FDM 9-20-1 General

February 28, 2001

The discipline of surveying consists of determining or establishing relative positions of points above, on, or beneath the surface of the earth. In Wisconsin, there are two primary spatial reference systems for defining the location of a point:

- The U.S. Public Land Survey System (PLSS).
- The National Spatial Reference System (NSRS).

The PLSS is based on a system of townships, ranges, and sections (see FDM 9-20-5). The PLSS provides the basis for almost all legal descriptions of land.

The NSRS, which includes the former National Geodetic Reference System (NGRS), is a mathematical reference system (see FDM 9-20-10). The NSRS consists of precisely measured networks of geodetic control that support accurate mapping over large areas.

To understand the roles of these reference systems, it is important to recognize that the PLSS was designed for land ownership purposes but not for accurate mapping, and the NSRS was designed for geodetic surveying and mapping but not for land ownership documentation.

Since accurate property maps are becoming essential with digital-based ownership documents, it is important that there be a substantial link between the two reference systems. Methods are needed to utilize the spatial characteristics of the NSRS when addressing the location of landmarks. Fortunately, recent technological developments such as the Global Positioning System (GPS), electronic total station survey instruments, and computer aided drafting (CAD) now make the task of using the PLSS and NSRS together more efficient, economical, and practical.

FDM 9-20-5 The Public Land Survey System

July 23, 2015

The interest of the present-day engineer or surveyor in the Public Land Survey System (PLSS) is in the preservation of existing monumentation, retracing of original survey lines and in the subdivision of sections into smaller units. For these reasons, it is imperative that one be familiar with the methods used in the original survey.

The PLSS consists of a rough grid network of surveyed lines and monuments originally established for the purpose of subdividing federal lands prior to public sale. This network covers approximately 72 per cent of the United States and covers 30 states, including Wisconsin. The network partitions the landscape into one mile by one mile areas called ‘sections’, nominally containing 640 acres. Thirty-six sections constitute a township. Each township is identified by its ‘Township’ number (north or south) and its ‘Range’ number (east or west) from an Initial Point. An Initial Point is the origin for PLSS surveys for a given area; there are several Initial Points throughout the United States.

The PLSS was introduced in Wisconsin in 1831 when the Initial Point for the 4th Principal Meridian was established by a government surveyor on what is now the border with Illinois. From this Initial Point, a true north-south line called a principal meridian was run to the north to the limits of the area to be covered. A base line was then extended to the east and west from the initial point as a true parallel of latitude to the limits of the area to be covered. This base line defines the Illinois/Wisconsin state line. The area covered by the 4th Principal Meridian covers all of Wisconsin and parts of Minnesota north and east of the Mississippi River to the Canadian border. The upper peninsula of Michigan is not included in the area covered by the 4th Principal Meridian.

The land was then subdivided into townships by surveying lines that define townships and ranges at 6 mile intervals. The resulting pattern of PLSS Townships and Ranges for the State of Wisconsin is shown in Attachment 5.1. Each township is identified by its number north or south of the base line, followed by its number east or west of the principal meridian. An example is Township 5 North, Range 7 East, of the 4th Principal Meridian. Abbreviated, this becomes T5N, R7E, 4th PM. All townships in Wisconsin are numbered north from the state line.

The subdivision of a township into sections was the final step undertaken by the original land surveyors. Sections were numbered from 1 to 36, beginning in the northeast corner of a township and ending in the southeast corner, as shown in Attachment 5.2. The underlying principle of subdividing townships into sections was to produce the maximum number of sections with a nominal dimension of 1 mile on a side. A section was the basic unit of land transfer but often land continues to be patented in parcels smaller than a section. Further subdivision of sections continues to be performed by local surveyors under rigid guidelines established by the Bureau of Land Management (BLM). The legal descriptions for nearly every parcel of land in Wisconsin reference the PLSS.

For more detailed information on the PLSS, please consult any introductory surveying textbook or the Manual of Surveying Instructions published by the Bureau of Land Management (BLM),

http://www.blm.gov/pgdata/content/wo/en/prog/more/cadastralsurvey/2009_edition.html

There are three key points to note about the PLSS.

1. It is a legal not a mathematical system. The length of one mile for a section boundary line and 640 acres for its area are nominal. Measurements could vary by hundreds of feet and many acres and still were accepted by the federal government. Easy to understand boundary locations were paramount, so corner locations as monumented by the original surveyors, right or wrong, are the legally recognized corner locations.
2. Perpetuation of original locations of section and quarter section corners is vital to the long term viability of the PLSS. The federal government was responsible for establishment of the PLSS but is not responsible for its maintenance. It is the responsibility of state and local agencies to maintain the PLSS. The department's policy on perpetuation of landmarks is detailed in FDM 9-5-1.
3. PLSS corners and Geodetic Survey Control Stations are two of the most significant types of monuments found within road rights of way. PLSS corners are used to help identify land ownership boundaries and geodetic survey control stations mark a location with a precise elevation and/or latitude and longitude. They are two completely separate entities. If PLSS monuments are disturbed or destroyed, they can be replaced in substantially the same location using local references. Geodetic survey control stations, if disturbed or destroyed, must be replaced and resurveyed in their entirety due to their precision.

There are two key points to remember about the PLSS. First, it is not a mathematical system. The measures of one mile for a section line and 640 acres for the area of a section are only nominal and can be off by hundreds of feet and numbers of acres, respectively. The law has dictated that PLSS boundaries were fixed by surveyors' monuments, not surveyors' measurements (which are never perfect). This leads to the second key point, perpetuation of original locations of section and quarter section corners is vital to the long term viability of the PLSS. The federal government was responsible for establishment of the PLSS but is not responsible for its maintenance. It is the responsibility of state and local agencies to maintain the PLSS. The department's policy on perpetuation of landmarks is detailed in FDM 9-5-1.

LIST OF ATTACHMENTS

Attachment 5.1	Pattern of PLSS Townships & Ranges for Wisconsin
Attachment 5.2	Method of Numbering Sections

FDM 9-20-10 The National Spatial Reference System (NSRS) *July 23, 2015*

The National Spatial Reference System (NSRS) is a consistent national coordinate system that specifies latitude, longitude, height, scale, gravity, and orientation throughout the nation, as well as how these values change with time. The system is managed by the National Geodetic Survey (NGS). NSRS information is available at the NGS web site:

http://www.ngs.noaa.gov

The NSRS incorporates the horizontal data and the vertical data from the old National Geodetic Reference System. The NSRS, however, can better accommodate positioning with the Global Positioning System (GPS) by use of a three-dimensional geographical coordinate system. When only horizontal positioning is needed, the position may be adequately referenced to a two-dimensional rectangular coordinate system at a single selected height.

For NSRS accuracy standards refer to “Geospatial Positioning Accuracy Standards, Part 2: Standards for Geodetic Networks, FGDC-STD-007.2-1998,” available at:

https://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part2/chapter2

10.1 Horizontal Network

The horizontal geodetic control network in Wisconsin consists of monumented points (geodetic control stations) with accurately determined horizontal positions. Typically, horizontal control stations in the Wisconsin High Accuracy Reference Network (WI HARN) are spaced 50 km apart. The horizontal position of WI HARN control stations has been determined using GPS which is more accurate than the previously used triangulation methods. WI HARN stations have minimum horizontal accuracy of A-order or B-order (95 percent confidence of 0.01 m to 0.05 m, respectively). The 95 percent confidence for area triangulation was typically 0.2 m to 0.6 m.

