Local Vertical Datum Conversion, NAVD vs. NGVD

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Datums

A vertical datum is a fixed reference used to determine elevations (heights) or depths. The datum is an established zero and is used for surveying, engineering, mapping and other applications. Appendix A includes the list of tidal datums published by the National Oceanic and Atmospheric Administration (NOAA) and Appendix B includes the definitions of the two geodetic vertical datums commonly used in the conterminous United States. These definitions can be found through the NOAA Center for Operations Oceanographic Products and Services (CoOps).

Most planning, mapping, surveying and engineering projects require the use of one of four datums: Assumed, Approximate, Tidal and Geodetic.

An assumed datum is an adequate elevation base if the project does not require exact elevations. If the subject or locus is far from flood hazard zones (flood plains), is sufficiently higher than estimated or known adjusted high groundwater elevation and additionally has no other reason to be on a defined datum, then it is acceptable to use an assumed datum.

Water elevation is not the only reason to use a defined datum. A restriction based on the proximity to an airport could be another situation requiring a defined datum. Logically, if a project is going to be incorporated into a larger project, like a geographic information system (GIS), then the assumed datum would not be appropriate. Further, if there is a need to compare one project with another, maintaining the same or a similar datum between the projects becomes essential. For example, this would become important when analyzing the stormwater and drainage patterns of a given region.

Given the vast amount of information and resources available there are good reasons to use a defined datum over an assumed one.

An approximate datum is a preferred to an assumed datum as this will place the vertical component of a project close to the actual. The typical approximate datum is based on a

USGS Quadrangle contour or aerial topographical elevation. Given the source of these elevations, this method is not much better than the assumed datum, but at least the resulting plan datum will approach the actual elevation. With the use of any datum, especially an approximate datum, it is important to reference the source of the base elevation. It would be unfortunate for an approximate datum to be confused with an actual datum because a reference was not included. Approximate datums are inadequate for critical elevations.

Tidal and geodetic datums are very similar. Geodetic datums are based on the average of a tidal datum and every tidal station published by CoOps has a reference to a geodetic datum. Tidal stations are combinations of specific devices used to determine the various tidal datums at a given location. It is possible for an individual or a firm to establish their own tidal station, in which case the height relative to a geodetic datum may or may not be determined by that individual or firm. The definitions of the commonly published tidal and geodetic datums are listed in Appendices A and B. These include mean sea level, mean high water and mean low water.

It is important to note that geodetic datums are valid over very large areas and tidal datums are valid for specific water bodies. When a tidal datum is required for a project, the typical procedure is to establish an elevation at the project site based on a geodetic datum, select the applicable tidal datum, based on a tidal benchmark, then perform the conversion from one datum to the other. There are several projects that require the use of the relative elevation of one of the tidal datums to a geodetic datum. For example, some projects require the location of mean high water. The elevation of mean high water relative to a particular geodetic datum can be calculated from a datum sheet, see Appendix I.

Geodetic Datums and Benchmarks

There have been several geodetic datums established in North America, but only two have been widely used in the conterminous United States. The older datum is the National Geodetic Vertical Datum of 1929 (NGVD or NGVD 29) and the newer is the North American

Vertical Datum of 1988 (NAVD or NAVD 88). The NOAA definitions for these datums are located in Appendix B.

While NAVD 88 has been available for over two decades, it is not the most commonly used on Cape Cod because the Federal Emergency Management Agency, Flood Insurance Rate Maps (FEMA FIRMs) are based on NGVD 29. Conversely, the CoOps tidal datums are referenced to NAVD 88. Most professionals rely on the conversion software VERTCON to adjust the tidal datums to NGVD 29. The quality of that conversion is reviewed later.

FEMA is in the process of completing a new set of FIRMs for Cape Cod. The first major difference between the current FIRMs and the preliminary FIRMs is the basis. The preliminary FIRMs are based on NAVD 88, not NGVD 29. The second major difference between the old and new FIRMs are the RMs (Reference Marks). The older FIRMs include locations, descriptions and elevations of benchmarks and the newer maps contain no reference control points.

It has been common knowledge that the RMs from the older FIRMs are not very reliable. Many have been set on low quality structures like the flange bolts of fire hydrants or the abutments of bridges that may be subject to settling. The precision of the level surveys performed to establish the elevations are unknown as are the base starting points.

The National Geodetic Survey (NGS), Massachusetts Geodetic Survey (MAGS) and MassDOT Survey Division (formerly MassHighway Survey Division) have all established geodetic control including benchmarks. MassDOT publishes the MAGS data and purposefully publishes elevation information on both datums when available. The NGS no longer supports NGVD 29 and will only publish elevations on NGVD 29 when there are no NAVD 88 elevations available.

A Brief History of the Geodetic Datums

The history of NGVD is interesting as it was known as the Sea Level Datum of 1929 until 1973 when it was officially changed to the National Geodetic Vertical Datum of 1929. The reason for the change was “in order to avoid such apparent confusion and the costly errors that may result through failure to consider local sea level when engineering projects are undertaken.” [FR Doc.73-9694 Filed 5-15-73; 8:45 am], see Appendix C.

The Sea Level Datum of 1929 was established by averaging the mean sea level elevation at 26 tidal stations located in the United States and Canada. As can be surmised from this statement, mean sea level varies at different locations. The variations are caused by a myriad of factors including “currents, prevailing winds and barometric pressures, water temperature and salinity differentials, topographic configuration of the bottom in the area of the gauge site, and other physical causes." [History of Geodetic Leveling in the United States, by Ralph Moore Berry, Assistant Director, National Geodetic Survey, National Ocean Survey, NOAA, June 1976, Appendix D].

Over 100,000 km of leveling was performed to determine the relative elevations of the 26 tidal stations. "In spite of these known variations in the elevations of local mean sea level, it was concluded (1) that these variations were <u>probably</u> of <u>about</u> the same order of magnitude as the observational errors in the leveling network, and (2) that confusion would be caused in the operations of the engineering community if the published elevations of bench marks near the coast would not be compatible with the local mean sea level as determined by tidal observations. Accordingly, in the 1929 adjustment, the network was constrained to hold fixed the observed local mean sea level at each of the 26 gauge sites listed above." [History of Geodetic Leveling in the United States, by Ralph Moore Berry, Assistant Director, National Geodetic Survey, National Ocean Survey, NOAA, June 1976, Appendix D]. In simpler terms, the datum was warped to match the local tidal datum. Of course, the datum has remained fixed as sea levels have changed, thus today the NGVD 29 datum is not as similar to local mean sea level as it was in 1929.

The establishment of the North American Vertical Datum of 1988 was performed in a similar fashion as the National Geodetic Vertical Datum of 1929. Approximately 625,000 km of leveling had been added to the 100,000 km network established by 1929. Additionally, the National Geodetic Survey ran approximately 80,000 km of leveling to re-establish the first-order NGS vertical control network. The data was adjusted using more robust methods and the order of magnitude of the observational errors were accurately calculated.

Ultimately, the mean high water elevation at Father Point, Rimouski, Quebec, Canada was held fixed to determine the datum. This was done for two reasons: 1.) This elevation was within the order of magnitude of the error of the leveling network, [see Appendix B] and 2.) This was an advantageous elevation due to it being the elevation fixed for the International Great Lakes Datum of 1985 (IGLD '85). Elevations on IGLD are different as they are based on dynamic heights where the elevations on NAVD 88 are Helmert orthometric heights, but at least the basis is the same.

As previously stated, many professionals using elevations will not use the newer elevations until the FIRMs are updated to NAVD 88 even though NAVD 88 is the appropriate datum to use when determining the relative elevations of the tidal datums like mean high water, mean low water, etc. Until the transition from NGVD 29 to NAVD 88 is complete and all NGVD 29 benchmarks have been converted to NAVD 88 elevations, it will be critical to know an accurate conversion from one datum to the other. This leads directly to the basis of this paper.

How Does One Convert From NGVD to NAVD?

The conversion from one datum to another is a simple concept: define a conversion factor and apply it. The direction of the conversion around Cape Cod is negative as sea level has risen here. Therefore, the factor is subtracted from an NGVD 29 elevation to become an NAVD 88 elevation. The conversion on Cape Cod is about a foot, therefore, elevation 10 (NGVD 88) is equal to elevation 9 (NAVD 29).

The conversion factor is actually not uniform. NAVD is closer to a uniform and regular shape than NGVD. NAVD is still subject to distortions due to errors in the level networks, gravitational influences not corrected and other factors that commonly affect leveling. NGVD, however, is warped more than NAVD as it was purposefully modified to reflect the local mean sea level at each of the 26 tidal stations. Further, the acquisition, analysis and adjustment of the level data was not performed to the same rigorous degree as the more recent work.

The first step in the process is to test the record data. This requires researching the various sources of high-quality benchmarks for published elevations on both datums on the same monuments. This method will fail as there may not be a suitable number of high-order benchmarks with published data on both datums in the area being examined.

The best method to create a conversion is to physically measure from high class, high order, stable benchmarks on one datum to high class, high order, stable benchmarks on the other datum. The methods for level runs can be reviewed in Bench Mark Reset Procedures, Guidelines to preserve elevation data for soon-to-be disturbed or soon-to-be destroyed bench mark, Documented by Curtis L. Smith, National Geodetic Survey, Silver Spring, MD 20910, May 2007. The proper methods for using Geographic Positioning Systems (GPS) to perform these measurements can be found in NOAA Technical Memorandum NOS NGS 59, Guidelines for Establishing GPS-Derived Orthometric Heights, by David B. Zilkoski, Edward E. Carlson and Curtis L. Smith, National Geodetic Survey, 26 March, 2008.

Physically measuring between control points will take time. Once that data is adjusted, it can be analyzed and adjustments can be computed. Before performing a significant amount of fieldwork, one should look at the record information to determine if there are an adequate number of existing benchmarks to determine a conversion.

The third method is to use VERTCON. VERTCON is a computer program offered by the NGS as part of the geodetic toolbox. VERTCON was created by establishing a grid of conversions; the program interpolates the conversion based on the location input. The model has been incorporated into CORPSCON which is easier to use and has more functionality than

VERTCON. A link to CORPSCON can be found through the NGS Geodetic Toolbox but it is maintained and distributed by the US Army Corp of Engineers.

Appendix F contains the NGS overview of VERTCON as published in Professional Surveyor, NGS Toolkit, Part 9: The National Geodetic Survey VERTCON Tool, by Donald M. Mulcare. Appendix G contains the Federal Register Notice of the implementation of VERTCON as the recommended method to convert between the subject datums. Appendix H contains the readme file for VERTCON.

These three sources of information contain a significant number of clues that would lead one to realize that the quality of the conversion should be verified before depending on the VERTCON Tool and that VERTCON may not be appropriate for many applications:

"Because the VERTCON model can be considered accurate at the 2 cm (one sigma) level, it is suitable for a variety of mapping and charting purposes. As a model, it cannot maintain the full vertical control accuracy of geodetic leveling. Users needing high accuracy should adjust their observations using published NAVD 88 values. ... In the exercise [elsewhere] a point with adjusted heights in both NAVD 88 and NGVD 29 was transformed using VERTCON. In this case we transformed the published NAVD 88 height (44.901 meters) to its NGVD 29 value. A comparison of the published NGVD height (45.121 meters) with the transformed height (45.118 meters) shows an excellent agreement (0.003 meters). **Your results may vary.** Like all transformation packages based on grids of differences, the accuracy of the transformations is dependent on the quantity and quality of the underlying data." [Appendix F].

"Note that **VERTCON is not appropriate** to transform between NGVD 29 and NAVD 88 **for first-, second- or third-order heights**, as defined in the Federal Geodetic Control Committee (FGCC), <u>Standards and Specifications for Geodetic Control Networks</u>, and retain first-, second- or third-order accuracies in the results. Method 1, recomputation or readjustment of survey observations, is usually more appropriate to maintain first-, second-, or third-order FGCC accuracies." [Appendix G] The Standards and Specifications for Geodetic Control Networks for vertical control can be found in Bench Mark Reset Procedures, Guidelines to

preserve elevation data for soon-to-be disturbed or soon-to-be destroyed bench mark, Documented by Curtis L. Smith, National Geodetic Survey, Silver Spring, MD 20910, May 2007.

