IMPACT OF THE NORTH AMERICAN VERTICAL DATUM OF 1988 ON THE NATIONAL MAPPING PROGRAM

William H. Chapman
U.S. Geological Survey
510 National Center
Reston, Virginia 22092

BIOGRAPHICAL SKETCH

William H. Chapman is currently the Chief, Branch of Geometronics, Office of Technical Management of the National Mapping Division, U.S. Geological Survey. Mr. Chapman was bom and raised in Sacramento, California, and obtained a degree in Civil Engineering at the University of California. He began his career in 1950 in the Pacific Region of the U.S. Geological Survey where he specialized in field surveys for map control in rugged mountainous areas. In 1957 he participated in the first of three expeditions to Antarctica to establish control for reconnaissance mapping. He completed 2 years of graduate studies in 1966 and received an M.S. degree in Geodetic Science from the Ohio State University. Mr. Chapman is a registered professional engineer in the State of Virginia and is a member of the American Society of Civil Engineers.

ABSTRACT

The National Mapping Program includes more than 83,000 different map products, of which over 7 million copies are distributed annually. Almost all of these products contain elevation information as contours and spot elevations on maps or as elevation arrays in Digital Elevation Models. Changing these products, both graphic and digital, to the North American Vertical Datum of 1988 will be a massive and costly undertaking and will require a decade or more to complete. This transition will occur as the maps or digital data are revised or updated. Changing the Geological Survey third-order leveling data to the North American Vertical Datum 88 is under consideration and presents a significant challenge. Because of the destruction of large numbers of benchmarks, the conversion effort might not be cost-effective.

INTRODUCTION

The present United States national vertical datum, the National Geodetic Vertical Datum of 1929 (NGVD 29), was established by the U.S. Coast and Geodetic Survey's 1929 General Adjustment. About 75,000 km of U.S level-line data were combined with about 35,000 km of Canadian level-line data in this adjustment, and mean sea level was held fixed at 26 tide gauges that were spaced along the east and west coast of North America and along the Gulf of Mexico. It was known at the time of the adjustment that because of the variation of ocean currents, prevailing winds, barometric pressures, and other physical causes, the mean sea level determinations at the tide gauges would not define a single equipotential surface. However, it was believed that the variations in the different determinations of mean sea level were probably of the same magnitude as the errors in the leveling data. This datum was originally named "Mean Sea Level Datum of 1929" and was changed to NGVD 29 in 1973 to eliminate reference to "sea level" in the title. This was a change in name only; the definition of the datum established in 1929 was not changed. Since the 1929 adjustment, new leveling has been established that now totals about 625,000 km and each new line has been adjusted to the network. Through the years, the agreement between the new leveling and the network benchmark elevations slowly grew worse. There are three reasons for this disagreement.

1. Many benchmarks were affected by unknown vertical movement due to earthquake activity, postglacial rebound, and ground subsidence.

2. Numerous benchmarks were disturbed or destroyed by highway maintenance, building, and other construction projects.

3. New leveling became more accurate because of better instruments and procedures and improved computations.

It was decided in 1977 that the high accuracy achieved by the new leveling was being lost when forced to fit the 1929 network, and plans were made to begin developing a new national vertical network.

NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD 88)

Development of a new national network has been underway for over a decade and consists of:

- Establishing about 100,000 km of trunk line leveling to reinforce weak areas in the network.

- Modernizing the vast amount of leveling observation and description data that has been collected for over a century.

- Performing adjustments of sections of the network to verify the quality of the observation data.

- Informing the public and users of the network of the pending change and determining the impact on the nation's engineering activities.

The final task is performing the least squares adjustment of the whole network, which is to be completed in 1991. However, first a definition of NAVD 88 must be established.

The Federal Geodetic Control Committee created the Vertical Subcommittee in 1989 to study the impact of the NAVD 88 on the programs of member agencies and to recommend a datum definition. Several different datum definitions for NAVD 88 were studied by the subcommittee and three were selected for final consideration:

1. Fix the elevation or mean sea level at a single point,

2. Fix mean sea level at four tide gauges located at the network comers.

3. Fix the NGVD 29 elevations at 18 existing, well-scattered benchmarks.

Figures 1-3 show the approximate elevation changes from the NGVD 29 to each of the datum definitions under consideration.