Some counties have developed a subsequent set of points within their county as a User Densification Network (UDN) with stations positioned relative to the WI HARN stations. Often referred to as “County HARN” stations, the UDN stations typically are spaced at 25 km, 12 km, and 6 km for primary, secondary, and tertiary control, respectively.

10.2 Vertical Network

The vertical geodetic control network in Wisconsin consists of monumented points (bench marks) with accurately determined elevations (orthometric heights). Typically, bench marks are spaced 1.5 to 2.5 km apart along level lines spaced approximately 50 km apart. In the 1900s, the elevation of a bench mark was determined by the traditional method of measuring successive elevation differences between adjacent bench marks along railroads or highway corridors.

The vertical accuracy of a bench mark was based on the leveling methods used and the difference of two series of vertical measurements between adjacent bench marks. Typically, accuracy ranged from 0.001 m for difference in elevation between two adjacent bench marks to 0.110 m for a vertical control loop. In 1999 GPS technology started to provide a three-dimensional position for selected WI HARN, User Densified Networks (UDN), and project stations with an orthometric height accuracy of 0.020 m.

10.3 Monumentation

To use NSRS data effectively, a system of monumentation must exist. Permanently monumented geodetic control stations and bench marks serve as necessary references for mapping; for Geographic and Land Information Systems; and for planning, design, and construction of engineering projects. When linked to the U.S. Public Land Survey System (PLSS), geodetic control monuments can help perpetuate the system of land ownership. State and local agencies have built upon the WI HARN to further densify the horizontal and vertical geodetic control monumentation.

FDM 9-20-15 Horizontal Datums *July 23, 2015*

A horizontal datum consists of a geodetic reference surface, an origin, and an orientation. The geodetic reference surface is a mathematically defined ellipsoid, also called a spheroid. A horizontal geodetic control network provides the horizontal positional information (e.g., latitude and longitude) on a horizontal datum. The following horizontal datums[1] have been used for transportation projects in Wisconsin.

- NAD 27
- NAD 83 (1986)
- NAD 83 (1991)(see FDM 9-5-10)
- NAD 83 (1997)
- NAD 83 (2007)
- NAD 83 (2011)

Horizontal surveying measurements are made on the surface of the earth (ground), but position computations are usually made on the ellipsoid. It would not be practical to use the actual surface of the earth as a basis for the mathematical positions because the surface is too irregular. Therefore, the ellipsoid is the reference surface for latitude and longitude positions.

15.1 North American Datum of 1927

The North American Datum of 1927 (NAD 27) was used as the primary reference datum for horizontal positions in the United States from 1927 until 1986. NAD 27 has its origin at Meades Ranch in Kansas and is based on the Clarke spheroid of 1866. The Clarke spheroid of 1866 is a regional ellipsoid with a “best fit” for the North American continent. The dimensions of the Clarke spheroid of 1866 are as follows:

Equatorial Radius (a) = 6 378 206.4 m

[1] Technically, “NAD 83 (1986),” “NAD 83 (1991),” and “NAD 83 (1997)” are three different adjustments on the NAD 83 datum; however, they are commonly referred to as different datums.

Polar Radius (b)= 6 356 583.8 m

Flattening (a-b)/a= 1/294.978

Because NAD 27 is a based on a regional ellipsoid and not a geocentric (earth centered) one, it became apparent that there was an increasing need to develop a new geocentric datum for worldwide applications. Advances in surveying technology and original datum design limitations also contributed to making NAD 27 obsolete.

15.2 North American Datum of 1983 (1986)

This new geocentric datum is called North American Datum of 1983 (NAD 83). The original name for this datum was NAD 83, but subsequent refinements of station latitude and longitude values necessitated adding an adjustment year after the NAD 83 whenever an adjustment to station coordinates was made by NGS. The original NAD 83 adjustment should be referred to as NAD 83 (1986). Any outdated latitude and longitude positions published by NGS become a permanent part of the superseded data for that station. However, NGS does not provide coordinate or elevation values on outdated adjustments for new stations. NAD 83 (1986) is based on an ellipsoid defined by the Geodetic Reference System of 1980 (GRS 80). GRS 80 is an earth-centered ellipsoid useful for the entire world. The dimensions of the GRS 80 ellipsoid are:

Semimajor axis, a= 6 378 137 m (exact by definition)

Semiminor axis, b= 6 356 752.314 140 3 m (14 significant digits by computation)

Flattening, (a-b)/a= 1/298.257 222 100 88 (14 significant digits by computation)

The North American Datum of 1983, adjustment of 1986 (NAD 83 (1986)) was the first adjustment to fit data to the GRS 80 ellipsoid. Although NAD 83 (1986) is more compatible with Global Positioning System (GPS) technology than its predecessor, NGS could not take full advantage of this "new" technology when performing the first adjustment. Continuing GPS developments, including higher accuracy and greater densification, led to a readjustment of Wisconsin stations in 1991. As a result, NAD 83 (1986) will probably be used very little in the future in Wisconsin.

15.3 North American Datum of 1983 (1991)

In 1988, the National Geodetic Survey (NGS) and WisDOT began establishing what is now called the Wisconsin High Accuracy Reference Network (WI HARN). This is a network of 80 accurate (A-order and B-order) geodetic control stations which are evenly spaced at approximately 50 kilometers throughout the state with additional (first-order) control stations at many Wisconsin airports. The 1990 and 1991 GPS observations of these stations have been adjusted and the results published by NGS as referenced to the North American Datum of 1983, adjustment of 1991 (NAD 83 (1991)). The department currently uses the WI HARN as base control for surveying and large-scale mapping for transportation projects (see FDM 9-5-10).

Information concerning locations and coordinates of the WI HARN stations is at NGS Web site.

http://www.ngs.noaa.gov/

For descriptions of WI HARN stations and other network stations, go to the NGS Data Sheets Web site and select a method of retrieval.

http://www.ngs.noaa.gov/cgi-bin/datasheet.prl

15.4 North American Datum of 1983 (1997)

During the 1997 WI HARN survey NGS and WisDOT observed many of the stations previously observed in 1990 and 1991 during the first WI HARN survey, observed new stations at airports, and observed stations which were tied to the International Great Lakes Datum (see FDM 9-20-20). The 1997 observations have been adjusted and published by NGS as referenced to the North American Datum of 1983, adjustment of 1997 (NAD 83 (1997)).

15.5 North American Datum of 1983 (2007)

In 2007, the National Geodetic Survey completed a nationwide adjustment of nearly all historic documented GPS projects. This adjustment includes only GPS surveyed projects and no longer includes historic triangulation observations. Older triangulation stations will no longer be updated to a new adjustment unless they are part of a GPS project. Previous to this adjustment, projects were usually adjusted state-by-state, resulting in a good fit within a state, but sometimes there were accuracy issues between adjoining states. The 2007 national horizontal adjustment provided more reliable horizontal coordinate results between adjoining states. This adjustment was constrained to the NGS Continuously Operating Reference Stations (CORS) network realization known as NAD 83 (CORS 96). The 2007 horizontal adjustment is identified as NAD 83 (2007).

