Helping Vermonters Visualize Choice

HORIZONTAL DATUM CONVERSIONS

A Discussion, Examples, and Recommended Conversion Methodology for the Transformation of ARC/INFO Coverages from the North American Datum of 1927 to the North American Datum of 1983 in Vermont. This paper would not have been made available without the thoughtful writing of ***Milo Robinson****, NGS Geodetic Advisor to the State of Vermont, and* ***Gary Smith*** *of Green Mountain Geographics. These recognized leaders in the VGIS community have all of our thanks.*

EXECUTIVE SUMMARY

This paper outlines the steps required to convert ARC/INFO coverages from the **North American Datum of 1927 (NAD27)** to the more accurate **North American Datum of 1983 (NAD83)**.

Until recently, most contemporary maps of Vermont used the NAD27 as the reference datum. This made it the logical option for direct digital conversion and subsequent inclusion in the Vermont GIS database. With the arrival of the new Vermont Digital Orthophotography, expanded GPS activity and new maps from the U.S. Geological Survey being prepared using NAD83, it is increasingly necessary to convert existing NAD27 data to NAD83 to properly incorporate new information. The need of particular data developers or users to convert data depends on the location in the State, and particular mapping requirements.

As this paper is released the Vermont counties for which NAD83 digital orthophotos are available are **Rutland, Windsor, Franklin, Grand Isle** and **Addison**, plus portions of **Washington** County. The remainder of Washington and Orange Counties will be available soon, with the remainder of Vermont to be processed in coming years.

The remainder of this paper provides more detail on the datum change, suggests new data entry guidelines, details the coordinate and naming convention for Vermont's orthophotos, and provides the procedures for converting Vermont's NAD27 data to NAD83 using software by ESRI (Environmental Systems Research Institute, Redlands, CA).

I. BACKGROUND

What's a Datum?

A datum provides a reference for surveying and mapping the Earth. It is a mathematical model of the Earth that includes a set of precise measurements of the Earth. The datum serves as a basis to compute all subordinate horizontal and vertical positions. A datum is realized by a set of control points, typically survey monuments, that have known positions. These monuments are connected by a network of precise measurements that enable the computation of a position. In summary, a datum is the mathematical model that serves as the foundation for spatial referencing of the Earth.

Appendix A: *Datums and More*, provides further information on this topic.

II. DATUM DIFFERENCES

In North America we are usually concerned with the difference between NAD27 and NAD83. *In order to use NAD27 and NAD83 together we need to know the difference between them and convert one to the other. The purpose of this paper is to provide users with information about important differences, and the conversion process.* In Vermont, most mapping and GIS products are based on NAD27. In 1994, work on new digital orthophotos commenced based on NAD83. With the increased use of the **Global Positioning System (GPS)** we also encounter the **World Geodetic System of 1984 (WGS84)**.

WGS84 and NAD83 -- WGS84 is used by the Department of Defense; thus the GPS is based on WGS84. There is no practical difference between WGS84 and NAD83 (Defense Mapping Agency 1987). This stems from the cooperation between the **National Imagery and Mapping Agency — NIMA** (formerly the Defense Mapping Agency -- DMA) and the **National Geodetic Survey -- NGS** in developing the datums. For all practical applications, NAD83 is the same as WGS84.

NAD27 and NAD83 -- Significant difference exists between NAD27 and NAD83. There is no exact mathematical equation that will convert data built from a surface oriented local datum like NAD27, to an earth centered global datum like NAD83. The shift to NAD83 affects the location of all latitude/longitude values. Locations of some points are shifted by as much as 160m. In Vermont, the difference averages about 35m in magnitude.

