Return to Table of Contents

BASE MAP DATA

The term "base map" is one that is widely used in the context of GIS implementation, and unfortunately, a wide range of meanings accompanies its wide use. The American Society of Photogrammetry provides a general definition of base map as,

> *"A base map is the graphic representation at a specified scale of selected fundamental map information; used as a framework upon which additional data of a specialized nature may be compiled."*[21]

Other definitions include: "a map on which information may be placed for comparison or geographical correlation," or as, "a map from which other maps are prepared by the addition of information."[22]

Two Fundamental Base Map Types. The URISA and IAAO in their joint publication, GIS for Assessors, noted the multifaceted nature of the base map concept. "Base map data are all the features needed to map the cadastral and attribute data. Generally, these features are *physical items* such as roads, railroads, rivers, lakes, and other objects that can be seen from an airplane or referenced from the ground. In some cases, base map data may include *public land survey system townships and sections,* county and municipal boundaries, and fence lines." [23]

The Multipurpose Land Information Systems, The Guidebook provides some clarity to this issue by highlighting the dual use of the term "base map". The Guidebook suggests that "base maps" fall into one of two general types: a) large-scale surface feature maps, or b) cadastral reference information. "There are several ways to classify base maps and one of the most useful ways is by their information content. The base map consists of either cadastral information (the legal identification of features), or planimetric information (the physical identification of features), or it may consist of a combination of both cadastral and planimetric information"[24]

It is important to note, that both of these general types of base map data are represented in the consensus list (page III-1) of four fundamental elements of a multipurpose GIS/LIS. This reflects the reality that both types of information are needed—regardless of whether one, or the other, or both are referred to as the base map. The earlier review and recommendations related to Geographic / Geodetic Control, also highlighted the fact that in addition to the need for both types of base maps, they also both need to be tied together spatially, via reference to the National Spatial Reference System (NSRS).

> ***To provide the foundational framework upon which the development a local government multipurpose land information system can be based, we recommend both a Public Land Survey System base map and a surface features base map. Both base maps should be tied to the National Spatial Reference System and have a level of spatial accuracy appropriate to the range of applications planned for a given area.***

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[21] American Society of Photogrammetry, 1980: *Manual of Photogrammetry,* 4th ed., Falls Church, VA. cited in National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, DC, 37 p.

[22] National Geodetic Survey, 1986*: Geodetic Glossary*, National Geodetic Survey, Rockville, MD, 142 p.

[23] Urban and Regional Information Systems Association and International Association of Assessing Officers, 1992: *GIS Guidelines for Assessors*, Washington, DC and Chicago, IL, 21-22 p.

[24] Federal Geodetic Control Committee, January 1993: *Multipurpose Land Information Systems, The Guidebook,* "The Base Map", 12-3 p.

These two types of base maps, together with their link to a common ground coordinate system, provide the framework upon which to construct a multipurpose land information system. Within a multipurpose GIS/LIS, these base maps provides the primary medium by which the locations of property parcels can be related to the geodetic reference framework; to major natural and man-made features such as bodies of water, roads, buildings, and fences; and to municipal and political boundaries. The base maps also provide the means by which all land-related information may be related graphically to property parcels.[25]

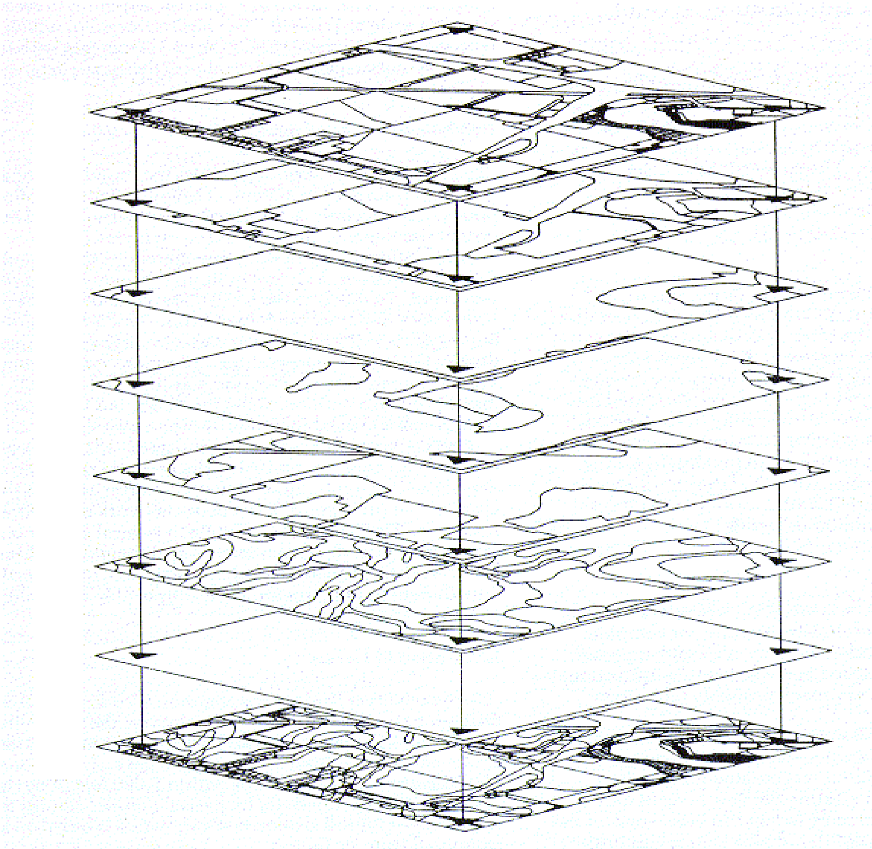

Fig 9.) This view illustrates the concept of having multiple layers in a GIS. Once the base map is set and in place, other thematic layers of data can be created that are tied to, or geo-spatially connected to the control base.

Base Map Data Quality. Regardless of the type of base map being considered, careful attention to required base map accuracy and other indices of data quality is critical in any GIS/LIS development effort. Data quality is an important consideration in all phases of geospatial data development and maintenance, however, it is particularly important with regards to base maps. Base maps are the foundation upon which most, if not all, other geospatial data layers are built. In most cases, it will be very difficult and costly to enhance the overall quality of one's geospatial data beyond that of the base map upon which it was originally developed. The importance of this consideration was emphasized by the Federal Geodetic Control Committee in their Multipurpose Land Information Systems, The Guidebook when they noted, *"GIS/LIS developers should keep in mind that it is easy to build a less*

[25] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, DC, 37 p.

accurate map on a more accurate base, but virtually impossible to build a more accurate map on a less accurate base.[26]"

Positional Accuracy. There are many measures of the quality of geospatial data, however the most commonly used measure is spatial or positional accuracy. Positional accuracy is a measurement of the variance of the position of a map feature from the true position of the entity. The importance of positional accuracy for base maps was highlighted by URISA and IAAO in their joint publication, GIS for Assessors. In their discussion of geographic control, they noted that it must have the level of accuracy that is necessary to support the development of an accurate base map and must be cost-effective. Their recommendation is, that *it is best to get the highest level of accuracy possible within budget constraints.*[27]

Two types of positional accuracy are commonly discussed: relative and absolute. *Relative accuracy* is a measure of the accuracy of individual features on a map when compared to other features on the same map. An example of relative accuracy might be a comparison of how closely the distance (adjusted for scale) between two features plotted on a map (i.e., a road intersection and a driveway) represents the actual real world distance of 500 ft. between that road intersection and driveway. Absolute accuracy, on the other hand, is a more rigorous measure of positional accuracy, which also incorporates the concepts included in relative accuracy. *Absolute accuracy* is a measure of the location of features on a map compared to their true location on the face of the earth. An example of absolute accuracy might be a comparison of a section corner's latitude/longitude location (as measured on a map) to the actual latitude/longitude of the section corner monument, as measured on the ground with highly accurate global positioning satellite (GPS) technology. Absolute accuracy becomes very important when different map layers are created independently and then integrated later on the basis of their physical location on the surface of the earth (a common GIS/LIS practice).

