at two different times, they are said to be a *sequential conveyance.* As shown in Figure 5-7, the older parcel has *senior rights* over the younger one if the boundaries are found to overlap, that is, the owner of the older parcel has a *superior claim* to the land in dispute. (See Chapter 4.) If there is a gap between the boundaries, it will go to the parent parcel if the second parcel was cut out of the older parcel, or to the state (theoretically) if both were taken out of unpatented land.

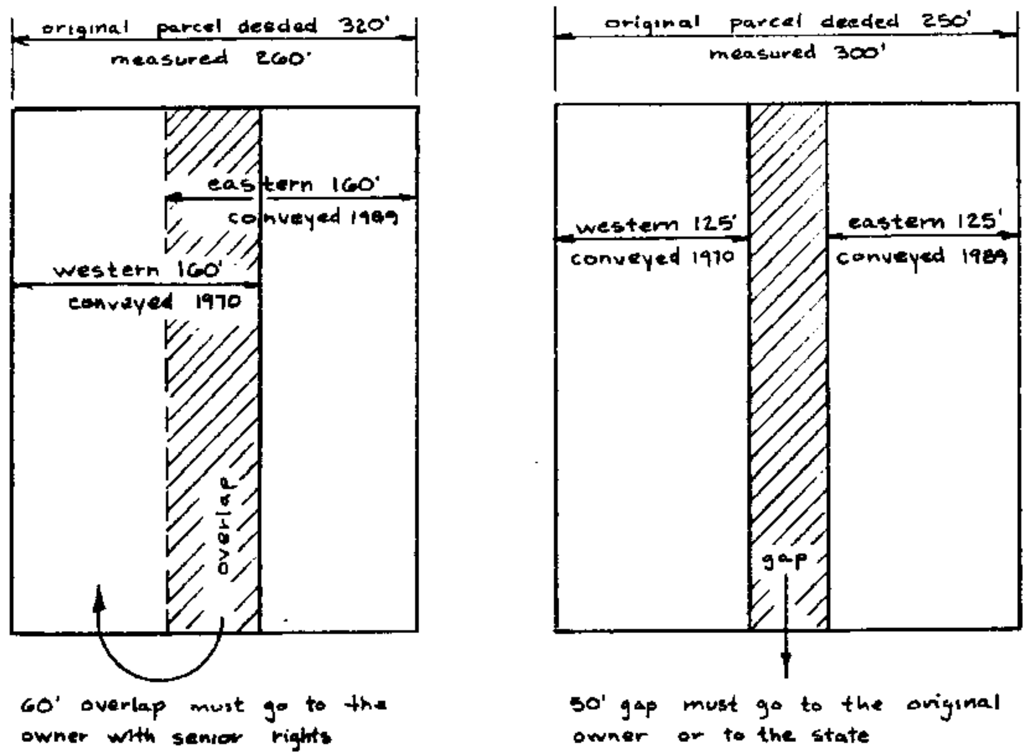
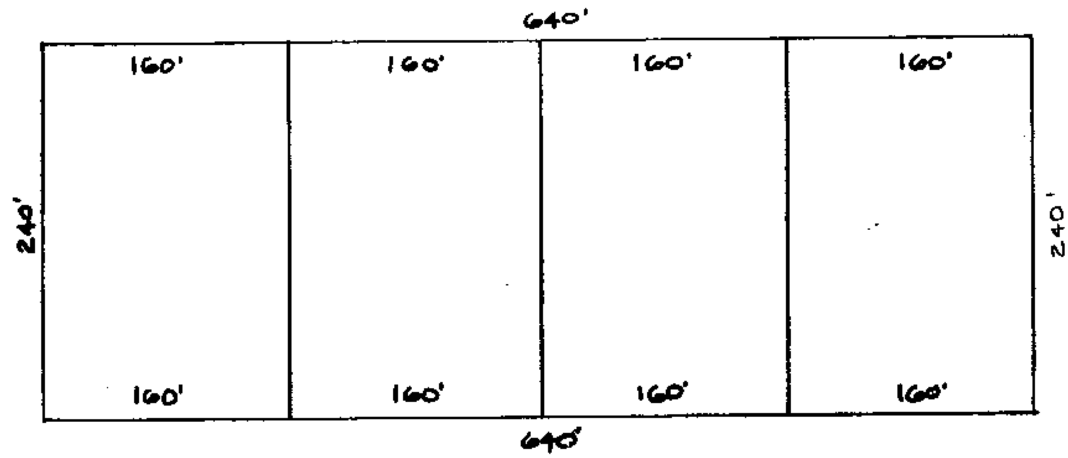
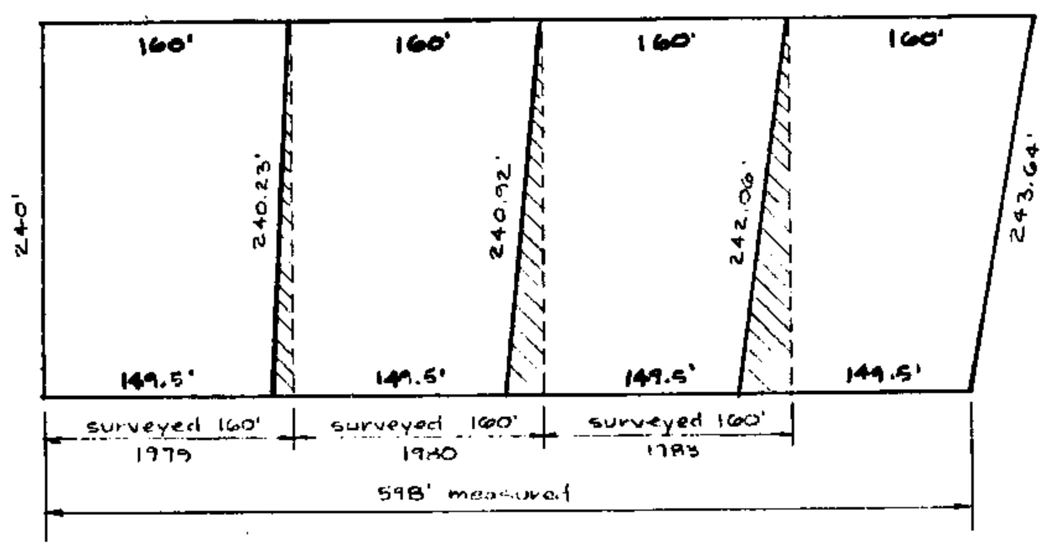


Figure 5-7: Sequential conveyance.

Simultaneous conveyance refers to the conveyance of parcels that were created at the same time, such as those created by a subdivision. Although senior and junior rights might exist between subdivisions, all lots within the subdivision have equivalent rights in the event of gaps or overlaps *even if they were conveyed at different times.* In resolving problems within a simultaneous conveyance, the error is distributed among the lots. Figure 5-8 shows a subdivision 640 feet long by 240 feet deep divided into four lots of equal size. In this example, when each of the three western lots was sold, it was surveyed from the western boundary. When the fourth lot was sold, the total length of the subdivision was found to be 598 feet. Since the lots were created at the same time, the principle of simultaneous conveyance dictates that the error be distributed among the lots. When the actual measurement between land corners differs from the record measurement, new distances are calculated for each lot or part based on the proportion of its recorded dimensions to the recorded distance between corners.



a. Simultaneous conveyance by subdivision plat.



b. The error is distributed along the south line and the sidelines adjusted.

Figure 5-8: Simultaneous conveyance.

EVIDENCE OF PROPERTY BOUNDARIES

Words, measurements, and drawings constitute property descriptions—the written evidence of property boundaries. There are other kinds of evidence, though, some of which carry greater weight when the location of a boundary is in dispute. In general, our legal system gives greater weight to the physical evidence of the boundary, to the historical or commonly understood location of a boundary, and to well-established *occupation* of the land giving correspondingly less weight to measurements, which are presumably taken from the physical markers, or *monuments*. Therefore, a call for a monument will be given the most weight if elements in the legal description are inconsistent. Monuments can be natural (lakes, rock outcrops, trees) or manmade. A *record boundary* is a boundary described elsewhere in the public record, such as on a map or deed. Record boundaries and calls for ties to monuments or record boundaries are next in weight. Distances and bearings follow. Area is given even less weight if it is not given as a specific call. Because physical evidence in the field is more vulnerable to loss and destruction than the recorded measurements, records of measurements and calculations and of the standards and procedures used often become important in finding and reestablishing monuments, but while measurements and calculations can be precise, there is no guarantee that they are either precise or accurate.

FIXED AND MOVABLE BOUNDARIES

In most cases, the boundary of a parcel is fixed in position even if the exact ground location is uncertain. There are exceptions, however, which can cause uncertainty and dispute. Under riparian (water boundary) law, land can be gradually gained and lost by *accretion* and *erosion*. By common law, the land owner "has a right to all accretions that attach to his land" (Brown 1986, p. 247). Land gradually eroded away is lost to the owner. *Avulsion* is the sudden loss or gain of land, as when a stream changes course. The ownership of land does not change as a result of an avulsive event. *Reliction* refers to the increase in land caused by the withdrawal of water, for example when a non-navigable lake dries up. Such land belongs to the owner of the attached land, although various methods may be applied in determining the boundaries.

Many land records call for a stream or river as a boundary. Some are slightly more specific, naming the bank, the channel, or the thread of the stream. These descriptions are not very precise to begin with; uncertainty and the potential for dispute are increased when waterways change their banks and channels.

DISCREPANCIES AMONG PROPERTY BOUNDARIES

Many apparent discrepancies and errors can be uncovered when property descriptions and other land records are compiled onto a single map. These may be rooted in the original grant or patent, or they may have been introduced over the years. They may also be a product of the mapping process and may not exist on the ground.

NATURE OF THE ORIGINAL GRANT

In the United States, the origin of a particular conveyance reaches back through ownership changes, subdivisions, and other episodes to a grant or charter by a sovereign nation, or to a patent from the U. S. Government in the case of PLSS lands. In colonial America, the boundaries of the original conveyance were usually described by metes-and-bounds, such as in the charter from the King of England to The Massachusetts Bay Company in 1628, shown in the box. With original boundaries described like this, it was not uncommon for the same land to be granted to or claimed by more than one party. Some of these cases were brought to court for final disposition based on the evidence presented and the laws in effect; many others persist.

The Charter from the King of England to the Massachusetts Bay Company, 1628:

> All that part of new England in America which lies and extends between a great River ther [sic] commonly called Monomack River, alias Merrimack River and a certain other River ther, called Charles River, being in the Bottom of a certain Bay ther, commonly called Massachusetts, alias Mattachusetts, alias Massatusetts Bay; and also all and singular those lands and hereditaments whatsoever, lying within the Space of Three English miles on the South part of the said River, called Charles River, or of any, or every part thereof; and also all and singular the lands and hereditaments whatsoever, lying and being within the space of three English miles to the southward of the Southern most part of the said Bay, called Massachusetts, alias Mattachusetts, alias Massatusetts Bay; and also all these lands and hereditaments whatsoever, which lie and be within the Space of Three English miles in the Northward of the said River called Monomack, alias Merrimack, or to the Northward of any and every part thereof, and all lands and hereditaments whatsoever, lying with the limits aforesaid, North and South, in latitude and breadth, and in length and longitude, of and within all the Breadth aforesaid, throughout the main lands ther, from the Atlantic and Western Sea and Ocean on the East Part, to the South Sea on the West part.
>
> *(Brown 1981, pp. 155-156)*

The PLSS was designed to solve some of these description problems by specifying standard surveying procedures, by requiring a field survey in advance of settlement, and by making the survey field notes, the plats, and the surveying standards and procedures all part of the public record. Nonetheless, the limitations of equipment, difficult field conditions, economic conditions, and surveying errors resulted in the mislocation of corners. *Once the corner has been placed, however, its true and legal location is its ground position, not* *where records or calculations say it should have been.* Subsequent divisions and conveyances based on record measurements rather than field surveys have resulted in overlaps and gaps between recorded descriptions. (See Figure 5-3.)

The history of original conveyance varies greatly from state to state and even within a state. Knowledge of one locality is not transferred easily to another, and it is important not to assume that what is true in one area is true in another.