III. IMPROVEMENTS to NAD83, the HIGH ACCURACY REFERENCE NETWORK

The use of GPS has impacted NAD83. Though measurements from satellite technology were used in developing NAD83, the use of GPS was very limited. As a consequence the positions in NAD83 were found to have errors on the order of about 0.5m. To improve the accuracy of the NAD83 datum, a set of high accuracy GPS control points were established in Vermont. This project is known as the **High Accuracy Reference Network (HARN)**. The Vermont HARN was completed in 1992 and resulted in small changes to the published

NAD83 positions and are designated NAD83 (1992). In contrast, the original NAD83 positions are designated NAD83 (1986). The differences between NAD83 (1986) and NAD83 (1992) are normally *less than 0.5m*.

IV. STATE PLANE COORDINATE SYSTEMS

Because of the difficulty in working with latitude and longitude, the NGS -- after requests by various States -- developed plane coordinate systems for use in each state. The original state plane coordinate systems were developed using NAD27 during the 1930's. With the development of NAD83, there have also been modifications to state plane coordinate systems.

The state plane coordinate system is a set of conformal map projections that cover the entire United States. A conformal map projection preserves the property of shape; for a small area, angles measured on the map equal angles measured in the field.

Vermont Coordinate Systems
Title 1 of Vermont Statutes Annotated, Chapter 17, sections 671-679, defines the **Vermont Coordinate System of 1927 (VCS27)** and **Vermont Coordinate System of 1983 (VCS83)** as the state plane coordinate systems for Vermont. Furthermore, VCS83 will be the sole system for projects commenced after January 1, 2000.

VCS27 is a Transverse Mercator projection using NAD27, and VCS83 is also a Transverse Mercator projection, but using NAD83. The following defining parameters of the map projections are the same for both systems:
- central meridian,
- scale factor, and
- origin.

Though the numeric values for the central meridian and origin are the same, they are different locations because they refer to different datums. One very important difference is the **false easting parameter**. The X coordinate, or easting, of the origin is given a large value to ensure that all eastings for the state of Vermont are positive values. In VCS27 a false easting of 500,000 survey feet was used. In contrast to survey feet, VCS83 uses a false easting of 500,000 meters. (1200/3937m = one survey foot).

The differential is an offset of 347,599.695m between the eastings — the X value -- of the two coordinate systems. One advantage of this large offset is that it is easy to distinguish between VCS27 and VCS83--just examine the easting or X coordinate.

VI. VERMONT'S ORTHOPHOTO BASE MAPS AND THE DATUM CHANGE

Vermont's orthophoto mapping program began producing image maps in 1974. These maps are produced at a 1:5,000 scale and up until 1994 they were based on NAD27. Beginning in 1994, the horizontal datum changed to NAD83. Thus all new orthophotography that is available from the Vermont Orthophoto Mapping Program will be based on NAD83. From 1990 to 1993, orthophoto map sheets for Chittenden, Windham and Bennington Counties were based on NAD27, but also contained approximate tic marks for the equivalent NAD83 locations. For use of these three counties' map sheets for digitizing purposes, refer to Section VIII *"Entering Data From NAD83 MAP Sheets."*

Vermont orthophoto map sheets are 4,000 meters square (except for the 1:1,200 scale imagery over some urban areas). This allowed map sheets to have easily defined corners in 4,000 meter increments. Corner values have numbers like *104,000m* in the X or easting and *128,000m* in the Y or northing for VCS27. Each sheet was numbered using the first three numbers of the X and Y coordinate values from the southwest corner of the image. Using the coordinates of *104,000* and *128,000*, the sheet with those values for the southwest corner would be *104128*. Each sheet also has a name that corresponds to a geographic point on the sheet.

Since the change to NAD83 changes the Vermont Coordinate System, coordinate numbers for the same location are different, but the new NAD83 map sheet is designed to cover *almost* the same area as the NAD27 map sheet. For continuity, the sheet numbering and naming of the NAD83 sheets remains unchanged. This means that identification numbers for sheets based on NAD83 still use the NAD27 map sheet numbers. To provide values which can be read easily for the corners of all NAD83 map sheets, the corner values end in *"000"* for the Y values and *"500"* for the X value. For example, the NAD83 map sheet *104128* will have the southwest coordinates of X = *451500* Y=*128000*. As you recall, this X difference is due to the change in eastings between the two map projections of approximately *347500m*. The Y coordinate or northing remains unchanged. In summary the NAD83 map sheet has the same number as the NAD27 map sheet and covers approximately the same area, but the southwest X coordinate or easting no longer corresponds directly with the map sheet number.

