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ILLIMAP—A Computer-Based Mapping System for Illinois

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ILLIMAP—A COMPUTER-BASED MAPPING SYSTEM FOR ILLINOIS

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ABSTRACT

ILLIMAP is a computer-based system designed to construct maps of any portion of the state of Illinois, at any scale, with a high degree of accuracy. It also can convert locations expressed in section-township-range notation into rectangular coordinates that can then be used to plot maps with an incremental plotting machine.

ILLIMAP has three features not normally found in other mapping systems: (1) all section corners are located in accurate relation to their position on the ground, as depicted by U.S. Geological Survey quadrangle maps; (2) only the four section corners of the section in which a point is to be located are needed in calculating a location; and (3) any point or location in Illinois having a legal description (section-township-range notation) — such as oil wells, coal mine shafts, sampling locations, highway cuts, and pipeline pumping stations — may be plotted. Coordinate values are in the Lambert Conformal Conic Projection.

The system has been designed to help the Illinois State Geological Survey present geologic and mineralogic data. However, it may be useful to those outside the Survey who wish to construct maps of Illinois or to create a similar mapping system.

INTRODUCTION

Most records used by the Illinois State Geological Survey are filed geographically. Drill hole logs, well data, descriptions of outcrops, mine records, chemical and physical analyses, and geophysical measurements are generally arranged by county, township within the county, and section within the township. Excluding duplications, more than 300,000 geographic locations pertinent to specific items are now in various Survey files. The research and service activities of the Survey include the interpretation of information in these files and its presentation to industry and private citizens in convenient, practical form. At some stage in nearly every project, data are plotted on maps. Drawing a base map or plotting by hand is tedious, time-consuming, and prone to error. Plotting by machine, however, is accurate and much less expensive in the long run than hand plotting.

A plotting machine cannot cope directly with a file item such as "Summum (No. 4) Coal Member is 2.1 feet thick in a test hole drilled 10 feet south and 1320 feet east of the NW corner, SE$\frac{1}{4}$ sec. 34, T. 30 N., R. 3 E., Livingston County." The information must be converted to a machine order such as "Draw a circle of radius 0.020 inches centered 7.6415 inches from the bottom and 11.130 inches from the left margin of a sheet of map paper and print the number 2.1 beside the circle." ILLIMAP is a computer-based system for accomplishing such conversions, drawing the base map on which the plot is to appear, and using the conversions and base to prepare machine-plotted maps of all or parts of Illinois.

ILLIMAP programs are written in Fortran IV and IBM 360 Assembler languages for use with a CalComp plotter. The system is designed to fill the needs of the Illinois Geological Survey, but it will eventually be made available on tape to others who can use it.

LEGAL LAND DESCRIPTION

Land ownership in almost all of Illinois is described in terms of numbered sections, townships, and ranges that were surveyed according to the Federal Land Act of 1796 (Treat, 1910). Each township is theoretically 6 miles square and is divided into 36 sections, each section being a mile square and containing 640 acres. The townships are numbered in rows north and south of a base line and in ranges east and west of a principal meridian. Two different base lines and three principal meridians are used in Illinois (fig. 1). In the original survey, each square section was divided into quarter sections, which were again quartered. A third quartering into 10-acre plots has commonly been added to legal description, and a fourth subdivision is occasionally used in strictly informal spot locations. Although many of the monument stones set on the ground in the original survey have been lost, their location is indicated by witness posts, roads, property lines, and fence lines. The regular checkerboard appearance of Illinois from the air and the street pattern in its cities attest to the influence of the 1 mile by 1 mile sections.

The apparently regular pattern of section lines is misleading, however, for the early surveys were not precise. For example, the Third Principal Meridian in Illinois deviates more than a mile from a true north bearing in running the length of the state. Therefore, provisions were made in the original surveying plan for any necessary adjustments in township units. Partitioning of townships began, if possible, at the southeast corner, and small surveying errors, usually less than 200 feet, were normally, but not always, adjusted along the west and north boundaries of each township. Further complications were introduced by Indian treaty boundaries (Matousek, 1966) and by land grants dating from the French colonization.

