SPECIAL ISSUE—DATUM CONVERSION

REGIONAL PLANNING NEWS

A publication of the **Southeastern Wisconsin Regional Planning Commission** Volume 3, Issue 3, March 2016

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Fundamental Elements of Parcel Based Land Information and Public Works Management Systems

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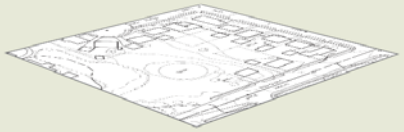
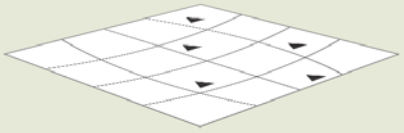
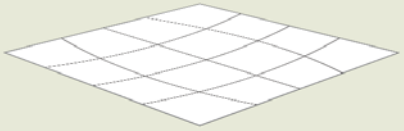


Vertical Datum and Topographic Map



Geodetic Survey Control Network



Horizontal Datum and Map Projection

REGIONAL SURVEY DATUM ISSUES

Introduction

The November 2015 issue of this newsletter noted that the Commission has since 1961 provided technical guidance and advice to its constituent counties and municipalities regarding surveying and mapping practices. This guidance and advice has taken the form of the publication of planning guides on official mapping and land subdivision control, the preparation of contracts and specifications for aerial photography and large scale topographic and cadastral mapping projects carried out by counties and municipalities within the Region, the provision of technical guidance and advice concerning the conduct of both plane and geodetic surveys in support of planning and engineering activities, and the provision of the foundational elements of the land information and public works management systems within the Region. Importantly, the Commission has, in cooperation with its constituent counties and municipalities, created a high order survey control network within the Region to support topographic and cadastral mapping, land records modernization, and the conduct of land and engineering surveys. This survey control network combines the United States Public Land Survey System (USPLSS) and the national geodetic survey control system. The creation of the survey control network involved the location and monumentation of all 11,753 USPLSS corners within the Region, and the establishment of geodetic coordinates for each corner together with the elevation of the corner monuments and accessory benchmarks. In this survey control network the coordinate positions of the survey control stations—the USPLSS section and quarter section corners—are based upon the North American Datum of 1927 (NAD27), while the attendant elevations are based upon the National Geodetic Vertical Datum of 1929 (NGVD29).

Corner monument. Source: SEWRPC

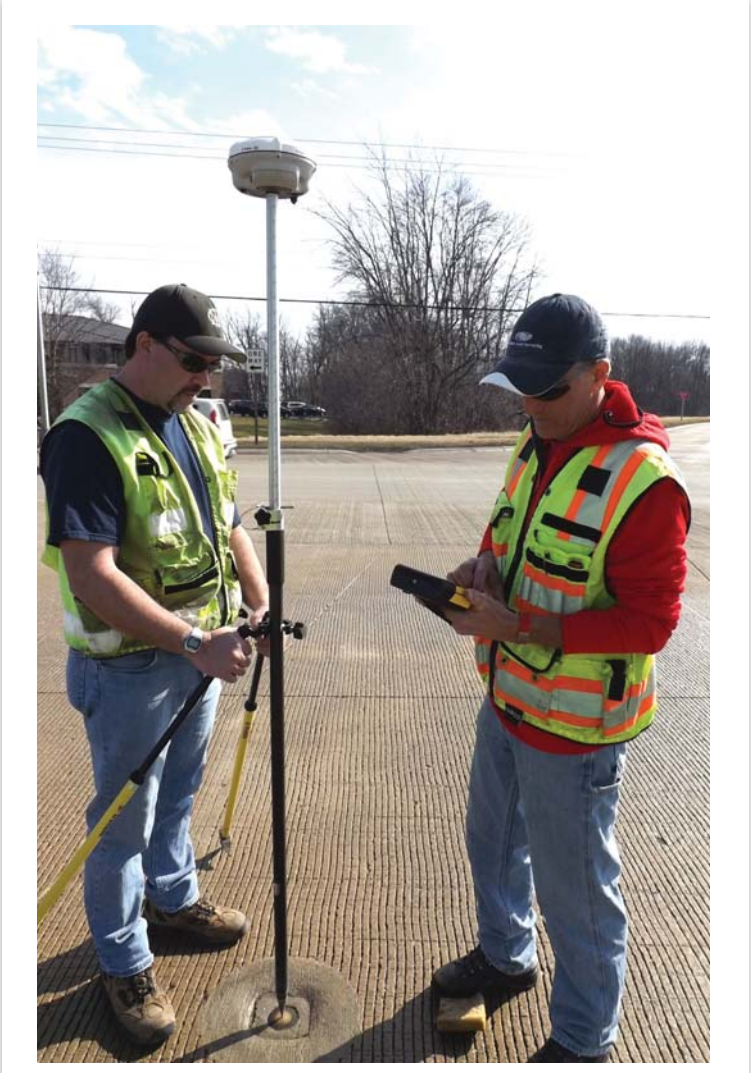
In the 1980's the Federal government established new horizontal and vertical datums—for horizontal positions the North American Datum of 1983 (NAD83), and for elevations the North American Vertical Datum of 1988 (NAVD88). These actions by the Federal government caused the county land information system managers that are responsible for the creation and maintenance of the county land information systems within the Region to consider the conversion of the regional survey control network to the new Federal datums. In response to requests from the county land information managers, the Commission developed two means for effecting the desired conversion. The selection of which of these two means to utilize in a conversion and, indeed, whether or not to proceed with a conversion, constitute important issues facing the county land information managers, the County Land Information Councils, and other concerned interests such as municipal engineers and surveyors. A good understanding of these issues requires some basic knowledge about the concept of survey datums. Therefore, a description of that concept is appended to this newsletter article.