Because Vermont's new orthophotos are delivered in a digital format, the ability to mosaic and output imagery for any area will be possible and will be independent of corner coordinate values. Only people using the traditional paper copies will need to carefully consider the extent of the area required.

VII. COORDINATE CONVERSION METHODOLOGY USING ESRI SOFTWARE

There are two very similar processes available to the ARC/INFO or ArcCAD user to convert data and coverages from NAD27 to NAD83:

- The first involves the use of the datum transformation program NADCON.
- The second method uses NADCON with the **High Precision GPS Network (HPGN)** option. With this option, Vermont's network of high accuracy control points is used that further refines the datum transformation.

> Appendix C: *ESRI Datum Conversion Syntax*, include the argument strings for the PROJECT command for both methods (NADCON and HPGN).

VIII. ENTERING DATA FROM NAD83 MAP SHEETS

The general rules for entering data from maps prepared in NAD83 are no different than entering data from maps using NAD27. The general rule of digitizing maps in the projection/datum in which they are drawn still applies. Once the data has been correctly digitized it can then be projected to the desired projection. By following this general rule, the correct spatial representation of information can be anticipated.

Common Map Sheets for Digitizing

Two different types of maps are generally used in Vermont for the construction of spatially referenced databases. These maps are the **U.S. Geological Survey 1:24,000 Topographic Maps** and the **Vermont 1:5,000 scale Orthophoto Base Maps.** For a great many years, each of these products will be available in a mix of NAD27 and NAD83. Users of these maps MUST be cognizant of the datum employed for each map. The datum and projection information is presented in the lower left corner of the map sheet.

Digitizing Map Sheets

For new USGS topographical maps produced using NAD83, the user will need to generate tic values for the 4 corners of the map to obtain proper registration for digitizing. Syntax for using the *FILE* option in the ESRI *PROJECT* command are included in *Appendix C*.

Using the Vermont Orthophotos is much simpler since the tic coordinate values can be read directly from the map sheet and entered into a tic file from the keyboard. Vermont orthophotos generated between 1974 and 1994 used the Vermont Coordinate System of 1927. Sheets produced between 1990 and 1994 covering Chittenden, Windham and Bennington Counties also contain approximate tic marks for the Vermont Coordinate System of 1983. These points are approximate and should NOT be used in an attempt to directly register a NAD27 sheet in NAD83 coordinates for digitizing purposes. Sheets should be digitized using NAD27 values and the projected to NAD83, following procedures previously outlined. Since 1994 all Vermont Orthophotos have been produced using NAD83.

References

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Acronyms and Definitions

CLARKE 1866 SPHEROID	An ellipsoid model of the earth's size and shape that was defined by Clarke in 1866 and serves as the basis for NAD27
DATUM	Any quantity or set of quantities used as a basis to compute other quantities.
ELLIPSOID	A shape formed by rotating an ellipse around its axis and is used to mathematically model the earth.
FGDC	Federal Geographic Data Committee, consisting of 14 Federal Agencies, established by OMB Circular A-16
GPS	Global Positioning System
GRS80	Geodetic Reference System of 1980. NAD83 ellipsoid uses GRS80 parameters.
HARN	High Accuracy Reference Network, synonymous with HPGN
HPGN	High Precision GPS Network, synonymous with HARN
NADCON	North American Datum Conversion computer program written by the National Geodetic Survey to convert data to and from NAD27 and NAD83. Can be obtained from *http://www.ngs.noaa.gov/PC_PROD/pc_prod.html*
NAD27	North American Datum of 1927
NAD83	North American Datum of 1983
UTM	Universal Transverse Mercator, a series of 60 Transverse Mercator map projections that cover the entire globe
VCS27	Vermont Coordinate System of 1927, Vermont’s state plane map projection of NAD27
VCS83	Vermont Coordinate System of 1983, Vermont’s state plane map projection of NAD83
WGS84	World Geodetic System of 1984. Department of Defense datum and is used for GPS. For all practical purposes WGS84 is the same as NAD83