When considering the level of base map accuracy that will be required for the implementation of any GIS/LIS, a good starting point is a determination of the map scales that will likely be used for particular GIS/LIS applications, both present and future. A determination of the map scales that have been used for applications in the past, and are likely to be desired for specific GIS/LIS applications in the future is one of the easiest ways to conceptualize map accuracy requirements. For this reason, a discussion of map scale is important, even though a digital map or a geospatial database in a GIS/LIS do not have a fixed map scale and can be enlarged or reduced at will.

Map Scale. Map scale is the ratio of the units of measurement on the map to the units of measurements on the earth. Scale is often stated as *uniform parts* such as 1:2,000, where one part or unit of measurement on the map is equal to 2,000 parts or *identical units* of measurement on the earth. At times, scale is stated in specific units such as 1" = 200', where 1 *inch* on the map is equivalent to 200 *feet* on the earth [this same scale could also be stated at 1:2,400, where 200 ft. x 12 inches/ft = 2,400 inches].

The commonly used terms of "large-scale" and "small-scale" maps are often confusing, in part because a large-scale map generally covers a relatively small geographic area. The large- and small-scale terms refer to the size of the scale and not to the area covered or to the sheet size. For a map of 1:1,200 scale, the ratio (1/1,200) of maps units to ground units is relatively large (thus a "large-scale" map), compared to a map of 1:12,000 scale, where the map ratio (1/12,000) is relatively small.

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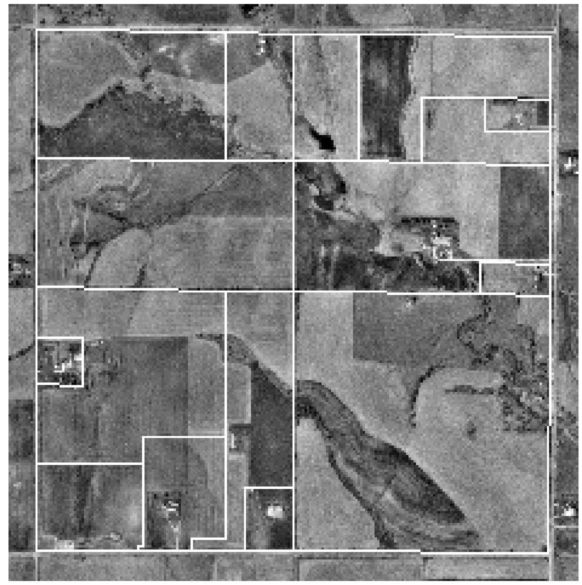
[26] Federal Geodetic Control Committee, January 1993: *Multipurpose Land Information Systems, The Guidebook,* "Introduction to Mapping Concepts", 2-13 p.

[27] Urban and Regional Information Systems Association and International Association of Assessing Officers, 1992: *GIS Guidelines for Assessors*, Washington, DC and Chicago, IL, 46-47 p.

Small scale map = Large area

Mapscale = 1:144,000

Large scale map = Small area



Mapscale = 1:24,000

Fig 10.) The differences of two scales are easily seen in this example. A small-scale map covers a large area whereas a large-scale map covers a small area and reveals greater detail.

The scale of a printed map is a commonly used factor in evaluating the positional accuracy of a map. Accuracy standards are generally stated in terms of an acceptable tolerance that must be achieved and the proportion of measured features that must meet the criteria. For example, the United States National Map Accuracy Standards (NMAS) specifies a horizontal accuracy for maps of scales larger than 1:20,000, that not more than 10 percent of the points tested can be in error by more than 1/30 of an inch, as measured on the printed map[28]. These tolerances are applied to well-defined points selected for evaluation. This means that for a 1:4,800 (1" = 400') scale map to meet National Map Accuracy Standards, not more than 10 percent of the well-defined points on the map can be misplaced more than ±13.3 ft. from there true position on the earth [4,800in. ÷ 30 = 160 inches or 13.3 ft.].

National Map Accuracy Standards (NMAS) were originally developed for paper maps in the 1940's — prior to the advent of digital mapping technologies. Currently, national standards efforts are underway to develop a variation of NMAS, that more closely parallels the realities of today's digital mapping world. However, even though digital maps or geospatial databases within a GIS/LIS can be enlarged or reduced at will, NMAS still provide one of the best guidelines for determining the optimal positional accuracy that should be sought in the development of base map databases upon which to develop a GIS/LIS.

As an example, if you are planning a GIS/LIS application, such as rural parcel mapping, that may have traditionally been mapped at a scale of 1" = 400' (1:4,800) or 1" = 800' (1:9,600), then having a base map in which 90 percent of the major points have a positional accuracy within a range of ±13.3 ft. or ±26.7 ft. is probably appropriate. However, if you were planning an application, such as urban property parcel mapping, where the lot frontages may be 50 ft. or less, then using a base map with a positional accuracy in the range of ±13.3 ft. or ±26.7 ft. is probably not appropriate. Traditionally these types of applications

[28] Antenucci, John C., Kay Brown, Peter L. Croswll, et al.: *Geographic Information Systems - A Guide to the Technology*, Van Nostrand Reinhold, New York, NY, 102-104 p.

have been mapped at a scale of 1" = 100' (1:1,200) or larger, and a base map positional accuracy that parallels the NMAS for that scale (±3.3 ft.) is probably more appropriate for that type of work.

One of the strengths of computerized digital mapping is the capability it provides users to easily enlarge or reduce the scale of a map. However, this capability can present serious problems, when a map is enlarged beyond its original intended use, and then subsequent map measurements and policy decisions are made based on that enlarged map. Unless noted on the map, the fact that a map or geospatial database designed for use at a scale of 1:4,800 has been enlarged to a scale of 1:1,200 is not readily apparent to the user of the generated map. This can cause serious problems when a map with a positional accuracy of ±13.3 ft. or ±26.7 ft. is used to tear up a street to find a buried water main in an urban area. This capability to easily enlarge a map has increased the importance of specifying map accuracy standards. Map accuracy standards allow users of the digital database or printed map to have an understanding of the positional accuracy of a map, regardless of the scale in which the map might be presented.

Base Map Scale and Positional Accuracy Recommendations. Given the importance of positional accuracy for base maps, and the relationship of traditional positional accuracy standards to map scale, what are the recommended map scales and positional accuracy standards that should be considered in the development of base maps upon which to build a local government GIS/LIS?

A joint ACSM-ASPRS Geographic Information Management System Committee suggested that the base map scale selected for a multipurpose local government GIS should be appropriate for the density of the number of lots in a given area. Since the parcel is likely to be the smallest unit mapped, this should dictate the scale to be used. As an example, they noted that the state of North Carolina uses the criteria that the lot should be at least 1/4" wide on the map. However, they also stated that the accuracy needs for utility/facility management maps vary depending upon the item mapped. They note that larger scale maps will be needed to delineate underground features where service to the facility requires accurate knowledge for that feature for excavation.[29] The chart on page V-6 shows typical scale ranges for depiction of certain map features.[30] Based on a review of the available literature, the following map scale/accuracy guidelines are recommended for developing multipurpose GIS/LIS for local governments.

The following map scales and their corresponding National Horizontal Map Accuracy Standards are recommended guidelines for determining the positional accuracy needed for base maps in the development of a multipurpose local government GIS/LIS:

Relative Size of Property Parcels	***Map Scale***		***Nat'l Horizontal Map Accuracy Std.***	***Equivalent Metric Scale***
Urban areas	***1:600***	***(1" = 50')***	***±1.7 ft.***	***1:500***
	1:1,200	***(1" = 100')***	***±3.3 ft.***	***1:1,000***
Large urban and suburban	***1:2,400***	***(1" = 200')***	***±6.7 ft.***	***1:2,500***
Rural areas *	***1:4,800***	***(1" = 400'***	***±13.3 ft.***	***1:5,000***
	1:9,600	***(1" = 800')***	***±26.7 ft.***	***1:10,000***
	1:12,000	***(1"= 1,000')***	***±33.3 ft.***	***1:10,000***

* *see "Making Choices" page V-18, 19.*

[29] Joint Geographic Information Management System Committee of the American Congress on Surveying and Mapping, and the American Society for Photogrammetry and Remote Sensing, 1989: "Multi-Purpose Geographic Database Guidelines for Local Governments," *ASPRS Bulletin,* 1360 p.

