A PRIMER ON COORDINATE SYSTEMS
Commonly Used in Michigan

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Reference Surfaces

Datum

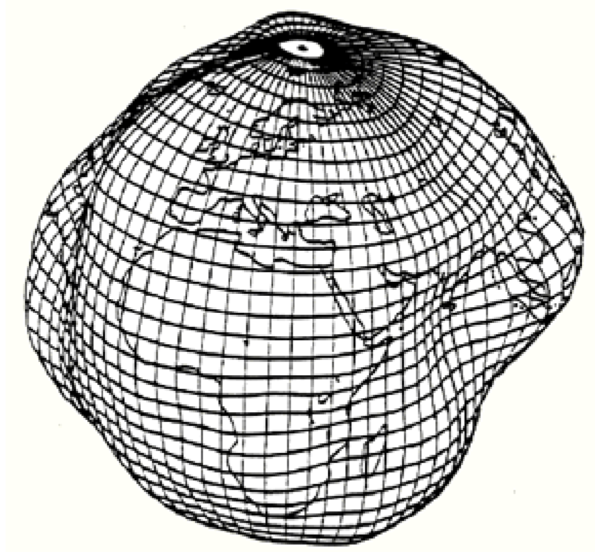
A reference datum is a known and constant surface that can be used to describe the location of unknown points. On Earth, a common reference datum is sea level. As will be discussed in greater detail below, the Earth is slightly flattened at the poles and bulges at the equator. Given that shape, an ellipsoid (a 3-D ellipse) best approximates its shape. A geodetic datum is defined by its ellipsoid (reference surface) and its origin (starting point). If the datum is applicable in a local area, it is called a local geodetic datum. The North American Datum 1927 (NAD 27) is an example of a local geodetic system. Its reference surface is the Clarke 1866 ellipsoid; its origin is a point in north-central Kansas; and its area of applicability is North America. An example of a system with worldwide applicability is the World Geodetic System 1984 (WGS 84). Its origin is at the center of the earth.

Figure of the Earth

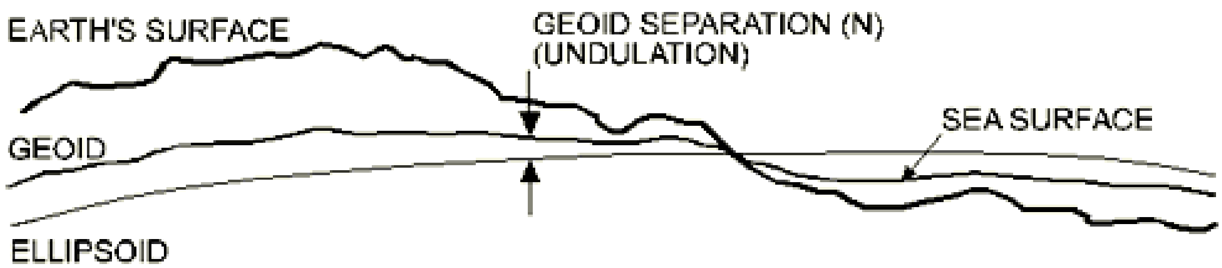
The earth's surface is anything but uniform. At one level of precision, the oceans can be treated as reasonably uniform, but the surface of the land masses exhibits large vertical variations between mountains and valleys that make it impossible to approximate the shape of the earth with any reasonably simple mathematical model.

One approach to creating a simplified reference surface is to idealize the ocean surface as extending below the continental landmasses. If tidal and current effects on this "global ocean" are also neglected, the resultant theoretical water surface is affected only by gravity. This has a certain consequence on the shape of this surface because the direction of gravity - more commonly known as plumb line - is dependent on the distribution of mass inside the earth. Due to irregularities and anomalies in this mass distribution, the "global ocean" exhibits an undulating surface. This surface is called the **geoid** or the "physical figure of the earth". The plumb line through any surface point on the geoid is always perpendicular to it.

If the earth was of uniform density and the earth's topography didn't exist, the geoid would have the shape of an oblate ellipsoid centered on the earth's center of mass. Unfortunately, the situation is not this simple. Where a mass deficiency exists, the geoid will dip below the mean ellipsoid. Conversely, where a mass surplus exists, the geoid will rise above the mean ellipsoid. These influences cause the geoid to deviate from a mean ellipsoidal shape by up to +/- 100 meters. The deviation between the geoid and an ellipsoid is called the Geoid undulation (N). The largest presently known undulations are the minimum in the Indian Ocean with N = -100 meters and the maximum in the northern part of the Atlantic Ocean with N = +70 meters.



Perspective view of the Geoid (Geoid undulations 15000:1)



Relationships between the earth's surface, the geoid and a reference ellipsoid

Approximations of the Earth's figure

The curvature of the geoid displays discontinuities at abrupt density variations inside the earth. Consequently, the geoid is not an analytic surface and it is thereby not suitable as a reference surface for the determination of locations. If we are to carry out computations of positions, distances, directions, etc. on the earth's surface, we need to have some mathematical reference frame. The most convenient geometric reference is the oblate **ellipsoid** as it provides a relatively simple figure which fits the geoid to a first order approximation. For small scale mapping purposes we can also use the **sphere** which fits the geoid to a second order approximation.

The Ellipsoid

An ellipsoid is formed when an ellipse is rotated about its minor axis. The shape of an ellipsoid may be defined in a number of ways, but in geodetic practice the definition is usually by its semi-major axis and flattening. Flattening **f** is dependent on both the semi-major axis **a** and the semi-minor axis **b**.

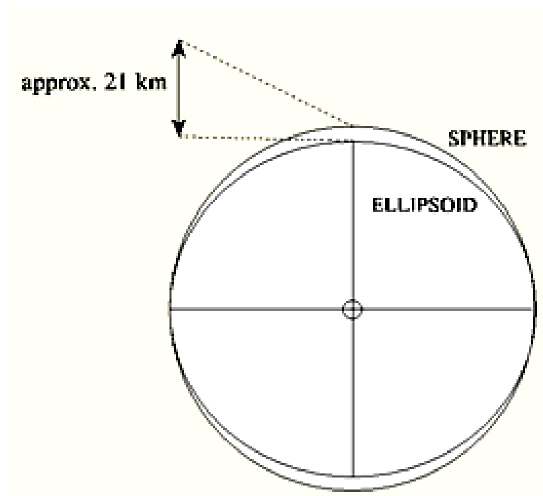
$$\mathbf{f = (a - b) / a}$$

The ellipsoid may also be defined by its semi-major axis **b** and eccentricity **e**, which is given by:

$$e^2 = (1 - (b^2/a^2)) = (a^2 - b^2) / a^2 = 2f - f^2$$

Given one axis and any one of the other three parameters, the other two can be derived.

As can be seen from the dimensions of the earth ellipsoid, the semi-major axis a and the semi-minor axis b differ only by a bit more than 21 km. A better impression on the earth's dimensions may be achieved if we refer to a more "human scale". Considering a sphere of approximately 6 m in diameter then the ellipsoid is derived by compressing the sphere at each pole by 1 cm only. This compression is rather small compared to the dimension of the semi-major axis a.