15.6 North American Datum of 1983 (2011)

Shortly after completing the 2007 horizontal adjustment, NGS began an extensive project to compute improved positions on the National Geodetic Survey (NGS) CORS network stations. The project took 4 years to complete and was known as the Multi-Year CORS Solution (MYCS). Officially released in September of 2011, it is often identified as the MYCS or MYCS (2011). Because the published positions of the CORS were revised by the MYCS project, the positions of passive marks (marks in the ground) were now slightly inconsistent with the CORS network. Wisconsin and a handful of other states requested that NGS readjust the GPS vectors that were used to position the passive marks. The NGS was receptive to this and agreed to complete the requested readjustment nationwide. The result was that published positions of the passive marks were now consistent with the CORS values that were established by the new MYCS (2011). This new realization of the positions of the passive marks is identified as NAD 83 (2011). In Wisconsin, the shift between NAD 83 (2007) and NAD 83 (2011) is approximately 0.06 feet horizontally and approximately 0.11 feet vertically.

15.7 Datums Compared

The latitude and longitude of the passive geodetic survey control stations in the national control network have changed as a result of shifting from one adjustment to another; i.e. NAD 83 (2007) to NAD 83 (2011). Most of the differences are due to additional GPS measurements to the stations resulting in different positional determinations. Other factors may include advances in GPS technology and methodology, a slight shift of the physical location of the monument, crustal motion or in the case of NAD 27 to NAD 83 (1986), a complete redefinition of the ellipsoid defining the datum. Additionally, the State Plane Coordinate System of 1983 was defined to differ significantly from the State Plane Coordinate System of 1927 (see FDM 9-20-25).

The range of differences between the geographic coordinate values in different systems is shown in the table below.

Table 15.1 Differences in Geographic Coordinates Between Systems

Systems being compared	Δ Latitude	Δ Longitude
NAD 27 and NAD 83 (1986)	-28 ft to +8 ft	+16 ft to +52 ft
NAD 83 (1986) and NAD 83 (1991)	-1.3 ft to +1.0 ft	-1.0 ft to +1.0 ft
NAD 83 (1991) and NAD 83 (1997)	-0.3 ft to +0.3 ft	-0.3 ft to +0.6 ft
NAD 83 (1997) and NAD 83 (2007)	-0.01 ft to +0.06 ft	-0.01 ft to +0.02 ft
NAD 83 (2007) and NAD 83 (2011)	-0.02 ft to +0.01 ft	+0.05 ft to +0.07 ft

Although there are tools available to convert between most of the various datums, they should be used with caution (see FDM 9-20-30).

FDM 9-20-20 Vertical Datums

July 23, 2015

20.1 Introduction

In addition to latitude and longitude, each point also has an elevation, i.e, its distance above or below a vertical datum surface. Vertical measurements are made with respect to gravity, thus the vertical network is based on a geoid, a surface of equivalent gravity. The geoid is represented by the surface formed if the oceans were free to flow and adjust to the combined effects of the forces due to gravity and the earth's rotation. This is equivalent to mean sea level without any continents - a surface of equal gravity.

20.2 National Geodetic Vertical Datum Of 1929 (NGVD 29)

The National Geodetic Vertical Datum of 1929 (NGVD 29) was originally named the Sea Level Datum of 1929 and based on an approximation of what was believed to be mean sea level in 1929. NGVD 29 was based on 26 tidal stations in the U.S. and Canada. Numerous errors and distortions have been revealed over the years and thousands of benchmarks have been lost. These factors have made it increasingly more difficult to fit new data to old projects.

20.3 North American Vertical Datum Of 1988 (NAVD 88)

The re-leveling and densification of the NGVD 29 vertical network resulted in the North American Vertical Datum of 1988 (NAVD 88). Refer to the NOAA web site for more information on the establishment of NAVD 88.

http://www.ngs.noaa.gov/faq.shtml

20.3.1 Wisconsin Vertical Adjustments on NAVD 88

In certain parts of Wisconsin, there are three vertical adjustments to NAVD 88. Generally, if a geodetic survey control station was surveyed and the results published by NGS prior to the release of a new adjustment, then the station will likely have an elevation in both the old and new adjustment. Any outdated elevations or coordinates published by NGS become a permanent part of the superseded data for that station. However, NGS does not provide coordinate or elevation values on outdated adjustments for new stations. The vertical adjustments in Wisconsin are referred to as NAVD 88 (1991), NAVD 88 (2007), and NAVD 88 (2012). WisDOT no longer uses the datum tag of NAVD 88 without an adjustment year because of the potential confusion among the three adjustments. The original NAVD 88 adjustment is called NAVD 88 (1991). The datum tag NAVD 88 without an adjustment year shall no longer be used.

20.3.2 Comparison of NGVD 29 to NAVD 88 (1991)

The "zero" line for the shift between NGVD 29 and NAVD 88 (1991) values runs through the center of Wisconsin, resulting in a minimal impact for the state. In Wisconsin, the shifts in elevation between the two datums range from +0.15 to -0.25 foot.

20.3.3 NAVD 88 (2007)

The Wisconsin Height Modernization Program (HMP) (see FDM 9-5-1.2) has produced a large quantity of differential leveling data that identified some updates to geodetic control station elevations that were originally published as NAVD 88 (1991). Because there were a large number of changes to previously published elevations, NGS did an adjustment of leveling data in 2007 in the southern and eastern portion of the state. At some geodetic survey control stations, the differences between the NAVD 88 (1991) and NAVD 88 (2007) values were as much as 0.25 foot.

20.3.4 NAVD 88 (2012)

The addition of more HMP leveling data in the Door County area and in the northwestern areas of Wisconsin revealed issues trying to match elevations of previous work done in Minnesota, Michigan, and along the Great Lakes level network (see FDM 9-20-20.4). Consequently, all the HMP vertical data finished to this point was adjusted simultaneously to determine the 2012 adjustment. The 2012 adjustment was constrained similarly to the 1991 adjustment; therefore, the elevations of the 2012 adjustment are generally closer to the 1991 elevations than the 2007.

20.4 International Great Lakes Datum (IGLD)

Persons doing survey work along the rivers and lakes of the Great Lakes system will often encounter the International Great Lakes Datum (IGLD 1955 or IGLD 1985). The geodetic basis for level networks such as NGVD 29 and NAVD 88 is known as "orthometric heights or elevations." For these heights, one equipotential surface, mean sea level is selected for the reference surface to which heights are measured. The International Great Lakes Datum uses dynamic height, which is referenced to the equipotential surface at a particular point. The dynamic height varies with the elevation and latitude of the point.

The IGLD is based on water levels that are readjusted every 25 to 35 years to correct for movement of the earth's crust. This rate of movement is not uniform across the great lakes, causing the benchmarks to shift over time, both with respect to each other and with respect to the initial reference point.