[30] Vonderohe, A.P., R.F. Gurda, S.J. Ventura, and P.G. Thum, 1991: *Introduction to Local Land Information Systems for Wisconsin's Future,* Wisconsin State Cartographer's Office, Madison, WI, 20 p.

The above recommendations for base map positional accuracy *(except for the 1:12,000 scale)* follow what is identified by the International Association of Assessing Officers (IAAO) as "commonly used mapping scales", in their publication, Standard on Cadastral Maps and Parcel Identifiers, 1988[31]. The related text notes, "A map scale that covers the largest possible area while showing necessary detail should be selected. Parcel size and the complexity of parcel descriptions in the area to be covered by a single map are the major determining factors in choosing map scales." The Multipurpose Land Information Systems: The Guidebook[32] also references these same IAAO mapping scales.

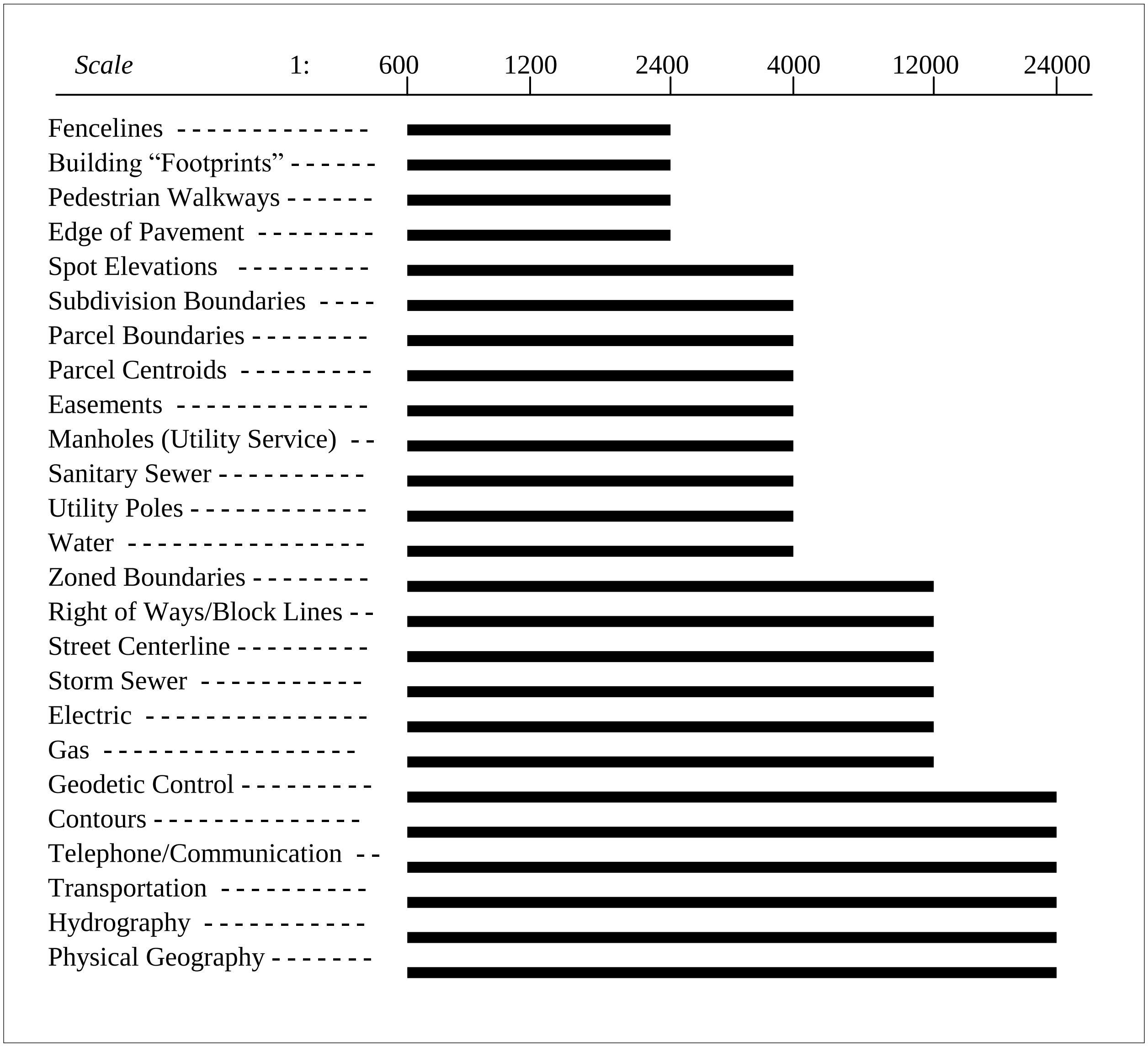


Fig 11.) Typical scale ranges for depiction of certain map features (from Vonderohe, et.al., 1991) after (ACSM-ASPRS (1989)).

[31] International Association of Assessing Officers, January 1988: *Standard on Cadastral Maps and Parcel Identifiers*, Chicago, IL, 7 p.

[32] Federal Geodetic Control Subcommittee, 1989-1994: *Multipurpose Land Information Systems: The Guidebook,* 13-8, 9 p.

Similar map scale suggestions are made in Procedures and Standards for a Multipurpose Cadastre,[33] published by the National Research Council in 1983. However, for rural cadastral mapping they do not suggest a map scale smaller than 1:4800. This publication relates its map scale recommendations to specific size ranges of what they refer to as "Customary Lot Frontage".

Type of Area	Customary Lot Frontage	Comparable Base-Map Scale	Metric-Map Scale
Urban	15' to 40'	1:600 (1" = 50')	1:500
Urban	40' to 90'	1:1200 (1" = 100')	1:1000
Suburban	100' to 180'	1:2400 (1" = 200')	1:2000, 1:2500
Rural	200' and greater	1:4800 (1" = 400')	1:2000, 1:5000
Resources		1:12,000, 1:24,000	1:10,000, 1:25,000

Similar map scales are also recommended or required by the states of North Carolina,[34] New York State,[35] Kansas,[36] and Louisiana[37]. All of these state publications parallel the National Research Council recommendations for rural cadastral map scales, in that they do not recommend a map scale smaller than 1:4800 for rural areas. These same National Research Council map scales are suggested in the Multi-Purpose Geographic Database Guidelines for Local Governments[38], prepared by the joint ACSM-ASPRS GIMS committee. This joint ACSM-ASPRS publication also specifically recommends that all map products within a GIS should meet the National Map Accuracy Standards.

The Nebraska Dept. of Revenue's Real Property Regulations[39] state, "In the preparation of a cadastral map, the following scale of measurement shall be used as applicable:

Regulation			
Urban lot	Scale - 1 inch	= 100 ft.	*(1:1,200)*
Large urban & suburban	Scale - 1 inch	= 200 ft.	*(1:2,400)*
General rural	Scale - 1 inch	= 1,320 ft.	*(1:15,840)*
General rural & range	Scale - 8 inches	= 1 mile"	*(1:7,920)*

The somewhat unusual relationship between the map scales for "General rural" and "General rural & range" was noted as part of the current review. The Property Tax Division is currently in the process of reviewing and revising these regulations.

A review of the literature shows that there is a considerable degree of consensus on the appropriate mapping scales to use for property parcel mapping in various levels of population density. For rural property parcel mapping, the consensus is not quite as strong. The limited support for rural property parcel mapping at scales smaller than 1:4,800, is an indicator that local governments should carefully weigh the long-term gains and losses before deciding to develop a multipurpose GIS/LIS based on rural

[33] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, D.C. 44 p.

