THE U.S. STATE PLANE COORDINATE SYSTEM (SPCS):
(Including comments on International versus U.S. Survey Foot)

This item is part of Chapter 10 on Map Projections and State Plane Coordinates in the book "The 3-D Global Spatial Data Model: Foundation of the Spatial Data Infrastructure" by Earl F. Burkholder and published April 2008 by CRC Press.

The SPCS zones in the United States were designed in the 1930's for use on the NAD27. Although other projection options were considered for use on the NAD83, the defining SPCS zone parameters were largely unchanged for implementation on the NAD83. The SPCS on the NAD83 consists of 54 transverse Mercator projections, 68 Lambert conic conformal projections, and 1 oblique Mercator projection. Some states are covered by a single zone but most states require more than one zone due to the limiting width of 158 miles and due to choosing SPCS zone boundaries to follow county boundaries. Other incidental changes were made during the transition from NAD27 SPCS to NAD83 SPCS and can be gleaned from two important publications. Claire (1968) is the "bible" for working with SPC on the NAD27 and Stem (1989) is the "bible" for working with SPC on the NAD83. Each booklet contains a description of the underlying map projections, a listing of the defining parameters for each zone, and a list of equations that can be used to perform bi-directional transformations between latitude/longitude positions and plane coordinates on the respective datum.

History: The following quote is by Joseph Dracup, former geodesist for the United States Coast & Geodetic Survey (USC&GS), now the National Geodetic Survey (NGS), www.ngs.noaa.gov/PUBS_LIB/geodetic_survey_1807.html.

> *In 1933-34, Oscar S. Adams ably assisted by Charles N. Claire developed the State Plane Coordinate System (SPCS) at the request of George F. Syme a North Carolina Highway engineer. Syme died shortly after the North Carolina system was developed being succeeded by O.B. Bestor to carry on the cause. Bestor was in charge of the State local control project established in 1933, later identified as the North Carolina Geodetic Survey. Most State and the few county projects involved in this program also were so named. Colonel C. H. Birdseye of the USGS, with a strong interest in Statewide coordinate grids also participated in the several conferences leading to the decision to honor Syme's request.*
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> *The first tables for computing Lambert coordinates were developed for North Carolina and the first tables for the transverse Mercator grid were for New Jersey. Tables were prepared for all States early in 1934. For the first time all horizontal control stations previously defined only by latitudes and longitudes would be available in easy to use plane coordinates.*

Features: Special Publication 235 (Mitchell and Simmons 1945/1971) is a booklet that describes details of the state plane coordinates system. It is of both practical and significant historical value because it documents surveying policies and practices prior to the electronic revolution. Several important features of the SPCS described in Special Publication 235 include:

- The state plane coordinate system provides a method by which the latitude/longitude positions of the national triangulation network can be represented by plane coordinates. That meant local surveyors/engineers could continue using plane surveying procedures yet realize the benefits of basing their work on the national network of geodetic control points established by the federal agencies. This item is still valid except that the GSDM does for 3-D data what the SPCS does for 2-D data.

- Normal land surveying measurements in the 1930's were made with a transit and steel tape. Expected accuracies were often in the range of 1:5,000 to 1:8,000 or better. Under those circumstances, a routine distance distortion of 1:10,000 could be tolerated without making a scale factor correction and without significant detrimental impact on the quality of the survey. With newer technology, this assumption is no longer valid because measurement accuracies today routinely exceed those of 80 years ago. Better accuracy is not a problem because high-quality computational results are obtained by applying the grid scale factor correction. With the corrections applied, the SPCS is fundamentally sound for 2-D applications. Elevation is typically used to handle the 3rd dimension.

- There are two distance "corrections" to be made when working with the SPCS (Burkholder 1993a); 1) the grid scale factor is used to correct for the distortion between the ellipsoid and the grid and 2) the elevation factor is needed to reduce a ground level horizontal distance to the ellipsoid. These two corrections are often combined into one "combination factor" (the product of the grid scale factor and the elevation factor). The grid distance between the plumb lines through two points is the product of the horizontal ground distance and the combination factor. Special Publication 235 explains both factors quite well but, as discussed later, this is the primary disadvantage of using the SPCS. Regretfully, when using the SPCS, a foot on the grid is not a foot on the ground. In many cases, such as centerline stationing on a highway project, the difference between grid and ground distances becomes intolerable (see Appendix III of Burkholder 1993b).

- Although the NGS has always performed and computed their geodetic surveys in meter units, the NAD27 state plane coordinates were published in foot units - see sidebar discussion of the U.S. Survey Foot.