History of Horizontal Datums within the Region

In the 1920's the Federal government established the first official continental horizontal survey datum for use in geodetic surveying, topographic mapping, and hydrographic charting operations. Within the United States, this datum was known as the North American datum of 1927 (NAD27). It utilized the Clarke spheroid of 1866 as its ellipsoid. The NAD27 datum, and the related Federal survey control stations, and Federal mapping and charting activities have served the nation well for many years.

The 1927 datum was used in the development and promulgation of the state plane coordinate system within Wisconsin. That datum was also used in the creation of the regional survey control network and, therefore, in the development of the foundational elements of the county and municipal land information and public works management systems within the Region.

In the 1980's, the Federal government established a new horizontal datum known as the North American Datum of 1983 (NAD83). The new datum was established in response to scientific and military needs for a global datum as opposed to a continental datum, and utilized a new ellipsoid known as the Geodetic Reference System of 1980. No mathematical relationship exists between the legacy 1927 datum and the new 1983 datum. Any relationships between the two datums must be developed by mathematical modeling of that relationship.



Source: SEWRPC

The Federal Government also created a new state plane coordinate system based upon the new datum. The coordinate values under the new system are expressed in meters as opposed to the U.S. Survey feet used to express the coordinate values under the original system. Unlike the legacy datum, the newer datum is subject to refinement based upon field surveys. The refinements are known as datum tags and epochs, the latest such datum tags and epochs applicable to the Southeastern Wisconsin Region being known as NAD83 (2011), epoch 210.00.

History of Vertical Datums within the Region

Also in the 1920's, the Federal government established an official continental vertical datum. This datum which under present practice is known as the National Geodetic Vertical Datum of 1929 (NGVD29) was originally known as the Sea Level Datum of 1929. It did not utilize an ellipsoid in its definition. The datum was expressed in the elevations of benchmarks, the elevations being determined by precise differential leveling carried landward from 26 coastal tide gaging stations. The leveling lines and benchmarks concerned were generally located along railway lines. This legacy vertical datum also served the nation well for many years.

In the 1980's, the Federal government established a new vertical datum known as the North America datum of 1988 (NAVD88). The new datum is referenced to the geoid but incorporates measurements that are related to the same ellipsoid as the new horizontal datum. It is based upon a single tide gage, approximately 51,000 miles of new differential leveling surveys, and upon adjustment and use of the leveling data obtained in the creation of the legacy datum. Again, no precise mathematical relationship exists between the legacy and new datums.

