L E O I - PC

CONVERSION BETWEEN LEGAL AND GEOGRAPHIC REFERENCE SYSTEMS IN KANSAS

Version I + PC Use

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1. INTRODUCTION

Spatially-related data, whether in analog or digital form, are associated explicitly or implicitly with locations, which may be specified in various systems of reference. Because there are three widely used reference systems for mapping and geoscience applications, software systems have been developed to provide the capability of converting data among the three reference systems.

The three reference systems include **geographic** reference, which, partitions (figuratively) the earth using evenly-spaced, polar circles for longitude and smaller circles parallel to the equator for latitude, **projected** reference with cartesian coordinates (as in digitized map data) that result from "projecting" the surface of the earth to a flat paper, and finally, **legal** reference, with "coordinates" of township, range, section, etc., seemingly man's best attempt at a real-world reference system.

Of these reference systems, the geographic reference system is the common link to the other two, the intermediary by which spatial data representing locations on the earth's surface may be converted to other reference systems for expanded application or for communication to other computer sites. Considered to be the "universal" reference system, the geographic system is the source from which projected reference systems originate by way of some very complex mathematical equations (map projection).

With the locations of valuable geologic data based in these different reference systems, it becomes necessary to provide a method of converting between any two systems. This process is an ideal exercise for the computer. Computer software to support conversion between reference systems helps to completely utilize available digital data and to put data in a form readily usable for graphic display and for efficient spatial analysis.

In particular, much geologic data, in both digital and non-digital forms, exist with locations specified only in the legal reference system. Unfortunately, the legal reference system is incompatible with accurate representation of absolute locations in mapping, graphics, and spatial analysis applications. This problem has not been overcome in the past, because it has not been possible to convert between geographic and legal locations with acceptable accuracy throughout the state.

The **legal**/**geo**graphic reference conversion system, known as **LEO**, converts locations between legal and geographic reference. LEO, developed at the Kansas Geological Survey (KGS), is used to convert point locations, defined by legal description, into their equivalent geographic (longitude, latitude) coordinates. These, in turn, could be projected into Cartesian (x,y) coordinates for mapping and graphics applications, if desired.

Conversion between the legal and geographic systems was made possible by the creation of the LEO database, **LEOBASE**, containing the (geographic) locations of all township and section corners in Kansas. With the projection and deprojection capabilities made available by the **PROJCT** system, (KGS Open File Report 89-9), and the digitized locations of all section corners in the state, it is now possible to convert between any two of the three reference systems. Thus, any data in any of the systems may be converted by LEO or PROJCT into either of the other two systems.

