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# AUTOMATED LEGAL AND GEOGRAPHIC REFERENCE SYSTEM CONVERSION IN KANSAS

**Version II of the LEO System**

by

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Technical Information Services
KANSAS GEOLOGICAL SURVEY

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## Acknowledgements

This report and the LEO2 project have been inspired and fueled in large measure by the efforts of David R. Collins, Section Chief of Technical Information Services. His curiosity and persistent desire to make things perfect provided the necessary support and inspired much of the research and labor. Without his interest, LEO2 would have had a much lesser, albeit swifter, conclusion.

In addition, J. C. Wong deserves credit for writing software to confirm, map, and measure many PLSS idiosyncrasies, and the only software that helps find ways to correct the PLSS data.

The Automated Cartography group, managed by Chris Roche and then Gina Ross and consisting of countless graduate and undergraduate students, made LEO2 possible by digitizing and editing more than 80,000 section corners from the (USGS) 1:24,000 topographic maps. Development of GIMMAP software[1] made handling this large data set manageable and supported construction of the Kansas Cartographic Database, including the LEO2 section corner locations. Below is an admittedly incomplete list of the student operators.

> Aspiazu, Jorgina; Goetz, Stan; Kau, Chee; Kaufman, Brad; Kirshen, Deborah; Lee, Siew; Luu, Thang; Martin, Kristin; Moore, Pat; Puntenney, Peter; Schmickt, Britta; Sterba, Jeannette; Schroff, Scott; Squires, Vicki; Tessalee, Wirote; Thornberg, Jeff; Wong, Michael; Wong, Racky; Wong, Weng; Wong, William Kwok; Yee, Weng-Liang; Yeung, Charlotte (and a number of plotter operators whose work was invaluable)

Still others who played small or large parts in the long effort to create LEO2 are: James O. Deputy, Owen T. Spitz, Douglas L. Beene, John C. Davis, Thomas D. Mettille, and John H. Doveton.

This documentation is a large labor, one quite distinct from the design and implementation of the software. It should have been written by a good technical writer, rather than by the author of the software, whose role should be to guide, assist, and review. Furthermore, there is currently no staff member both willing and qualified to perform the review function.

**"All good writing is swimming under water and holding your breath."**

F. Scott Fitzgerald

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[1] The GIMMAP automated cartography system was created by Tho Trang Cao of the French B.R.G.M. GIMMAP was written at the KGS, principally by Charles G. Ross who also contributed critically to system design. Joe Brentano and Rick Brownrigg made significant contributions to the software and in other areas.

# C O N T E N T S

# I. INTRODUCTION

Most geologic and other geoscience data are directly related to spatial locations, usually points on or below the surface of the earth. In order to utilize such data for meaningful analyses and communicate the resulting ideas, a consistent form of reference, a **spatial reference system**, must be adopted. A reference system defines (assigns coordinates to) and locates (maps coordinates to) points in the defined space. Effective communication of the results arising from analysis of **spatially-referenced data** may be facilitated best through a method of graphic representation that is consistent with and complementary to the reference system.

In geoscience research, the map is the graphic form that is relied upon by scientists to explicitly and implicitly relate attribute data to spatial locations. Here, the term "attribute" refers to the broad range of numerical and descriptive values associated with physical, real-world phenomena at their various locations within the space. Though they may be unaware of the reference system involved, geoscientists accept and use maps and their implied reference systems to provide spatial display, if only by copying from a map or by drawing field observations.

Today's widespread availability of digital computers coupled with an increasing dependence upon them to provide the basic tools for the analysis, display (mapmaking) and capture of scientific data (such as map, well-log and seismic data) significantly increases the need for explicit knowledge of the meanings and methods of spatial reference systems. Computer software that is written for an environment with multiple reference systems, must be written with complete knowledge of the structure, definitions, and rules governing each reference system, including scope and purpose, and the forms and functions which each provides.

The growing knowledge about reference systems has illuminated the advantages that are gained with the ability to convert a location defined by coordinates in one reference system into an equivalent set of coordinates in a second reference system. This, in turn, has encouraged development of effective and efficient computer-based methods to perform reference system **conversions** to meet the need for translating data among the three reference systems with acceptable and predictable accuracy.

In particular, much geologic information available to the KGS was originally referenced according to the township-range-section or Legal description system. As a result, much of these data are of little benefit because their use for mapping or analysis requires conversion by the scientist. It is this sort of reference system conversion that makes otherwise unusable data available for use.

The automated cartography system[2] written and used at the KGS is the Geodata Interactive Management Map Analysis and Production or **GIMMAP** system. GIMMAP provides reference conversion in the form of two computer-based **reference conversion systems**, which provide functions to convert locations among the reference systems used to locate geoscience data in Kansas. The conversion systems will convert any location described in one of the reference systems to equivalent coordinates in either of the other two systems, in at most two conversion steps.

One of these reference conversion systems is composed of computer software only, because its conversion process requires only the set of mathematical operations performed on the set of initial values. The **PROJCT** system, created at the KGS, is named for the **map projection** process by which features on the earth's surface are translated onto the flat piece of paper called the map. The PROJCT system consists of a library of (FORTRAN77) routines that support map projection and map **deprojection**, the inverse process. These are the two conversions performed by PROJCT, which has been described in the KGS Open File Report 89-9 (Ross, 1989a).

The second KGS reference conversion system requires software and a source database of section corner locations that were extracted from the collection of statewide map databases[3] at the KGS. This reference conversion system is called **LEO2**, a name derived from letters in the names of the reference systems between which LEO2 performs conversions, namely the **Le**gal and **G**e**o**graphic systems.

The original LEO system (version I) provided the first accurate, state-wide conversion between Geographic and Legal reference in Kansas, as described in the Open File Report 89-10 (Ross, 1989b). LEO2 is the second version of the LEO system, and is the subject of this report. LEO2 expands the capabilities of the system by allowing new forms of location specification, improving accuracy, extending precision, signaling where "non-standard" sections are found, and preparing for future processing in such sections.

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[2] Computer mapping operations at the KGS are performed with the GIMMAP ('jim-'map) system, a software package written at the KGS. GIMMAP provides computer mapping functions that include map data collection; map database construction; feature, symbology, and legend box creation and editing; reference system conversion; "quilting" of adjacent map areas; network and polygon analysis; intelligent feature retrieval; point symbol generation, automatic line annotation, preparation of color separations; production of publication- quality map products; and transfer of digital data. Because it is highly interactive, the GIMMAP system is more aptly referred to as "computer-assisted" rather than "automated".

[3] Creation of the KGS cartographic databases is described in the section on the creation of the LEO2 section corner database.

## II. REFERENCE AND CONVERSION

A spatial reference system is a set of definitions, rules, and procedures that can be applied to locate points consistently and uniquely within a well-defined and limited **space** (such as the surface of the earth) by reference to a pair (or larger set) of numerical coordinates or other "descriptors" of some form. The spatial reference system defines or maps every set of coordinates to a consistent location. Conversely, it provides a mechanism to define (locate) the (generally) unique coordinates for any point, given some systematic description of the position of the point within the space of the reference system.

Geoscientists at the KGS use primarily three spatial reference systems to support analysis, display, mapping and other research functions. The three reference systems are the **Legal**, **Projected**, and **Geographic** reference systems. Of these, only the Projected and Geographic reference systems (generally) associate locations with a single pair of coordinates.

In the Legal reference system locations are associated with a variable number of numeric and alphabetic descriptor values or coordinates. The number of coordinates used to describe a point depends on the point location and the style used by the person describing the location. Also, point locations may be defined so that two or more different sets of coordinates describe a single location within the resolution of Legal description techniques.

Furthermore, Legal descriptions, which actually identify areas rather than single points (such as for properties), may thus be considered to define the locations of infinitely many points. In contrast, each pair of coordinates in the Projected or Geographic reference systems defines one point. However, in the context of LEO2, only single points are of interest. LEO2 converts points from one reference system to another. Using LEO2 for conversion of complete area boundaries, requires that each areal boundary is treated as a sequence of points, which are sent one-by-one by the calling program to LEO2 for conversion. (It should be noted that LEO2 always reduces the area defined by a Legal description to a single point, according to the rules outlined in this report.

These three reference systems are essentially equivalent in the sense that each maps every location that can be defined within a prescribed resolution; that is, every location within the defined space on the earth's surface to (at least one) set of coordinates in the reference system. All possible sets of coordinates in the Geographic and Projected systems define a single location on the earth . (Legal coordinates define areas in Kansas or the U.S.).

Therefore, any location defined by a set of (two or more) coordinates in one of the reference systems must also be defined by a corresponding set of coordinates that identify the same location in the other two systems. Hence, given that there exists such a correspondence between pairs of reference systems (all of which define coordinates to reference every location in the space), it is conceivable to convert (by hand or by computer) coordinates from one reference system to another and vice-versa.

Analysis of the systems and mathematics involved shows that it is possible to perform conversions from one reference system to another. And consideration of potential applications show it to be desirable to perform such conversions. Together with the existence of many KGS sets of geoscience data in nearly unusable form, these facts provided the justification for the creation of the two reference conversion systems, PROJCT and LEO2.

### A. Geographic Reference

The Geographic system of reference has been used in some form since long before Magellan's circumnavigation of the earth (ending in 1522) actually proved that the earth was round. The Greeks used elements of the system prior to the Christian era (Robinson, 1984). Geographic reference is simple in design and easy to understand, to visualize, and to apply in a global sense. It supports many useful functions, from aiding in the calculation of the size of the earth (Wilford, 1981) to charting courses on the open sea in search of the Indies or the Northwest Passage.

Due to the global model on which the Geographic reference system is based and the relative ease (this was not always the case) of determining the local coordinates of any place on the surface of the earth, it has long been used for land, sea, and air navigation. Its role as an intermediate reference system for conversions among other reference systems (including those for LEO2 and PROJCT) makes Geographic reference the "universal" reference system.

For these reasons, Geographic reference has remained in use for many hundreds of years. Recent advances in geodesy (the science of the shape and size of the earth and positions on its surface) have guaranteed continued use of Geographic reference in the foreseeable future. A new technology, using the longstanding method of triangulation for locating positions on the earth in Geographic coordinates, has recently come into popular use.

The Global Positioning System (GPS) is precisely what the name might imply. The GPS consists of a network of satellites continuously broadcasting information sufficient for any number of people at any locations on the earth to simultaneously locate their positions in Geographic coordinates. At any point on the earth, a surveyor, equipped with the appropriate GPS receivers, can determine his position with a high degree of accuracy at any time. Not since John Harrison's 1735 creation of an accurate clock (forerunner of the marine chronometer) made it possible to determine longitude at sea within a half-degree (Wilford, 1981) has such a significant advance been made in determining accurate Geographic positions.

The originally spherical model on which the Geographic reference system is defined subdivides the world into parts using geometric constructs. Intersecting circles[4], passing through the north and south poles of the earth and separated by a fixed angle measured from the center of the earth, form lines of **longitude**, known as the **meridians**. Perpendicular to the meridians, circles in planes parallel to that of the equator, and of decreasing radius as they approach the poles (also separated by fixed angles, measured from the center of the earth), form the **parallels** of **latitude**.

Longitudes and latitudes represent angles, measured at the center of the earth, between the equator and a parallel of latitude, and between the (arbitrary) Greenwich meridian and a location. These angles are measured in degrees (from 0 to 360 or, usually, from negative 180 to positive 180) minutes (sixty minutes in a degree) and seconds (sixty seconds in a minute). Sometimes, the degrees, minutes and seconds are combined into one single, real value, the "decimal degrees", one for longitude, and one for latitude.

The latitude of a point is defined as the angle between the two rays originating at the center of the earth, one to the point and the other to the equator at the same longitude as the point. The latitudes are well-defined as positive north of the equator, from 0 degrees at the equator to 90 degrees at the North pole, and as negative values below the equator, from 0 to -90 degrees at the South pole. Accurate latitudes may be accurately determined by measuring angles between the horizon and the sun or the stars.

Assignment of the angle of longitude must be made relative to an arbitrarily selected starting circle of longitude. By agreement of European countries, such an arbitrary selection was set (for modern times). This reference semi-circle of longitude, at which the longitude is zero, is known as the **prime meridian**, and is the semi-circle that passes through Greenwich, England. Adoption of a prime meridian fixed all longitudes from 0 at Greenwich east to positive 180, and west to negative 180. West and east longitudes meet on the side opposite side of the Greenwich meridian or half-way around the world, and approximately at the International Date Line which does not follow a meridian, but meanders.

The "grid" formed by the circles of (north-south) longitude and the parallels of (east-west) latitude divides the surface of the earth into regions which, viewed in Geographic reference, are square. Actually, in the normal view of Projected reference, as

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[4] Approximate circles.

on maps, these areas are not square, and may not be rectangular. In fact, they may even have variably-curved sides, depending on the type of projection. Within these areas, additional longitude and latitude lines may be constructed to any level. Location of points may be made precise by constructing the lines of longitude and latitude intersecting at the point or by interpolation from existing lines.

The location of any point on the surface of the earth can be described in Geographic reference by the angles that locate the unique circle of longitude and parallel of latitude that meet at the point. For this reason, the grid of longitude and latitude lines is usually placed on maps for easy reference to locations anywhere in the world. Using the Geographic grid also helped to improve maps of the day once explorers of the time learned how to measure the Geographic position of their ships or survey parties using the sun and the stars. These skills, providing ever more precise location by Geographic reference, allowed them to follow the routes set by their predecessors and to properly locate newly discovered features on the new maps they made (Wilford, 1981).

**B. Legal Reference**

The Legal reference system was created for use by surveyors responsible for locating and mapping the parcel (the basic land unit) boundaries for ownership (and later for taxing) purposes. The Legal system arose at a time when other, perhaps preferable, systems of reference (such as Geographic) were not implemented accurately and measurement techniques were too imprecise for land ownership purposes (and later, for collection of taxes), which required an accurate and consistent method for location of the boundaries and measurement of property holdings over very small distances.

The Legal system is not tied to any other reference system, nor can it be mapped easily into either of the other two systems of reference. It is the most complex of the three reference systems for processing by computer, requiring numerous descriptive and numerical values (coordinates) to identify locations that are not unique. That is, two or more distinct descriptions may identify a single location (or area, as described above).

The complexity of the Legal reference system and its requirement for specific and voluminous knowledge of the world (such as the section corner locations in LEO2BASE) mandates a digital computer for accurate and consistent conversion. Legal reference suffers from its use of the "divide-and-conquer" tactic in subdividing an area repeatedly. Using subdivision, the precision a location is limited by the size of the smallest area, which is dependent on the maximum number of coordinates or descriptors allowed. Legal reference allows a more precise method (footages) for location, but it is not universally used.

Following the Revolutionary War, the idea of surveying the public lands of the new country was championed by John Adams and Thomas Jefferson. Their objectives were to promote private ownership of land through the sale of 640 acre sections surveyed on the public lands and to generate needed funds to pay debts from the war.

Their efforts resulted in establishment of the **Public Land Survey** by an act of congress. As a result of this act, the **Public Lands Survey System** (**PLSS**) was created. It was eventually extended to the Kansas territory nearly seventy years later, with appointment of the first Surveyors General for the territories of Kansas and Nebraska. Details of the mechanisms behind the land survey were provided in the 1855 Manual of Surveying Instructions (Unknown, 1855), which established the PLSS system of baselines, principal meridians, and correction lines for Kansas.

The PLSS or Legal reference system is based on and (legally) tied to a network of physical markers that were surveyed and located on the land (most can no longer be located without re-survey) to act as a framework within which all Legal locations are defined. Establishment of the rectangular survey system with the placement of "permanent" markers was part of the Public Land Survey System, which authorized the survey and sale of nearly a billion acres of public lands to help pay for the war (Collins, 1989).