The contours on figure 1 represent the elevation changes that result from adopting a new datum defined by fixing a single point, the most recent mean sea level value for the tide gauge at Key West, Florida. The contours show a cross-country elevation difference of about 1 meter caused by the fact that the Pacific Ocean coastal sea

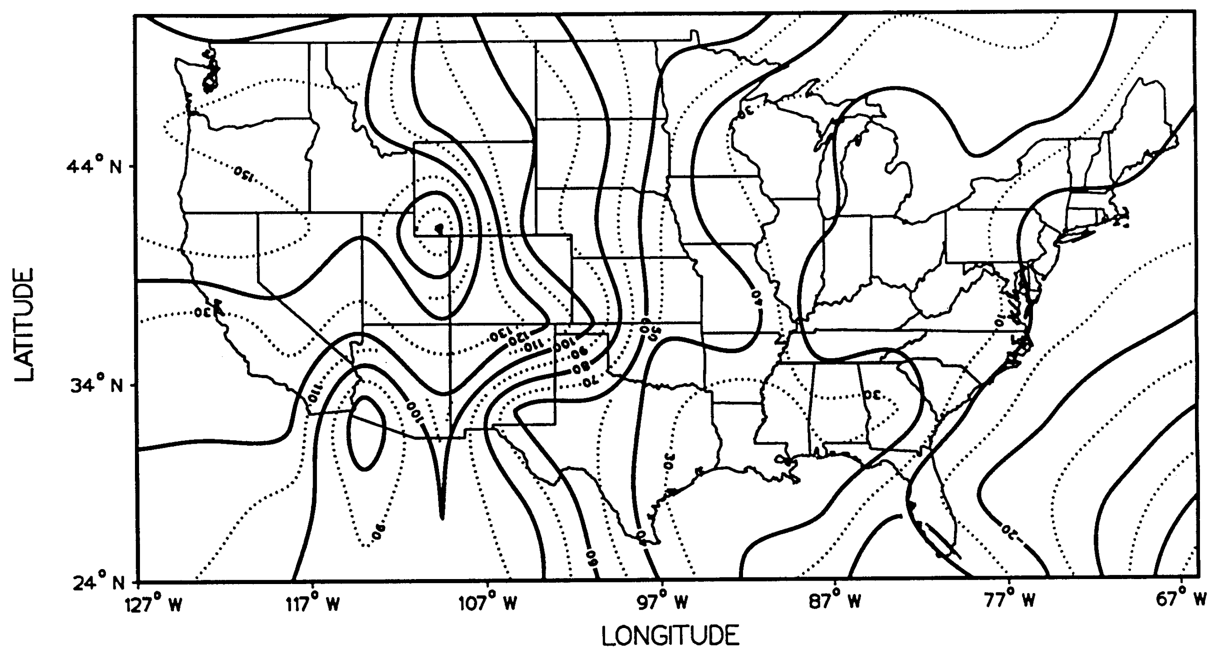

Figure 1.--NAVD 88 minus NGVD 29 heights (cm.).
Constraint: Key West, Florida

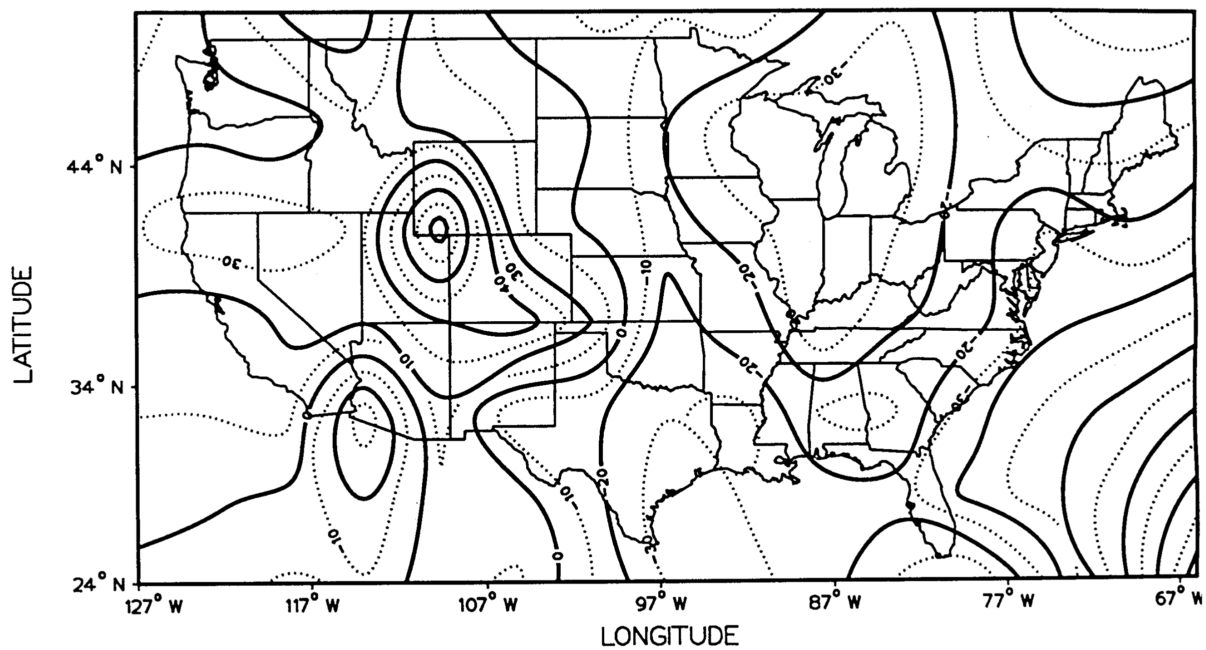

Figure 2.--NAVD 88 minus NGVD 29 heights (cm.).
Constraints: Key West, Florida; Portland, Maine; San Diego, California; Neah Bay, Washington