[34] North Carolina Management Program, North Carolina Department of Natural Resources and Community Development, November 1987: *Technical Specifications for Base, Cadastral and Digital Mapping,* 2.2 p.

[35] State Board of Equalization and Assessment. State of New York, 1975: *Model Technical Specifications for Tax Mapping in New York State, Second Revised Edition,* 18 p.

[36] Division of Property Valuation, State of Kansas, May 1992: *Contract Agreement and Revised Technical Specifications for Property Ownership Mapping Services and Ownership Maps*.

[37]Division of Administration Office of State Lands, State of Louisiana, February 1991: *Louisiana Land Information Mapping and Map Records System Standards*. Baton Rouge, LA, II-1,2 p.

[38] Joint Geographic Information Management System Committee of the American Congress on Surveying and Mapping, and the American Society for Photogrammetry and Remote Sensing, 1989: "Multi-Purpose Geographic Database Guidelines for Local Governments," *ASPRS Bulletin,* 1360 p.

[39] Nebraska Department of Revenue, 1993: *Real Property Regulations, Title 316, Chapter 40*, Lincoln, NE, 40-004.02.

mapping scales smaller than 1:4800, and at a corresponding level of positional accuracy less than ±13.3 ft.

The 1:12,000 scale base map was included in the recommendations on page V-5 because digital orthophotography, at that scale and level of positional accuracy, will soon be available for all of Nebraska at little or no cost to local governments[40]. If used in conjunction with a Public Land Survey System database which provides a higher degree of positional accuracy for section corner locations, these 1:12,000 digital orthophotos can provide a cost-effective aerial photo base map background for rural property parcel mapping[41]. However, users of this data should consider the potential limitations involved for future GIS/LIS applications from data that has a positional accuracy of ±33.3 ft. and a pixel resolution of one meter *(see page V-17, 18).*

In making a determination of the level of positional accuracy needed for a GIS/LIS, local government officials must ultimately decide how much positional error they can tolerate, over the long-term, in their GIS/LIS applications. For example, policy makers must determine the costs and consequences of having long-term positional errors of up to ±26.7 ft. in the GIS/LIS applications upon which they will base their policy and operational decisions, versus the costs involved in developing base maps for a given area that have a positional accuracy in the neighborhood of ±6.7 ft. Achieving higher levels of positional accuracy in base maps costs significantly more money. However, once a GIS/LIS has been developed based on less accurate base maps, it is very difficult and costly to attempt to increase the accuracy of the GIS/LIS overall. For this reason, URISA and IAAO in their joint publication, GIS for Assessors, recommended that *it is best to get the highest level of accuracy possible within budget constraints.*[42] This document's recommendations for the map scales and related levels of horizontal map accuracy standards that should be used for GIS/LIS base map development are outlined on page V-5.

Other Map Quality Standards. The National Horizontal Map Accuracy Standard that has been recommended here provides a common, quantifiable means to specify and measure the horizontal positional accuracy of a map or geospatial database. For those GIS/LIS applications requiring elevation or topographical detail, there is also a National Map Standard for vertical accuracy.

> *National Map Accuracy Standards of vertical accuracy specify that not more than 10% of the points tested shall be in error by more than one-half of the contour interval used on a map.*

The National Research Council in its publication, Procedures and Standards for a Multipurpose Cadastre, notes that the added expense for contours is substantial. Because of this substantial added expense careful consideration should be given to determine the required applications for this type of data. However, if required, the National Research Council notes that contour intervals should be selected in conjunction with the map scale, the terrain relief, and the elevation information requirements. The National Research Council outlined the following as "typical combinations".[43]

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[40] Statewide development of Digital Orthphotos at 1:12,000 scale is a joint project of the Nebraska Natural Resources Commission and the United States Geological Survey.

[41] State of Kansas Geographic Information Systems (GIS) Policy Board, December 1995: *Digital Orthophotography Pilot Project,* 29 p.

[42] Urban and Regional Information Systems Association and International Association of Assessing Officers, 1992: *GIS Guidelines for Assessors*, Washington, DC and Chicago, IL, 46-47 p.

[43] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, D.C. 43-45 p.

Appropriate Vertical Contour Intervals for Suggested Map Scales

Customary Base-Map Scale		Typical Contour Interval	Metric Base-Map Scale	Typical Contour Interval
1:600	(1" = 50')	1', 2'	1:500	0.5 m
1:1200	(1" = 100')	1', 2', 5'	1:1000	0.5m, 1m
1:2400	(1" = 200')	2', 5'	1:2000	0.5 m, 1 m, 2 m
1:4800	(1" = 400')	2', 5', 10'	1:5000	0.5 m, 1 m, 2 m
1:12,000	(1" = 1000')	5', 10', 20'	1:10,000	1m, 2 m, 5 m
1:24,000	(1" = 2000')	5', 10', 20', 40'	1:25,000	2 m, 5 m, 10 m

Public Land Survey System Base Map. It was noted earlier in this section, that for the development of a local government multipurpose GIS/LIS, two types of base maps are recommended: a Public Land Survey System (PLSS) base map, and a surface features base map.

> ***In Nebraska, a PLSS base map data should be in the form of a digital database that includes all the original government (PLSS) corners, all restored survey marks representing those corners, and all county boundaries within a given area of coverage. Each government corner and monumented survey mark should be referenced in a related attribute database by a unique identifier and by the best available approximation of its coordinate location.***[44]

The PLSS grid of townships, ranges and sections was originally developed according to an established set of survey rules and principals which are outlined in the Manual of Surveying Instructions - 1973[45], published by the Bureau of Land Management, U.S. Department of Interior. These surveying principals are still the controlling authority for determining the legal location of property defined by the PLSS grid. Database developers, seeking to recreate the PLSS grid in the form of a digital base map, should be familiar with and follow these same principals (see Figure 12).

For PLSS states like Nebraska, the PLSS base map/database is based on essentially the same information, or reference network, that is recommended for providing the Geographic / Geodetic Control of a GIS/LIS (see pages IV-9, 10). For a given type of application, the recommended positional accuracy standards for a PLSS base map parallel those outlined on page V-5 of this section.

Sources of PLSS Base Map Data. There are four possible sources of data for a PLSS base map/database: a) digitizing from existing maps, b) aerial photography, c) re-surveying, and d) COGO (coordinate geometry). In most instances, a combination of the re-surveying and COGO options is the most feasible approach for developing a PLSS base map for multipurpose local government land information systems.

In most cases, an **existing map** with accurate coordinates for PLSS points will not be available, and therefore the first option, a) digitization from an existing map is not feasible. The National Research Council suggests, that unless there has been a consolidation and standardization of the mapping efforts within the various local government departments, and a recent large-scale mapping program completed, existing maps for a given county or municipality are likely to be less than ideal for use as a mapping base

[44] Property Parcel Task Force, Nebraska GIS Steering Committee, July 1996: *Facilitating Land Record Modernization in Nebraska, A Working Paper*, Lincoln, NE, 8 p.

[45] Bureau of Land Management, U.S. Department of Interior, 1973: *Manual of Surveying Instructions - 1973.*

Rules of Survey. The public lands shall be divided by north and south lines run according to the true meridian, and by others crossing them at right angles, so as to form townships of six miles square, unless where the line of an Indian reservation, or of tracts of land surveyed or patented prior to May 18, 1796, or the course of navigable rivers, may render this impracticable; and in that case this rule must be departed from no further than such particular circumstances require.

Second. The corners of the townships must be marked with progressive numbers from the beginning; each distance of a mile between such corners must be also distinctly marked with marks different from those of the corners.

Third. The township shall be subdivided into sections, containing, as nearly as may be, six hundred and forty acres each, by running parallel lines through the same from east to west and from south to north at the distance of one mile from each other, and marking corners at the distance of each half mile. The sections shall be numbered, respectively beginning with the number one in the northeast section and proceeding west and east alternately through the township with progressive numbers, until the thirty-six be completed.…
(Page 5)

GENERAL RULES

1-20. From the foregoing synopsis of congressional legislation it is evident:

First. That the boundaries and subdivision of the public lands as surveyed under approved instructions by the duly appointed surveyors, the physical evidence of which survey consists of monuments established upon the ground, and the record evidence of which consists of field notes and plats duly approved by the authorities constituted by law, are unchangeable after the passing of the title by the United States.

