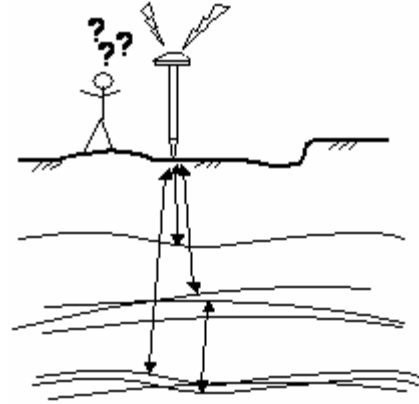


The Rodman's Guide to Madison Vertical Datums

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1.1. INTRODUCTION This document explains the various vertical datums used for determining elevations in the City of Madison, Wisconsin area. It is based on the author's experience and is intended for land surveyors and other spatial data professionals. Sections 2.X on the City, NGVD 29 and NAVD 88 datums are basic information for any spatial data user. Sections 3.X and 4.X are more complex information relevant to the Global Positioning System (GPS). Recommended RTK GPS configuration parameters are compiled in a separate document.

1.2. DISCLAIMER The author has compiled this document to increase understanding of Madison-area vertical datums within the land surveying and spatial data community. Users of this document are solely responsible for their own vertical datum-related measurements, computations and related work. The author and the City of Madison make no representation about the accuracy or completeness of this document, and in no event shall the author or the City be liable for any damages whatsoever resulting from its use.

Data for the GPS sections of the document were originally obtained from National Geodetic Survey data sheets retrieved on July 30, 2007 and December 2, 2007. Periodic checks through Feb 21, 2011

found no changes to those data sheets. NAD 83(2011)(Epoch 2010.00) and NAVD 88(2012) data were obtained initially from Aug 14, 2012 data sheets, but NAVD 88(2012) elevations were not found for non-leveled stations until Jan 11 2014 data sheets (other data used from Aug 14 2012 data sheets had not changed). Station MADISON S GPS (DF9799) was destroyed in 2010 but has 2011/2012 adjustment values, so it remains in the analysis.

2.1. IF LIFE WERE SIMPLE... Historically, the "City" vertical datum was established at the water level of Lake Monona at some historical moment or average. This was determined to be 845.6 feet above the National Geodetic Vertical Datum of 1929 (NGVD 29), which has also been called the "sea level" or "USGS" datum. The National Geodetic Survey (NGS) later readjusted NGVD 29 to create the North American Vertical Datum of 1988, called NAVD 88(1991) here to distinguish it from subsequent adjustments. The NGS determined the NAVD 88(1991) datum to be about 0.2 feet above NGVD 29 in the Madison area (per VERTCON 2.0 software at www.ngs.noaa.gov). Subtracting 0.2 feet from 845.6 feet means the old "City" datum is theoretically 845.4 feet above NAVD 88(1991). In other words, if a point has a "City" elevation = 100.0 feet, it should have a NGVD 29

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elevation = (100.0 + 845.6) = 945.6 feet, and a NAVD 88(1991) elevation = (100.0 + 845.4) = 945.4 feet. Figure 01 illustrates these relationships.

2.2 ...IT WOULD BE TOO EASY Unfortunately, it's not that simple, and it never has been. Elevations are not physically measured directly from the datum, because the datum is only a conceptual level surface. Even the "City" datum, based on Lake Monona, is not visible today because it is based on some historical water level. Rather, elevation is computed by measuring *change* in elevation from a bench mark, which has a predetermined elevation relative to datum. If the bench mark elevation is wrong, any elevation determined from it is wrong.

Experience has shown that across the city, the network of bench marks (such as fire hydrant top nuts and section corner monuments) with older "City" elevations is consistent within local areas, but there are "fault lines" between areas. These are most probably due to measurement and computation errors when establishing the bench mark elevations, or subsequent monument disturbance (such as replaced hydrants), rather than post-measurement physical ground shifts. The author has observed inconsistencies of up to 2 feet, and greater ones may exist. Thus, a national bench mark with a NGS-published NAVD 88 elevation of 945.4 feet, and a nearby fire hydrant with a "City" elevation of 100.0 feet, are not necessarily at the same elevation.