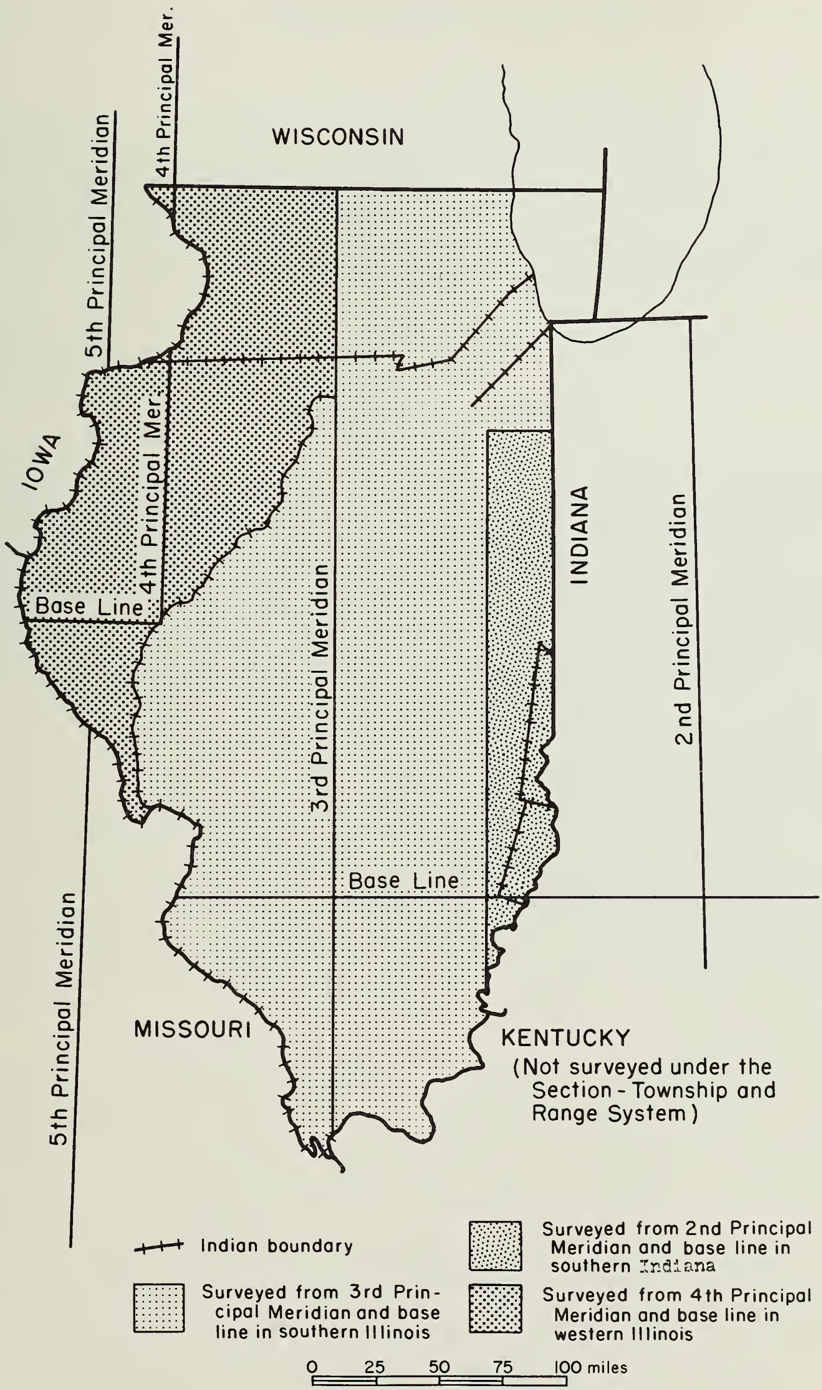

Fig. 1 - Township and Range System.

Larger corrections than those for surveying error are needed to compensate for the curvature of the earth. Such corrections generally are made every 24 or 30 miles and may result in offsets of half a mile or more in the township and range grid.

Because of its apparent regularity, the township and range system has usually been treated as being essentially equivalent to a rectangular coordinate system, and X-Y coordinates of section corners have been mathematically estimated on this premise. As shown by Good (1964), this method can lead to errors of more than a mile in the converted locations of some section corners, making it unsuitable if a high degree of map accuracy is needed.

SPHERICAL COORDINATES

In addition to the network of visible township and section line fences and roads, Illinois is, of course, covered by a network of perfectly spaced invisible lines, the north-south meridians of longitude and the east-west parallels of latitude. Unlike lines on a flat plane, sets of lines on a spherical surface cannot be both parallel and straight. Straight lines on a sphere are defined as the shortest paths on the surface between pairs of points. Such lines cannot be parallel and two parallel lines on the surface of a sphere everywhere equi-distant from each other cannot both be straight. They are the great circles formed where a plane through the center of the sphere meets the surface. The meridians are straight lines (great circles) that are spaced widely apart at the equator, but converge and meet at the north and south poles.

East-west lines of latitude are parallel, but, except for the equator (a great circle), they are not straight. In the language of geometry they are small circles. In the northern hemisphere they form a series of concentric circles around the earth's axis that get smaller northward. The shortest distance between two points on the same latitude (e.g., Chicago and Rome) is the great-circle arc that swings northward toward the pole rather than following around the circumference of the latitude circle. This is particularly apparent near the pole, where the latitude circles are small and where the straight line (great circle) shortcut across them becomes obvious.

A square cannot exist on a spherical surface. Simply stated, you cannot wrap a square sheet of paper around an orange without wrinkling it. If the area covered by the sheet of paper is small in comparison to the area of the sphere, the distortion is not apparent. In central Illinois, if you go precisely 1 mile south, 1 mile east, 1 mile north, and 1 mile west, you will return to a point nearly 13 inches west of your starting point. Delicate surveying instruments and exact methods of measurement would be needed to show that your path had not closed. If, however, each leg of the journey were 100 miles, the trip would end nearly $2\frac{1}{2}$ miles from the starting point. Because of the convergence of the straight meridians and the curvature of the parallels, maps using the latitude-longitude net as though it were a simple rectangular system are generally suitable for only very small areas. However, the network can be mathematically transformed into systems that provide rectangular (left-right and up-down, or X-Y) coordinates.

RECTANGULAR COORDINATES

The example in the preceding paragraph concerned squares, but it is equally impossible to transfer more complex figures from a spherical surface to a flat one without distortion. In squashing a ball flat, something must give — be broken, stretched, crowded, or twisted. The map designer may choose the map properties he believes most important to keep or the map areas to be least disturbed, but he cannot make a "perfect" map. He may decide either that it is better for his purposes to keep areas equal throughout the map at the expense of shape or that shape is primary, that direction is more important than distance or vice versa, that north-south distortion be minimal or that east-west accuracy be emphasized. Such decisions will indicate the particular mathematical formulae to be used for transforming the earth's spheroid into a plane. The mathematical formulae (or set of rules) are called a map projection.

In a simple conic projection, the sheet of paper on which the map is printed can be thought of as having formed a cone set over the globe like a pointed paper cup resting on a small ball. Ball and cone touch on a line that corresponds to a small circle of latitude. If the ball (the earth) were transparent with a single light source at its center, features on the surface would be projected onto the paper as shadows. If the cone were cut from rim to point, it would flatten to a pie-shaped map on which the longitude lines converge toward the pole and the parallels of latitude are concentric circles. A rectangular coordinate grid of straight lines could then be laid over this flat map, so that points on the map could be assigned X (left-right) and Y (up-down) values.

There is no distortion along the standard parallel where the cone touched the globe, but distortion increases north and south away from this line. The distortion can be lessened by letting the imaginary cone sink into the sphere so that it cuts the surface at two standard parallels instead of grazing it at only one. In this form of conic projection the distortion increases away from each of the two error-free standard parallels. The standard parallels 33° N. and 45° N., which pass through Louisiana and Wisconsin, respectively, are ideal for making maps of the continental United States by conic projection (Deetz and Adams, 1945). These parallels are used for the standard U.S. Geological Survey base maps of the entire country and for the base maps of Illinois and of several neighboring states.

The projection chosen for ILLIMAP is the Lambert Conformal Conic Projection with two standard parallels at 33° N. and 45° N. latitude (fig. 2). The central meridian selected, 89° 30' W. longitude, bisects Illinois. The intersection of latitude 33° N. and longitude 89° 30' W., a point in central Mississippi, is assigned the X (east-west) coordinate value of 3,000,000 feet and the Y (north-south) value of 0 feet (DuMontelle et al., 1968). Positive values are thus assured for all Illinois coordinates.

The shapes of small areas are correct on conformal maps that are based on the Lambert projection. The only distortion is the variation in scale between different parts of the map. The result is that a "foot" in Lambert values becomes increasingly shorter between the selected parallels of plane intersection (fig. 2). The ground distance represented by an inch at the standard parallels 33° N. and 45° N. shows an average reduction in scale for Illinois lying wholly within both parallels of about one part in 200. However, the Lambert values calculated for ILLIMAP can be corrected by multiplying them by the Illinois compatible scale factor that was calculated by a computer program (DuMontelle et al., 1968).