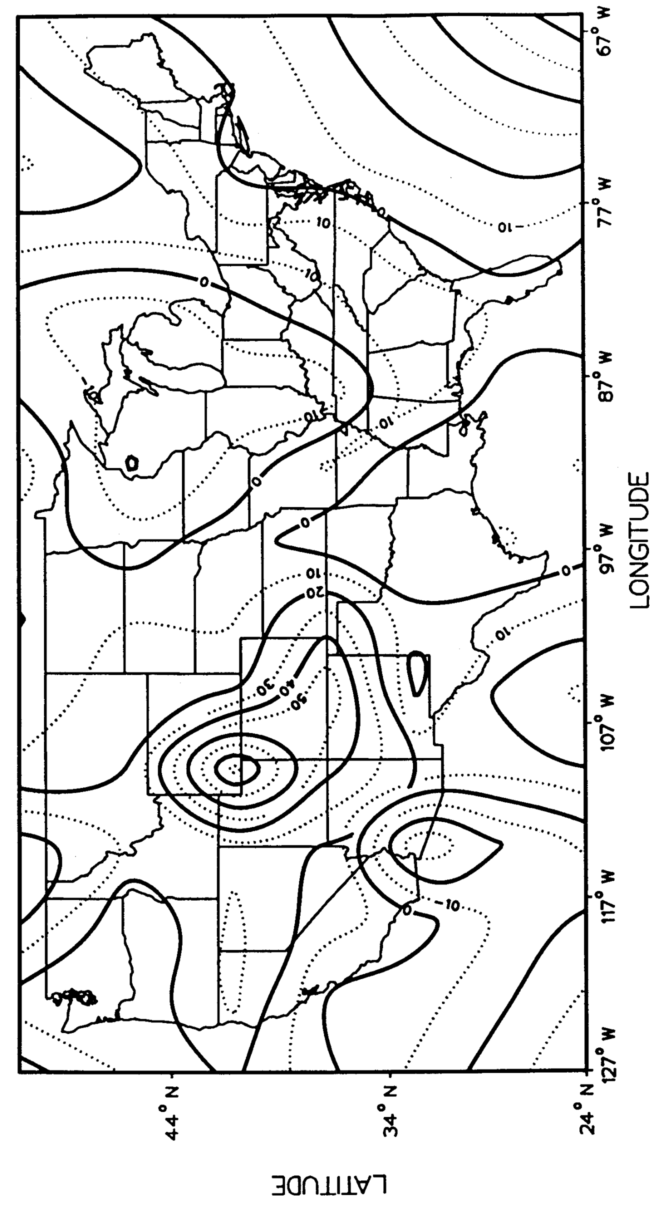

Figure 3.--NAVD 88 minus NGVD 29 heights (cm.).
Constraints: Heights of 18 NGVD 29 benchmarks

level is higher than the Atlantic. Oceanographers estimate this height difference is about 70 cm. The two datums agree along the east coast, but there is an unexplained 50-cm slope along the west coast. The hump in the Rocky Mountain area is caused by the difference in the processing systems. The new leveling data have additional corrections applied for refraction and rod correction and are adjusted in geopotential units rather than the orthometric system used in the past. This datum definition is the most scientifically acceptable of all the definitions considered and is the most natural because it is based on an undisturbed representation of the Earth's gravity field. It is the most suitable for the geoid height computations needed for the reduction of Global Positioning System (GPS) ellipsoidal heights. The main disadvantage is the differences with mean sea level on the west coast At Seattle, Washington, a person standing on the zero elevation contour will barely have his head above water at midtide.

The plot of the contours from the second datum definition is shown in figure 2. In this case, mean sea level was fixed at Key West, Florida, Portland, Maine. San Diego, California, and Neah Bay, Washington. These constraints tilted and twisted the network to obtain better agreement with mean sea level along the east and west coast. The hump in the Rocky Mountain area is still there, and the contours depict more irregularities. The main disadvantage is that the warping of the leveling data makes geoid height computations on this datum definition less accurate than on the first option. Although the main purpose of this datum definition is to force a better agreement with mean sea level along the coastlines, differences as large as 30 to 40 cm still occur.

