Return to Table of Contents

GEOGRAPHIC / GEODETIC CONTROL

A GIS/LIS is a system of spatially referenced information or data. Spatially referenced information or data have a unifying characteristic, in that they are associated with specific places on the Earth's surface. Geographic or geodetic control refers to the common geometric framework which ties objects in a GIS/LIS to a point on the surface of the Earth, and to each other through a mathematical spatial relationship. This control provides the foundation upon which the various elements of a GIS/LIS are systematically and spatially related.

Because geographic control provides the unifying foundation for a GIS/LIS, there are several important issues involved in establishing geographic control that merit special consideration.

- Geodetic Datums
- Coordinate Systems
- Geodetic Reference Framework
- Accuracy and Spacing Density of Framework Control Stations

Geodetic Datums. A geodetic datum refers to a particular model of the earth's surface, based on assumptions about its size and shape (Fig. 1). A given datum is the underlying basis for most systems of calculating the coordinate values for points on the earth's surface. There are two kinds of datums: one for calculating relative horizontal positions and one for calculating relative vertical positions. For many years, surveys and mapping in this country were based on the North American Datum of 1927 (NAD 27) and the National Geodetic Vertical Datum of 1929 (NGVD 29). These datums are the underlying foundation for many of the existing maps currently in use. In the 1980's, based on increased knowledge about the size and shape of the earth, both the horizontal and vertical datums were updated. These new datums are referred to as the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88).

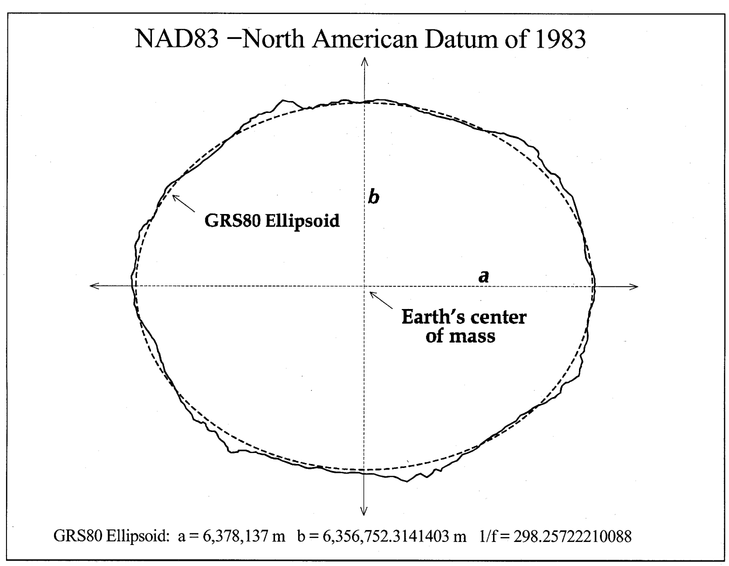

Fig 1.) NAD83 is a geocentric datum which is based on the GRS80 ellipsoid. An ellipsoid is a mathematical model that approximates the shape of the earth. The GRS80 ellipsoid was created based on satellite measurements of the earth's size and shape.

With both versions of the horizontal and vertical datums currently in everyday use, cartographers or a 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 first converting one data set to a common datum.[5] This potential problem is reduced by the fact that most current GIS/LIS software has the capability of making conversions from one datum to another. However, particularly in the case of the horizontal datums, the relationship between the datums is non-linear, and transformations are approximations.

We recommend that new multipurpose GIS/LIS are based on NAD 83 and NAVD 88 from the beginning, thus avoiding some of the possible problems associated with transformations.[6]

<u>Coordinate Systems</u>. Horizontal coordinate systems, referenced to a particular datum, provide a mathematical reference framework for describing the relative position of objects to each other, and their position on the surface of the earth. There are three general types of coordinate systems commonly used in mapping:

- Common grid coordinates
- Spherical coordinates
- Planar coordinates.