Interrelationships among the three reference systems and the conversions made by PROJCT and LEO are illustrated in Figure 1. Data referenced in the geographic system may arise as data being archived or transferred in or out of the Survey. Data referenced in projected coordinates generally result from digitizing and are used for graphic display and production. Legal descriptions are usually used for property definition and well location.

```
                                                  ******************
                       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 1: Reference Systems inter-related by PROJCT and LEO

2. THE LEGAL REFERENCE SYSTEM IN KANSAS

In Kansas, the legal reference system is based on a grid of approximately rectangular cells covering the state, in which the corners of the cells were systematically surveyed on the ground. Each cell in the surveyed grid is uniquely identifiable by a set of mostly numeric designations. The smallest unit in this system is called a **section**, each of which is (approximately) one mile square[1]. The sections are grouped in six-by-six squares to form **townships**, within which sections are numbered from one to thirty-six, in an unusual fashion. The surveyed points defining section boundaries are called **section corners**, and those that also define corners of townships are called **township corners.**

Construction of the grid of townships and sections began at two carefully surveyed reference lines[2]. The survey's horizontal **base line**, located at 40 degrees north latitude, was the state's northern border. The vertical (longitudinal) base line was the **"6th" principal meridian**, located at 97 degrees, 23 minutes west longitude. From these lines, a number of additional latitudinal and longitudinal reference lines were surveyed to create a coarse grid within which townships could be properly surveyed. Starting at the base lines, townships were surveyed within the coarse grid cells, with each beginning where the previous one ended.

The legal system, known as the **Public Lands Survey System** or the **PLSS**, comprises (in Kansas) a grid of 35 rows and 68 columns of townships. The rows of this grid are designated by **township numbers.** A row of townships forms a continuous, curved path from west to east on a map, with the north and south borders aligning at the corners.

Columns in the township grid are specified by **range numbers** (east and west of the principal meridian). Unlike rows, columns of townships do not evenly align from north to south, because of corrections that must be made to prevent sections from becoming

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[1] Actually, section and township lines were surveyed to go due south from their starting points, causing the southern edges of sections to be larger than the northern edges. Furthermore, although sections are intended to be quadrilateral, (though not exactly rectangular), there are cases in which either natural or artificial obstacles precluded this.

[2] Actually, the first attempt at surveying the 6th Principal Meridian resulted in a longitudinal line that was some 48 miles east of the correct location. The line was used as a guide line, but the error was discovered only after the eastern part of the state was surveyed. The rest of Kansas was surveyed with the 6th principal meridian as a base. This incompatibility resulted in the very wide sections in the western part of range 8 east.

ever wider to the south. Longitudinal boundaries of townships are spaced six miles apart originally. But after six rows, their divergence is great enough that **correction lines** are introduced, at which point they begin at six miles apart again.

Each township is referenced by a **township designation** and a **range designation.** In Kansas, a township designation is the row number of the township. A range designation is the column number of the township, relative to the 6th Principal Meridian. Because the vertical base line is in the middle of the state, the range designation requires a range number and a letter indicating its direction from the 6th Principal Meridian, namely, 'W' for west or 'E' for east. In Kansas, range lines are numbered from 1 to 25 east, and 1 to 43 west of the vertical base line.

For example, the township located in row 14 and column 22 of the grid would be designated "Township 14 South, Range 22 West", usually written "T14S" and "R22W". Figure 2 shows the ordering of township and range designations in Kansas.

```
     R43W          . . .           R1W R1E   . . .    R25E
       |                            |   |               |
       V                            V   V               V
T1S->  **********************************************
       *                                             **
       *                                             *
       *                                              * *
       *                                                *
       *                                                *
       *                                                *
       *               K  A  N  S  A  S                 *
       *                                                *
       *                                                *
       *                                                *
       *                                                *
       *                                                *
       *                                                *
T35S-> **************************************************
```

Figure 2: Township and Range Designations in Kansas

Townships are generally[3] divided into thirty-six **sections,** each approximately one mile square. Sections are referred to by unique numbers, as illustrated in Figure 3 below, which begin in

---

[3] Except where it is terminated by the state boundary or borders some land that is excluded from the survey, such as happened with some private company lands, federal government lands, or properties held by Native Americans.

the northeastern corner and then proceed in a snakelike fashion to end in the southeast corner.

Along the state boundary, sections may be cut off by the state line. In such cases, if the state line is straight, then extension of the section lines to their intersections with the state boundary are used to approximate the outer corners of the section. Along the Kansas river, no such approximation can be applied to create a rectangular section at the boundary. Many sections along the river are incomplete, having only 3 or fewer corners. These sections are unavailable for conversion, but the locations of existing corners may be obtained.

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 3. Section Numbering Within Townships

Specification of locations within the section (see below), corner or center selection, area subdivision, and application of footages[4] (not currently supported in LEO).

[4] The use of footages for specifying locations within sections is expected to be incorporated in a future version of the LEO system.

3. SPECIFYING LOCATIONS WITHIN A SECTION

Specification of a legal location within the named section may be performed in several ways within the LEO system. LEO supports five different options for specifying the location of points within sub-areas within the section. These options are applied to the conversion from legal to geographic reference, though one method (footages) is used for both conversions.

The five methods applied to locating points within a section are described as dividing the original section only. All of the methods which use SUBD to subdivide to an area or to a corner or a midpoint may be applied to the sub-areas of the section which are created in previous subdivisions. That is, a quarter-section may be quartered or halved, and the result of that may also be quartered or halved up to a maximum of four such operations.

The Default Method

The first (default) option is to stop at the selection of the section and to make no further subdivision. The center of the section, defined as the average of the four corner locations (also equal to the centroid of the quadrilateral) as defined by the corners found in the LEO database is the location returned as the equivalent in geographic coordinates to the legal location.

Subdivision By Half-Areas

The second option allows subdivision of the section into successively smaller **half-areas**, to a maximum of four levels of subdivision (sub-areas of 1/2, 1/4, 1/8 or 1/16). Subdivision is specified by values in the SUBD array (see below). The selected point is the center (average of the four corners) of the smallest sub-area. Subdivision by half-areas is specified by setting the values in SUBD, at successive levels (SUBD(1-4)) according to the table below. In LEO, the largest sub-area (or first subdivision) is specified first, and the smallest is last, up to four levels. Thus, when applied from largest index to smallest (1), each SUBD specification is a half-area of the next. All unused positions in SUBD are set to blank (' ').

<u>Specifying Half-Area Subdivision</u>