Appendix A — Datums, and More Information about Them

In North America there are several datums in use. These datums are divided into horizontal and vertical. Vertical datums are used to reference elevations. Horizontal datums are the basis for computing latitudes and longitudes. Control points may have a vertical datum and/or a horizontal datum associated with them. Often the term "benchmark" is used for a control point, yet it's intended to refer only to vertical control points. Now let's examine the horizontal datums in more detail.

Horizontal Datum

Horizontal datums serve as a spatial reference for surveying, mapping, and GIS. For many years the North American Datum of 1927 (NAD27) has served as this reference and existing maps created in NAD27 continue to be the primary source for GIS data in Vermont. Early in the 1970's it became apparent that with advances in measurement technology, particularly satellite technology, that NAD27 would need replacement. Thus work on a new datum, the North American Datum of 1983 (NAD83), was started. In 1989, after more than a decade of work, NAD83 was affirmed as the official civilian datum for the Federal Government and is recognized by Vermont Statute. The transition to NAD83 is now taking place. For more information on the development of NAD83 see Schwarz (1989).

Ellipsoid Models the Earth

Horizontal datums provide a mathematical model for the Earth. The chosen mathematical model is an ellipsoid--a sphere that is flattened at the poles. Frequently the term spheroid is used to describe this mathematical model, but spheroid is a more general term used to describe anything that is nearly a sphere. The ellipsoid model that we use for the Earth is generated by rotating an ellipse on its axis. Because the Earth bulges out at the equator, we rotate an ellipse along the polar axis so that the bulge of the ellipse matches the bulge of the Earth. An ellipsoid is completely defined by two parameters, semi-major axis (the equatorial radius of the Earth), and flattening. A horizontal datum includes an ellipsoid model that is defined by two parameters.

Local Datums

Equally important to defining a datum, is the physical connection of ellipsoid model to the Earth. Historically ellipsoid models were connected at a single point, called an origin point, thus establishing a local datum. Each local datum has a different origin point, therefore different datums can have the large differences in position. In a local datum, the value of latitude and longitude was defined and assigned to a single horizontal control monument. All subsequent positions were computed from this origin point. In addition, all measurements connecting the control points were terrestrial, mostly triangulation. As a consequence of these early practices, there are, by today's standard, large errors in these local datums and significant differences between them. An example of a local datum is the North American Datum of 1927 (NAD27) with its origin point at Meades Ranch, Kansas.

Global Datums

In contrast to local datums, modern horizontal datums are based on using satellite measurements and other advanced space-based measurements, like **Very Long Baseline Interferometry (VLBI)**. These measurements are used to connect the ellipsoid model of the Earth to a network of control points. This technique contrasts greatly from using a single origin point and provides a globally best fitting connection of the ellipsoid model to the earth. The North American Datum of 1983 (NAD83) and the World Geodetic System of 1984 (WGS84) are examples of these globally best fitting datums.

In addition to a different global connection, the ellipsoid parameters of global datums have been changed to better fit the Earth. For example, NAD27 uses the Clarke 1866 ellipsoid, where as NAD83 uses the ellipsoid defined by the Geodetic Reference System of 1980 (GRS80).

Summary

There are two types of horizontal datums: an older, now obsolete, local origin datum, and a modern globally best fitting datum. Older datums were developed using surface measurements and modern datums incorporated satellite measurements. NAD27 is a local datum and NAD83 is a global datum.