The **common grid coordinate system** shown in Fig. 2 is based upon a flat grid, with an arbitrary point of origin for the grid, and provides information on the relative distance and direction between map objects (i.e., one object is 2 1/2 miles north of another). However, the common grid coordinate system is not geo-referenced, that is grid coordinates do not provide a direct reference or tie to a specific location on the earth's surface.

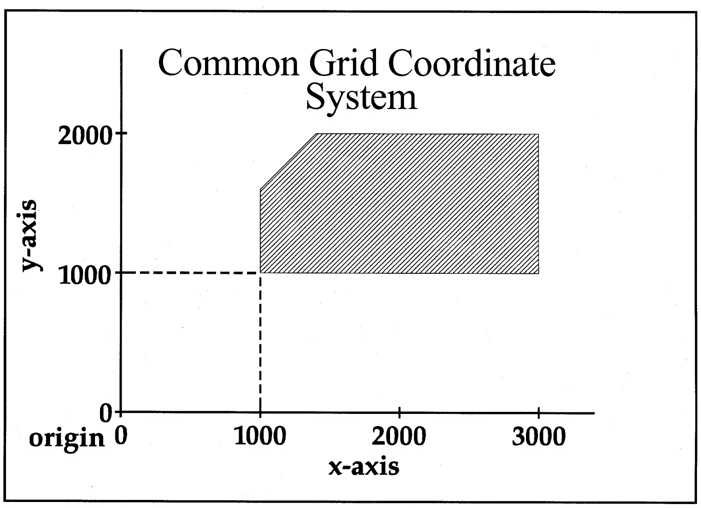

Fig 2.) The common grid coordinate system is used to depict the measurements of a particular piece of property without referencing it to real world coordinates.

[5] Federal Geodetic Control Committee, October 1989: *Multipurpose Land Information Systems, The Guidebook,* "Introduction to Mapping Concepts," 2-10 p.

[6] Federal Geodetic Control Committee, October 1989: *Multipurpose Land Information Systems, The Guidebook,* "Introduction to Geodetic Reference Frameworks," 3-15, 18 p.

Spherical coordinate systems, such as the common geographic coordinate system (latitude and longitude), are based on a spherical grid that roughly parallels the earth's "curved" surface. Through the geographic coordinate system, and its underlying datum, specific latitude and longitude coordinates are tied to specific locations on the earth's surface as shown in Fig. 3. However, the spherical (curved) grid makes it difficult to use for flat maps and makes any related mathematical manipulation of geographic coordinate values rather complex.

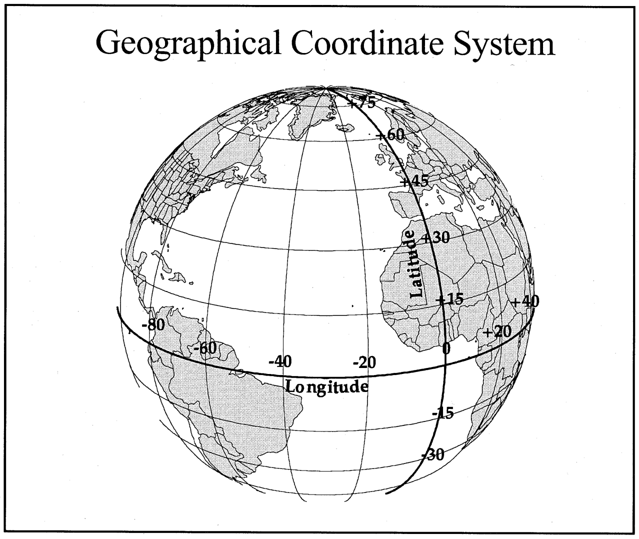

Fig. 3) The geographic coordinate system uses the prime meridian (Greenwich, England) and the earth's equator as the origin for latitude, longitude coordinates.

Planar coordinate systems are based on a rectangular grid derived from mathematically projecting a specific section of the earth's curved surface onto a flat surface (a map). Like the geographic coordinate system, coordinates in a planar coordinate systems are geo-referenced, i.e. tied to specific locations on the earth surface. The Universal Transverse Mercator (UTM) Coordinate System is a metric worldwide planar coordinate system of predominate use in federal mapping environments. Fig. 4 shows the 3 UTM zones that cover Nebraska.