HISTORICAL SURVEY PRACTICE AND CUSTOMS

Some of the inconsistency in our land records can be traced back to claims to the same piece of ground, regardless of how it is measured, but many of the overlaps, gaps, and uncertainties result from vagaries and changes in historical survey practice and customs. With relevant U.S. land records originating in Spain, England, France, Holland, and other countries, parcels in the United States are described in a number of linear units including feet, chains, miles, vara, toises, and meters. Areal units include acres and arpents. Further, several variations of any particular unit may have been in use. For example, a geographic mile is longer than an English mile, and a French foot is longer than an English foot. Measures sometimes change, as the Standard Foot did in 1959, and the meter in 1983. Some terms were used whose meanings, though clear at the time, have since changed or gone out of use. In some cases, the unit of measure was approximate since no standard existed, as with the Spanish vara and the French arpent. In Louisiana, the accepted English measure equivalent of the vara differs from parish to parish.

The limitations of equipment have also introduced discrepancies over the years. Most early surveys used the magnetic compass to determine the orientation of a boundary. The magnetic compass measures direction relative to the magnetic pole, which is not the same as the geographic pole. The difference between the two directions is an angle, called *magnetic declination,* which varies depending on location. In the contiguous United States, the magnetic declination ranges between 22 degrees east of north to 24 degrees west of north, 46 degrees altogether. Annual and daily variations also affect measurements taken by magnetic compass, as will magnetic storms and iron-bearing ore near the land's surface. With these variations, and the graduations on the compasses typically used by surveyors, "an angular error equivalent to an error of 1 foot in 300 feet can be expected in many older surveys" (Brown 1986, p. 32). In contrast, subdivision surveys today commonly meet third-order, class II standards of 1 foot in 5,000 feet.

The magnetic compass has been replaced by the transit and theodolite to measure angles. Optical theodolites introduced a magnifying eyepiece to improve visibility of the scales, and the electronic theodolites now available automatically measure the angle. Today's total stations measure both angles and distance. This term is commonly used to describe instruments that read the measurements electronically and store them in computer-readable form. These instruments, which have greatly improved the measurement of angles and distance, are gradually replacing older field instruments.

Early boundary surveys measured distance by pace, chain, rope, or line. Steel tape is a more modern method, and most recently tachymetric and electronic distance measuring (EDM) instruments have been used. Clearly, pacing is an imprecise measurement technique, and chain, rope, and line are subject to stretch and shrinkage with age, temperature, and moisture. Calibration was not rigorous, and a break might be repaired without much care to the effect on the measure. Modern equipment is far less vulnerable to these factors, and precise standards have been established for the foot, meter, and other common measurement units. Survey equipment is routinely calibrated to these standards. Modern surveying instruments are all capable of meeting reasonable standards, making surveying procedures and practice at least as important as equipment to achieving acceptable results.

Customary surveying practices vary across time and space. In some areas it was the custom to throw in 5 percent to allow for variations in chain length. The weight given to survey accuracy varies not only over time but from surveyor to surveyor. Some of the early PLSS surveys are considered quite accurate even by today's standards. Others show very poor practice by any standards. With the PLSS, standards and procedures were standardized and made part of the public record, and today professional surveying standards are published along with the accuracies that can be expected from them. (See Chapter 3, Appendix 3-1.)

MONUMENTS AND RESURVEYS

Surveys to locate property boundaries are conducted for a variety of reasons. The land surveyor collects the relevant documents and attempts to locate the monuments, witnesses, bounds, and other calls in the description. The land surveyor may be asked to perform a *dependent resurvey* or *retrace-*

ment, "following in the footsteps of the original surveyor," following the description and replacing the monuments if they are gone.

The point of beginning for a typical property description is a monumented point such as a PLSS corner. Property descriptions that were never surveyed or monumented and those whose monuments no longer exist rely on less certain evidence for the location of the boundary in the field. A wide variety of monuments are called out in land records. Early surveys in the United States refer to blazed trees, wooden stakes, piles of stones, boulders, land marks, buildings, streams, fences, railroad tracks—whatever was available. The permanence of these monuments varies, and many monuments and their *witness marks* have been lost over time. Some monuments have been replaced through boundary resurveys, but not all resurveys have been conducted by the book or recorded in the public record. Over time, resurveys (both official and unofficial) can result in the placement of monuments for the same point at more than one location. Local surveyors may disagree as to which monument represents the true location. If multiple monuments come into use for a single land corner because of uncertainty about its original location, then subsequent surveys that locate the property will mark off different pieces of land even though the description remains unchanged.

POOR SURVEY PRACTICE

A properly conducted survey of a parcel boundary requires the collection of "all the written, physical, and testimonial elements surrounding" the project (Brinker and Minnick 1987, p. 930). This would include researching all historic deeds and surveys for the parcel in question and adjacent parcels. Unfortunately, clients are often unwilling to pay for extensive research, and may feel that such an in-depth investigation would only cause trouble. This means that parcels may be surveyed many times before a problem is uncovered.

Figure 5-8 shows one example of how poor survey practice can perpetuate an error and make its correction more expensive. Good practice would have the survey of the first, second, and third lots measure the perimeter of the subdivision, as well as measure in to their clients' lots. The surveyor of the first lot would have discovered that the entire length did not match and the apportionment would have been accomplished immediately. If the first few surveyors fail to follow this practice, houses might be in place before the error is finally discovered.

POOR DESCRIPTIONS

Writing a good land description is both an art and a discipline. Unfortunately, the records are full of erroneous and ambiguous descriptions, which are often perpetuated either because the problems are not detected or because changes in the description might slow a transaction, or because the descriptions are prepared by unqualified people who do not understand the importance of a good legal description in correctly identifying and correctly locating a property boundary.

OCCUPATION

Discrepancies can arise between a property description and its corresponding survey and what is occupied. These may take the form of an *encroachment,* when a fence or building corner impinges on the parcel. Or they may be more serious, affecting most or all of a boundary or title. Under certain circumstances, occupation can in fact carry greater weight than written evidence. Therefore, occupation boundaries may be a legitimate description of the extent of a land interest.

SUMMARY

A number of factors have resulted in an accumulation of discrepancies, errors, uncertainties, and inconsistencies in this country's land boundary descriptions. The responsibility for these problems—and for their resolution—does not lie with a single profession, level of government, or agency. Under our system of law, the responsibility for final resolution almost always lies with property owners and the courts. Government agencies and public surveyors have critical roles to play, however, in making information available so that these problems can be discovered and resolved, and in establishing regulations and systems that will lead to the gradual improvement of land records.

Perhaps the most important point for those unfamiliar with land boundary descriptions is that they are not cut-and-dry. The compilation of land boundary descriptions onto a single map often brings many inconsistencies to light. No amount of mapping accuracy or geodetic control will erase years of change, error, and inconsistency. A second important point is that property boundaries are not necessarily simple, uniform, or fixed. A system that records property boundaries must be flexible enough to handle inconsistency, complexity, diversity, and change.

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APPENDIX 5-1
LAND DESCRIPTION TERMINOLOGY

Accretion: increase by external addition; where, from natural causes, land forms by imperceptible degrees upon the bank of a river, stream, lake, or tidewater, either by accumulation of material or recession of water (Brown 1986).

Aliquot parts: refers to the approximately rectangular subdivisions of the township and section.

Avulsion: the sudden loss or gain of land, as when a stream changes course.

Bounding description: reads as if the narrator were standing looking outward, describing each boundary as it is observed from the inside by direction such as northerly, southerly and a distance.

Description by reference: deed may contain description of the parcel's perimeter, but refer to a plat or other description.

Encroachment: when a fence or building corner impinges on the parcel.

Erosion: in riparian law, the washing away of land by a stream or a body of water (NGS 1986, p. 76).

Independent resurvey: runs and marks new lines and monuments regardless of previous surveys.

Land corners: a point on a land boundary at which two or more boundary lines meet. The term is often used to refer to the monument erected to mark the land corner (NGS 1986, p. 49).

Magnetic declination: the angle between the geographic meridian and the local magnetic meridian. Also called *magnetic variation.*

Metes: measures of angles or distance.

Metes and bounds: refers to two kinds of description: *running descriptions* and *bounding descriptions.*

"Of" description: used to specify a portion of an already described parcel, as in "the easterly 35 feet of Lot 12" or "the western half of Section 20."

Patent: the original grant.

Plat: generally used to describe a map or drawing showing property boundaries.

Proportionate measurement: a method of dividing a measured boundary so that each segment bears the same proportion to the whole as the record segment did to the record boundary.

PLSS: Public Land Survey System, the system by which the public domain of most of 30 states was divided into parcels.

Record boundary: a boundary described elsewhere in the public record, such as on a map or deed.

Reliction: refers to the increase in land caused by the withdrawal of water, for example when a non-navigable lake dries up.

Retracement: in a survey it usually means the retracing of an original survey, that is, following the footsteps of the original surveyor (Brown 1986).

Running description: the narrator starts at a *point of beginning (POB)*, which may or may not be related to other landmark features in its vicinity. The description then runs either clockwise or counter-clockwise around the perimeter boundary, using directions (or bearings) and distances. The line is described as running along or "by" an abutter's property or an abutting street. Each line ends at an angle point or corner, sometimes described by a monument, such as a fence corner, stone bound, or iron pipe. The description leads back to the point of beginning and usually gives an area in square feet or acres.

Sequential conveyance: two parcels created at two different times.

Simultaneous conveyance: refers to the conveyance of parcels that were created at the same time, such as those created by a subdivision or by the PLSS.

Strip description: describes a strip of land by describing the location and measurements of a reference line, either directly or by referring to another document, and a width.

Total stations: instruments that read the measurements electronically and store them in computer-readable form.

Witness post (also witness corner): a monument placed at a known distance and direction from a property corner as an aid in the recovery and identification of the survey marker. (NGS 1986, p. 26).

6 THE PUBLIC LAND SURVEY SYSTEM

Gary Speight and Jon Abrams

The Public Land Survey System (PLSS) was created to establish the original property boundaries for most of the land area for 30 states—about 78 percent of the land area of the continental United States. It was the means by which the Federal Government surveyed and disposed of public lands, and has shaped property ownership and land use patterns across most of the country by dividing the land into nominally square sections. The PLSS firmly established three new concepts in land administration:

- the principle of survey before settlement
- the principle of a mathematically designed plan, to be followed throughout the entire area of the public domain
- the creation of a standard land unit of uniform shape and area, with the corners of boundaries physically marked on the ground.

For a vast area of the United States, the PLSS was the original division of land into parcels. An understanding of its history and of the laws and rules that have governed its creation and maintenance are essential to an understanding of land boundaries in this country.

THE EXTENT OF THE PLSS

The terms *public domain* and *public lands* refer to land held by the Federal Government. Lands entered the public domain in several ways: the Colonial states turned land over to the Federal Government; land was acquired by purchase and by conquest; and when a state joined the Union, unappropriated lands often came to the Federal Government as a condition of statehood.

The total area of the 50 states is 2.3 billion acres. At one time or another, the Federal Government has held title to approximately 1.8 billion acres. Today, Federal, civil and defense agencies administer 727 million acres, or 32 percent of the total area. Over the years, some 1.1 billion acres have

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been conveyed to individual citizens, businesses, and non-Federal Government organizations under Federal legal authority, collectively referred to as the *land laws*. The Homestead Laws and grants to individual states to help support public schools, develop transportation systems, and promote economic development account for approximately 50 percent of the land disposed. The PLSS now extends over 1.4 billion acres. Some areas have yet to be surveyed. All of this unsurveyed area is found in 11 western states; 75 percent of it is in Alaska.

PLSS HISTORY

In early America, several types of surveys were performed, using the best surveying instruments of the day, and calling principally on mathematicians, astronomers, and navigators to perform as land surveyors. Most of these earlier surveys were of the metes and bounds type (see Chapter 5), and land parcels were not laid out in a regular pattern.

In the late 1700s, the new government of the United States authorized what would become the most ambitious program of land disposal, ownership recording, and on-the-ground boundary marking ever undertaken. Described as a "marvel of simplicity," the U.S. rectangular survey system was designed to lay out mile square parcels over all of the Federal lands outside of the original thirteen colonies and their western territories.