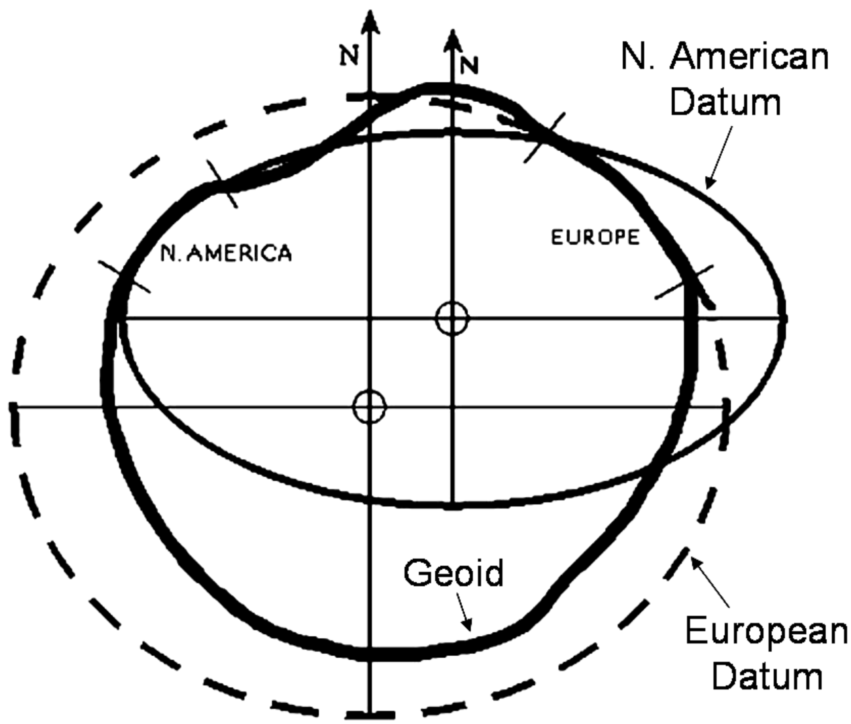


Comparing the ellipsoid and the spheroid

Local Reference Ellipsoids

Many maps are compiled with respect to a *horizontal datum* (also referred to as geodetic datum or reference datum). A horizontal datum is defined by the size and shape of an ellipsoid, as well as several known positions on the earth's surface. In the United States, we use the North American Datum, but there are many other datums used around the world (in Japan, the Tokyo Datum; in some European countries, the European Datum; in Germany, the Potsdam Datum, etc.).

Horizontal datums have been established to fit the geoid well ***over the area of local interest***, which in the past was never larger than a continent. A position on the geoid will have a different set of latitude and longitude coordinates on each reference datum. In the figure below, the North American datum is extrapolated to Europe. Even though the datum fits the geoid within the North American continent pretty well, it does not fit the European geoid. Conversely, the European datum extrapolated to the North American continent shows a similar misfit.

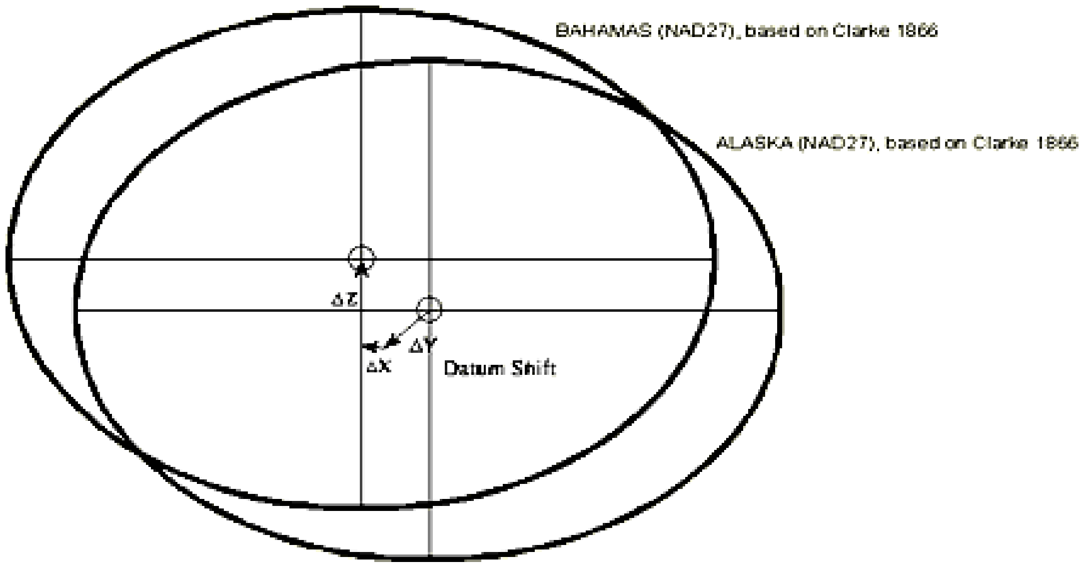


The geoid compared to two best-fitting local ellipsoids for the North American and European Datums

Horizontal datums are defined by the size and shape of an ellipsoid, as well as its position and orientation. Worldwide, there are a few hundred defined local horizontal datums. The table below lists a few examples of local datums that all use the same ellipsoid (Clarke 1866), but in different positions (referred as datum shifts).

Datum	Ellipsoid	Datum shift (m)* Δx, Δy, Δz
CONUS (NAD 27)	Clarke 1866	0, 0, 0
Alaska (NAD 27)	Clarke 1866	-5, 135, 172
Bahamas (NAD 27)	Clarke 1866	-4, 154, 178
Cent. America (NAD 27)	Clarke 1866	0, 125, 194