It is not uncommon for transportation improvement projects along the Great Lakes to require elevations in both types of elevation systems. A conversion factor relating the land and water datums must be computed for each project for which a relationship is desired. This can become a very complex subject because of the non-uniformity of crustal movement, combined with different reference surfaces. The best source of information on conversion factors is the Office of Ocean and Earth Sciences, a part of the National Oceanic and Atmospheric Administration. When provided with a NGVD 29 benchmark value, they can compute a conversion factor suitable for a particular project site.

The recent incorporation of IGLD(85) into NAVD 88 have brought these two datums closer together. Today they are essentially the same datum, the only remaining difference being the published heights (dynamic vs. orthometric, respectively).

20.5 Local Vertical Datums

Many public and private entities have established local vertical datums unique to a given area. The basis for these local vertical datums may be as simple as assigning elevation zero to the outlet of the sewer line at the sewage treatment plant, or assigning an arbitrary elevation to the city hall steps.

Local vertical datums shall not be used for WisDOT projects without written permission of the Region Survey Coordinator in consultation with the Central Office Surveying & Mapping Section Chief (see FDM 9-5-10).

FDM 9-20-25 Coordinate Systems

February 28, 2001

25.1 Map Projections

A two-dimensional coordinate system using rectangular coordinates (X and Y) is convenient for mapping, measuring project distances, and computing engineering quantities. Unfortunately, the surface of the earth is three-dimensional and ignoring the third dimension introduces errors that increase in magnitude as the project area expands. One way of decreasing this distortion error is to use a projection that defines a mathematical correlation between a three-dimensional reference surface and a two-dimensional developable surface. The two most common projections used to minimize the distortion in shape, area, scale, and direction are the Lambert conformal conical map projection and the transverse Mercator map projection.

25.1.1 Lambert Conformal Conical Map Projection

The Lambert conformal conical map projection uses a cone whose axis is coincident with the axis of rotation of the earth. The cone may be tangent to the reference surface at one predetermined parallel of latitude or cut the reference surface at two predetermined parallels of latitude (see Attachment 25.1, Detail A). If the area of the cone between the two parallels of latitude is developed into a two-dimensional planar surface, it will appear as in Attachment 25.1, Detail B. From a study of these figures, the following observations can be made:

- The meridians (lines of longitude) on the reference surface will appear as straight lines converging at the apex of the cone.
- The parallels (lines of latitude) will appear as segments of concentric circles whose center is the apex of the cone.
- Since the surface of the cone and the reference surface are coincident at the standard parallels (point A to point B, and point C to point D in Attachment 25.1 Detail A and B), the scale along these lines will be exact.
- The scale will be smaller in the area between the standard parallels than along the standard parallels. The scale will be larger in the area outside of the standard parallels than along the standard parallels.
- The closer together the standard parallels are chosen, the more nearly the surface of the projection (i.e., the cone) becomes coincident with the reference surface and the more nearly the projection becomes conformal (distortions are minimized).
- The Lambert projection can be extended indefinitely in an east-west direction without affecting the accuracy of the projection. This projection is more suitable for an area with its greater extent in the east-west direction.

25.1.2 Transverse Mercator Map Projection

The transverse Mercator map projection uses a cylinder whose axis is in the equatorial plane. The cylinder is either tangent to the reference surface along a meridian (the radius of the cylinder is the same as the radius of the reference surface) or the cylinder cuts the reference surface along two lines (the radius of the cylinder is slightly less than the radius of the reference surface). Only the latter case will be addressed further (see Attachment 25.1, Detail C) As the cylinder is developed into a plane surface, it will appear as in Attachment 25.1, Detail D. From a study of these figures, the following observations can be made:

- The meridians (lines of longitude) will appear on the plane surface as curved lines, except the central meridian which will appear as a straight line.
- The parallels (lines of latitude) will appear on the plane surface will appear as curved lines.
- Since the surface of the cylinder and the reference surface are coincident at two lines (point A to point B and point C to point D in Attachment 25.1 Detail C and D), the scale along these lines will be exact.
- The scale will be smaller in the area between the two coincident lines than along the two coincident lines. The scale will be larger in the area outside of the two coincident lines than along the two coincident lines.
- The closer together the two coincident lines are chosen, the more nearly the surface of the projection (i.e., the cylinder) becomes coincident with the reference surface and the more nearly the projection becomes conformal (distortions are minimized).
- The transverse Mercator projection can be extended indefinitely in a north-south direction without affecting its accuracy. This projection is more suitable for an area with its greater extent in the north-south direction.

25.2 Geographic Coordinate System

The global coordinate system of latitude and longitude has angular units (degrees, minutes, and seconds of arc). While this works well for exchanging point data, such units are very difficult to use for computing typical quantities such as length and area. Length and area computations are performed more easily using rectangular coordinates.

25.3 Rectangular Coordinate Systems

The rectangular coordinate systems used in Wisconsin can be described as being either a regional, local, area, or project rectangular coordinate system.

25.3.1 Regional System

This system is commonly used for mapping a large area such as in a geographic information system (GIS) or computer-aided design (CAD) application. The advantage of a regional system is a seamless map over several counties or the entire state. Disadvantages include less accuracy than local systems and problems related to converting the map data from grid coordinates to ground values needed for high-accuracy field work. The regional rectangular coordinate systems used in Wisconsin include the State Plane Coordinate (SPC) system (see FDM 9-20-26), the Universal Transverse Mercator (UTM) coordinate system, and the Wisconsin Transverse Mercator (WTM) coordinate system.

The UTM coordinate system is a global system developed by the U.S. Department of Defense (DOD) for military purposes and the civilian component of the Army Corps of Engineers. The UTM coordinate system has 60 north-south zones arranged edge-to-edge around the equator, each zone being 6 degrees of longitude wide. Zones are numbered from west to east beginning at the 180th meridian. Wisconsin lies partly in UTM zone 15 and partly in UTM zone 16 (see Attachment 25.2). Each UTM zone has an origin on the equator at the intersection of the zone central meridian and the equator. A false easting value of 500,000 meters was assigned to the central meridian to avoid negative coordinate values. Defining parameters for zones 15 and 16 may be found in the “Wisconsin Coordinate Reference System” booklet published in 2009 by the Wisconsin State Cartographer’s Office available at the SCO web site:

http://www.sco.wisc.edu/images/stories/publications/WisCoordRefSys_January2012.pdf

The Wisconsin Department of Natural Resources developed the WTM projection, centered on the 90th meridian, to avoid splitting the state into two UTM zones, as had been done with the DOD UTM coordinate system. This projection created one standard-UTM-size zone (sometimes referred to as UTM Zone 15( ) to cover the entire state (see Attachment 25.3). WTM is an example of a local system designed and created to match a particular need. Defining parameters for WTM 27 and WTM 83 may be found in the “Wisconsin Coordinate Reference System” booklet published in 2009 by the Wisconsin State Cartographer’s Office available at the SCO web site:

http://www.sco.wisc.edu/images/stories/publications/WisCoordRefSys_January2012.pdf

25.3.2 Local System

This system is typically used for smaller areas, often the size of a county, to minimize scale distortions that would occur with a larger regional projection. Advantages of a local system include better "nominal" accuracy and grid (mapped) lengths which are closer to ground lengths. In many cases the difference in lengths is negligible and there is no need to convert between grid lengths and ground lengths. The disadvantages of a local system include a lack of consistent coordinates across local boundaries and the constant need to transform data obtained from outside the local area. The Wisconsin County Coordinate System (WCCS) is an example of a local coordinate system (see FDM 9-20-27).