Appendix B — NADCON Software and Conversion

There are several methods to convert from NAD27 to NAD83 and vice versa. To simplify and provide a consistent process for conversion, the National Geodetic Survey developed a program called NADCON (Dewhurst 1990). NADCON converts latitude and longitude from NAD27 to NAD83 and vice versa. It's endorsed for use by the Federal Geodetic Control Subcommittee of the **Federal Geographic Data Committee (FGDC)**. As a result, NADCON has become the standard conversion method and is incorporated into other software packages to perform this conversion. NADCON software is freely available at *(http://www.ngs.noaa.gov/PC_PROD/pc_prod.html*).

Comparison of NAD 27 to NAD83

The NADCON conversion software can be used to convert coordinates of points; however, NADCON provides only an approximation. As an example, consider a control point located near Montpelier, VT:

```
NAD83
LAT: N  44 deg, 12 min, 44.72514 sec
LON: W 72 deg, 33 min, 26.36052 sec

NAD27
LAT: N 44 deg, 12 min, 44.50681 sec
LON: W 72 deg, 33 min, 27.97574 sec

Difference
N:   0.21833 sec
W:   1.61522 sec
```

Figure 1 Control Point "RUNWAY": Comparison of NAD27 and NAD83

This difference corresponds to about 7 m in the latitude and 34 m in the longitude. These values are close to the average change for Vermont. The magnitude of the datum change in Vermont ranges from a minimum of about 31m to a maximum of about 37m.

Differences within NAD83

The differences in coordinates between locations expressed in NAD83 (1986) and NAD83 (1992) are small (normally less than 0.5m). For example, let's examine control point RUNWAY again:

```
NAD83 (1986)
LAT:  N 44 deg, 12 min, 44.72514 sec
LON:  W 72 deg, 33 min, 26.36052 sec

NAD83 (1992)
LAT:  N 44 deg, 12 min, 44.71791 sec
LON:  W 72 deg, 33 min, 26.35918 sec

Difference
N     0.00723 sec
W     0.00134 sec
```

Figure 2 Control Point "RUNWAY": Difference between NAD83 (1986) and NAD83 (1992)

This difference corresponds to about 0.21m in the latitude and 0.03m in the longitude. The average magnitude of this change for Vermont is about 0.25m. NADCON has incorporated these upgrades to NAD83 as HPGN. The magnitude of the difference between the two is probably not significant for many mapping and GIS applications, and NADCON -- with or without HPGN -- should suffice for conversions from NAD27 to NAD83 (1992) for Vermont GIS data users.

Comparison of Vermont Coordinates Systems

For an example of the difference between VCS83 and VCS27, let's examine control point RUNWAY once again:

```
VCS83 [NAD83 (1992)]
Northing or Y          190,244.308m
Easting or X           495,419.020m

VCS27
Northing or Y          190,235.684m
Easting or X           147,783.300m

Difference
N           8.624m
E     347,635.720m
```

Figure 3 Control Point "RUNWAY": Difference between VCS83 and VCS27

This difference corresponds to the change between the two datums, plus the change between the map projections primarily due to the change in eastings. If we correct the easting by subtracting 347,599.695m, then the change for the easting becomes 36.025m, a value about what we expect from the datum change.

UTM Coordinates

Another map projection that is frequently used in Vermont is the **Universal Transverse Mercator (UTM)** projection. This projection results in larger scale distortions, but provides a simpler system of map projections that cover not only the United States, but the entire globe. The UTM projection can reference either NAD27 or NAD83. For an example of the difference, let's again examine control point RUNWAY:

```
UTM Zone 18  NAD83 (1992)
Northing or Y        4,898,368.029m
Easting or X           695,141.180m

UTM Zone 18  NAD27
Northing or Y        4,898,144.110m
Easting or X           695,111.159m

Difference
N    223.919m
E     30.021m
```

Figure 4 Comparison of data projected in UTM

This difference corresponds to the change between the two datums, plus the distortions of the UTM map projection. The large change in the Northing is a consequence of the UTM map projection and shows the advantage of using the Vermont Coordinate System. These systems are designed to fit Vermont, thus minimizing the projection’s scale distortions.