"Tests of the predictive capability of the physical model show a 2.0 cm RMS agreement at our 381,833 data points. … **It should be emphasized that VERTCON 2.0 is a datum transformation model, and cannot maintain the full vertical control accuracy of geodetic leveling.** Ideally, one should process level data using the latest reduction software and adjust it to established NAVD 88 control. However, VERTCON 2.0 accuracy is suitable for a variety of mapping and charting purposes." [Appendix H]

It is important to take note of the disclaimer from the Federal Register [Appendix G]: "VERTCON is not appropriate … for … third-order heights." The maximum acceptable error for a third-order height is 12.00 mm times the square root of the distance leveled in kilometers. This converts to 0.05 feet times the square root of the distance in miles. In Massachusetts, pursuant to 250 CMR 6.00: Procedural and Technical Standards for the Practice of Land Surveying, § 6.02 (2) 4. b.: "For the purposes of establishing bench marks, level loops shall close to a minimum accuracy of 0.05 feet times the square root of the length of the level run in miles." The standard for surveyors in the Commonwealth of Massachusetts matches the standard for 3rd-order geodetic control, therefore, VERTCON conversions do not meet the minimum standards for surveying and their use should be limited to mapping and charting purposes.

Testing The Transformation

The example from Appendix F provides a method to test the accuracy of VERTCON. If one researches the elevation difference as reported by one or more agencies who have performed geodetic leveling, then one can determine an accurate difference between the two datums. This difference can then be compared to the VERTCON value at the same location to determine if the VERTCON conversion is adequate and accurate.

If the comparisons of several record benchmarks in a given area match the relative VERTCON values, then the VERTCON values can be considered accurate to the standard purported by the software developer.

If that comparison of the record benchmarks in a given area do not match the relative VERTCON values, then a better conversion can be calculated. The documentation states that "local distortions of 20 cm [0.66'] or more were found in the NGVD 29 network." [Appendix F] In these areas, the use of VERTCON would be inappropriate for accurate work.

There are areas where the difference between the datums compared with the VERTCON values are less than 20 cm and more than 2 cm. As will be shown later, the average difference between the datums on Cape Cod is 1.06' where VERTCON returns an average conversion of 0.86'. This is a 0.20' (6 cm) difference. Therefore, the VERTCON conversion is not appropriate to use for high accuracy work on Cape Cod.

The Problem: Real or Not?

If there is an issue with the conversion between NGVD 29 and NAVD 88, does it really matter? Or a better form of the question is: When does it become significant enough to become a concern? Returning to the numbers published above; Does 0.20' make a difference in the grand scheme of things?

For the most part no, but in several cases, yes.

When measuring far enough away from a water body, the elevation could be off by feet without an issue. The use of an assumed or approximate datum for these locations is usually adequate.

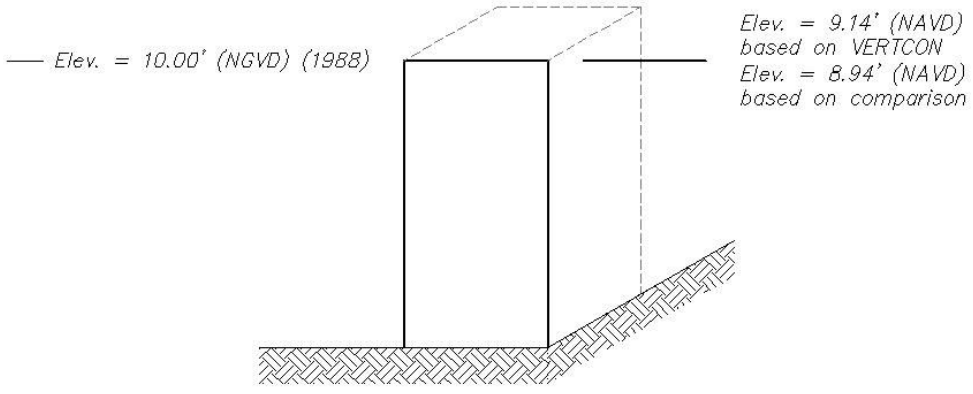
When measuring near a water body, the elevation can often become critical. Certain water bodies have a very flat bottom and a vertical difference of 0.20' can extend several feet to tens of feet horizontally, see the photograph of the flats to the west of Eastham. Like tidal flats,

flood plains can extend into very flat areas resulting in a horizontal location that could vary by feet due to a slight change in the vertical elevation.

The flats in Eastham, MA.

Where the problem could cause a significant issue is not in reality per se, but rather in the insurance and compliance of a structure or property. Flood insurance is assessed to a particular property based on the elevations relative to estimated flood hazards. These flood hazard zones are estimated to the nearest foot. The compliance under local, State or Federal regulations can often be interpreted in a draconian view, thus a 0.20' discrepancy could result in a significant problem.

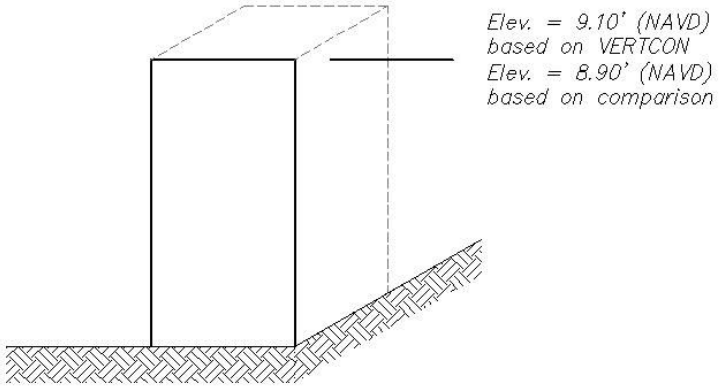
Assume a structure is designed and built while the NGVD 29 datum is applicable based on an NGVD 29 benchmark at elevation 10.00' (NGVD) where the flood elevation contour is 10' and the structure is fully compliant with all applicable regulations. Further assume that the relative elevation of the floodplain remains unchanged with the conversion to NAVD 88, so that the flood elevation contour of 10 (NGVD) becomes 9 (NAVD). Using the conversion factors of 1.06' and 0.86', the elevation of the top of the structure would be 9.14' (NAVD) based on VERTCON or 8.94' (NAVD) based on the comparison method.



The relative elevations of a wall or piling.

Using the comparison method, the compliant structure becomes non-compliant in this scenario. Even if the structure is considered pre-existing, non-conforming from a regulatory viewpoint, the insurance company will adjust the cost of insurance accordingly.

If we change the assumptions used in this example, we can see there could issues for the surveyor and/or the engineer. Assume the initial benchmark is based on NAVD 88 and the elevation is converted to NGVD 29 based on VERTCON, then assume the structure is built at an elevation of 10.06' (NGVD). The top of this structure converts to either 9.1' (NAVD) based on VERTCON or 8.9' (NAVD) based on the comparison method. Because the conversion based on the comparison method is based on actual published benchmarks, an elevation based on the conversion will be the same as an elevation established by measuring from an NAVD benchmark. The discovery of this issue would likely occur when the structure is remeasured for additional permitting or during a re-evaluation of flood insurance. This example could prove to be a problem as the use of VERTCON would create a non-compliant structure. Grandfathering may not be applicable in this case which could lead to liability issues for the surveyor and/or engineer who relied on VERTCON.



The relative elevations of a wall or piling.

It cannot be emphasized enough that VERTCON is not accurate enough to convert third-order elevations and that the surveyors and/or engineers contributing to the design of coastal structures must meet a third-order accuracy with their elevations.

Case Study: Cape Cod, including the Town of Plymouth

Cape Cod is a peninsula that extends from Plymouth out into the Atlantic Ocean. It is comprised of 14 towns with three major roadways traversing just over half of the land and one extending to the end of the Cape. This becomes somewhat important as level runs are usually performed along the major roadways. The Town of Plymouth, which is not technically part of the Cape was included in the analysis. The entire subject area will be called Cape Cod or the Cape.

Based on multiple surveys using levels, trigonometric leveling (total station) and GPS, it was easily determine that the difference between NGVD and NAVD is <u>not</u> the same as the VERTCON conversion. Therefore, the comparison method will be used to determine the difference between the two datums.

There are 113 published benchmarks on Cape Cod that meet the following criteria:

- The work was performed by the National Geodetic Survey (NGS), the Massachusetts Geodetic Survey (MAGS) or the Massachusetts Highway Survey Division (MassDOT).
- The published data is listed as first-, second-, or third-order. Most of which are second-order.
- There are both NAVD 88 and NGVD 29 elevations published for each benchmark.

The NGS benchmark database was downloaded and modified to include the following information:

- Benchmark name.
- Benchmark location (geographic coordinates and State Plane Coordinate coordinates).
- Benchmark elevation on both datums (the MassDOT NAVD data is in metric, so these were added and an additional field was created to publish the converted imperial elevation).
- Conversion based on VERTCON.
- Conversion based on comparison of the published elevations.
- Benchmark quality (order).
- The Town within which the benchmark is located.

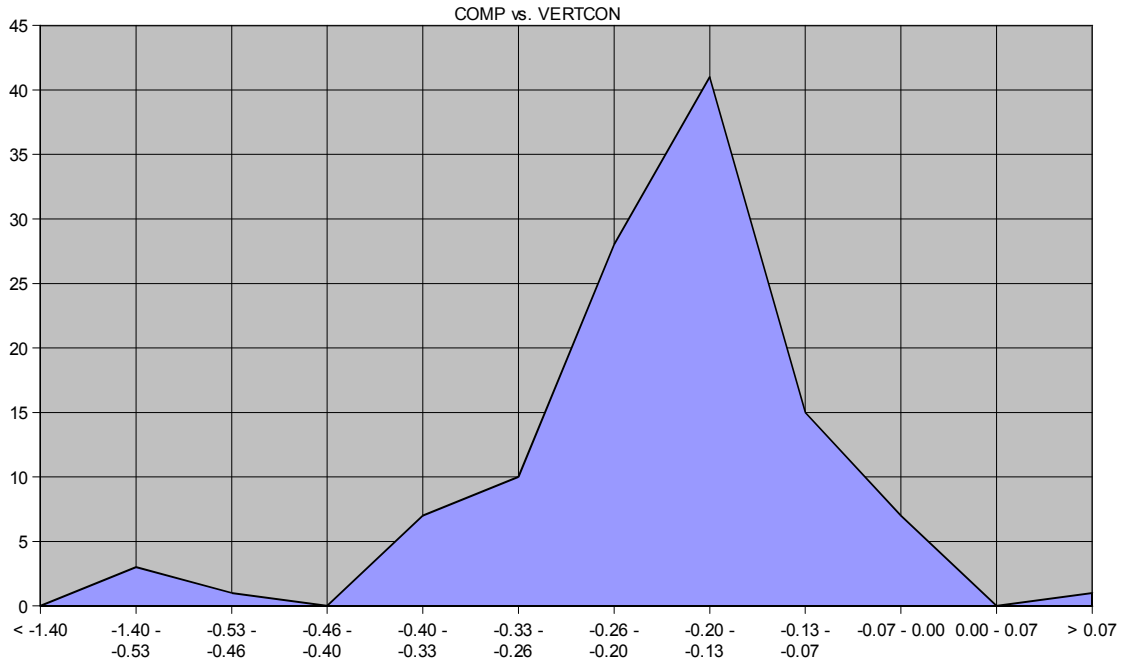
The database was converted to a spreadsheet with only the pertinent information to make it easier to perform statistical analysis as the database contains 37 fields, most of which are not necessary for the analysis. Please note that the results at the bottom of the following spreadsheet are based on all 113 benchmarks located on Cape Cod including five that are significantly outside of the range of benchmarks. Note the Max “DELTA_OBS” is -0.490 and the Min “DELTA_OBS” is -2.241 which represents a range far greater than the 4 cm (0.132') (+/- 2 cm) value that we hope to observe. Only Plymouth has been shown in these examples, the entire spreadsheet is included as Appendix J.

