DATUM SHIFTS AND DIGITAL MAP COORDINATE DISPLAYS

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Paper maps may be printed with reference points for several different grid systems. Changing the datum of the map can cause these grid systems to shift by different distances. When digital maps–such as U.S. Geological Survey (USGS) digital raster graphics (DRG)–are used in geographic information systems (GIS), screen coordinate readouts may be very different from the values printed on the original paper map and may not match users' estimates of what the shifted values should be.

Since the mid-1980's, USGS topographic maps have shown the shift between the 1927 North American Datum (NAD 27) and the 1983 North American Datum (NAD 83) as dashed crosses near the corners of the map. All USGS quadrangle revisions are now done on NAD 83. Changing the datum of a quadrangle moves the neatline relative to the ground, which means that adjacent quadrangles on different datums will not join exactly.

Quadrangle neatlines are defined by latitude and longitude lines. The network of these lines is called the graticule. Plane coordinate systems are also shown on USGS maps, and these also shift when datums are changed. But changing the datum may cause different grid systems to shift by different distances.

The Real World, Maps, and Coordinate Systems

Maps are abstract representations of the world. USGS topographic quadrangles show selected surface features, such as roads, water bodies, and buildings, as well as the positions of small fixed objects, such as survey markers.

Many different coordinate systems are used to describe the positions of these features. Some coordinate systems are spherical, some are ellipsoidal, and some are planar. But in all cases, the coordinate systems are mathematical abstractions. Coordinate grids and numbers may be printed on a map along with roads and buildings, but these grids are not real-world features and should not be thought of as being "fixed" in the same sense that roads and buildings are.

There are infinitely many cartographic coordinate systems; USGS topographic quadrangles often show reference points for as many as four. The relationships of these systems to each other and to the ground can be quite complex.

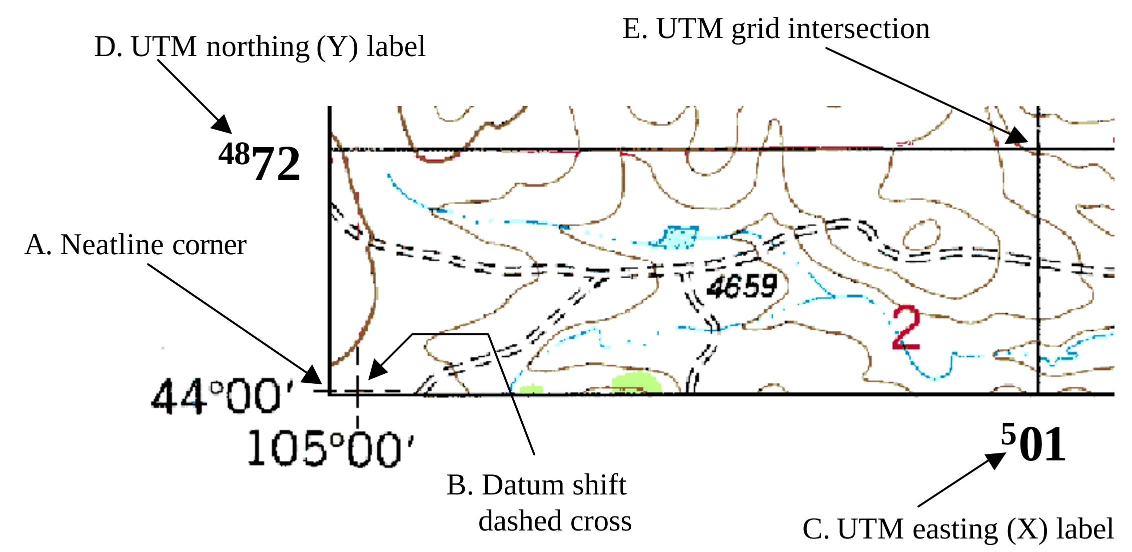

Figure 1. Southwest corner of a USGS quadrangle in northeastern Wyoming.

Table 1. Graticule shift of the map in figure 1.

		NAD 27		NAD 83	
		a	*b*	*c*	*d*
	Fig. 1	Longitude	Latitude	Longitude	Latitude
1	A	105° 00' 00"	44° 00' 00"	105° 00' 01.91245"	43° 59' 59.92221"
2	B	104° 59' 58.08761"	44° 00' 00.07778"	105° 00' 00"	44° 00' 00"
3	E	104° 59' 15.09669"	44° 00' 11.12662"	104° 59' 17.00750"	44° 00' 11.04918"

The NAD 83 graticule is shifted 42.6 meters east and 2.4 meters north of the NAD 27 graticule in the area of point A. Only the values in cells 1a, 1b, 2c, and 2d can be read or inferred directly from the map. All the other values are computed with software as described in the text.

Graticules and Datums

Consider a point such as the southwest corner of the USGS quadrangle illustrated in figure 1. The NAD 27 geographic values for this point, N44° W105°, are shown in table 1, cells 1a and 1b. Suppose the corner happens to fall exactly on some physical feature – say, a survey marker. Designating the point to be N44° W105° on NAD 27 is one of innumerable ways to describe this marker's location.