Because certain projects such as sewer and road construction usually require very precise elevations, the theoretical datum transformations above cannot be trusted to relate different bench marks in different datums. Bench marks must be checked with current measurements to ensure that any one bench mark hasn't moved, or that a bench mark's published elevation doesn't have measurement or computation errors.

Of course, measurements between bench marks can only check elevation *change* between bench marks. If the measured difference between two bench marks doesn't agree with the difference computed from published elevations, it is impossible to determine, from relative measurements alone, which (if either) of the published bench mark elevations *above datum* is correct. This is why project documentation including bench marks used, published elevation value, source and date of elevation value, and (supposed) datum, are critical to consistent vertical control.

2.3. ...AND THEN, THE NAVD 88

READJUSTMENTS In 2007 and again in 2012, NAVD 88 elevations for bench marks (stations) in the Madison area were adjusted by very systematic shifts. NAVD 88(2007) elevations are on average 0.11 feet larger than original NAVD 88(1991) values, and NAVD 88(2012) elevations are on average 0.06 feet larger than NAVD 88(2007) values (Figure 02). Unfortunately, currently (Jan 2014) the NGS refers to all these datums as NAVD 88 without a suffix for the adjustment year, even though the net average shift through 2012 in the Madison area is 0.17 feet. Suffixes have been added in this document to differentiate. Coincidentally, the NAVD 88 datum adjustments through 2012 are heading back toward the NGVD29 datum, so confusing the 4 datums only results in a maximum of 0.2 ft error (assuming no other errors are present).

The shifts in Figure 02 are average values for the Madison area. They are not necessarily correct for a particular bench mark, which may have measurement errors or may have been disturbed since measurement. Note that as of Sept. 2012, NGS's VERTCON 2.0 software (at www.ngs.noaa.gov/TOOLS) predicts a 0.2 foot shift (with slight variations by location) between NGVD 29 and the *original* NAVD 88(1991), not the later NAVD 88 adjustments.

The NAVD 88 elevations established for section corner monuments in the City of Madison starting in 2004 were in NAVD 88(1991). See http://gis.cityofmadison.com/Madison_PLSS/

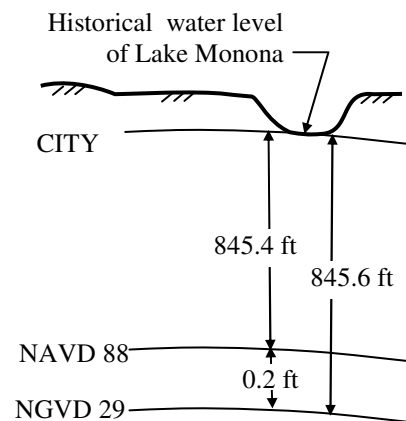


Figure 01. If Life Were Simple (Profile View)

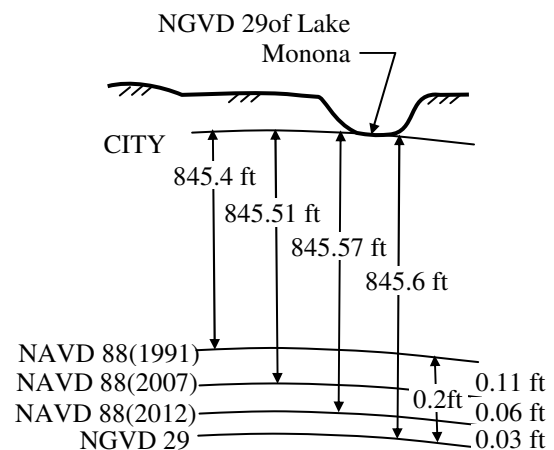


FIGURE 02. The Various NAVD 88 Datums (Profile view showing average shifts)