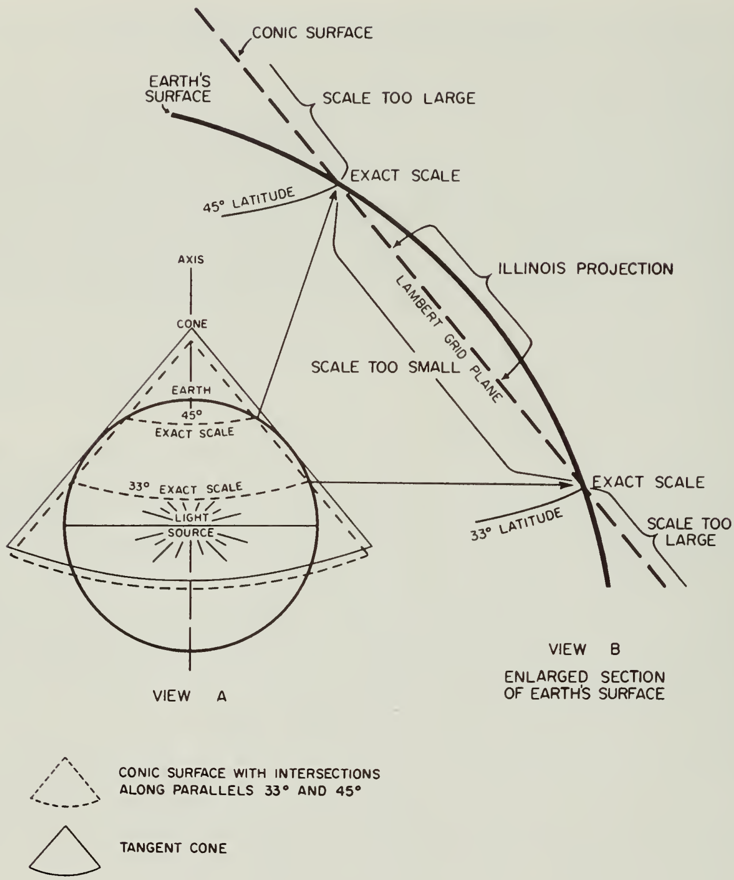

Fig. 2 - Lambert Conformal Conic Projection.

The great advantage of using the Lambert Conformal Conic Projection is that the Illinois maps prepared with it will be compatible with the maps in the U.S. Geological Survey topographic map series of the state, of adjacent states, and of the United States. A disadvantage is that the change in scale across the map, although small, is greater than for some other projections. If it is more important to minimize scale error than to emphasize compatibility, either of two rectangular coordinate systems (Illinois East and Illinois West) developed by the U.S. Coast and Geodetic Survey (1953) may be used. They are based on transverse Mercator projections in which the meridians other than the central meridian are slightly curved and the parallels of latitude are ellipses rather than circles. As a result, the greatest scale error in the area covered by the Illinois East projection is only one part in 40,000, and error in the Illinois West projection is one in 17,000. The extremely low error in scale makes these systems particularly suitable for specialized uses such as land surveying. However, maps prepared on these two projections are not compatible with each other or, in general, with any other maps.

Computer programs have been written to convert ILLIMAP coordinates into those of the Illinois East and Illinois West systems or into latitude and longitude. If coordinates are converted to latitude and longitude first, conversion into any other projection is possible.

SECTION CORNER COORDINATES

The central feature of the ILLIMAP system is a catalog of the Lambert conformal coordinates of all section corners in the state and the coordinate values of the state boundary and all county boundaries. This file now consists of more than 100,000 coordinate values. It also includes imaginary corners needed to complete partial sections cut off by the state line, by rivers, or by Indian treaty boundaries. Section corners that lie on state, county, or township boundaries are identified separately in the system, as are the imaginary corners.

The procedure used in preparing a U.S. Geological Survey map for ILLIMAP processing outlines the following:

1. Assign a number to each U. S. Geological Survey topographic map necessary for complete coverage of the state
2. Circle and number (16) the $2\frac{1}{2}$' or 5' latitude-longitude intersections on the map.
3. Denote any county boundary lines on the map.
4. Denote any state boundary lines on the map.
5. Outline township and range lines on the map.
6. Determine which counties are represented on the map and print the names in the margin.
7. Record the county numbers (from the Township code book) beside the proper counties in the map margin.
8. For each county represented, determine (from the Township code book) the township code numbers and record these numbers on each township on the map.
9. Draw any necessary I points* to complete section grid before numbering map.

   *I points are imaginary points positioned on the map to provide the slope direction for plotting boundary lines of incomplete or cut-off sections and to calculate spot locations. Proportional subdivision of sections utilizes all four section corners.
10. Place a dot of ink over each of the following points on the map, numbering the ink dots consecutively as they are placed on the map, beginning with point number 17:
    a. Section corners (real or I points).
    b. Points where section lines cross straight state boundary lines.
11. Number the points where an Indian boundary crosses section lines.
12. When the map has been completely numbered and proofread, transfer by township the digitized section corner numbers to individual sheets to identify specific numbered points with section corners.

13. Numbered points and line segments are then machine digitized to produce a deck of numbered X-Y locations.
14. The information from the individual township sheets is keypunched to produce a township data deck.
15. The digitizer (X-Y locations) and township data decks are processed by the ILLIMAP system.

The catalog was compiled from U.S. Geological Survey quadrangle topographic maps by means of an Autotrol digitizer. Maps drawn to a 7.5-minute scale (1:24,000, 40-foot accuracy) were used for part of the state, but for parts of the state not yet mapped on that scale, 15-minute maps (1:62,000, 100-foot accuracy) were used on a temporary basis. The catalog will be up-dated as additional 7.5-minute mapping is completed. Classification and identification of the points on the topographic maps, digitizing, data checking, and filing were all done satisfactorily by personnel having no previous computer or map reading experience.