Appendix C — ESRI Datum Conversion Syntax

This coordinate conversion command syntax includes changes to both the datum and the map projection. The only difference between the input and output specifications is the change in the name of the reference datum. The arguments for use of the NADCON program to convert VT GIS data from NAD27 to NAD83 are listed below. Please note that the use of the secondary DATUM arguments “NADCON” and “HPGN” in figures 5 and 6 are optional but recommended.

```
INPUT
PROJECTION      STATEPLANE
UNITS           METERS
ZONE            5526
DATUM           NAD27 NADCON
PARAMETERS

OUTPUT
PROJECTION      STATEPLANE
UNITS           METERS
ZONE            5526
DATUM           NAD83 NADCON
PARAMETERS
END
```

Figure 5 VCS27 to VCS83 Parameter Options

Should the need exist to convert data from NAD83 to NAD27 the PROJECT command supports this and it's accomplished simply by switching the datum names. When the Vermont HPGN option becomes available and is incorporated into the ESRI software, then the argument string for the PROJECT command would appear as follows:

```
INPUT
PROJECTION      STATEPLANE
UNITS           METERS
ZONE            5526
DATUM           NAD27 HPGN
PARAMETERS

OUTPUT
PROJECTION      STATEPLANE
UNITS           METERS
ZONE            5526
DATUM           NAD83 HPGN
PARAMETERS
END
```

Figure 6 VCS27 to VCS83 Conversion using HPGN option

Appendix D — Digitizing Procedures

This section has been written to assist users of digital geospatial data to move over from the old datum of NAD27 to that of the newer NAD83 datum. VCGI recommends that you convert your NAD27 coverages into NAD83 Datum using the following methods.

Digitizing from NAD27 quad maps to create NAD83 digital data

Because of complications with production of NAD83 USGS quadrangle topographic maps, not all areas are available yet in this format. Hence, some will still be required to use NAD27 maps as their source maps when digitizing geographic data.

If, for example, you are using a USGS quadrangle NAD27 paper map as your digitizing source, digitize it normally and re-project it into NAD83 using the Arc/Info command 'PROJECT'. For your initial digitizing coverage, use the VGIS coverage **QUAD_27**. VCGI can also provide users with the appropriate projection parameters file (*.PRJ) when necessary.

It is not recommended that users try to digitize directly into NAD83 from a NAD27 source map. This is because the origins or corner tics on the newer NAD83 topographic quadrangle maps have slightly different "X,Y" origin locations than their NAD27 predecessors. According to a USGS representative, the general difference in position can be off by 100 feet, or greater.

Digitizing from NAD27 orthophotos to create NAD83 digital data

When using a USGS NAD27 paper orthophoto as the digitizing source, then insure that you are using an empty copy of the VGIS coverage **ORTHO_27** when registering control points to the digitizer. Be sure to then use the Arc/Info 'PROJECT' command to re-project the finished coverage into NAD83.

Digitizing from NAD83 orthophotos to create NAD83 digital data

Do not use the VGIS coverage **ORTHO**. Although it is NAD83 datum, it is simply a re-projection of the old NAD27 **ORTHO** coverage and does not account for the shift in location that **ORTHO_83** does account for. Use the VGIS coverage, **ORTHO_83** when digitizing from an orthophoto that is NAD83 datum.

Creating NAD27 data from NAD83 data

Just in case someone needs to create NAD27 data, VCGI maintains coverages (**ORTHO_27** and **QUAD_27**) which are useful for either creating NAD27 directly.

Other Formats

If you are using AutoCAD for all of your data development and cartographic output, there is a company which will convert your digital NAD27 AutoCAD drawing files into NAD83. The URL is *http://lino.com/~frabilod/acad_e.htm*.