Another way is with latitude and longitude on the NAD 83 datum. The two datums use similar math models, but with different parameters. Equations exist that transform coordinates from one datum to the other, and these equations are coded in computer programs such as NADCON, written by the National Geodetic Survey (NGS). Converting the NAD 27 geographic values to NAD 83 values gives the coordinates shown in table 1, cells 1c and 1d.

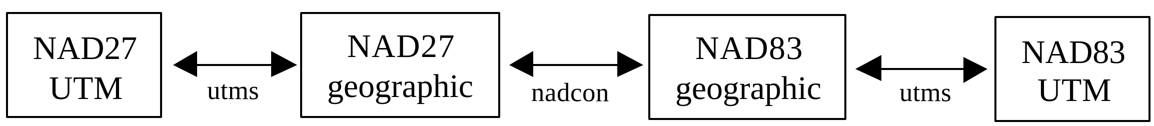

Figure 2. Conceptual view of computation steps for NAD 27-NAD 83 coordinate conversions. The arrows are labeled with the names of National Geodetic Survey freeware. Other software may hide these details to make conversion between any two coordinate systems more convenient.

This conversion labels the survey marker with different numbers, though the physical marker has not moved. But the quadrangle corner **has** moved, because quadrangle neatlines are mathematical abstractions, not real features. The NAD 83 quadrangle neatline corner (N44° W105°) is 42.6 meters east and 2.4 meters north of the survey marker. This offset is shown with a dashed cross on the USGS quadrangle.

Table 2. Universal Transverse Mercator grid shift of the map in figure 1.

		NAD 27		NAD83	
		a	*b*	*c*	*d*
	Fig 1	Easting (X)	Northing (Y)	Easting (X)	Northing (Y)
1	C	501,000 m		500,957 m	
2	D		4,872,000 m		4,872,213 m
3	E	501,000 m	4,872,000 m	500,957 m	4,872,213 m

In the NAD 27-NAD 83 conversion, the UTM X grid line with value 501,000 moved 43 meters east and the UTM Y grid line with value 4,872,000 moved 213 meters south.

Plane Grids

Universal Transverse Mercator

The Universal Transverse Mercator (UTM) grid values in the area of the quadrangle corner do not shift by the same ground distance. The relationship between NAD 27 UTM and NAD 83 UTM is so complex that it is reasonable to say there is no direct relationship. Coordinate values are normally converted between these systems in the three-step process illustrated in figure 2.

The map in figure 1 has UTM grid labels printed close to the southwest corner (points C and D). The NAD 27 UTM values for the grid intersection at point E are given in cells 3a and 3b of table 2.

The NAD 27 UTM values can be converted to NAD 27 geographic values with another NGS program called UTMS. The geographic values are then converted between datums with NADCON, and the new geographic values converted to NAD 83 UTM values with UTMS. The final results of these calculations are shown in cells 3c and 3d, table 2. The intermediate latitude and longitude values for point E are shown in table 1.

The datum change shifted the UTM grid 43 meters east and 213 meters south, a much greater distance than the graticule shift. Changing the shape of the reference ellipsoid causes changes in Y values to accumulate with distance from the origin. Since the UTM grid system has its Y origin at the equator, a large difference accumulates between latitude 0º and latitude 44º.

Of course, the details of this three-step coordinate conversion can be hidden in software, making the conversion between any two coordinate systems appear direct. The freeware program Corpscon for Windows, maintained by the U.S. Army Corps of Engineers Topographic Engineering Center, does direct conversions between several common combinations of grids and datums.

State Plane Coordinate System

USGS topographic maps also print tick marks for the State Plane Coordinate System (SPCS) grid. Figure 3 shows an easting tick mark on the south edge of the same Wyoming quadrangle.

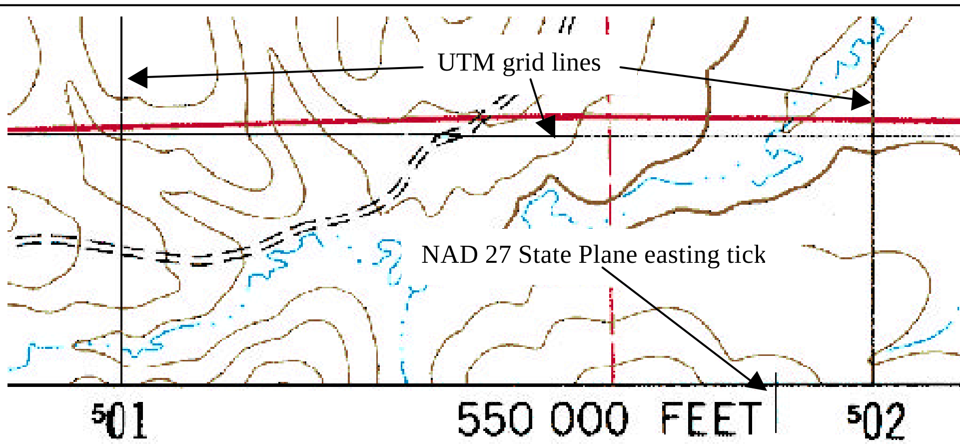

Figure 3. State Plane Coordinate System tick mark.