The fixed markers, or "monuments," constructed to preserve the locations, were placed at the corners of the basic units of area in the "Land Grid" of the state. The corner locations fix the locations of the sides of the land units, intended to lie along the cardinal directions. Interior to the marked areas, a set of rules applies to define ever smaller areas of land. At finer levels, the land units may be the actual parcels owned by people.

As a part of the PLSS, surveys were instituted in Kansas to lay out the land grid system for the state. The Surveyor General was charged with the task of surveying the initial point of the Sixth Principal Meridian by locating a point one hundred eight miles west from the Missouri River along the fortieth parallel. But, unfortunately, when the Kansas survey began, this starting point was established incorrectly only sixty miles west of the Missouri river. This was the first of many errors made during the twenty-one year long land survey of Kansas.

The goal of the survey was to locate and mark the corners (and quarter-section corners) of the sections in the Kansas grid by measuring distances on the ground across the state. Starting at the base lines for the survey, the grid of sections was to be laid out across the state, section by section, placing permanent markers at each section corner.

Like laying out dominoes or tiles on a floor, the idea of finding and marking the corners and side midpoints of squares on the ground seems simple, but is not in practice. The technology of the day was not capable of today's standards (thus, few if any sections are a mile square). By the time the initial survey was completed, many corner markers were already obliterated and had to be resurveyed. Today, only a small percentage of corners can be found by their monuments, without additional surveying.

### C. The Legal System In Kansas

The Legal reference (or Public Land Survey) System in Kansas is based on a set of carefully[5] surveyed "land grid" corners and lines with an arbitrary origin defined at the intersection of the **baseline** with the **Sixth Principal Meridian.** The baseline for the Kansas survey was set approximately at the north border of Kansas at about forty degrees north latitude, while the Sixth Principal Meridian was located at 97 degrees, 23 minutes west longitude[6].

The Legal system in Kansas comprises a grid of 35 rows and 68 columns of **townships**, each approximately six miles square. The rows of this township "grid," as designated by **township numbers**, form a continuous, slightly curved path from west to east. The north and south boundaries of each neighboring pair of townships meet exactly at the corners of their common border. The columns of the grid, formed by the east and west sides of townships, are referenced by **range numbers.** The east and west sides of adjacent townships meet evenly except at the six "correction lines" where surveyors made adjustments to compensate for the curvature of the earth. At correction lines, the range lines of any two adjacent townships are offset to the east and west by varying amounts.

Each township in the PLSS of Kansas are uniquely identified by a **township designation**, the grid row number south of the baseline, and a **range designation**, the number of grid columns east or west of the Sixth Principal Meridian. For example, the township that lies in the fourteenth row from the north and the fourth column to the east of the principal meridian is referenced as "township 14 south", written "T14S", and "range 4 east", written "R4E". Furthermore, the township in the twenty-third row and the thirty-

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[5] Actually, as described below under "Eccentricities" of the PLSS in Kansas, the section corners were not always surveyed as carefully as they might have been. However, the surveying errors made in the basic grid were more serious than the errors made in surveying individual sections.

[6] See the note above in "Legal Reference" concerning errors made in locating the Sixth Principal Meridian.

fourth column west of the principal meridian would be "township 23 south and range 34 west", written "T23S, R34W".

The grid of townships in Kansas is illustrated in Figure 1. Note that the full grid of 35 rows and 68 columns extends outside the state boundary, and includes "false townships" that do not exist in Kansas. As a result, the use of this grid in LEO2 means that it is possible to designate some non-existent township, which are rejected as errors by LEO2.

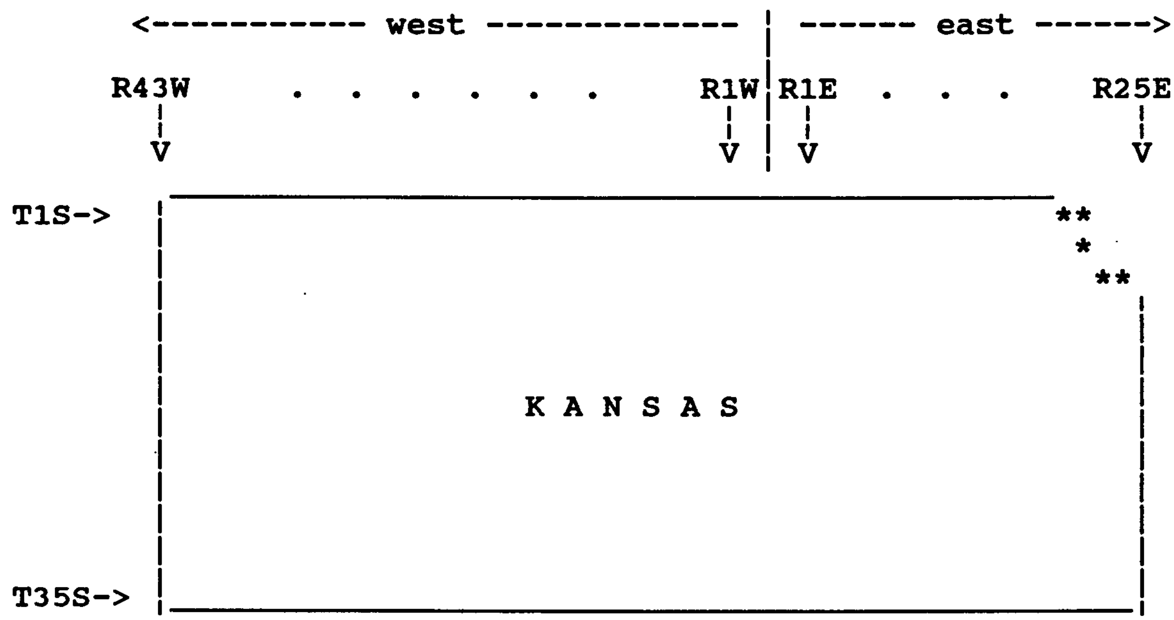


**Figure 1: Township and Range Designations in Kansas**

Nearly all[7] townships are divided into 36 **sections**, each of which is intended to be one square mile. Sections are referred to by unique numbers as defined by the PLSS, and are ordered in a snakelike pattern (illustrated in Figure 2) starting with section one in the northeast corner. Sections two through five proceed in a line to the west from section one, ending with section six in the northwest corner of the township. Section number seven lies directly to the south of section six, with sections eight through twelve lying to the east of section seven.

This pattern continues to the last section (section 36) in the southeast corner. All townships in Kansas that have a full (36)

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[7] Except at the state boundary, especially along the border with Missouri where some townships have very few sections. Also, in areas excluded from the survey there are missing sections.

complement of sections are numbered this way, but some townships do not contain thirty-six sections. This anomaly usually occurs because of encounters with natural or artificial boundaries that blocked the original surveys.

| | | | | | |
|---|---|---|---|---|---|
| 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 |

**Figure 2: Section Numbering Within Townships**

Except for areas that were specifically excluded from the PLSS, every point location in Kansas lies within a unique section in a unique township, both specified by the Legal description. Legal reference for any location consists of the township designation, the range designation, the section number, and a more detailed location of the point within the section, which may be specified by a number of methods.

Specification methods for locating points within sections provide a substantial improvement in the precision of the location. With conventional methods, the location can be specified to be within an area that is 1/256th the size of the section. The traditional form for intra-section location is to subdivide the section into halves or quarters, and then subdivide the half or quarter which contains the location, and so on for up to four subdivisions that are applied recursively, each to the result of the previous. The LEO2 system improves on this by allowing the selection within the final subdivision of the closest point from the corners, the side midpoints, and the center. Alternatively, precision may improve by defining locations with two approximately orthogonal distances (footages) measured from a section corner.

Eccentricities

Some areas in Kansas do not conform to the usual PLSS rules and structures for the Legal system as used in the rest of the state, in which sections approximate a square mile in area. One such exception is the column of townships in Range Eight east (R8E). In these townships, the western half of the westernmost sections (6, 7, 18, 19, 30, and 31) are as large as two miles wide (the sections are three miles wide). This problem resulted from the surveying errors made in originally locating the Sixth Principal Meridian, the longitudinal baseline for the state survey. This error caused the misalignment of two separate surveys that met in Range Eight east, where extra wide half-sections filled a gap.

Other sections were surveyed to have irregular boundaries, in which one or more parts of the (normally rectangular) section were missing. Often, such peculiarities resulted from physical barriers encountered during the survey. For example, sections along a river may be defined by boundaries that include part of the river edge, connecting two section sides that terminate at that edge. In Kansas, sections bordering on the Missouri river are not whole, because the state boundary, which lies along the river, cuts through many sections, leaving three or fewer of the section corners within the state. Similar problems occur along rivers internal to the state, when they prevented the surveyor from proceeding normally.

Problems such as these often resulted in further subdivision of the section into smaller areas called **lots.** Lots are usually square (rectangular), 40-acre areas, but sometimes are larger or have irregular (non-rectangular) boundaries requiring more than the usual four (corner) points to define. Lots were arranged and numbered differently within each county. The LEO2 system does not incorporate the use of lots for reference conversion, but may do so in the future as part of the special processing of sections currently marked for exclusion from standard conversion[8] .

One set of anomalies in the PLSS in Kansas are the sections that

[8] Nearly all sections are "standard" in the sense that they are assumed to be acceptably close to the "ideal" section (a mile square) and subdivision of the section is acceptably performed by the "standard" subdivision process. Standard subdivision by half is accomplished by bisecting two sides in geographic coordinates. By quarters, the center-of-mass (average of all four corners) is connected to the bisected sides, creating four quarter-areas.

are not properly defined by a set of four corner locations only. Such sections often require six or more "corners" to describe the boundary. In other parts of the state (such as near Fort Riley), the application of Legal reference is not possible, because some areas were exempted by law from the PLSS, and therefor, the land grid does not legally exist. The existence of natural obstacles in the field and the governmental exclusion of certain areas from the state survey are the principal explanations for the creation of sections with irregular boundaries.

These special cases of sections that require lots, whether or not they have four corners, are noted here, because in LEO2BASE the township records containing these sections will show them to be special. Certain values of the **section flags** indicate sections that require special or **non-standard** methods for subdividing to identify locations within the section. This special handling is not available in LEO2, and the user can not currently reference these sections[9] for conversion. However, future work is expected to resolve these issues and support conversions in these areas.

### D. Projected Reference

A map projection may be thought of as a translation of locations from the surface of the earth onto a geometric object, usually a plane, cone, cylinder, sphere or ellipsoid ( all of which may be easily converted into a flat map). Any well-defined mathematical process that translates locations on the earth's surface onto the reference object might be referred to as a map projection. But, different forms of projection, all of which produce coordinates in Projected reference, produce map images and relationships with differing properties, such as distortions of scale, area, shape, and direction.

One major goal in map design and map-mapmaking is to minimize the distortion of properties that are important to the purpose of the map. John Wilford (1981) wrote, "The cartographer's task is to design maps that will show the least distortion or no distortion in those properties the map's intended user deems desirable." It is fortunate that distortion may be greatly controlled by proper selection of the projection, so that errors may be controlled.
Only on the globe can the surface of the earth be displayed with minimum distortion over the whole area. Any attempt to display

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[9] Sections with fewer than 4 corners can not currently be used for conversion, but non-standard techniques may eventually be incorporated for them. Sections that are non-standard, but which have all 4 corners will be treated with standard methods, producing a conversion result if there are no errors. The result may be worthless or not, but the fact that the section is marked as non-standard is communicated to the calling program.

the curved surface of the spheroidal earth on flat paper results in the distortion of one or more map projection characteristics, the graphic properties of a map. Among these properties are the scale (distance), shape (angles at a point), direction, and area.

For example, the Mercator projection, used to map the whole world in 1569, has the property that many of the "rhumb lines," (lines of constant bearing or direction), are straight lines on the map. This property simplified the navigator's task, and ended the need for constant course corrections to adhere to the routes of great circles that had been followed in the past (Wilford, 1981).

Projected coordinates may be referred to as rectangular, planar, or Cartesian coordinates. In the context of LEO2, a projected reference system results from the application of a mathematical transformation or "map projection" that transforms locations on the three-dimensional surface of the earth into two-dimensional locations on a (flat piece of paper called a) map. Of the map projections, the Mercator projection, may be best known.

The use of the Projected reference system arises because, being a system for representations on the flat map, it can support the desired function of accurate and effective map-making. Neither the Geographic nor the Legal system may be used to produce maps with properties desired by cartographers and others who use them. For example, assuming it is possible, construction of accurate maps using Legal reference would require a tremendous store of empirical knowledge of the sizes, shapes, and relative positions of the more than eighty thousand sections in the state of Kansas. Locating point data in such a reference system would (for most data) require a conversion to Legal reference.

Mapping directly in the Geographic reference system would ignore the existence of map distortion and distort the surface of the earth, as represented by the map, in ways that most map readers could not adjust to. For example, the actual length in feet on the ground of an arc of constant latitude and fixed length in longitude varies depending on the latitude of the arc, becoming zero at the poles where the meridians converge.

However, various arcs of fixed length (in latitude) lying along a line of longitude, but at different latitudes, will be reasonably constant in their length on the ground, but will vary slightly, as a result of the slightly oblate shape of the spheroidal earth. Thus, the scales of the two axes that would be used for a display of locations represented in Geographic coordinates would not be the same, and the aspect ratio, or the ratio of the scales of the longitude and latitude axes (the X and Y axes in an image), would differ by significant amounts. Thus, non-linear distortion would increase at the higher latitudes.

Although such a "projection" (actually the absence of projection) would facilitate the location of features expressed in Geographic coordinates, it would also significantly distort the true nature of the map area, the features represented on the map, and their inter-relationships. The projected reference system is superior for the purposes of communicating and understanding relationships among map features; communicating themes and ideas; calculating errors of distortion; measuring distances, angles, and areas; and for plotting a land, sea, or air course.

The advantages gained by using Projected reference in automated cartography and, in general, for processing by computer are many. Data acquired by map digitizing are in Projected reference since the source map itself is created by projection. Displays of map data look like the original map, and appear undistorted, only if they are in coordinates from Projected reference. This effect is important to those who build and edit map databases and to those who only use the end product, the digital map. Only map data in Projected reference is ready for immediate plotting to create a conventional paper map. And finally, different sets of data from different Projected reference, may be joined or "quilted" into a common map or database through reprojection.

**E. Reference Conversion**

A spatial reference system consists of definitions, rules, and a set of procedures, which combine to consistently locate points in a defined space. Since there are three or more spatial reference systems, there is a need to translate locations from any of them to any other reference system. This process is called **reference conversion.**

A spatial **reference conversion system** consists of definitions, rules, and procedures capable of translating (the coordinates of) locations between two reference systems. Like reference systems, the reference conversion system is a set of definitions, rules, and procedures (including those defining the reference systems) whose function is to transform locations from either reference system into equivalent descriptions (coordinates) in the other.

To illustrate reference conversion, two examples are presented to show the equivalent locations as described by the three different systems of reference. These examples were created by use of the LEO2 and PROJCT conversion systems. First, a point located at 95.24 degrees west longitude and 38.95 degrees latitude would be converted by LEO2 into the Legal location of "township 13 south, range 20 east, the southeast quarter of the southwest quarter of the southwest quarter of the northwest quarter of section six".

The Projected coordinates for the same location, as determined by the PROJCT software, are dependent upon the parameter values used to define the map projection. Given the parameters that are used for the (GIMMAP) standard, 1:500,000 scale projection for Kansas (Lambert Conformal Conic with standard parallels at thirty-three and forty-five degrees), the Projected coordinates of the point would be: X = 48.485, and Y = 18.834.