OBJECTID	FeatureId	TOWN	ELEV_29	ELEV_88m	ELEV_88	ELEV_SRCE	DELTA_OBS	DELTA_VERTCON	ELEV_29_Order	Elev_88_Order
95	198	Plymouth	45.694	13.642	44.757		-0.937	-0.827	2	2
96	199	Plymouth	68.062	20.47	67.159		-0.903	-0.830	2	2
97	200	Plymouth	132.808	40.194	131.870		-0.938	-0.827	2	2
98	201	Plymouth	265.192	80.552	264.278		-0.914	-0.830	2	2
99	202	Plymouth	167.039	50.655	166.191		-0.848	-0.823	2	2
100	203	Plymouth	168.314	51.05	167.487		-0.827	-0.823	2	2
					AVERAGE		**-1.077**	**-0.864**		
					Max		-0.490	-0.823		
					Min		-2.241	-0.886		
					Range		-1.751			

Removing these presumed erroneous published benchmark comparisons results in the following:

OBJECTID	FeatureId	TOWN	ELEV_29	ELEV_88m	ELEV_88	ELEV_SRCE	DELTA_OBS	DELTA_VERTCON	ELEV_29_Order	Elev_88_Order
95	198	Plymouth	45.694	13.642	44.757		-0.937	-0.827	2	2
96	199	Plymouth	68.062	20.47	67.159		-0.903	-0.830	2	2
97	200	Plymouth	132.808	40.194	131.870		-0.938	-0.827	2	2
98	201	Plymouth	265.192	80.552	264.278		-0.914	-0.830	2	2
99	202	Plymouth	167.039	50.655	166.191		-0.848	-0.823	2	2
100	203	Plymouth	168.314	51.05	167.487		-0.827	-0.823	2	2
					AVERAGE		**-1.059**	**-0.864**		
					Max		-0.827	-0.823		
					Min		-1.273	-0.886		
					Range		-0.445			

These results are the source of the -1.06' and -0.86' figures used in the examples above. However the range is well outside of the 4 cm (0.132') value as it is 0.445'. Further review is necessary to have confidence in these figures.



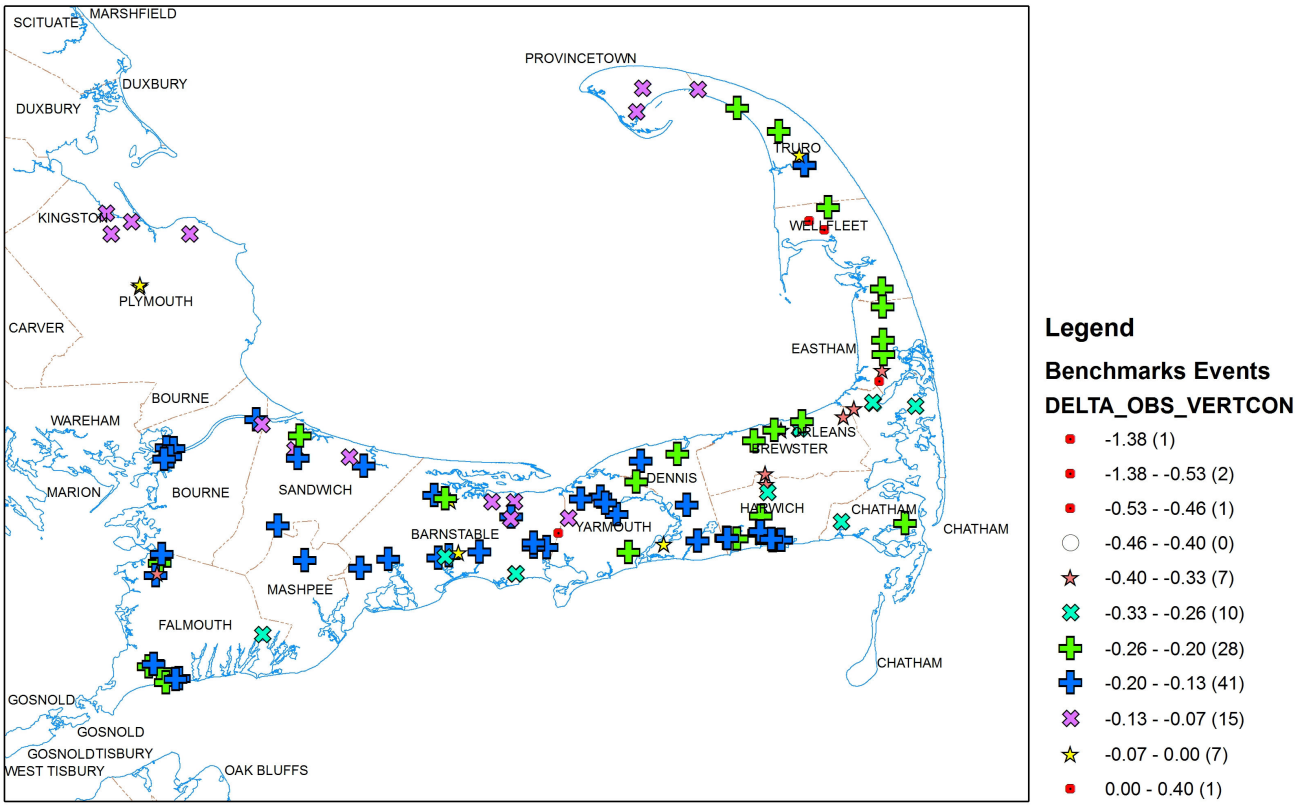
This graph depicts the range of the compared (COMP) differences versus the VERTCON differences. The majority of the values are within the 0.20' difference. This would correspond to the average comparison value of -1.06' where the average VERTCON value of 0.86'.

To review the basic statistics of this dataset:

- 7 comparisons (6.2% of the dataset) are within 2 cm of the respective VERTCON value.
- 5 comparisons (4.4% of the dataset) are too far outside of range to be included in the solution and have been removed from the final solution.
- The average of the 108 remaining comparisons (95.6% of the dataset) is -1.059' or 0.20' from the average of the VERTCON values.
- 69 comparisons (61.0% of the dataset) are within 2 cm (0.066') of the respective VERTCON value minus 6 cm (-0.198'), this translates to -1.063' ± 0.066').

Therefore, to consider the overall area, the use of -1.06' for the average comparison value and -0.86' for the average VERTCON value is acceptable. The local conversion should be closer, so the data should be separated into smaller geographic areas. The best solution might be to break these areas down to a grid size similar to the VERTCON model, but starting with larger areas will determine if that level of work is necessary. Further, based on the fluctuations in the conversion, as better shown on the map below, the grid would be very inconsistent. There are benchmarks whose direct conversions do not reasonably match those conversions computed nearby.

As there is a database with geographic coordinates, it is easy to use ESRI's ARCmap program to import it into a map and view it:

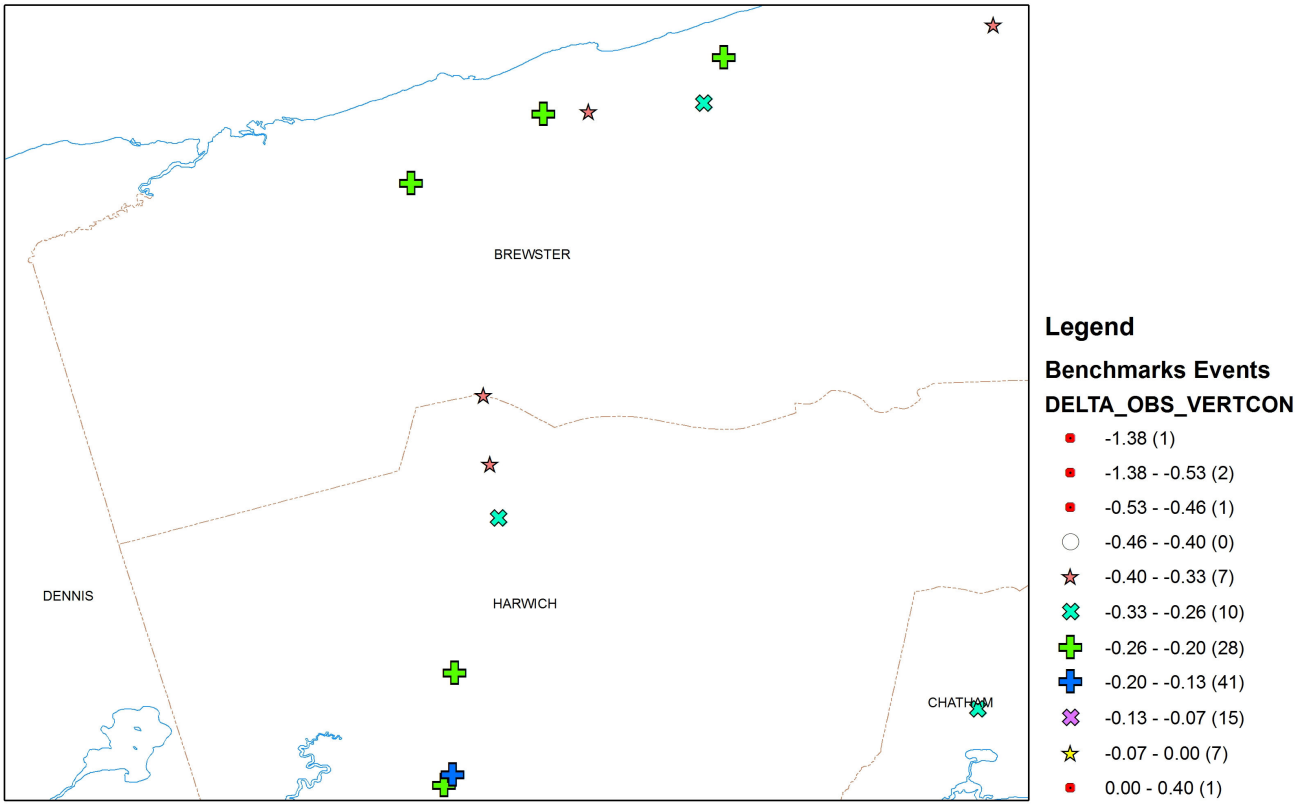


Cape Cod, Massachusetts depicting locations of benchmarks compared with the range of values.

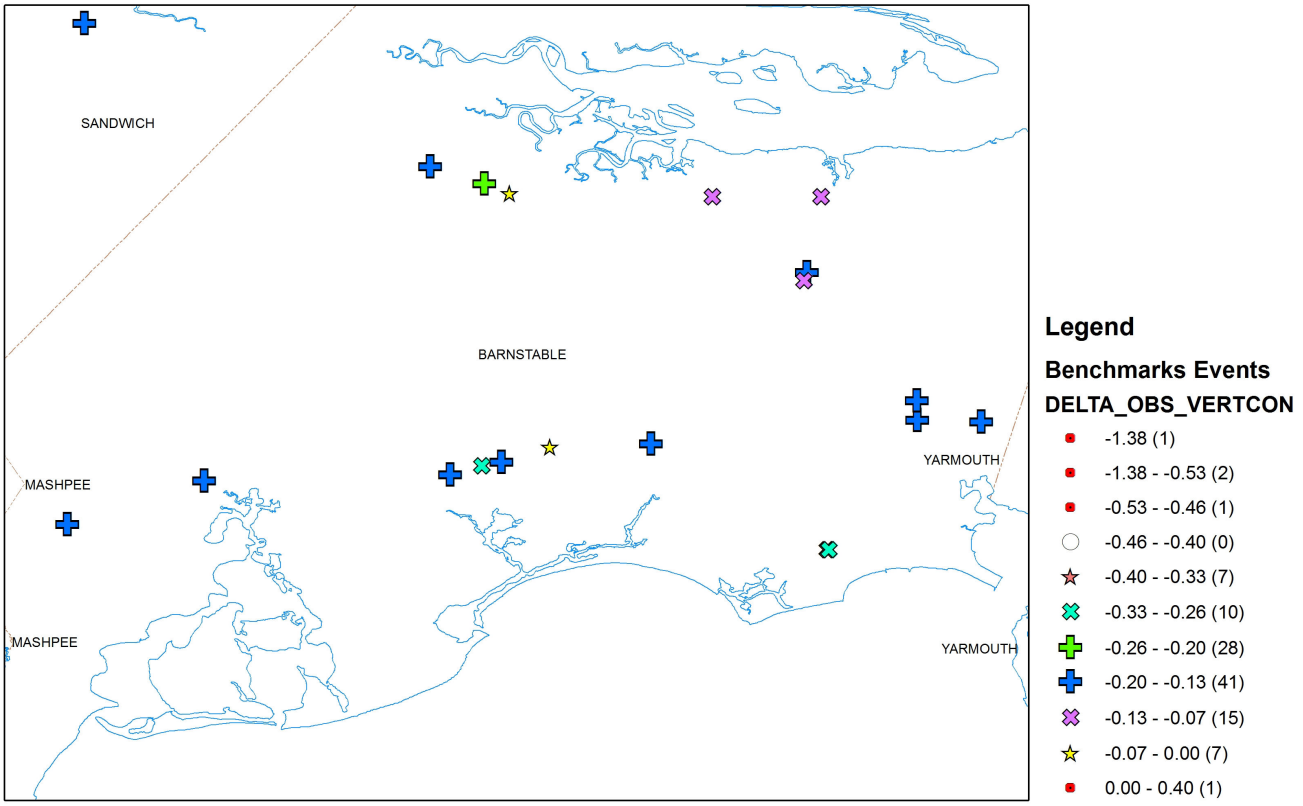
The 69 benchmark comparisons that are within a 4 cm (0.132') range of the VERTCON conversion minus 0.198' (6 cm) (-1.06') are depicted in the largest icons. It seems apparent that there is a predominance of the blue crosses in the western portion of the Cape and a predominance of the green crosses on the east side of the Cape. Perhaps one could analyze the results of splitting the data into two geographical zones, but given the range of data, the geographic area should be a bit smaller.