2.4. NAVD 88(2007) DETAILS Based on NGS data sheets retrieved July 30, 2007 from www.ngs.noaa.gov, the leveled NAVD 88 elevations of 120 Second Order Class I stations within 25 km (~15 mi) of the Madison GPS base station had NAVD 88 elevations larger than their previous (1991 through 2004) values between +0.04 and +0.15ft, with an average of +0.11ft. The low station at +0.04ft was E 108 (NGS PID# OM0450). It is far west of Madison and an outlier with an older (1991) previous elevation. 89% of the 120 stations had elevation shifts between +0.09 ft and +0.13 ft (within 0.02 ft of the average). A slight tilt is evident between NAVD 88(1991) and NAVD 88(2007), with the larger shifts mostly northerly and westerly and the smaller shifts mostly southerly and easterly. However, these tilts were only hundredths of a foot over ~30 miles. Shifts on Madison's Isthmus were slightly below the average (+0.07ft to +0.08ft).

Figure 03 shows a plot of NAVD 88 elevation changes (1991 to 2007) at these NGS stations. Differential leveling was used to compute NAVD 88(1991) elevations at the old Sayle Street GPS base station (discontinued in 2009) relative to Station 2V02, and at the new Emil Street GPS base station (MAON) relative to Station MADISON S GPS (destroyed in 2010). See Appendix 2 and http://gis.cityofmadison.com/Madison_GPS/