For another example, a location might be described originally in Legal reference as the "center of the northeast quarter of the southeast quarter of the north half of the southwest quarter of section 20 in Township 10 south, Range 8 east". The Geographic coordinates of this location, given after conversion by LEO2, are at a longitude of 96.5487 degrees west, and a latitude of 39.1647 degrees north. After projection by PROJCT, (once again assuming the GIMMAP standard projection for Kansas), this location has the Projected coordinates of: X = 39.568, and Y = 20.464. These are the cartesian coordinates of the point on a flat map.

Advantages

Reference systems exist and are used because each supports one or more useful functions, which, in some cases, are exclusive to that reference system. Thus, the ability to convert among the different reference systems multiplies the advantages inherent in each, thus increasing the value of data that exist or are being gathered in each of the three systems. That is, when data can be converted to an additional reference system, the advantages of that reference system and the reasons for its existence will be gained. Some of the advantages of the three systems of reference used at the KGS are given below.

It is true that geoscience and other spatially-related data at the KGS, whether stored in analog or digital form, are associated explicitly or implicitly with locations that are defined in one of the three systems of reference. Because such data sets are of value in different reference systems for different reasons, it is necessary to provide methods for converting locations in any one reference system to any other system. This conversion process is an ideal task for the digital computer. Hence, computer software to support conversion among reference systems helps to completely utilize available digital data and to put data in a form readily usable for graphic display and efficient spatial analysis.

Data stored in, and functions supported by, these three reference systems (Legal, Geographic, and Projected) became more accessible and more useful to the KGS with the creation of the two reference conversion systems, PROJCT and LEO2. Among the advantages of the reference conversion software is the ability to transfer digital data in any of these three reference systems to other computers, where a particular reference system may be desired.

Of these three reference systems, the Geographic reference system is the common link by which spatial data, representing locations on the earth's surface, may be transported to the other reference systems and to other computer sites. Considered the "universal" system, Geographic reference is the source from which Projected reference originates, by way of some quite complex mathematical transformations known as map projections.

Projected reference is used exclusively to produce maps on flat paper with controlled distortion in direction, scale, area, and shape. Projecting data onto maps is a function that is essential to data comprehension, analysis, and testing, and is essential to drawing conclusions about geographic information. Map projection is also the principal method for communication of results with spatially related data in the research process.

Point locations, described in Legal reference, can be posted at the correct places on a (projected reference) map by a computer using the LEO2 and PROJCT conversion systems in sequence. The LEO2 system converts the Legal description of the location into Geographic reference (longitude and latitude coordinates), which are converted into Projected reference by the PROJCT system. The result is a location in Cartesian (x,y) coordinates that may then be plotted directly on the map. The projected boundary lines and points for elements of the Legal system (sections, townships, and corners) may be added to the maps so that viewers can approximate Legal reference directly on the map.

Non-digital data tied to Legal description locations abound at the KGS (e.g. petroleum and hydrologic well locations, API field boundaries, and geologic outcrop boundaries). However, because Legal description does not represent locations in a manner that is precise enough for mapping, graphics, and spatial analysis by computer, such data are not useful for these applications until they are converted to Geographic or possibly Projected reference. Once freed from Legal reference, these same point locations may be transferred to other sites, may be used for computer mapping functions (listed above), or they may be archived in Geographic or Projected reference.

### F. KGS Conversion Systems

Two computer-based reference conversion systems, PROJCT and LEO2, were developed at the KGS to provide KGS researchers the ability to convert locations among the reference systems used at the KGS, namely, Geographic, Projected, and Legal. Some of the functions of these systems and the interrelationships among the reference and conversion systems are illustrated in Figure 3. The advent of these conversion systems made it possible to convert locations between any two of the three reference systems.

Locations in Geographic reference, with coordinates given in the form of angles of longitude and latitude, are universal. For example, they are used for data being archived or transferred in or out of the KGS. In addition, the spatial component of large sets of source data archived at the KGS (and elsewhere) is given in Geographic reference. This usually occurs as the result of a conversion from Projected reference locations that in turn were associated with a map or digitized data.

Point locations in Projected reference result from the digitizing of maps (and other sources). In fact, projected reference is the system that is inherent in (projected) paper maps. The (x,y) coordinates used in Projected reference are also used to transfer and archive spatial data, and to provide graphic images with less distortion (in comparison to other reference systems) for display and map production.

```
                                                   ******************
                       L E G A L                   * well locations *
                   R E F E R E N C E       <<******* & property     *
                             * /|\                 * descriptions   *
                             |  |                  ******************
                             |  |
      L E O                  |  |
CONVERSION ---->>            |  |
    SYSTEM                   |  |
                             |  |
                             |  |                  *********************
                            \|/ *                  * external map data *
                  G E O G R A P H I C      <<******* for transfer in.   *
                   R E F E R E N C E       *****>>* map data to be     *
                             * /|\                 * transferred out    *
                             |  |                  * or archived.       *
                             |  |                  *********************
                             |  d
                             p  e
                             r  p
P R O J C T                  o  r
CONVERSION ---->>            j  o
    SYSTEM                   e  j
                             c  e
                             t  c
                             |  t
                             |  |
                            \|/ *                  *******************
                  P R O J E C T E D        <<******* digitized data. *
                  R E F E R E N C E        *****>>* map display     *
                                                   * & production.   *
                                                   *******************
```

**Figure 3: Spatial Reference and Conversion Systems**

Finally, Legal coordinates (as proscribed by law) have been used for property definition and for locating wells and other point or area features. The Legal reference system abounds in the legal world, dating back to the Public Lands Survey, which caused the Legal system to come into existence by an act of Congress. For this reason, all lands defined since that time have been done so under the auspices of this act, and thus, under the Legal system.

The LEO2 (from **LE**gal-g**EO**graphic) reference conversion system provides reference conversions between the Legal and Geographic reference systems in the state of Kansas. Using the LEO2 system, locations represented as Legal descriptions can be converted into the equivalent Geographic coordinates and, conversely, locations that are defined in longitude and latitude (Geographic reference) can be converted into Legal descriptions.

Using the PROJCT conversion system, locations that are described in Geographic coordinates may be converted by "projection" into Projected (x,y) reference. Conversely, Projected locations are "deprojected" by PROJCT, back into Geographic locations. These may then be converted by LEO2 to Legal descriptions (township, range, section... ).

The LEO2 conversion system was made possible by linking the Legal and Geographic reference systems in Kansas via construction of the LEO2BASE database. LEO2BASE contains the spatially-ordered locations of all Kansas township and section corners, referenced in Geographic coordinates. These locations were digitized from the USGS 7.5' quadrangle maps and then, using PROJCT, they were converted to Geographic coordinates by deprojection. They were organized by spatial/logical relationship to promote fast access to each section and township, and were stored in LEO2BASE.

Prior to the implementation of the (LEO and now) LEO2 conversion system, it was not possible to convert point locations between Geographic and Legal reference with acceptable accuracy, across the state. As a result, the creation of the LEO2 system has made available a number of data sets that previously were not readily accessible, especially for use in computer applications.

## III. THE CONVERSION SYSTEM

The LEO2 reference conversion system consists of one (FORTRAN77) subroutine, **LEO2CVT** (for LEO2 ConVerT), and an associated spatial database, called LEO2BASE, containing section and township corner locations stored in Geographic coordinates, and ordered according to spatial and logical relationships. LEO2 converts between the Geographic and Legal reference systems within Kansas. It can not be used outside the state, since LEO2BASE contains locations of Kansas section and township corners.

Given a Legal description that includes the township, range, and section numbers, and some form of location specification within the section, LEO2 produces the Geographic coordinates of a point within the specified area. The selected point may be the center, a corner or a side midpoint of the section or of a sub-area (via subdivision) of the section. Alternatively, the selected point may be a location within the section, specified by two distances on the ground (footages), measured from the section corner that is implied by the footage directions. The Geographic coordinates that result from conversion are real values representing decimal degrees of longitude and latitude. Optionally, they may be in the form of separate values for **d**egrees, **m**inutes, and **s**econds for longitude and latitude. This is the **DMS** option.

LEO2 can also convert a Geographic location (as either decimal degrees or the DMS form) into the equivalent Legal description of an area containing the specified point, or a specific point in this area. This Legal description will include township, range, and section numbers, all four levels of quarter-area subdivision, and identification of the closest of nine significant points in the area (four corners, four side midpoints, or the center).

### A. The Spatial Database

The LEO2BASE database contains the spatially-ordered, Geographic locations of all section and township corners in Kansas. It was derived from the original LEOBASE database, which was constructed in 1985 from the Projected reference locations of the section and township corners. These corner locations, digitized beginning in 1980-81, were entered into one of the more than 2,300 databases, collectively known as the **Kansas Cartographic Database or KCD**, (originally, called the Kansas Data Base or KDB).

The KCD has been constructed at the KGS in the past eleven years by digitizing and editing operators, which were all graduate and undergraduate students of the University of Kansas, of which the KGS is a part. The students were trained to use the (KGS) GIMMAP software and procedures to digitize and edit map data, under the supervision of a KGS staff member.

The source maps that were digitized for construction of the KCD, and which were the original source maps for the corner locations in LEO2BASE, were the 1:24,000 scale, 7.5' series of topographic maps, referred to as "quadrangle", "quad" or "topographic", maps. These maps, produced by the U.S. Geological Survey (USGS), were and are the most comprehensive and accurate maps available.

The complex process of constructing the LEOBASE was accomplished by the application of a series of (FORTRAN77) programs to extract and transform the section corner locations into the special form required for the LEO system. The first steps were to extract the section and township corners from the multiple KCD databases, to deproject from Projected coordinates into Geographic coordinates. The locations were sorted and analyzed by complex spatial rules and knowledge of the real world in an attempt to determine which legal description belonged to which (randomly-extracted) section corner location from the KCD.

During this process, the LEO software also had to recognize and ignore duplicate corners on some county boundaries, to accept or correct identical corners across boundaries where expected (most of the time), and to find and accept different corner locations along correction lines. The construction software, using only what was believed to be the correct set of corner locations, had to extract and order corner locations by township (according to a fixed order internal to townships), and to build the LEOBASE as a structured, spatially ordered, direct-access database in which each record contains the section and township corner locations for all sections in a single township.

More than eighty thousand section and township corner locations (in Projected reference) were extracted from KCD databases and converted to Geographic reference. The Geographic locations were sorted by latitude, separating them into groups representing the approximately 210 east-west rows of section corners in the state grid. Each row was then sorted separately by longitude, creating the first approximation of the complete section corner grid with proper recognition and matching of corners to Legal descriptions.

Correction lines, lines of latitude where longitudinal township boundaries were shifted due to the shape of the earth, have more than twice the number of corners as the other rows. The corner locations collected in correction line rows had to be treated by a separate process to accommodate their numbers and to support a special process for selecting those corners. In addition, the number of correction row corners was increased by the coincidence of county boundaries, along which section corners were digitized two or more times, for separate databases.

Creation of the LEO database required a sequence of many separate steps related only by their sequence. Many problems prevented a straightforward analysis with a simple ordering process to assign all of the corner locations to the appropriate Legal positions in the database. Among the problems that had to be overcome for the proper construction of the database were: (1) redundant section corners along the county lines, (2) non-alignment of longitudinal section and township lines at correction lines, and (3) the large number of corners along correction lines.

In addition, logical errors in the algorithm used to recognize and match corners along correction lines combined with a lack of knowledge about the existence of "special" sections (those with boundaries requiring more than four points) introduced additional (unnecessary) errors into LEOBASE.

The result of the analysis and construction process was the set of unique section corner locations for each position in the near-grid of the Kansas PLSS or land grid and Legal reference system. It should be noted that each corner location lying on a township line was duplicated for the adjacent townships so that section boundaries in LEOBASE are identical across townships.

It should be noted that, although township and range lines were available from the KCD, they were not used in the construction process. Hence, the township boundaries (assumed by LEO2 to be straight lines between township corners) do not coincide with section boundaries along the township edges. This discrepancy sometimes leads to a slightly more complicated search procedure when trying to locate a point. LEO2 may find that a point does not lie within a township, but later, after failing to locate the point inside a neighboring township, the same point will be found to lie inside a section within the first township.

Also, for the second version of LEO, an updated version of the database was created. The LEO2BASE database includes corrected locations for some section corners, as well as flags to mark non-standard sections (described elsewhere). The spatially-ordered, direct-access LEO2BASE database adheres to the LEO2 model of the Land Grid, and parallels the quasi-grid model generally used for describing the Legal system in the state. In this grid model, sections are expected to be quadrilaterals. Section boundaries are certainly not polygons that require more than four points to define. However, such boundaries do exist for isolated sections in Kansas. These are examples of non-standard sections.

**B. Database Content**

The original spatial database for LEO contained the locations of all Kansas section (and township) corners in Geographic reference as decimal degrees of longitude and latitude. They were stored in a logically-structured form, based on geographic relationship, with all (49) corners for a township stored in a specific record in the database. This provided direct retrieval of the township information for a section, and hence, prompt determination of the Geographic location of any corner, given the Legal description of the section. Direct retrieval was made possible by the fact that each valid Legal description was translated into a single, unique record number for the record that containing the locations of all section corners in the township[10].

Within each township record were forty-nine pairs of coordinates. Each pair represented the Geographic location of a single section corner. The locations were stored as (longitude, latitude), with negative (west) longitudes, and positive (north) latitudes. Both longitudes and latitudes were stored as binary, real numbers (of four bytes each), representing decimal degrees. Where townships had missing corners, corners outside the state, or unknown corner locations, the non-existent corner locations were marked in the database by values of (9.9,-9.9). Hence, a positive longitude or a negative latitude indicates an unavailable corner location.

Within each township record, the 49 section corner locations were ordered by row, then by column. The first row stored was the top or northernmost row (those above sections 1-6), in order from the west to the east, and with longitude preceding latitude for each location. Then the second row from the north (the corners below sections 1-6) is stored, from east to west, and so on down to the corners of the southernmost row, again stored from west to east.

A township record from LEOBASE might be represented as a pair of (7x7) matrices, with row 1 (the north corners from section 6, 5, ..., 1; from west to east) as the top row and with row 7 at the bottom (the south corners from sections 31, 32, ...,36; from west to east):

```
lon(1,1),lat(1,1)        . . .        lon(1,7),lat(1,7)
        .                                      .
        .                                      .
        .                                      .
lon(7,1),lat(7,1)        . . .        lon(7,7),lat(7,7)
```

Accordingly, the location of the northwest corner of section six is stored first (longitude, then latitude). This is followed by the northwest corners of sections 5, 4, 3, 2, and 1, and then the northwest corners of sections 7 through 12, and so on. Accessing section corner locations (where each is a longitude followed by latitude) in the township record is done (by rows) in the order:

(1,1),(1,2),..(1,7),(2,1),(2,2),..(2,7),..(7,1),(7,2)..(7,7)

---

[10] Fast retrieval also required that all section corners on the edges of townships must be redundantly stored in the township record for the township across the township or range line. For township corners, four copies of the location are stored.

where the pairs of indices (r,c) represent both the longitude and latitude (decimal degrees) of the corner located at the specified row (r) and column (c) in the longitude and latitude arrays.

## Changes for Version II

For LEO2, the structure and content of the database were changed to prepare for possible future addition of software for secondary processing of "special" sections. The township records have also been expanded, with the addition of flags marking unavailable or non-standard sections that may not be used for conversion. And some corner locations that were found to be in error in the first LEO were corrected for LEO2. Other errors do exist.