The idea of creating a grid should be explored. The ultimate goal of such a grid would be a fairly smooth shape, which would require the use of consistent benchmarks. Those

inconsistent benchmarks would have to be removed from the project. There are several locations on Cape Cod where the benchmarks are near each other, but the relative comparisons to their VERTCON values are significantly inconsistent. To create a grid similar to the VERTCON model with these benchmarks would result in spikes or depressions within that grid.



In Brewster and Harwich, there are several benchmarks whose comparisons vary significantly over a short distance.



In Barnstable, the benchmarks contain more inconsistencies. A grid created from all of the benchmarks would be variable over short distances and would likely not properly reflect the differences between the datums. It is apparent that the creation of such a grid will require the exclusion of several benchmarks. Given the lack of coverage of benchmarks over Cape Cod and the number of benchmarks that would be excluded from such a model, it may be sufficient to establish conversions on a Town by Town basis.

Next is an analysis of the datum conversions contained in each Town. This results in the use of a significant percentage of the benchmarks and their respective conversions.

Provincetown	AVERAGE	**-0.939**	Max	-0.922	Min	-0.956	Max Diff	0.017	VERTCON **-0.850**
Truro	AVERAGE	**-0.990**	Max	-0.925	Min	-1.071	Max Diff	0.082	VERTCON **-0.857**
Wellfleet	AVERAGE	**-1.393**	Max	-1.076	Min	-2.241	Max Diff	0.847	VERTCON **-0.863**
Eastham	AVERAGE	**-1.189**	Max	-1.109	Min	-1.348	Max Diff	0.159	VERTCON **-0.874**
Orleans	AVERAGE	**-1.178**	Max	-1.166	Min	-1.186	Max Diff	0.012	VERTCON **-0.877**
Brewster	AVERAGE	**-1.176**	Max	-1.076	Min	-1.253	Max Diff	0.100	VERTCON **-0.876**
Chatham	AVERAGE	**-1.152**	Max	-1.108	Min	-1.196	Max Diff	0.044	VERTCON **-0.886**
Harwich	AVERAGE	**-1.108**	Max	-0.895	Min	-1.273	Max Diff	0.213	VERTCON **-0.880**
Dennis	AVERAGE	**-1.044**	Max	-0.928	Min	-1.081	Max Diff	0.117	VERTCON **-0.877**
Yarmouth	AVERAGE	**-1.042**	Max	-0.995	Min	-1.111	Max Diff	0.069	VERTCON **-0.872**
Barnstable	AVERAGE	**-1.009**	Max	-0.490	Min	-1.179	Max Diff	0.520	VERTCON **-0.867**
Mashpee	AVERAGE	**-1.045**	Max	-1.045	Min	-1.045	Max Diff	0.000	VERTCON **-0.860**
Falmouth	AVERAGE	**-1.109**	Max	-0.999	Min	-1.604	Max Diff	0.495	VERTCON **-0.858**
Sandwich	AVERAGE	**-1.015**	Max	-0.966	Min	-1.095	Max Diff	0.080	VERTCON **-0.853**
Bourne	AVERAGE	**-1.001**	Max	-0.969	Min	-1.064	Max Diff	0.062	VERTCON **-0.850**
Plymouth	AVERAGE	**-0.895**	Max	-0.827	Min	-0.938	Max Diff	0.067	VERTCON **-0.827**

The spreadsheet above shows the average of the benchmark comparisons, the maximum and minimum values of each, the overall range and the average VERTCON value relative to the benchmarks used. The range has been colored green when the difference between the average comparison value is less than 2 cm (0.066') to both the maximum and minimum values used, yellow when it is just above that range and red when it is significantly greater than the desired range. Please note that this spreadsheet currently includes the five benchmarks that are clearly erroneous.

Removing the erroneous values results in a group of conversions that are close to the VERTCON standard of 2 cm.

Provincetown	AVERAGE	**-0.939**	Max	-0.922	Min	-0.956	Max Diff	0.017	VERTCON **-0.850**
Truro	AVERAGE	**-0.990**	Max	-0.925	Min	-1.071	Max Diff	0.082	VERTCON **-0.857**
Wellfleet	AVERAGE	**-1.091**	Max	-1.076	Min	-1.101	Max Diff	0.014	VERTCON **-0.863**
Eastham	AVERAGE	**-1.189**	Max	-1.109	Min	-1.348	Max Diff	0.159	VERTCON **-0.874**
Orleans	AVERAGE	**-1.178**	Max	-1.166	Min	-1.186	Max Diff	0.012	VERTCON **-0.877**
Brewster	AVERAGE	**-1.176**	Max	-1.076	Min	-1.253	Max Diff	0.100	VERTCON **-0.876**
Chatham	AVERAGE	**-1.152**	Max	-1.108	Min	-1.196	Max Diff	0.044	VERTCON **-0.886**
Harwich	AVERAGE	**-1.112**	Max	-1.080	Min	-1.138	Max Diff	0.032	VERTCON **-0.880**
Dennis	AVERAGE	**-1.044**	Max	-0.928	Min	-1.081	Max Diff	0.117	VERTCON **-0.877**
Yarmouth	AVERAGE	**-1.042**	Max	-0.995	Min	-1.111	Max Diff	0.069	VERTCON **-0.872**
Barnstable	AVERAGE	**-1.029**	Max	-0.980	Min	-1.086	Max Diff	0.057	VERTCON **-0.867**
Mashpee	AVERAGE	**-1.045**	Max	-1.045	Min	-1.045	Max Diff	0.000	VERTCON **-0.860**
Falmouth	AVERAGE	**-1.048**	Max	-0.999	Min	-1.110	Max Diff	0.062	VERTCON **-0.858**
Sandwich	AVERAGE	**-1.015**	Max	-0.966	Min	-1.095	Max Diff	0.080	VERTCON **-0.853**
Bourne	AVERAGE	**-1.001**	Max	-0.969	Min	-1.064	Max Diff	0.062	VERTCON **-0.850**
Plymouth	AVERAGE	**-0.895**	Max	-0.827	Min	-0.938	Max Diff	0.067	VERTCON **-0.827**

Removing the benchmarks that are outside of the range results in the following:

Town	COMP	Max	Min	Max Diff	VERTCON	# Used	# Not Used	% Total
Provincetown	**-0.939**	-0.922	-0.956	**0.017**	**-0.850**	2	0	100.0%
Truro	**-0.969**	-0.925	-1.071	**0.044**	**-0.857**	4	1	80.0%
Wellfleet	**-1.091**	-1.076	-1.101	**0.014**	**-0.863**	3	2	60.0%
Eastham	**-1.119**	-1.109	-1.128	**0.009**	**-0.873**	3	2	60.0%
Orleans	**-1.178**	-1.166	-1.186	**0.012**	**-0.877**	3	0	100.0%
Brewster – B	**-1.235**	-1.209	-1.253	**0.026**	**-0.876**	4	4	50.0%
Chatham	**-1.152**	-1.108	-1.196	**0.044**	**-0.886**	2	0	100.0%
Brewster – A	**-1.117**	-1.076	-1.151	**0.042**	**-0.876**	4	4	50.0%
Harwich	**-1.112**	-1.080	-1.138	**0.032**	**-0.880**	9	4	69.2%
Dennis	**-1.067**	-1.058	-1.081	**0.014**	**-0.876**	5	1	83.3%
Yarmouth	**-1.023**	-0.995	-1.050	**0.029**	**-0.872**	7	2	77.8%
Barnstable	**-1.029**	-0.980	-1.086	**0.057**	**-0.867**	15	6	71.4%
Mashpee	**-1.045**	-1.045	-1.045	**0.000**	**-0.860**	1	0	100.0%
Falmouth	**-1.048**	-0.999	-1.110	**0.062**	**-0.858**	11	3	78.6%
Sandwich	**-0.999**	-0.966	-1.041	**0.043**	**-0.854**	5	1	83.3%
Bourne	**-1.001**	-0.969	-1.064	**0.062**	**-0.850**	7	0	100.0%
Plymouth	**-0.908**	-0.848	-0.938	**0.060**	**-0.827**	5	1	83.3%
						86	27	76.1%

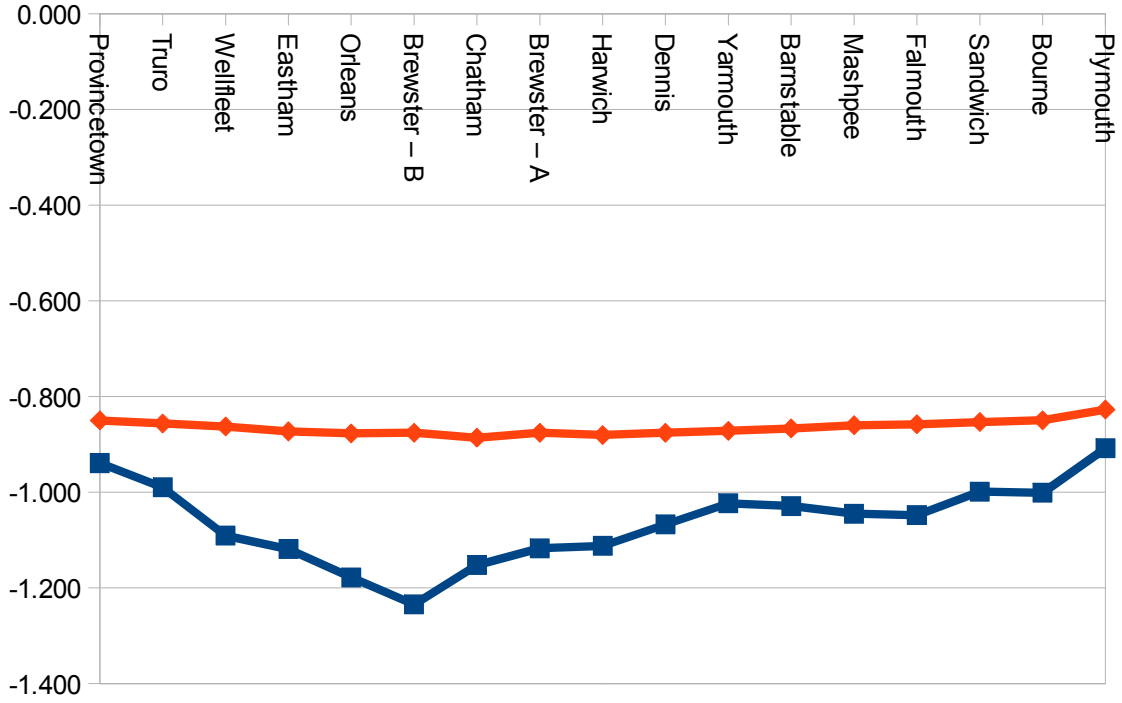
This spreadsheet represents the use of 76.1% or 79.6% of the benchmarks. Every benchmark used is within 2 cm (0.066') of the average of the benchmarks used in the geographic area (Town). Note that Brewster has two conversions as half the benchmarks in that Town conform to one average and the other half conform to another average. The total number of benchmarks used is based on choosing one conversion is 76.1%. If both conversions are used, then then 79.6% of the benchmarks are used.