25.3.3 Area Project System

This system may be established as a simplified version of a regional or local rectangular coordinate system. By using a single combination factor for the entire project area, the computation between grid and ground lengths or coordinates will be simplified. Project coordinates may be necessary when mapping and computations are performed on the grid, yet the final stakeout of right-of-way points, alignment points, etc. must be done with ground distances. The process used to transform the grid coordinate positions to the ground coordinate positions is known as grid to ground coordinate conversion (see FDM 9-20-40). The project coordinate systems that use a combination factor for an area cannot be directly converted to another coordinate system without first converting the coordinates back to their grid values. Past experience has found this to be a confusing issue as data are shared between surveys, design, real estate, construction, and the public.

25.3.4 Project System

This system can be as simple as an “assumed” coordinate system or can be very similar to a local coordinate system but only valid within the area of a transportation project. An “assumed” project rectangular coordinate system may be used on a small project where it is not economical or feasible to establish geodetic control. For a small project, assuming a coordinate system with an origin of X=10,000 and Y=10,000 may be a reasonable choice; however, follow FDM 9-5-10. The disadvantage of using an “assumed” project coordinate system is that the system is not mathematically related to any other established coordinate system. Most likely, future work in the same area will not be able to use the survey data previously acquired; therefore, additional expense will occur to survey the same area again. An “assumed” project coordinate system should be requested for a project only after knowledgeable consideration of potential resurvey costs and the inability to relate the project coordinates to other global coordinate systems.

25.4 Using More Than One Coordinate System

Coordinate systems (geographic or rectangular) referenced to the same horizontal datum, are mathematically related and positional data can be accurately converted from one system to another (see FDM 9-20-30). For example, the coordinates of a point initially in SPC on NAD 83 (1991), may be converted to WCCS on NAD 83 (1991), to another county in WCCS on NAD 83 (1991), or to geographic coordinates (latitude and longitude), and vice versa.

LIST OF ATTACHMENTS

Attachment 25.1	Map Projection
Attachment 25.2	Universal Transverse Mercator Coordinate System
Attachment 25.3	Wisconsin Transverse Mercator Coordinate System

FDM 9-20-26 Wisconsin State Plane Coordinate System

February 28, 2001

The State Plane Coordinate (SPC) system has historically been the most used rectangular coordinate system in Wisconsin. The SPC system is based on three separate Lambert conformal conic map projections, each of which covers one of the zones shown in Attachment 26.1. Because the SPC system is intended for local applications, the boundaries of these zones follow county lines; however, the system is usable for quite some distance beyond the county line with minimal loss of accuracy. The SPC system eliminates problems created by having individual surveys with different project coordinate systems. It provides a common grid plane for all surveys in the zone and each zone is mathematically related to one another. Each zone has a false origin to the south and west of the zone so that all coordinates will have positive values. Defining parameters for SPC systems are found in the “Wisconsin Coordinate Reference Systems” booklet published in 2009 by the Wisconsin State Cartographer’s Office available at the SCO web site:

http://www.sco.wisc.edu/images/stories/publications/WisCoordRefSys_January2012.pdf

Grid coordinate values for the Wisconsin SPC system are typically within the ranges listed below. If values outside of these ranges are encountered, consult with the District Survey Coordinator or the Surveying & Mapping Section.

System	SPC 27 (feet)	SPC 83 (meters)	SPC 83 (feet)
North Zone			
Easting	1,252,000 to 2,508,000	372 000 to 755 000	1,221,000 to 2,476,000
Northing	77,000 to 715,000	23 000 to 218 000	77,000 to 715,000
Central Zone			
Easting	1,252,000 to 2,829,000	372 000 to 853 000	1,221,000 to 2,798,000
Northing	54,000 to 747,000	16 000 to 228 000	54,000 to 747,000
South Zone			
Easting	1,617,000 to 2,659,000	483 000 to 801 000	1,586,000 to 2,627,000
Northing	186,000 to 873,000	57 000 to 266 000	186,000 to 873,000

If an easting coordinate value in feet is less than 1,200,000 in Wisconsin, that coordinate value is not a SPC system value. Some projects have used easting coordinate values of 1 or 2 million less than the SPC system value. Those projects are on a local coordinate system and should not be confused with projects on the SPC system.

LIST OF ATTACHMENTS

Attachment 26.1	Wisconsin State Plane Coordinate System

FDM 9-20-27 Wisconsin County Coordinate System *July 22, 2009*

The Wisconsin County Coordinate System (WCCS) was developed for WisDOT to avoid the confusion associated with grid versus ground coordinates and distances on construction plans and right-of-way plats. The WCCS was developed based on NAD 83 (1991). Current WisDOT policy (see FDM 9-5-10) is to use WCCS or the Wisconsin Coordinate Reference Systems (WISCRS) (see FDM 9-20-28) for all large-scale (small-area) conformal mapping (1:4,800 or larger). Coordinate values listed on construction plans and right-of-way plats will now be listed in the WCCS and indicated by "Y=" and "X=." Because the reference surface occurs at the most commonly occurring ground level in the county, there is no longer a need to convert between grid and ground distances as they are essentially equal for all large-scale mapping.

Caution: Precise geodetic control surveys are not to be conducted in WCCS, use latitude and longitude in a geographic coordinate system.

The WCCS covers the State of Wisconsin with 59 separate sets of projection-defining parameters to cover the 72 zones (see Attachment 1). Some adjacent counties have common parameters but each county has a unique zone number. Defining parameters for the 72 county zones may be found in the "Wisconsin Coordinate Reference Systems" booklet published in 2009 by the Wisconsin State Cartographer's Office or at the SCO web site:

http://www.sco.wisc.edu/images/stories/publications/WisCoordRefSys_January2012.pdf

When using the WCCS for a project in multiple counties, it is important to consider accuracy and legal requirements as data are acquired near or across a county line. Usually loss of accuracy will not be critical unless there is a great difference in elevation between the counties. Legally, there may be a requirement to file documents using the zone of the resident county. Specific requirements should be checked for each project. General requirements are:

- For transportation projects that are continuous in more than one county, the WCCS zone used should change at the county line. Photogrammetric mapping will be provided to the requester with approximately 1000 feet (305 m) of overlap of mapping in both zones. Design plans and plats should be completed in the respective county coordinate system zone.
- For transportation projects that extend into an adjacent county approximately 1000 feet (305 m) or less, the WCCS zone used may remain that of the primary county. Those projects that extend more than approximately 1000 feet (305 m) into the next county should follow the guidance in the previous paragraph.
- For transportation projects that tend to parallel the county line mostly within 1000 feet (305 m) of the county line, the WCCS zone used should be the zone for county A (county A to be selected by the requester which will usually be the county with the majority of the project). The WCCS zone for county A may be used on the plat to be recorded in county B. In this case, it is crucial to document the WCCS zone used and to clearly label the coordinate zone on plans, plats, computer files, and all other documentation.
- For transportation projects which tend to parallel the county line more than 1000 feet (305 m) from the county line, the WCCS zone used should changed at the county line. Photogrammetric mapping will be provided to the requester with approximately 1000 feet (305 m) of overlap of mapping in both WCCS zones. Design plans and plats should be completed in the respective county WCCS zone.