It is not true, as some have said, that the state plane coordinate systems distort distances by 1:10,000. It is true to say that, when compared to a distance on the map, the equivalent distance on the ellipsoid <u>may</u> be distorted by up to 1:10,000. On a secant projection, the distortion is zero along the lines of exact scale where the two surfaces intersect and the distance on the map is the same as the distance on the ellipsoid. At the center of the zone, the distance is compressed by 1:10,000 or by whatever distortion value was selected by the zone designer. In some cases, a zone width of 158 miles was not quite sufficient to cover the area required and the distance distortion at the center of the zone is greater than 1:10,000, i.e, the grid scale factor at the zone center is less than 0.9999 - see constants for California Zone 1, both Oregon zones, Zone 10 in Alaska, North Carolina, South Carolina, four of the five Texas zones, Utah Central Zone, and the offshore zone for Louisiana.

The grid scale factor is only part of the distortion. The elevation factor also contributes to the difference between a horizontal ground distance and the state plane grid distance. Modern practice looks more closely at the grid/ground distance difference (as a result of using the combination factor) and many resort to using surface coordinates or project datums as a way to avoid the mismatch between grid and ground distances. More recently the use of "Low Distortion Projections" has been discussed as being a way to minimize the grid/ground distance distortion. The distance distortion issue is largely moot when using the GSDM.

NAD27 and NAD83: The NAD27 was the only logical datum choice available when the state plane coordinate zones were developed during the 1930's. The zones were selected by attempting to match the projection type with the general configuration of the state. Lambert conic projections were selected for states long in the east/west dimension while transverse Mercator projections were selected for states oriented primarily north/south. Some states have only one projection; other states require more than one zone to cover the needed width; and some states have more than one projection type. For example, the State of Florida utilizes two transverse Mercator projections and one conic projection; New York employs three transverse Mercator projections and one conic projection; and the State of Alaska uses nine transverse Mercator projections, one conic projection, and one oblique Mercator projection. All projections used for the SPCS are conformal projections.

The USC&GS developed a "model law" which was promoted by the Council of State Governments for several decades and, by 1971, was adopted in one form or another by 26 states (Mitchell and Simmons 1945/1971). However, the Michigan Legislature adopted a different projection than that proposed by the USC&GS. Originally, Michigan was to be covered by three transverse Mercator projections but when the state plane coordinate law was written, professionals within the state opted instead for three conic conformal projections based upon an elevated reference surface selected to minimize the need for the elevation reduction. The elevated system worked as intended and was deemed very beneficial but, because it was "non-standard," there was confusion, both in practice and in the published literature, about computing the correct combination factor for a line (Burkholder 1980). The Michigan state plane coordinate law for NAD83 returned the reference surface to the ellipsoid.

<u>Sidebar</u> (Relationship between the Meter, the International Foot, and the U.S. Survey Foot):

1. The length of the meter was established as 1/10,000,000 of the distance from the Equator to the North Pole as determined by a geodetic survey in France in the 1790's. Alder (2002) provides a fascinating account of that effort.

2. In the early 1800's, prototype meter bars were made and distributed to the nations of the world.

3. Although the meter has been used as the standard of length for geodetic surveys in the USA since establishment of the Coast Survey (predecessor to the NGS) in 1807, the meter length unit was declared legal for trade in the U.S. in 1866. The relationship between the foot and meter was stated in 1866 to be 39.37 inches = 12.00 meters exactly.

4. Leading up to and during World War II; Canada, the USA, and Great Britian each used a slightly different relationship between the foot and meter.

US:	1.00 meter = 39.37 inches	or 1 inch = 2.540005 cm
England:		1 inch = 2.539997 cm
Canada:		1 inch = 2.540000 cm

5. Following WWII, NATO aircraft mechanics discovered that parts of aircraft engines built according to the same blueprints were not interchangeable due to differences in unit definitions. A compromise was reached that adopted the Canadian relationship (1 inch = 2.54 centimeters) as the International Foot (1 foot = 0.3048 meters).

6. However, to avoid re-computing and republishing thousands of existing state plane coordinates, the U.S.A. retained use of 12 meters = 39.37 feet and gave that long standing relationship a name, the U.S. Survey Foot. A Federal Register Notice (24 FR 5348) published in 1959 stated that the U.S. Survey Foot should be used "until such time as it becomes desirable to readjust the basic geodetic networks in the United States, <u>after which the ratio of a yard, equal to 0.9144 meter, shall apply</u>" (emphasis added).

7. In 1960 the Eleventh General Conference of Weights and Measures redefined the meter, but not the length. The redefinition made it possible to duplicate the 1.00 meter distance in terms of wavelengths of Krypton 86 gas instead of relying upon the distance between two marks on a prototype bar.

8. The definition of the length of the meter was changed again in 1983 – this time in terms of the distance light would travel in a vacuum in 1/299,792,458 seconds. The new definition is the equivalent to saying that light travels 299,792,458 meters in one second.