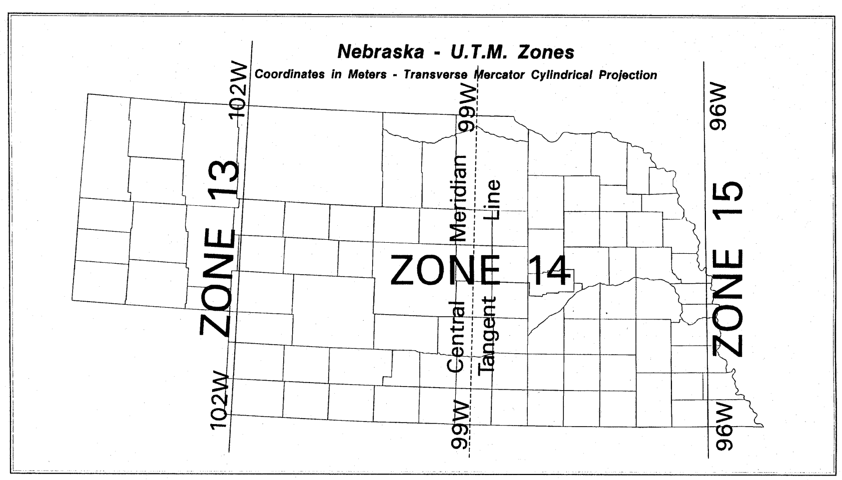

Fig. 4) UTM is a planar projection with central meridians every 6 degrees of longitude. Three separate UTM zones cover Nebraska.

Like UTM projection, the State Plane Coordinates System is a series of predefined planar map projections, with specific map projection zones designed for use in each state. [7] The State Plane Coordinate System is the system most commonly used by state and local governments and by private surveyors in the United States.[8] Nebraska has a one zone map projection as shown in Fig. 5.

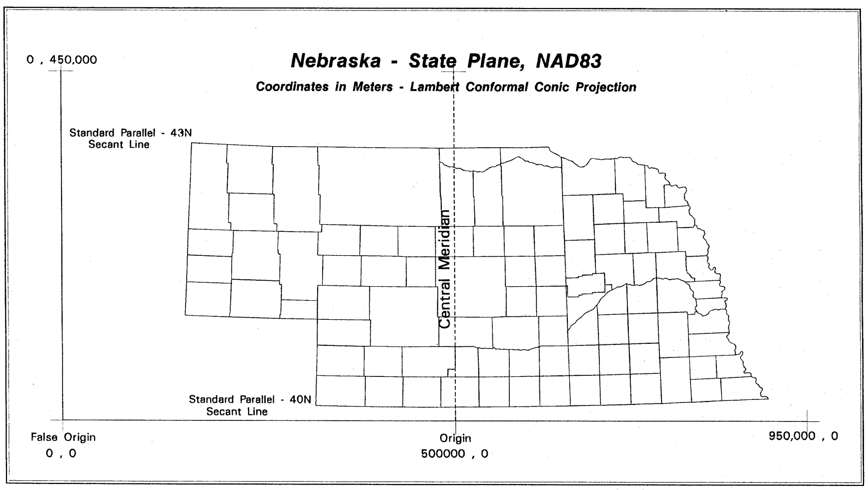

Fig. 5) The Nebraska State Plane coordinate system is based on a conical projection with its central meridian crossing the middle of the state.

The most common coordinate systems in current use throughout the United States are as follows:

Common grid coordinates

- Non-Geo-referenced, Grid

Spherical coordinates

- Geographic Coordinates, NAD 27
- Geographic Coordinates, NAD 83

Planar coordinates

- Universal Transverse Mercator (UTM), NAD 27
- Universal Transverse Mercator (UTM), NAD 83
- State Plane Coordinates, NAD 27
- State Plane Coordinates, NAD 83

The National Research Council notes that the universality of coordinate values expressed in terms of the State Plane Coordinate System provides a compelling argument for the use of these systems in the development of a geometric framework for land-data systems. The state plane coordinates can be transformed readily, precisely, and within known accuracy limitations into other coordinate systems, thereby permitting the correlation and use of the data in regional, state, and national as well as local systems.