```
'N '  ->  North half of area
'S '  ->  South half
'E '  ->  Eastern half
'W '  ->  Western half
```

Thus, setting the values of SUBD to the following values:

```
SUBD(1) = 'S '
SUBD(2) = 'E '
SUBD(3) = 'N '
SUBD(4) = '  '
```

specifies the south half of the east half of the north half of the section. Note, the smallest area is specified first.

NOTE: When calculating half-sections, the midpoints of the sides to be divided are calculated as the averages of the two corners. The midpoints are joined by a straight line, resulting in two equal half-areas. Two such lines are used for quartering sections (see below).

Subdivision By Quarter-Areas

The third option for subdivision of sections is to divide by **quarter-areas**. As with half-areas, a maximum of four levels of subdividing is allowed. Thus, sub-areas of one-quarter, one-sixteenth, one-sixty-fourth and one-two hundred and fifty-sixth the original area may be generated.

The center of the smallest subdivided area (the averaged location of the four corners of the sub-area) is the location returned. Selection of quarter-areas is made by one of two equivalent methods of letter assignment (see below), with up to four subdivisions being specified in the SUBD variable. The order of specification is, again, first the smallest area, and last the largest area.

Specifying Quarter-Area Subdivision

'NE'	or	'A '	->	Northeast
'NW'	or	'B '	->	Northwest
'SW'	or	'C '	->	Southwest
'SE'	or	'D '	->	Southeast

Thus, setting specifications in SUBD to:

```
SUBD(1) = 'NW'          SUBD(3) = 'SW'
SUBD(2) = 'SW'          SUBD(4) = 'NE'
```

selects the Northwest quarter of the Southwest quarter of the Southwest quarter of the Northeast quarter of the section.

Note: Quarter-area subdivision in LEO divides sections which are known to be (virtually) rectangular. Thus, quartering is performed by finding the center (average) of the four corners and the midpoints of the two affected sides.

Note: The half-area and quarter-area subdivision methods may be used in combination to specify the sub-area of a section or of a sub-area of the section.

Selecting Corners

The fourth option is to select a section or township **corner** using the value of the first element in SUBD to specify which of the four corners. The quarter-area specifications of NW, NE, SW, and SE, or alternately A, B, C, and D select the corner. The LEO software must be told of this option by selecting the CORNER = 1 option. The exact (as stored in LEOBASE) longitude and latitude of the selected corner is returned in this case.

Intra-Section Location Examples

In Figure 4, the various types of specification within the section/area are illustrated. This is followed by explanations of the types of section and area subdivision and specification of point locations.

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

Figure 4: Intra-Section Subdivision

The number 1 point is specified as the center of the section by default method 1, CORNER = 0, for the center of the area, and by setting all four elements in SUBD to blank (' '), to use the whole section as the area. Point 2 is specified as the center of the Northeast quarter of the North half of the Southwest quarter of the section. This is done by setting SUBD(1) = 'SW' or 'C ', SUBD(2) = 'N ' and SUBD(3) = 'NE' or 'A ', SUBD(4) = ' ', and CORNER = 0 in the calling program.

Point 3 is located as the center of the Southeast quarter of the Northeast quarter of the section (CORNER = 0, SUBD(1) = 'NE' or 'A ', SUBD(2) = 'SE' or 'D ', and SUBD(3 & 4) = ' '). The fourth point (the southeast corner) is specified as the Southeast corner of the section by selecting the corner method (CORNER = 0) and specifying the Southeast corner in the first element of SUBD (SUBD(1) = 'SE' or 'D ', and SUBD(2,3,4) = ' '). Similarly, the other corners (marked **C**) could be selected. Other locations in the section are indicated by their subdivision specifications.

In summary, the geographic location produced by LEO from a legal description is the averaged or central location of the four corners defining the smallest specified area, unless the corner option is selected by CORNER = 1. Then, the location returned is the exact location of the section or township corner as specified by the letters in the first subdivision, SUBD(1), of the section.

When LEO is used to perform the inverse conversion, that is, from geographic coordinates to legal descriptions, the resulting legal description includes township and range designations, the section number, and four levels of quarter-area subdivision using the NW, NE, SE, and SW specifications.

4. THE LEO SYSTEM

The LEO reference conversion system consists of a single FORTRAN77 subroutine (**LEOCVT**) and an associated spatial database of section and township corner locations, spatially ordered, and stored in geographic (longitude and latitude) coordinates. The LEO database is called LEOBASE. LEO performs conversions between the geographic and legal reference systems, but only in Kansas. The LEO system is a part of the computer-assisted cartography system called the **G**eodata **I**nteractive **M**anagement **M**ap **A**nalysis and **P**roduction system, or **GIMMAP**, developed in-house at the KGS.

The LEO conversion system was made possible by construction of the LEOBASE, which is the collection of all township and section corner locations, stored as geographic coordinates and spatially organized to reflect the structure of the legal system. This information was extracted from the digitized and edited data contained in the **Kansas Cartographic Database (KCD)**, a collection of more than 2,000 cartographic databases covering the state of Kansas. Virtually all of the KCD data, including the section and township corners with which LEOBASE was built, was digitized from the 7.5′ quadrangle maps produced at a scale of 1:24,000 by the U.S. Geological Survey (USGS).

Compilation of the KCD has progressed steadily since 1980 through the efforts of the Automated Cartography section, (now a part of Technical Information Services - TIS) at the Kansas Geological Survey. Construction and application of the KCD and LEOBASE was achieved by use of GIMMAP and a series of spatial analysis and database construction programs.

Given a legal description in the form of township, range, and section numbers, up to four levels of subdivision within the section (e.g. a quarter-quarter-quarter-quarter-section), and (possible) footages (distances from a known point or from the sides of the section or the sub-area), LEO returns the equivalent location in geographic coordinates. The selected point may be the center, the corner or the mid-side of the section or selected sub-area, or may be the location specified by footages.

Given a geographic location, LEO returns an equivalent legal description with township, range, and section numbers; all four levels of subdivision (using NW, NE, SE, SW, see below); and footages within the smallest subdivision. The point lies within the smallest sub-area, located as closely as is possible in the legal system by the footage values.

5. USING THE LEO SYSTEM

Proper use of the LEO system includes following the steps described below. Among these are:

* The calling program must be LINKed to the object file that contains LEOCVT.
* It must OPEN the LEO database (LEOBASE), using a unit number which is subsequently passed to the LEOCVT routine.
* Calls to LEOCVT to perform reference system CONVERSION must properly set the values of the arguments prior to the call.
* All ARGUMENTS in the call to LEOCVT must be given the proper types and sizes in the DECLARATIONS area, must be given appropriate values and must be used in the proper order.

The calling program must check the value of SUCCESS after each call to LEOCVT to make certain that the conversion occurred without error (the meaning of error codes is given below) . If the conversion was successful, the value of the SUCCESS variable will equal one. The calling program should report any errors which are the fault of the database or the LEOCVT software (this subset of error codes is defined below).

LINK

To use the LEOCVT routine, the user must LINK the calling program to the LEOCVT object file: LEOCVT.OB

> **NOTE:** On the Data General, the object file that contains the LEOCVT routine is in :UTIL and is: GIMMAP.LEOCVT.OB

OPEN

Prior to using the LEOCVT routine for conversions, the user must open the database as follows:

```
      OPEN (LEOFC, FILE='LEOBASE', ACCESS='DIRECT', RECL=400,
     +     FORM='UNFORMATTED', IOINTENT='INPUT')
```

where the unit number for the LEOBASE database, LEOFC, is also passed to the LEOCVT routine (see below).

> **NOTE:** On the Data General, the LEO database resides in :UTIL and is named: GIMMAP.LEOBASE

DECLARATIONS

The proper declarations for arguments to LEOCVT are:

```
CHARACTER EW*1, SUBD*2(4)
INTEGER*2 CORNER, LEOFC, LORG, RANGE, SECT, SUCCESS, TSHIP
REAL PLAT, PLON
```

CONVERSION

To convert between geographic and legal reference systems:

```
        :
        :

  <set values for TSHIP, RANGE, EW, SECT, METHOD, SUBD, LEOFC
      and LORG=1 for legal -> geographic>
or
  <set PLON, PLAT, LEOFC and LORG=2 for geographic -> legal>

        :
        :

   CALL LEOCVT (TSHIP, RANGE, EW, SECT, CORNER, SUBD, PLON,
  &    PLAT, LEOFC, SUCCESS, LORG)

        :
        :

  <check the value of SUCCESS>
      <if error, take appropriate action>

  <if LORG=1, use PLON and PLAT>
or
  <if LORG=2, use TSHIP, RANGE, EW, SECT, and SUBD>