In LEO2, the database is a single file of direct-access, fixed-length (466 byte) records, one per township. Thus, calculation of the record number for the township record is the same as in the original LEO system (see below).

The township record contains the locations of the section corners in geographic coordinates plus a **township flag** and a **section flag** for each section. These markers provide quick information about the absence of data for townships or sections, and may eventually provide connections for special conversion in such sections.

## Standard Subdivision

The so-called "standard" sections are, simply, the vast majority of sections for which the usual four corners represent the entire boundary of the section and for which the locations of these four corners are known and are available in the LEO2 database. As a result, these sections may be "subdivided" in a standardized way.

Subdivision is a process for increasing the precision of a Legal description by recursively selecting ever smaller areas within a section. The practical application of subdivision is explained elsewhere. In general, each subdivision selects either a half or a quarter of the area to which it is applied (the area resulting from the previous subdivision, or the section). Subdivision may be applied up to four times in a typical Legal description.

Standard sections support subdivision by the process of averaging two corners to find side midpoints and averaging all four corners to find the center. Viewed geometrically, half-area subdivision in standard sections involves construction of a line joining the midpoints of the indicated sides. Quarter-area subdivision may be seen as constructing two such lines (one north-south and one east-west) that intersect at the centroid, dividing the area into quarters. The selected quarter-area is defined by the centroid, the indicated (original) corner, and the midpoints of the sides that intersect at the original corner.

**C. Conversion From Legal To Geographic**

Conversion from Legal to Geographic reference via the LEO2 system is straightforward. The "input" Legal description of a location is completely specified and given to the conversion routine which produces the Geographic result. The minimum Legal location must include township, range, and section numbers, and an indicator of the range as east or west of the Sixth Principal Meridian. The location may be refined by use of subdivisions; selection of the center, a corner, or a side midpoint of the subdivided area; or the application of two footages from an indicated corner. The information used to define a Legal location is summarized below:

1. township number
2. range number
3. range direction, east or west
4. section number
5. up to four half- or quarter-area subdivisions
6. selection of the center, corner, or side midpoint
7. two footage distances (instead of 5 and 6 above)

The conversion requires four steps. First, the township record, whose number is defined by the township and range numbers, and the east-west indicator, is obtained. Second, the four corner locations defining the section are extracted. Third, the section is subdivided and the selected point is obtained or footages are applied from the implied section corner. The Geographic location is calculated from the locations of the corners of the final area or the original section as follows:

From the township number, range number and the east or west indicator, the township record number is calculated by:

RECNUM = 68 * (TSHIP - 1) + RANGE

where

TSHIP = the township number (1-35)

RANGE = 44 - range number, if 'West'
= 43 + range number, if 'East'

The township record is read from LEO2BASE. Based on the section number, the row and column numbers of the northwest corner of the section are determined. The Geographic coordinates of the four corners of the section provide access to the coordinates required for the conversion. The township flag, also obtained in reading the record, is checked to see if conversion is not allowed within the township. This may occur when the township record represents a (non-existent) township outside of Kansas.

The section flag of the specified section, also obtained as part of the township record, is examined to verify that the standard conversion method may be applied. If the section flag is set for special processing with a non-standard section (none are set that way initially in LEO2), reference conversion by LEO will require additional software, not currently available. Currently, LEO2 simply subdivides all sections that have all four corners, in the standard way. Any conversion attempt in a non-standard section that has all four defined corners is flagged (using the value of the NONSTD variable in LEOXTR), to indicate that the quality of the result is questionable.

For standard (quadrilateral) sections, conversion continues with either the subdivision or the application of footages. The new corners resulting from selection of one part of the subdivided quadrilateral are used as the corners for the next quadrilateral and the next subdivision. The process is repeated for as many as four levels of subdivision.

If a subdivision is by half-area, say North/East, divide the east and west/north and south sides in half, averaging the NW and SW/ NW and NE and the NE and SE/SE and SW corner locations. The two new points, the averaged midpoints of the west and east/north and south sides, together with the two original NW and NE/NE and SE corners form the new sub-area.

For quarter-area subdivision, the average of the corner locations is calculated and used as the center of the section. The corners used for the next subdivision will be the corner specified by the subdivision, the averaged center, and the midpoints of the sides that meet at the specified corner. The two sides that are split would be the north and west sides if the subdivision is "NW", or the north and east sides if it is "NE", and so on.

The subdivision process concludes after zero to four subdivisions with the smallest sub-area, called the **target area** being defined by its four corners. The target may be the whole section (or the township) or, with quarter-area subdivision, may be as small as 1/256th the of the original section. It can be any of the 256 areas resulting from such subdivision, and it can be any power of two multiple of contiguous areas of that size.

When selected, the corner, center, or midpoint option is applied to the target area to determine the conversion location. If one of the four corners ("NW", "NE", "SE", "SW") is named, then the coordinates of the named corner of the target area are used for the conversion. If one of the four sides (N, S, E, W) is named, then the location of the midpoint of the named side in the target area is used for conversion. This location is found by averaging the locations of the endpoints of the named side.

When footages are specified, they are applied from the indicated section corner, and no subdivision is allowed. Footages measured against the calculated lengths in feet on the ground of the sides of the section produce ratios. The ratios in turn are applied to the appropriate changes in longitude and latitude to produce the Geographic coordinates of the conversion location. The location is checked to make certain it lies within the original section.

The process uses Projected coordinates that are calculated using the GIMMAP projection software. For this application, a scale of 1:12 is employed to produce feet on the ground. The projection is the Modified Polyconic and the area of projection is defined as the minimum bounding rectangle (in Geographic coordinates) for the section involved. The method by which footages are applied in LEO2 is somewhat arbitrary, though mathematically sound. It is expected to perform in acceptably well for most applications, and should be better than any other computer conversion system.

It should be noted that proper application of footages in digital applications is not clearly defined. Calculation of distance on the ground, and application methods including the proper sequence of application, and the direction of application of both initial and secondary footages are not well-defined. Even the location from which footages are begun (quarter-corner vs. some distance away from a corner) is not consistently determined. And little historical evidence is available to resolve the matter.

The resulting Geographic coordinates, the longitude and latitude, may be returned by LEO2 in two forms. The first combines degrees with minutes divided by 60 and seconds divided by 3,600 to form a single number containing both whole and fractional degrees. This is referred to as "decimal degrees." In this form, there is one real value for longitude and one for latitude. These values are communicated via the parameters of the conversion routine. The alternate form for Geographic reference is to communicate three values (degrees, minutes, seconds) for longitude and three values for latitude. This (DMS) form is transfers through a mechanism that does not use the normal LEO2 parameters.

Conversion from Legal to Geographic reference generally results in coordinates as described above. However, some circumstances may lead to a failed conversion. The nature of these situations is described in greater elsewhere. When LEO2 fails to convert a point, this fact is indicated by the values returned.

### D. Geographic To Legal Conversion

Converting Geographic locations to Legal reference is similar to the inverse process. The goal of this conversion is to generate from a given Geographic location, a Legal description specifying all possible levels of detail, and one that defines the smallest possible area containing the given point. The process consists of three basic steps.

First, the township that contains the location to be converted is identified. The (approximately) linear relationship between the township and range numbers in Kansas and longitudes and latitudes may be assumed to be linear. From this assumption, a calculated guess can usually identify the township containing the point on the initial attempt. If a subsequent test shows the guess to be incorrect, the appropriate (as indicated by the test) neighboring township may be tried. Once the correct township has been found, the next step is to identify the section that contains the point.

As with the initial township guess, this process relies on a simplifying assumption to generally identify the correct section with the initial guess. Finally, all levels of subdivision are determined so that the point lies within the smallest possible target area (1/256th of the section) that can be specified with Legal coordinates. The subdivision process is a straightforward quartering of the area, and determination of which quarter-area the point lies in. Then, of the center, corners and midpoints of the sides of the target area, the location of the point that lies closest to the conversion location is selected.

These three conversion steps are presented in greater detail in the subsequent discussion. Application of the steps concludes with the point location converted to Legal coordinates that are equivalent to the input Geographic coordinates. The conversion may also conclude with the recognition and an indication (of the source (from database, user and software) of a conversion error.

When converting from Geographic to Legal reference, only the longitude and latitude of the location are given. These values may be given as two real values (decimal degrees of longitude and latitude) or as six real values (degrees, minutes, and seconds of longitude and latitude). The desired result of the conversion is to produce the equivalent Legal location: the township and range designators, the east-west indicator, the section number, four quarter-area subdivisions defining a sub-area that is 1/256th the size of the original section, and an indicator of the closest of the corners, center, and side midpoints within the target area.

The grid of sections in Kansas approximates a rectangle, and the approximate height and width of rows and columns of the grid are used by LEO2 to make a (usually) very close initial guess of the township in which a point lies. When township selection has been completed, the next step is to effect an analysis to determine if the point lies within the chosen township, using the four corners of the township. This is a straight-forward process, essentially the "point-in-polygon" (**PIP**) analysis from computer graphics, and results in a determination that the point is inside or outside of the polygon. Points lying on an edge are inside by definition.

If the point lies inside the township, then another initial guess (based on the simplifying assumption) is made of the section that contains the point. Then, a PIP analysis is performed to see if the point lies within the section. This is necessitated by the fact that (as described above) section boundaries are usually not coincident with township boundaries.

If the point lies outside the township, then one of the eight townships surrounding the chosen one is selected for a second township (PIP) analysis. Selection of this second township is guided by the location of the point relative to the original township, which arises naturally from the PIP analysis.

The search continues until a township is found to contain the point or until a township is visited more than twice. If that happens, a special "township thrashing" error is declared, and LEO2 terminates the conversion, returning an appropriate error indication. The thrashing error does not occur when the search process visits a township for the second time. A township may be visited legitimately in the search on two separate occasions in situations where the township and section lines do not exactly match due to digitization and LEO2BASE construction procedures. Such an occurrence would be considered unusual but not an error, and the conversion should conclude properly.

Once the correct township has been found, a section within that township must be found to contain the point, if one exists. An initial guess for the section is made by assuming the extent of the township as defined by its corners is evenly divided by the rows and columns of sections. The point must lie within one of the rectangles defined by this construction, and the section corresponding to that rectangle in the simplified grid becomes the initial section for analysis.

The initial section is examined in a manner parallel to that used in the township analysis. If the point lies within this section, then the conversion process moves on to subdivision or one of the other options. However, if the point lies outside, then the PIP analysis will choose one of the eight neighbor sections to become the next search section. The new section will be in a different township when the first section lies on the edge of a township. If any section is visited more than once in the search process, a "section thrashing" error is noted and LEO2 stops the conversion. Section thrashing errors, though they should not occur unless the LEO2 database is improperly constructed, could occur only across township boundaries.

Assuming the township and section containing the point have been identified, only the subdivision specifications and closest point are left to calculate. Four levels of quarter-area subdivision are determined using a process similar to the one described for performing subdivision when converting from Legal to Geographic reference. At each level, the center of the area is calculated by averaging the locations of the four corners. The Geographic location is checked against the corners and center to see which of the four sub-areas it lies in, and the specification for that level is set to the indicated quarter-area using the two-letter codes for quarter-area subdivision.

The four corners of the sub-area defined at each level are the (averaged) center of the area, the corner corresponding to the selected quarter-area, and the midpoints of the two sub-area sides (outside edges) connected to the selected corner. The four subdivision specifications found in this way are stored in the order of their finding. The final, target area quadrilateral is analyzed to determine which of the corners, side midpoints, or center is closest to the conversion location. The appropriate indicator is set to reflect the result.

**E. Conversion Software**

There are three primary software units related to LEO2, excluding the LEO2 database, which is described in detail elsewhere. The first of these is the conversion routine itself, called LEO2CVT for LEO2 system convert. As with all of the LEO2 software, the conversion routine is written in FORTRAN77, comprising some 1700 lines of code. This routine replaces the original LEOCVT routine from the LEO system. This routine resides in a special file for general use, as is indicated in a later section on LEO2 use.

The conversion routine is a single FORTRAN77 routine. As such, it is not capable of executing or running. To use the routine, a calling program must exist and be linked with this routine, and must execute a call to this routine. Successful conversion can occur only when proper set-up and communication is performed by the calling program. These aspects are described in the section on using LEO2.

When used correctly, the conversion routine will accept a single location, described in either Legal or Geographic reference by the appropriate variable values, and will convert this location into the equivalent location of the other reference system. By using this routine, a calling program can convert locations from a file of data, referenced in one system into locations of the other reference system and write the result to a second file. By this process, information is made available that would otherwise be inaccessible due to the choice of reference system employed in the location component.

In addition to the LEO2CVT conversion routine, there exist other LEO2 programs, one for use in calling the conversion routine, and one to examine (and modify) the LEO2 database. The first program is the LEO2CVT conversion program. Although this program has the same name, it should not be confused with the conversion routine.

The LEO2CVT program is designed to accept locations expressed in the Legal or Geographic reference systems, and convert each upon its entry (done interactively at a terminal) into the equivalent location in the other reference system.

The LEO2QUERY program allows a user to examine the contents of the LEO2 database interactively by selecting a township through the township and range numbers and indicating whether the range is east or west. The locations of the corners of the township are displayed as decimal degrees of longitude and latitude, and arranged spatially on the screen just as they are in the field.

From this the user may name one or more sections by number, and the locations of the four corners of each section are similarly displayed. In both the township and range displays, the Legal description of the township or range is posted above the corner locations. Once done within a particular township, the user may then select a different township and repeat the process.

The LEO2QUERY program has an added feature that allows the user to examine and modify the section and township corner locations in the database. When the section or township is identified, the user then selects the corner to be modified using the specifiers that are employed for quarter-area subdivision (NW, NE, SW, SE). The user then enters a new corner location, which is checked for being a delete location (longitude = 9.9, latitude = -9.9). If the new location is so, the database will be set to the default values. Otherwise, the new location is checked to be certain it lies within the state (but not in a thorough manner).

When section corner locations are changed and the section corner lies on the edge of the township or is a township corner, then the other township records that also contain the corner must be updated as well. This function is performed automatically by the LEO2QUERY program. All changes are immediate, and are permanent, at least until a new location is entered through LEO2QUERY.

Two other programs may be available with the LEO2 system. These are the utility programs, LEO2PRINT and LEO2ASCII. The LEO2PRINT program may be used to create a hardcopy of the complete database with locations shown in decimal degrees of longitude and latitude and organized to be spatially parallel to their positions in each township. That is, corner locations are grouped by the townships in which they lie, with the corner locations appearing from left to right and top to bottom in the same order as the corners do in the field, from west to east and from north to south. The corner in the northwest of the listing is the northwesternmost corner in the township, and so on. The listing of LEO2BASE is rather large and hence is not to be printed often, but it can be helpful.

The LEO2ASCII program creates a special file for transfer of the contents of the LEO2 database by magnetic tape to other computer sites. The transfer file contains the section corner locations as Geographic coordinates in an ASCII format. The output from LEO2ASCII is formatted in fixed-length records, each containing the locations of all the section corners in a township.

**F. Errors and Accuracy**

There are many sources of potential error in the section corner locations in LEO2BASE. As one example, the original surveying of the section (and quarter-section) corner locations resulted in a number of sections which, though not legally in error due to the liberal (nearly automatic) acceptance of corner locations by the courts (Collins, 1989), varied conspicuously from the ideal (one mile square, with all sides aligned to the four compass points). Furthermore, construction of the USGS 7.5' topographic quadrangle maps probably created some additional (though small) error in the section corner locations as well as in other features.