[7] NOAA Manual NOS NGS 5, January 1989: *State Plane Coordinate System of 1983*, "SPCS 83 Design," 4-11 p.

[8] Federal Geodetic Control Committee, October 1989: *Multipurpose Land Information Systems, The Guidebook,* "Introduction to Mapping Concepts," 2-6 p.

We recommend the use of the State Plane Coordinate System, NAD 83, as the basis for the recording of positions in local land-data systems in Nebraska. Selection of any other projection should be done reluctantly and only after most careful consideration.[9]

This recommendation is also supported in the Multipurpose Land Information Systems, The Guidebook, published by the Federal Geodetic Control Subcommittee.[10] The Urban and Regional Information Systems Association and International Association of Assessing Officers in their publication, GIS Guidelines for Assessors, also supports the combination of NAD 83 and the State Plane Coordinate System for use in local government GIS/LIS.

In North America, GIS conversion and mapping efforts should be using a datum that locates maps and records accurately to the face of the earth. The recent international program that lead to the North American Datum of 1983 (NAD 83) should be considered a starting point for all GIS mapping/record efforts in North America. Use of the 1983 datum and state plane coordinates tied to NAD 83 allow for important simplification of coordinate and positioning calculations as they relate to mapping efforts over small portions of the earth's surface, such as a county. The use of state plane coordinates also minimizes complex calculations as they relate to the curvature of the earth's surface. Simply stated, "most County or City scale GIS/mapping programs can benefit from a flat earth, geographic approach."[11]

Geodetic Reference Framework. A geodetic reference framework consists of permanently monumented stations whose locations are accurately measured and mathematically described relative to a common datum. The spatial relationship among the points is known, so the relationship between features that are related to these points is also known. For a GIS/LIS, these monumented, known locations of a geodetic reference framework serve as the basis for tying together the physical locations of features on the Earth's surface to their locations on a map, through the map's coordinate system. These monumented locations also provide the reference for relating the location of the natural and man-made features on the earth's surface (rivers, streets, buildings, etc.) to legal property boundaries.

The National Geodetic Survey (NGS) is responsible for maintaining a nationwide geodetic reference framework known as the National Spatial Reference System or NSRS (*formerly known as the National Geodetic Reference System*). The NSRS consists of 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. As shown in Fig. 6 Nebraska contains over 3060 horizontal control monuments.

[9] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, DC, 24 p.

[10] Federal Geodetic Control Committee, October 1989: *Multipurpose Land Information Systems, The Guidebook,* "Introduction to Geodetic Reference Frameworks," 3-16 p.

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

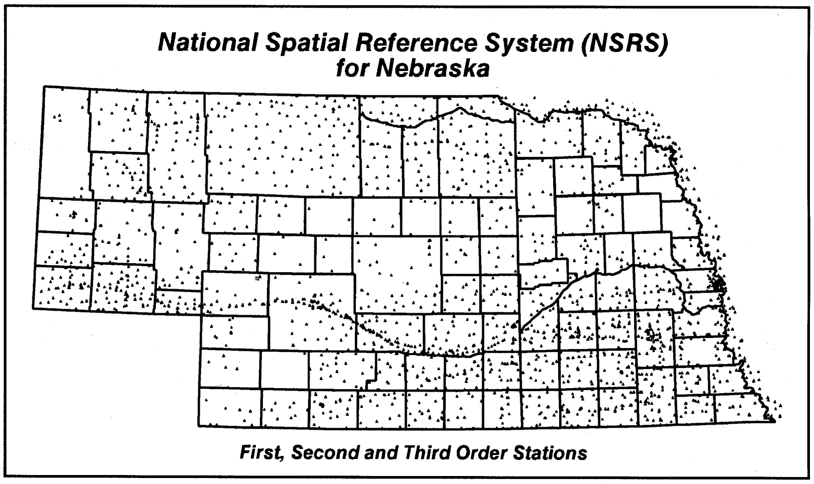

Fig. 6) NSRS monuments located in Nebraska. Each point is geo-referenced and has a published latitude, longitude and elevation value.