LIST OF ATTACHMENTS

Attachment 27.1	Wisconsin County Coordinate System
Attachment 27.2	Wisconsin County Coordinate System Zones

FDM 9-20-28 Wisconsin Coordinate Reference System *July 22, 2009*

The Wisconsin Coordinate Reference Systems (WISCRS) was developed as a mathematical alternative to the Wisconsin County Coordinate System (WCCS) (see FDM 9-20-27). Details on the development of WISCRS and the mathematical differences are available at the State Cartographer's Office (SCO) Web site:

http://www.sco.wisc.edu/

WISCRS may be used in any application that WCCS may be used. The difference in coordinate values computed by the two systems will normally be less than approximately 0.006 feet and never greater than 0.016 feet, with one exception. Because the values computed may not be the same, the coordinate values should be labeled as either WCCS or WISCRS coordinates, as appropriate.

The one exception where WISCRS coordinate values differ substantially from WCCS coordinate values is for Jackson County. The WISCRS coordinate values in Jackson County are the same as the coordinate values for the previously referenced Jackson County Official Coordinate System (JCOCS) (see FDM 9-5-10). For future Department projects, the WISCRS name should be used for coordinates in Jackson County in lieu of JCOCS.

Guidelines for using WISCRS are the same as for using WCCS and therefore are not repeated in this procedure (see FDM 9-20-27). See Attachment 28.1 for a map of WISCRS counties and Attachment 28.2 for a listing of WISCRS Zone numbers.

LIST OF ATTACHMENTS

Attachment 28.1	Wisconsin Coordinate Reference Systems Map
Attachment 28.2	Wisconsin Coordinate Reference Systems Zone Numbers

FDM 9-20-30 Coordinate Transformation

December 13, 2006

Coordinate transformations can be easily accomplished with existing computer programs between:

- Different coordinate systems which may be based on the same or different datums,
- Different zones of a coordinate system,
- Different measurement units.

The department supports several computer programs for coordinate transformation, one of which is WISCON. Coordinate transformations should be used with caution between different datums as none will produce exact results.

30.1 Definitions

A coordinate transformation is a process by which the coordinate of a point in one coordinate system can be transformed to a coordinate for the same point in another coordinate system. The transformation process is a mathematical manipulation of the coordinate in the first coordinate system. An exact mathematical coordinate transformation can be performed only when both coordinate systems are mathematically defined systems and defined exactly with respect to each other.

The following are examples of mathematically defined coordinate systems (see FDM 9-20-15).

- North American Datum of 1983, adjustment of 1986 (NAD 83(1986));
- North American Datum of 1983, adjustment of 1991 (NAD 83(1991)); and
- Each of the counties in the Wisconsin County Coordinate System (WCCS)

The North American Datum of 1927 (NAD 27) is an example of a coordinate system that is not completely mathematically defined because the vertical component of NAD 27 is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) which is a nonmathematical surface. Therefore, the Wisconsin State Plane Coordinate System based on NAD 27 is not completely mathematically defined even though it is mathematically defined with respect to NAD 27.

30.2 Methods

When the coordinate of a point is known in one coordinate system (system A) and the coordinate of the point is desired in a different coordinate system (system B), use one of the four methods listed below to determine the coordinate in the second system.

A **Mathematical Coordinate Transformation** is a quick and easy process when using coordinate transformation software to determine the coordinate of a point in another coordinate system when both coordinate systems are mathematically defined coordinate systems and defined relative to the each other. This method may be used for transformation in both directions (to and from) without degradation of accuracy. No additional field work is required and it is the least expensive of the four methods.

The **survey method** involves redoing the field work of surveying stations that were previously surveyed. The survey method is usually more accurate than a coordinate transformation, is applicable for all systems, incorporates changes in location of the monuments that may have occurred since the previous survey, and is usually the most expensive method. Normally, this method will be used only when the requirements of the project cannot be met by another less expensive method. This method is often selected when the coordinate of a point needs to be transformed either from or to a coordinate system based on the NAD 27 datum. It is also a good choice if monuments have been disturbed, or may have been disturbed. This method may be employed when the position for some stations in a project is based on NAD 83 (1991) and others on NAD 83 (1997).

The **readjustment method** is a good method to select when the previous ground survey data are still available and valid but the starting point coordinate of the previous survey is in question, was erroneously selected, or does not have a coordinate in a mathematically defined system. Once a revised coordinate of the starting point is available in coordinate system B, then the original survey measurements are used to readjust the entire project in coordinate system B.

The **interpolation method** involves transforming coordinates using an interpolation of shift values between the two coordinate systems. The primary purpose of this method is for transforming coordinates either to or from a coordinate system that is not completely mathematically defined relative to the other coordinate system; e.g., NAD 83 (1991) to NAD 83 (1997).

30.3 Horizontal Transformation

A coordinate transformation may be performed between various coordinate systems based on various datums (see FDM 9-20-25) used for transportation projects with the following accuracy.

30.3.1 Exact Coordinate Transformation

A coordinate transformation between any two of the below listed coordinate systems within a datum adjustment, or between any two zones within a system will yield exact results.

30.3.1.1 NAD 27

Geographical coordinates (i.e., latitude and longitude)

State Plane Coordinates (north, central, or south zone)

Universal Transverse Mercator Coordinate System

Wisconsin Transverse Mercator Coordinate System

30.3.1.2 NAD 83 (1986)

Geographical coordinates (i.e., latitude and longitude)

State Plane Coordinates (north, central, or south zone)

Universal Transverse Mercator Coordinate System

Wisconsin Transverse Mercator Coordinate System

30.3.1.3 NAD 83 (1991)

Geographical coordinates (i.e., latitude and longitude)

State Plane Coordinates (north, central, or south zone)

Universal Transverse Mercator Coordinate System

Wisconsin Transverse Mercator Coordinate System

Wisconsin County Coordinate System (any zone)

Jackson County Official Coordinate System

30.3.1.4 NAD 83 (1997)

Geographical coordinates (i.e., latitude and longitude)

Wisconsin State Plane Coordinate System (north, central, or south zone)

Universal Transverse Mercator Coordinate System

Wisconsin Transverse Mercator Coordinate System

Wisconsin County Coordinate System (any zone)

Jackson County Official Coordinate System

30.3.2 Approximate Coordinate Transformation

A coordinate transformation between any datum adjustments listed above and any NAD 27 based coordinate system will yield approximate results.

30.3.3 Special Considerations

The parameters to define a coordinate transformation between a system based on NAD 83 (1997) and a system based on NAD 83 (1991) have not been defined by NGS. NGS does not plan to publish program parameters for a coordinate transformation between NAD 83 (1991) and NAD 83 (1997). The difference between NAD 83 (1991) and NAD 83 (1997) HARN station positions averages approximately ±0.14 ft, which is less than half of the accuracy of the NADCON computation.