Figure 3 displays contours for a datum definition where 18 scattered NGVD 29 elevations are fixed. Although this datum definition minimizes the differences between the new datum and the NGVD 29, it should not receive serious consideration because the leveling data are warped to agree with many arbitrary constraints.
Geoid height computations for this datum definition would be less accurate than for the others.

NATIONAL MAPPING PROGRAM

The National Mapping Program (NMP) includes more than 83,000 different map products, of which over 7 million copies are distributed annually. Of the 60,000 maps, about 55,000 are in 7.5-minute, l:24,000-scale, primary quadrangle map series.
Once-over coverage of the lower 49 States by this series is now available, and efforts are underway to concentrate on the digitizing and revision of this series. Because the 7.5-minute map series is the largest scale in the NMP and contains the greatest detail and elevation accuracy, it will be affected the most by the vertical datum change.

The contour intervals of the 7.5-minute map series are selected to best express the topography of the area. With a few exceptions, contour intervals range from 5 feet for very flat country to 80 feet for rugged mountainous terrain. In between the two limits are 10-, 20-, and 40-foot contour intervals. A few maps, in recent years, have been compiled with metric value contours. The distribution of the 7.5-minute map series by contour interval is shown in figure 4. In the lower 48 States, 14 percent of this series contains 5-foot contour intervals, 34 percent contains 10-foot, 29 percent contains 20-foot, 18 percent contains 40-foot, and 5 percent contains 80-foot.

U.S. Geological Survey production processes were designed to produce maps that meet the requirements of the National Map Accuracy Standards (NMAS). The national standard for vertical accuracy requires that the error in 90 percent of the test points be less than one-half the contour interval (allowing for an appropriate horizontal shift). Field survey methods are generally used to test the maps, and the elevation on the map is determined by interpolation between contours.