Surveying activities performed by state, local, and private agencies often originate at NSRS geodetic stations. When Federal standards and specifications are used to perform and connect surveys of other agencies to the NSRS, the surveys all become part of a single spatial reference system. A local geodetic reference framework consists of the NSRS geodetic stations plus all properly connected stations of other agencies, whether they are included in the NSRS database or not. The National Geodetic Survey encourages users to use and improve both the NSRS and local geodetic reference frameworks for the development of multipurpose LIS and for traditional engineering, surveying, and mapping. [12]

The NSRS provides the only national (and statewide) system of geodetic control that can provide spatial correlation of independent data sets. Referencing GIS/LIS databases to a local geodetic reference framework, that is tied to the NSRS, provides the framework for establishing the proper spatial relationships among features across the geographic area (i.e. county) of the project, and also provides the basis for sharing and integrating these geospatial data bases across jurisdictional lines. It is for these reasons that the National Research Council cites the NSRS as the foundation by which all land data should be related (NRC 1983).[13]

In 1995 NGS utilized Global Positioning System (GPS) equipment and completed a High Accuracy Reference Network (HARN) for Nebraska. These A and B order control points represent the highest level of spatial accuracy currently available (Fig. 7). Based on this higher level of control, NGS was then able to perform a mathematical re-adjustment of all first, second and third order points. These stations are now compatible with the more accurate HARN values.

[12] Federal Geodetic Control Committee, October 1989: *Multipurpose Land Information Systems, The Guidebook,* "Introduction to Geodetic Reference Frameworks," 3-2 p.

[13] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, DC, 26 p.

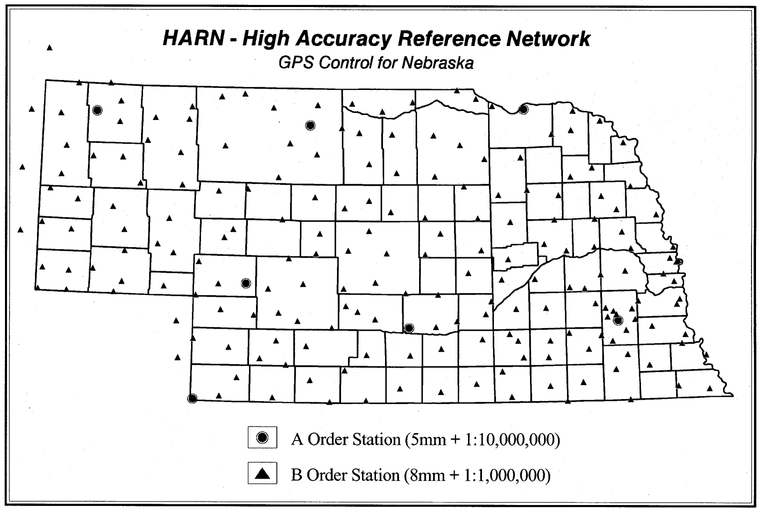

Fig. 7) 214 HARN control points for Nebraska. These A and B Order stations are the highest level of survey control currently available in Nebraska.

We recommend that GIS/LIS systems developed with the goal of providing a multipurpose cadastre for local government use should be referenced to a local geodetic reference framework that is properly connected to the National Spatial Reference System (NSRS).