This highlights the necessity to determine the basis of an elevation. Any elevation set from a benchmark used to determine the Brewster-B conversion should not be converted using the Brewster-A conversion value.

The use of 76.1% or 79.6% of the total number of benchmarks is better than the use of 60.1% as was the case with averaging the compared differences across the entire Cape. Separating the data by Town allows for easy use of the data.

Are there any explanations?

Because the Cape is more or less one-dimensional in that there are no level runs being performed over the water bodies and one is confined to a relatively narrow stretch of land, the differences between the comparison of the benchmarks and the VERTCON values can be plotted linearly representing the approximate profile of the datum conversion across Cape Cod.

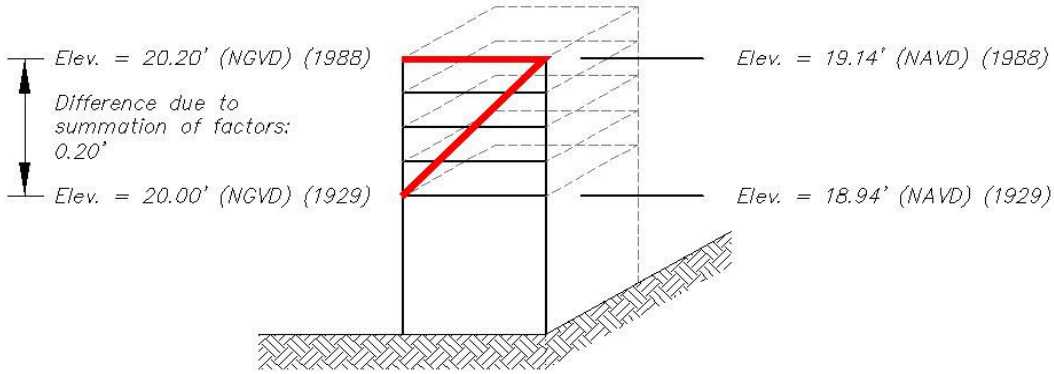


The blue lines and squares represent the compared values between the benchmarks averaged by Town and the red lines and dots represent the average VERTCON values for the same benchmarks isolated to each Town. This profile more or less follows the paths that a survey crew would follow when performing a level run across the Cape. The Y-axis values are the differences between NGVD and NAVD.

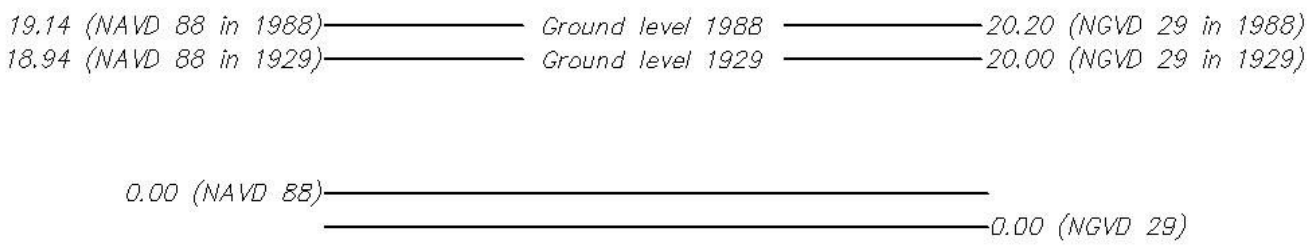
There are several other factors that can affect the work performed to establish the benchmarks. For the most part, these can be categorized as errors, blunders and

environmental factors. To expound upon some of the factors that could account for an irregularities in the record benchmarks and thus irregularities in the VERTCON conversions:

- The Cape is a very windy location and level runs can accumulate error.
- The soils are mostly sand and therefore there are few monuments that can be set with any reliable stability.
- The topography is primarily rolling hills, though along the major roadways, the topography is generally very gradual.
- There may be some gravitational inconsistencies that could amount to noticeable differences in different level runs.
- The Cape is subject to crustal movement due to post glacial isostatic rebound. It has been approximated by some that this change is around 0.5' per century, though no report or model was found to determine the actual shift due to rebound.
    - The following analysis assumes the benchmarks were established in 1929 and 1988:
        - If the 1929 elevation was held in 1988, then the VERTCON value was calculated, the average difference of 0.86' would be appropriate. This is represented below by the diagonal red line.
        - However, if the monument did rise by the summation of the various factors, then the actual difference would be the average difference of 1.06' This is represented below by the horizontal red line.
        - Unless an adjusted elevation is determined, published and used, this difference is irrelevant for anyone using the benchmark.



The effect of the earth rising on a monument.



The effect of the earth rising.

This theory is that the comparison between NGVD and NAVD did not take into account the rise in the ground. If there is error due to gravitational inconsistencies, then the actual elevation in 1929 would be incorrect. Assuming that the 1929 elevation was correct and place any adjustment due to gravitational inconsistencies in the 0.20' difference between the VERTCON values and the comparison method values.

Conclusion

The generalized version of the process to create a conversion between NGVD and NAVD can be and should be applied before anyone uses the VERTCON software. The generalized procedure to determine the comparison conversion:

- Research all quality benchmarks that have published elevations on both NGVD and NAVD.
- Determine the geographic coordinates (georeference) the benchmarks or research coordinate values for each benchmark.
- Calculate the comparison for each benchmark; the comparison being the difference between the published elevations.

- Determine the VERTCON values between the two datums at the given coordinates.
- Perform basic statistical analysis on the data:
  - Review the differences between the comparison values and the VERTCON values.
    - If these differences are within 2.0 cm (0.066') then the VERTCON model is as good as it is purported to be.
    - If these differences are more than 2.0 cm (0.66') then the VERTCON model fails for the area.
  - Average the elevation differences over different areas and sub-areas.
  - Determine any elevations that are erroneous.
  - Examine patterns in the elevation differences based on location.
  - Review the data to try to make a model that works to the VERTCON standard: most of the comparisons should be within 2.0 cm (0.066') of the conversion used for a given area.
  - Clearly publish your results for future use.

This can be a time consuming task, but there is value in having confidence in the conversion being used.

In conclusion, it would be best to abandon the older datum and use the newer datum. While conversion factors between the datums can be calculated, the conversion will not be applicable for every elevation.

Appendix A
Tidal Datums

MHHW* Mean Higher High Water	The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
MHW Mean High Water	The average of all the high water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
DTL Diurnal Tide Level	The arithmetic mean of mean higher high water and mean lower low water.
MTL Mean Tide Level	The arithmetic mean of mean high water and mean low water.
MSL Mean Sea Level	The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. Shorter series are specified in the name; e.g. monthly mean sea level and yearly mean sea level.
MLW Mean Low Water	The average of all the low water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
MLLW* Mean Lower Low Water	The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
GT Great Diurnal Range	The difference in height between mean higher high water and mean lower low water.
MN Mean Range of Tide	The difference in height between mean high water and mean low water.

DHQ Mean Diurnal High Water Inequality	The difference in height of the two high waters of each tidal day for a mixed or semidiurnal tide.
DLQ Mean Diurnal Low Water Inequality	The difference in height of the two low waters of each tidal day for a mixed or semidiurnal tide.
HWI Greenwich High Water Interval	The average interval (in hours) between the moon's transit over the Greenwich meridian and the following high water at a location.
LWI Greenwich Low Water Interval	The average interval (in hours) between the moon's transit over the Greenwich meridian and the following low water at a location.
Station Datum	A fixed base elevation at a tide station to which all water level measurements are referred. The datum is unique to each station and is established at a lower elevation than the water is ever expected to reach. It is referenced to the primary bench mark at the station and is held constant regardless of changes to the water level gauge or tide staff. The datum of tabulation is most often at the zero of the first tide staff installed.
National Tidal Datum Epoch	The specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present NTDE is 1983 through 2001 and is actively considered for revision every 20-25 years. Tidal datums in certain regions with anomolous sea level changes (Alaska, Gulf of Mexico) are calculated on a Modified 5-Year Epoch.

http://tidesandcurrents.noaa.gov/datum_options.html

Appendix B
Geodetic Datums

North American Vertical Datum of 1988 (NAVD 88)	A fixed reference for elevations determined by geodetic leveling. The datum was derived from a general adjustment of the first-order terrestrial leveling nets of the United States, Canada, and Mexico. In the adjustment, only the height of the primary tidal bench mark, referenced to the International Great Lakes Datum of 1985 (IGLD 85) local mean sea level height value, at Father Point, Rimouski, Quebec, Canada was held fixed, thus providing minimum constraint. NAVD 88 and IGLD 85 are identical. However, NAVD 88 bench mark values are given in Helmert orthometric height units while IGLD 85 values are in dynamic heights. See International Great Lakes Datum of 1985, National Geodetic Vertical Datum of 1929, and geopotential difference. NAVD 88 should not be used as Mean Sea Level.
National Geodetic Vertical Datum of 1929 (NGVD 29)	A fixed reference adopted as a standard geodetic datum for elevations determined by leveling. The datum was derived for surveys from a general adjustment of the first-order leveling nets of both the United States and Canada. In the adjustment, mean sea level was held fixed as observed at 21 tide stations in the United States and 5 in Canada. The year indicates the time of the general adjustment. A synonym for Sea-level Datum of 1929. The geodetic datum is fixed and does not take into account the changing stands of sea level. Because there are many variables affecting sea level, and because the geodetic datum represents a best fit over a broad area, the relationship between the geodetic datum and local mean sea level is not consistent from one location to another in either time or space. For this reason, the National Geodetic Vertical Datum should not be confused with mean sea level. See North American Vertical Datum of 1988 (NAVD 88). NGVD 29 should not be used as Mean Sea Level. NGVD 29 is no longer supported by NGS.

http://tidesandcurrents.noaa.gov/datum_options.html

Appendix C

NATIONAL VERTICAL CONTROL NET

Proposed Action

MAY 7, 1973.

Elevations of marked points (benchmarks) in the National Vertical Control Net are based on the "Sea Level Datum of 1929." Since this datum was derived from the overall average sea, level of 26 tide stations, the official elevation at any particular one of these tide stations does not necessarily reflect the actual local "mean sea level." In order to avoid such apparent confusion and the costly errors that may result through failure to consider local sea level when engineering projects are undertaken, it is proposed to change the present name of the vertical control datum from the "Sea Level Datum of 1929" to the "National Geodetic Vertical Datum of 1929."

This change is proposed to be effective on or before July 2, 1973. Comments on this proposed action may be directed to the Director, National Ocean Survey, NOAA, Rockville, Md. 20852.

ROBERT M. WHITE,
Administrator.

[FR Doc.73-9694 Filed 5-15-73; 8:45 am]
FEDERAL REGISTER, VOL. 38, NO. 94-WEDNESDAY, MAY 16, 1973

Appendix D

Exceprts from History of Geodetic Leveling in the United States, by Ralph Moore Berry, Assistant Director, National Geodetic Survey, Natinoal Ocean Survey, NOAA, June 1976

The 1929 General Adjustment

After a pattern of comparatively short intervals between adjustments, 17 years elapsed before the next adjustment. The net had become much more extensive and complex and had more sea-level connections. An innovation introduced was the inclusion of the Canadian first-order network in the adjustment computation. The composition of the network by agencies is not determined, but the lengths included 75,159 km. of U.S. Lines and 31,565 km. of Canadian lines for a total of 106,724 km. of leveling included in the adjustment. The U.S. and Canadian networks were connected at 24 points, extending from Calais, Me./Brunswick, N.B., to Blaine, Wash./Colebrook B.C. There were 693 "links" in the network (including 19 long water-level transfers in the Great Lakes), 253 in Canada, 416 in the United States, and 24 international, which were combined to make 246 closed circuits and 25 sea-level circuits. The adjustment provided elevations for 450 junction points.