The Continental Congress authorized the project on May 20, 1785, when it approved the modified recommendations of a committee chaired by Thomas Jefferson. The committee's work was the culmination of much thought, debate, and evolvement of earlier survey activities. Two military engineers, Colonel Henry Bouquet and Thomas Hutchins, were among the original major contributors. (Hutchins later became the first Geographer of the United States.) The 1785 Land Ordinance laid the legal and technical foundation for the country's public land surveys. With Hutchins' personal attention, the first surveys under the ordinance were conducted in Ohio, where the west boundary of Pennsylvania crossed the north shore of the Ohio River. The first township was surveyed by Absalom Martin of New Jersey in 1786. Ohio was the testing ground for the new type of survey, and some changes were made in the law as a result of experience gained in the surveys in that state. By 1805, the rectangular surveys were progressing across Indiana. The system's elements had been well settled by then, and the surveys were eventually extended westward to the Pacific Ocean and Alaska.

The Treasury Department managed the surveys and the public lands until 1812 when, in recognition of the need for an agency that would focus on land management, the Congress created the General Land Office (GLO). Edward Tiffin of Ohio, the first Commissioner of the GLO, made significant contributions to land surveying by consolidating and organizing land and survey records. Later, as Surveyor General, he designed a plan of correction lines to allow the rectangular pattern of surveys to conform to a round Earth.

Until 1910, the public land surveys were usually administered by regional Surveyors General, who contracted with authorized Deputy Surveyors to perform the work. For the most part, the contract system of conducting government surveys had been successful for more than one hundred years. The Civil Appropriations Act of March 4, 1910, ended the contract system of surveys and a corps of government surveyors was appointed. Since then, most Federal cadastral surveys have been performed by Federally employed surveyors.

The Surveyor General often issued a set of instructions to the Deputy to specify the method of survey and the accuracies expected, but, recognizing the need for a consolidation of officially authorized surveying procedures, the *Oregon Manual of Surveying Instructions* was published in 1851. A revision of this manual was published by GLO in 1855 for national use, and later revisions were issued in 1871, 1881, 1890, 1894, 1902, 1930, 1947, and 1973. Subsequent legislation and regulations have added many significant refinements, but the PLSS retains the basic elements set forth in the Land Ordinance of 1785.

DESCRIPTION OF THE PLSS

The PLSS is a rectangular survey system, dividing land into *townships* and *sections.* A regular township is 6 miles on a side, bounded on the north and south by *township lines* and on the east and west by *range lines.* This regular township is further subdivided into 36 sections, each 1 mile on a side. Because the system covers such a large area, adjustments to allow for the curvature of the Earth were needed to allow the system to be locally square. Before each extension of the PLSS, surveyors establish and monument an *initial point,* and determine an accurate latitude and longitude for it. As shown in Figure 6-1, surveyors ran two lines from this point, one north-south and one east-west. The north-south line, called a *principal meridian,* and the east-west line, called a *base line,* act as the reference axis for the rest of the survey. The township lines are intended to be run as true parallels of latitude and the range lines are intended to be true meridians.

As explained in Chapter 2, *meridional lines* (lines of meridian) will converge as they are extended northerly. This convergence is 20 to 50 feet per township in the United States. To compensate for this convergence and to keep townships full size, *standard parallels* are established every 24 miles, that is, every four townships. For a more detailed explanation of the needs for and procedures involved with Standard Parallels, see the *Manual of Surveying Instructions (1973)*.

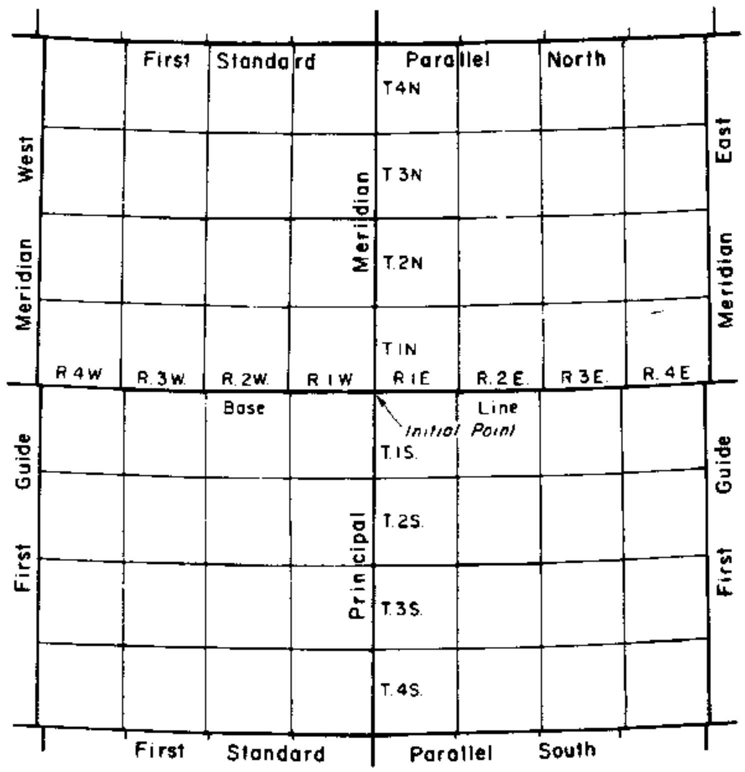


Figure 6-1: Principal meridian and base line (BLM 1973).

Working along the principal meridian and the base line, the surveyor set corners every 1/2 mile and established township corners at 6-mile intervals. Then, the surveyor laid out a 1/2 mile grid, setting monuments at every section corner and quarter corner, as shown in Figure 6-2. Each of the 6-mile squares is a township of 36 square miles, or approximately 23,040 acres. Any specific township can then be located according to its relationship to the appropriate principal meridian and the base line. The township is divided into sections of 1-mile squares containing approximately 640 acres. Individual sections are identified by a numbering system shown in Figure 6-2 starting with section 1 in the northeast corner of the township and ending with section 36 in the southeast corner. The section can be further subdivided into quarter sections of about 160 acres, which became the basic unit under the Homestead Act of 1862. Quarter sections can be divided into half quarter sections of approximately 80 acres and further divided into quarter quarter sections of approximately 40 acres, etc. These subdivisions are called *aliquot parts,* meaning "contained in something else, an exact number of times" (Black 1982, p. 58).

TOWNSHIP LINE

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

RANGE LINE

Figure 6-2: Method of numbering sections (BLM 1973).

Metes and bounds surveys are considered a part of the Public Land Survey System when they are surveyed within any of the public land states and define boundaries of irregular areas of land that do not conform to the legal subdivisions of the PLSS, as shown in Figure 6-3. These surveys may involve prior grants of land, mineral claims, small-holding claims, private land grants, forest-entry claims, national parks and monuments, Indian reservations, lighthouse reservations, trade and manufacturing sites, homestead claims in Alaska, etc. Metes and bounds surveys located upon surveyed land within the PLSS are connected to a regular corner of the rectangular survey. If the location is within an unsurveyed township, a location monument may be set and tied, or the geographic position of the beginning point of the survey may be determined.

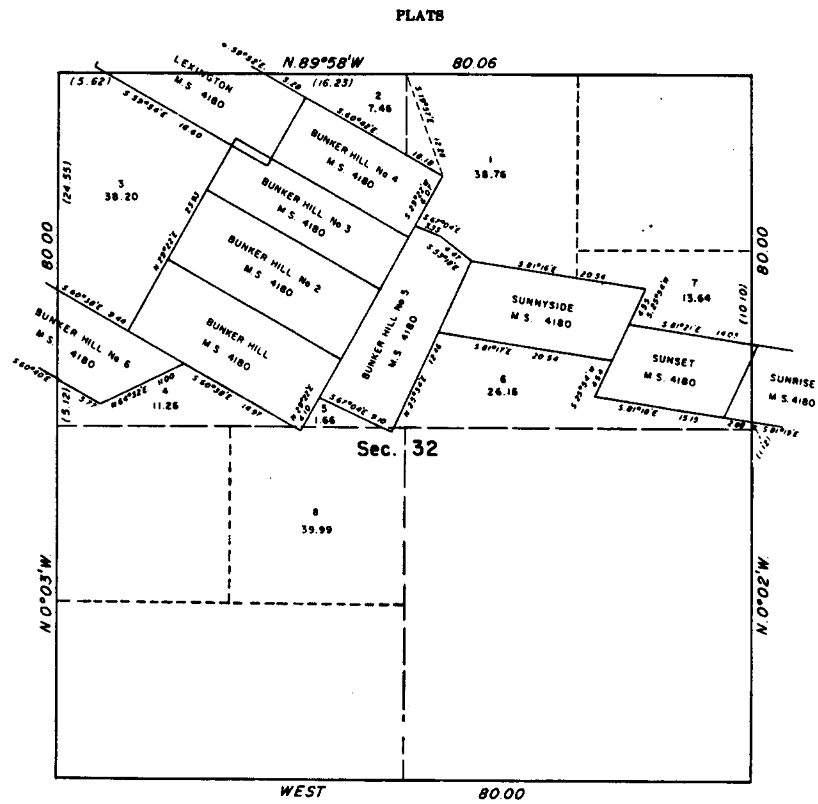


Figure 6-3: Section showing metes and bounds surveys (BLM 1973).

Meander lines are another form of metes and bounds surveys. They are run to segregate a permanent body of water from the public lands. Meander lines roughly define the sinuousities of the banks of rivers or other bodies of water and are used to determine the amount of usable acreage contained in the survey. The instructions regarding which bodies of water should be "meandered" were refined as the PLSS advanced, but in general they specified that navigable waters and waters more than 3 chains across would be meandered. The 1973 Instructions state that meander lines are to be set at mean high-water (Manual of Surveying Instructions 1973, p. 93), but earlier instructions were less specific. Under general land laws, the land under navigable waters is reserved from patent, remaining in public ownership, usually in the hands of the state. While the surveyor was instructed to set meander lines on both sides of navigable rivers, the decision as to whether or not a particular water body is navigable is beyond the surveyor's purview. *"Numerous court decisions in the United States Supreme Court assert the principle that meander lines are not boundaries defining the area of ownership of lands adjacent to water"* (Manual of Surveying Instructions 1973, p. 93). As shown in Figure 6-4, the ownership of land bordering on a meanderable body of water is defined by ordinary or mean high-water of the river or lake, not by the meander line.

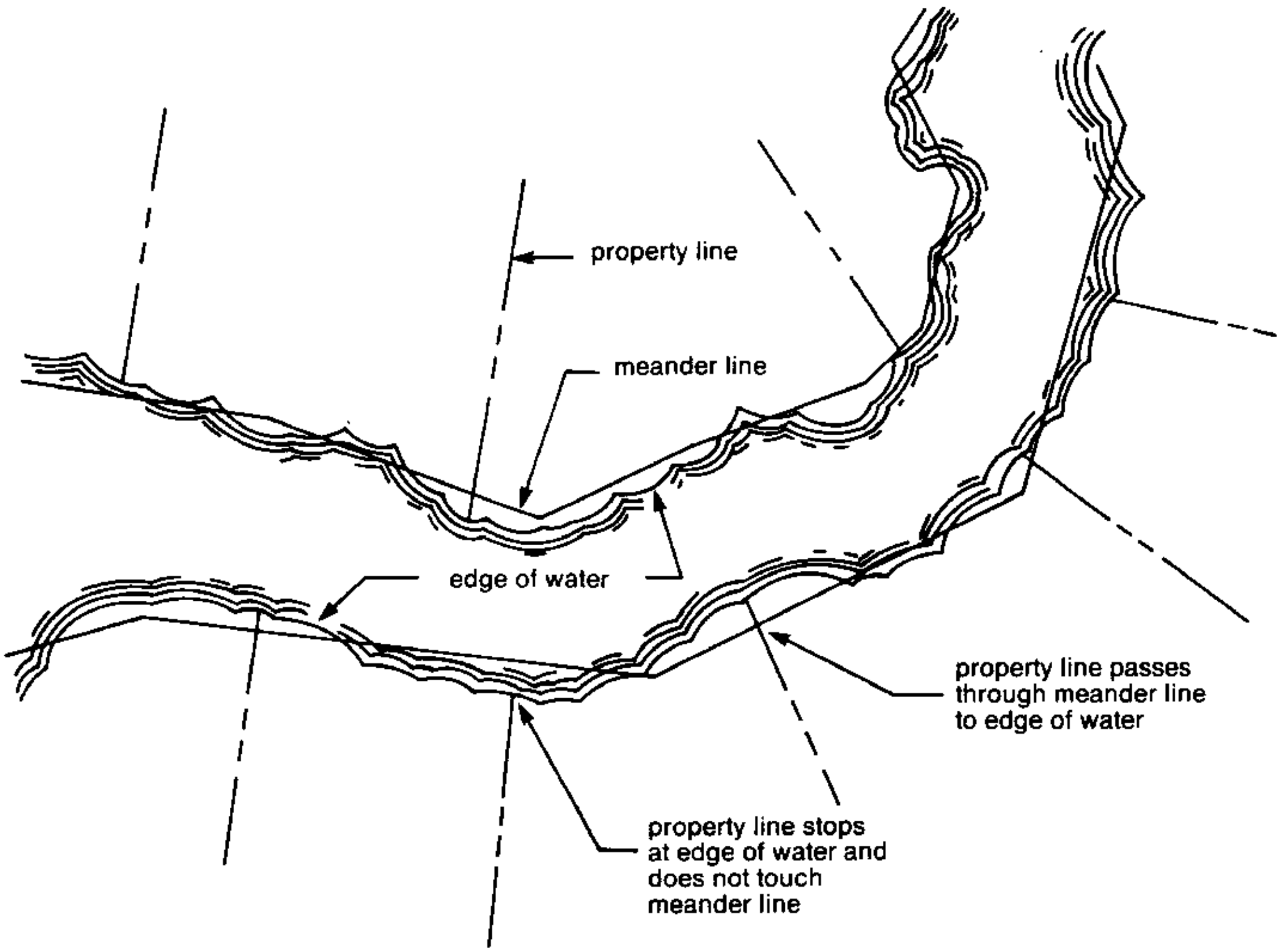


Figure 6-4: Meander lines and ownership.