Accuracy and Spacing Density of Framework Control Stations. The type and quality of geometric framework to be provided for any new land-data system is one of the key determinations affecting the long-term, as well as the initial, utility and efficiency of the system. Decisions in this area should be made on the side of potential long-term utility. A misapplied capital investment may form an insurmountable impediment to later evolutionary development of the system, since the committed decision will, with time make it increasingly difficult and costly to effect any required reforms. In this respect, it is particularly important to resist the temptation to use only paper records of mapped locations or low accuracy digital maps as a basis for the development of the land-data system in order to save initial costs.[14]

Accuracy is a measure of how well something represents the truth. For geographic control, accuracy means how well coordinate values represent the true location. For example, if a point had a very low accuracy, its true position might be known only to the nearest 100 feet, whereas a point with high accuracy might be know to within 0.0001 feet. The Federal Geodetic Control Committee has defined survey requirements for various accuracy levels. Each accuracy level is called an order and there are three orders: first, second, and third. Within each order, there are also a further subdivisions of class. Historically, first order has been the most accurate and third order the least accurate. In recent years, satellite technology has pushed the limits of accuracy so now there are three new orders, called AA, A and B to define satellite accuracy, that are more accurate than first order.

[14] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, DC, 22 p.

With respect to accuracy, the determining factor will be the extent to which the control survey stations are to serve multiple purposes. 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 II. Graphic integration refers to a practice where the positional integration of the land data is accomplished solely by the necessary correlation being provided by reference to the coordinate grid shown on the maps. An example of this would be only needing positional data to fit together the "jigsaw pieces" of property parcels, so that they would all visually fit together on a cadastral tax map. If, however, the data are to be integrated numerically and if the control surveys are to have multiple applications, minimum accuracy's at least attendant to the federal classification of third-order, class I, or second-order, class II, should be met. An example of this, would be the need to bring together multiple layers of diverse types of information and conduct analysis based, at least in part, on their relative positions. Numerical 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.[15]

URISA and IAAO note in GIS for Assessors, that the accuracy of geographic control must both support the development of the base map and must be cost-effective. They also observe that in this age of satellite technology, higher levels of accuracy are becoming less and less expensive. Their recommendation is, that it is best to get the highest level of accuracy possible within budget constraints.[16]

The National Research Council recommends that monumented points of known position on the State Plane Coordinate System should be so distributed throughout the area concerned as to permit their ready use in the collection of both cadastral and earth-science data. "*Typical recommendations range from 0.2 to 0.5 miles (0.3 to 0.8 km) between monuments in urban areas to 1 to 2 miles (1.6 to 3.2 km) in rural areas"* (Zieman, 1976; McLaughlin, 1977). The National Research Council noted their concurrence with these recommended densities of monumented points, and suggested that in those areas of the United States covered by the Public Land Survey System (PLSS), monuments established at approximately one-half-mile intervals at the section and quarter-section corners and at the centers of sections would meet the system design for control stations. They also noted that an accurate position of the center point of a section is required in order to provide a proper basis for the compilation of cadastral maps and data.

Ideally, the entire area concerned should be covered at a uniform density with a simultaneously adjusted network of control survey stations As a practical matter, however, the necessary survey work will have to be carried out over an extended period of time. To provide the required uniformity in such successive surveys, a higher-order control net may have to be established. The spacing of the higher-order stations can be up to 10 miles (16 km) but is usually 3 to 5 miles (5 to 8 km).[17]

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

[16] 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.

[17] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, DC, 24 p. Citing: Ziemann, H. 1976: "Geodetic referencing of location and the use of coordinates in a land data system", prepared for the Land Records Commission, Dept. of Community Affairs, Commonwealth of Massachusetts, Boston. and McLaughlin, J.D., 1977: *Maritime Cadastral Accuracy Study, Land Registration and Information Service Technical Report,* U. of New Brunswick, Fredericton, New Brunswick, Canada.

The Federal Geodetic Control Committee (FGCC), in their Multipurpose Land Information Systems, The Guidebook, also note that in PLSS states such as Nebraska, section corners and quarter corners may be sufficient to establish a framework for the parcel map. This is true if corner locations are known to an accuracy consistent with the required needs for information derived from products based on those locations, such as a parcel map. The spatial relationship between each boundary and the monuments to which it is tied must be known. However, they caution that the spatial relationships among monuments and therefore among monuments, objects, and boundaries, are frequently unknown. Therefore, the distinction between local survey control, such as a well maintained PLSS, and the geodetic reference framework becomes important.