Mean sea level was held fixed at 26 gauge sites, 21 in the United States and five in Canada at the following locations:

Father Point, Que.	St. Augustine, Fla.
Halifax, N.S.	Cedar Keys, Fla.
Yarmouth, N.S.	Pensacola, Fla.
Portland, Me.	Biloxi, Miss.
Boston, Mass.	Galveston, Tex.
Perth Amboy, N.J.	San Diego, Calif.
Atlantic City, N.J.	San Pedro, Calif.
Baltimore, Md.	San Francisco, Calif.
Annapolis, Md.	Fort Stevens, Ore.
Old Point Comfort, Va.	Seattle, Wash.
Norfolk, Va.	Anacortes, Wash.
Brunswick, Ga.	Vancouver, B.C.
Fernandina, Fla.	Prince Rupert, B.C.

The elevations of junction points and of intermediate bench marks on "links" connecting the junction points define a datum to which the elevations of all bench marks in the U.S. vertical control network are referred. This datum is defined by the observed heights of mean sea level at the 26 tide gauges listed above and

the set of elevations of all bench marks resulting from the adjustment of the network to these specific sea level determinations.

It should be further noted that, while the extensive Canadian first-order net was used to strengthen the 1929 adjustment, the datum was not adopted in Canada because an independent adjustment of the separate Canadian network had been accomplished in 1928, [Cannon, J.B., "Adjustment of the Precise Level Net of Canada, 1928," Geodetic Survey Publication No. 28, Ottawa, 1929.] and the resulting elevations published in a series of official books. Consequently, since the 1928 adjustment defined the official datum for elevations in Canada, which is still in use today [June, 1976], differeing elevations are published by the United States and Canada for the set of bench marks which constitute the junction points between the U.S. network and the Canadian network.

Shortly after the accomplishment of the 1929 adjustment, the resulting datum was designated as the "Sea Level Datum of 1929," because of its dependence on a series of mean sea level determinations.

It was known at the time of the adjustment that, beacuse of currents, prevailing winds and barometric pressures, water temperature and salinity differentials, topographic configuration of the bottom in the area of the gauge site, and other physical causes, a series of discrete mean sea level determinations, based on tide gauge observations, would not define a single equipotential surface. The result of this situation is that, in actuality, no two determinations of mean sea level at different localities will be on the same level surface, and they will, therefore, have different elevations as determined by the differential leveling process.

In spite of these known variations in the elevations of local mean sea level, it was concluded (1) that these variations were probably of about the same order of magnitude as the observational errors in the leveling network, and (2) that confusion would be caused in the operations of the engineering community if the published elevations of bench marks near the coast would not be compatible with the local mean sea level as determined by tidal observations. Accordingly, in the 1929 adjustment, the network was constrained to hold fixed the observed local mean sea level at each of the 26 gauge sites listed above.

It is now known that thsi constraint resulted in some deformations in the level net as defined by the leveling observations alone. Furthermore, since the elevations of mean sea level at different sites do not vary linearly along the coast line segments that connect them, it follows that elevations of mean sea level as defined by tidal observations at intermediate points between the 26 points held fixed in the adjustment will not agree precisely with the "zero" elevations at the same points as defined by leveling adjusted to conform to the 1929 adjustment (the "Mean Sea Level Datum of 1929").

This has resulted in considerable confusion and misunderstanding, especially in these times when substantial emphasis is being applied to the precise determination of coastal boiundary lines and offshore jurisdictional limits. These lines and limits are almost universally defined by reference to some line (mean low water, "ordinary high water line", etc.) defined by the rise and fall of the tide. It is probable cause for considerable error to assume that these lines

can be fixed by reference to the "zero" line as defined by leveling from bench marks whose elevations are referred to the geodetic datum for elevations.

To eliminate some of the confusion caused by the original name of the current geodetic datum for elevations ("Sea Level Datum of 1929"), the name of the datum has been changed to "National Geodetic Vertical Datum of 1929," eliminating all reference to "sea level" in the title. [see Appendix 3] This is a change in name only; the mathematical and physical definitions of the datum established in 1929 have not been changed in any way.

Appendix E

Federal Register / Vol. 58, No. 120 / Thursday. June 24, 1993 / Notices **34245**
[Docket No. 930650-3150]
Affirmation of Vertical Datum for Surveying and Mapping Activities

SUBAGENCY: National Ocean Service, Coast & Geodetic Survey. National Oceanic and Atmospheric Administration, DOC.
ACTION: Notice.

SUMMARY: This Notice announces a decision by the Federal Geodetic Control Subcommittee (FGCS) to affirm the North American Vertical Datum of 1988 (NAVD 88) as the official civilian vertical datum for surveying and mapping activities in the United States performed or financed by the Federal Government. and to the extent practicable, legally allowable, and feasible, require that all Federal agencies using or producing vertical height information undertake an orderly transition to NAVD 88.

FOR FURTHER INFORMATION CONTACT. Mr. James & Stem, N/CG1x4, SSMC3, Station 9357, National Geodetic Survey. NOAA, Silver Spring, Maryland 20910; telephone: 301-713-3230.

SUPPLEMENTARY INFORMATION The Coast and Geodetic Survey (C&GS), National Geodetic Survey (NGS), has completed the general adjustment portion of the NAVD 88 project, which includes approximately 80 percent of the previously published bench marks in the NGS data base. The remaining "posted" bench marks which comprise approximately 20 percent of the total will be published by October 1993. Regions of significant crustal motion will be analyzed and published as resources allow.

NAVD 88 supersedes the National Geodetic Vertical Datum of 1929 (NGVD 29) which was the former official height reference (vertical datum) for the United States. NAVD 88 provides a modem, improved vertical datum for the United States, Canada, and Mexico. The NAVD 88 heights are the result of a mathematical least squares general adjustment of the vertical control portion of the National Geodetic Reference System and include 80,000 km of now U.S. Leveling observations undertaken specifically for this project.

NAVD 88 height information in paper or digital form is available from the National Geodetic Information Branch, N/CG174, SSMC3, Station 9202, National Geodetic Survey. NOAA, Silver Spring, Maryland, 20910; telephone: 301-713-3242.

Dated: June 21, 1993.
W. Stanley Wilson,
Assistant Administrator for 0cean Services and Coastal Zone Management, NOAA.
[FR Doc. 93-14922 Filed 6-23--93; 8:45 am)
BILLING CODE 351

Appendix F

From Professional Surveyor Magazine:

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NGS Toolkit, Part 9: The National Geodetic Survey VERTCON Tool

Donald M. Mulcare

The National Geodetic Survey (NGS) role in managing and defining the National Spatial Reference System (NSRS) includes the responsibility to develop tools allowing users to transform data between different systems.

To support users needing to transform data between the National Geodetic Vertical Datum of 1929 (NGVD 29) and the North American Vertical Datum of 1988 (NAVD 88) NGS has developed the VERTCON program. The magnitude of the differences between the two height systems is shown in Figure 1.

VERTCON, currently version 2.0, is available as an element of the NGS Geodetic Toolkit and is available for download from the NGS website.

The web-based version of VERTCON does not allow users to upload a file of points. The version available for download includes this feature. Operation of the download version will not be discussed here.

What Data Was Used to Create VERTCON?

VERTCON computes the modeled difference in orthometric height for a given location specified by its latitude and longitude.

The model was derived from 381,833 datum difference values. These differences reflect not only the physical differences in the height systems but also the removal of distortions in the level data.

Models of the refraction effects on geodetic leveling and the gravity and elevation influences on the new NAVD 88 datum were used to improve the accuracy of the model.

The datum difference values were converted to a grid. VERTCON interpolates the datum transformation at a user-specified coordinate using these grids.

Where Can it Be Used?

VERTCON is not considered to be reliable beyond the boundaries of the lower 48 United States.

Because the grid structure extends beyond the conterminous states, it is possible to obtain values in Canada, Mexico, and in offshore regions. As these values do not contain important model components, they should not be considered to be reliable.

When Should it Be Used?

Users with a need to transform height data between NGVD 29 and NAVD 88 can use the VERTCON tool. Because the VERTCON model can be considered accurate at the 2 cm (one sigma) level, it is suitable for a variety of mapping and charting purposes. As a model, it can not maintain the full vertical control accuracy of geodetic leveling. Users needing high accuracy should adjust their observations using published NAVD 88 values.

Problem Lines in VERTCON

In rare cases, local distortions of 20 cm or more were found in the NGVD 29 network. The existence of these distortions can be determined by performing transformations around the project area. If dramatically different transformations are obtained over a small area, the presence of a problem NGVD 29 line is indicated. Users encountering these problem lines should contact NGS for further assistance.

Using the VERTCON Tool

Data for a bench mark in Maryland illustrates the use of VERTCON. Current data for a first-order bench mark, 106 A, is shown in Figure 2. The height in the superceded system, NGVD 29, is shown in Figure 3.

Selecting the VERTCON tool will display the page (Figure 4). Selecting "Height Conversion" will open the form (Figure 5). Enter the position and height for bench mark 106 A here.

The program uses a user-entered geographic position to interpolate the shift at that point. The entry of an orthometric height is optional.

As most of the horizontal positions used to generate VERTCON were scaled from topographic maps, the uncertainty in the scaling exceeds the difference between NAD 27 and NAD 83. The latitude and longitude you enter can be either NAD 27 or NAD 83. Users can convert a height or merely determine the shift at a point. Heights can be entered in either meters or feet. The default unit is the meter. When entering heights in units of feet you must add either "ft" or "FT" to the value.

The output from our conversion of an NAVD 88 height to its NGVD 29 value is shown in Figure 6. The output shows our input values as well as the datum shift and the transformed height for the location we specify.

If the conversion were performed from NGVD 29 to NAVD 88 the datum shift value would be the same. The output will always show the shift in the sense NAVD 88 minus NGVD 29.

If no height had been entered for the conversion, only the datum shift value would have been shown. Remember that when subtracting negative numbers, we add them together.

Concluding Remarks

In the exercise above a point with adjusted heights in both NAVD 88 and NGVD 29 was transformed using VERTCON. In this case we transformed the published NAVD 88 height (44.901 meters) to its NGVD 29 value. A comparison of the published NGVD 29 height (45.121 meters) with the transformed height (45.118 meters) shows excellent agreement (0.003 meters). Your results may vary. Like all transformation packages based on grids of differences, the accuracy of the transformations is dependent on the quantity and quality of the underlying data.

Donald Mulcare is a Geodesist with the Geodetic Services Division of the National Geodetic Survey. He currently serves as Geodetic Advisor to the State of Maryland.

Appendix G

Federal Register / Vol. 72, No. 132 / Wednesday, July 11, 2007 / Notices

DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Notice To Adopt a Standard Model for Mathematical Vertical Datum Transformations

AGENCY: National Geodetic Survey (NGS), National Ocean Service (NOS), National Oceanic and Atmospheric Administration.

ACTION: Notice.

SUMMARY: The purpose of this notice is to announce a decision by the Federal Geodetic Control Subcommittee (FGCS) to recommend adoption of a standard method for mathematical transformations between the vertical geodetic datums: The National Geodetic Vertical Datum of 1929 (NGVD 29) and the North American Vertical Datum of 1988 (NAVD 88). These methods are designated, in descending order of accuracy: (1) The recomputation or readjustment of survey observations method, (2) the mathematical transformation method, and (3) the average shift method. In order to maintain consistency of results and to minimize misuse associated with the mathematical transformation method, FGCS recommends software identified as VERTCON (Vertical Conversion) as a Federal standard.

DATES: Individuals or organizations wishing to submit comments on the adoption of VERTCON as the standard method, should do by August 10, 2007.

ADDRESSES: Written comments should be sent to the attention of David Doyle, Chief Geodetic Surveyor, Office of the National Geodetic Survey, National Ocean Service (N/NGS2), 1315 East-West Highway, Silver Spring, Maryland 20910, fax 301–713–4324, or via e-mail *Dave.Doyle@noaa.gov.*

FOR FURTHER INFORMATION CONTACT:
Requests for additional information should be directed to David Doyle, Chief Geodetic Surveyor, National Geodetic Survey (N/NGS2), 1315 East-West Highway, Silver Spring, MD 20910; Phone: (301) 713–3178.