The digitizer measures the X and Y position, to the closest thousandth of an inch, of a movable transparent target placed on the map. A keypunch machine connected to the digitizer records the measurements on a card. The 16 latitude-longitude intersections shown on each quadrangle are measured, along with section corners and sets of closely spaced points on river and other irregular boundaries. The digitized measurements of the latitude-longitude intersections are fitted by a least-squares method to their calculated coordinates in the Lambert conformal projection. This fitting technique provides the means for converting digitizer output for each map to Lambert conformal coordinates. A CalComp plot of each quadrangle is drawn using the ILLIMAP catalog of section corners. These plots are checked for accuracy by placing them on the published quadrangle map. Although the projections are not strictly compatible, the area of a quadrangle is so small that there is little difference between the CalComp plot of the Lambert projection and the printed U.S. Geological Survey quadrangle, which is drawn by polyconic projection. Any section corner on the overlay that deviates from the corresponding section corner on the quadrangle map by more than 200 feet is corrected. The coordinates of each section corner location are then arranged into their appropriate township array of section corners and lists of points for drawing irregular boundaries.

The section corner catalog is used in computing coordinates for locations that are expressed in the section-township-range system. When used in conjunction with the lists of digitized points on irregular boundaries, the catalog provides the basis for preparing machine-plotted base maps.

CONVERTING LEGAL LOCATIONS TO COORDINATES

The location of a spot within a given section may be expressed in many ways—for example, in distance from any of the lines or corners, from the center of the entire section, the quarter section, the 40-acre quarter quarter, the 10-acre quarter quarter quarter, the $2\frac{1}{2}$-acre quarter quarter quarter quarter, or from several admissible combinations of quarters and halves. In certain files the lack of specified footage implies that the spot is at the center of the designated area, but in other files the same convention indicates that the exact location is unknown. Certain files use various special codes to indicate different parts of the section. The ILLIMAP programs adapted from Murray, DuMontelle, and Heidari (1967) for converting legal spot location data to Lambert coordinates are correspondingly complex and may be modified as experience dictates. In our programs, the Lambert coordinates of the four corners of a section are obtained from the catalog and used to calculate the coordinates of a spot within the section.

The coordinate location of a point that is to be determined from the legal description is calculated by using the rules established by the Bureau of Land Management (U.S. Department of Interior, 1963) for the resurveying of sections. First, whether the section being subdivided is regular, oversized, or fractional must be determined (fig. 3). Regular sections in the ILLIMAP system are at present defined as sections in which the digitized length of all of the four sides lies (as short as or as long as) between 5100 and 5500 feet. These length limits may be changed if necessary. All other sections are classified as fractional or oversized. Experience limited to 20 township units in the catalog indicates that this criterion is effective in placing 98.2 percent of the digitized sections in the system in the proper category. Further experience may indicate that a catalog of the oversized or fractional sections in each township should be compiled from the original township plots.

SUBDIVIDING REGULAR SECTIONS

When the section is classified as regular, the proportionate method of subdivision is used. For the ILLIMAP system, this means that the digitized length of each section line in a section is subdivided into equal units (i.e., halves, quarters, and eighths). Interior corners are then established as the intersections of straight lines that connect the same subdivision points on opposing pairs of section lines. If section lines are not equal in length, are nonparallel opposite lines, or are nonperpendicular adjacent lines, the interior subdivision lines are most influenced by the length and bearing of the section lines closest to them. When footage measurements are given in spot location they are measured parallel to the nearest interior or exterior lines referred to in the description.

SUBDIVIDING IRREGULAR SECTIONS

Oversized or fractional sections, generally those sections that lie adjacent to the irregular north and west township boundaries, are subdivided, starting at the southeast corner of the section, into regular units measuring a quarter of a mile square. The subdividing lines are drawn parallel to the south and east section lines. The number of regular quarter-quarter units that can be defined in this way is determined by the size of the section being subdivided. In sections that are oversized or fractional in both the north-south and east-west directions (fig. 3, sec. 6), from zero to nine regular quarter-quarter units can be identified. In sections that are oversized or fractional in only one direction, (fig. 3, sec. 5) from zero to twelve regular quarter-quarter units can be drawn. The remaining oversized or fractional units are termed lots. In most well location records the term "lot" has not been

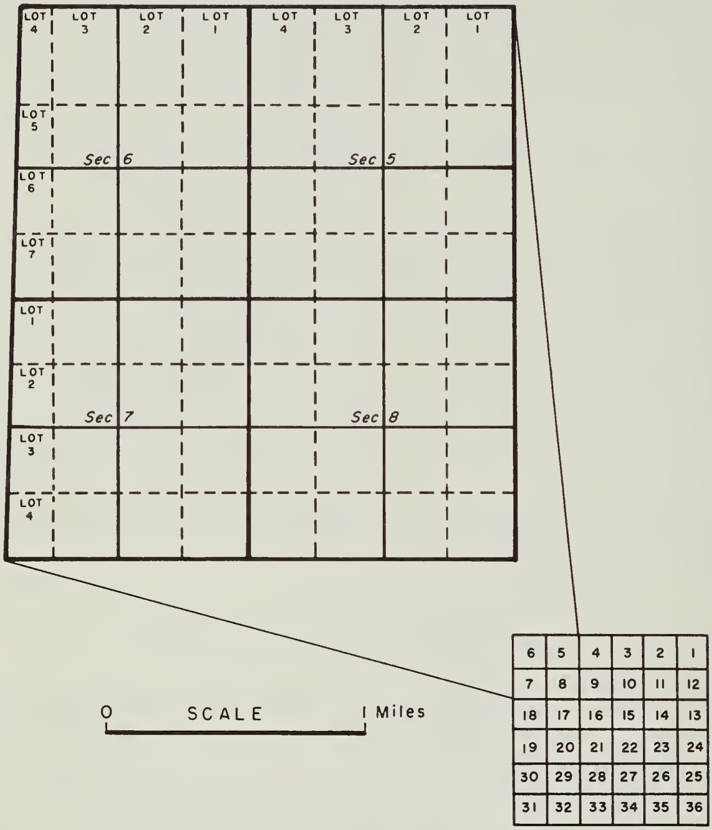

Fig. 3 - Diagram showing normal subdivision of fractional and oversized sections.

consistently applied, and locations in lots have generally been referred to the corners or lines of the section. If the term "lot" is used in the legal description, it is changed to the corresponding quarter or quarter-quarter designation for input to the ILLIMAP system. As in regular sections, footage measurements are made parallel to the lines referred to in the description. All converted locations are tested to determine whether the location spot lies within the boundaries of the section.

Indian treaty boundaries are particularly troublesome because real locations hundreds of feet apart and on opposite sides of the boundary may have identical spot descriptions. To be adequate, in such cases, a description must state on which side of the boundary the spot lies. This information is generally not supplied on location records. Fortunately, in most cases in these sections, a rough plot of the spot location should show which side of the Indian boundary the spot location lies.