  <REPEAT to convert additional locations>
or
  <STOP>
```

ARGUMENTS

TSHIP = Township number (integer, 1-35)

RANGE = Range number (integer, 1-25E, 1-43W)

EW = Range Indicator, 'E' = East, 'W' = West

SECT = Section number (integer, 1-36)

CORNER = 0 for center of smallest subdivision
= 1 for sub-area corner specified in SUBD(1)

SUBD(4) = Specification for section/area subdivisions

Quarter- or half-area subdivision is applied to the area resulting from previous subdivision, with SUBD(1) as the largest and (4) the smallest. The process of subdivision stops at the first blank.

SUBD Values for Quarter-area Designations

'NE'	or	'A '	->	NORTHEAST
'NW'	or	'B '	->	NORTHWEST
'SW'	or	'C '	->	SOUTHWEST
'SE'	or	'D '	->	SOUTHEAST

SUBD Values for Half-area Designations

'N '	->	NORTH
'S '	->	SOUTH
'E '	->	EAST
'W '	->	WEST

NOTE: Unused subdivisions are blank: SUBD(unused) = ' '

PLON = West longitude in decimal degrees, positive or negative as input, is always positive on output.

PLAT = North latitude in decimal degrees

LEOFC = Unit number of the LEO database (LEOBASE).

SUCCESS = 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 -> Illegal Subdivision #1
= -6 -> Illegal Subdivision #2
= -7 -> Illegal Subdivision #3
= -8 -> Illegal Subdivision #4
= -9 -> Illegal LORG indicator
= -10 -> Invalid longitude for LEO/Kansas
= -11 -> Invalid latitude for LEO/Kansas
= -12 -> Insufficient information in LEOBASE
= -13 -> Error in LEOBASE data
= -14 -> Thrashing error at township level
= -15 -> Thrashing error at section level

LORG = 1 -> convert Legal to Geographic (TRS to LL)
= 2 -> convert Geographic to Legal (LL to TRS)

6. LEGAL SYSTEM ANOMALIES IN KANSAS

Several areas of Kansas do not follow the normal structure for the legal system as used in the rest of the state, usually due to the surveying techniques employed at the time. Included in this group is the column of townships in Range 8 east, in which the western half of the western column of sections (6, 7, 18, 19, 30 and 31) are exceptionally wide due to the poorly planned meeting of separate surveys. Solutions to this problem were settled upon by each of the affected counties, resulting in further subdivision into **lots** which are arranged and numbered in ways defined by each county.

Converting locations in sections bordering on the Missouri river may not be possible due to the fact that only the corners which exist in Kansas are available in LEOBASE. Sections along the river terminate prematurely due to the state boundary. In addition, all sections along the state border are likely to be smaller than average, in fact they may be quite small since they are terminated prematurely at the state boundary.

One clear subset of anomalies in the PLSS data is the set of sections which can not be properly described using a set of four corner locations only. Some sections require six or more points to describe the boundary. Still others, assuming that the basic section grid is extended, lie in areas which were exempt from the surveys and do not legally exist - no land grid is assumed to exist there.

Thus, in the PLSS of Kansas there exist sections which are overly large or small (in comparison to the average section), some sections with internal areas which are outside the land survey system (some navigable rivers are this way), some sections which are not close enough to rectangular to use in the normal process of conversion, and other sections which, due to rivers or other obstacles, require more than 4 points to define the section boundary.

These special sections are only partially known to LEO. In general, LEO will not currently perform reference conversions in these areas. Future research is expected to provide conversion capabilities in all sections in Kansas. Any attempt to convert locations in these areas are likely to result in errors or in the special error code of -12 being returned in the SUCCESS variable. There are some sections in which conversion errors will occur without warning.

7. CONVERSION ERRORS

The LEOBASE database of section and township corners has been constructed from the Kansas Cartographic Database. The features in the KCD were digitized from the USGS 7.5′ quadrangle series of (paper) topographic maps covering the state at 1:24000.

Errors certainly exist in the representation of features on these maps, and errors have occurred in creating the KCD and subsequently the LEOBASE. Therefor, some section corner locations may be in error beyond normal tolerances. **Users of the LEO system are requested to report such errors** to correct the database for future use.

The LEO system has been tested minimally, and some errors have been found and corrected. Still others are expected to be found with further use. Errors are expected along "correction" lines where recognition of township and section corners was the most difficult in construction of the LEOBASE database, and at the state boundary lines where definitions and practices may be poorly defined. As reported in the Introduction (above) some section corner location errors have been found and have been corrected in LEOBASE.

In the LEO system, the SUCCESS variable is used to indicate when the conversion is successful (+1) or to indicate what the error is when it fails to convert (SUCCESS is negative). Thus, when using LEO, **the value of SUCCESS should be checked after every call to the LEOCVT routine.** Values for SUCCESS range from -15 to +1, with +1 being the only successful value.

If the value of SUCCESS is between -11 and -1, it indicates a user error in the specification of values to LEOCVT. SUCCESS values below -11 but above -16 indicate LEO software errors, which may be errors in the program or in LEOBASE, or may indicate missing information in the database. Please report any unresolved errors (SUCCESS = 0) you may encounter to the T.I.S section. Such errors may be the result of problems in the database which could be fixed for future use. Also, report all errors in the range -12 to -15.

When reporting errors, note the error number and if possible the exact values of all parameters for the call to LEOCVT that resulted in the error. There are no guarantees for the accuracy of locations in the database or for the LEO system. Correction of database and software errors will improve LEO for everyone.

8. LOCATIONAL ACCURACY

There are many sources of potential error in the locations of the section and township corners. The original surveying of the locations certainly introduced some error. Construction of the USGS 7.5' maps probably created some additional error in the section corner locations as well as in other features. Shrinking and stretching of (USGS) paper quadrangle maps results in non-linear distortions which are not completely corrected by rubber-sheeting techniques. Digitization and processing may add errors from the hardware, software and human operator.