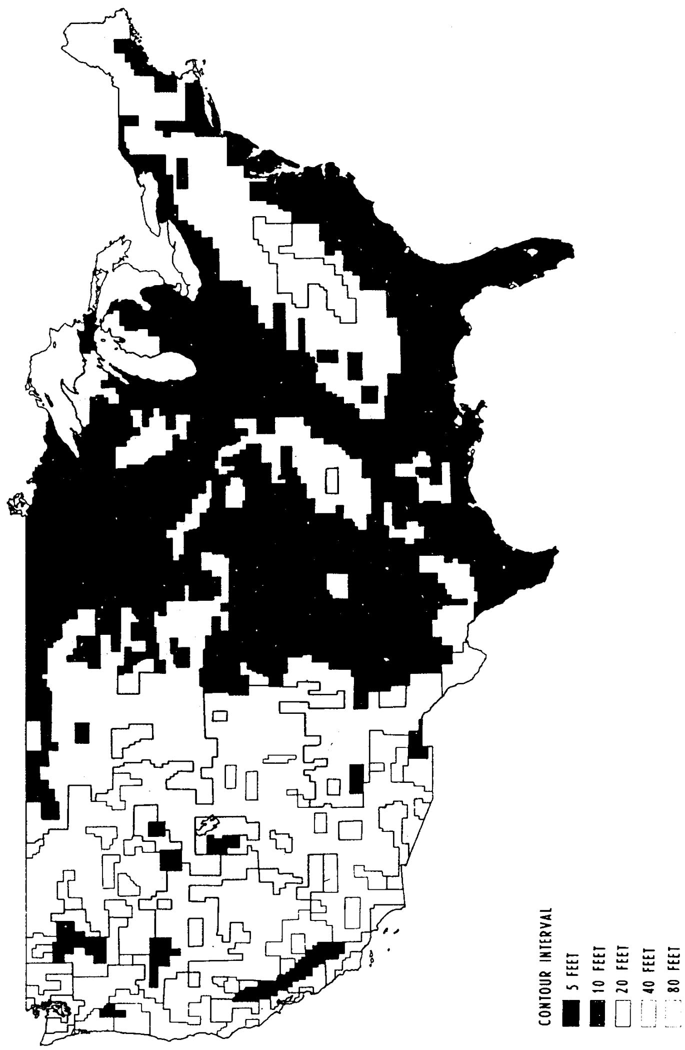

Figure 4.--Distribution of topographic maps by contour interval.

Other forms of vertical information shown on Geological Survey 7.5-minute maps are benchmarks and useful elevations, which are indicated by a cross symbol with the elevation given to the nearest foot. These are established by geodetic leveling of third-order accuracy or better. Another form are spot elevations that are measured by field or photogrammetric methods at readily identifiable features, such as:

- Natural lakes,
- Definite tops and saddles,
- Fence comers, or
- Road intersections.

These elevations usually are placed at a density of about one-per-square mile and are considered to be accurate to within three-tenths of the contour interval.

The digital files of topographic information will also be affected by a change in the vertical datum. A Digital Elevation Model (DEM) consists of a sampled array of elevations for ground positions that are usually, but not always, at regularly spaced intervals. The spacing of the elevation points (posts) is constant for a given series, but varies from series to series. For the 7.5-minute DEM, the horizontal framework is the Universal Transverse Mercator (UTM) system and the spacing is 30 meters.
The 1-degree DEM horizontal coordinate system is based on the latitude and longitude positions of the World Geodetic System (WGS) 72 datum and the spacing is 3 arc seconds. Another form of the digital topographic data that will be affected are the hypsography category Digital Line Graphs (DLG). These are the contours from maps digitized in the DLG format.

In support of the production of Geological Survey topographic maps, a third-order level network was established that resulted in few places being more than 5 miles from basic vertical control. These lines were usually established along farm roads, railroads, desert track roads, and mountain trails. The density of lines was less in remote mountainous areas where access was difficult and where there were few roads and trails. As the national vertical network was developed and densified, first by the U.S. Coast and Geodetic Survey and now by the National Geodetic Survey, the requirement for establishing level lines by Geological Survey field parties became less necessary. Additional geodetic leveling is now seldom needed to support the present National Mapping Program. Geological Survey field surveyors have established nearly 500,000 benchmarks. The geodetic elevations and descriptions of these benchmarks are published for distribution to the public.