Under certain circumstances, the subdivision of a township results in irregular parcels of land, which are called *government lots*. The most commonly occurring government lots are those township exteriors along the north and west boundaries of townships. PLSS surveying procedures are such that the effects of convergence and allowable error are pushed to the northern township line and the western range line. In some cases, this resulted in "sections" that were significantly larger or smaller than 640 acres. These areas are subdivided into as many regular aliquot parts as possible down to the quarter quarter section (40 acres) and the remaining parcels are numbered as government lots. (See Figure 6-5.)

Government lots also occur when meanderable bodies of water or metes and bounds claims intrude on the regular rectangular divisions as shown in Figure 6-5. This kind of township or section is described as *fractional*. It too is subdivided into as many regular aliquot parts as possible down to the quarter quarter section, and the remaining parcels are numbered. Finally, government lots may be created as a result of dependent and independent surveys.

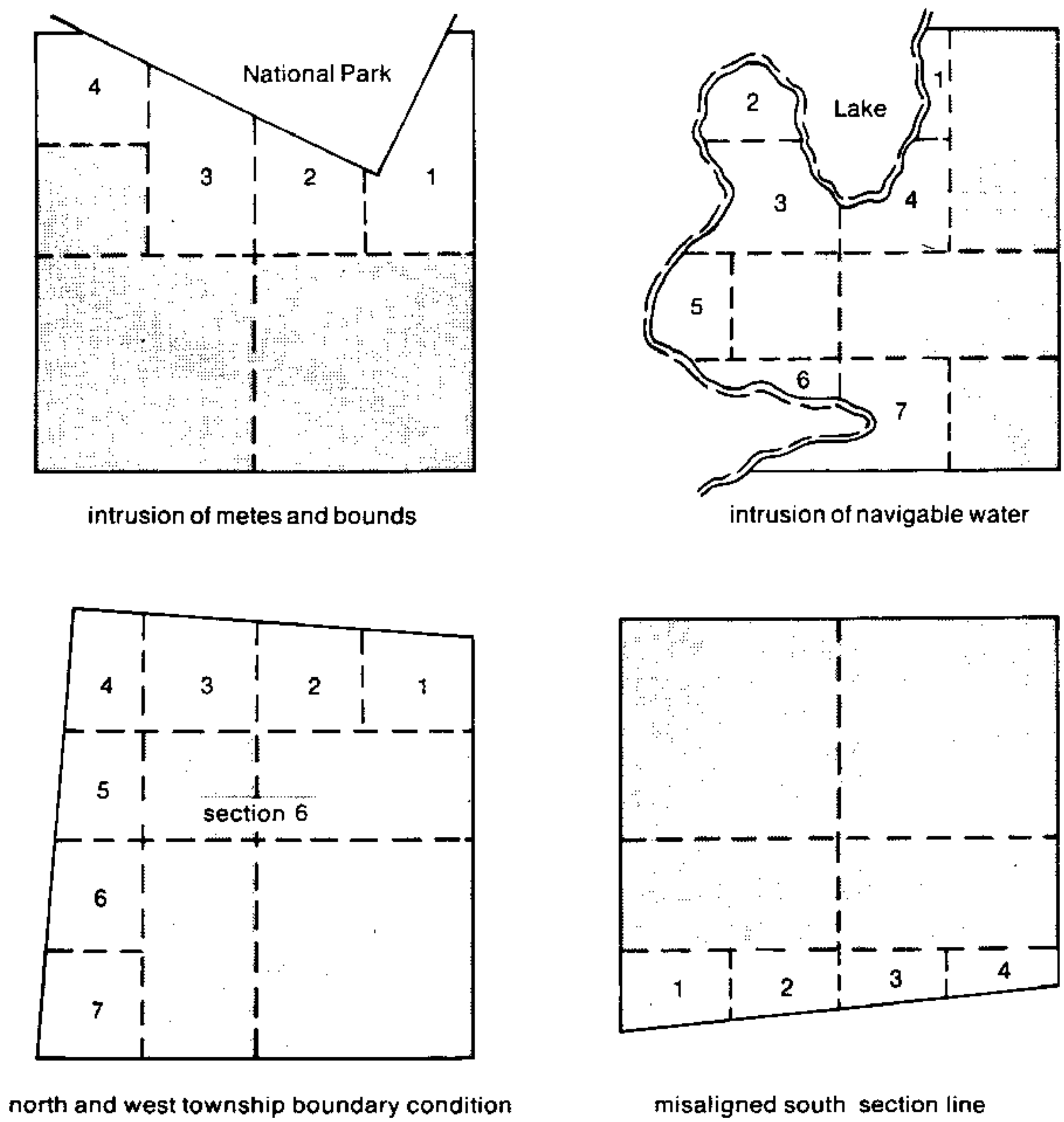


Figure 6-5: Government lots under the PLSS.

LEGAL DESCRIPTIONS IN THE PLSS

The PLSS makes it very easy to describe uniquely each parcel of land created by the rectangular survey. A township is an area defined by township lines and range lines, which together create a grid, as shown in Figure 6-1. The second row of townships south of the base line is called Township 2 South; the third column of townships west of the principal meridian is called Range 3 West. This township would be called "T. 2 S., R. 3 W." for short. Formal land descriptions include the name of the principal meridian, but most local governments will omit this reference because all of the land in their jurisdiction refers to the same one. If the description refers to one or more sections, these are listed ahead of the township and range: "sec. 14, T. 2 S., R. 3 W."

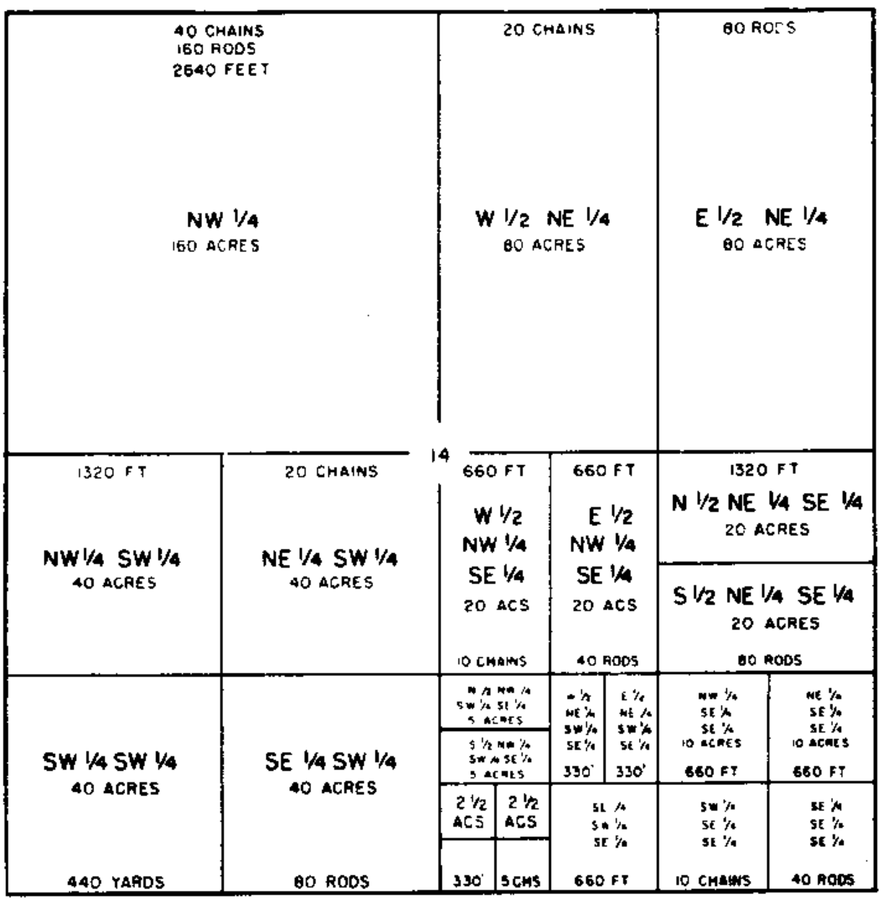


Figure 6-6: Normal division of a section (NRC 1982).

The quarter divisions of a section of land are known as *aliquot parts*. Figure 6-6 shows the normal division of a section into aliquot parts. An aliquot part is always described in relation to the four points of the compass. For instance, a quarter quarter section could be described as the "northeast quarter of the northwest quarter (NE1/4NW1/4) sec. 14, T. 2 W., R. 3 W." and the name of the principal meridian. Contiguous units may be combined. For example, if both NW1/4 sec. 10 and SW1/4 sec. 10 are included, the symbol W1/2 sec. 10 is used. If NE1/4NW1/4 sec. 22 and SE1/4NW1/4 sec. 22 are included, the resulting 80 acre unit can be designated E1/2NW1/4 sec. 22.

Fractional parts are described by substituting the lot number (Lot 7) in place of the aliquot part descriptor. A legal description of such a lot would be Lot 7, Sec. 22, followed by the township, range, and meridian information.

RETRACEMENT SURVEYS AND CORNER RECOVERY

Cadastral surveys, or *land surveys,* create, reestablish, mark, and define boundaries of tracts of land. Unlike surveys that collect information about resources and conditions in the field, "cadastral surveys cannot be ignored, repudiated, altered, or corrected." Other surveys can be redone to collect current information, or to use more accurate methods, but the boundaries created or reestablished by cadastral surveys cannot be changed so long as they control rights vested in the lands affected. The official record of a PLSS survey ordinarily consists of a drawing (a plat or map) and a written description of the field work (field notes). The drawing represents the lines surveyed, showing the direction and length of each such line, and the boundaries, description, and the topography, culture, and improvements within the limits of the survey.

Cadastral surveys under the PLSS fall into two main categories, *original surveys* and *retracement surveys* (or *resurveys).* Original surveys for the PLSS have been completed for the majority of the land in the lower 48 states. Most of the original survey work being done now is in Alaska. Resurveys now present the most challenging and complex projects for the surveyor. These have always been necessary in marking the public lands in order to restore *obliterated* or *lost* original survey lines and monuments. Legally, resurveys must not impair the *bona fide* land rights of affected claimants. Corners established in original cadastral surveys are forever fixed in position even though they may not fall precisely at a stated bearing and distance from a previous point.

The function of the original surveyor has been fulfilled when the survey has been completed and monumented properly, and the official plat and field-composed note record have been approved and filed. The function of the local surveyor begins with the identification of lands which have passed from the government into private ownership based upon the description derived from the original survey. The work may be simple or quite complex, depending largely upon the existence of the original corner monuments or acceptable perpetuations of the corner positions.

In those states where the public land surveys are essentially complete, the so-called *closed states*, the field notes, plats, and other papers relating to those surveys have been transferred to appropriate state offices for safekeeping as public records. The records of 13 states are still held by the *Bureau of Land Management (BLM)* in its state offices. The addresses of these offices in both open and closed states are listed in Appendix 6-1. Survey records in the 20 non-PLSS states are housed in a wide variety of state and local government offices in the respective states.