Practice within the Region

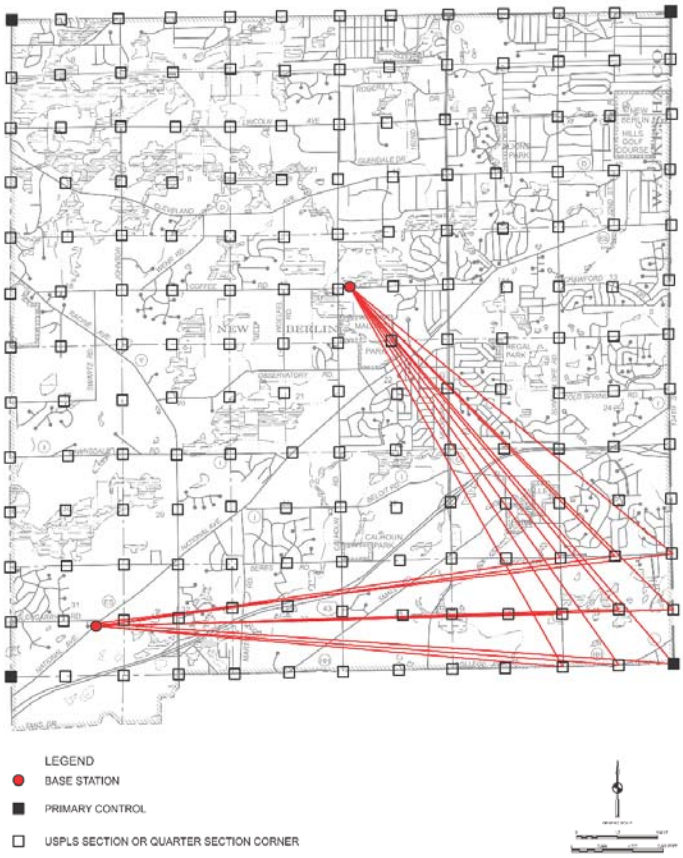
Since 1961, the Commission has recommended the use within the Region of the two legacy Federal datums: NAD27 and NGVD29. These two datums were used in the creation of the regional survey control network, the preparation of large scale aerial photographs and the preparation of the topographic and cadastral maps which constitute two foundational elements of the parcel-based land information and public works management systems being created within the Region, and for the conduct of land and engineering surveys in support of various land use and infrastructure development and re-development projects. Consequently, a large information base has been referenced to the legacy datums consisting of the survey control network itself; of land subdivision plats, certified survey maps, and ordinary plats of surveys; of the topographic and cadastral maps that constitute two of the foundational elements of the County and municipal land information and public works management systems; and of the many different types of attribute data included in those systems.

Datum Conversion – SEWRPC Memorandum Report No. 206 Process

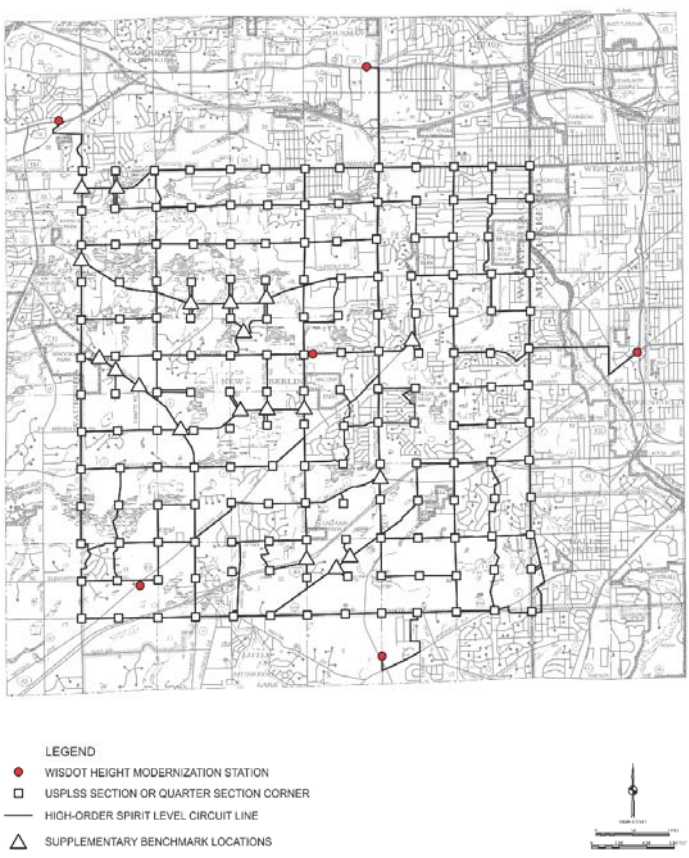
As already noted, the Commission in response to requests from the county land information managers in 2012 developed a method for converting the legacy datums in use within the Region to the new Federal datums. This method was documented in SEWRPC Memorandum Report No. 206, "Revised Estimate of the Costs of Converting the Legacy Datums within the Region to National Datums," published in October 2012. With respect to the horizontal datums, the method employs static global positioning system (GPS) techniques in a resurvey of the existing survey control network. It requires the establishment of two base stations per typical USPLSS township. These base stations would be tied to

FIGURE 1
Datum Commission — Memorandum Report No 206 Process

GPS Observations Required at Two Base Stations Per Township and at All USPLSS Corners



Field Leveling Required — Level Lines Through All USPLSS Corners in Township



Source: SEWRPC

the continuously operating reference stations of the Federal survey control network by high order GPS surveys. All 169 section and quarter-section corners within the township would then be occupied utilizing GPS instrumentation to obtain state plane coordinate system values referenced to the new datum. The coordinate observations made at the individual section and quarter-section corners would be controlled by ties to the base stations. (See Figure 1) The accuracy of the new coordinate values would meet Second Order Class I standards, equivalent to one part in 50,000 or better. This level of accuracy would approximate an allowable error of about 0.05 foot in the approximately 2,640 feet—one-half mile—length of a USPLSS quarter-section line.