Shrinking and stretching of the USGS paper quadrangle maps, both during and after the printing process, resulted in some clearly noticeable, non-linear distortions which could not be completely corrected by rubber-sheeting techniques (mathematical procedures used to fit map data to known control points) that were employed. And digitization, even on an accurate table (with a repeatability of 0.003 inches) may add to or propagate error. In addition, the LEO2 database construction and editing processes both affect the level of accuracy in the database, due to errors which may arise from the hardware, the software, and the human operator.

And, within the computer, the accuracy of point locations may be affected by mathematical operations performed on the map data and by input or output operations. For example, the application of reprojection to aid in the rectification of the newly input map data to the mathematical (projection) model for the map database is one operation performed on all data. The errors created by processes in the computer can often be measured and minimized.

With respect to accuracy, the primary objective in the processing of cartographic information by computer is to attempt to maintain the previous level of accuracy and to try to prevent any loss in that level from computer operations. To that end, the use of the USGS map series as the primary source of data, the storage of map data in single precision, the choice of point digitizing over the more popular stream method and other aspects have all contributed to achieving the accuracy objective.

The (Geographic) locations of section and township corners in the LEO2 database were acquired through a process of systematic and carefully planned and executed data capture techniques applied to the USGS 7.5' topographic map series. The USGS quadrangle maps were (and are) the most accurate, large-scale map series that is consistent with the national map standards[11]. They were the only comprehensive source known for general cartographic feature data and the PLSS data in Kansas. From these 1:24,000 USGS maps, the PLSS section and township corners were digitized and entered into cartographic databases containing map data for a particular area in Kansas. These were edited by operators, with re-digitization of the corners a possibility in the case of serious errors.

The section corners were extracted from the map databases by their feature codes, four-digit numbers assigned to distinguish features by types (Ross, 1988). These points were deprojected (to Geographic coordinates), then doubly sorted to create an approximate and implicit order. The corners were then selected and placed in LEOBASE with no knowledge of proper order other than the absolute and relative positions gained from sorting.

Some errors (less than 1% of sections) occurred in the complex process of identifying which section corner locations belonged in which township records in LEOBASE, especially along "correction" lines. Furthermore, the existence of "special" sections (those requiring non-standard conversion) was unknown, and this caused some problems in the original LEOBASE. But, thanks to a recent analysis of the database (Collins, 1989), many errors have been detected. Since then, most of the known errors in section corner locations have been corrected. The LEO2 database is probably the most accurate, state-wide collection of section corner locations with accompanying software for reference conversions in Kansas.

The LEO2 database and conversion system has been tested somewhat, by staff and KGS users, and by some special analysis programs for the database. Some errors in the corner locations were found and have been corrected, but additional errors are expected to appear with further use. Some are expected along the correction lines, where corner identification during construction of LEO2BASE was the most difficult. Other errors may be found in sections along the Missouri River part of the state boundary, where sections are irregular, and where other unexpected correction lines exist.

In reference conversion, the use of four levels of subdivision within a section, followed by specification of one of nine key points of the resulting area, translates into the potential to attain a level of precision that bounds the maximum error to at most 165 feet on the ground. Of course, this does not guarantee that such accuracy is provided by LEO2 or exists in the database since errors are introduced in every process from the source maps to LEO2 and the application program.

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[11] If indeed any maps really are.

## IV. CONVERSION OPTIONS

In the use of the LEO2 system to convert locations between Legal and Geographic reference, there are a number of options that may be selected to further control the definition of Legal locations, to alter the form for defining Geographic descriptions, and to obtain complete information about all four corner locations and the lengths of the four sides of a section in one direct request.

### A. Area Subdivision

The basic Legal description including township and range numbers, an east-west indicator for the range, and a section number, will identify a single section, barring errors in the numbers. This is and area that is approximately one mile square. As such, it does not provide enough information to locate points in a precise manner (searching a square mile on the ground is not acceptable). Therefor, the complete Legal description must include additional specifications to reduce the size of the area in which a point is supposed to lie, according to the Legal definition. One method for specifying locations within a section is called **subdivision**, in which the section is partitioned into smaller, (almost) equal parts, with only one part containing the point. And then, this part may also be subdivided.

Specification of a Legal location usually includes one or more **subdivisions** of the section into smaller and smaller sub-areas. Three types of subdivision may be used to increase the precision of the location definition by zooming in on increasingly smaller regions inside the section. These are the "default option", in which the section is the "target area"; half-area subdivision, in which the section and then successively smaller areas are divided into halves; and quarter-area subdivision, in which the divisions of the section and subsequent sub-areas are by quarters. In each case, the subdivision is applied to the sub-area that was created by the preceding subdivision.

Default Method

The default option for subdivision of the section is to make no subdivision of the original section; to accept the section as the "target area", and to make no further subdivision. This default option is assumed when the Legal location to be converted by LEO2 includes only blank subdivision specifications.

Half-Areas

The second subdivision option allows division of the section into successively smaller and smaller **half-areas**, with each subsequent subdivision being applied to the half-area that results from the previous subdivision. With the arbitrary maximum of four levels of subdivision, half-area subdivision may be used to create sub-areas of one half, one quarter, one eighth, or one sixteenth the size of the original section.

The four levels of half-area subdivision in a Legal description are each specified by a single letter. The "target area" is the area resulting from the fourth, or last non-blank specification. The specification of half-area subdivisions for LEO2 is made by using appropriate letters from the table below. The largest sub-area (the first subdivision) is specified first and the smallest sub-area is specified last.

| "Half-Area" | | Sub-Area Specified |
|---|---|---|
| **"Nb"** | = | North half **(b = blank)** |
| **"Sb"** | = | South half |
| **"Eb"** | = | Eastern half |
| **"Wb"** | = | Western half |
| **"bb"** | = | (blank) Unused, no more subdivision |

For example, to calculate the north half-area of a section or of a sub-area of a section, the midpoints of the east and west sides are calculated. The side midpoints are calculated as the average of the locations of the two corners (endpoints) of the side. An imaginary, straight line drawn between these two midpoints splits the area into two approximate half-areas. To use the north half, the east and west side midpoints are combined with the northwest and northeast corners of the original area. A similar technique, employing two such lines, is used for quarter-areas (below).

Quarter-Areas

The third subdivision option is to divide sections and sub-areas into four parts by **quarter-area subdivision.** Each quarter-area subdivision quarters the area by finding the averaged center (the centroid), which, connected to the four side midpoints (again by imaginary construction), divides the area into four approximately equal quarters, each selected by a pair of letters specifying the direction of the quarter-area from the center.

Using quarter-area subdivision, some 341 unique sub-areas may be defined. These would vary in size from the original section to areas 1/256th the size of the original section. With quartering, sub-areas could be generated with one quarter, one sixteenth, and one sixty-fourth the size of the section. If the average section were a mile on a side, the smallest possible target area would be 330 feet on a side. A finer resolution (precision) can be gained only by using footages (see below).

Specification of quarter-area subdivisions is made by one of two equivalent methods of letter assignment (see table), with up to four quarter-area subdivisions being specified. Again, the order of specification is the largest area first and the smallest area last. The specifications letters and associated areas selected for quarter-area subdivision are shown in the table below.

| "Quarter-Area" | | | | Sub-Area Specified | |
|---|---|---|---|---|---|
| **"NE"** | or | **'Ab'** | = | Northeast quarter | (b = blank) |
| **"NW"** | or | **'Bb'** | = | Northwest " | |
| **"SW"** | or | **'Cb'** | = | Southwest " | |
| **"SE"** | or | **'Db'** | = | Southeast " | |

For example, if the northwest quarter of a section or a sub-area of a section is specified ("NW" or "B"), the center of the area is calculated as the average of the four corners of the area, the centroid of the quadrilateral. Then, the side midpoints of the two affected (north and west) sides are calculated as the average location of the two (endpoint) corners. Along with the northwest corner of the original area, these points define the quarter-area that results from subdivision of the original area by quartering and selecting the northwest quarter.

Application

The non-default forms of subdivision, namely, half- and quarter--areas, may be freely combined in any Legal description. That is, it is permissible to follow a half-area subdivision by a quarter-area subdivision or vice-versa. In fact, this kind of mixture is sometimes the most accurate way to specify certain locations with the limit of four levels of subdivision. And, in some cases, it may be the most precise way to identify locations using less than four levels of subdivision.

Regardless of the form of subdivision used, the resulting area is referred to as the target area. This means that the point should lie within this area, which may not be specific enough. In LEO2, identification of a point within the target area may be augmented by the selection of one of nine well-defined points within that area as being the closest to the desired locations. These points (defined below) are the center, the midpoints of the four sides, and the four corners.

When a conversion from Geographic to Legal reference is made, the LEO2 conversion routine will produce a Legal description in which every available specification is used. For such conversions, all four possible levels of subdivision are always used, and for the greatest precision, all four are quarter-area subdivisions. And, all four are created from 'NW', 'NE', 'SW', and 'SE'.

**B. Corners And Midpoints**

The township, range, east-west designator, and section selections identify the unique section that contains the point location that is being converted to Geographic coordinates. Then, subdivision is applied from zero to four times to create a sub-area that also contains the point. The final sub-area is the target area, which may be the final specification for the Legal location. In this case, the center of the target area is arbitrarily selected to be the equivalent Geographic location for the point. The center of the target area is assumed to be equivalent to the Legal location by default, in the absence of further specification.

In some cases, however, a different point in the target area may be more accurate in locating a point, assuming the information is available. It may be that a particular section corner or a side midpoint lies closer to the location than does the center. It is possible that a section corner may be the precise point location that is closest. In these cases, LEO2 allows the specification of any of these nine points (of the center, corners, side midpoints) as a means of increasing the precision of the Legal definition.

Identification of the closest point in the target area is made by using the same designations as are used in half-area subdivision to select side midpoints, using the quarter-area designations to select corners, or selecting the default center of the area with a blank specification. To specify a side midpoint, the side must be identified by "N ", "S ", "E ", or "W " for the north, south, east, or west side. To select a northwest, northeast, southwest, or southeast corner of an area, the corner is identified as "NW", "NE", "SW", or "SE". When LEO2 converts from Geographic to Legal reference, the indicator for the closest point of the center, side midpoint, or corner of the target area, to the converted location, is automatically set.

When the corner/midpoint option is unused (blank), <u>the geographic (longitude & latitude) locations of all four corners of the target area are returned through the new storage area (LEOXTR), just as the four corners of a setion or township may be returned via the four corners option (below).</u> In both cases, the order of storage of the locations is NW, NE, SW, and SE.

**C. Footages**

A more (theoretically) precise method for specifying a location within a section is to pinpoint the location with two distances, measured in feet on the ground, called **footages**, that are to be applied from an implied starting corner. The two footages define two vectors that are to be applied on the ground along two nearly orthogonal directions starting from a section corner. One vector is north or south, and the other is east or west. The directions of these two vectors will combine to indicate the starting corner from which the footages are applied. For example, given a north footage and a west footage, the southeast corner is implied to be the starting corner of the section.

Footages for this conversion are used to locate points within the section in lieu of subdivision techniques. That is, footages are not applied within subdivided sub-areas of the section, but only within the original section, defined by its corner locations in the LEO2 database.

Application

In general, there are numerous procedures for applying footages to locate a point within a section. The use of footages and the methods of their application were defined for those who executed the surveys of the state (White, c.1982), but not in a rigorous manner, and the concepts were not well-defined. It is possible that the surveyors assumed they would be able to measure squares of 5,280 feet on all sides. If so, a recent analysis of all the sections in Kansas (Collins and Wong, c1991) shows how wrong the assumption was, thus complicating the application of footages.

It is probably not possible for there to exist an "ideal" section in the Kansas PLSS. Sections in Kansas generally do not fit the criteria of being a mile square, with their sides oriented along the cardinal directions, as was originally intended (Collins and Wong, c1991). This circumstance is probably due both to the lack of means and methods in the original survey as well as the mutual exclusivity of the defining criteria.

In conjunction with ill-defined, non-standard footage application procedures, the predominance of non-rectangular sections confuses and complicates the use of footages, with the result that little consistency can be expected in their use. Application of varying footage methods to (geometrically) irregular sections may produce varying results. If Kansas sections were square, these different application methods would result in identical coordinates for the converted locations.

Application of footages begins at the corner that is implied by the two footage directions. In the application process, footages are compared to the lengths of the section sides in feet on the ground, as projected from the Geographic locations of the section corners as stored in the LEO2 database. The resulting ratios are applied to the component differences of vectors between section corners (in Geographic coordinates) to locate the desired point.

Footage calculations in LEO2 rely upon the simplifying assumption that, within a section, the ratio of a Projected distance to the equivalent Geographic distance is (essentially) constant, in all directions, across the section. Furthermore, it is assumed that the error resulting from this assumption will be negligible with respect to the overall process. Finally, note that in converting from Geographic to Legal reference, footages are not generated by the LEO2 conversion routine.

## D. Four Corners

The **Four Corners** option, provides the mechanism for obtaining the locations (in Geographic coordinates) of all four corners of the section specified in the Legal description. And, if the section number is unspecified, then the locations of the four corners of the township are produced. In either case, the locations are not returned through the original parameters of the conversion routine. Instead, in the second version of LEO, they are returned through special variables as described in the section on using LEO2.

The four corner locations, read directly from the LEO2 database, are returned as four longitude and latitude pairs in the preset order: NW, NE, SW, and SE, northwest, northeast, southwest, and southeast. The longitudes and latitudes may be returned in the default form of decimal degrees, or alternatively, may be given in the degrees, minutes, and seconds, or DMS form.

The advantage of the four corners option is to allow the user to get the locations of all four section corners with a single call to the conversion routine rather than the four calls that would otherwise be required. Having these four corners may be useful for many different applications. Among these are to generate a plot that includes section boundaries for reference. Another is to use the four corners to locate points inside the section using methods of subdivision, footages, or other device, in a manner that is different than that employed in LEO2.

As explained above, the locations of the four corners of a target area that is not a section or a township may be obtained (using the same method as for the four corners option) by using subdivision without specifying a closest point other than the default center of the area. These are returned in the same order as are the four corner locations, namely: NW, NE, SW, and SE, but are returned only as decimal degrees. There is no DMS option in this case.

## E. Section Side Lengths

Another potentially useful option is to obtain the lengths of the four sides of a section. Because the process used for the option may only be reliable in very small areas, the side lengths option is not permitted for townships. The lengths of the sides of each section are given in feet on the ground, generated by projecting the section corners at a scale of one to twelve. The lengths of the sides are presented in the order: N, E, W, and S, the north, east, west, and south sides, and, as a LEO2 extension, the values are returned by special variables described below in the section about using LEO2.

Selection of the section side lengths option can be made only by selecting the footages option, with both footage values set equal to zero. <u>The side lengths produced are only approximations, and as such may be unreliable as estimations of the ground lengths of the sides of the actual section.</u> The four distances correspond to the projected lengths of the sides of the sections as they are represented in the LEO2 database only. They may bear no relation to the lengths of the sides of the actual section, and should be used with that in mind.