SUPPLEMENTARY INFORMATION: The intent of this notice is to standardize a vertical datum transformation method when a mathematical transformation is desired. FGCS selected the method incorporated in the software identified as VERTCON. It is not the intent of the notice to declare when to use a datum transformation or by what method but only to declare that when a mathematical transformation is appropriate, VERTCON is recommended. Note that VERTCON is not appropriate to transform between NGVD 29 and NAVD 88 for first-, second-, or third-order heights, as defined in the Federal Geodetic Control Committee (FGCC), Standards and Specifications for Geodetic Control Networks, and retain first- or second-, or third-order accuracies in the results. Method 1, recomputation or readjustment of survey observations, is usually more appropriate to maintain first-, second-, and third-order FGCC accuracies. VERTCON can be accessed for on-line computation from the NGS Geodetic Tool Kit at http://www.ngs.noaa.gov/*TOOL/Vertcon/vertcon.html,* or copies of the VERTCON software are available for free download from the NGS Web site http://www.ngs.noaa.gov/*PC_PROD/pc_prod.shtml#VERTCON.*

Dated: July 5, 2007.

Elizabeth R. Scheffler,
Associate Assistant Administrator for Management, Ocean Services and Coastal Zone Management.

[FR Doc. 07–3377 Filed

Appendix H
VERTCON Readme File

"@(#)vertcon.doc 1.1 - 00/04/17 10:27:24 NGS"

README file for VERTCON v2.0 199408.18 RJF/dgm
README file for VERTCON v2.1 200309.29 RWS

PURPOSE: Program VERTCON computes the modeled difference in orthometric height between the North American Vertical Datum of 1988 (NAVD 88) and the National Geodetic Vertical Datum of 1929 (NGVD 29) for a given location specified by latitude and longitude.

A partial list of contents of the VERTCON distribution is:

vertcon.exe VERTical datum CONversion program
(compiled from VERTCON.FOR, a FORTRAN source code)

vertcone.94 VERTCON datum transformation grid file; eastern USA
(non-readable, i.e., binary, file)

vertconc.94 VERTCON datum transformation grid file; central USA
(non-readable, i.e., binary, file)

vertconw.94 VERTCON datum transformation grid file; western USA
(non-readable, i.e., binary, file)

README.TXT User's instruction file (this file you are reading)

A number of sample output and batch files are included as examples, in addition to some utility routines described later in this document.

To install:
1) Open a DOS window (or a Command Prompt window).
2) Make a subdirectory on hard disk;
for example: mkdir NGVDCONV
3) Go into subdirectory;
for example: cd NGVDCONV
4) Copy the downloaded files into the subdirectory

To execute:
Type vertcon and follow the prompts.

To terminate:
VERTCON computations can be stopped at any time by the Control-C (i.e., <ctrl-c>) key combination. Interactive processing can also be terminated by entering 0. (i.e., zero WITH DECIMAL POINT)

BUT PLEASE DON'T START YET; KEEP READING THIS DOCUMENT.

How program VERTCON works:
The software and three files of datum transformation grids for the conterminous United States (CONUS) are provided in the distribution. VERTCON returns the orthometric height difference between NAVD 88 and NGVD 29 at the geodetic position specified by the user. VERTCON interpolates the datum transformation at a point from the appropriate grid in your subdirectory.

Data Input:
The user can key in latitude and longitude on a point-by-point basis or can create an input file using a text editor. Several file formats are provided, including the internal bench mark file record format of the Vertical Network Branch, NGS. These formats are detailed in a "Help" menu option which appears when the input filename is specified.

Most horizontal positions of the bench marks used to generate VERTCON were scaled from USGS topographic maps. The estimated uncertainty of the scaled positions, 6", is greater than the differences between NAD 27 and NAD 83. Therefore, the latitude and longitude provided to VERTCON can be on either

the NAD 27 or NAD 83 datum.

Data Output:
Results are collected into an output file. The default name of this file is VERTCON.OUT, but the user can choose any legal filename. (A word of advice: don't use misleading extensions such as .EXE, .BAT, etc.). The format of the output file is linked to the format of the input file to maintain consistency.

----------> THE SENSE OF THE SIGNS <----------

The grids contain a model of (NAVD 88 - NGVD 29) height differences.

If a NAVD 88 height is desired when a NGVD 29 height is given,
ADD the model value ALGEBRAICALLY to the NGVD 29 height.

If a NGVD 29 height is desired when a NAVD 88 height is given,
SUBTRACT the model value ALGEBRAICALLY from the NAVD 88 height.

The VERTCON 2.0 Model
The VERTCON 2.0 model was computed on May 5, 1994 using 381,833 datum difference values. A key part of the computation procedure was the development of the predictable, physical components of the differences between the NAVD 88 and NGVD 29 datums. This included models of refraction effects on geodetic leveling, and gravity and elevation influences on the new NAVD 88 datum. Tests of the predictive capability of the physical model show a 2.0 cm RMS agreement at our 381,833 data points. For this reason, the VERTCON 2.0 model can be considered accurate at the 2 cm (one sigma) level. Since 381,833 data values were used to develop the corrections to the physical model, VERTCON 2.0 will display even better overall accuracy than that displayed by the uncorrected physical model. This higher accuracy will be particularly noticable in the eastern United States.

Using VERTCON 2.0
It should be emphasized that VERTCON 2.0 is a datum transformation model, and can not maintain the full vertical control accuracy of geodetic leveling. Ideally, one should process level data using the latest reduction software and adjust it to established NAVD 88 control. However, VERTCON 2.0 accuracy is suitable for a variety of mapping and charting purposes.

The VERTCON 2.0 model expresses datum differences between NAVD 88 and NGVD 29 due to removal of distortions in the level data, as well as due to the physical differences in the height systems. In some rare cases, these local NGVD 29 distortions could be 20 cm or more. If both ends of your old vertical survey were tied to one of these "problem" lines, then the datum difference of the problem line is appropriate to use to transform the survey data. If both ends of a vertical survey are tied to "undistorted lines", then it is appropriate to use a slightly distant point to compute the transformation, no matter how close your survey data may approach a given problem line. The possible presense of a problem NGVD 29 line in the vicinity of your survey will become evident if dramatically different datum transformation values are computed within a small area.

It must also be emphasized that VERTCON 2.0 is not to be considered reliable beyond the boundaries of the lower 48 United States. The VERTCON program will interpolate values in Canada, Mexico, or in the ocean, due to the grid structure of the model. Those values do not contain important model components present in the conterminous U.S. model. Future versions of VERTCON may be extended into neighboring countries.

The Defense Mapping Agency
The Defense Mapping Agency (DMA) has been of immense help in this endeavor. DMA has provided a major portion of the NGS land gravity data set. DMA has also been instrumental in the creation of the various 30" elevation grids in existence. Although the work of the DMA generally precludes public recognition, their cooperation in this work is gratefully acknowledged.

Other Programs:
The datum shift grids and VERTCON software are provided on standard disc

operating system (DOS) controlled (IBM-compatible) personal computers (PC). In support of other computer systems, the following utility software is included:

convasci -- copy unformatted (binary) grid files into ASCII files for transfer to other systems

convbin -- will restore the ASCII files into binary grid files on the new system.

Other Future Plans:
A continuing development effort is underway to improve VERTCON results. NGVD 29 normal orthometric heights are being analyzed for localized monument and/or crustal motion effects, for inconsistent adjustments, and other effects. Computed height differences which are significantly influenced by such effects will be flagged and rated for reliability in future versions.

For More Information

For Products Available From the National Geodetic Survey:

National Geodetic Information Center
N/NGS1, SSMC3-9450
National Geodetic Survey, NOAA
Telephone: 301-713-3242
E-Mail: ngs.infocenter@noaa.gov

David B. Zilkoski
NOAA, National Geodetic Survey, N/NGS
E-Mail: Dave.Zilkoski@noaa.gov

A special word of thanks goes to our colleague, Sandford R. Holdahl, who has recently retired. Sandy made the first predictions of the vertical datum differences in 1983, and is a co-author of the VERTCON 2.0 model.

README file 199408.18 RJF/dgm

Vertcon 2.10 is a modification of Vertcon 2.0 code to make it accessible via the National Geodetic Survey (NGS) Geodetic TOOL Kit on the Web and allow negative orthometric heights to be entered.

The program was modified to accept a single command line parameter. The parameter may be either a blank, OHT or WEB. No parameter, the blank option, will be cause the program to execute with the normal output. If the "OHT" option is used, e.g. vertcon oht, the program will execute so that the user may see the program prompts and enter an orthometric height and select either the NGVD29 or NAVD88 datum. The "WEB" option is used only for web execution, e.g. vertcon web.

Warnings to those who compile the source code: (1)The grid files are in binary format. If you download these files from the NGS web site, you should receive the binary data in little endian form, which is correct for Intel processors.
(2) The grid files are opened for direct access with a record size of 1848 bytes. The Fortran standard says that the unit of measurement of the record size is implementation dependent, and the default for some compilers is to measure this in (4 byte) words. Most compilers allow the user to override the default.

README file 200309.29 RWS

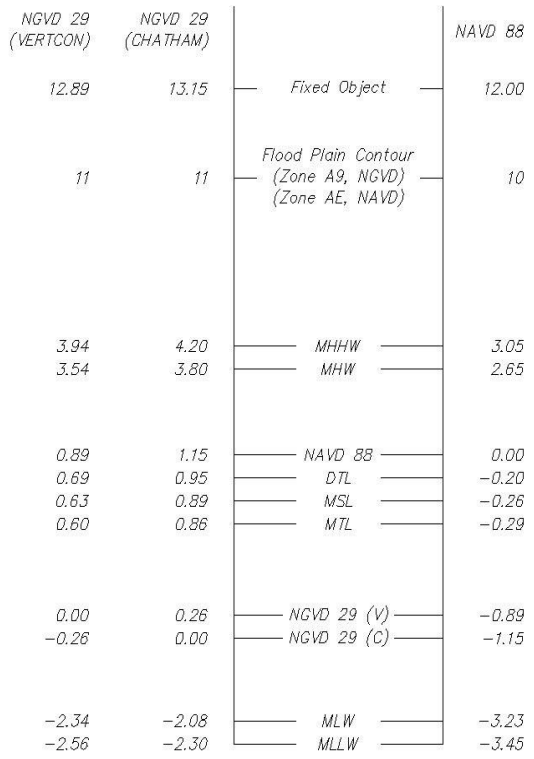
Appendix I
Tidal Datum Conversions

Station: 8447435
Name: Chatham, LYDIA COVE, MA
Status: Accepted

Data Units: Feet

DATUM	Station Datum	NAVD 88	NGVD 29 (VERTCON)	NGVD 29 (CHATHAM)
MHHW	9.73 Ft.	3.05 Ft.	3.94 Ft.	4.20 Ft.
MHW	9.33 Ft.	2.65 Ft.	3.54 Ft.	3.80 Ft.
NAVD	6.68 Ft.	**0.00 Ft.**	0.89 Ft.	1.15 Ft.
DTL	6.48 Ft.	-0.20 Ft.	0.69 Ft.	0.95 Ft.
MSL	6.42 Ft.	-0.26 Ft.	0.63 Ft.	0.89 Ft.
MTL	6.39 Ft.	-0.29 Ft.	0.60 Ft.	0.86 Ft.
NGVD (V)	5.79 Ft.	-0.89 Ft.	**0.00 Ft.**	0.26 Ft.
NGVD (C)	5.53 Ft.	-1.15 Ft.	-0.26 Ft.	**0.00 Ft.**
MLW	3.45 Ft.	-3.23 Ft.	-2.34 Ft.	-2.08 Ft.
MLLW	3.23 Ft.	-3.45 Ft.	-2.56 Ft.	-2.30 Ft.

This is a chart of the tidal datums for Aunt Lydia's Cove, Chatham, Massachusetts relative to the geodetic datums. Refer to Appendix J for the average VERTCON value and Comparison value in Chatham. Below is the same information expressed in a more visual way.



Appendix J

The 113 benchmarks located across Cape Cod with published elevations on both NGVD 29 and NAVD 88.