When a survey has some points with NAD 83 (1997) coordinates and some on a different coordinate system, use the "survey method" for most situations to get all stations on the same system. Some situations may warrant considering the "readjustment method" or the "interpolation method."

30.4 Vertical Transformation

A coordinate transformation of a height (elevation) between NGVD 29 and the North American Vertical Datum of 1988 (NAVD 88), or between NAVD 88 and a GRS 80 ellipsoid height associated with an NAD 83 horizontal position will yield approximate results.

30.5 Software

30.5.1 Original NADCON

The National Geodetic Survey (NGS) developed the horizontal data transformation computer program NADCON to transform coordinates for low-accuracy surveying or navigation purposes. NADCON is the Federal Standard for NAD 27 to NAD 83 datum transformations. At the 95-percent confidence level, NADCON has an expected horizontal accuracy of ±1.0 ft within the conterminous United States for transformations between NAD 27 and NAD 83 (1986). Accuracy is dependent upon the density of control and the quality of control surveyed on NAD 27.

30.5.2 Revised NADCON

The revised version of NADCON will also transform coordinates to the High Accuracy Reference Network (HARN)[2]. At the 95-percent confidence level, NADCON has an expected horizontal accuracy of ±0.33 ft for transformations between NAD 83 (1986) and NAD 83 (1991) and an expected horizontal accuracy of ±1.33 ft for transformations between NAD 27 and NAD 83 (1991).

30.5.3 VERTCON

NGS developed the computer program VERTCON to compute the modeled difference in orthometric height between NAVD 88 and NGVD 29 for a given location specified by latitude and longitude. At the 95-percent confidence level, VERTCON software using the VERTCON 2.0 model has an expected difference in orthometric height accuracy of ±0.13 ft for transformations between NAVD 88 and NGVD 29.

30.5.4 WISCON

The department has developed the computer program WISCON which combines the computations of original/revised NADCON and VERTCON into a single program. WISCON also provides conversion between geographical and rectangular coordinate systems, as well as conversion of measurement units (the U.S. Survey Foot to the meter or the meter to the U.S. Survey Foot). WISCON is a Windows-based program for coordinate and datum transformation among geographic coordinate systems and rectangular coordinate systems based on various horizontal and vertical datum combinations. For more information on WISCON see the State Cartographer's web page:

http://www.sco.wisc.edu/

For information on the current version of WISCON being used by the department, contact the Chief Surveying & Mapping Engineer at 608-267-9639.

30.6 Interpolation

The department does not currently use or support software that can transform the coordinate of a point in one coordinate system (system A) to a second coordinate system (system B) based only on the coordinates of nearby points whose coordinates are known in both coordinate systems. Special situations may warrant using interpolation based on a user-developed spreadsheet or on specific application software if it is suitable and available.

30.7 Trimble Geometrics Office (TGO)

Trimble Geomatics Office (TGO) is a program used to view and manipulate data collected with the Trimble

[2] The program parameters used for the HARN are those based on the NAD 83 (1991) HARN data for Wisconsin.

Survey Controller. TGO comes with a utility program called Coordinate System Manager. This utility program allows the user to define various coordinate systems and datums, and then transform the coordinate of a point between these systems. The process for doing a transformation involves opening a project in TGO in one of the defined coordinate systems, importing points to be transformed, changing the project properties to another one of the defined coordinate systems, and then exporting the points from the project with their changed coordinate values.

FDM 9-20-35 Combination Factor Selection *February 28, 2001*

This procedure explains using a combination factor with the Wisconsin State Plane Coordinate (SPC) System. When working with the Wisconsin County Coordinate System (WCCS) refer to FDM 9-20-27.

The combination factor is the ratio of the length of a line on a map projection (often called the “grid” distance) to the horizontal length of the corresponding line at ground elevation. The combination factor value is calculated as the product of an elevation or sea level factor and a scale factor. **Use elevation factor with North American Datum of 1983 (NAD 83) and sea level factor with North American Datum of 1927 (NAD 27).**

The elevation or sea level factor and the scale factor are computed and applied separately for each measured distance in precise surveys. These computations are part of the least squares adjustment program used by the department. For less precise surveys, a combination factor is used to obtain a grid coordinate or grid distance from a ground coordinate or ground distance. For previous projects, often the average ground elevation was used for all work in a county or township. The procedure for deriving a combination factor involves the following steps.

35.1 Elevation or Sea Level Factor

35.1.1 Elevation Factor

The elevation factor is the ratio of the length of a line on the surface of the ellipsoid for NAD 83 to the horizontal length of the corresponding line at ground elevation. The elevation factor value is calculated as the ratio of the mean radius of the earth divided by the sum of the mean radius of the earth and the mean ellipsoidal height of the line.

$$Elevation\ Factor = \frac{R}{R + h}$$

Where:

R is the mean radius of the earth of 20,906,000 feet (6 372 000 m), and

h is the mean ellipsoidal height of the line above the ellipsoid in feet (or m).

The value for **h** may be selected for a line or for an area (see below under “Point or Area Elevation”). In Wisconsin, the value of **h** will always be positive. The mean radius of the earth may be used as the value for **R** for all but the most precise surveys.

The distance on the surface of the ellipsoid, the geodetic distance, is calculated by the equation:

$$Geodetic\ Distance = Horizontal\ Distance * Elevation\ Factor$$

35.1.2 Sea Level Factor

The sea level factor is the ratio of the length of a line on the surface of the ellipsoid for NAD 27 to the horizontal length of the corresponding line at ground elevation. The sea level factor value is calculated as the ratio of the mean radius of the earth divided by the sum of the mean radius of the earth and the mean height of the line above mean sea level, i.e., the National Geodetic Vertical Datum of 1929 (NGVD 29) elevation.

$$Sea\ Level\ Factor = \frac{R}{R + H}$$

Where:

R is the mean radius of the earth of 20,906,000 feet (6 372 000 m), and

H is the mean NGVD 29 elevation of the line in feet (or m).

The value for **H** may be selected for a line or for an area (see below under “Point or Area Elevation”). In Wisconsin, the value of **H** will always be positive. The mean radius of the earth may be used as the value of **R** for all but the most precise surveys.

The distance on the surface of the ellipsoid, the geodetic distance, is calculated by the equation:

$$Geodetic\ Distance\ =\ Horizontal\ Distance\ *\ Sea\ Level\ Factor$$

35.1.3 Point or Area Elevation

To calculate an elevation or sea level factor, the mean elevation of the line or area must be determined. If a horizontal length of line (a distance) is to be converted to a geodetic distance, then the mean of the elevations at each end of the line is used when calculating the elevation or sea level factor. If an area is the subject of conversion, then the needed accuracy must be addressed. An area elevation is usually determined by inspection of USGS quadrangle maps. During this inspection, the extremes in elevation, both high and low, should be noted. These are later used to determine computational accuracy. The average elevation selected for use will not necessarily be a mean value of the high and low elevation for the area; rather, it should be a value that approximates a weighted arithmetic mean. This can be shown by an example.