Second. That the original township, section, quarter-section, and other monuments as physically evidenced must stand as the true corners of the subdivisions which they were intended to represent, and will be given controlling preference over the recorded directions and lengths of lines.

Third. That quarter-quarter-section corners not established in the process of the original survey shall be placed on the line connecting the section and quarter-section corners, and mid-way between them, except on the last half mile of section lines closing on the north and west boundaries of the township, or on other lines between fractional or irregular sections.

Fourth. That the center lines of a regular section are to be straight, running from the quarter-section corner on one boundary of the section to the corresponding corner on the opposite section line.

Fifth. That in a fractional section where no opposite corresponding quarter- section corner has been or can be established, the center line of such section must be run from the proper quarter-section corner as nearly in a cardinal direction to the meander line, reservation, or other boundary of such fractional section, as due parallelism with section lines will permit.

Sixth. That lost or obliterated corners of the approved surveys must be restored to their original locations whenever this is possible.…*(Page 8)*

3-4. By law, (1) the corners marked in public land surveys shall be established as the proper corners of sections, or of the subdivisions of the sections, which they were intended to designate, and (2) the boundary lines actually run and marked shall be and remain the proper boundary lines of the sections or subdivisions for which they were intended, and the lengths of these lines as returned shall be held as the true length thereof (R.S. 2396; 43 U.S.C. 752). The original corners must stand as the true corners they were intended to represent, even though not exactly where professional care might have placed them in the first instance. Missing corners must be reestablished in the identical positions they originally occupied. When the positions cannot be determined by existing monuments or other verifying evidence, resort must be had to the field notes of the original survey.... *(Page 59-60)*

Fig. 12.) Excepts from Manual of Surveying Instructions - 1973, U.S. Department of the Interior, Bureau of Land Management

for the property parcel overlay.[46] The US Geological Survey's 7.5 minute quadrangle maps provide another existing map that is a potential source for the locational coordinates for the PLSS section corners. However, these maps have an original scale of 1:24,000, and therefore the positional accuracy, even for well-defined points, is in the neighborhood of ±40 feet. For the PLSS corners identified on these maps, which are not particularly well defined, it is doubtful that they meet even this ±40 feet positional accuracy level. While this level of positional accuracy is sufficient for many types of natural resource mapping applications, it is not recommended for a base map for a local government multipurpose GIS/LIS.

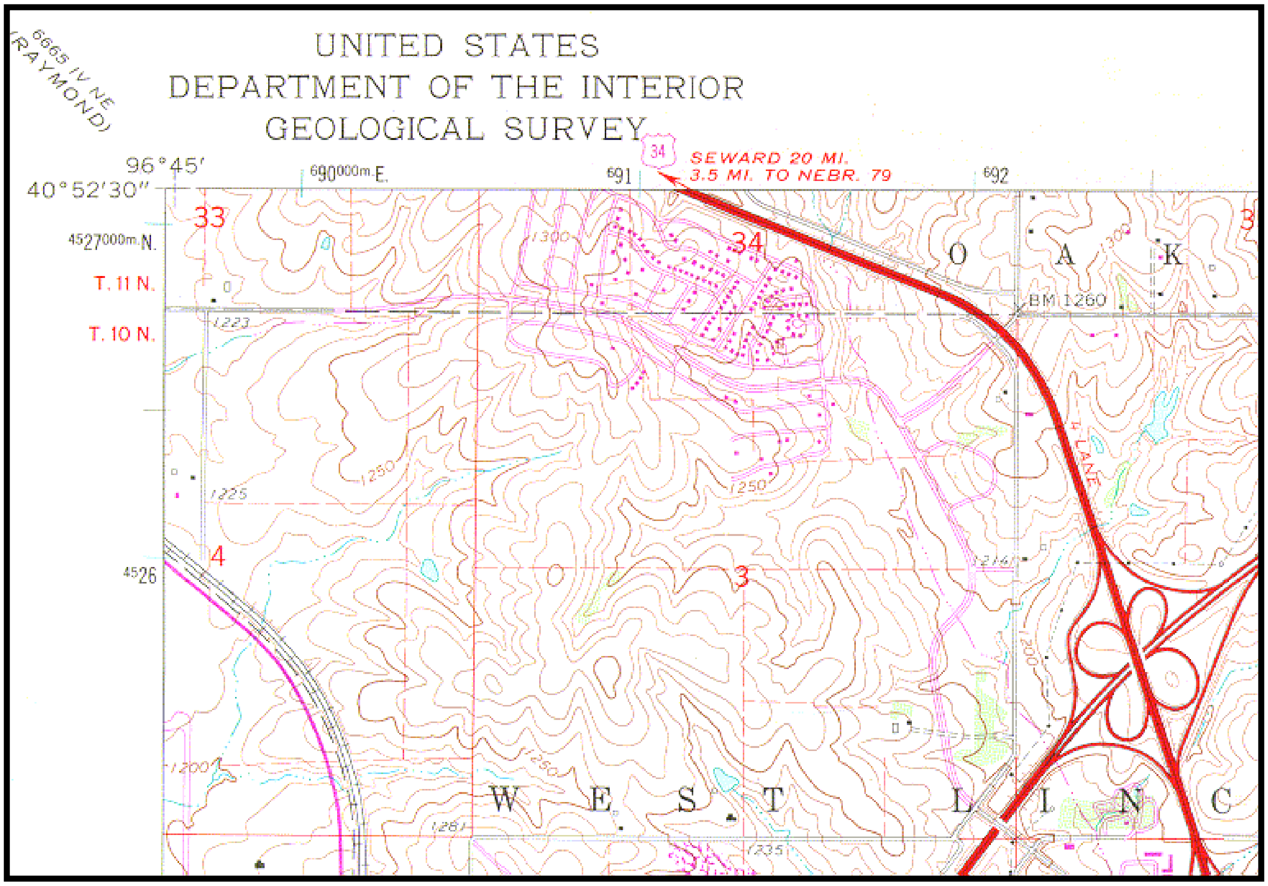

Fig 13.) A portion of a USGS Quadrangle showing roads, section lines, 10 foot contours and some physical features.

Aerial photography and photogrammetric techniques can be used to determine the locational coordinates for PLSS corners. However, for photogrammetry to be used one must be able to clearly see the points in question in the photograph. In the case of PLSS corners, this is difficult on a practical level. Experience has shown that in building a base map upon which property parcel boundaries will ultimately be defined, it is not a good practice to assume that current fence corners and road intersections coincide with the original PLSS corners. If the actual original PLSS corners were located and physically marked with large visible "targets" in advance of the aerial photography, then the PLSS coordinate locations could be determined in this manner. In most instances, this is not a practical, or cost-effective approach to determining the coordinates of PLSS corners for a PLSS base map.

[46] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, D.C. 39 p.

Surveying techniques, particularly when combined with the use of Global Positioning Satellite systems (GPS) technology, can provide a reliable, accurate means of determining the locational coordinates of PLSS corners. Once the original location of a PLSS corner has been identified, GPS technology can then be used to very accurately determine its locational coordinates. However, unless the moumentation of the local PLSS network has been maintained in a given area, it will require a very large commitment of time from qualified surveyors, to identify the original location of most of the PLSS corners. For most local governments, this approach is probably not practical for large (countywide) areas.

For most local governments, a **combination of COGO techniques and surveying**, offer the most cost-effective approach to developing a PLSS base map for a multipurpose land information system. COGO techniques involve the use of computer software to input the distance measurements between points and the bearing (direction) of those measurements. The COGO software then plots the location of these points using the mathematical relationships of coordinate geometry. If absolute positional accuracy of some of these points is determined by the use of GPS, this information can then be input into the computer calculations to provide a real world locational anchor for all of the points. COGO computer programs vary considerably in the sophistication of their mathematical relationships. In Nebraska, the Nebraska State Surveyor's Office has worked with several counties to develop a model for mathematically estimating PLSS corner coordinates using a sophisticated COGO software package (Geographic Measurement Management [GMM]) developed by the U.S. Bureau of Land Management.