With respect to vertical positioning, the method envisions obtaining the needed elevations referred to the new datum by the conduct of high order differential level surveys through each of the 169 corners in a typical USPLSS township. (See Figure 1) The accuracy of the new elevations would meet Second Order Class II standards, equivalent to an allowable error of about 0.02 foot between benchmarks spaced one half mile apart.

The cost attendant to the horizontal datum conversion using the method set forth in Memorandum Report 206 was estimated at $2.2 million for the Region as a whole, or about $31,000 per typical USPLSS township. The cost of the vertical conversion was estimated at $4.5 million for the Region as a whole. The horizontal datum conversion could be accomplished by subareas of the Region—such as counties, townships, or municipalities. The vertical datum conversion, however, should be accomplished for the Region as a whole to insure the integrity of the data transcending county, township and municipal boundaries and the boundaries of planning areas such as watersheds. When presented to the county land information system managers, these costs were generally regarded as prohibitive, and the Commission was asked to explore less costly means.

Datum Conversion—Addendum Process

In response to this request from the county land information system managers, the Commission staff developed alternative methods for datum conversion within the Region. These methods are set forth in an Addendum to Memorandum Report No. 206, published in August 2015.

Under the revised methods, only a minimum number of USPLSS section and quarter-section corners within a township would be occupied using GPS instrumentation to obtain direct measurement of the state plane coordinate system values referred to the new

datum. (See Figure 2) Using state-of-the-art GPS positioning techniques, these observations would be tied only to the continuously operating reference stations of the Federal survey control network. Approximately 18 of the 169 corners per township would be so occupied. Utilizing measurements made in the creation of the legacy horizontal survey control network, coordinate values referenced to the new datum would then be computed for the remaining 151 corners.

The accuracy of the new coordinate values would meet Third Order standards, equivalent to one part in 10,000 or better, as does the existing regional survey control network. This level of accuracy would approximate an allowable error of about 0.26 foot in one-half mile. The cost of the horizontal datum conversion using the revised procedure is estimated at $400,000 for the Region as a whole, or approximately $7,600 per a typical USPLSS township.

With respect to the vertical datum conversion, the revised procedure would utilize the height modernization benchmarks (WI-HMP benchmarks) established by the Wisconsin Department of Transportation within the Region. High order differential level surveys would be used to transfer regional survey control elevations referred to the legacy datum to the height modernization system benchmarks. (See Figure 2) Approximately 400 such height modernization benchmarks exist within the Region, and approximately a one-half mile of differential level survey line would be required to transfer the legacy datum elevations to each of the height modernization benchmarks. The level surveys would provide a direct measurement of the difference between the legacy and new datums, and these differences could then be used to develop a conversion map. Use of the conversion map would provide an accuracy equivalent to Second Order Class II, as does the existing regional survey control network. The cost of the revised vertical datum conversion procedure is estimated at $300,000 for the Region as a whole.