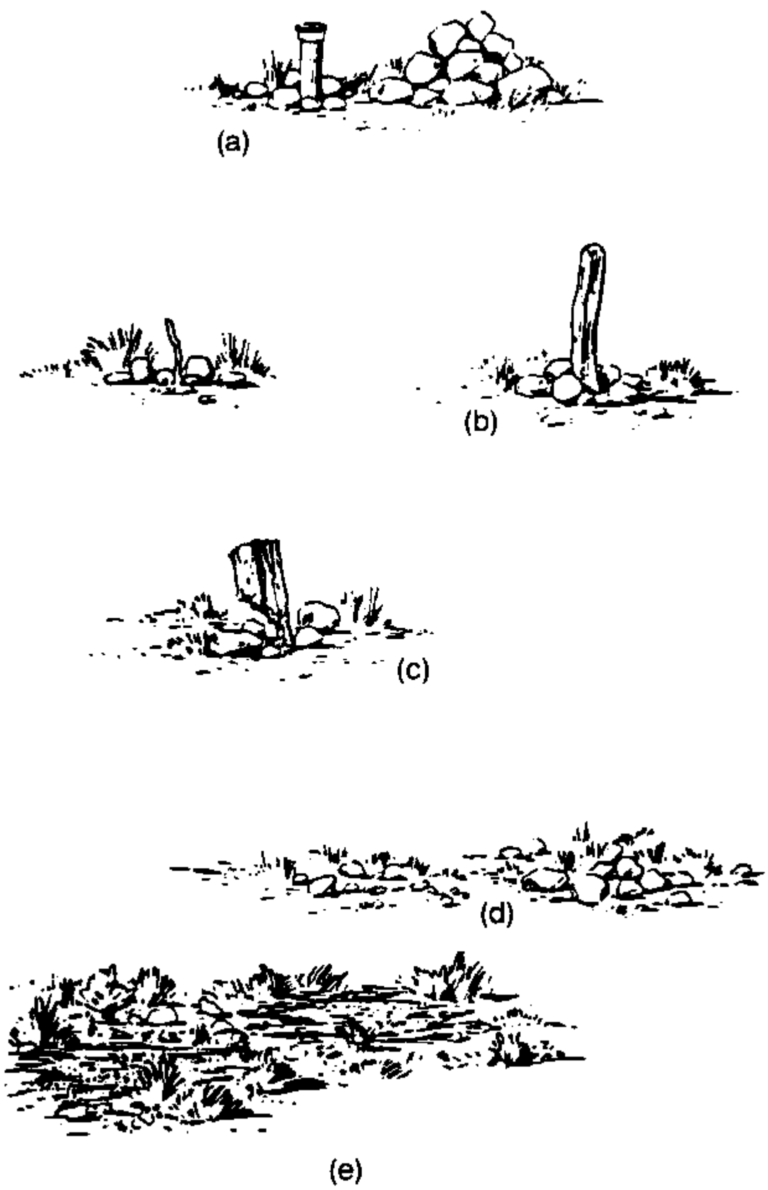
VERIFICATION AND PLACEMENT OF CORNERS

The section and quarter section corners established in the original PLSS survey control the location of the original section lines and create the basic parcel framework in PLSS states. Subsequent subdivisions refer to these original land corners, which should be found, or restored following proper procedures, before any subdivision takes place.

As shown in Figure 6-7, PLSS monuments have taken many forms, including the deposit of some durable memorial, a marked wooden stake or post, a marked stone, an iron post with an inscribed cap, a marked tablet set in solid rock or in a concrete block, a marked tree, and other special types of markers, some of which are more substantial. The original survey usually includes calls to various accessories such as bearing trees, bearing objects, reference monuments, mounds of stone, or pits dug in the sod or soil. Even articles like glassware, stoneware, a marked (X) stone, a charred stake, a quart of charcoal, or pieces of metal have been used as markers. When an old monument is replaced, the old marker is preserved as a memorial.

In many cases, however, the monuments marking the corners have been lost or destroyed, or surveyors disagree as to which monument marks the true location of the corner. The law has established that the original position of the land corner defines the land parcel. When discrepancies occur, evidence of the location of the monument marking the corner is given greater weight than the measurements of angles or distance.

An *obliterated corner* is one whose monument has been destroyed or lost, but whose location can be determined beyond a reasonable doubt from acceptable evidence or testimony. A corner is considered a *lost corner* only when every means has been employed to identify its original position. Lost corners are restored by *proportionate measurement,* in accordance with approved surveying practice and considerations of law and equity. (The rules for the restoration of lost corners have remained substantially the same since 1883.) Proportionate measurement distributes the excess or deficiency in measurement between existing corners in such a manner that the amount given to each interval bears the same proportion to the whole difference as the record length of the



a. Modern post with brass cap and mound of stone

b. Wooden post

c. Wooden post decaying at ground level

d. Corner monument obliterated; remnants of stone mounds identify corner position

e. Corner monument obliterated; evidence of old pits fixes corner position

Figure 6-7: PLSS monuments have taken many forms (BLM 1974).

interval bears to the whole record distance. After applying the proportionate difference, the sum of the parts will equal the measurements of the whole distance.

The process of restoring lost or obliterated corners requires an exhaustive search for relevant documents and field evidence, so maintaining the monuments is generally less expensive than replacing them. The courts may become involved if conflicts arise that cannot be resolved by the parties, generating even higher costs. Unfortunately, the costs are often borne by different segments of society. Maintenance costs generally fall to State and local government (in the closed states), and to the Federal Government's BLM in open states, while legal and surveying costs arising from disputes caused by lost or obliterated monuments are borne by the parties to the dispute, who are often private individuals and companies.

SUMMARY

The Public Land Survey System (PLSS) is the system of rectangular surveys that established the original property boundaries for most of the land area of 30 states. First established by the Land Ordinance of 1785, the PLSS is governed by rules that have been modified over the years. The current procedures are documented in the *Manual of Surveying Instructions, 1973,* published by the Department of the Interior, Bureau of Land Management, the custodian of public lands in the United States.

The PLSS divides land into townships and sections. These can be further subdivided into aliquot parts. Metes and bounds surveys and permanent bodies of water break the rectangular pattern of subdivision. The resulting irregular parcels, as well as aliquot parts that are either larger or smaller than allowed as a result of convergence or error, are called government lots. Retracement surveys and corner recoveries are generally done to reestablish property boundaries. Where corners have been obliterated or lost, an exhaustive search for relevant documents and field evidence is required to assure the bona fide rights of land owners. Retracement surveys of corner monuments can result in bearings and distances that are very different from those shown on the plat and field notes.

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APPENDIX 6-1
REPOSITORIES OF ORIGINAL PLSS RECORDS BY STATE

When the Bureau of Land Management (BLM) has completed the public land survey and turned the records over to the state for management, that state is described as *closed*. In open states, the BLM continues to archive the records. The addresses given below are current as of February 1990.

Alabama:	*closed*	Secretary of State, Montgomery, AL 36104
Alaska:	*open*	701 C Street, Box 13, Anchorage, AK 99513
Arizona:	*open*	3707 N. 7th Street, Phoenix, AZ 85014
Arkansas:	*closed*	Department of State Lands, State Capitol, Little Rock, AR 72201
California:	*open*	Federal Building, 2800 Cottage Way, Sacramento, CA 95825
Colorado:	*open*	2850 Youngfield Street, Lakewood, CO 80215
Florida:	*closed*	Department of Natural Resources, 3900 Commonwealth Boulevard, Tallahassee, FL 32399
Idaho:	*open*	3380 Americana Terrace, Boise, ID 83706
Illinois:	*closed*	Illinois State Archives, Secretary of State, Springfield, IL 62706
Indiana:	*closed*	Archivist, Indiana State Library, 140 North Senate Avenue, Indianapolis, IN 46204
Iowa:	*closed*	Secretary of State, First Floor, Capitol Building, Des Moines, IA 50319
Kansas:	*closed*	Secretary, Historical Society, 120 West 10th, Topeka, KS 66612
Louisiana:	*closed*	Register, State Lands Office, Baton Rouge, LA 70804
Michigan:	*closed*	State Library, Historical Division, 717 W. Allegan Street, Lansing, MI 48918
Minnesota:	*closed*	Secretary of State, 180 State Office Building, St. Paul, MN 55155
Mississippi:	*closed*	Secretary of State, Division of Public Lands, P.O. Box 136, Jackson, MS 39205
Missouri:	*closed*	Department of Natural Resources, Division of Geology and Land Survey Repository, P.O. Box 250, Rolla, MO 65401
Montana:	*open*	222 North 32nd Street, P. O. Box 36800, Billings, MT 59107

Nebraska:	*closed*	State Surveyor, State Capitol Building, 555 North Cotner Boulevard, Lower Level, Lincoln, NE 68505
Nevada:	*open*	850 Harvard Way, P.O. Box 12000, Reno, NV 89520
New Mexico:	*open*	P.O. Box 1449, Santa Fe, NM 87501
North Dakota:	*closed*	State Water Commission, State Office Building, 900 E. Boulevard, Bismarck, ND 58505
Ohio:	*closed*	Ohio Auditor of State Land Office, P.O. Box 1140, Columbus, OH 43266
Oklahoma:	*open*	See New Mexico
Oregon:	*open*	825 Multnomah Street, P.O. Box 2965, Portland, OR 97208
South Dakota:	*closed*	Archives—Cultural Heritage Center, 900 Governors Drive, Pierre, SD 57501
Utah:	*open*	324 South State Street, Salt Lake City, UT 84111
Washington:	*open*	See Oregon
Wisconsin:	*closed*	Public Lands Office, Department of Justice, 110 E. Main St., Madison, WI 53701
Wyoming:	*open*	2515 Warren Ave., Cheyenne, WY 82001

7 WHY IMPLEMENT A MULTIPURPOSE LAND INFORMATION SYSTEM

D. David Moyer

This chapter is designed for use as a stand alone piece for policy makers and others who want an overview of why improvements in local and state government land information systems are needed, and why now is an especially appropriate time to implement such an improvement program.

This *Guidebook* provides considerable information on HOW to improve the land information systems (LIS) in local and state government offices. This chapter provides a summary of WHY. It considers the current status of parcel level land information and technology available. This discussion should be useful to decision makers who are considering modernizing LISs.

FORCES DRIVING IMPROVEMENTS OF LAND INFORMATION SYSTEMS

Two basic forces are driving the current widespread interest in LIS improvements: the *demand* for quicker access to more and better land information at a reasonable cost and the *stream of technology* useful for LIS improvements. This technological stream includes mainframe and personal computers, software, scanners, digitizers, Global Positioning System (GPS) receivers, and more precise geodetic reference frameworks that form the foundation for an MPLIS. Figure 7-1 suggests how these two forces are interacting in society.

Technology flows through the technology gate, depending on a variety of factors including research and development experience and success rates, management attitude, resources, and timely, requested standards. Social demand, on the left side of Figure 7-1, pulls the technology to the left through the social gate. The flow through the social gate is affected by factors ranging from the need for survival to assistance in dealing with increased complexity. Innovations move through

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the social gate when they increase efficiency, meet economic needs, contribute to the common good of society, and are perceived as being lawful.

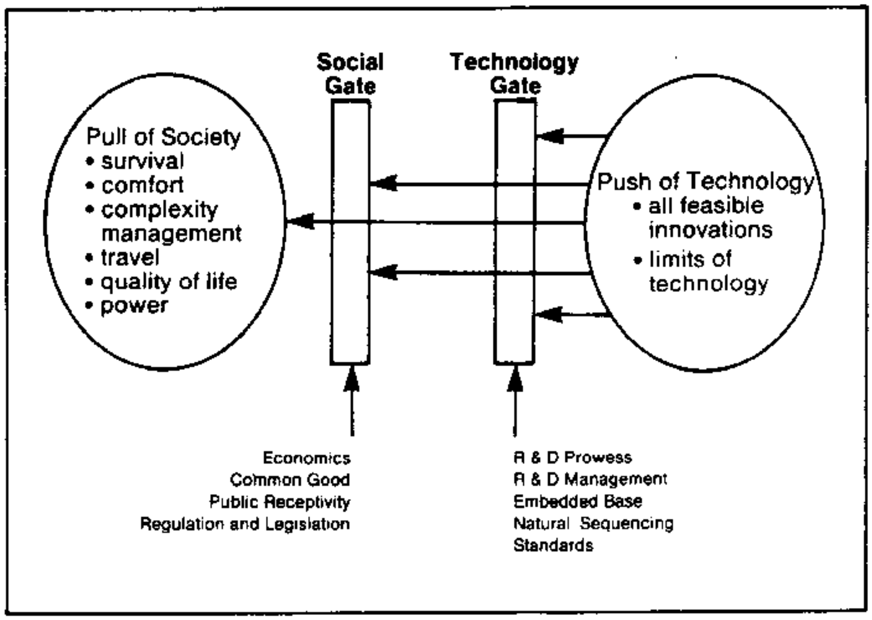


Figure 7-1: The flow of innovations into society (Mayo 1985).