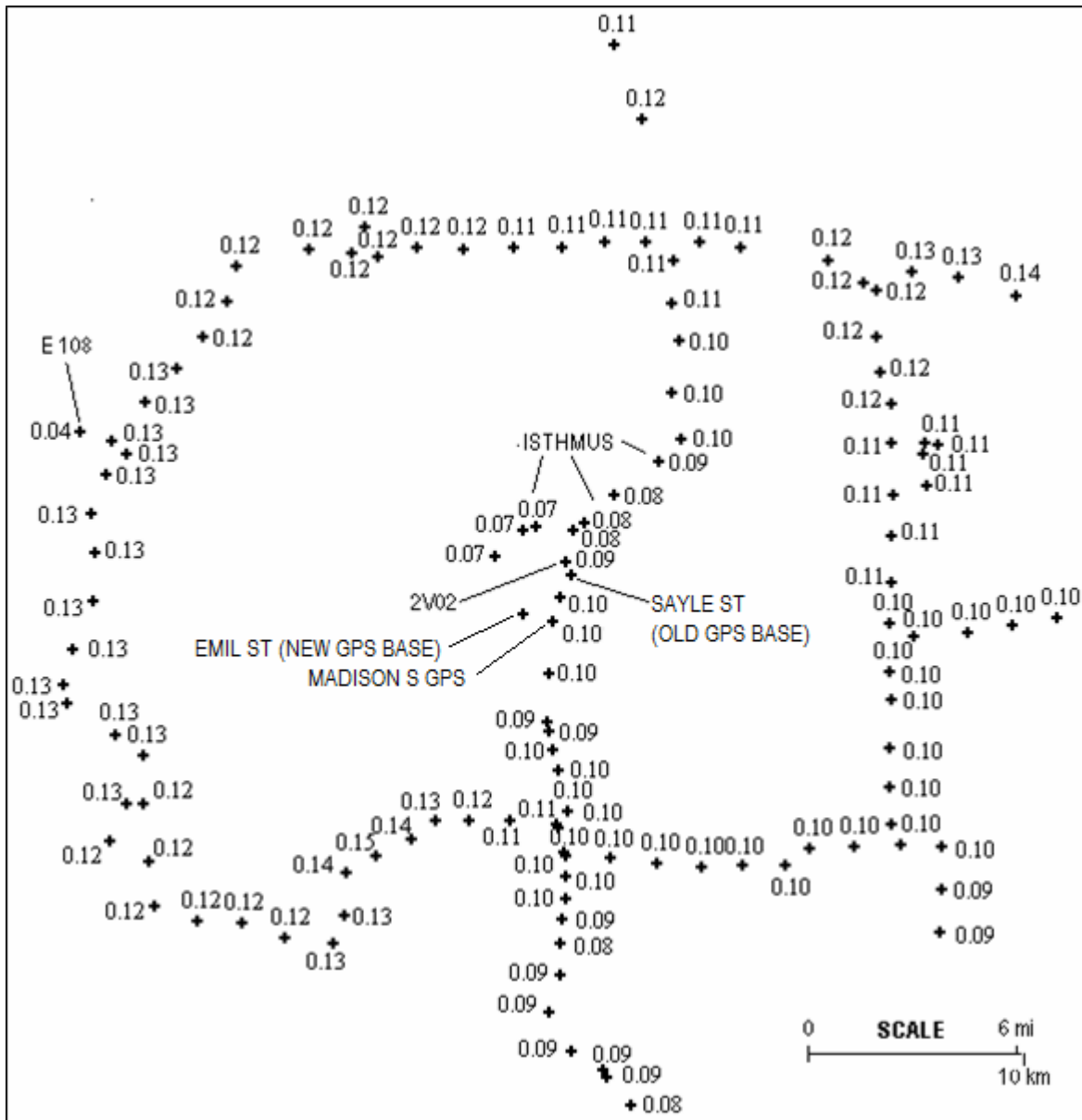


Figure 03: Elevation shift at NGS Bench Marks, NAVD 88(2007) minus NAVD 88(1991), feet

2.5. NAVD 88(2012) DETAILS For the analysis of the May 2012 NAVD 88 adjustment, NGS data sheets were retrieved August 26, 2012 from www.ngs.noaa.gov for stations with leveled NAVD 88 elevations of Second Order Class I or better accuracy (all are Second Order Class 1) within 25 km (~15 mi) of the old Sayle St GPS base station. Of the 159 stations in this selection set, 43 were excluded because most recent NAVD 88 elevation was from June 1991. Station 2V11 (PID# DF9957) was also excluded because of vertical instability noted on the data sheet. 115 were retained for analysis, including MADISON S GPS (PID# DF9799) which was destroyed in 2010 but included in the 2012 adjustment. 112 of the 115 were in the July 2007 comparison of NAVD 88(1991) and NAVD 88(2007).

These 115 stations had NAVD 88(2012) elevations larger than their NAVD 88(2007) values by between +0.04 and +0.08ft, with an average of +0.06 ft. The 53 of the 115 within 17 km (10.6 mi) from the old Sayle St base station near the center of Madison have differences within +0.06 to +0.07ft (average rounds to 0.06 ft). A very slight tilt is evident between NAVD 88(2007) and NAVD 88(2012), with larger shifts to the northeast and smaller shifts to the west. However, these tilts were only hundredths of a foot over ~30 miles.