**F. Location Examples**

Figure 4 (below) illustrates the different methods for specifying location locations within a section, as described above. These examples illustrate half and quarter subdivision of sections; the corner, side midpoint, or center option; the Four Corners option, and footages. Legal descriptions for the locations used in these examples are described or constructed in the text. The outermost rectangle in the illustration is the section. It should be noted that two or more Legal definition may refer to a single point.
The first point, in the center of the section, may be specified by selecting no subdivisions, and selecting, using a blank value, the center of the target area, which is the section. LEO2 will use the center-of-mass of the quadrilateral, namely, the location found by averaging the four corners from the LEO2 database as the center, as decimal degrees or in degrees, minutes, or seconds.

```
C-------------------------------------------C
|                    |          |           |
|                    |  NE, NW  |  NE, NE   |
|                    |          |           |
|         NW         |----------------------|
|                    |          |           |
|                    |  NE, SW  |  NE, SE   |
|                    |          |           |
2--------------------1----------------------|
|                    |                      |
|       SW, N        |                      |
|                    |                      |
|--------------------|          SE          |
|SW, S, NW |    4    |                 3... |
|--------------------|                    . |
|SW, S, SW | SW, S, SE|                   . |
C-------------------------------------------C
```

**Figure 4: Sub-Section Specifications**

The second point, at the midpoint of the west side, is specified as the side midpoint of the west side of the section. Again, no subdivision is needed. The target area is the section, and the side midpoint of the west side is selected using the 'W ' or west value for the corner, side midpoint, or center option. The same point may also be defined by selecting a quarter-area subdivision (the northwest), to define the target area, and then specifying the southwest corner of the target area. The point could also be identified as the northwest corner of the southwest quarter-area, or in many other equivalent ways.

The third point is located by two footages, one to the north and one to the west. These two footages imply the starting corner to be the southeast corner. Hence, the north footage is compared to the length of the east side and the west footage to the length of the south side. These ratios are used to scale the longitude and latitude changes, between the section corners, needed to find the desired Geographic location[12].

Locations for the four corner points of the section, labelled **C**, are obtained through the Four Corners option. Only the township, range, and section numbers, and the east-west (range) direction need to be specified. Again, there are many other ways to select the corner locations, but only by selecting one corner at a time.

The fourth point may be described as the (default) center of the northeast quarter of the southern half of the southwest quarter of the section. It may also be defined as the center of north half of the south half of the east half of the southwest quarter of the section, but with less efficiency. Similarly, the first point in these examples could have been defined as the northwest corner of the southeast quarter of the section.

Some subdivided areas of the section represented in Figure 4 are labelled with sequences of the letters used to specify the half- and quarter-area subdivisions that would define the areas, listed from largest area (applied first) to smallest (last). None uses more than three levels of subdivision.

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[12] Actually, each footage is compared to both sides in the calculation of the ratios, and the influence of each is dependent upon the inverse of the distance from the side, as determined by the other footage. For example, a north footage is compared to the latitudinal change of both the east and west sides. But the ratio that is used is a combination of the two, each in inverse proportion to its side's distance from the application point. In this example, the west ratio is multiplied by the fraction which is the western footage divided by the width of the section at the approximate latitude of the north footage. The eastern ratio is multiplied by the complimentary fraction, the section width minus the west footage divided by the section width.

In summary, the Geographic coordinates, (longitude and latitude), produced from a Legal description, represent the location of the center of the smallest specified sub-area, the target area, when no other options are selected. This target area is the section when no subdivision is selected, or may be the township, when no section is specified. When the corner/midpoint option is used, they represent the location of the corner or the midpoint of the side of the target area. When the footages option is selected, they are the coordinates of the point located by footages applied from the indicated corner and in the specified directions.

In addition, the locations of all four corners of the section may be obtained in one operation using the four corners option with a special setting of the footage values (to zero) when the footages option is selected, will produce the approximate lengths, in feet on the ground, of the four section sides.

**G. The DMS Form**

Geographic coordinates (longitude and latitude) to be converted to Legal reference may be given as input to the LEO2 conversion routine in two forms. First, they may be passed as two arguments in the form of decimal degrees, in which the minutes and seconds of longitude or latitude are converted to equivalent fractions of degrees, and combined with the degrees. Alternatively, they may be communicated to LEO2 as separate values for degrees, minutes, and seconds, a form referred to as the **DMS** option. Use of this form is indicated in the basic options being selected.

For the decimal degrees option, decimal degrees of longitude and latitude are computed by converting minutes and seconds of each into equivalent fractions of degrees and adding both to the whole degree parts. First, the seconds are divided by sixty to produce fractions of minutes, which are added to the whole minutes. The resulting values are again divided by sixty to produce fractions of degrees, which are added to the whole degrees of longitude and latitude. This process must be performed prior to attempting to convert Geographic reference to Legal reference with LEO2, unless the DMS option is selected, or unless the original values are in decimal degrees.

With the DMS option, separate, real (decimal) values may be given for the degrees, minutes, and seconds of both the longitude and the latitude. These values are set in special variables for each point in Geographic reference that is to be converted by LEO2 to Legal reference. The DMS form may also be produced by LEO2 when converting from Legal to Geographic, in addition to the standard, decimal degrees form, if requested by the user. LEO2 creates DMS values with whole values for degrees and minutes, and the seconds include a fractional part, if necessary.

## V. THE CONVERSION ROUTINE

Using LEO2 to convert point locations between the Geographic and Legal reference systems requires that several basic steps must be performed in the calling program. Some of these steps, are done once in the set-up, and others must be done once for every point that is to be converted. In general, use of the LEO2 conversion routine, LEO2CVT, involves several basic steps:

* creating a **calling program** which declares all parameter and COMMON area variables to the correct size and type

* **linking** a suitable calling program that is designed to process the input data correctly, to LEO2CVT. within that calling program, performing the following steps..

* **opening** and accessing the **LEO2BASE** database using a preset unit number that will be passed to LEO2CVT

* for each point to be converted, **setting** the **parameter values** to select the desired operations and options

* for each conversion, **setting** the appropriate "input" or source **location coordinates**

* for each point to be converted, **calling LEO2CVT** to perform the conversion

* following each conversion, **checking** the **status** (STATUS) of the conversion and react accordingly

* after executing the program, **reporting** certain types of status **errors**, if they occurred

To use the LEO2 system, the calling program must declare the LEO2 parameters properly, must be linked to the (LEO2CVT) conversion routine, and must open the LEO2BASE database of corner locations. Each call to the LEO2CVT routine results in a single conversion or a conversion failure with an associated error number. In the latter case, the calling program should, in general, not use any of the values returned by LEO2. Instead, the calling program may examine the value of the conversion status variable (STATUS) to learn the reason for the failure and take appropriate action.

Prior to each call to LEO2CVT, the calling program must properly set the values of the variables (parameters) that are used in the call to make certain that the desired options have been selected. The parameters that must be set prior to a call differ, depending on the direction of the conversion (Legal to Geographic reference or the inverse) and other options selected. Among these options are the specification of sub-areas within the section; the form for input or output of longitude and latitude values; selection of closest point locations within the target area; and the sizes and direction for application of "footages." All these facets of LEO2 are covered in subsequent sections.

## A. Initialization

Prior to calling LEO2CVT to perform conversions, three tasks must be performed by the calling program. First, all parameters used in the call and any used COMMON variables must be declared to be the correct type and size as expected by LEO2. Second, the file containing the LEO2 database, LEO2BASE, must be opened with the correct record size and options, and with a unit number that is later passed to the LEO2CVT routine. Lastly, the calling program must be linked to LEO2CVT, which exists in the form of an object module in an accessible file. These tasks are described below, with examples that are specific to FORTRAN77 and the Data General minicomputer environment, which together define the environment for using LEO2 at the KGS.

### Declaration of Variables

All of the extended capabilities of the LEO2 system over the LEO system involve extra values being communicated between the LEO2 conversion routine and the calling program. To implement these changes, a labelled COMMON area was created to communicate values of the new variables (for the four corners; DMS; corner, center, or side midpoint; footages; and the section side lengths options; as well as the non-standard section indicator). This COMMON area is labelled "LEO2XTR", for the extra values used in LEO2.

Proper declarations for the type and size of all arguments to the LEO2CVT conversion routine plus all extra variables added for the /LEO2XTR/ COMMON area are shown as they might appear in a typical FORTRAN77 calling program. Ampersand signs (&) mark continuation from the preceding line. The meaning and use of each variable is given in the section on communication of values.

```
      CHARACTER CORNR*2, EW*1, SUBD*2(4)

      INTEGER*2 SOURCE, LEO2FC, OPTION, RANGE, SECT, TSHIP,
     &     STATUS, NONSTD

      REAL FOOTNS, FOOTEW, LATXTR, LONXTR, PLAT, PLON

      COMMON /LEO2XTR/ LONXTR(4,3), LATXTR(4,3), FOOTNS,
     &     FOOTEW, NONSTD, CORNR
```

Opening the Database

Before calling the LEO2CVT routine, the calling program must open the LEO2BASE database as shown. The unit number (LEO2FC) that is assigned to the LEO2BASE database file must be assigned a value prior to the OPEN statement and must be passed as a parameter to the LEO2CVT routine to allow LEO2CVT access to the database.

```
    OPEN (UNIT=LEO2FC, FILE=':UTIL:GIMMAP.LEO2BASE', RECL=466,
  &      ACCESS='DIRECT', FORM='UNFORMATTED', IOINTENT='INPUT')
```

Linking

To use the LEO2CVT conversion routine, the calling program must be LINKed to the LEO2CVT routine (in the object file) through an appropriate mechanism. Those who use LEO2 on the Data General at the KGS must link to the file GIMMAP.LEO2CVT.OB in the :UTIL directory. For example, linking to LEO2CVT may be performed on the Data General with a statement such as the following (generic) CLI statement:

```
X LINK/switches objectfiles :UTIL:GIMMAP.LEO2CVT.OB libraries
```

**B. Communication of Values**

Certain variables used as parameters in the call to LEO2CVT must be given values prior to the call to define the location in the "input" reference system and to select options for processing in LEO2. The variables that are used in the LEO2CVT call are listed and defined below along with the options that are made available by setting the parameters to specific values prior to the call. Values set for and returned from LEO2 are shown separately for the two conversion directions.

Each variable that must be given a value before calling LEO2CVT and each variable that returns a value from the call are listed and defined. Each is typed as character, integer, or real, and each shows the size (such as integer*2 for a 2-byte integer) as well as the meaning of (acceptable) significant values given or received. The variables that must be given values before calling LEO2CVT are labelled with "Variable to Set", and each variable name on the left is accompanied by the variable meaning, size and type, and meaning of possible values, on the right. Similarly, variable that return values are labelled "Variable with Value" on the left, with equivalent information on the right.

## Legal To Geographic

Values must be set for the township, range, and section numbers, the east-west indicator, all levels of subdivision that are used, the unit number for the LEO2BASE database, and the indicator of the conversion type or data source (Legal or Geographic). If the footages, Corner/Center/Side Midpoint, or Four Corners option is selected, additional values must also be set.

> **Note:** Some variable names have changed for version 2; some have new functions. All new variables are in the /LEOXTR/ COMMON area. Their names are underlined below.

..........................................................................

| **Variable to Set** | | **Meaning of Values** |
|---|---|---|
| **TSHIP** | = | **Township number (integer*2, 1-35)** |
| **RANGE** | = | **Range number (integer*2)** |
| | = | 1 to 25 when EW = "E" |
| | = | 1 to 43 when EW = "W" |
| **EW** | = | **Range direction (character*1)** |
| | = | "E" for east of the Sixth Principal Meridian |
| | = | "W" for west of the Sixth Principal Meridian |
| **SECT** | = | **Section number (integer*2, 1-36, 0 = township)** |
| **OPTION** | = | **Location within section (integer*2)** (=CORNER) |
| | = | 0 for center of smallest subdivision (default) or may use CORNR for corner or side midpoint |
| | = | 1 for the closest point of the 4 corners or side midpoints or the center, identified in SUBD(1) or CORNR, of section or township (SECT=0) |
| | = | 2 for footages from implied section corner. If footages are zero, lengths of the section sides in feet on the ground are returned in LONXTR(1-4,1) in order N, E, W, and S |
| | = | 3 Four Corners, the longitudes, latitudes of 4 township/section corners in LONXTR(1-4,1) and LATXTR(1-4,1) in the order: NW, NE, SW, SE |
| | = | 4 Same as 0, but location returned as DMS in LONXTR(1,1-3) and LATXTR(1,1-3)...(DMS) |
| | = | 5,6 Same as OPTION = 1,2 but returned in DMS |
| | = | 7 Same as OPTION = 3, Four Corners, but in DMS in LONXTR(1-4,1-3) and LATXTR(1-4,1-3). Row 1 of LONXTR has the DMS of the NW longitude and row 2, the DMS of the NE longitude, etc. |

**Note:** When the DMS option is requested, degrees, minutes, and seconds of longitude are returned as positive values. (=METHOD)

**SUBD(4)** = **Subdivision specifications (character*2)**
= "Nb", "Sb", "Eb", or "Wb" for the north, south, east, west half-areas (b = blank)
= "NW", "NE", "SW", or "SE" for the northwest, northeast, southwest, southeast quarter-areas
= 'bb' <u>All unused subdivisions must be set blank</u>

**Note:** Up to four subdivisions may be specified, each is applied to the area resulting from the previous. Together, they define the target area. Half- and quarter-area subdivisions may be mixed.

**SOURCE** = **Conversion type indicator (integer*2)**
= 1 for Legal source data, the conversion is from Legal to Geographic reference (=LORG)

**LEO2FC** = **Unit number of opened LEO2BASE (integer*2)**

**<u>CORNR</u>** = **Corner/midpoint identifier (character*2)**
= "N ", "S ", "E ", or "W " for midpoints
= "NW", "SW", "NE", or "NW" for corners
= "bb" for the (default) center (b = blank)

**Note:** To select a corner or side midpoint of the target area, if OPTION = 0,4, and source = Legal. When unspecified, the 4 corners of the target area are returned as decimal degrees in /LEOXTR/ (LONXTR and LATXTR) in the order NW, NE, SW, and SE.

**<u>FOOTNS</u>** = **Footage north/south of implied corner (real*4)**
= -5280. to +5280., for feet on the ground

**<u>FOOTEW</u>** = **Footage east/west of implied corner (real*4)**
= -5280. to +5280., for feet on the ground

**Note:** FOOTNS is applied north if > 0, south (in absolute value) if < 0. FOOTEW is applied east if positive or west (absolute value) if negative. The implied starting section corners are:

| FOOTNS | FOOTEW | IMPLIED CORNER |
|---|---|---|
| > 0 (North) | > 0 (East) | SW |
| > 0 (N) | < 0 (West) | SE |
| < 0 (South) | > 0 (E) | NW |
| < 0 (S) | < 0 (W) | NE |

**Note: SECTION SIDE LENGTHS OPTION**

To obtain approximate <u>section</u> side lengths in feet on the ground, set FOOTNS = FOOTEW = 0, OPTION = 2. APPROXIMATE lengths are returned in LONXTR(1-4,1) in /LEOXTR/, in the order N, E, W, and S.

When the proper values for all variables are set, the call to the LEO2 conversion routine is made. If LEO2CVT does not encounter any errors in the input values for the Legal definition, logical errors in the selection of options, or errors in the conversion process itself (or in the database), the Geographic equivalent of the location defined in Legal reference will be returned to the calling program. Otherwise, an error status will be indicated.

..............................................................

**Values Returned** — **Meaning of Values**

**PLON** = **Longitude in decimal degrees (real*4)**

**Note:** (Positive) longitude west of Greenwich

**PLAT** = **North latitude in decimal degrees (real*4)**

**STATUS** = **Conversion Status: Success or Error** (=SUCCESS)
= 1 if the conversion was successful
= -1 to -99 for an error (see STATUS below)

**NONSTD** = **Non-standard Section Indicator**
= 0 if the section named in the Legal description is marked "standard"
= 1 if the section is "non-standard", in which case, the result may not be usable

**Note:** Standard sections have four corners and are subdivided in the standard way - see text above. Non-standard sections require other methods that are not available in LEO2. Sections are marked as one or the other in the database. Initially, all sections with four corners are marked as standard.