Once in the computer, the accuracy of the locations may be affected by any mathematical operations or by any input or output operations. However, these errors can be measured and kept at a minimum. The basic objective in the handling of map information in GIMMAP is to maintain the level of accuracy and to prevent any loss in that level. To that end, storage of map data in single precision and other aspects of GIMMAP philosophy are believed to comply with this objective.

The geographic locations of the section and township corners in the LEOBASE database were created through careful data capture techniques applied to the most accurate, known source of the PLSS data for Kansas. Construction of map databases, editing and selection of section corners from multiple data points all applied strict and appropriate methods to preserve accuracy of corner locations. Some errors of selection on correction lines and late recognition of special areas left some problems (most are now known and have been dealt with). The LEOBASE is still the only known comprehensive set of very accurate section corner locations with software providing nearly complete conversion for geographic and legal reference systems.

9. STRUCTURE AND CONTENT OF LEOBASE

The LEOBASE database contains locational information for the township and section corners in Kansas. The locations of section corners are stored as binary numbers representing coordinates in decimal degrees of longitude and latitude. These are stored in a structured form in LEOBASE allowing LEO to obtain the geographic location of any section corner, given its legal description.

The legal description of each township translates directly into a number (below) that points to the record in LEOBASE that contains the geographic locations of all 49 corners associated within the township (section corners on the township edges are duplicated in the adjoining township records).

By translating Range numbers from 43W to 1, from 1W to 43, from 1E to 44, and from 25E to 68, the Range designation used to specify a township can become a column number in an array, which is equivalent to the column of the Kansas township grid. Thus, the record number of a township defined as township = TSHIP (1-35) and a range = RANGE (1-68) is calculated as:

RECNUM = 68 * (TSHIP - 1) + RANGE

Township 25 south and Range 4 west would translate to TSHIP = 25 and RANGE = 40. The record in LEOBASE containing the 49 longitude and latitude pairs for this township would be:

RECNUM = 68 * (25 - 1) + 40 = 1632 + 40 = 1672

Within each township record are 49 pairs of coordinates, each of which is the geographic location of a section corner. The corners are ordered first by row, then by column from the seven by seven matrix of section corners for the township. First is the top (northernmost) row from west to east, then the second row from the north (west to east), and so on, ending with the southernmost row from west to east.

All pairs of coordinates are stored as: **longitude, latitude**, with negative (west) longitudes, and positive (north) latitudes, both in decimal degrees, and both stored as binary, floating-point numbers of four bytes each. Where locations are unknown or non-existent, a location of (9.9,-9.9) is stored. Thus, a positive longitude or negative latitude indicates an unused or unknown corner.

The order of storage of the 49 section corner locations in the township record is illustrated below in Figure 5. If the locations are read into an array from the township record then they should be read and stored by rows in the order specified by the row and column numbers listed in Figure 5. Row 1 is stored first, from column 1 to column 7, with a longitude and latitude pair for each element. Then row 2 from column 1 to column 7, and so on through the elements of row 7 from column 1 to 7, is the order in which the section corner locations are stored.

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

Figure 5: Order of corner locations in township records.

Accordingly, the content of a township record (see above for calculating the record number of a specified township) in the LEO database is shown below. For this illustration, assume LL(R,C) contains the longitude and latitude of the section corner located at row R and column C in Figure 5, (for any legitimate R and C).

LL(1,1), LL(1,2), ..., LL(1,7), LL(2,1), ..., LL(2,7), LL(3,1),

..., LL(3,7), LL(4,1), ..., LL(4,7), ...

..., LL(6,7), LL(7,1), LL(7,2), ..., LL(7,7)

10. USING LEO ON THE PC

NOTE: The information in this section is intended as a supplement for PC users, to the information in section 5, "Using the LEO System".

The LEO system is available for the PC. Included on a high-density floppy disk (1.2 MB) are the executable files for LEOPC and LEOPCEMU, both conversion programs which input data in fixed format from a disk file and output converted data to a second file, both specified by the user. The input file contains the Legal descriptions of points to be converted to longitude and latitude (geographic) locations. The fixed format required for the input is described below. The LEOPC version is for systems with an 8087 math co-processor and the LEOPCEMU version is for systems in which the math co-processor is emulated by software.

Both programs access the LEO database, LEOBASE, to perform conversions. The LEOBASE file, nearly 1 megabyte in size, must be copied into a directory named DATA at the root of the default drive for the system, in order for LEOPC and LEOPCEMU to work.

The input format for these programs is fixed, and is presented by the programs when they begin. The information to be included in each record (legal description) is shown below, with the column numbers given above it. The letters (b,T,D,...) which represent the individual data items, are defined below.

									1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	
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	(columns)
b	**T**	**T**	**b**	**R**	**R**	**b**	**D**	**b**	**S**	**S**	**b**	**C**	**b**	**S**	**1**	**b**	**S**	**2**	**b**	**S**	**3**	**b**	**S**	**4**	(input record)

where:

b	=	blank column
TT	=	the Township number (1-35), always 2 columns
RR	=	the Range number (1-43 west or 1-25 east)
D	=	direction indicator for Range ('E' or 'W')
SS	=	the Section number (1-36)
C	=	Corner option, 0 = center, 1 = corner as specified in SUBD(1)
S1	=	first subdivision by half or quarter method
S2	=	second subdivision (applied to the area that results from the first subdivision, if used)
S3 and S4	=	third and fourth subdivision, if used

The output from the LEOPC programs is one set of geographic (longitude and latitude) coordinates for each converted point, in the form of two real numbers representing decimal degrees of west longitude and north latitude, in the form (F10.5, F9.5) as shown below. In Kansas, longitudes range approximately from 102.125 to 94.5, and latitudes range approximately from 36.875 to 40.125.