The National Research Council (NRC) statement that there is an "increasing demand for land information at all levels of government" is more relevant now than when written in 1980 (NRC 1980, p. v). The demand for land information arises from the need to make choices about use of the land and its related resources.

The value of information, and thereby the effectiveness of the decision-making process, are directly related to the quality of and capacity of the system that produces the information, as well as the information itself. Current users of land information agree that most current LISs are no longer capable of doing the job and that major improvements are needed very quickly.

WHY CHANGE NOW?

There are many reasons why now is an opportune time for governments to improve their LIS. This section examines the demands that are being made on government for land information and also considers the technology that has recently become available for use as part of LIS. Information systems presently in use can be costly, overly complex, and slow to respond. These systems are unable to respond to many of the emerging problems and policy mandates placed on local and state government. There are additional technological and institutional reasons for making changes now, changes that will increase efficiency and accuracy, reduce costs, and overcome certain constraints to modernization.

AFFORDABLE TECHNOLOGY

Major advances have been made in technologies relevant to LIS. A number of these technologies are now more available and more affordable:

- computer hardware and software
- new survey coordinate reference system
- Global Positioning System (GPS)
- remote sensing
- scanning devices

Data networks, telecommunication systems, and distributed data bases have all emerged as generally available, reliable technologies. Technical expertise is much more readily available—from vendors, consultants, and educational institutions. Data sharing and data access from other agencies is becoming an operational reality. Data such as hydrography, transportation, elevations, and government boundaries from digital line graphs (DLG) from the U.S. Geological Survey, soils from the U.S. Soil Conservation Service, wetlands from state natural resources departments, and Census geography, population, and housing data from the U.S. Bureau of the Census are now all available in digital form. This availability helps reduce the significant cost of database development.

Computer Hardware and Software

Personal computers (PCs) with adequate storage capacity and speed of operation for many land information tasks are now available. Software continues to decline in price and increase in sophistication of problems it can handle. Availability of PC-based systems also makes implementation and training easier, since many personnel in LIS offices are already familiar with PCs.

Application specific software such as 9-1-1 emergency dispatching systems, land use planning, and routing systems are now available. Customized user interfaces make training of personnel on new systems easier and faster. Menu driven systems with a mouse for quick access to icons on the screen help reduce errors, speed results, and reduce operator fatigue.

New Survey Coordinate Reference System

Linking spatial data from different sources depends on a common coordinate system that can be related to all such spatial data. Indeed, the NRC suggested that the national network of geodetic survey monuments is the foundation on which all other parts of the MPLIS must be built. Because the geodetic coordinate reference system for North America had not been revised for over 50 years and tens of thousands of new monuments had been added to the network since the last adjustment in 1927, the National Geodetic Survey recently recomputed the horizontal control portion of the geodetic reference system. Details on geodetic datums and related matters can be found in Chapter 3 of this *Guidebook.*

The new coordinates assigned to the 300,000 horizontal monuments in the National Geodetic Reference System (NGRS) provide an improved, more accurate database. However, some jurisdictions that have a substantial database in place may elect to retain their existing coordinates until less expensive conversion systems become available. The key to minimizing these costs, and to making other aspects of database conversion as efficient as possible, is a carefully developed plan of action, agreed to by both data users and data custodians.

The recomputed geodetic referencing system, known as the North American Datum of 1983 (NAD 83), with its increased accuracy is also most suitable for use with GPS surveying technology. Therefore, jurisdictions considering the use of GPS technology in the near future should strongly consider adoption of NAD 83.

Global Positioning System

Recent advances in land surveying have resulted in improved performance and reduced costs of technologies, which in turn facilitate the adoption of an MPLIS. Until 10 years ago, most land surveyors used traditional instruments such as theodolites and similar ground-based manual systems. However, the implementation of techniques such as Doppler, Inertial, and GPS have cut costs dramatically in many cases. GPS, in particular, has reduced costs and at the same time, improved accuracy. Cost studies in Wisconsin have documented that, compared to manual systems, GPS has reduced time requirements from days to hours and costs from $1,000s to $100s.

An excellent example of the impact of GPS on county LIS modernization is the case of Wyandotte County, Kansas. In 1973, the County Surveyor began a program to build a base map for cadastral mapping that far exceeded the usual accuracy of local mapping efforts. However, to add parcel data to this base map, precise coordinates were needed for each of the Public Land Survey System corners in the county. These coordinates were not available in 1973 and the cost to obtain them was prohibitive, so the Wyandotte County program continued without the coordinate base. However, as a result of the efficiencies and economies of GPS, Wyandotte County has recently put into place a GPS network. This GPS network will now be used as the base for determining coordinate precise positions for each of the PLSS section corners in the county.

Remote Sensing

Various remote sensing techniques—for capturing data from wide geographic areas instantaneously and for monitoring changes in particular geographic areas over a period of time using airplanes and satellites—have been in use for many years. Recent advances in the availability and quality of data captured via satellite have made remote sensing even more cost effective.

Remote sensing techniques, such as photogrammetry, are relatively mature technologies using stereocompilation, analytical aerotriangulation, and orthophoto production. These technologies have continued to become more sophisticated and relatively cheaper.

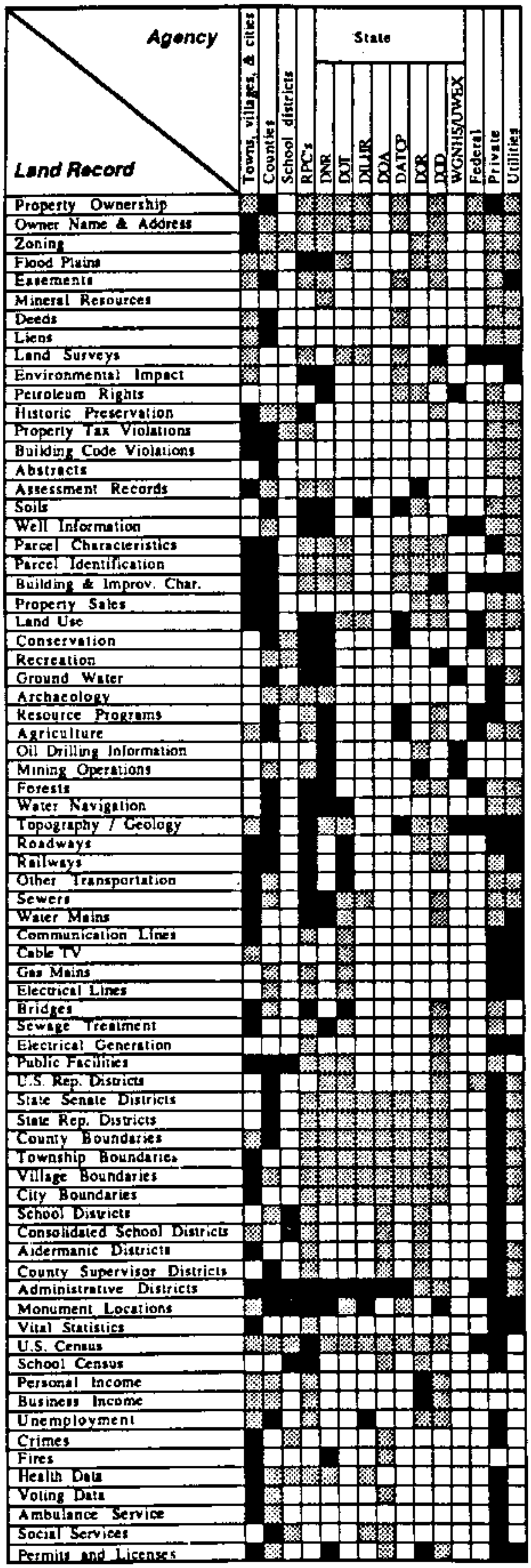
A recent prototype project in Wisconsin included the development of land cover and agricultural land use data for all agricultural lands in a 1200 square-mile area (Dane County, Wisconsin). Historically, these data were obtained by interpreting 35-mm slides collected via aerial photography, requiring considerable time and skill. Satellite imagery from the Landsat program proved to be of satisfactory quality, and meets the needs at an order of magnitude cost savings.

Scanning Devices

The development of a digital database is one of the most important, and most expensive, steps in the development of an MPLIS. Map data capture may be accomplished by use of a digitizing table or with a digital scanner. Scanners capture the map data through a process similar to photography, converting the points, lines, and polygons to digital form with much less human intervention. Evaluation of time requirements for digitizing soils data in Wisconsin found a reduction of two-thirds in the time needed for scanner digitizing, compared to manual digitizing techniques.

INFORMATION DEMANDS

Many demands for information are directed to government agencies every day. Generally information demands fall



Key

■ Collect and use data

▒ Use data collected by others

DNR	Dept. of Natural Resources
DOT	Dept. of Transportation
DILHR	Dept. of Industry, Labor, and Human Relations
DOA	Dept. of Administration
DATCP	Dept. of Agriculture, Trade, and Consumer Protection
DOR	Dept. of Revenue
DOD	Dept. of Development
RPC's	Regional Planning Commissions
GNHS/ UWEX	Geological & Natural History Survey (within University of Wisconsin-Extension)

Figure 7-2: Examples of land information collection and use in Wisconsin.

into several broad categories including: management of facilities and personnel, planning and siting, data acquisition, and service to individual citizens.

Management of Facilities and Personnel

- *Infrastructure Management:* The infrastructure of the United States (roads, bridges, sewers, pipelines, and other utilities) has been seriously neglected over the past three decades. One recent estimate indicates the United States needs to spend $3 trillion dollars to repair our existing infrastructure (Simmons 1990).

New ways of planning for the rebuilding of our infrastructure must be priority based, using several factors including an accurate inventory of the present condition of each segment of each facility, budgets available, safety of citizens and construction workers, usage patterns, and other resource needs and availability. MPLIS is the only efficient and effective way to integrate all of the data necessary and to develop a comprehensive plan.

- *Law Enforcement and Emergency Management:* Managers of police, fire, and other emergency resources face a wide range of geographical problems. Up-to-date statistics are needed for incidences in order to allocate resources to deal most effectively with crime and safety problems. Siting of fire stations to ensure adequate response times requires data on population, types of structures, contents of structures, and traffic patterns at various times of day to construct travel times. These and similar data affect facility siting, personnel allocation, and system design to optimize emergency dispatching and responses to 9-1-1 and 9-1-1 enhanced system demands.
- *Facility Impacts:* Noise and other impacts from airports, freeways, and parks are causes of increasing citizen concern. Means of evaluating noise levels, economic impacts, and social impacts at specific locations, at specific times, with a link to parcel-impacted addresses are needed to separate real problems from frivolous complaints.

Planning and Siting

- *Waste Disposal Siting:* Despite recycling efforts, landfill sites will be needed for the foreseeable future. Detailed information about soils, geology, groundwater and groundwater movement patterns, land use, zoning, and similar matters will become increasingly important, for both locating suitable sites and for monitoring conditions of existing sites.

- *Zoning and Land Use:* Rapid growth and increasing complexity of zoning laws make it increasingly difficult to keep master zoning maps current. The notification of affected land owners of proposed changes is an increasingly costly process. Correct information that can be delivered in a timely manner is essential to avoid political embarrassment, delays, protests, and costly lawsuits.

Competition is increasing among communities for industrial and commercial development. An MPLIS can be used to provide a competitive advantage, by quickly locating acceptable sites, acceptable in terms of existing infrastructure and compatibility with existing plans for the future.