In the ILLIMAP system, section corner coordinates are filed in township arrays. When a township is divided by Indian boundaries, separate, partial township arrays are established and identified for each portion of the township.

Each partial township array contains the coordinates for the real section corners, the imaginary section corners (missing because Indian treaty boundaries interrupt the normal grid), and the intersections of section lines with the Indian boundaries. Imaginary corners for the sections are constructed by extending the section lines of the available section corners through the Indian boundaries. If these data are insufficient for determining the length or the bearing of an imaginary section line, the line is assumed to be equal in length and parallel (or 1 mile long and parallel) to the opposite section line. The same system for constructing imaginary corners is used where the boundaries of a section are determined by a river, a circumstance that occurs in several places in Illinois, such as along the Illinois River, which makes up part of the western boundary of the area surveyed from the Third Principal Meridian (fig. 1).

To determine the location of a particular spot, the corresponding township array is retreived from the ILLIMAP file. If two or more partial arrays have the same township designation, the township is divided by Indian boundaries. To verify this possibility, the partial arrays are searched for duplicate sets of section corners. If two or more sets of four corners for a given section are found in the array, the spot is in a section divided by Indian boundaries.

Location of the spot in question is then calculated for all possible sets of section corners in the manner described for regular, fractional, and oversized sections. Each coordinate location is then tested to see if it lies within the limits of the real portion of the partial township area used in its computation. In general, only the correct location will meet the above criterion because spot locations are determined from the real and imaginary section corners. Because different geographic areas may have identical descriptions in some parts of these divided sections, this test may occasionally result in two or more possible locations. If this occurs, the true location cannot be calculated until additional data are supplied.

CONSTRUCTING BASE MAPS AND PLOTTING DATA

The catalog of section corners and points on irregular boundaries is used in ILLIMAP to draw base maps on a CalComp Model 763* incremental plotter. The arm of this plotter may be moved from one position to another, with the pen either lowered on the paper, or raised above it. The shortest possible moves are 0.005 inch up, down, or sideways and 0.007 inch in a diagonal direction. All lines and characters are formed by combinations of these movements. Subprograms for ILLIMAP provide for constructing lines between points and alphabetic, numeric, and graphic symbols for labeling. Section corners on state, county, and township boundaries are filed in the catalog so that these boundaries may be differentiated from section lines and drawn in different line weights or characters designated by the user.

Plotters of the drum type in the University of Illinois Digital Computer Laboratory provide plotting areas 11 or 29 inches wide and as long as 120 feet on paper or 60 feet on Mylar. Flat-bed plotters allow a comparable selection of map sizes and drafting materials and will produce comparable maps.

ILLIMAP is designed for presenting information in relation to its geographic setting. Information may be conveyed by a map showing spot locations or areas with appropriate labeling. Data may be in original form or may be modified to emphasize significance. Because complex situations will demand graphic symbols,

*Also for the Calcomp Model 563 plotter.

contouring, perspective maps, or block diagrams, means of producing more sophisticated types of presentation are being added to ILLIMAP. The value of the system will be multiplied as information, now available in many forms, is converted into a form that can be used by the computer.

ACCURACY OF ILLIMAP

Many factors influence the accuracy of a mapping system, including uncertainties about the earth's size and shape, errors in surveying the land, in manufacturing quadrangle maps, in measuring section corners on those maps, in relating the ground position of drill holes and other points to the section corners, and in computing and plotting. Considerable care has been taken during the construction of the ILLIMAP system to identify and resolve the problems introduced by these various factors. For example, substituting satellite determinations of the size and shape of the earth in the ILLIMAP system for the values used in the Lambert formula would shift all of the Illinois coordinates several feet. But their relation to one another would remain about the same, as would any geodetic constant used in the Lambert conversion or in preparation of quadrangle maps. However, if changed values are incorporated in the ILLIMAP system, coordinates computed with different sets of constants must not be intermingled. This caution cannot be emphasized too strongly because the replacement of any value in the present ILLIMAP file by one calculated from a different set of constants will cause errors in location when the file is used for either drawing base maps or spotting locations.

Most U.S. Geological Survey topographic maps in the 15-minute series are accurate within 100 feet; the 7.5-minute maps are accurate to 40 feet (U.S. Geological Survey, "Topographic Maps"). The control for quadrangle mapping is a series of intersecting third-order traverses connecting points on the U.S. Coast and Geodetic Survey's triangulation net. The traverses are several miles long and are accurate to 1 part in 5000 of their length. Identifiable points on these lines are generally correct to 10 feet, but occasional discrepancies as great as 50 feet have been disclosed by resurveys of older lines. Several third-order points, including a few section corners, can be identified in any quadrangle. The maps are compiled from areal photography oriented with third-order survey points whose admissible error is no greater than 100 feet. Standards for photogrammetric mapping are comparable. Random error is increased by the drafting, scribing, engraving, and printing processes during map manufacture.

Errors in identifying section corners during the mapping are perhaps more serious than the random surveying errors. Some section corners are off by a few hundred feet because a cultural feature, such as a roadway, was mistaken for the section boundary. Such errors are uncommon, however.

The rated accuracy of the Autotrol digitizer is 0.001 inch, equivalent to slightly over 5 feet on a 15-minute quadrangle or 2 feet on a 7.5-minute map. The critical determinant is not the machine, therefore, but the precision with which a human operator can identify points on the map and cover them with the crosshairs of the transparent Autotrol target. On a 15-minute quadrangle, the printed line is about 12 scale feet wide and a road about 100 scale feet wide.

Some of the precautions taken to guard against the above problems include the use of the 16 latitude-longitude intersections on each topographic map to check the accuracy of digitizing. The ILLIMAP conversion program rejects any quadrangle in which there is an error of 200 feet or more in the position of any latitude-longitude intersection with respect to the other 15. Most mistakes in identifying section corners are caught by superposing the machine plot of the quadrangle over the original printed map. Operator error in measuring latitude-longitude intersections is averaged for the entire quadrangle by the least-squares method, which is used to fit digitized data to the 16 latitude-longitude intersections on each quadrangle. These checks have shown that operator error is random, rather than systematic, relative to position on the map.

The operator error in measuring section corners could be reduced if each point were read several times and the values averaged. However, in our experience the amount of time consumed by repeated point reading and subsequent averaging is substantially more than would be taken for redigitizing maps found to have an excessive number of errors. In setting up the ILLIMAP system, about 1 in every 5 maps had to be redigitized at some stage in the determination of the correct Lambert conformal coordinates.