> ***It is recommended that local governments considering the development of a multipurpose GIS/LIS, consult with the Nebraska State Surveyor's Office to explore the suitability of the Geographic Measurement Management approach for developing their PLSS base map. It is further recommended that local governments adopt the system of unique PLSS corner identification numbers developed by the U.S. Bureau of Land Management for this purpose.***

Surface Features Base Map. In addition to a PLSS base map, a surface features base map is necessary foundation for developing a multipurpose land information systems. As is suggested by its name, a surface features base map provides the shapes and locational coordinates of major surface features such as roads, railroads, rivers, lakes, and other objects that might be seen from an airplane.

The positional accuracy of these mapped surface features is possibly the key variable to be considered, because this base map provides the primary basis for integrating these surface features with other elements within a GIS/LIS. As was discussed earlier in this section, positional accuracy requirements are directly related to the anticipated applications of the GIS/LIS. Recommended positional accuracy guidelines for different types of GIS/LIS applications are outlined on page V-5.

Planimetric Map or Aerial Photography. Surface features base map data is generally available in one of two forms: planimetric maps or aerial photography. Planimetric base maps consist of line drawings that accurately represent the shape and position of important features visible on the Earth's surface. Planimetric maps can be developed from either ground surveys or aerial photography. Most new planimetric maps are now based on aerial photography, due to the relatively higher costs of ground surveys. The amount of detail collected for inclusion in a planimetric base map varies, depending on such factors as the uses the base map will serve, existing data sources, and the financial resources available. One jurisdiction might include only roads, railroads, and major lakes and rivers. Other jurisdictions with more resources and more planned uses, might also include: sidewalks, fire hydrants, bridges, fence lines, trees, etc. As a general rule, the more detail that is included in a surface features base map, the higher the development costs.

In their discussion of base map data, URISA and IAAO discussed two types of aerial photography that are used for base maps: rectified photography and orthophotography. A rectified photograph is one in which the distortions caused by the tilt of the airplane or the camera angle have been removed, but not the distortions caused by terrain. Orthophotographs have been processed to remove both the distortions resulting from the camera angle and from terrain variations (hills and valleys). Orthophotographs produce an image with true and constant scale across the photo. URISA and IAAO noted that in some cases, rectified photography can provide adequate base data for the needs of an assessor. The use of this type of rectified photography for base map data, should only be considered in an area with little surface relief. However, URISA and IAAO note that for a successful, long-term, multi-participant GIS/LIS, a higher degree of positional accuracy is often necessary. For the development of multi-agency GIS/LIS applications, they suggest the use of either orthophotography or a planimetric map for a base map.

Hardcopy or Digital. Both planimetric and aerial photography forms of base maps are available in either a hardcopy (paper or mylar) or digital formats. Base maps in a digital format are generally much more flexible and useful in the development of a GIS/LIS. For use in a multipurpose GIS/LIS, the features or elements in either format must be geo-referenced in the mapping coordinate system (i.e., State Plane Coordinate System) of choice.

Raster or Vector Data. In planning a local government GIS/LIS, there is at least one other variable in base map format that needs to be considered. Raster and vector data are two different ways of organizing digital geospatial data that closely correlate with aerial photographs and planimetric maps.

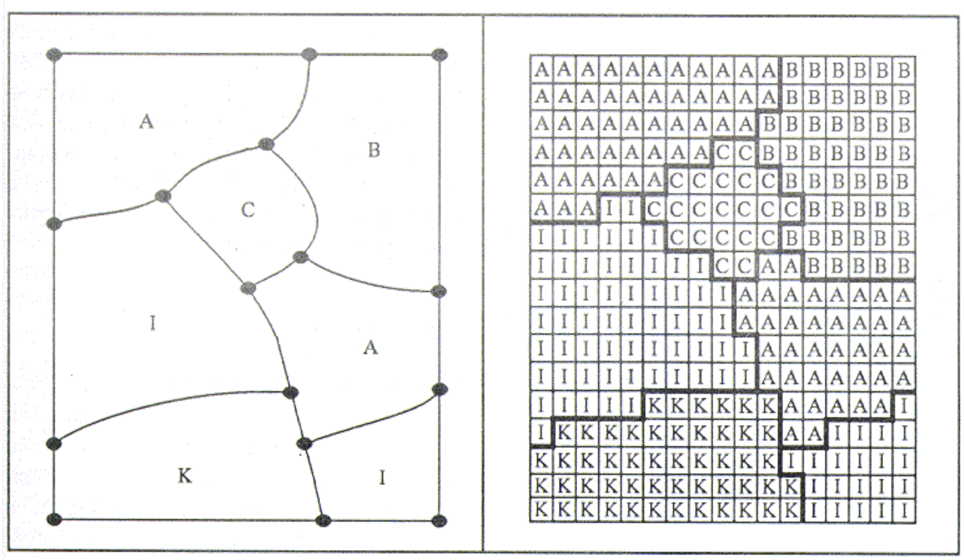

Fig 14.) A comparison of vector data to raster data. Both formats are useful in GIS operations.

The information in a digital aerial photo is in a series of points, dots, or cells, that make up the image much like a scanned picture. In general, this data format allows very limited information to be stored or associated with each of these numerous points or cells. In the common aerial photo, the associated information is limited to horizontal and vertical position and differing shades of gray (or colors in the case of color photography). This is commonly known as a *raster* data model. It is possible, with a digital raster aerial photograph to capture a large amount of information about the position and general shape of surface features, at a relatively low cost and within a shorter timeline, when compared to developing a vector line map of those same features. This relatively lower cost also makes it more feasible to periodically collect updated information via new aerial photographs. A downside to the raster format are the limitations it has in performing many of the specialized map production and analytical functions commonly desired in a multipurpose GIS.

The primary alternative GIS data model is known as a *vector* format. This is comparable to the line drawings of a planimetric map, in which the coordinates of the beginning and end points of the lines are known, or the coordinates of the points that define an area or polygon. The vector data format allows for an almost unlimited amount of additional information to be associated with these lines, points or polygons. For example, a line vector representing a street could have associated with it information regarding the width of the street, the surface materials, the speed limit, etc. In addition, a vector data format provides the GIS user with the capability to easily select and manipulate databases features (such as street center lines) based on this associated data (i.e. select all the gravel roads). This capability is one of the key underlying functions of a GIS/LIS, and it is severely limited when base map data is only in a raster format. The greater flexibility it provides in performing many of the common functions desired in a local government GIS/LIS is one the primary strengths of the vector data format. These analytical/functional capabilities of vector data provide a strong argument for having at least some of the surface feature data in a vector format.

A valuable use of orthophotos is to capture information about the shape and position of the broad array of surface features on the earth. These raster orthophotos can then be used as the base maps from which to capture selected features in a vector data form. Surface features commonly converted to a vector format include roadway center lines, edges of pavement, river and stream beds, railroads, etc. The features converted to vector format depend on one's planned analytical needs and resources available. Another advantage of the orthophoto is that if additional vector data is needed, it can be digitized at any time from the orthophoto.[47]

<u>Topographical Map</u>. A topographic map describes the land as a sequence of contour lines that model the "lay of the land". The contour lines connect lines of equal elevation. Contour lines are constructed either by surveying, or more commonly by stereoscopic plotting techniques based on stereo aerial photography.[48] The National Research Council notes that the added expense for contours on a base map is substantial. Many common local government GIS/LIS applications do not require contour information. In a digital environment, the "lay of the land" or elevation data is commonly presented in a format known as a Digital Elevation Model (DEM). With the availability of DEM data, many GIS software packages have the capability to construct 3-D models of the terrain's surface *(see Fig. 15, page 15).* The development of DEM data is a standard step in the process most commonly used today to develop orthophotographs. Therefore DEM data for a given area, is likely to be available if an orthophoto has been prepared for that area. Before a local government invests additional resources in the development of more detailed topographical information, a review should be conducted to identify the particular GIS/LIS applications that would warrant this investment. The National Research Council suggests that if required, contour intervals should be selected in conjunction with the map scale, the terrain relief, and the elevation information requirements *(see page V-9).*[49]

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[47] Cowden, Rex W. and Robert F. Brinkman, May 1993: *Digital Orthophotos: A New Alternative for Creating Base Maps,* Geo Info Systems, Eugene, OR, 55 p.