**LONXTR(4,3)** = **Special storage for longitudes and side lengths**
When OPTION = 3 or 7, contains the longitudes of the section or township corners:
LONXTR(1,x) = NW longitude
LONXTR(2,x) = NE longitude
LONXTR(3,x) = SW longitude
LONXTR(4,x) = SE longitude
If OPTION = 3, longitudes are decimal degrees in column x = 1.
If OPTION = 7, they are degrees, minutes, and seconds (DMS) in columns x = 1, 2, and 3.
If OPTION = 4, 5, or 6, longitude is in DMS form in LONXTR(1,x) with x = 1, 2, and 3.
If OPTION = 2 or 6 and footages are zero, the section/township side lengths are returned in LONXTR(1-4,1) in the order: N, E, W, S.

**LATXTR(4,3)** = **Latitudes Corresponding to the LONXTR longitudes**

## Geographic To Legal

Conversion from Geographic to Legal reference requires setting the longitude and latitude of the point to be converted, the source data indicator, and the LEO2BASE unit number. If the DMS option is selected, the longitude and latitude variables in the /LEO2XTR/ COMMON area must be set to the degrees, minutes, and seconds of the location. If DMS is not selected, the location is specified in decimal degrees in the LEO2CVT call arguments.

..............................................................

| Variable to Set | | Meaning of Values |
|---|---|---|
| **SOURCE** | = | **Source Data Indicator (integer*2)** (=LORG) |
| | = | 2 conversion from Geographic to Legal |
| **LEO2FC** | = | **Unit number of opened LEO2BASE** |
| **OPTION** | = | **Indicates the form of the input (integer*2)** |
| | = | 0 for decimal degrees in PLON and PLAT |
| | = | 1 for DMS option, input is in LONXTR, LATXTR |
| **PLON** | = | **West Longitude, + or - decimal degrees (real*4)** |
| **PLAT** | = | **North latitude in decimal degrees (real*4)** |
| **LONXTR(4,3)** | = | **DMS Longitude of point to convert (real*4)** |
| | = | degrees, minutes, seconds in LONXTR(1,1-3) |
| **LATXTR(4,3)** | = | **Latitudes paralleling DMS longitudes (real*4)** |

..............................................................

| Values Returned | | Meaning of Values |
|---|---|---|
| **TSHIP** | = | **Township number (integer*2)** |
| | = | 1 to 35 for township south |
| **RANGE** | = | **Range number (integer*2)** |
| | = | 1-25, if range east, 1-43 if west (EW="E","W") |
| **EW** | = | **Range direction (character*1)** |
| | = | "E"=east,"W"=west of Sixth Principal Meridian |
| **SECT** | = | **Section number (integer*2)** |
| | = | 1 to 36 (see Figure 2) |
| **SUBD(4)** | = | **Subdivision specifications (character*2)** |

**Note:** Four quarter-area subdivisions in SUBD(1-4). The first SUBD(1) making the largest area (1/4 section) to the last, SUBD(4) - the smallest area (1/256 section).

**STATUS** = **Conversion Status: Success or Error (integer*2)**
= 1 if conversion was successful
= -1 to -99 if an error is found (see below)

**NONSTD** = **Non-standard Section Indicator (integer*2)**
= 0 if the point lies within a standard section
= 1 if the section is non-standard

**CORNR** = **Closest point identifier (character*2)**
= "Nb", "Sb", "Eb", or "Wb" for a midpoint
= "NW", "SW", "NE", or "NW" for a corner
= "bb", for the default center (b = blank)

**Note**: CORNR is the closest of the corners, midpoints or center to the input location in the target area.

..................................................................

## C. Subroutine Calls

The call to the conversion routine, LEO2CVT, is made when the calling program has obtained a point to be converted from a file or from the user at a terminal. The calling program describes the point location in the input reference system by setting the values for the parameters used in the call to LEO2CVT. The call to LEO2CVT requires the proper number of arguments of the correct type and size and in the proper order as shown below, assuming that proper declarations were made for all and that proper values have been set for all input parameters, as described above.

LEO2CVT is called once for each point to be converted. Values of the variables used in the call to LEO2CVT with associated options and meanings are detailed above. The form of the FORTRAN77 call to LEO2CVT from the calling program is shown (below) as it would appear using the given variable names. It is assumed that, prior to the call, all appropriate parameters have been declared and have been assigned values as described above.

```
      CALL LEO2CVT (TSHIP, RANGE, EW, SECT, OPTION, SUBD, PLON,
   &          PLAT, LEO2FC, STATUS, SOURCE)
```

## D. Conversion STATUS

The status (success or failure), of a conversion by LEO2CVT is always indicated by the value returned via the STATUS variable. A successful conversion is signalled by the return of a positive one (+1) in STATUS. Any other value means that the conversion failed for one of various reasons. Regardless of the value of the STATUS variable, a second variable (NONSTD) will indicate if the conversion involved a section that is marked in the database as "non-standard". If so, the conversion was attempted and may have been completed successfully in either case. When conversion occurs successfully in a non-standard section, the results may be incorrect and unusable. Secondary tests, not available in LEO2, are required to resolve this.

When an error occurs, the value of the STATUS variable identifies the error and thus the reason that LEO2 terminated the conversion process. The possible reasons recognized by LEO2 for the failure are listed below. Checking the value of STATUS is the only way for a calling program to determine the success or failure of the conversion process. If the calling program does not do this, a conversion error could go undetected, and the incorrect location that results may be used. Using such incorrect coordinates may generate additional errors.

No indication of a conversion error is given other than the value of the STATUS variable; no bells are beeped, nor are there error messages printed in files, on paper, or on screens. It is up to the calling program to check the value of STATUS following every call to the conversion routine. When a conversion fails and the value of STATUS is negative, then the point location returned is (usually) incorrect or incomplete. The value of NONSTD is set to indicate if the section is non-standard without any effect on the status. Partial results from a failed conversion may be useful.

Two groups of errors may be encountered in using the LEO2 system. The first results from assignment of incorrect values or failure to assign required values to variables being passed to LEO2CVT by the calling program. These "user" errors result from programmer mistakes or omissions, from incorrect operator selections or from faulty data in an input file read by the calling program.

The second class of errors are those resulting from problems in the LEO2 database, such as incorrect values for corner locations or omissions of corner locations. These errors may also result from errors in the algorithms used to perform conversions. Also, any attempt to perform conversions in one of the sections marked for special processing results in an error (no sections have been so marked at this time). A complete list of the errors in both classes is given below.

STATUS values range from -99 to +1, with +1 the only successful value. If STATUS is negative, an error occurred and conversion was not completed. Users are requested to report certain errors identified by LEO2CVT in order to correct the conversion routine and the database for everyone. Errors should be reported to:

**Chief, Technical Information Services (TIS)**
**Kansas Geological Survey**
**1930 Constant Avenue**
**Lawrence, Kansas 66047 (913) 864-3965**

Please report all errors that are starred* in the list below and include the information listed below. Furthermore, please report any successful conversions that seem to be clearly in error, that is, conversions resulting in obviously incorrect locations. When reporting an error, include the error number (STATUS value) and all parameter values used and received in the failed conversion, including the location to be converted and the result.

| STATUS Value | Meaning of STATUS Value |
|---|---|
| 1 | **Successful Conversion** |
| -1 | Township number out of range |
| -2 | Range number out of range |
| -3 | Illegal EW indicator value |
| -4 | Section number out of range |
| -5 | Unacceptable Subdivision #1 |
| -6 | Unacceptable Subdivision #2 |
| -7 | Unacceptable Subdivision #3 |
| -8 | Unacceptable Subdivision #4 |
| -9 | Illegal SOURCE value |
| -10 | Invalid longitude for LEO2/Kansas |
| -11 | Invalid latitude for LEO2/Kansas |
| -12 | Inconsistent or invalid OPTION value |
| -13* | I/O Error reading LEO2BASE |
| -14* | Thrashing error at township level |
| -15* | Thrashing error at section level |
| -16 | Illegal Footage (too large/small) |
| -17 | Illegal DMS value in LEO2XTR |
| -18 | Missing SUBD value for OPTION = 1, 5 |
| -19 | No usable sections in township record |
| -20* | Point-in-Polygon error |
| -21 | One section/township corner missing |
| -22 | Two section/township corners missing |
| -23 | Three section/township corners missing |
| -24 | Four section/township corners missing |
| -25 | Unacceptable CORNR specification |
| -26 | Illegal option for townships |
| -27* | Illegal record # in township search |
| -28* | Failed search within an incomplete township[13] |
| -99* | Section requires non-standard subdivision |

[13] An incomplete township is one in which one or more of the section corner locations is unknown or lies outside the state.

## VI. CONVERSION SOFTWARE

There are three primary functions related to the LEO2 conversion system and LEO2 database for which FORTRAN77 programs have been created for the Data General super minicomputer at the KGS. The first of these functions is to perform conversions from Legal to Geographic reference and vice versa for point locations that are read from an input disk file or are entered interactively at the terminal. In the former case, converted locations are written to a designated disk file. In the latter case, they are printed at the user console. The program that performs these two operations is called **LEO2CNVRT** (these names are for the DG version only).

The second function is to examine and update the locations of the section corners in the LEO2 database by specifying the full Legal description of the township or section for which the Geographic coordinates (longitude and latitude) of the four corners would be displayed for examination or direct modification. The FORTRAN77 program written for this purpose is called **LEO2QUERY**.

The third function is to create a transportable file containing all section corner locations in the state, each marked in such a way that any Legal description is explicitly connected to the coordinates of the corners of the section. In this case, a file of ASCII characters is created to contain just that information. The **LEOASCII** program was written to perform this task, organizing each record in the output file to contain all the section corners of a single township.

### A. Reference Conversion

The LEO2CNVRT program provides for Legal and Geographic reference conversions either in an interactive environment, communicating directly with the user, or in a non-interactive environment, in which information is obtained directly from a disk file and the converted locations are output to a second disk file. In either case, the parameter information (definition of the location to be converted) is obtained and the parameter values are passed to the LEO2 conversion routine, LEO2CVT.

In the conversion to Legal reference or the conversion from Legal to Geographic reference, the input location is described (either by the user, or from the disk file) in complete detail, and with all conversion options that are available with LEO2. Though this information may contain erroneous values, which are passed to the conversion routine (and checked there), it is left to LEO2CVT to respond correctly and to flag results appropriately. Converted coordinates are reported for interactive operations. Conversion errors are always reported. This process may be repeated for as many conversions as are desired.

If interactive conversion is chosen, the procedure is as follows. First, the data source (Legal or Geographic) is selected. This choice determines the direction of the conversion. If the source is Legal, then the program prompts for the full Legal description including township, range, and section numbers; the east or west indicator; the location option; and if selected, up to four area subdivisions, a closest point indicator (the center, a corner, or a side midpoint), or two footages. The result is one Geographic location or the four section corner locations in decimal degrees or in degrees, minutes, and seconds (DMS), or the lengths of the four sides of the section in feet on the ground. These results are always printed at the console, with the conversion status and the value of the non-standard section indicator.

If the data source is Geographic, the user specifies a location in decimal degrees or in degrees, minutes, and seconds (DMS) of longitude and latitude, in response to prompts from the program. After the conversion, the full Legal description is printed at the console, along with the conversion status and the value of the non-standard section indicator. The Legal description will contain the township, range, and section numbers; the east-west range indicator; four levels of quarter-area subdivision; and the closest point of the center, corners, and side midpoints. The equivalent footages are not determined in this operation.

The conversion program (LEO2CNVRT) may be used to convert point locations, taken from a specified (input) disk file, from Legal to Geographic reference and output them to a second disk (output) file. In this non-interactive option, the source locations must exist in the preset form, and the resulting Geographic locations are written to the output file, also in a preset format.

With the non-interactive option, the first input to the LEO2CNVRT program are the complete pathnames of the input and output disk files. Once these files and the LEO2 database file are opened, the LEO2CNVRT program requests the type (Legal or Geographic) of source data, thus fixing the direction of conversion. LEO2CNVRT then reads records from the input file, calls LEO2CVT to convert from the input to the output reference, writes the results to the output file along with the status and the non-standard indicator, and then repeats the above process for all of the points in the input file.

The operation of this option is similar to that of the PC version of the conversion program called LEO2PC, which is described below in the PC section, where the format of the input file is given in detail, along with the output file format. While Geographic data are input in "free format" (separated by blanks or commas), Legal locations are strictly formatted for input. Both Geographic and Legal location data are formatted for output to a disk file. All formats are predefined, as shown in the PC section on conversion.

**B. Query/Modify The Database**

At times, the Geographic location of a section corner or of all four corners of a section or a township may be of interest for a number of reasons. Also, when erroneous or suspicious locations result from conversions by LEO2CVT, the cause may be that corner locations in the LEO2 database are in error. In such a case, it is necessary to correct these corner locations by replacing them with carefully determined and verified new Geographic locations. Both the inspection and modification functions may be performed with the LEO2QUERY program.

The operation of LEO2QUERY begins with the option to modify the database or not. If selected, any corner location in the state may be modified in the LEO2 database. If not selected, changes in location are not allowed. This option is offered only once, at the beginning of the operation. (Operation of this program is also described below in the section on the PC version).

The remainder of the operation is repetitive, with the operator first defining a township, for which the four corner locations in Geographic reference are obtained from the database and displayed at the console, arranged in a rectangle with the northwest corner in the upper left, the northeast corner in the upper right, the southwest corner in the lower left, and the southeast corner in the lower right. With a label for township identification, the rectangular display parallels the geometry of the actual township corners on the earth's surface:

```
                          TnS  Rn*
                                   (n=tship/range #, *='E' or 'W')

NW longitude, latitude             NE longitude, latitude


SW longitude, latitude             SE longitude, latitude
```

Given a township, the operator may repetitively name sections in the township, for which a similar display is produced. Selection of section zero (0) will return operation to the point at which the township is described, at which point, entry of zero (0) as a township number will cause the program to be halted.

When modification is on, any section corner and any section flag or township flag may be modified by following the instructions of the program to identify the item and to enter a new value or the modified location. Modification of the database is immediate and can only be reversed by additional operations of LEO2QUERY. Use of this function is not advised, except by appropriate KGS staff who are responsible for maintaining the LEO2 source database.

### C. Print/Transfer the Database

There are two functions of LEO2 that are not available for the PC version of the system, but are available on the Data General at the KGS. One such function is to generate a complete listing of the locations of all section corners in the state and in the LEO2 database. This function can be very useful in locating errors or inconsistencies in the LEO2 database or in finding section corner locations quickly. The second function is to provide the section corner locations in a transportable form for easy distribution to external agencies or private companies.

<u>Printing</u>

Perhaps the simplest function of the LEO2 system is to provide a complete listing of the longitudes and latitudes of all section corners in Kansas, in a form that minimizes search time to find a particular corner, section, or township. The **LEO2PRINT** program allows the user to obtain a complete listing from the LEO2BASE, with or without the addition of section and township flags. All the user need do is to specify the name of the file to which the listing is to be sent, and the task is performed. The resulting file must then be printed on the system printer (not on printers that produce standard size paper output since the output from the LEO2PRINT program uses about 130 columns). The output requires more than 350 pages for the entire database.

The listing from the LEO2PRINT program groups the section corner locations by township, displaying forty-two of forty-nine corners arranged in the (approximately) correct geographic relationships. The longitude and latitude of the northwest corner of section six (and of the township) is displayed in the upper left-hand corner of the listings for the township. The display for each township group makes a matrix of seven rows and six columns of locations, as shown in Figure 5, where nn is a township/range number, LL is longitude and latitude, and in () is a section number and corner, I is the east-west range indicator, and each township is labeled with its unique township and range identification.