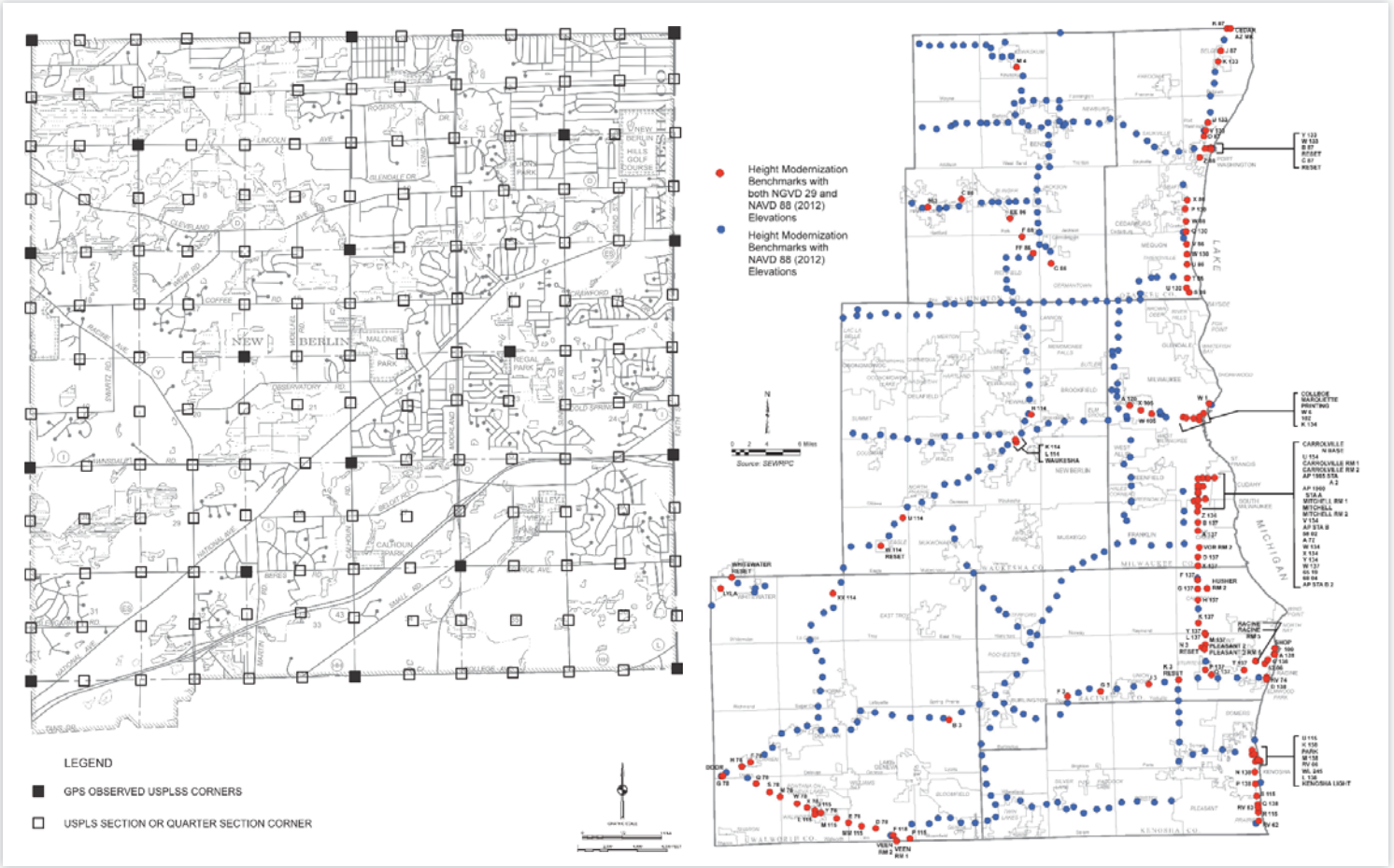
Summary and Some Comments on Datum Conversion

In response to concerns raised by some practicing surveyors and land information system managers concerning the continued use of the legacy datums within the Region, in 2012 the Commission prepared Memorandum Report No. 206 entitled, *"Estimate of Costs of Converting the Foundational Elements of the Land Information and Public Works Management Systems in Southeastern Wisconsin from Legacy to New Datums,"* published

FIGURE 2
Datum Converson — Memorandom Report No 206 Addendum Process

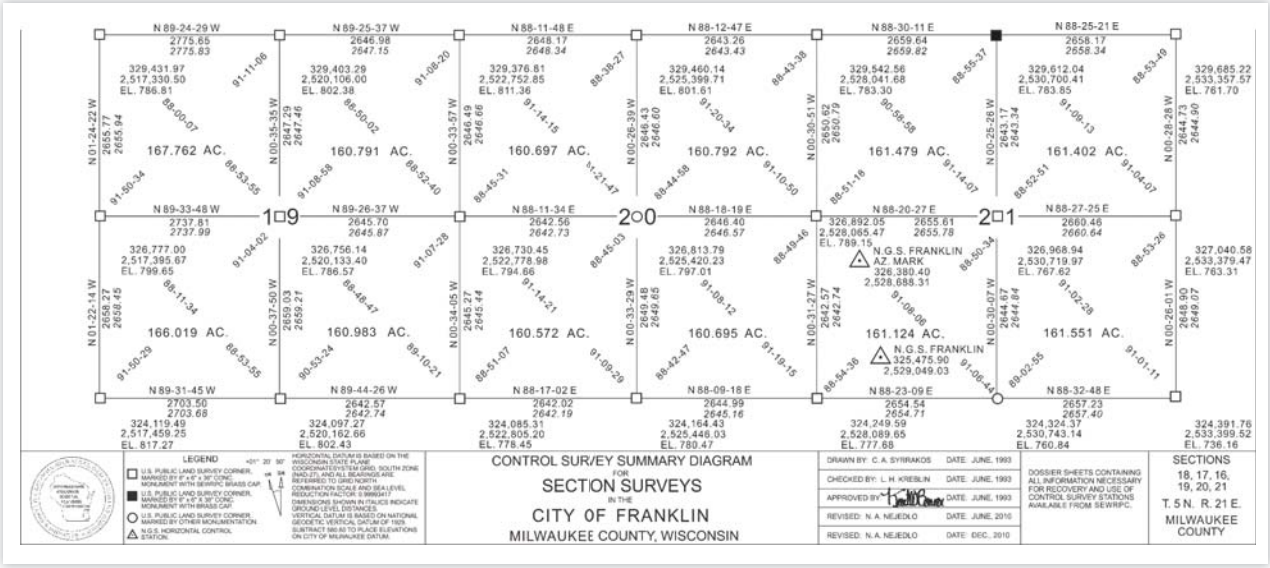
GPS Observations Required at Limited Number of USPLSS Corners Per Township, Position of Remaining Corners Determined by Computation Using Legacy Measurements