[48] Urban and Regional Information Systems Association and International Association of Assessing Officers, 1992: *GIS Guidelines for Assessors*, Washington, DC and Chicago, IL, 23-27 p.

[49] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, D.C. 43-45 p.

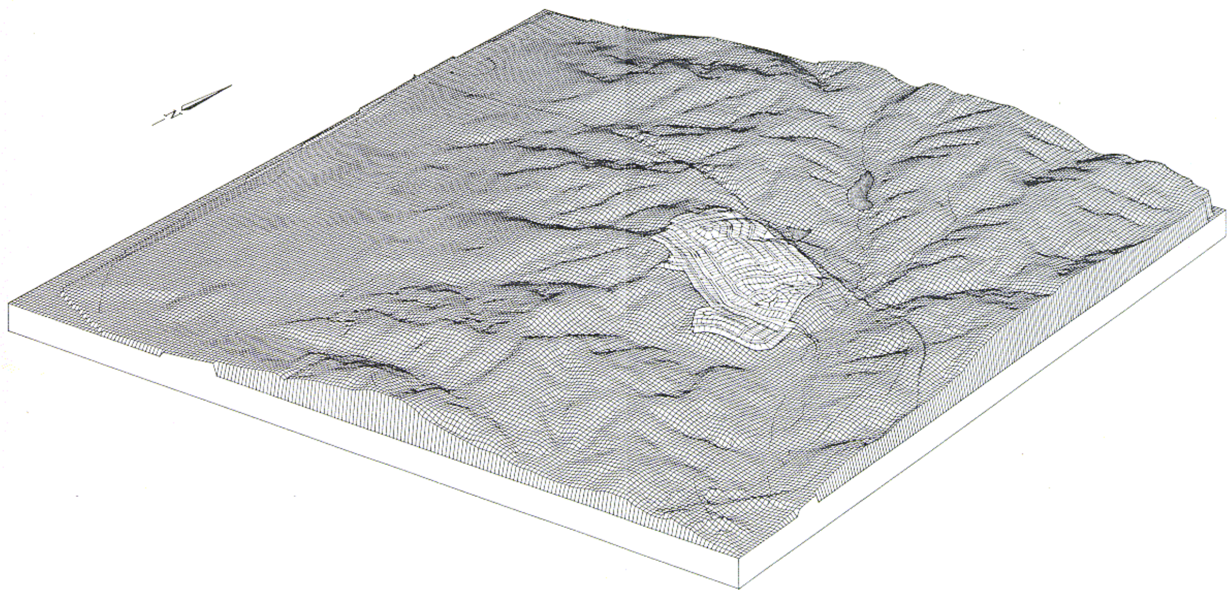

Fig. 15.) This view shows a digital elevation model with a proposed subdivision drawn in place. DEM's are a necessary element in the creation of an orthophotgraph.

The selection of the form and format of the surface feature base map data for a multipurpose GIS/LIS depends upon the intended applications of the GIS/LIS, 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 data from one form to another.

Sources of Surface Feature Base Map Data. There are three potential alternatives for source materials to be considered for use in developing a surface feature base map: (1) existing maps (planimetric or photographic), (2) existing maps updated with new map information during the course of on-going operations, and (3) new maps or aerial photography. The primary tradeoffs among these alternatives are uniformity and accuracy of the base map data versus the cost of new mapping.

As noted before, the National Research Council suggests, that unless there has been a consolidation and standardization of the mapping efforts within the various local government departments to a single, unified mapping activity, and a recent large-scale mapping program completed, existing maps for a given county or municipality are likely to be incomplete, out of date, or otherwise less than ideal for use as a mapping base for a multipurpose GIS/LIS.[50] The basic mapping functions in a typical local government environment, at the county level for example, are generally spread among a number of departments or divisions, primarily (1) assessment, (2) public works, and (3) planning. The base-map requirements for each of these departments vary, especially with regard to map scale, format, and content. This situation fosters a general lack of coordination among departments, duplication of effort, and often an absence of

[50] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, D.C. 39 p.

adequate, professional mapping personnel.[51] The combination of these factors make it difficult to maintain the quality of map products that would be suitable as source material upon which to build a multipurpose GIS/LIS to ultimately serve all of these needs.

The accuracy of the existing maps may be unknown or, if known, the accuracy may not be adequate for present-day requirements, particularly for suburban/urban areas. On the other hand, the cost of immediate new mapping may appear to be prohibitive. Thus there is a need to consider the alternatives. Substantial savings are possible, if a new map system can be adapted to existing base maps, if they are adequate. Existing base maps to be considered, include not only the base map data available within the local government, but also that data that might be available from regional, state or federal sources *(see DOQs, page V-17,18).*

In evaluating existing maps or other geospatial data as potential sources for base map data, the following characteristics of spatial data should be considered.

- Positional accuracy — This key characteristic is a measurement of the variance of the position of a map feature from the true position of the entity on the earth's surface. Existing sources that do not have given estimates for their positional accuracy should be considered suspect. The positional accuracy of existing sources can be estimated by comparing them with a sampling of the real world locational coordinates of surface features or by comparing them to a map of known higher positional accuracy.
- Attribute accuracy — This refers to the accuracy, or reliability of information about or associated with surface features. For example, if a road is shown on an existing map to be gravel, is it?
- Timeliness — This refers to the currency of existing maps or geospatial data. Developing a GIS/LIS based upon a surface features base map that is not reasonably current will likely result in costly modifications, potential policy mistakes based on out-of-date information, and a loss of credibility for your product.
- Lineage — Lineage refers to the original source material for the existing product that you are evaluating. The original source provides valuable clues to the potential suitability of existing maps or data. If it is not known how the existing map or data was derived, then it is difficult to evaluate its accuracy, completeness, and other characteristics of concern.
- Resolution — This map and data characteristic refers to the smallest detail that can be reliably distinguished in a map or database. In the case of a digital aerial photo the resolution refers to the area (i.e. one square meter) that is represented by each pixel (dot) in the photo. In evaluating the resolution of an aerial photo, it is important to keep in mind that it usually takes a grouping of several adjacent pixels to reliably define the shape and position of objects from a photo. In the case of a printed map, resolution may refer to the distance, or scale, at which two objects plotted on a map or drawing become one feature or occurs at the same place (i.e. a road and a parallel railroad).
- Extent — This characteristic refers to the geographic area covered by a single map or drawing or by a collection of similar sets or series of maps and drawings. For example, what area is covered by one map? What area is covered by all maps of the same precision, accuracy, and resolution? How completely does the map or series of maps represent the features being plotted?
- Completeness — This refers the degree to which a map or database includes all of the possible universe of features and values. For example, in the case of an existing map did the original developer choose to not include some features (occasional runoff streams) that will be needed in a GIS/LIS base map?

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[51] Archer, A.J., November 1980: *American Congress on Surveying and Mapping Bulletin No. 17,* "A Unified Approach for Mapping in Prince William County, Virginia," 17-19 p., cited in National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, D.C. 39 p.

- Consistency — This refers to the degree that similar features and values are represented the same throughout the map or database. This is an area of concern that is particularly appropriate when maps or databases are "pieced together" from different sources or time periods.