* compared to WGS84

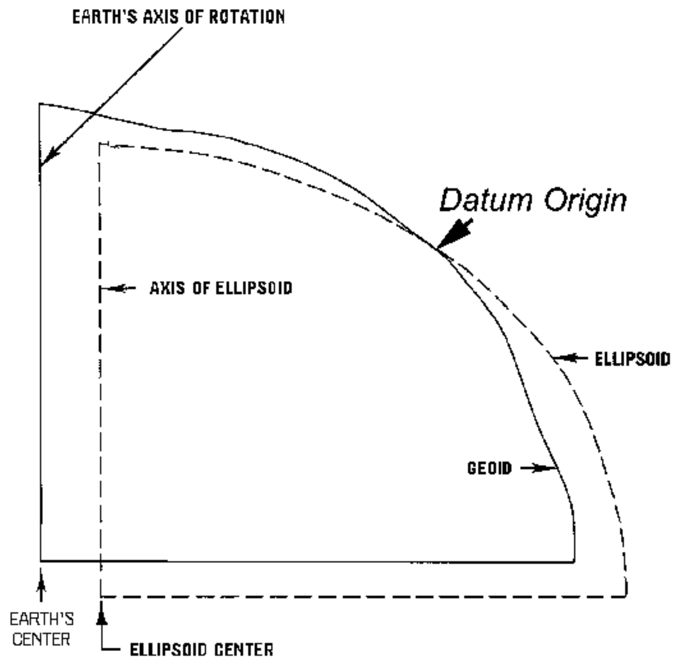


Example of a datum shift

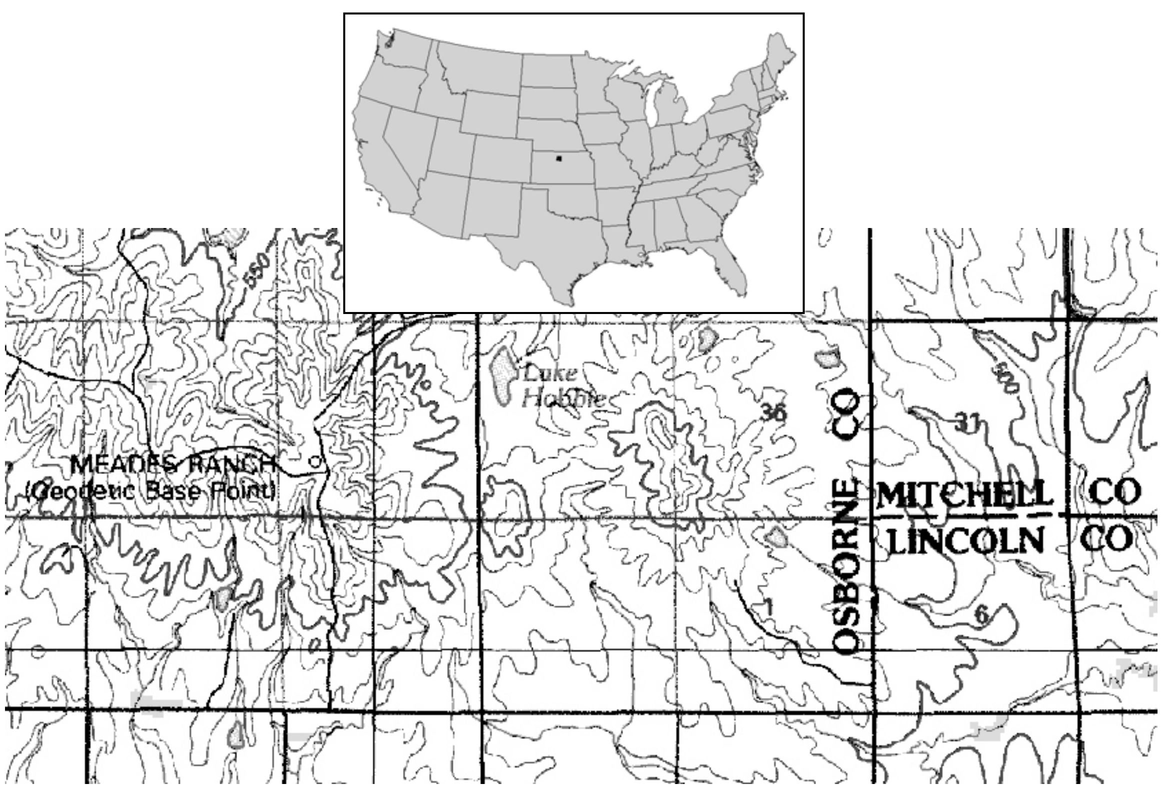
The North American Datum

The first official geodetic datum in the United States was the New England Datum, adopted in 1879. It was based on surveys in the eastern and northeastern states and referenced to the Clarke 1866 Ellipsoid. Over time, this datum was extended to the south and west and, in 1901, the extended network was officially designated the United States Standard Datum. The triangulation station at Meades Ranch, Kansas was selected as the origin. In 1913, Canada and Mexico formally agreed to base their triangulation networks on the United States Standard Datum. This expanded datum was renamed the North American Datum. Adjusting new surveys to fit into this new network created many problems so during the five-year period 1927-1932 all of the available first-order data in the three countries were adjusted into a system now known as the **North American Datum of 1927 (NAD 27)**.

NAD 27 was defined by the location and azimuth of the survey station at Meades Ranch, Kansas (39^o 13’ 26.686” N, 98^o 32’ 30.506” W) on the Clarke ellipsoid of 1866. The geoid height at Meades Ranch was assumed to be zero. **NAD 27 is now obsolete and has been replaced by the North American Datum of 1983.**



Meades Ranch, Kansas the datum origin of NAD 27on the Clarke 1866 ellipsoid



Meades Ranch, Osborne County, north-central Kansas

Many technological advances in surveying and geodesy developed after the establishment of NAD27 (e.g., electronic theodolites, GPS satellites, Very Long Baseline Interferometry, and Doppler systems). These improved methods revealed severe weaknesses in the existing network of control points that became particularly noticeable when linking the existing control network with newly established surveys. The horizontal control network had expanded piecemeal since the completion of NAD 27 to cover much more of the three countries. It became increasingly difficult to add new surveys to the network without altering large areas of the previous network. Field observations had added thousands of accurate Electronic Distance Measuring Instrument (EDMI) base lines, hundreds of additional points with astronomic coordinates and azimuths, and hundreds of Doppler satellite determined positions. It was also recognized that the Clarke Ellipsoid of 1866 no longer served the needs of a modern geodetic network.

A ten-year multinational effort tied together a network of control points for the United States, Canada, Mexico, Greenland, Central America, and the Caribbean. The North American Datum of 1983 (NAD 83) was computed by the geodetic agencies of Canada (Federal and Provincial) and the National Geodetic Survey of the United States. NAD 83 is based on the adjustment of 250,000 points, including 600 satellite Doppler stations, which constrain the system to a geocentric origin.

The North American Datum of 1983 (NAD 83) is the current horizontal control datum for the United States, Canada, Mexico, and Central America. NAD 83 is based on both Earth and satellite observations, using the Geodetic Reference System 1980 (GRS80) spheroid, a geodetic reference system consisting of a global reference ellipsoid and a gravity field model. The origin for this datum (GRS80) is the Earth's center of mass. This affects the surface location of all latitude-longitude values enough to cause the locations of control points in North America to shift. In Michigan, the NAD 27 *vs.* NAD 83 shift is small in the X-domain, but unacceptably large in the Y-domain:

At the maximum latitude in Michigan (48^{o}11’24” N), the NAD 27 - NAD 83 shift is

- Δ 7m in X
- Δ 220 m in Y

At the minimum latitude in Michigan (41^{o}42’00” N), the NAD 27 - NAD 83 shift is

- Δ 7m in X
- Δ 213 m in Y

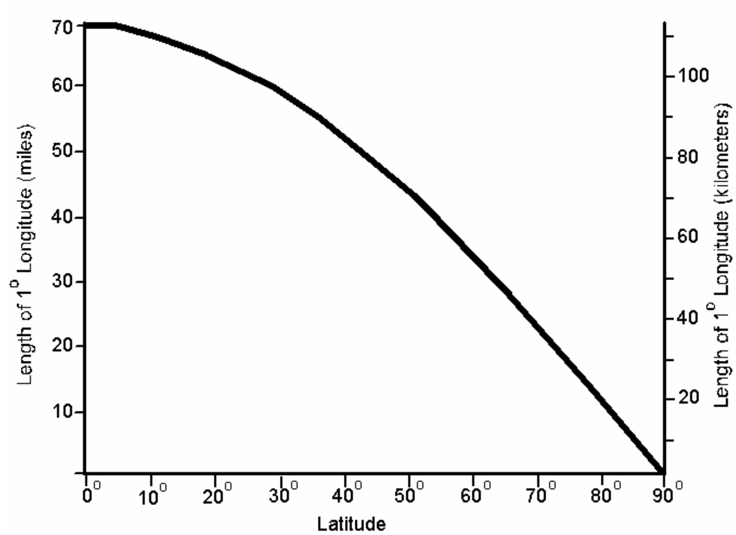
Geodetic Reference System 1980

parameter	symbol	value
Defining constants		
equatorial radius of the Earth	a	6378137 m
geocentric gravitational constant (including the atmosphere)	GM	$3986005 \cdot 10^{8}$ $m^3 s^{-2}$
dynamical form factor (excluding permanent tides)	J_2	$108263 \cdot 10^{-8}$
angular velocity of the Earth	ω	$7292115 \cdot 10^{-11}$ rad s^{-1}
Derived geometrical parameters		
semiminor axis (polar radius)	b	6356752.3141 m
first eccentricity	e^2	0.00669438002290
flattening	f	1 : 298.257222101
mean radius	R_1	6371008.7714 m
radius of sphere with same surface	R_2	6371007.1810 m
radius of sphere with same volume	R_3	6371000.7900 m

Geographic coordinates (latitude – longtitude)

Landscape managers are increasingly adopting GIS and GPS technologies to assist them in their duties. Both of these geospatial tools use earth coordinates to reference the locations of points, lines and areas. Topographic maps have been a staple of landscape managers for many decades, but only rarely was it necessary to determine the earth coordinates of any feature of interest; orienteering skills were far more important. Now, however, with the advent of GIS and GPS in both office and field applications, users must become proficient with a number of earth coordinate systems.