Obtain Legacy Elevations at WI-HMP Bench Marks Using Neighboring USPLSS Reference Bench Marks. Elevation Differences are Determined at WI-HMP Bench Marks Between New and Legacy Datums and a Map of the Differences Prepared.



Source: SEWRPC

Example of a Typical Control Survey Summary Diagram



Source: SEWRPC.

in October 2012. The report described the legacy and new datums in use within the seven-county planning Region. The report also described the regional survey control network and attendant topographic and cadastral mapping that together provide three of the foundational elements for the creation of parcel-based land information and public works management systems within the Region. In response to specific requests from some land information system managers, the report presented methods for converting the legacy datums within the Region to the newer datums and presented an estimate of the cost of such conversion meeting land and engineering survey accuracy standards.

Given the high cost of the conversion methods proposed in the report, datum conversion was considered to be impractical by most of the land information system managers concerned. Some practicing land surveyors and land information system managers, however, continued to express a desire to pursue such a conversion.

Given this continued concern about datum conversion within the Region, and the significant changes in surveying technology that had taken place since the publication of Memorandum Report No. 206, the Commission in early 2015 undertook a reevaluation of the methods for, and attendant costs of, conversion. The findings of that reevaluation are fully set forth in an Addendum to Memorandum Report No. 206, published in August 2015. The revised methods developed for the conversion of the datums within the Region as set forth in the Addendum to Memorandum Report 206, provided significantly reduced costs over the costs of the methods originally proposed in Memorandum Report No. 206. The reductions of the costs were sufficient to make the conversions practicable. While the costs of conversion are known, the benefits of conversion remain largely intangible. However, the conversion of the horizontal datum using the method set forth in the Addendum to Memorandum No. 206 would have one very important, although intangible, benefit. Namely, it would retain the relative positions of all the survey control stations within the Region as given by the legacy lengths and bearings of the quarter-section lines, thereby preserving the integrity of the legacy horizontal survey control network. That network establishes the relative positions of the USPLSS corners within the Region to specified levels of accuracy. Those positions – expressed in terms of grid bearings and distances – have been used for over 50 years within the Region in the conduct of land and engineering surveys and in the preparation of attendant plats and maps, thus accumulating a vast amount of survey data. Any changes in the relative positions of the USPLSS corners within the Region would needlessly complicate the use of this invaluable historic record in the conduct of future land and engineering surveys within the Region. The benefits attendant to maintaining the integrity of the legacy horizontal survey control network as changes in the datums are made, may be considered sufficient to warrant the relatively modest cost of horizontal datum conversion utilizing the method set forth in the Addendum.

The Commission staff has recommended that based upon the findings presented in Memorandum Report No. 206 and in the Addendum to that report, each of the individual county land information system managers, and the cognizant Land Information Councils, determine if the County wishes to proceed with the conversion of the legacy horizontal and vertical datums now in use in the Region to the new Federal datums. If it is determined to proceed, one of the two methods for such conversion developed by the Commission should be used to implement the conversion. In this respect, the principal benefit to be derived from application of the methods set forth in Memorandum Report No. 206 would be the significantly higher order of accuracy that would be attributable to the new coordinate positions. The principal benefit of the use of the conversion procedure set forth in the Addendum to Memorandum Report No. 206 would be the greatly reduced cost of conversion, and the maintenance of the relative positions of the survey control stations as determined in the existing regional survey control network. It is important to note that both of the methods developed by the Commission would accommodate another conversion in the future should this become necessary due to the adoption of yet another horizontal or vertical datum by the Federal government. Indeed, new horizontal and vertical datums are currently under preparation by the Federal government, and planned to be released in 2022.

The estimated costs of the datum conversion as set forth in Memorandum Report No. 206 and in the Addendum to that report relate to two of the four foundational elements—the map projection and survey control network—of any good parcel-based land information or public works management system, that is, to the survey control network underlying the systems. Each of the other two foundational elements, the topographic maps providing ground truth for use in system creation, and the parcel-based cadastral maps will require recompilation, or in the alternative some form of

adjustment if those elements are to remain usable with coordinate positions on the new horizontal datum. Such coordinate positions cannot be plotted on the map projection, or on the existing topographic and cadastral maps, of the legacy systems.