If it is determined that new surface features base map data is needed—to either supplement existing base map data or to entirely replace it—the most common method for collecting surface features base map information for large areas is the use of aerial photography and photogrammetry. Photogrammetry is the science and art of obtaining spatial information from photographs. Photogrammetry is cost effective because the aerial photography captures information for a wide assortment of surface features and over a large area. To obtain the quality of aerial photography and surface features data that is required for a GIS/LIS, one should contract with professionals specializing in photogrammetry. Some of the variables to be considered in contracting for this type of work include: positional accuracy requirements, flight height, photo resolution, photo overlap, and targeted seasons for aerial photography.

> ***It is recommended that a digital orthophoto be utilized as the surface features base map for a multipurpose GIS/LIS. A surface features base map provides the shapes and locational coordinates of major surface features such as roads, railroads, rivers, lakes, and other objects that might be seen from an airplane. In evaluating the adequacy of a given digital orthophoto to serve as a surface features base map, the spatial accuracy, resolution, and timeliness of a digital orthophoto should be compared to the requirements of planned and anticipated applications of the multipurpose GIS/LIS for a given.***

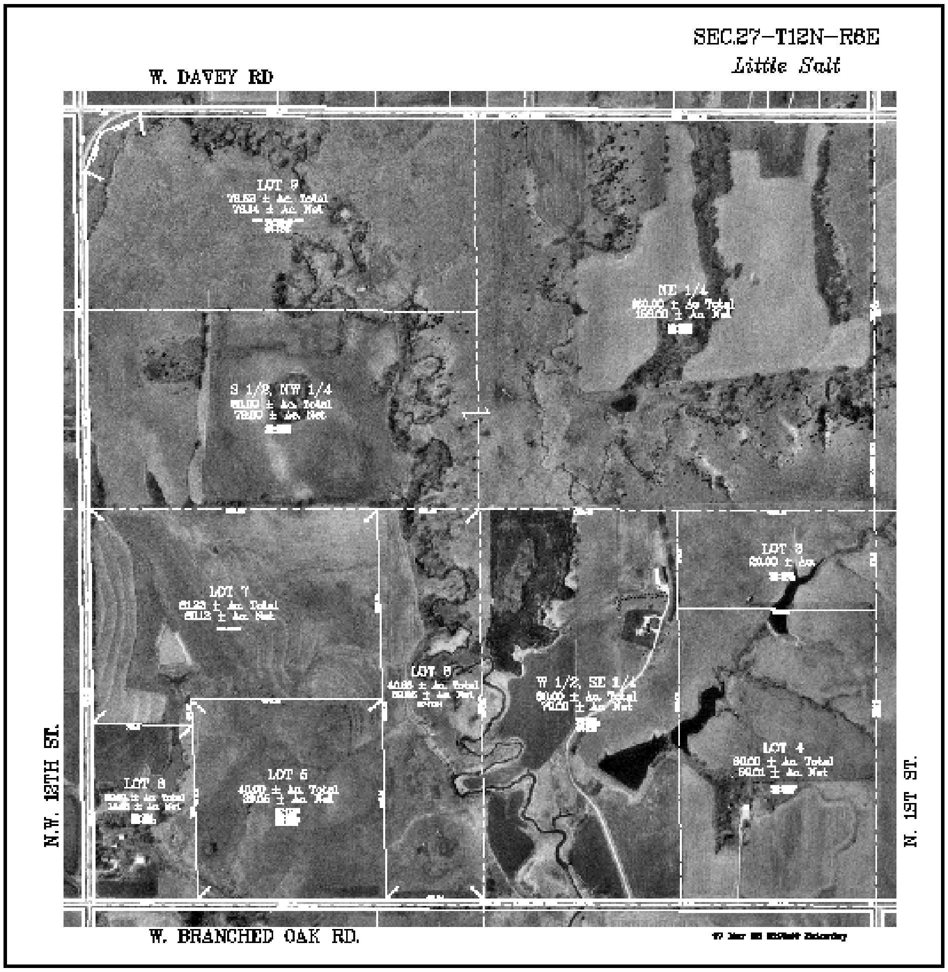

Fig 16.) This view illustrates the combining of an ortho-rectified aerial photograph with parcel property lines to create a basemap. The physical features of the land are easily identifiable and the parcels are derived from the PLSS.

Making Choices, Nebraska DOQs An Example. In making decisions and choices regarding the appropriateness of base map data upon which to build a GIS/LIS, it is frequently a choice between variables such as greater spatial accuracy, resolution, and timeliness versus lower costs. The implications of these choices should be weighed carefully and in detail. As noted above, *GIS/LIS developers should keep in mind 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.*[52] Nevertheless, practical considerations such as costs must be weighed.

In Nebraska, the future statewide availability of Digital Orthophoto Quads (DOQs), as a result of a joint Nebraska Natural Resources Commission/U.S. Geological Survey (USGS) project, is an important resource to be considered in looking for base map data for rural areas. In addition to their availability in the near future, at little or no cost, these orthophotos can be thought of as two tools in one: a picture and a scaleable map.

52 Federal Geodetic Control Committee, January 1993: *Multipurpose Land Information Systems, The Guidebook,* "Introduction to Mapping Concepts", 2-13 p.

Technical specifications for these DOQs call for them to have a photo pixel resolution of one-meter and to meet or exceed 1:12,000 Horizontal National Map Accuracy Standards, (± 33.3 ft.). The one-meter resolution means each small dot in the orthophoto represents a one-meter square on the earth's surface. Consequently, for a surface object to be identifiable in the photo, it will need to be large enough to be represented by several adjacent pixels or dots in the photo. The positional accuracy specification for these DOQs (± 33.3 ft.) is outside the map accuracy standards associated with the smallest map scale recommended by IAAO[53], and the Federal Geodetic Control Subcommittee[54] for "Rural areas" (1:9,600 or ±26.7 ft.) *(see page V-6).* A comparison of DOQs produced as part of the Lancaster County DOQ pilot project with existing geospatial data for the county indicates that the NRC/USGS DOQ product may be more accurate than the minimum 1:12,000 horizontal accuracy standard. The results of a study by the State of Kansas, Digital Orthophotography Pilot Project, December 1995, are also worthy of note. That study compared the applicability of four different DOQ products, varying resolution and ground control. In examining the suitability of the standard one-meter DOQ for property parcel mapping, the study concluded:

> *"The 1-meter standard product was found to be more than suitable for rural database development and analysis.…For general studies such as urban development projects and development of zoning boundaries, 1-meter DOQs could serve a role. Most urban database development and analysis of images will require high-resolution digital orthophotography. The half-meter low-altitude DOQs were an improvement from the 1-meter product, but 1-foot digital orthophotography would be ideal. Urban parcel and infrastructure mapping and planning will demand a higher resolution adequate for their needs."* [55]

The results of the Kansas DOQ study, the early comparisons of the DOQs from the Lancaster County Pilot Project to the accuracy of existing geospatial data, and the likely near-term statewide availability of these DOQs, provide three arguments for the use of the NRC/USGS DOQs as a surface features base map for developing a local government multipurpose GIS/LIS for rural areas.

As noted above, professional associations recommend rural mapping for assessment and many other multipurpose GIS/LIS applications to be conducted in the 1:9,600 to 1:4,800 map scale range. These recommendations are an indicator that local governments should carefully weigh the potential gains and losses before deciding to use a 1:12,000 DOQ as a rural surface feature base map for a multipurpose GIS/LIS. This is perhaps best accomplished by a detailed assessment of the surface features for which one might wish to extract the shape and location from a photo base map, and make a determination of adequacy of the DOQs produced by the NRC/USGS joint project to meet these needs. In making this assessment, both the positional accuracy and the resolution of the DOQs should be considered. This assessment will be made easier by the fact that the specific DOQs for each area will be available for evaluation.

Return to Table of Contents

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[53] International Association of Assessing Officers, January 1988: *Standard on Cadastral Maps and Parcel Identifiers*, Chicago, IL, 7 p.

[54] Federal Geodetic Control Subcommittee, 1989-1994: *Multipurpose Land Information Systems: The Guidebook,* 13-8, 9 p.

[55] State of Kansas Geographic Information Systems (GIS) Policy Board, December 1995: *Digital Orthophotography Pilot Project,* 29 p.