OBJECTID	FeatureId	TOWN	ELEV_29	ELEV_88m	ELEV_88	ELEV_SRCE	DELTA_OBS	DELTA_VERTCON	ELEV_29_Order	Elev_88_Order
101	1	Chatham	46.42	13.811	45.312		-1.108	-0.886		1
102	2	Barnstable	12.31	3.404	11.168		-1.142	-0.873		1
103	60	Harwich	8.4	2.245	7.365		-1.035	-0.879		1
104	61	Dennis	17.82	5.109	16.762		-1.058	-0.879		1
105	62	Harwich	21.8	6.372	20.905		-0.895	-0.879		1
106	63	Bourne	10.45	2.861	9.386		-1.064	-0.883		1
107	65	Barnstable	39.35	11.678	38.314		-1.036	-0.866		1
108	66	Barnstable	26.5	7.718	25.321		-1.179	-0.866		1
109	67	Barnstable	59.56	17.881	58.665		-0.895	-0.866		1
110	68	Yarmouth	50.61	15.12	49.606		-1.004	-0.869		
111	69	Harwich	12.01	3.33	10.925		-1.085	-0.876		1
112	70	Harwich	17.34	4.956	16.260		-1.080	-0.883		1
113	71	Falmouth	18.87	5.431	17.818		-1.052	-0.883		1
1	104	Provincetown	24.675	7.24	23.753		-0.922	-0.850	2	2
2	105	Provincetown	27.062	7.957	26.106		-0.956	-0.850	2	2
3	106	Truro	9.83	2.692	8.832		-0.998	-0.860	2	2
4	107	Truro	22.38	6.515	21.375		-1.005	-0.860	2	2
5	108	Truro	13.98	3.972	13.031		-0.949	-0.850	2	2
6	109	Truro	16.36	4.66	15.289		-1.071	-0.853	2	2
7	110	Truro	19.15	5.555	18.225		-0.925	-0.860	2	2
8	111	Wellfleet	34.67	10.232	33.569		-1.101	-0.869	2	2
9	112	Wellfleet	13.74	3.745	12.287		-1.453	-0.863	2	2
10	113	Wellfleet	43.35	12.885	42.274		-1.076	-0.856	2	2
11	114	Wellfleet	41	12.163	39.905		-1.095	-0.863	2	2
12	115	Wellfleet	21.86	5.98	19.619		-2.241	-0.863	2	2
13	116	Eastham	29.02	8.467	27.779		-1.241	-0.876	3	2
14	117	Eastham	20.78	5.99	19.652		-1.128	-0.873	2	2
15	118	Eastham	53.15	15.862	52.041		-1.109	-0.873	2	2
16	119	Eastham	51.28	15.289	50.161		-1.119	-0.873	2	2
17	120	Eastham	17.25	4.847	15.902		-1.348	-0.876	2	2
18	121	Orleans	53.42	15.927	52.254		-1.166	-0.876	2	2
19	122	Orleans	46.569	13.834	45.387		-1.182	-0.879	2	2
20	123	Orleans	59.831	17.875	58.645		-1.186	-0.876	2	2
21	124	Chatham	46.38	13.772	45.184		-1.196	-0.886	2	2
22	125	Brewster	21.84	6.329	20.764		-1.076	-0.876	2	2
23	126	Brewster	64.96	19.449	63.809		-1.151	-0.876	2	2
24	127	Brewster	48.3	14.34	47.047		-1.253	-0.876	2	2
25	128	Brewster	33.51	9.84	32.283		-1.227	-0.876	2	2
26	129	Brewster	52.28	15.554	51.030		-1.250	-0.876	2	2
27	130	Brewster	61.12	18.283	59.983		-1.137	-0.876	2	2
28	131	Brewster	48	14.262	46.791		-1.209	-0.876	2	2
29	132	Brewster	47.635	14.182	46.529		-1.106	-0.876	2	2
30	133	Harwich	31.64	9.298	30.505		-1.135	-0.879	2	2
31	134	Harwich	12.603	3.496	11.470		-1.133	-0.879	2	2
32	135	Harwich	11.614	3.193	10.476		-1.138	-0.879	2	2
33	136	Harwich	53.11	15.8	51.837		-1.273	-0.879	2	2
34	137	Harwich	29.75	8.706	28.563		-1.187	-0.879	2	2
35	138	Harwich	18.92	5.431	17.818		-1.102	-0.883	2	2
36	139	Harwich	17.39	4.956	16.260		-1.130	-0.883	2	2
37	140	Harwich	10.5	2.861	9.386		-1.114	-0.883	2	2
38	141	Harwich	17.856	5.109	16.762		-1.094	-0.879	2	2
39	142	Dennis	63.892	19.149	62.825		-1.067	-0.876	2	2
40	143	Dennis	31.99	9.421	30.909		-1.081	-0.873	2	2
41	144	Dennis	24.44	7.126	23.379		-1.061	-0.873	2	2
42	145	Dennis	21.833	6.372	20.905		-0.928	-0.879	2	2
43	146	Dennis	8.435	2.245	7.365		-1.070	-0.879	2	2
44	147	Yarmouth	80.988	24.382	79.993		-0.995	-0.873	2	2
45	148	Yarmouth	80.361	24.188	79.357		-1.004	-0.873	2	2
46	149	Yarmouth	31.71	9.351	30.679		-1.031	-0.873	2	2
47	150	Yarmouth	71.86	21.585	70.817		-1.043	-0.873	2	2
48	151	Yarmouth	62.11	18.594	61.004		-1.106	-0.873	2	2
49	152	Yarmouth	36.57	10.831	35.535		-1.035	-0.869	2	2
50	153	Yarmouth	33.16	9.787	32.110		-1.050	-0.873	2	2
51	154	Yarmouth	12.036	3.33	10.925		-1.111	-0.876	2	2
52	155	Barnstable	50.435	15.074	49.455		-0.980	-0.866	1	2
53	156	Barnstable	43.089	12.82	42.060		-1.029	-0.863	1	2
54	157	Barnstable	37.054	10.995	36.073		-0.981	-0.866	1	2
55	158	Barnstable	98.394	29.679	97.372		-1.022	-0.869	2	2
56	159	Barnstable	99.619	30.058	98.615		-1.004	-0.869	2	2
57	160	Barnstable	44.631	13.282	43.576		-1.055	-0.869	1	2
58	161	Barnstable	14.204	4.013	13.166		-1.038	-0.866	1	2
59	162	Barnstable	40.72	12.105	39.714		-1.006	-0.873	1	2
60	163	Barnstable	38.249	11.509	37.759		-0.490	-0.873	1	2
61	164	Barnstable	20.64	6.011	19.721		-0.919	-0.863	1	2
62	165	Barnstable	38.666	11.466	37.618		-1.048	-0.863	1	2
63	166	Barnstable	14.446	4.085	13.402		-1.044	-0.863	1	2
64	167	Barnstable	40.74	12.097	39.688		-1.052	-0.863	2	2
65	168	Barnstable	12.31	3.404	11.168		-1.142	-0.873	2	2
66	169	Barnstable	50.426	15.047	49.367		-1.059	-0.873	2	2
67	170	Barnstable	17.972	5.147	16.886		-1.086	-0.863	1	2
68	171	Barnstable	123.27	37.27	122.277		-0.993	-0.869	2	2
69	172	Mashpee	96.921	29.223	95.876		-1.045	-0.860	2	2
70	173	Sandwich	94.43	28.488	93.464		-0.966	-0.850	2	2
71	174	Sandwich	53.555	16.021	52.562		-0.993	-0.856	1	2
72	175	Sandwich	27.986	8.233	27.011		-0.975	-0.856	1	2
73	176	Sandwich	17.814	5.096	16.719		-1.095	-0.850	1	2
74	177	Sandwich	165.29	50.07	164.271		-1.019	-0.853	2	2
75	178	Sandwich	141.425	42.789	140.384		-1.041	-0.853	2	2
76	179	Falmouth	36.372	10.748	35.262		-1.110	-0.860	1	2
77	180	Falmouth	26.337	7.701	25.266		-1.071	-0.860	1	2
78	181	Falmouth	45.312	13.459	44.157		-1.155	-0.860	1	2
79	182	Falmouth	3.76	0.657	2.156		-1.604	-0.863	2	2
80	183	Falmouth	44.175	13.148	43.136		-1.039	-0.846	1	2
81	184	Falmouth	100.09	30.188	99.042		-1.048	-0.846	2	2
82	185	Falmouth	27.09	7.947	26.073		-1.017	-0.860	2	2
83	186	Falmouth	5.46	1.335	4.380		-1.080	-0.863	2	2
84	187	Falmouth	11.906	3.307	10.850		-1.056	-0.863	2	2
85	188	Falmouth	10.658	2.944	9.659		-0.999	-0.863	2	2
86	189	Falmouth	38.589	11.451	37.569		-1.020	-0.850	1	2
87	190	Falmouth	44.89	13.305	43.651		-1.239	-0.850	2	2
88	191	Falmouth	38.057	11.284	37.021		-1.036	-0.846	2	2
89	192	Bourne	20.389	5.915	19.406		-0.983	-0.846	1	2
90	193	Bourne	63.003	18.897	61.998		-1.005	-0.843	1	2
91	194	Bourne	40.91	12.174	39.941		-0.969	-0.846	2	2
92	195	Bourne	17.964	5.174	16.975		-0.989	-0.843	1	2
93	196	Bourne	10.691	2.953	9.688		-1.003	-0.843	1	2
94	197	Bourne	16.439	4.707	15.443		-0.996	-0.843	1	2
95	198	Plymouth	45.694	13.642	44.757		-0.937	-0.827	2	2
96	199	Plymouth	68.062	20.47	67.159		-0.903	-0.830	2	2
97	200	Plymouth	132.808	40.194	131.870		-0.938	-0.827	2	2
98	201	Plymouth	265.192	80.552	264.278		-0.914	-0.830	2	2
99	202	Plymouth	167.039	50.655	166.191		-0.848	-0.823	2	2
100	203	Plymouth	168.314	51.05	167.487		-0.827	-0.823	2	2
					AVERAGE		**-1.076**	**-0.864**		
					Max		-0.490	-0.823		
					Min		-2.241	-0.886		
					Range		-1.751			

Appendix K

Town by Town Conversion from NGVD to NAVD

Town	COMP	Max	Min	Diff	VERTCON	Used	Not	% Total
Provincetown	**-0.939**	-0.922	-0.956	**0.017**	**-0.850**	2	0	100.0%
Truro	**-0.969**	-0.925	-1.005	**0.044**	**-0.858**	4	1	80.0%
Wellfleet	**-1.091**	-1.076	-1.101	**0.014**	**-0.863**	3	2	60.0%
Eastham	**-1.119**	-1.109	-1.128	**0.009**	**-0.873**	3	2	60.0%
Orleans	**-1.178**	-1.166	-1.186	**0.012**	**-0.877**	3	0	100.0%
Brewster – B	**-1.235**	-1.209	-1.253	**0.026**	**-0.876**	4	4	50.0%
Chatham	**-1.152**	-1.108	-1.196	**0.044**	**-0.886**	2	0	100.0%
Brewster – A	**-1.117**	-1.076	-1.151	**0.042**	**-0.876**	4	4	50.0%
Harwich	**-1.112**	-1.080	-1.138	**0.032**	**-0.880**	9	4	69.2%
Dennis	**-1.067**	-1.058	-1.081	**0.014**	**-0.876**	5	1	83.3%
Yarmouth	**-1.023**	-0.995	-1.050	**0.029**	**-0.872**	7	2	77.8%
Barnstable	**-1.029**	-0.980	-1.086	**0.057**	**-0.867**	15	6	71.4%
Mashpee	**-1.045**	-1.045	-1.045	**0.000**	**-0.860**	1	0	100.0%
Falmouth	**-1.048**	-0.999	-1.110	**0.062**	**-0.858**	11	3	78.6%
Sandwich	**-0.999**	-0.966	-1.041	**0.043**	**-0.854**	5	1	83.3%
Bourne	**-1.001**	-0.969	-1.064	**0.062**	**-0.850**	7	0	100.0%
Plymouth	**-0.908**	-0.848	-0.938	**0.060**	**-0.827**	5	1	83.3%