ACCURACY INVESTIGATION

One method of investigating the accuracy of the data in the ILLIMAP section corner catalog is to compute the lengths of individual section lines. These lengths can then be compared with the surveyed distances as shown on the original township plats. In general, an error in digitizing a section corner will affect the computed length of four section lines. All section corners that deviate by more than 200 feet from the points on the quadrangle maps must be corrected, and the maximum error in section-line length should be less than 400 feet.

To compute the lengths of section lines, 20 townships were selected at random from the townships in the ILLIMAP section-corner catalog. All of these townships had been checked for accuracy in various ways, including the superposition of maps drawn from ILLIMAP data on U.S. Geological Survey topographic maps. Ten townships had been digitized on 7.5-minute quadrangles and 10 on 15-minute quadrangles. Only the 60 section lines in the 5 x 5 block of regular sections in the southeast portion of each township were used in making these length comparisons. Section lines from the irregular sections on the north and west side of the township were not used since most of the deviations between the township plats and the topographic maps should be concentrated in these areas.

Figure 4 shows the frequency distribution of the differences between the computed ILLIMAP distances and the original plat distances. For the townships digitized from 7.5-minute quadrangles, 95.2 percent of the ILLIMAP distances are within 100 feet of the recorded plat distances, and all are within 180 feet. In townships digitized from 15-minute quadrangles, 82.5 percent of the ILLIMAP distances are within 100 feet of the plat distances, and 98.7 percent are within 200 feet.

Of the total of 1200 section lines from both 7.5- and 15-minute quadrangles compared in this manner, only eight (0.7 percent) differed from the plat distance by more than the 200 feet. The variations in distance of these eight section lines are given in Table 1. The two largest of these variations are the results of a map

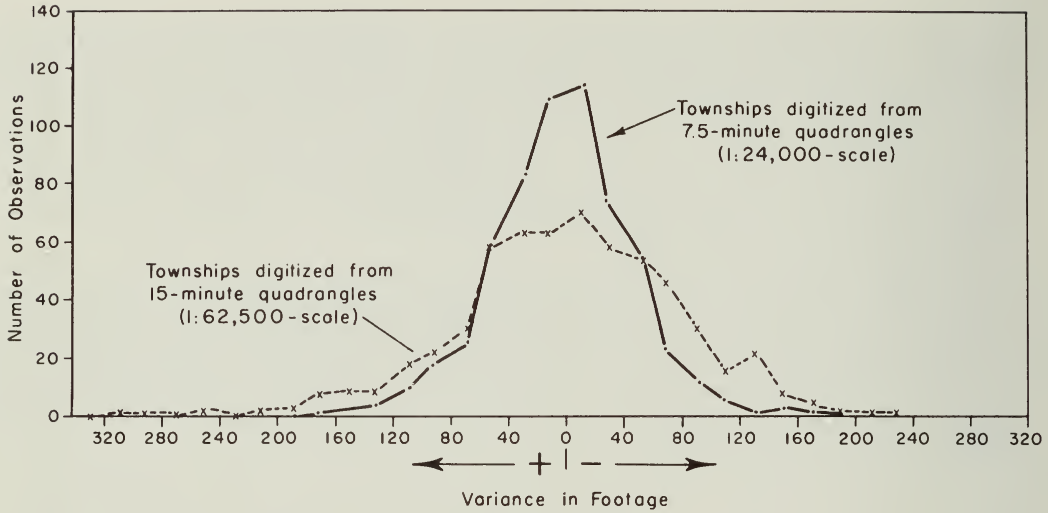

Fig. 4 - Frequency distribution of differences between ILLIMAP distance and original plat distance.

classification error in which a roadway was mistaken for a section line. None of the other six deviations exceed 248 feet.

We can draw some conclusions concerning the accuracy of the data in the ILLIMAP system if we assume that (1) the twenty townships investigated are representative of the data in the entire system; (2) the section line lengths on the township plats are equivalent to the lengths shown on the topographic sheets; and (3) the length variation observed is related to inaccuracies in only one of the two section corners used to compute each distance. These conclusions are necessarily conservative because inaccuracies in distance are actually shared by both corners used to determine distances.

Granting these assumptions, we estimate from the data in figure 4 that approximately 90 percent of the section corners in the ILLIMAP system are within 100 feet of their position on the quadrangle maps, and 99 percent are within 200 feet. Standards for quadrangle maps (U.S. Geological Survey, "Topographic Maps") are based on the criterion that at least 90 percent of the well-defined points shown on published quadrangle maps are within one fiftieth of an inch (about 100 feet on a 15-minute scale) on the map of their true ground position. Since the ILLIMAP system is based on quadrangle measurement rather than ground position, it must incorporate quadrangle map inaccuracies. Based on the townships investigated in the system that were digitized from 7.5- and 15-minute quadrangles, standards are estimated to be 80 feet for 7.5-minute and 120 feet for 15-minute quadrangle maps.

The proportionate method of determining spot locations assures that the error in determining the coordinates of a section corner will be shared to some extent by all points within the surrounding 4 square miles. For example, if a section corner should be measured 80 feet northwest of its true position (a reasonable assumption), and if all the surrounding section corners should be accurate, a point one quarter of a mile away from the affected corner would be mapped 60 feet too far northwest, a point half a mile away would be placed 40 feet too far northwest, and one three quarters of a mile distant would be off by 20 feet.

TABLE I — LENGTH VARIATION FROM PLAT TO ILLIMAP DISTANCE OF EIGHT SECTION LINES EXCEEDING 200 FEET

Sec.	T.	R.	Plat distance (ft)	ILLIMAP distance (ft)	Difference (ft)
8	39N	2E	5,292	5,062	230
28	39N	2E	5,304	5,619	315*
33	39N	2E	5,280	5,571	291*
8	41N	3E	5,280	5,489	209
24	19N	6E	5,264	5,481	217
12	23N	10E	5,193	5,441	248
25	23N	10E	5,240	5,486	246
33	23N	10E	5,280	5,062	218
Total section line comparison — 1,200					

* Road mistaken for section line on quadrangle map.

Wide variation exists in the precision with which items of geologic interest are located. Engineering borings concerned with highway or dam construction may be surveyed with horizontal control of about a foot. A 30-foot standard of accuracy is typical for Illinois oil wells, and if an oil well is drilled more than 30 feet from the surveyed location, a revised permit is required. Few water well locations are surveyed, but their map positions are estimated from a few to several hundred feet from the ground position. Similar standards are held for many coal test and outcrop locations, although coal test holes are increasingly being surveyed. For most types of data, the factor limiting the accuracy of ILLIMAP is ground control, that is, precise in-the-field measuring and recording of the relation of a point to section corners or section lines.