Assume an analysis of an area revealed the following:

10% of the area was at elevation700 ft (213 m)

60% of the area was at elevation900 ft (274 m)

30% of the area was at elevation950 ft (290 m)

Then:

If a mean NGVD 29 elevation is selected for an area from a quadrangle map, then the ellipsoidal height may be determined by the equation

$$Ellipsoidal\ Height\ (h) = \ Mean\ Elevation\ (H) + Geoid\ \ Height\ (N)$$

In the contiguous United States, the geoid height is a negative value. Geoid heights are published on NGS Data Sheets and on GEOID99.

- See the NGS web site home page at: http://www.ngs.noaa.gov/
- Retrieve Data Sheets at: http://www.ngs.noaa.gov/cgi-bin/datasheet.prl or
- see GEOID99 at: http://www.ngs.noaa.gov/GEOID/GEOID99/

35.2 Scale Factor

Scale factor is the ratio of the length of a line on a map projection (the grid distance) to the length of a corresponding line on the surface of the ellipsoid (the geodetic distance). The scale factor value is calculated based on the location of the line on the ellipsoid. Scale factor is location dependent. For the Wisconsin SPC System, the scale factor is latitude dependent but not longitude dependent.

To compute the scale factor, the mean latitude of the line or area must be known. In the case of a line, this can be derived from preliminary computations or scaled from a map. When an area scale factor is used, it is obtained by scaling the latitude from USGS quadrangle maps. The latitude to be scaled is the center of the project area in a north-south direction (scale varies only in the north-south direction with a Lambert Conformal Projection). In addition to the latitude of the center of the area, the latitude of the northern and southern limits of the area should be determined for computational accuracy.

With the datum, latitude, and zone (North, Central, or South) as the argument, the scale factor for the Wisconsin SPC System can be obtained from the appropriate Plane Coordinate Projection Tables. For NAD 27, use the publication: *U.S. Coast and Geodetic Survey Special Publication No. 288, Plane Coordinate Projection Tables, Wisconsin (Lambert) by C&GS, February 1952, 32 pp.* For NAD 83, the equations to compute the scale factor are in *NOAA Manual NOS NGS 5, State Plane Coordinate System of 1983*, by NGS, January 1989, 120 pp. Publications available from NGS are listed at web site:

http://www.ngs.noaa.gov/PC_PROD/Catalog/publications.htm

The scale factor may also be computed using WISCON software (see FDM 9-20-30). To get the Wisconsin SPC System scale factor from the WISCON software, it is necessary to transform a coordinate value to the desired Wisconsin SPC System zone at the latitude of interest.

A grid distance can be computed using the following equation:

$$Grid\ Distance\ =\ Geodetic\ Distance\ *\ Scale\ Factor$$

35.3 Combination Factor

The combination factor is the product of the elevation or sea level factor and the scale factor. It can be used to obtain a map projection (grid) distance from a horizontal project distance or a horizontal ground distance.

$$Combination\ Factor\ =\ Elevation\ Factor\ *\ Scale\ Factor$$

$$Combination\ Factor = Sea\ Level\ Factor * Scale\ Factor$$

$$Grid\ Distance = Horizontal\ Distance * Combination\ Factor$$

The combination factor can also be used to obtain a horizontal project distance or a horizontal ground distance from a SPC system (grid) distance with the following formula:

$$Horizontal\ Distance = \frac{Grid\ Distance}{Combination\ Factor}$$

Caution: The above equations are equally applicable when working with the ground elevation of a line or the project datum elevation of a line. Whichever elevation was used when determining the elevation or sea level factor must be the same elevation as the elevation of the measured (or calculated length) line in the equations.

35.4 Computational Accuracy

When an area combination factor is used, it should be tested for computational accuracy. The maximum permissible error introduced by the computation process using an area combination factor should not exceed the ratio of one part in 30,000 (1:30,000). When use of a single combination factor introduces more error than is acceptable, the area should be divided into two or more areas with a combination factor assigned to each area.

An area combination factor used for the Wisconsin SPC System can be tested for computational accuracy by comparing to four combination factors that represent the worst possible scenarios that may occur within the area. The worst possible case for an area occurs at one of the four following combinations:

Case 1. Lowest latitude and lowest elevation of the area.

Case 2. Lowest latitude and highest elevation of the area.

Case 3. Highest latitude and lowest elevation of the area.

Case 4. Highest latitude and highest elevation of the area.

After a combination factor is computed for each of the four cases, the absolute difference between the area combination factor and each of the worst possible case combination factors is determined.

For example: An area combination factor was computed as 0.999905

Combination Factor		Absolute Difference
Case 1	0.999925	0.000020
Case 2	**0.999875**	**0.000030***
Case 3	0.999895	0.000010
Case 4	0.999880	0.000025

*Case 2 has the greatest absolute difference between the area combination factor and the worst case combination factor.

Computational accuracy is then determined as 1 divided by the greatest absolute difference. Computational accuracy of the area combination factor for the above example is determined as:

$$\frac{1}{0.000030} = 1{:}33{,}333$$

The ratio 1:33,333 does not exceed the 1:30,000 criteria so the area combination factor may be used for the entire area.

FDM 9-20-40 Grid/Ground Coordinate Conversions *February 28, 2001*

This procedure describes the mathematical relationship of the Wisconsin State Plane Coordinate (SPC) System and a ground based project coordinate system.

Project design computations and survey data are based on ground coordinates. Map data are produced in grid coordinates in either the Wisconsin SPC system or in the Wisconsin County Coordinate System (WCCS). Data in the SPC system may be either SPC 27, based on the North American Datum of 1927, or SPC 83, based on either the North American Datum of 1983 adjustment of 1986 or 1991. Data in the SPC system has to be converted to ground (i.e., project) coordinates for field use. (Users working with the WCCS should not use methods in this procedure but refer to FDM 9-20-27.)

40.1 SPC Coordinates

Wisconsin Statute 236.18(6) differentiates between the way SPC 27 and SPC 83 system coordinates shall be labeled. For SPC 27 the north-south direction distance shall be the y-coordinate and the east-west direction distance shall be the x-coordinate. For SPC 83 the north-south direction distance shall be the northing and the east-west direction distance shall be the easting.

The NGS Data Sheet publishes the SPC northing and easting coordinate values based on NAD 83 (1991) under the headings of “North” and “East.”

It has been department practice to label SPC system coordinates, which are grid coordinates, “Y” for the north coordinate and “X” for the east coordinate, and to label the project coordinates, which are ground coordinates, “N” for the north coordinate and “E” for the east coordinate. Note that the SPC system is only defined on the grid and any coordinates at ground or project datum are not SPC system coordinates.

All data should be accompanied by metadata (data about the data), so that the source and quality are known. Parameters used should be recorded for future reference. When converting between grid and ground coordinates it is important to use the correct horizontal datum, coordinate system, coordinate zone, units, elevation, and combination factor. For a large project with more than one combination factor, use caution and document extensively when working near a town or county line where a coordinate equation exists.

40.2 Ground Coordinates

The following formula shows the relationship between a SPC system (grid) coordinate and a project (ground) coordinate:

$$N = \frac{Y}{CF} \quad \text{and} \quad E = \frac{X}{CF}$$

Where:

N is Northing ground coordinate

E is Easting ground coordinate

Y is Northing SPC (grid) coordinate

X is Easting SPC (grid) coordinate

CF is Combination Factor (see FDM 9-20-35)