- *Growth Management:* Rapid urbanization in many areas puts continuing pressure on all type of government services. Adequate data are needed to plan, finance, and monitor development, whether for residential, commercial, or industrial use.

Valuation and Voting Districts

- *Property Appraisal:* Continued inflation of property values produces greater revenues and greater citizen concerns about the property tax. This pressure, in turn, presents problems for the value appraisal process. More sophisticated appraisal techniques are available, but they require that more data be collected and maintained, and that these data be more precise than in the past. Photos, aerial photography, and traditional value assessment databases are available in many jurisdictions as free standing resources, but in order to be effectively used, they need to be linked to form a comprehensive database to support the assessment function.
- *Voter Redistricting:* The results of the 1990 Census will be available in 1991. This means that every voter district in the United States must be examined to ensure conformance with current statutory provisions regarding voter representation in Federal, state, and local elections. Data on a wide variety of population characteristics must be linked to additional social and economic data to evaluate and redesign voter districts.

SERVICE TO CITIZENS

Economies in Government

Ways to curtail costs of government—particularly curtailing the extent of duplicate land data—will continue to have major importance. The elimination of duplicate data files, duplicate records, and duplicate map production and compilation reduces costs and increases efficiency. More efficient routing of such services as public buses, school buses, garbage trucks, building inspectors, public health nurses, home bound meal delivery, and maintenance crews is necessary to stretch resources to their maximum. An MPLIS can produce these efficiencies.

Response to Citizen Requests

Citizen participation in the government decision-making process is generally increasing in many areas of the nation. Statutory requirements regarding freedom of information and privacy call for greater discretion and faster response to these information requests. Many local governments are looking for ways to deal more effectively with legitimate requests. Systematic, automated storage and retrieval are necessary for responsive government.

ISSUES IN LIS IMPROVEMENT

The NRC and others have identified several important issues in LIS improvement. These issues include costs—of both the present systems and the MPLIS that will replace them—and demands on LISs—how to assure accessibility, reduce duplication, facilitate aggregation, and ensure confidentiality. Institutional considerations as to how land information is captured, stored, analyzed, and shared are equally important. The importance of parcel-level data, with the opportunities these data provide to help quickly recoup some of the system costs, is also a major concern. Failure to recognize the full impact of these issues is a major factor in explaining the problems of current LISs.

COSTS OF LAND INFORMATION

A 1976 study examined expenditures in Wisconsin to collect and maintain land information at the local, state, and Federal levels of government. A recent update (1986) estimated that this state of 4.8 million people has expenditures of over $135 million per year associated with its land records (WLRC 1987). (See Figure 7-3.) This means that each Wisconsin resident is paying $31 per year for land information—information that is not adequate to meet societal needs as we move toward the 21st Century. (The inadequacy is due not only to the database itself, but also to present capabilities to manage and analyze these data.)

Not only are expenditures for land information large, they are also growing at a rapid rate. A recent study by Automation, Inc., a private market research firm, projected local government and utility expenditures in the United States ranging from $45 to $90 billion between 1986 and the year 2000 for information and systems to manage the nation's infrastructure.

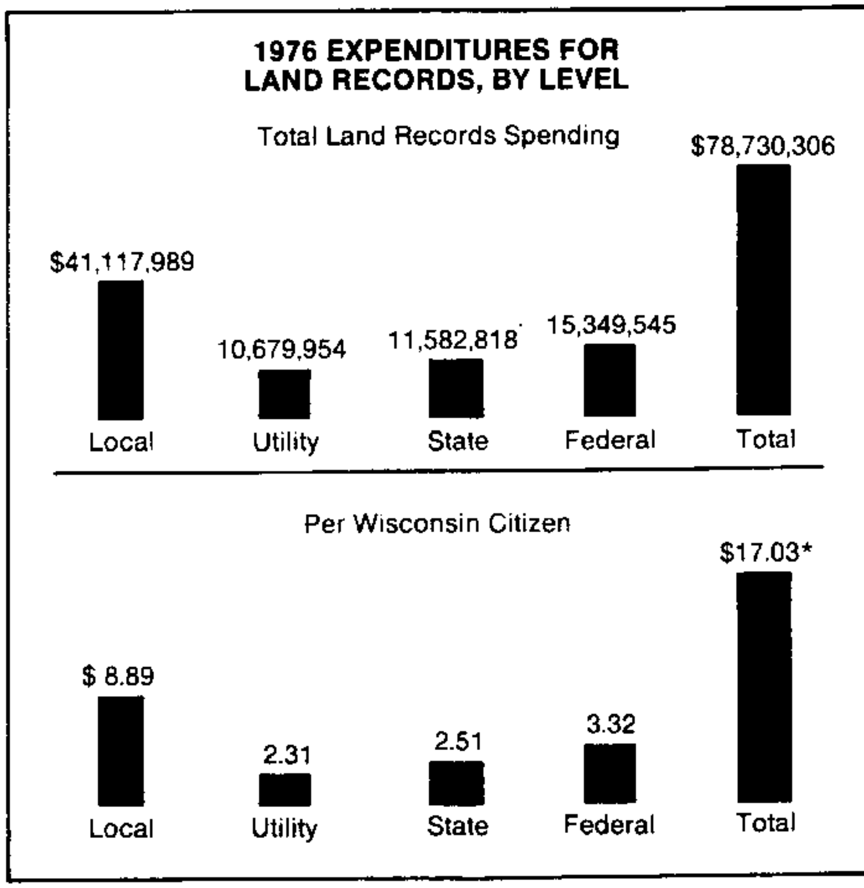


Figure 7-3: 1976 Expenditure for land records in Wisconsin, by level.

Expenditures of this magnitude, coupled with currently available technology, can provide the modern, accurate LIS we need. The large size of these expected expenditures on land information systems technology makes it imperative that the money be spent wisely. If these large sums are not invested wisely during this window of opportunity, it will be extremely difficult to find the resources to make a second attempt. Given the substantial investments that are needed to implement an MPLIS, a multi-year program is probably the best approach for most local and state governments. Finally, an incremental approach to modernization can provide cost savings for the present system through the use of the latest in data collection and management technology—savings that can in turn be used to help finance the next phase of the program.

HANDLING INFORMATION

In 1980, the NRC identified four data handling problems that characterize current LISs: duplication, accessibility, aggregation, and confidentiality (NRC 1980, pp. 21-22).

Duplication

A major factor that contributes to present high costs and conflicting databases in LIS is the duplication of maps, records, and other land data throughout the offices of local government. This duplication is responsible for a major part of the cost implications discussed above.

Duplication occurs when the same, or very similar, land data are collected and/or maintained by two or more government agencies or private companies (NRC 1980, p. 22). For instance, one organization may not be aware of what land data another agency may already have. The time frame in which one office plans to acquire and/or use certain data may be incompatible with the time frame of other organizations that need similar data items. Also, data classification systems among user agencies may not be compatible, leading an agency to infer that it is necessary to duplicate the database.

Even when several agencies start from a common base, each agency may diverge from the base over time. One example is a system based on the common tax parcel base, which over time is divided into separate parcel bases for the assessor, surveyor, zoning administration, and planning officials.

An example of duplication in data collection and storage became apparent in some recent work conducted at the University of Wisconsin. Two sister agencies in the U.S. Department of Agriculture both need data on individual crop fields that are part of each farm unit. Data needed about each field, often on an annual basis, include soil characteristics, the type of crop grown, crop yields, conservation practices planned and in place, and similar data. As a result of a lack of compatibility between the definition of farm "field" used by the two agencies, each collects and maintains its own database on these items. The duplication can be multiplied across more than 3,000 counties in the United States.

Accessibility

The 1980 NRC report identified a number of reasons for the accessibility problem, which they defined as a situation in which a government official or private citizen could not obtain land information. The information may not be available or a search of an unreasonable length may be necessary to locate it. (See Figure 7-4.) The data may be poorly organized with respect to file structure and/or classification scheme, thereby limiting access to data that do exist. Because of these constraints, even public and private users who regularly work with land records in a county may not know the true extent of "public" land information. Too often, many public and private decisions about land are made in ignorance of facts, simply because the information is too difficult or expensive to access.

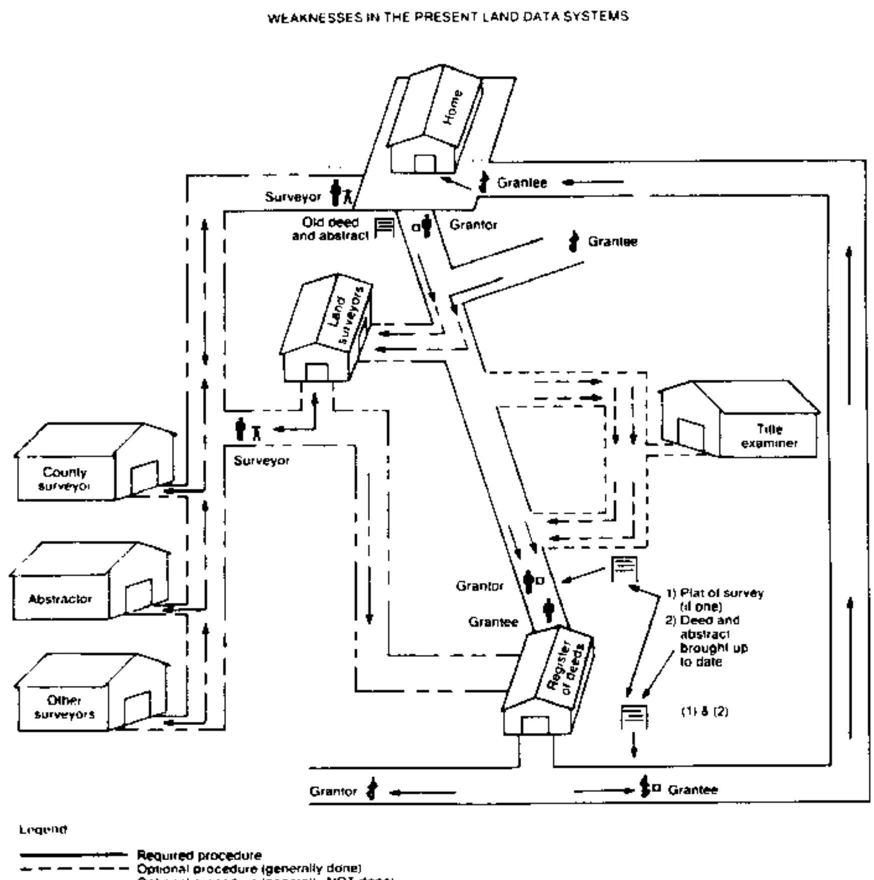


Figure 7-4: The sale of land under the present system (McEntyre 1985).

Limits on accessibility to land information have impact on governments as well as on individual citizens. For example, the State of Wisconsin found it was unable to seek designation as the site of the proposed High Speed Accelerator project because it could not compile and access the wide array of land data necessary. Instead, Wisconsin found it necessary to support the proposal of adjacent Illinois, which had a statewide LIS in place that was capable of linking many separate layers of data and performing the analyses necessary to develop and support a proposed site for the Accelerator.

In 1986, the Wisconsin Department of Transportation conducted a study of the economic impacts and accident rate effects of changing the geometry on highway curves. A full six months was required for one analyst to compile the data needed for the study (on accident rates, highway geometry, and traffic statistics). As part of a feasibility study for an MPLIS, necessary data for the study were collected and compiled in four hours, a savings of 250 to 1. These are the kinds of savings that are necessary if we are to rebuild the infrastructure in this country, and these are the kinds of savings that an MPLIS can provide.

Aggregation

Many information systems currently used in major land management agencies at the state and Federal level are not designed to serve the needs of individual data users, but rather are developed to serve the needs of a particular level or function of government. For example, data at higher levels of government may be so coarse that their usefulness at lower levels is severely limited. Conversely, local data are often so finely disaggregated that use by higher levels of government is similarly restricted.

Data aggregation problems often stem from lack of consistency in standards and quality of data. For example, states find it impossible to combine data from counties to carry out legislatively mandated analyses. Similar examples occur at the Federal level in regard to inconsistent data among the states. Aggregation problems also occur due to the inability to relate parcel level data, such as ownership, to resource polygon data about such items as geology, soils, wetlands, and wastelands (NRC 1983). Inconsistent classification schemes between units of government also make aggregation, analysis, and sharing of data among levels of government difficult or impossible. The inability to share data among departments and divisions within the same unit of government is equally important and common.