Geographic coordinates (i.e., latitude and longitude) are based on a *spherical* coordinate system in which lines of longitude (meridians) converge as one moves from the Equator to the poles. As a result of this convergence, one degree of meridian arc subtends varying linear distances on the earth's surface depending on your location north or south of the equator. Use of such a spherical coordinate system across large areas becomes problematic since a single "ruler" does not exist -- whereas one degree of longitude spans nearly seventy miles at the equator, it measures less than fifty miles at 45^{o} N (in northern Michigan).



Plot of longitude degree lengths against latitude showing how longitude degrees diminish in length towards the poles

As a consequence of the difficulties working with the geographic graticule (i.e., latitude and longitude), most geospatial data are referenced to rectangular or *Cartesian* grid systems. In Michigan, we need to know about three different rectangular coordinate systems: Michigan State Plane (three versions), Michigan GeoRef and UTM.

Latitude, Longitude Precision

- 1 degree of Latitude (averaged in MI)
  - 111,121.04 meters
    - 0.0001^o = 11.11 meters
    - 00^o 00' 00.1" = 3.11 meters

- 1 degree of Longitude (averaged in MI)
  - 79,467.75 meters
    - 0.0001^o = 7.95 meters
    - 00^o 00' 00.1" = 2.23 meters

Rectangular Coordinate Systems in Michigan

Michigan State Plane Coordinate System

It became obvious to surveyors and others that it would be much simpler if locations could be designated on planar, Cartesian grids, rather than on the spherical graticule. This is what was accomplished by the U.S. Coast and Geodetic Survey (now the National Geodetic Survey – NGS within NOAA) in the early 1930s. For each state, a flat grid network was constructed to confine scale distortions to no more than 1 part in 10,000 (i.e., 100 parts per million). If a state extended predominantly in an east-west direction,

the grid was positioned on a Lambert Conic Conformal projection. It was positioned on a Transverse Mercator projection in states whose principal span was north-south.
The logic of the state plane coordinate system (SPCS) is consistent across the nation. States are broken into zones whenever their area is too large to accommodate a single grid whose scale distortions are less than one in 10,000. Alaska, for instance, is covered by ten zones; California has seven and Rhode Island required just one. Michigan has three zones. The limits of these zones follow state and county boundaries. Each zone has its own central meridian and origin point. The actual Cartesian origin (i.e., the 0,0 point) is located south and west of the zone to which it applies. In the nomenclature of the state plane coordinate systems, however, "origin" refers to the point where the central meridian for the zone intersects the y = 0 parallel. The central meridian is assigned a *false easting* (i.e., x-value) of several million feet; *northing* values are incremented north from the y = 0 parallel for each zone. Michigan is unique among the states for having had three different state plane systems.

1934 version. The original state plane system for Michigan was created in 1934 and was based on the Transverse Mercator projection (Figure 1) and referenced to NAD 27. It required three zones to cover the state. These zones extended north-south and were called the West, Central and East zones. Each zone had its own central meridian, which was assigned a false easting of 500,000 feet (the unit of measure was the *U.S. Survey Foot* (the one we're all used to), which is equal to 12 / 39.37 meters = 0.3048006 ... meters). The origin parallel (41° 30' 00" N) was the same for all three zones. This produced very large y-values for the Upper Peninsula and northern Lower Peninsula, but the x-values were only a few hundred thousand feet because the zones were narrow in the E-W direction. **For users of old maps, it is important to note that all 7.5-minute quadrangles in Michigan that were printed by USGS before 1964 have this OBSOLETE SPCS printed on them (as tic marks along the neat lines).**

1964 version. Michigan's second SPCS was developed in 1964. It is based on the Lambert Conic Conformal projection and also uses three zones to cover the state. Unlike the previous system, though, these zones extend E-W and are labeled North, Central and South (Figure 2). The central meridian for each zone was given a false easting of 2,000,000 feet (*US Survey Feet*), but every zone had its own origin parallel. Since each zone has a central meridian value of 2 million feet, all x-values in this system are very large (usually > 1 million), while all y-values are constrained to a few hundred thousand feet. The 1964 SPCS was referenced to NAD 27 and is sometimes referred to as the Michigan Coordinate System of 1927 (MCS 27). This retronym came into use after the current (1983) state plane version in Michigan was developed (the previous, obsolete version was also referenced to NAD 27, but it was so outdated that it continued to be called the 1934 SPCS). **All 7.5-minute quadrangles in Michigan printed by USGS in 1964 or later have this SPCS noted on them as tic marks along their neat lines.**