THE CONCEPT OF A SURVEY DATUM

The term "datum" is used in different ways with different meanings that range from the generic meanings given in standard dictionaries to specific meanings as used within different disciplines. Within the surveying and mapping disciplines, the term "datum" may be used to mean a "survey datum," or to mean, more specifically, a "geodetic datum." When used to refer to a survey datum, the term may be defined to mean any point, line, or surface to which positions of points or features are referenced, often the points of beginning for the conduct of surveys.

When used to refer to a "geodetic datum, the term takes on a more precise meaning and that is the meaning used in this article. Accordingly, a geodetic datum may be defined as a system—or mathematical construct—that facilitates the conduct of surveys, the conduct of survey calculations, the location of points and features upon the surface of the earth, and the preparation of maps. A geodetic datum also serves as a referent for survey data.

A geodetic survey datum is not, in fact, required for the conduct of surveys and related calculations if the areas involved are relatively small. Surveys and survey calculations of relatively small areas can be made using what are termed plane surveying practices in which the surface of the earth is, as the name implies, considered to be a plane. This entails the application of certain simplifying assumptions, including among others, that plumb lines and lines in cardinal directions are parallel. The relative location of points on the surface of the earth are computed by application of the principles of plane geometry and trigonometry. With the exception of surveys conducted by the U.S. Coast and Geodetic Survey and the U.S. Army Corps of Engineers, essentially all of the land and engineering surveys and related platting activities conducted within the seven county Southeastern Wisconsin Region from the time of its settlement by Europeans until 1961 were conducted utilizing plane surveying practices without reference to a geodetic survey datum.[1]

Because of the inherent inaccuracies involved, plane surveying practices become inadequate for use in the conduct of surveys and for the preparation of accurate maps of large areas such as the seven county Region and of certain planning areas within that Region such as watersheds. The conduct of surveys over, and the mapping of, large areas requires the application of geodetic survey practices. Geodetic survey practices recognize that the surface of the earth is a curved surface, and that a survey datum—more specifically a geodetic survey datum—must be created to facilitate the conduct of surveys, the conduct of survey calculations, the location of points and features on the surface of the earth, and the preparation of accurate maps of relatively large areas on that curved surface.

The fundamental element of a geodetic survey datum is a mathematical ellipsoid which closely approximates the configuration of the earth. The ellipsoid is gravity centered and defined by the dimensions of its major and minor axes. Cardinal directions are related to the earth's rotational poles. The locations of points on a geodetic survey datum are expressed in terms of spherical coordinates—latitude and longitude—and the relative location of points are computed by application of the principles of solid geometry. Because calculations of the relative positions of points which are expressed in terms of spherical coordinates are complex, the U.S. Coast and Geodetic Survey in the 1930's developed an ingenious means of converting, within specified levels of accuracy, spherical—or ellipsoidal— coordinates on a geodetic survey datum to rectangular coordinates on a plane surface oriented under NAD27 to mean sea level and under NAD83 to the ellipsoidal. The system so developed is known as the state plane coordinate system. The system with certain variations, is adopted and applied on a state-by-state basis. The state plane coordinate system not only permits surveys and survey calculations to be conducted using the principles of plane geometry and trigonometry, but also provides a conformal projection for mapping—the projection converting the curved surface of the earth to the plane surface of a map.

The state plane coordinate system is the system that has been recommended by the Commission since 1961 for use within the Region. The system has been used by the Commission and its constituent counties and municipalities for the creation of the regional survey control network, for the preparation of large scale topographic and cadastral maps, and for the creation of parcel-based land information and public works management systems within the Region.[2] State plane coordinates systems have been prepared by the Federal government for use with both the legacy and the new horizontal datums—NAD27 and NAD83.

Although proposals have been advanced for the adoption of an integrated three dimensional datum, current practice utilizes separate horizontal and vertical datums. Locations of points and features referred to the horizontal datum are expressed in either the spherical coordinates of latitude and longitude, or in the attendant grid coordinates of the state plane coordinate systems.

Elevations of terrestrial points and features, and of water depths are referred to the vertical datum. The most current Federal vertical datum utilizes the same ellipsoid as the horizontal datum, and elevations, known as ellipsoid heights—directly measurable

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[1] *The U.S. Public Land Survey System (USPLSS) within the Region provides an interesting exception in this respect. The spherical shape of the earth was recognized in the design of the system by providing for the convergence of meridians of longitude—such as range lines, and for the curvature of lines of latitude—such as township lines. However, the field surveys were conducted and the resulting township plats were created by plane surveying. No datum was involved in the creation of the system. Similarly, plane surveying practices are largely employed in the perpetuation of the system.*