Using the Corpscon software, we can find the State Plane coordinates of the map neatline corner on both NAD 27 and NAD 83 (Table 3). Comparing these coordinates shows that the SPCS grid has shifted a huge distance: more than 150,000 feet west and 60,000 feet south.

This result may appear astonishing, but it is quite correct. Again, the reason is that coordinate systems are mathematical abstractions that can be defined in many ways. When the SPCS 83 was created, several significant changes were made in the zone definitions.

Table 3. State Plane Coordinate System shift of the map in figure 1.

	NAD 27		NAD 83	
Fig. 1	Easting	Northing	Easting	Northing
A	543,855.88 ft	1,214,737.75 ft	699,881.35 ft	1,275,457.87

The State Plane grid at the point NAD 27 N44° W105° is shifted about 156,025 feet west and 60,720 feet south. Most this changed is caused by changes in the SPCS parameters such as location of the grid origin, not by changes in the shape of the ellipsoid or other datum parameters.

One of these changes was to the numeric grid value of the origin of each zone. Most SPCS 27 Transverse Mercator zones have false eastings of 500,000 feet and false northings of 0 feet. SPCS 83 origin values are expressed in meters, and all were changed to make SPCS 83 coordinates noticeably different from SPCS 27 coordinates. The SPCS 83 false easting of the Wyoming East zone is 200,000 meters (656,168 feet), so more than 156,000 feet of the east-west datum shift is due simply to changing the false easting.

In addition, the projection constants for some zones were redefined. For Wyoming East, the scale factor at the central meridian was changed from 1:17,000 to 1:16,000 and the latitude of the grid origin was changed from N40º 40' to N40º 30'. Isolating the individual effects of these changes requires calculations beyond the scope of this paper, but moving the grid origin 10 minutes south accounts for most of the 60,720 foot north-south shift.

SPCS definitions are set by law in most States. Changes to those definitions for SPCS 83 therefore vary considerably. The defining constants for all SPCS 83 zones can be found in Stern (1990). The defining constants for SPCS 27 zones are printed in Snyder (1987).

Common User Problems Related to Datum Shifts

The differences between the graticule shift and a plane grid shift can be especially confusing in GIS environments:

- Imagine a USGS map published on NAD 27. The DRG for this map is also cast on NAD 27. It is not difficult to load this DRG into a GIS and recast it to NAD 83. The GIS coordinate readout will then show that the dashed datum shift crosses have "even" values characteristic of neatline corners (for example, N44° W105°), while the solid neatline corners will have "shifted" values. This is what most people would expect.

  However, when the screen cursor is moved to one of the UTM tick marks on the quadrangle neatline, the UTM coordinate readout is **not** what many people expect. The difference between the GIS readout and the label printed on the map may be several hundred meters, many times the ground distance of the graticule shift shown by the dashed crosses. This is even more true for SPCS values, which may change by thousands of meters.

- Confusion deepens when the user and the GIS have different ideas about what coordinate system is being used. Suppose that a user joins a number of quadrangle datasets, most of which are cast on NAD 27, but one of which is on NAD 83. Some software may recast the odd dataset to match the others. In other cases, the user may move the NAD 83 data to make the neatlines join without being fully aware of this procedure's effect on coordinate values. In either case, the coordinate values printed on the map will not change to reflect the digital manipulation.

- Strictly speaking, there is no obligation for different grid systems on the same map to be cast on the same datum. It is not a cartographic error to print a map with an NAD 83 graticule and an NAD 27 UTM grid, provided that adequate explanations are given in the legend or metadata. Some USGS quadrangles in Hawaii and other Pacific islands actually have neatlines and plane grids referenced to different datums. (The reasons for this are complicated, having to do with the islands' geodetic isolation before global positioning system technology.) Although the maps are correctly compiled, the coordinate labels appear to be inconsistent when digital versions of the maps are viewed in a GIS.

References

Snyder, John P. 1987. Map Projections--A Working Manual. U.S. Geological Survey Professional Paper 1395.

Stern, James E. 1990. State Plane Coordinate System of 1983. NOAA Manual NOS NGS 5.

Additional Information

The two references above are available only in hardcopy. Synder can be ordered from USGS Earth Science Information Centers; see http://ask.usgs.gov for price and ordering information. Stern can be purchased from the National Geodetic Survey (NGS); see http://www.ngs.noaa.gov/.

The NGS programs NADCON and UTMS can be downloaded for free from

- http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml

Corpscon software can be downloaded for free from

- http://crunch.tec.army.mil/software/corpscon/corpscon.html

Some Web pages with useful information about datums:

- http://www.colorado.Edu/geography/gcraft/notes/coordsys/coordsys_f.html
- http://164.214.2.59/GandG/geolay/TR80003A.HTM
- http://users.netonecom.net/~rburtch/geodesy/datums.html

A good nonmathematical explanation of geodesy:

- Introduction to Geodesy, James R. Smith, John Wiley and Sons, 1997.

A paper with more information about the relationship between map graticules and plane coordinate systems:

- http://mcmcweb.er.usgs.gov/drg/mercproj/index.html