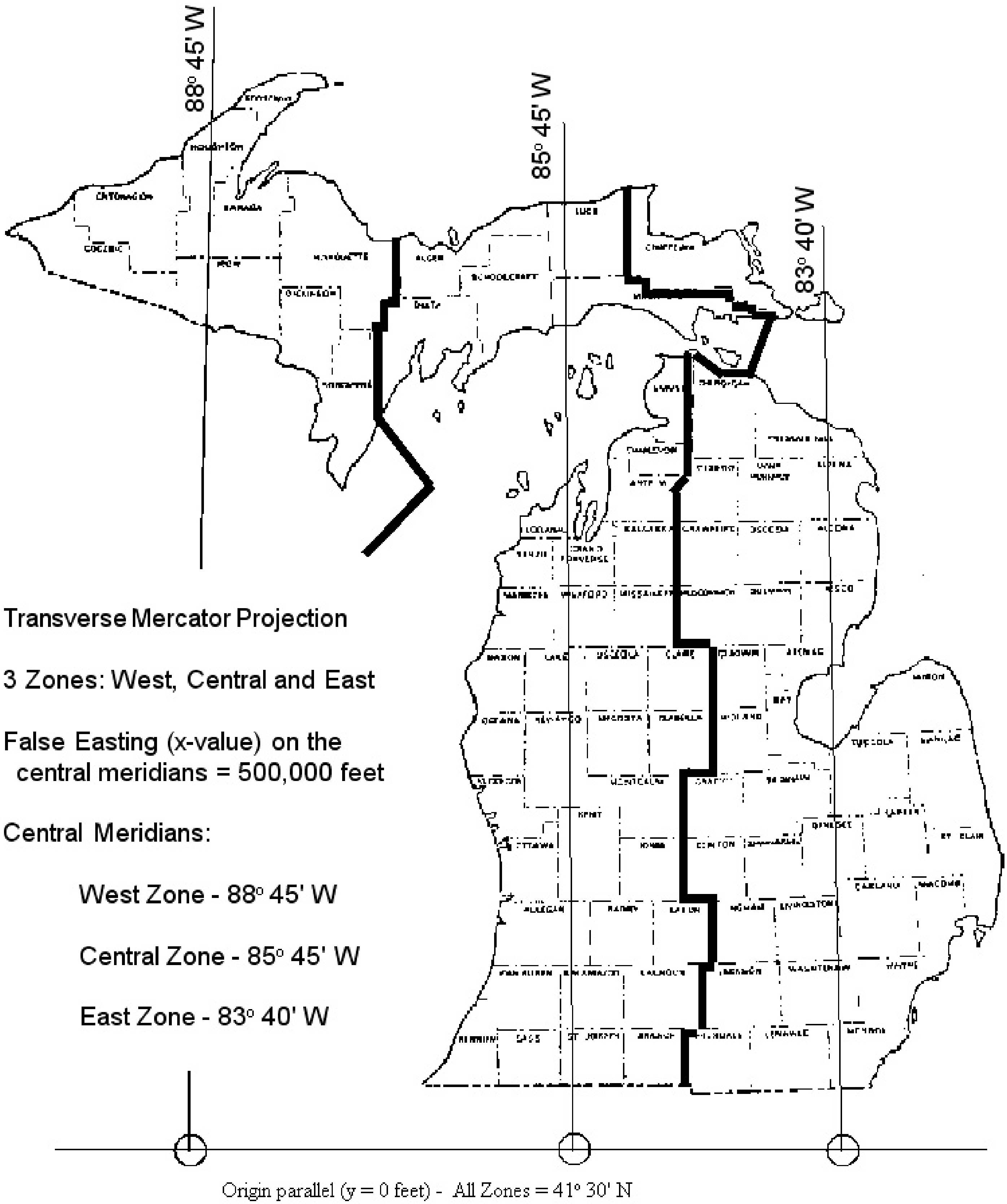


Figure 1. Michigan's original 1934 State Plane Coordinate System. OBSOLETE !

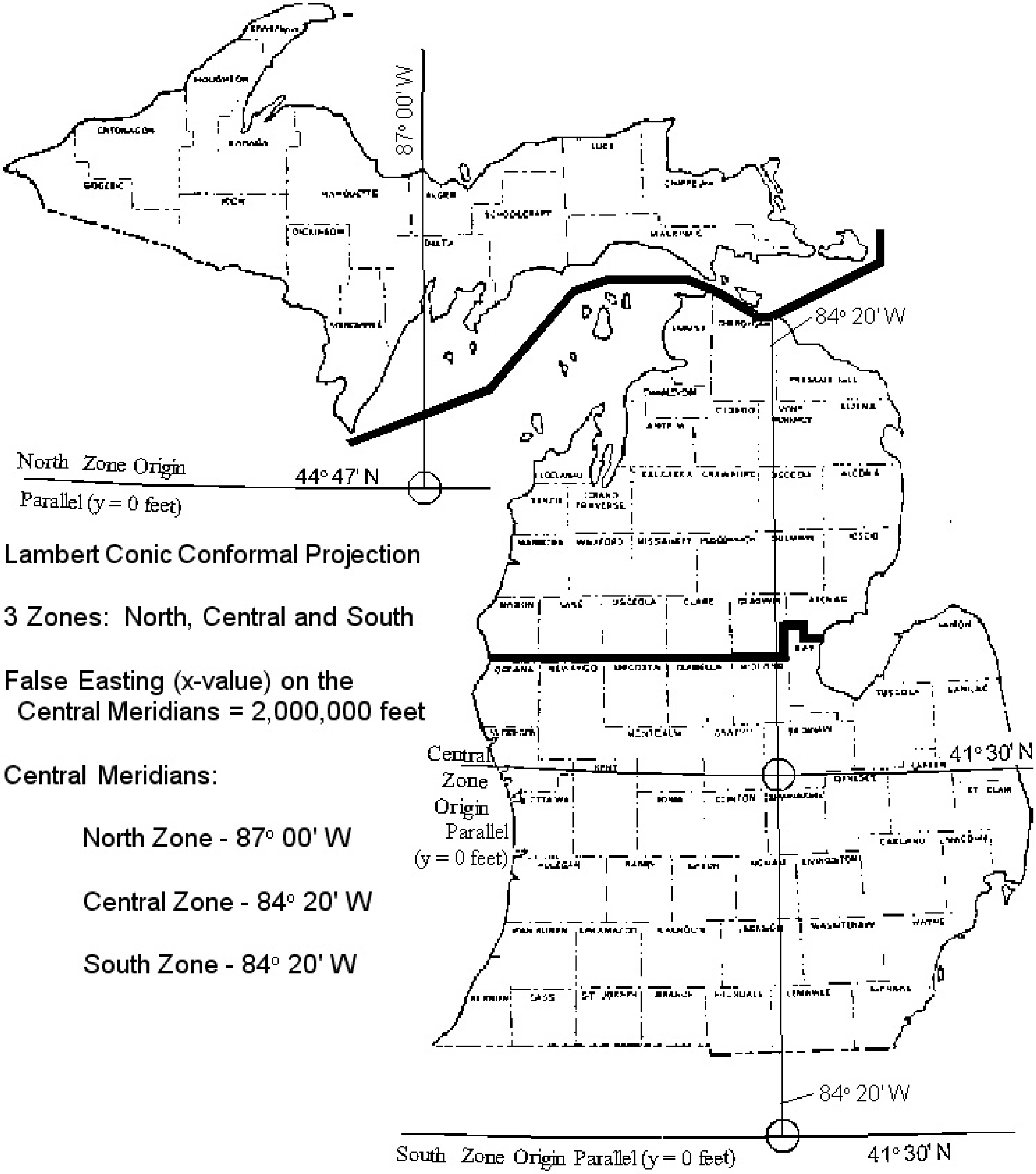


Figure 2. Michigan coordinate system of 1964 (sometimes called MCS 27). OBSOLETE!

1983 (current) version. Michigan Act 154 (P.A. of 1988) changed the coordinate values that are used in the Michigan SPCS because it required that the grid be referenced to NAD 83. This created the Michigan Coordinate System of 1983 (MCS 83), which has the same basic structure as the MCS 27 (i.e., based on the Lambert Conic Conformal projection and uses three zones), **but with altered central meridians and vastly different coordinate value ranges in the three zones** (Figure 3). Act 154 specifies that the unit of measure for the MCS 83 will be either the meter or the *International Foot* (the International Foot = 0.3048 meters, **exactly**, whereas the *U.S. Survey Foot* (the one we're all used to) is equal to 12 / 39.37 meters = 0.3048006 ... meters). The MCS 83 uses a *unique* false easting for *each* zone, so there is ***no x-coordinate value overlap between the zones***. Since the confusion between the International Foot and the U.S. Survey Foot is inevitable, ***it is strongly recommended that all MCS 83 coordinates be expressed in meters.*** Act 154, Section 9 states, "The Michigan coordinate system of 1927 shall not be used after December 31, 1989. The Michigan coordinate system of 1983 shall be the sole system used after December 31, 1989."

Michigan GeoRef Coordinate System

The Michigan GeoRef coordinate system (Figure 4) was designed in 1972 by Dr. Ralph Moore Berry, a professor of geodetic engineering at the University of Michigan. Its greatest advantage compared to the other rectangular coordinate systems is that the whole of Michigan, including its territorial waters of the Great Lakes, is contained within **one zone**. Although not commonly used in the past, it is now the state standard for geospatial data.