Confidentiality

There are two kinds of confidentiality problems. First, access to some land information should legitimately be restricted. Records placed in this restricted category often involve matters of health, finances, or individual employees. Since the system must be able to guarantee the security of such information, the information available from the system must be limited. However, all too often this is interpreted to mean that all information collected by an agency must be restricted, even when there may be compelling reasons to share some of the data with others.

Second, laws and standards defining "freedom of information" and "open records" are too often unclear or contradictory. For example, freedom of information and privacy regulations are often by their very nature in conflict. Also, in the area of land records, the magnitude of relevant legislation or ordinances almost guarantees some conflicts. A study in Wisconsin found over 600 references to land records in the Wisconsin Statutes (Massey 1987). Any conflicts in such legislation invariably lead to disputes that result in delays and restriction on accessibility to information.

INSTITUTIONAL CONSIDERATIONS

The primary barriers to MPLISs are institutional. Most local governments already have single purpose systems that currently contain information on title, taxes, land use, soils, geology, and similar data. What is necessary is a means of connecting these many data files not only to save on data collection and storage, but, more importantly, to make more effective use of this valuable reservoir of data waiting to be tapped. The technology is now available, in the form of LIS, to link the many existing databases to serve the expanding needs of government and industry. To use this technology effectively, we must modify institutional aspects of our offices and work to allow the LIS technology to produce the benefits.

Institutional factors affect land information system operation in at least two ways. First, there is a basic mismatch between how government is typically structured and how land information is collected and managed. Second, there exists a strong resistance to any major changes in both the public and private sectors.

The typical structure of existing governmental organizations is vertical. For instance, in state government, each of several offices is organized around a particular land-related task, such as property assessment, transportation planning, or solid waste management. Each of these offices requires land information, and each is typically part of a hierarchical system that does not relate horizontally to its sister agencies. At the local level, similar examples exist. In the private sector, parallel operations often exist within utility and title insurance companies, which in turn duplicate much local government land information.

In contrast, ownership, zoning, resource, land use, and similar data are most effectively organized on a horizontal layer basis. Building an LIS that is complete, comprehensive, and responsive requires the cooperation of all organizations that are organized vertically, to ensure the horizontal benefits of LIS are fully realized. The importance of the cooperation of governmental units at all levels of government can be seen in Figure 7-5. Through the cooperation of offices at the local, state, and Federal levels, all MPLIS users benefit.

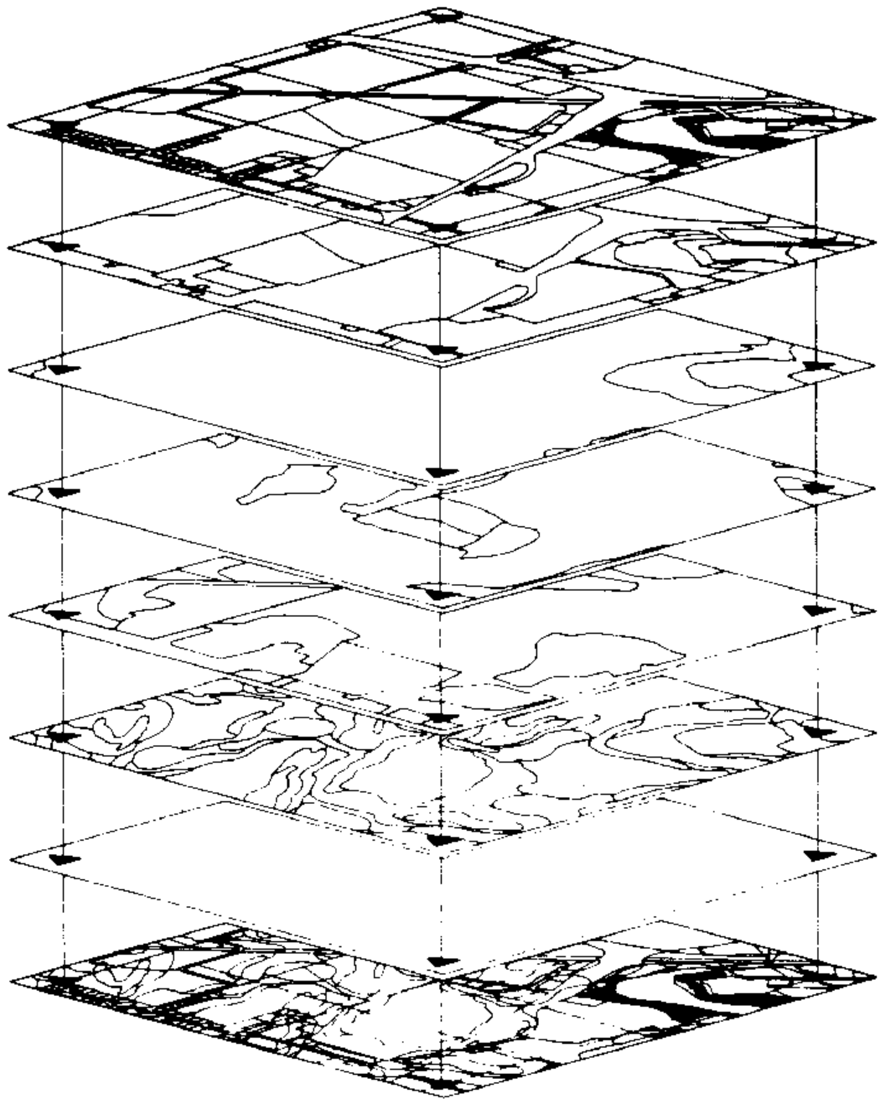
The resistance of many individuals to change contributes to institutional inertia. Overcoming this inertia may require specific legislative changes as well as training programs to assure that everyone knows what changes are being made and why they are being made. To make these institutional changes, we need better integration and standardization of existing activities.

Resistance to change is buttressed by factors such as legislative or administrative requirements for which an agency is responsible. Agencies correctly perceive that they are fulfilling the letter of the law by the use of existing methods. Many see no need to look at the bigger picture. This means that such direction, important if benefits of an MPLIS are to be realized, must come from a higher level (e.g., county executive, county board, governor, or legislature).

PUTTING IT ALL TOGETHER

An MPLIS is not a monolithic information system, but rather an approach that integrates the numerous land information files and offices. The four major structural parts of an MPLIS—parcel level data, the geodetic reference system, base maps, and parcel identifiers to link non-map data to the digital base—are key components to keep in mind. There are also several key institutional aspects of an MPLIS that are critical.

Most of the offices that presently collect and maintain land data will continue to do so. That is, the responsibility of serving as the *custodian* for data files will continue. The improvements under the MPLIS will come as the result of the integration of data from many different files and offices that are presently autonomous "systems." (See Figure 7-6.)



Concept for a Multipurpose Land Information System

Section 22, T8N, R9E, Town of Westport, Dane County, Wisconsin

Data Layers:	**Responsible Agency:**
A. Parcels	Surveyor, Dane County Land Regulation and Records Department.
B. Zoning	Zoning Administrator, Dane County Land Regulation and Records Department.
C. Floodplains	Zoning Administrator, Dane County Land Regulation and Records Department.
D. Wetlands	Wisconsin Department of Natural Resources.
E. Land Cover	Dane County Land Conservation Committee.
F. Soils	United States Department of Agriculture, Soil Conservation Service.
G. Reference Framework	Public Land Survey System corners with geodetic coordinates.
H. Composite Overlay	*Layers integrated as needed, example shows parcels, soils and reference framework.*

Figure 7-5: Concept for a multipurpose land information system.

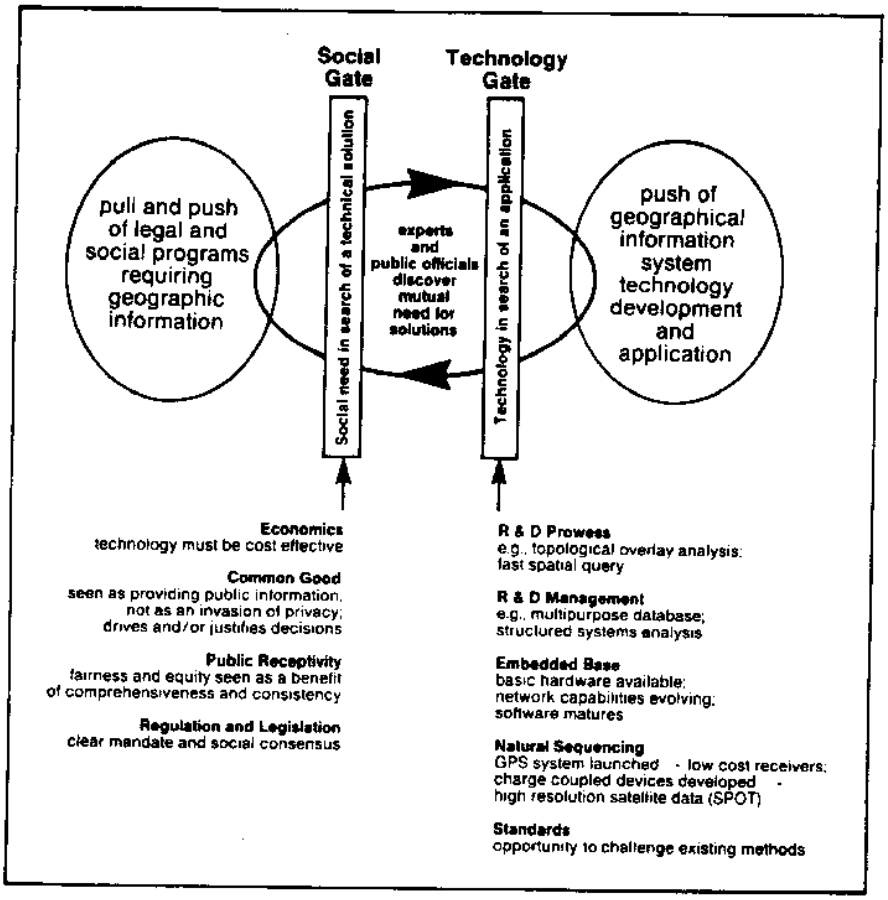


Figure 7-6: The symbiotic relationship between technology and society (Niemann et al. 1988).

The substantial value of investments in an LIS must be protected with a program that assures these databases are maintained. The best way to maintain LIS databases is through the use of on-going functions of government to provide the data for update when transactions occur. For example, changes in ownership, tax assessment, zoning, easements, etc. can all be used to update the database on a daily, weekly, or other periodic basis.

Use of coordinates to bring together disparate data sets is now technically and institutionally possible. Systems in operation in various parts of the United States have demonstrated a number of spatial operators that will have wide application for state and local government. These spatial operators include overlay, proximity, adjacency, and connectivity. Section 5 of this *Guidebook* contains documentation on several of these jurisdictions.

1. Overlay—makes it possible to examine the co-occurrence of information at a particular location or on a particular parcel. Linkage of tax and environmental data, and the linkage of conservation and ownership data are two examples of existing uses in operating systems.
2. Proximity—allows the analysis of areas, for example, of a specified distance from a parcel or polygon boundary. Can be used to determine the impacts of changes in environmental restrictions, as to water, air, etc.
3. Adjacency—facilitates extraction and examination of all parcels or polygons that abut another parcel or polygon. Can be used to notify abutters of zoning hearings or other proposed changes in occupancy or use.
4. Connectivity—permits use of MPLIS data for network analysis. Uses include routing of busses, garbage, and other service vehicles, and the dispatching and routing of emergency vehicles with 9-1-1 and similar systems.

As noted at the outset of this chapter, two major forces are driving the implementation of LIS in governmental units throughout the United States. The availability of technology that enables the use of the spatial operators outlined above is one of the forces that is pushing the technology in Figure 7-6. The second major force is the demand for better, cheaper, more timely information that is coming from users of land information at all levels of government. This demand is also noted in Figure 7-6. Coupled together, these two forces create an interactive process that will continue to drive LIS for the foreseeable future.

The need for improved LISs is increasing at a rapid rate. Traditional, manual land data systems, while they contain much of the data needed, are not organized in a way that permits the retrieval and use of these data in a timely manner.

The availability of state-of-the-art technology makes it possible to implement an MPLIS at an affordable cost. This affordability, coupled with the growing demands on decision-makers who must rely on LISs, makes this a logical time to look toward MPLIS development.

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