It is important to remember that parcel boundaries generally cannot be directly observed on the ground or on aerial photographs except where conspicuous objects or activity demarcate the boundary. To compile a parcel map, it is necessary to establish a link between the parcel map framework, such as the local reference network, and the geodetic reference network, to ensure that relationships between parcels and geographic features that can be observed in the field, are accurately reflected on the map. [18]

The National Research Council also notes that the property boundaries defined by the original PLSS monuments have the attributes of registered property boundaries in that they are immune to relocation by "adverse possession," even by fence lines that are long established. The correct, legal locations (or relocations) of the monuments are the very foundation that holds the PLSS together and without which the definitions of property boundaries in vast areas of the United States would come unraveled. The above considerations provide compelling arguments to support the Natural Research Council's recommendation for establishing a geodetic reference framework for a local GIS/LIS in a PLSS state like Nebraska. Fig. 8 illustrates how a typical County could progressively develop a geodetic reference framework.

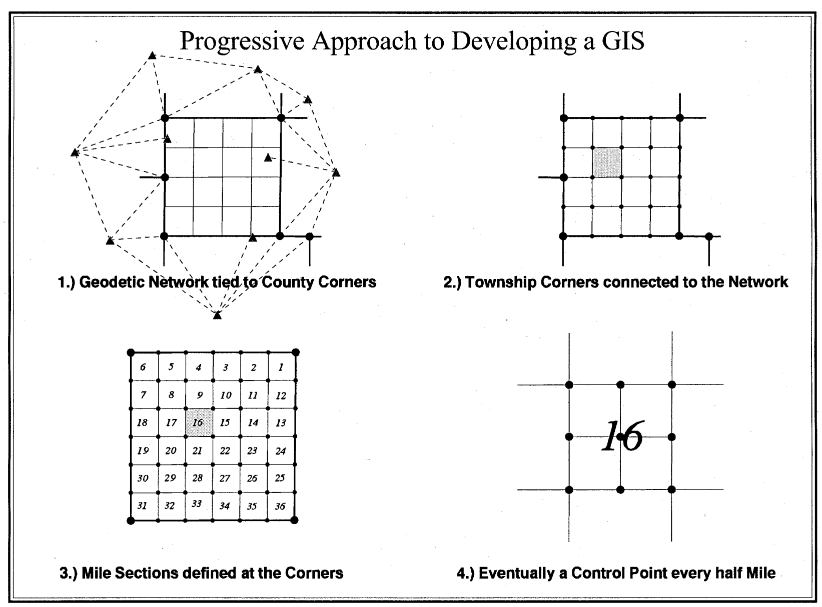

Fig. 8) A progressive approach to developing a GIS/LIS by building upon a framework of survey control and densifying the project as time and budget allows.

[18] Federal Geodetic Control Committee, June 1993: *Multipurpose Land Information Systems, The Guidebook,* 13-17, 18 p.

For all the nonfederal lands in Nebraska that are subdivided according to the Public Land Survey System (PLSS), we recommend that the geodetic reference framework for the cadastre be the section corners and the quarter-section corners of the PLSS, including the center point of each section. Each county (or municipality) that is planning to develop a GIS/LIS-based cadastre program should initiate a progressive program to relocate and monument these points according to the legally established procedures and properly connect them to the National Spatial Reference System to obtain geodetic coordinates.[19]

In summary, this chapter on Geographic / Geodetic control presents the basis for a solid foundation from which a multipurpose GIS/LIS should be built upon. These facts are further supported in the Draft Geospatial Positioning Accuracy Standards now undergoing review by the Federal Geodetic Control Subcommittee and the Federal Geographic Data Committee.[20]

Key emphasis placed on this important aspect in the early stages of any GIS/LIS development will help support the creation of the next phase, **Base Map Data**, and will help ensure the project adheres to a well defined framework of geodetic control.

Return to Table of Contents

[19] National Research Council, 1983: *Procedures and Standards for a Multipurpose Cadastre,* National Academy of Sciences, Washington, DC, 25-26 p.

[20] Federal Geographic Data Committee, January 1997: Draft Geospatial Positioning Accuracy Standards