The Michigan GeoRef coordinate system is based on an Oblique Mercator projection (sometimes called the Hotine Skew Orthomorphic projection) and referenced to NAD 83. The position of a Lambert projection on the spheroid, like the Michigan State Plane Coordinate System, is defined by a pair of parallels and a central meridian. A Transverse Mercator projection, like the UTM grid discussed below, is defined by a central meridian and a scale factor applied to it (0.9996 in the case of the UTM grid). The Oblique Mercator projection used for Michigan GeoRef is similar to a Transverse Mercator projection except that, instead of a central meridian, the center-line of the projection (i.e., the **projection axis**) is a geodetic line, or shortest path on an ellipsoid, corresponding to a Great Circle route on the sphere, having a specified azimuth (angle) at some selected defining point. A scale factor is also assigned along this line -- 0.9996 in the case of the Michigan GeoRef system.

The native coordinates in an Oblique Mercator projection are referenced to a skewed pair of axes, the principal one being the projection axis (called the *u-axis*) and the other one perpendicular to it (called the *v-axis*). As a concession to our cartographic instincts to keep "north at the top", these *u,v* coordinates are rotated through the angle that the projection axis (the *u-axis*) makes with the meridian at the central point. The rotated *u*-coordinates become the y-coordinates and the rotated *v*-coordinates become the x-coordinates. Thus, after rotation, the y-axis is parallel to the meridian that passes through

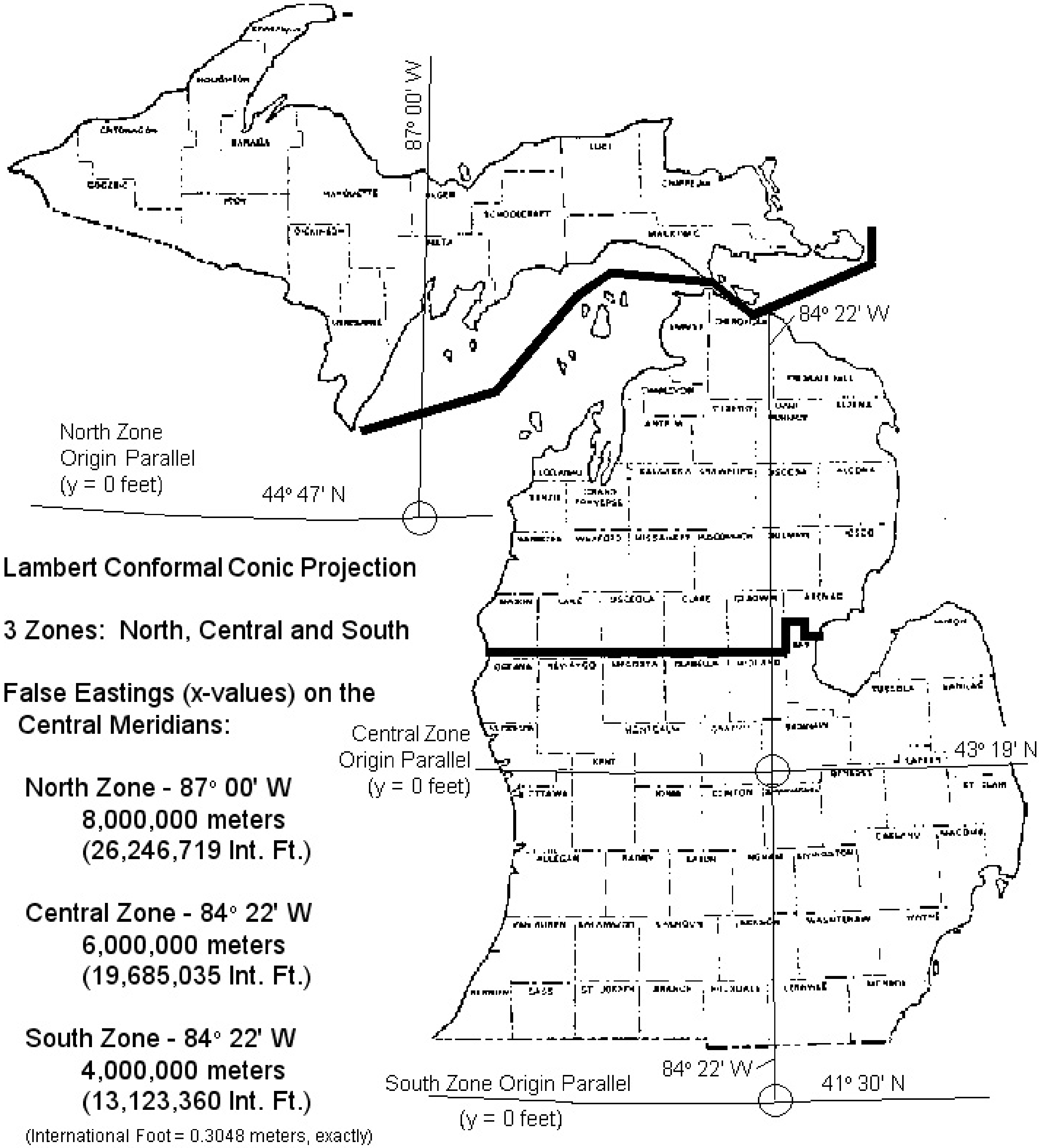


Figure 3. Michigan Coordinate System of 1983, based on NAD 83 (sometimes called MCS 83). Adopted in 1988. CURRENT !

the center point. Following axis rotation, the x,y coordinates are translated to ensure that both are always positive. The numeric values of the translated x,y coordinates are purely arbitrary. Professor Berry positioned the 0,0 origin for Michigan GeoRef in northeastern Missouri (40° 24' 05.6528" N, 91° 52' 56.2121" W) so that all of Michigan would have x- and y-coordinates in the six-digit range of 100,000 – 900,000 meters.