[2] *There are other grid coordinate systems in use within Wisconsin. One of these is known as the County Reference System (formerly County Coordinate System). The system is, in effect, an adaptation of the principles underlying the state plane coordinate system. As in the latter case, geodetic surveys and attendant calculations are made relative to the ellipsoid of the NAD83 datum. The map projection and related grid coordinate system is, however, conceptually positioned at the mean elevation of the individual county concerned. The resulting discrepancy between ground level and grid distances is resolved by adjusting the scale factor of the projection. This, of course, changes the conformal conic projection of the state plane coordinate system to a non-conformal projection—a change that can be neglected for practical purposes in Wisconsin.*

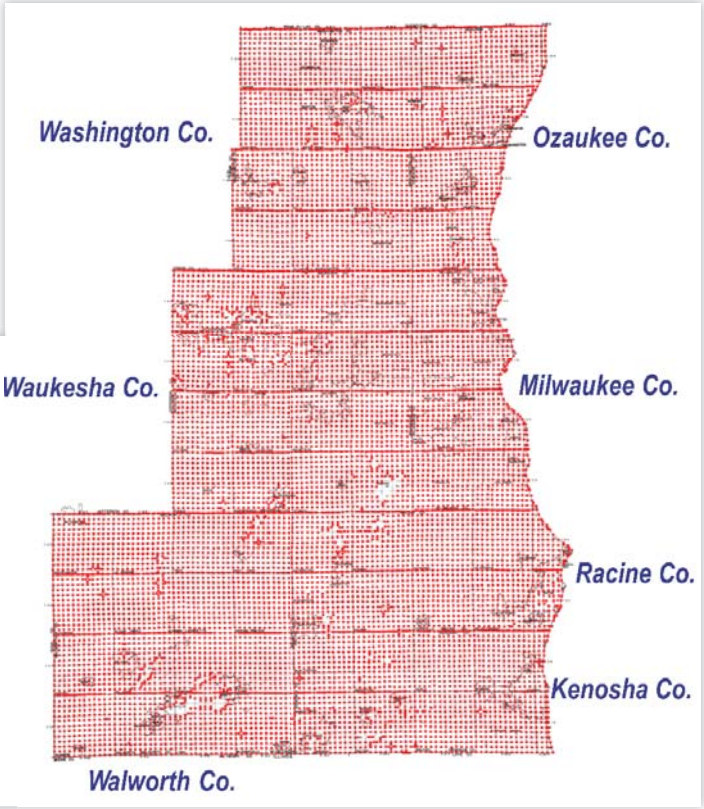
using GPS instrumentation—are referenced to the ellipsoid. Alternatively, elevations, known as orthometric heights, determined by differential leveling and referenced to a surface known as the geoid, may be used. The relationship between these two types of heights is established by the geoid height—the distance the geoid lies above or below the ellipsoid at any given point. The geoid, which is everywhere perpendicular to the direction of gravity, is the surface that is approximated by the ellipsoid used in a datum. Earlier Federal vertical datums were not referenced to an ellipsoid and elevations on such datums were directly referenced to mean sea level by field surveys.

It is important to note that both types of survey datums are made manifest on the surface of the earth by the erection of physical monuments referenced to the datums. Within the Region those monuments consist of the monumented USPLSS section and quarter-section corners and the accessory benchmarks.

Source: SEWRPC.

USPLSS Corners Within the Region

Total Corners by County	
Kenosha	1,203
Milwaukee	1,065
Ozaukee	1,064
Racine	1,478
Walworth	2,503
Washington	1,905
Waukesha	2,535
Region Total	11,753



Source: SEWRPC.

NEW MILWAUKEE LOCATION

The Southeastern Wisconsin Regional Planning Commission's Milwaukee office is now located in the Global Water Center at 247 W. Freshwater Way. Commission staff are available at this location by appointment. An online staff directory may be found at www.sewrpc.org/staff or call (262) 547-6721.

Paper copies of Commission plans, reports, and maps are available at the Waukesha office located at W239 N1812 Rockwood Drive, along Highway 164, north of I94. These resources are also available online at www.sewrpc.org.

The Global Water Center houses water-based research facilities for universities and existing water-related companies, and also serves as an accelerator space for emerging water technology companies. The Center is also the headquarters for The Water Council a freshwater research, education, and business development organization.

Watch for Updates

VISION 2050 is SEWRPC's land use and transportation planning effort for Southeastern Wisconsin.

Learn about VISION 2050 at **www.vision2050sewis.org**.

Follow us on Twitter at **@vision2050sewis**.

The **Southeastern Wisconsin Regional Planning Commission** is the official advisory areawide planning agency for land use and infrastructure for the seven counties in the Region.

More information can be found at **www.sewrpc.org.**

Please contact us at **sewrpcnews@sewrpc.org**.

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