**Township nnS, Range nnI**

| | | | | | |
|---|---|---|---|---|---|
| LL(6NW) | LL(5NW) | LL(4NW) | LL(3NW) | LL(2NW) | LL(1NW) |
| LL(7NW) | LL(8NW) | ... | ... | | LL(12NW) |
| : | : | : | : | : | : |
| LL(31SW) | LL(32SW) | ... | ... | LL(35SW) | LL(36SW) |

**Figure 5: Form Of Output From LEO2PRINT**

The easternmost column of the township's section corner locations is missing, due to page width, but these exist as the westernmost column of corner locations for the next township to the east, and their locations are usually on the same page.

Database Transfer

There are applications involving the information contained in the LEO2 database that are unrelated to the conversion and inspection operations described above. Such applications generally require only the locations of a subset, or all of the section corners in the state, in a form that is readily accessible to local computer facilities. For these applications, a general-purpose format for transfer of the LEO2 data was defined, and a program was written to create digital transfer (via magnetic tape) files by which the transfer form of the LEO2 data may be generated. This new ASCII form parallels the LEO2 database in some respects, but differs in the ASCII form of the numbers (with a corresponding change in the record size), the absence of section and township flags, explicit identification of township records, and sequential access rather than direct (or "random") access to the file.

The transportable LEO2 data is generated in ASCII from the binary form existing in the LEO2 database. The transfer format, which is generated by the **LEO2ASCII** program, essentially parallels the LEO2 database in logical structure and general order, although in ASCII, rather than the binary form. As in the LEO2 database, the corner locations, each represented as a longitude and a latitude, are grouped by township, with the same order as in the database. (See Appendix I for more detail). By duplicating section corners along township boundaries, as is done in the database, all forty-nine corner locations for each township are combined in a single record in the ASCII file. (The newly added section and township flags from the database are not included in the output records.)

The township records are 940 bytes long including three bytes of (blank) filler at the end. Each begins with a two-digit township number followed by the letter 'S' (south). This is followed by a two-digit range number and a letter 'E' or 'W' for east or west. Next are the forty-nine longitude and latitude pairs representing the corner locations. These are ordered west to east across the township rows, starting with the northernmost row and ending with the sourthernmost row. Longitudes are ten digits, latitudes are nine, both with five decimal places. In FORTRAN77, this becomes:

```
  write ... tship#, range#, ew, LL(1,1), LL(1,2), ..LL(1,7),
&     LL(2,1), ..LL(2,7), LL(3,1), ..LL(7,1), ..LL(7,7)

  format (i2, 'S', i2, a1, 7 (7 (f10.5, f9.5)), 3x)
```

where the east-west range indicator is ew = 'E' or 'W'. Using section numbers to identify sections and selecting corners of the sections by their directions (NW, NE, SW, and SE), then the order of the forty-nine pairs of corner longitudes and latitudes (LL) for the section corners of each township in the output file from the LEO2ASCII program is:

6NW, 5NW, .. 1NW, 1NE, 7NW, 8NW, .. 12NW, 12NE, 18NW, ..

13NW, 13NE, ... 31NW, .. 36NE, .. 31SW, 32SW, .. 36SW, 36SE

The order of the townships in the ASCII file, though not required since each record is identified, is parallel to the order for the records in the LEO2 database, except that unused records in LEO2 (those representing areas outside the state) are not added to the ASCII output. The township records are ordered by rows beginning with the northernmost row and ending with the southernmost row of townships (T35). Within each row, the townships are ordered from west (R43W) to east (R25E), excluding unused townships outside of the state. The order is diagrammed below:

| | | | | | | |
|---|---|---|---|---|---|---|
| T1S,R42W; | T1S,R42W; | ... | T1S,R1W; | T1S,R1E; | ... | T1S,R25E; |
| T2S,R42W; | ... | | T2S,R1W; | T2S,R1E; | ... | T2S,R25E; |
| : | : | | : | : | | : |
| : | : | | : | : | | : |
| T35S,R43W; | ... | ... | T35S,R1W; | T35S,R1E; | ... | T35S,R25E |

# VII. PC CONVERSION

The conversion and database query/modification operations of the KGS - LEO2 reference conversion system are available for any IBM-compatible Personal Computer (PC) system. The software available for the PC includes the conversion routine **LEO2CVT**, two programs (**LEO2PC** and **LEO2Q**) that support reference conversion and database query/modification, and the LEO2 database (**LEO2BASE**) itself. The LEO2ASCII program for producing a transfer file of LEO2 data, and the LEO2PRINT program for producing a listing of all LEO2 data do not exist for the PC version of the LEO2 system. The executable programs for the PC both exist in a form that supports operations for PC systems with or without a math coprocessor.

## A. PC Software and Database

Included in the PC version of LEO2 is the executable file for the LEO2PC program, the PC equivalent of the LEO2CNVRT program on the Data General minicomputer at the KGS. The LEO2PC program accepts input locations described in either Legal or Geographic reference and converts each into the other form of reference. Input to the LEO2PC program may be from a user-specified disk file, or may be entered interactively from the console. In the interactive mode, output values are sent to the console where the input values were entered. In the non-interactive mode, the input data must adhere to a fixed format when it is Legal reference, but free-format is applied when it is Geographic. All output is strictly formatted. The formats are defined below.

When input is from a disk file, the user specifies the file name and the input locations are taken from that file according to the fixed format, and are output as converted locations in Geographic reference to a second user-specified file. The fixed format for the input data is described below. The LEO2PC program accesses data from the LEO2 database to perform conversions.

The PC form of the LEO2 database is identical to the database on the Data General, with record content, form, and order the same as described in the documentation above. Just as use of the LEO2 system on the Data General requires accessing the database from a particular file, the LEO2 software for the PC expects to find the LEO2 database, LEO2BASE in a directory named **DATA**, at the root of the default drive for the system. Otherwise, the LEO2 programs will not function.

The query and modify functions for the database are supported in the PC environment by the **LEO2Q** program, which allows the user to interactively examine the contents of the LEO2 database, and when necessary, to modify them. Like the LEO2PC program, LEO2Q can be used on PC systems with or without a math co-processor.

**B. Using PC Software**

The LEO2 conversion programs, LEO2PC and LEO2CNVRT on the DG, are driving programs for the conversion routine, LEO2CVT. They allow the user to convert points from one reference system to the other one-at-a-time in an interactive mode, or in large numbers from a disk file without interaction. In the latter case, the input and output are stored in digital form in files (named by the user) on the disk, for subsequent processing operations. The interactive mode is generally used for a quick translation of a single (or a few) location(s) from one system to the other.

Legal to Geographic

The format for inputting data to LEO2PC is fixed when that data is in Legal reference. The information to be included in each record for entering a Legal description is shown below in Figure 6, with column numbers labeling the items. Letters (b, T, D,...) used to represent individual data items, are defined below.

```
                1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2    (col. x 10)
1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8   (col. x 1)
b T T b R R b D b S S b O b S 1 b S 2 b S 3 b S 4 b C C    (content)
```

**where:**

b = blank column

**TT** = the Township number (b1-35), always 2 columns

**RR** = the Range number (b1-43 west or b1-25 east)

**D** = east-west indicator (1 character, 'E' or 'W')

**SS** = the Section number (b1-36)

**O** = location option, 0 = center, 1 = corner in S1

**S1** = first subdivision by half- or quarter-area method

**S2** = second subdivision (if used, applied to the result of the first subdivision), blank if not used

**S3, S4** = third and fourth subdivisions, blank, if not used

**CC** = Corner, designates a corner, midpoint, or center using half- or quarter-area specifications as the point closest to the location to convert

**Figure 6: Form and Content for Legal Data in LEO2PC**

When a Legal description is converted by LEO2PC, the output from the program is a pair of coordinates (longitude and latitude), in the form of two real numbers representing decimal degrees of west longitude and north latitude, followed by the conversion status and the non-standard indicator. These values are written to the file as shown below, according to the FORTRAN77 format of (F10.5, F9.5, I4, I2).

In Kansas, longitudes range approximately from -102.125 to -94.5 degrees west; and latitudes range from 36.875 to 40.125 degrees north. In the output from LEO2PC, all longitudes are expressed as positive values, with the negative sign assumed. This reduces the record size by one for disk output, but is contrary to their usual (negative) representation for most applications. The fixed format for the Geographic ouput from LEO2PC is:

```
                    1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2    (column x 10)
1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5      (column x 1)
b l o n . g i t u d b l a . t i t u d b S T A b N      (b = blank)
```

where:

```
        S T A  =  STATUS of the conversion operation
               =  1, for success in a standard section
               =  2, for success in a non-standard section
                      (using standard subdivision technique)
               = -e, for LEO2 conversion error number e
and
            N  =  the non-standard section indicator
               =  0, if the location is in a standard section
               =  1, otherwise
```

The status value will be one if the conversion is successful and occurred in a standard section. It will be two when a standard conversion in a non-standard section succeeded. And it will be less than zero when an error prevented a successful conversion. The non-standard indicator will be 0 for standard sections, and will be non-zero for non-standard sections. The value indicates the nature of the section in which the conversion location was found to reside.

<u>Geographic to Legal</u>

The LEO2 reference conversion program, LEO2PC for the PC version and LEO2CNVRT for the Data General, also converts point locations from Geographic to Legal reference using LEO2CVT. Locations in Geographic reference, entered interactively or from a disk file, may be expressed in decimal degrees, or in degrees, minutes, and seconds of longitude and latitude. For interactive mode, these values are prompted and are entered in free format.

In the non-interactive mode, free format is also used (meaning that each record should contain a longitude and a latitude pair in decimal degrees with the two separated by one comma or by one or more blanks. The Degrees, Minutes, and Seconds option is not allowed with the non-interactive (disk file) mode of operation.

When a Geographic location is converted into an equivalent Legal description, LEO2PC or LEO2CNVRT, generates a complete set of all possible Legal coordinates, with the exception of footages, which could only be coarse approximations. These include the township and range designations (with east-west designation), the section number, and all four possible levels of quarter-area subdivision. Also included is an identification of the closest point among the four corners, the midpoints of the four sides, and the center of the target area (the area defined as the final result of the four subdivisions).

Whether interactive or disk file mode is used, the status of the conversion and the value of the non-standard section indicator are included in the output, either as output to the console or as an addition to each output record in the disk file. The form of Legal reference output to disk files, shown below in Figure 7, is similar to that for Legal input (described above).

```
                1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 3 3 3 3 3
1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4
b T T b R R b D b S S b O b S 1 b S 2 b S 3 b S 4 b C C b S T A b N
```

**where:**

| | | |
|---|---|---|
| b | = | blank column |
| **TT** | = | the Township number (b1-35), always 2 columns |
| **RR** | = | the Range number (b1-43 west or b1-25 east) |
| **D** | = | east-west indicator (1 character, 'E' or 'W') |
| **SS** | = | the Section number (b1-36) |
| **O** | = | location option, 0 = center, 1 = corner in S1 |
| **S1** | = | first subdivision by half- or quarter-area method |
| **S2** | = | second subdivision (if used, applied to the result of the first subdivision), blank if not used |
| **S3, S4** | = | third and fourth subdivisions, blank, if not used |
| **CC** | = | Closest point of the corners, side midpoints, or center using half- or quarter-area specification |

**STA** = status of the conversion operation
= 1, for a successful conversion (standard section)
= 2, successful conversion (non-standard section)
= -n, error status, error number n

**N** = non-standard section indicator, 0 = standard

**Figure 7: Form and Content for Legal Data in LEO2PC**

## Conversion Options

The first option for use of the conversion program is to select interactive or non-interactive (disk file) mode, by entering one for disk files or zero for interactive. The program may also be executed interactively at the console by specifying the input or output file as **CON** for console (for the PC version only). In this case, the program may be stopped by a blank (cr only) input record or by using the control-C interrupt.

Given the object code for the LEO2CVT routine, the PC user may, with information from the LEO2 documentation, create a customized reference conversion program to use in a procedure or environment ~~that~~ is tailored to the local needs, a program to fit any desired source and form of input. With a (Microsoft FORTRAN77) compiler and libraries, many options become open for the calling program.

Furthermore, a calling program may be written so that the output is optionally written to a disk file, to the console, or to both. Many other options may be built into the customized program. For example, the calling program might display a map and ask the user to select a point for conversion via mouse input, or the program could use LEO2CVT to convert from geographic to legal reference. It should be noted that the LEO2PC program has been developed for internal KGS use, and was not intended for external consumption.

## Query/Modify

Parallel to the LEO2QUERY program on the Data General, the LEO2Q program in the PC version can be used to interactively examine or modify the Geographic location of any section corner in the LEO2 database. The LEO2Q query program begins by asking the user to select whether or not modification of the LEO2 database is to be allowed during the current operation (1=yes, 0=no).

After that selection is made, the program enters a cyclical phase in which LEO2Q prompts the user for a complete Legal description, including the township and range numbers, and the east-west range designator. This identifies a unique township, whose four corner locations (longitude, latitude) are displayed in proper geometric relation to each other (i.e. the northwest corner is in the upper left, and so on), with the township label above (see above in the documentation on LEO2QUERY on the Data General).

The user then specifies the section number for a section within the selected township (0=the township itself). Then, the four corner locations for the section are displayed, again with proper geometric relationships, and with the proper Legal description.

If modify mode is on, the user may select a corner of the section or township by its direction (NW, NE, SW, or SE) and enter a new location longitude, latitude for the corner (9.9,-9.9 to delete). The user may repeat this process for as many sections and as many townships as desired. All modifications are immediate, and will be observed in subsequent examination.

**Note:** **LEO2BASE must reside in directory DATA at the root.**

## APPENDIX A: KANSAS SECTION CORNERS ASCII DATA SET

**TAPE:** 1600 or 6250 B.P.I., Unlabeled, ASCII format
940 characters/logical record
1 (1600) or 20 (6250) logical records / physical block
940 (1600) or 18800 (6250) characters / physical block

**RECORDS:** 1 township per record, (4 Township, 45 Section corners):

**Township number:** integer, 2 characters, 1-35S
**S**, for township south of base line: 1 character
**Range number:** integer, 2 characters, 1-43W, 1-25E
**East/West** of principle meridian: 1 character
**Longitude** of section/township corner: real, F10.5
(positive, assumed west of prime meridian)
**Latitude** of section/township corner: real, F9.5
(49 pairs of Longitude, Latitude, see order below)
**Three blanks**, filling the record to 940 characters

**ORDER OF SECTION/TOWNSHIP CORNERS WITHIN EACH RECORD (in bold):**

```
1---------2---------3---------4---------5---------6---------7
| Section |         |         |         |         | Section |
|    6    |    5    |    4    |    3    |    2    |    1    |
|         |         |         |         |         |         |
8---------9--------10--------11--------12--------13--------14
|         |         |         |         |         |         |
|    7    |    8    |    9    |   10    |   11    |   12    |
|         |         |         |         |         |         |
15--------16--------17--------18--------19--------20--------21
|         |         |         |         |         |         |
|   18    |   17    |   16    |   15    |   14    |   13    |
|         |         |         |         |         |         |
22--------23--------24--------25--------26--------27--------28
|         |         |         |         |         |         |
|   19    |   20    |   21    |   22    |   23    |   24    |
|         |         |         |         |         |         |
29--------30--------31--------32--------33--------34--------35
|         |         |         |         |         |         |
|   30    |   29    |   28    |   27    |   26    |   25    |
|         |         |         |         |         |         |
36--------37--------38--------39--------40--------41--------42
| Section |         |         |         |         | Section |
|   31    |   32    |   33    |   34    |   35    |   36    |
|         |         |         |         |         |         |
43--------44--------45--------46--------47--------48--------49
```

**NOTE:**
Unknown corner locations are represented as (9.9, -9.9).

## APPENDIX B: REFERENCES

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