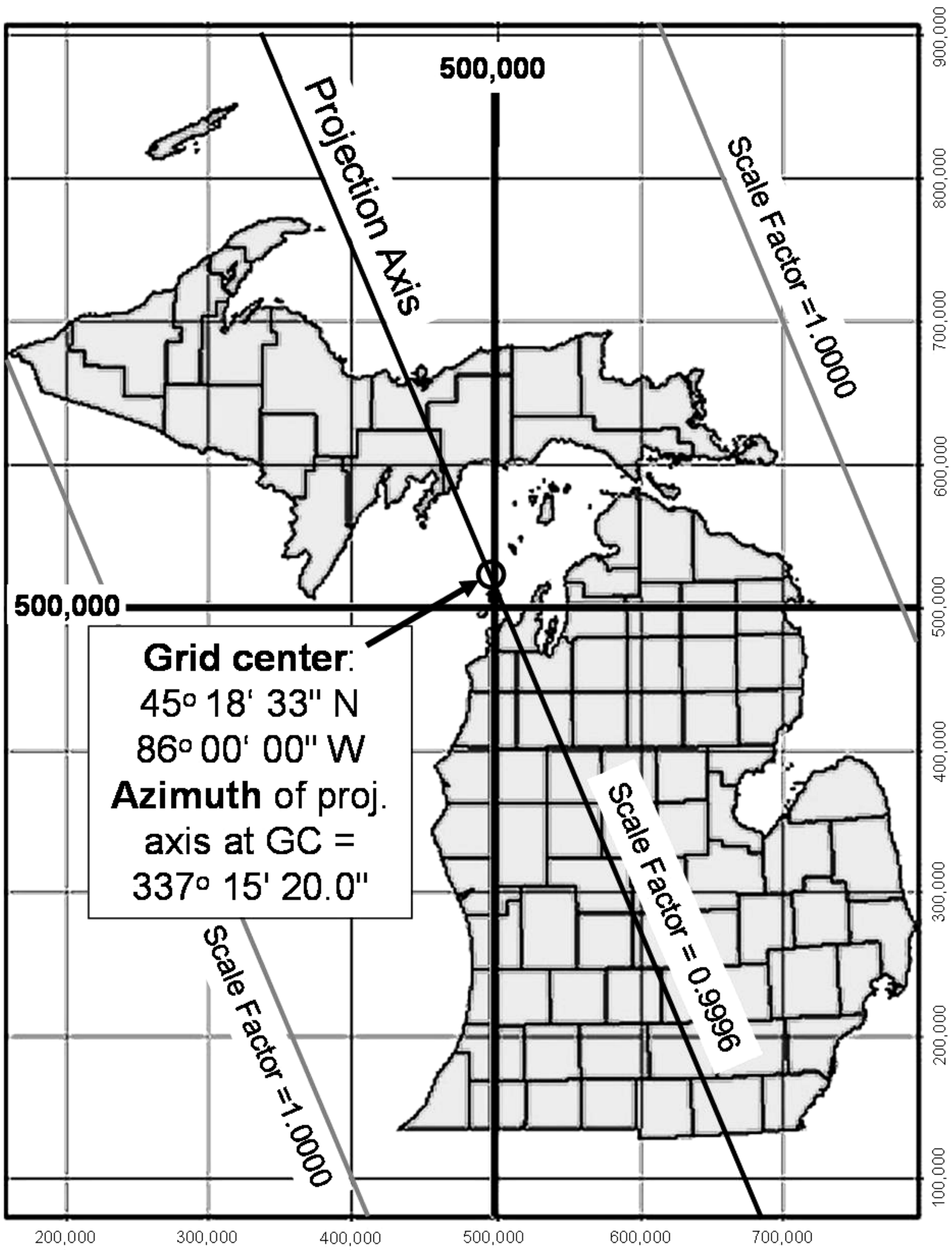


Figure 4. Michigan GeoRef coordinate system (NAD 83).

Universal Transverse Mercator (UTM) Grid

There is one more rectangular (i.e., Cartesian) coordinate system that is used in Michigan, especially by the Federal agencies. It is the Universal Transverse Mercator (UTM) grid (Figure 5). This system, developed by the U.S. Department of Defense, uses sixty 6-degree-wide zones that extend from 80^{o} N to 80^{o} S to cover the globe (the polar regions have there own special grid that is not described here). The UTM grid is based on either NAD 27 or NAD 83 and is projected onto a transverse Mercator, cylindrical projection. **All 7.5-minute, USGS quadrangle maps in Michigan were published before the conversion to NAD 83, so the UTM grids on them are based on the NAD 27 datum.**

Each zone grid is aligned to the central meridian of the zone, which is assigned a false easting value of 500,000 meters. In the Northern Hemisphere, the y-coordinate values simply increment northward from the equator. In the Southern Hemisphere, the equator is assigned a false northing value of 10,000,000 meters.

While the UTM grid has the advantage of covering large geographical areas in one grid zone, this large-area coverage also dictates that the scale distortion of the grid is one part in 2,500 (recall that the SPCS is accurate to one part in 10,000). Another, and more important, disadvantage of the UTM grid is that the zone boundaries are meridians of longitude which cut right through state, county and local government boundaries. This makes it difficult for many GIS users to maintain all of their data in one coordinate space.

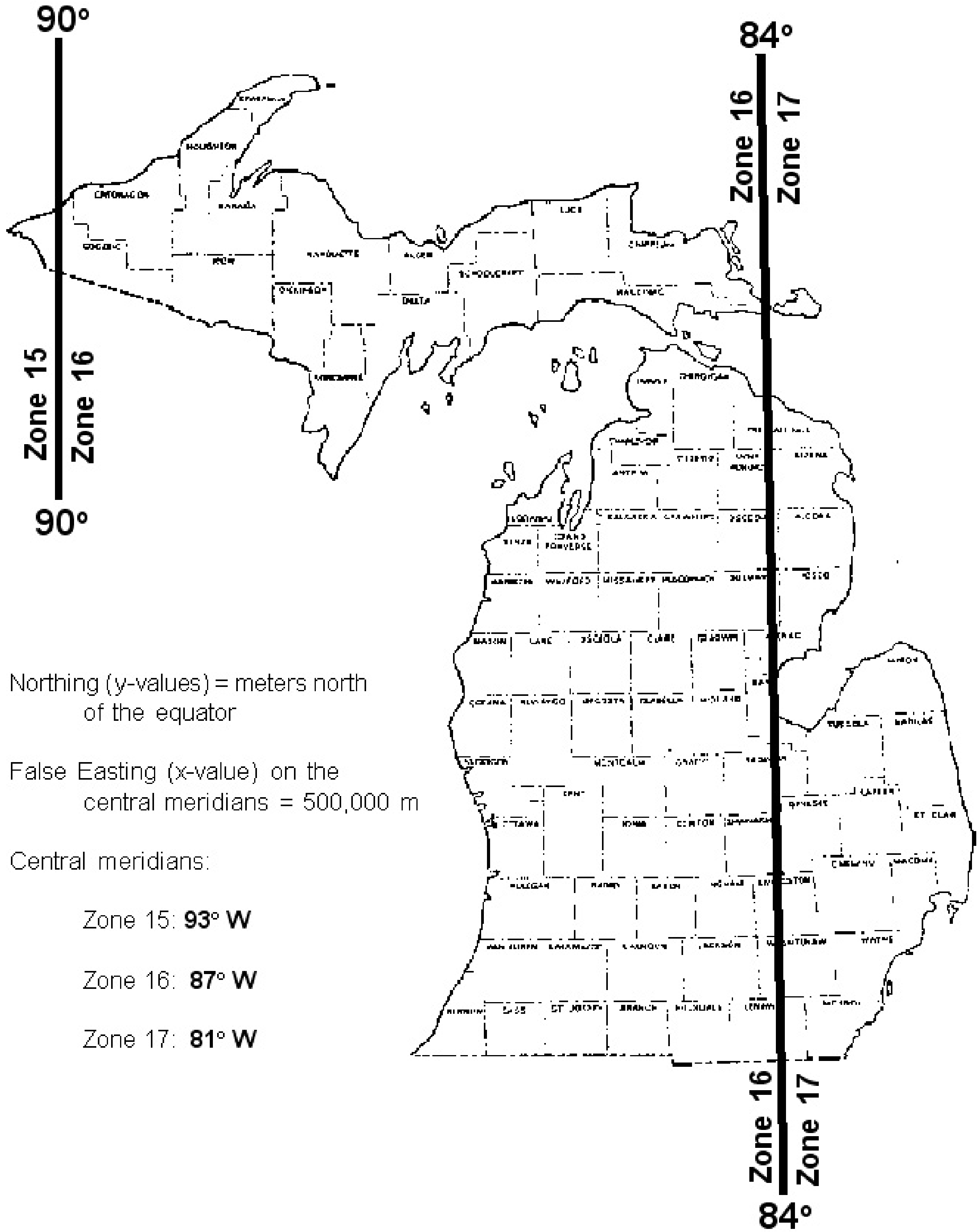


Figure 5. Universal Transverse Mercator (UTM) Grid in Michigan.