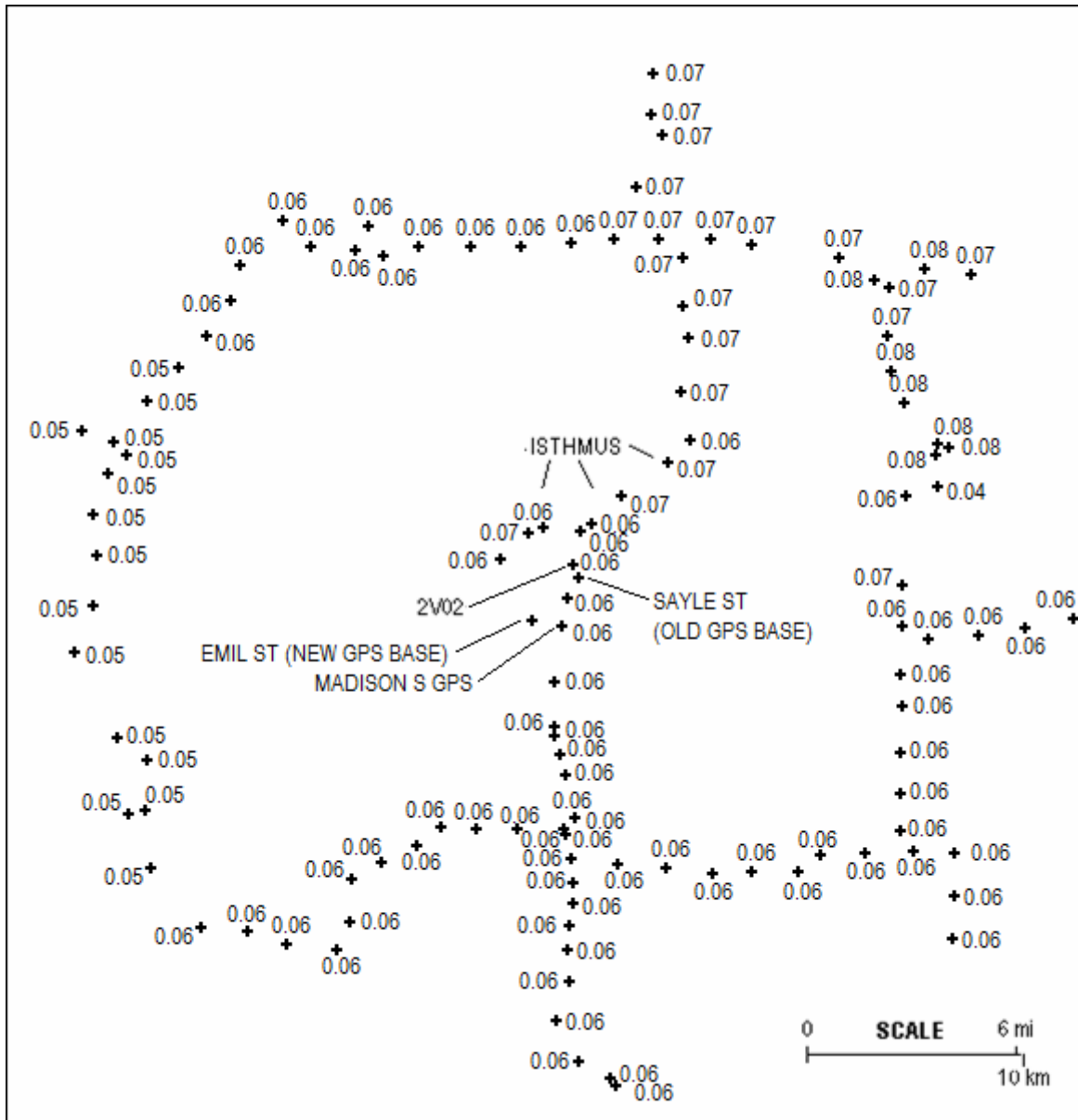


Figure 04: Elevation shift at NGS Bench Marks, NAVD 88(2012) minus NAVD 88(2007), feet

2.6. WHICH NAVD 88 DO I HAVE?

Section Corner Tie Sheets produced for the City of Madison (mostly by Carl Sandsnes) show original NAVD 88 (1991) elevations. As of January 2014, the city plans to stay on the original NAVD 88 datum.

http://gis.cityofmadison.com/Madison_PLSS/

NGS Data Sheets do not currently (Jan 2014) differentiate between different adjustments of NAVD 88, but it can usually be determined from the notes. In the Madison area, the author has found that NAVD 88 elevations with dates before April 2007 are NAVD 88(1991), April 2007 or after are NAVD 88(2007), and after May 2012 are NAVD 88(2012). However, it may be difficult to tell. For example, the data sheet for station MADISON GPS (PID# DG4910) retrieved on July 30, 2007 showed a GPS-derived NAVD 88 elevation of 272.26 m (893.24 ft, unrounded). The data sheet for the same station retrieved on August 28, 2007 showed the same elevation as 272.30 m (893.37 ft, unrounded), and on January 11, 2014 as 272.31m (893.40 ft, unrounded). The previous values appear under the Superseded Survey Control section of the January 11, 2014 data sheet, but not on the August 28, 2007 data sheet. Information in the data sheet about dates the station was visited may be useful.

Another important note is that as of January 2014, NGS's VERTCON 2.0 software (at www.ngs.noaa.gov/TOOLS) predicts a 0.2 foot shift (with slight variations by location) in the Madison area between NGVD 29 and NAVD 88(1991), not the later NAVD 88 adjustments. VERTCON may be updated in the future.