Although the definition used for duplicating the length of the meter has evolved over the years, the fundamental unit of length has not changed. The relationship of 12.00 meters = 39.37 feet has existed in the United States for over 100 years. The name "U.S. Survey Foot" was developed in 1959 to describe the relationship already in existence. "International Foot" is the name given to the relationship used before 1959 by Canada (1 foot = 0.3048 meters) and adopted for use around the world (except for surveying and mapping in the United States). Neither the U.S. Survey Foot nor the International Foot is part of the International System of Units (SI) adopted by the 11th General Conference on Weights and Measures in 1960. Although the GSDM is based exclusively on metric units, each user has the option of specifying linear units of choice when displaying or printing P.O.B. results when using the BURKORD™ software and the underlying 3-D data base,

When the NAD27 datum was readjusted and published as the NAD83, the legislative intent was for the International Foot to be used as an alternate to meters. Recognizing that, a number of states included the International Foot in the state plane coordinate legislation written and adopted to accommodate the NAD83. Other states objected and ultimately won. A notice published in the Federal Register on May 16, 1998, closes by saying, "The effect of this notice is to allow the U.S. Survey Foot to be used indefinitely for surveying and mapping in the United States. No other part of the 1959 notice is in any way affected by this notice." The NGS still uses meter units for all geodetic surveying operations.

The upshot is that NAD83 state plane coordinates in the United States may be meters, U.S. Survey Feet, or International Feet. Units for the GSDM are strictly metric. Provision is made for other derived units in the P.O.B. Datum option in which the user may select any linear units for output. It is intended that the underlying ECEF coordinates will always be metric when using the GSDM.

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<u>Current Status - NAD83 State Plane Coordinate Systems: (written in 2007)</u>

Although developed for use on the NAD27, design of the SPCS was revisited during the process of readjusting the horizontal network in North America. Arguments were advanced for taking advantage of the standardization offered by the UTM system and suggesting use of 2º zones instead of 6º zones on the NAD83. After many discussions and consideration of various alternatives, the decision was to adopt parameters of a different ellipsoid (the GRS 1980 in place of Clarke 1866) and to move the origin from "Meades Ranch" in Kansas to the Earth's center of mass. But the existing SPCS projections and zone parameters were retained for use on the NAD83. Notable exceptions include:

- The reference surface for Michigan was returned to the ellipsoid instead of being computed at an elevation of 800 feet.

- Zone 7 in California was eliminated. Zone 5 now covers that area.

- The states of Montana, Nebraska, and South Carolina elected to relax the arbitrary 1:10,000 criteria and to cover each state respectively with one zone.

Advantages: The advantages of using the SPCS today are largely the same as when the SPCS was first implemented. A map projection flattens a portion of the Earth and allows one to perform 2-D rectangular surveys within a defined zone using plane Euclidean geometry. Standardization and wide acceptance are two huge benefits. An incidental benefit of the SPC is that the back azimuth of a line is the same as the forward azimuth + 180º. This feature could also be called a disadvantage because it belies the fact that meridians converge at the poles

Disadvantages: A disadvantage of the SPCS for the GIS community is the absence of uniqueness. For inventory, and other purposes, it is highly desirable for the location of any point to be globally unique. State plane coordinates are unique within a zone but they are not globally unique. In addition to knowing the coordinate values for a point, the spatial data user must also know what zone or map projection is associated with the point. Two points having the same (or nearly so) coordinate values may appear to be the same or very close together while they are, in fact, many miles apart. A triplet of ECEF rectangular X/Y/Z coordinates used in the GSDM is unique within the "birdcage" of orbiting GPS satellites.

In the surveying/mapping/engineering communities, the biggest disadvantage of using map projections and the SPCS is that they are strictly 2-D mathematical models and spatial data users work with 3-D data. The GSDM is a rigorous 3-D model. Specific drawbacks to using the SPCS are listed by Burkholder (1993a) as:

- Lack of accessibility – control points are not easy to visit – permission etc.
- Lack of proximity – control points are too far away.
- Lack of quality – the published positions are not of sufficient high-quality.
- Lack of understanding – spatial data users need to learn more about the SPCS.
- Mapping distortion – ground distance may differ too much from grid distance.

With the advent of GPS, continued densification of the control network, higher levels of support from NGS, and greater awareness within the spatial data user community, the first 4 disadvantages have been mitigated significantly. But, the grid/ground difference is more of a problem than ever because more people have the equipment and use processes in which ignoring that systematic difference cannot be tolerated. An argument, with which this author is sympathetic, is that more education and enforcing uniformity of practice could overcome those disadvantages. Using the GSDM is another alternative in which spatial data users can fully exploit the three-dimensional characteristics of their data and in which 2-D applications are still supported as a sub-set of the 3-D model.

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