```
bxxx.xxxxxbxx.xxxxx      (longitude-blank-latitude)
```

Additional Options

The LEOPC programs may be used interactively at the terminal by specifying the input or output file as **CON** for console. In this case, the program may be stopped by a blank (cr only) input record or by using the control-C interrupt.

If the object code for the LEOCVT routine is provided, the PC user may, by reading the LEO documentation, create a custom program to perform reference conversions in a more appropriate process or environment, and using any desired source and form of input. It should be noted that the LEOPC programs were developed for internal use, and were not intended for external consumption.

Given a (Microsoft) FORTRAN77 compiler and libraries, any user can create a reference conversion program to support various forms and sources of input. Output may be optionally written to a disk file, the console, or both, and many other options may be built into the program. For instance, the program might display a map and ask the user to select a point for conversion via mouse input, or the program could use LEOCVT to convert from geographic to legal reference.

The LEOQUERY Program

If included on the floppy, the LEOQUERY program can be used to interactively examine (or modify) the geographic location of any section corner in LEOBASE. LEOQUERY prompts the user for a set of township and range numbers, an east-west designator, and a section number. The locations of the specified township and the section are shown in their proper geographic relationships. The user may repeat for as many sections or townships as desired.

This program may be used to change locations of section or township corners in LEOBASE, but use of the modify function is NOT RECOMMENDED since the changes are immediate and permanent, and could destroy the utility of the database.

> **NOTE:** The LEOQUERY program also expects the LEOBASE file to be in a directory called DATA, at the root of the default drive or in the current drive.