Michigan State Plane Coordinate Systems (SPCS)

OBSOLETE Michigan Coordinate system 1927 (Adopted in 1964)

MCS 27, Zone: North

Projection: Lambert Conformal Conic
Southern standard parallel: 45^o 29' N
Northern standard parallel: 47^o 05' N
Latitude of grid origin: 44^o 47' N
Central meridian: 87^o 00' W
Scale factor at 44^o 47' N: 1.00024228
Northing value at grid origin: 0 feet
Easting value at grid origin: 2,000,000 feet
Units: U.S. Survey feet (1 ft = 12/39.37 [0.3048006...] meters)
Spheroid: **Michigan Spheroid** which is based on the Clarke, 1866, but **is 800 feet above** it at 44^o N. The Michigan Spheroid has the same eccentricity as the Clarke, 1866, but with a semimajor axis equal to 6,378,450.1 meters (i.e., 1.0000382 times the semimajor axis of the Clarke, 1866 which is 6,378,206.4 meters).

MCS 27, Zone: Central

Projection: Lambert Conformal Conic
Southern standard parallel: 44^o 11' N
Northern standard parallel: 45^o 42' N
Latitude of grid origin: 43^o 19' N
Central meridian: 84^o 20' W
Scale factor at 43^o 19' N: 1.00031070
Northing value at grid origin: 0 feet
Easting value at grid origin: 2,000,000 feet
Units: U.S. Survey feet (1 ft = 12/39.37 [0.3048006...] meters)
Spheroid: Michigan Spheroid (see description in MCS 27, Zone: North, above)

MCS 27, Zone: South

Projection: Lambert Conformal Conic
Southern standard parallel: 42^o 06' N
Northern standard parallel: 43^o 40' N
Latitude of grid origin: 41^o 30' N
Central meridian: 84^o 20' W
Scale factor at 41^o 30' N: 1.00019585
Northing value at grid origin: 0 feet
Easting value at grid origin: 2,000,000 feet
Units: U.S. Survey feet (1 ft = 12/39.37 [0.3048006...] meters)
Spheroid: Michigan Spheroid (see description in MCS 27, Zone: North, above)

CURRENT Michigan Coordinate system 1983 (Adopted in 1988).

MCS 83, Zone: North (NOAA/NGS # 2111)

Projection: Lambert Conformal Conic
Southern standard parallel: 45^{o} 29' N
Northern standard parallel: 47^{o} 05' N
Latitude of grid origin: 44^{o} 47' N
Central meridian: 87^{o} 00' W
Scale factor at projection origin: 0.999902834466
Northing value at grid origin: 0 meters (0 Intnl Ft)
Easting value at grid origin: 8,000,000 meters (26,246,719 Intnl Ft)
Units: Meters or International Feet (1 Intnl Ft = 0.3048 meter, exact)
Spheroid: GRS 80

MCS 83, Zone: Central (NOAA/NGS # 2112)

Projection: Lambert Conformal Conic
Southern standard parallel: 44^{o} 11' N
Northern standard parallel: 45^{o} 42' N
Latitude of grid origin: 43^{o} 19' N
Central meridian: 84^{o} 22' W
Scale factor at projection origin: 0.999912706253
Northing value at grid origin: 0 meters (0 Intnl Ft)
Easting value at grid origin: 6,000,000 meters (19,685,039 Intnl Ft)
Units: Meters or International Feet (1 Intnl Ft = 0.3048 meter, exact)
Spheroid: GRS 80

MCS 83, Zone: South (NOAA/NGS # 2113)

Projection: Lambert Conformal Conic
Southern standard parallel: 42^{o} 06' N
Northern standard parallel: 43^{o} 40' N
Latitude of grid origin: 41^{o} 30' N
Central meridian: 84^{o} 22' W
Scale factor at projection origin: 0.999906878420
Northing value at grid origin: 0 meters (0 Intnl Ft)
Easting value at grid origin: 4,000,000 meters (13,123,360 Intnl Ft)
Units: Meters or International Feet (1 Intnl Ft = 0.3048 meter, exact)
Spheroid: GRS 80

Michigan GeoRef Coordinate System

Projection:	Oblique Mercator (Hotine Skew Orthomorphic)	
Latitude of grid center:	45° 18' 33" N	
Longitude of grid center:	86° 00' 00" W	
Azimuth of projection axis at grid center:	337° 15' 20.016"	(337.25556°) [1214120.016"]
Northing value at grid center:	528,600.240 meters (NAD 83)	
Easting value at grid center:	499,839.834 meters (NAD 83)	
Scale factor on projection axis:	0.9996	
Units:	Meters	
Datum:	NAD 83	
Ellipsoid:	GRS 80 (for NAD 83)	

UTM -- Universal Transverse Mercator

Zone: **15** Zone limits: 96^o - 90^o W
Projection: transverse Mercator
Latitude of grid origin: 0^o N
Central meridian: 93^o W
Northing value at grid origin: 0 meters
Easting value at grid origin: 500,000 meters
Scale factor on central meridian: 0.9996
Units: Meters
Spheroid: Clarke, 1866
Secant lines: 320,000 meters; 680,000 meters
(scale factor = 1.000)

Zone: **16** Zone limits: 90^o W, 84^o W
Projection: transverse Mercator
Latitude of grid origin: 0^o N
Central meridian: 87^o W
Northing value at grid origin: 0 meters
Easting value at grid origin: 500,000 meters
Scale factor on central meridian: 0.9996
Units: Meters
Spheroid: Clarke, 1866
Secant lines: 320,000 meters; 680,000 meters
(scale factor = 1.000)

Zone: **17** Zone limits: 84^o W, 78^o W
Projection: transverse Mercator
Latitude of grid origin: 0^o N
Central meridian: 81^o W
Northing value at grid origin: 0 meters
Easting value at grid origin: 500,000 meters
Scale factor on central meridian: 0.9996
Units: Meters
Spheroid: Clarke, 1866
Secant lines: 320,000 meters; 680,000 meters
(scale factor = 1.000)

Lengths of One Degree

Length of 1 degree of LATITUDE at various latitudes

LAT ZONE	1^o LAT =
41^o - 42^o	111,061.9 meters
42^o - 43^o	111,081.6
43^o - 44^o	111,101.3
44^o - 45^o	111,121.0
45^o - 46^o	111,140.8
46^o - 47^o	111,160.5
47^o - 48^o	111,180.2

Length of 1 degree of LONGITUDE at various latitudes

LAT	1^o LONG =
41^o	84,137 meters
42^o	82,853
43^o	81,543
44^o	80,208
45^o	78,849
46^o	77,466
47^o	76,058

Length of One Second of Arc (00° 00' 01")

based on the Clarke 1866 spheroid

In Michigan

latitude band	Length (meters) of **01" LAT**	Length (meters) of **01" LONG**
41° - 42°	30.851	23.193
42° - 43°	30.856	22.833
43° - 44°	30.862	22.465
44° - 45°	30.867	22.091
45° - 46°	30.872	21.710
46° - 47°	30.878	21.323
47° - 48°	30.883	20.929
48° - 49°	30.889	20.528