Steps in the computing programs are precise to a foot or less, maintaining the apparent accuracy of the input data. When proportional methods cannot be used, scale errors of 1 to 2 percent may cause position errors of up to 50 to 100 feet where points near one section line are computed from the opposite line. After the coordinates for a data point are computed, they are tested to determine whether they actually do define a point within the digitized section boundaries. When a map is drawn at a scale of several miles per inch, the CalComp plotting accuracy of 0.005 inch will be the determining factor in the accuracy of the completed map.

EXAMPLES OF MAPS CONSTRUCTED BY THE ILLIMAP SYSTEM

Figure 5 shows the boundaries of Illinois, county boundaries, and some of the Indian treaty boundary lines. A file containing more than 15,000 X-Y location points is used to draw the Illinois state boundary. More than 100,000 points are on file in the ILLIMAP system. The time required to draw maps with ILLIMAP varies with the scale and area designated. A 7.5-minute quadrangle base 1:24,000 can be drawn using the CalComp Drum Plotter 763 in 5 to 6 minutes. A 1:1,000,000 base map of Illinois showing county boundaries can be drawn in about 3 minutes.

Fig. 5 - Map of Illinois showing state boundary, county boundaries and some Indian Treaty lines.

Figures 6, 7, and 8 are comparisons of parts of U.S. Geological Survey 7.5-minute topographic maps and the ILLIMAP plot of the same area. Figure 6 shows a portion of Clark County, Illinois, in which the township and range grid is divided by an Indian treaty boundary. Sections along the Indian treaty boundary are offset approximately $\frac{1}{2}$ mile. Figure 6 also reproduces the topographic map of the same area. Comparison of the two maps shows that ILLIMAP can match the topographic map's representation of the township and range grid.

Figure 7 shows parts of the Cahokia 7.5-minute quadrangle maps in Illinois. This figure shows part of the state boundary along the Mississippi River that lies in a French Land Grant area. The French Land Grants are shown on the accompanying topographic map. As can be seen in figure 7, the ILLIMAP system merely extends the township and range network through French Land Grant areas.

Figure 8 shows the ILLIMAP and the topographic map representation of a portion of the Lake Michigan shoreline. The lake shoreline is the only map feature in the ILLIMAP system that does not correspond to a political subdivision line and is not part of the township and range grid.

CURRENT STATUS

The basic ILLIMAP system, which provides for the drawing of base maps and the plotting of data from legal descriptions by computer, has been completed. A file of Lambert conformal coordinate values, covering all points needed to draw a map of any portion of the state of Illinois at any scale will soon be on disk storage. The accuracy of these points is currently being checked by drawing each of the nearly 500 quadrangle maps in the state on the machine and superposing the machine-drawn maps on the U.S. Geological Survey topographic maps. Points on the machine-drawn maps that are more than 200 feet in ground distance from the corresponding point on the topographic map are being corrected. This procedure has resulted in the redigitizing of some of the U.S. Geological Survey quadrangle maps, with the values obtained subsequently being converted to Lambert values and entered into the file in the proper township location. When the accuracy check has been completed, the Lambert conformal coordinate values, plus all the programs developed for the ILLIMAP system, will be put on magnetic tape. These tapes will then be available for loan to those outside the Illinois State Geological Survey who request this information. Inasmuch as there are over 100,000 point values in the file to be checked for accuracy and about 500 overlays to be constructed as part of the accuracy check, the magnetic tapes are not expected to be ready for loan until the end of 1970.

EQUIPMENT REQUIREMENTS

All programs in the ILLIMAP system are written in Fortran IV and 360 Assembler languages for the IBM 360/75, which is equipped with disk storage. Plotting routines are written for the CalComp Model 763* Drum Plotter. Core storage requirements range from 20,000 words for the IBM 360/75 to 30,000 words for different programs in the system.

Some reprogramming may be necessary by those outside the Survey who wish to use these programs if a different computer is to be used. The entire system