IMPLEMENTING THE NAVD 88

Changing all of the NMP products, both graphic and digital, to the NAVD 88 will be a massive and costly undertaking and will require a decade or more to complete.
There arc several corrective actions that can be taken that vary in cost and degree of fulfillment:

1. A table of datum shift values can be produced that covers the United States and a user can correct a particular NMP map product by applying the table shift value. U.S. Geological Survey Bulletin 1875, "Map Data Conversion Tables," and the National Geodetic Survey program NADCON were developed for the horizontal datum change. The table value can be applied as a constant to DEM elevation files, or a higher order bilinear interpolation method can be used. A similar technique can be applied to the DLG hypsography file. The shift values can be shown in a correction note that can be applied during reprinting for graphic products. This correction note form of conversion can be applied to all products, but is considered a partial solution. A complete conversion should be done later.

2. In areas where the datum change is very small compared with the contour interval, advantage can be taken of the tolerance in the NMAS (that is, 90 percent of the test point errors are less than one-half of the contour interval.) If the datum change is only one-tenth of the contour interval, then the existing contours will still meet NMAS and will not require recompilation. The labeled elevations for benchmarks and spot elevations will need to be changed at a cost of about $200 per 7.5-minute map. This conversion is a "patch," but might be useful to extend the life of an otherwise sound map series. This is not a technically correct solution because a small bias is being introduced. Care must be taken that the contouring is in agreement with changed labeled elevations.

3. Recompiling the contours and spot elevations on a 7.5-minute map is the most geometrically correct method of fitting the new vertical datum. However, the total cost is unacceptable. Because the average cost of contouring a 7.5-minute map is about $7,000, recontouring because of an out-of-date datum is not cost-effective. However, consideration of other factors could justify the recontouring. Other factors are:

   - Changing to metric contours.

   - Terrain changes because of subsidence or other cause.

   - Inaccurate contours or inappropriate contour interval.

4. Adjusting the Geological Survey third-order leveling network to the NAVD 88 is a different challenge because high accuracy is needed to maintain its usefulness as geodetic data. This level of accuracy can only be provided by a least squares adjustment of the old observations to the new NAVD 88 primary network elevations. A cooperative pilot project is presently underway where the Geological Survey is organizing and digitizing the third-order leveling data, and the National Geodetic Survey will perform the least squares adjustment. The purpose is to determine production rates so

that a reliable estimate of the effort to process all the Geological Survey leveling data can be made. There is a possibility that the total cost of conversion could exceed the value of the data. If true, then a less expensive solution will have to be explored. There is also concern that many of the marks no longer exist and that a significant amount of effort would have to be expended that would have no return on the investment.

CONCLUSION

The datum definition that best fits the needs of the NMP is the one fixed by a single point, and the changes for the datum definition are given in figure 1. The important characteristics are:

- Small elevation changes for the eastern half of the United States where the7.5-minute map contour intervals are the smallest (see figure 4) and large changes for the western half where contour intervals are the largest.

- The isograms representing these changes are smoother and show less irregularities.

Both of these are important if the map patching conversion technique is to be used. The requirements are that the shift values be small compared with the contour interval and the gradient in the datum change be minimal so that a single change value can be applied over an entire 7.5-minute map with little noticeable error. A vertical shift (bias) in the defining elevation is desirable to expand the favorable contour interval/elevation change area over the entire United States. If the constrained elevation at Key West, Florida, is changed to -30 cm, then the map patching conversion can probably be applied to most (70 to 80 percent) of the 7.5-minute maps of the NMP.

The conversion of the Geological Survey third-order leveling data to the NAVD 88 presents significant challenges. How significant depends on the results of the pilot project. All of the NMP resources are presently committed to mapping programs, of which the revision and digitizing of existing maps are examples, and the competition for resources required for leveling data conversion would have to be weighed against these basic responsibilities. Several State geodetic surveying agencies, however, have indicated an interest and might help by doing some of the digitizing work. These offers indicate a genuine need for Geological Survey third-order leveling data.

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