*and 563 Drum Plotter

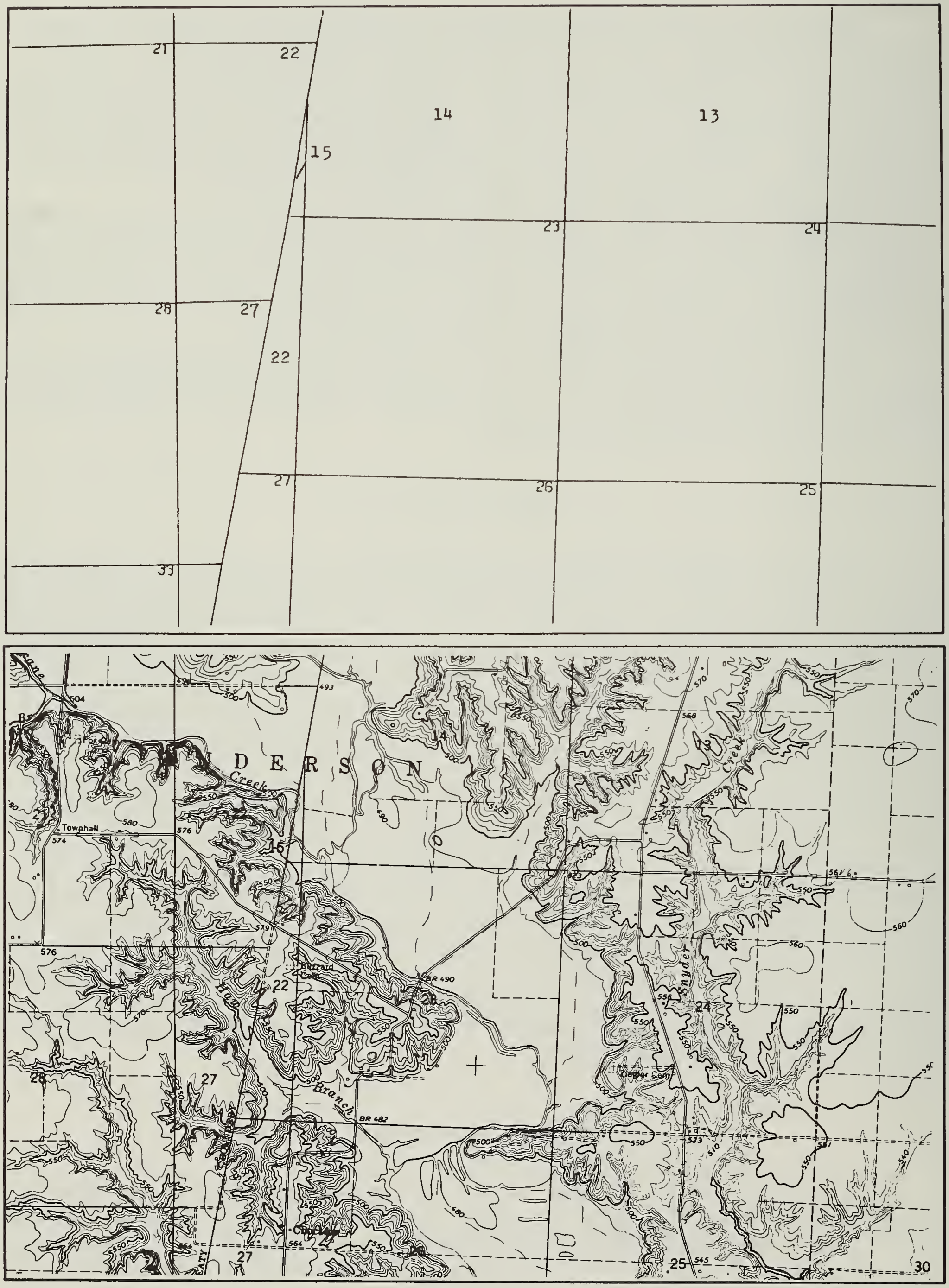

Fig. 6 - Maps of a portion of Clark County showing sections offset along Indian Treaty Boundary.

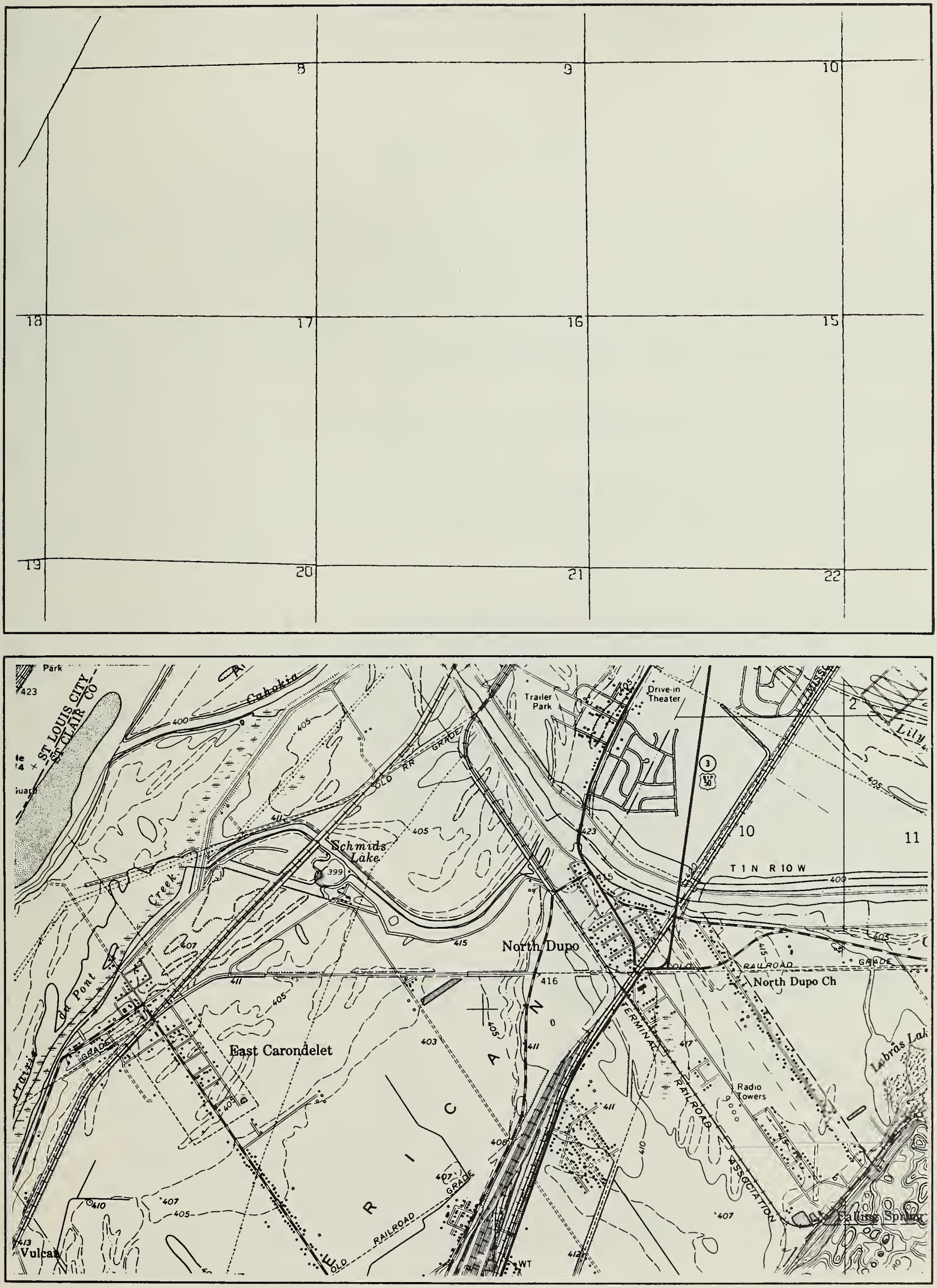

Fig. 7 - Portion of the Cahokia 7.5 minute quadrangle map and computer-drawn base showing section line comparison and state boundary line.

Fig. 8 - A segment of the Lake Michigan shorelines, Lake County, Illinois.

is written for a direct-access type of operation. If a different plotter is used, or plotting is done on a printer, the plotting routines may require considerable conversion.

ACKNOWLEDGMENTS

The ILLIMAP system was initially developed by the Survey Computer Mapping Committee, which consisted of P. B. DuMontelle (chairman), Manoutchehr Heidari, P. C. Heigold, F. N. Murray, and D. H. Swann. Other members of the Survey's professional staff helped the committee determine what the mapping system must be able to do. The program that converts the legal spot locations of data points into Lambert coordinates was originally written by F. N. Murray. Systems programming begun by Alfred C. Moresi and David H. Swann has been continued by Steven Heinecke.

We are grateful to the Illinois State Water Survey for the use of their Autotrol digitizer and to Marvin C. Clevenger, Data Processing Supervisor, for his suggestions and help in training our personnel.

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