Legacy height datums on the Mississippi and Illinois river systems

Chris Pearson, NGS geodetic advisor for Illinois
Dave Mick Illinois Department of Natural Resources

Abstract
In this paper we summarize the major vertical datums that are used along the Mississippi River and its tributaries in Illinois (Memphis datum, Mean Gulf Level and the 4th General adjustment of 1912) and show the approximate shifts between these systems and NAVD88. These height differences are not small. For example height differences of up to 8 ft are observed for Memphis datum.

Introduction

For most applications, there are only two vertical datums in common use in the United States. The North American Vertical Datum of 1988 (NAVD88), our current national height datum, is used for most high accuracy modern surveys and the National Geodetic Vertical Datum of 1929 (NGVD29) which is superseded but is still used for engineering applications and by numerous municipal governments. Very rarely do we encounter survey measurements in datums older than NGVD29. One major exception to this is the upper Mississippi River and its tributaries. Here, because of the great value of historical measurements of river levels, and because of the importance of maintaining continuity for diverse groups of users, pre 1929 datums remain important and, indeed, in some cases, are in common usage for water level measurements and bathymetric surveys.

In this paper we summarize the major vertical datums that are used along the Mississippi River and its tributaries in Illinois and show the approximate datum shifts between these datums and NAVD88. In conducting this study we have concentrated on mapping the local differences in heights recorded in the various legacy datums and NAVD88 (Zilkoski Richards and Young 1992) along corridors following the Mississippi and Illinois rivers, because this is where the legacy datums are most likely to be encountered by surveyors.

Datums in common use in the upper Mississippi River Valley.

In the Mississippi River Valley, the major legacy datums are:

1. Memphis Datum: Because no accurate datum for measuring heights existed in the Mississippi River Valley prior to the establishment of Mean Gulf Level and its propagation up the Mississippi River Valley after 1881, government surveys on the Mississippi conducted in latter part of the 19th centurary used an arbitrary datum established in Memphis, Tennessee.
2. Mean Gulf Level: This was the first sea level datum for the Mississippi. It was based on mean sea level determined by a tide gage in Biloxi, Mississippi established in 1881 by the Mississippi River Commission. These heights were then gradually propagated up the Mississippi by leveling parties
3. Fourth General Adjustment of 1912: The first datum based on geodetic quality leveling was established in 1900 by the U. S. Coast and Geodetic Survey (USC&GS) holding elevations referenced to local mean sea level

(LMSL) fixed at five tide stations (Boston MA, Sandy Hook NJ, Washington DC, New York, NY and Biloxi, MS). Readjustments of the leveling network were performed in 1903, 1907 and 1912. Only the Fourth General Adjustment of 1912 is widely used as a legacy datum in the Mississippi Valley today. It is the basis of all height and water level measurements conducted by the Rock Island office of the US Army Corps of Engineers (USACE) in Wisconsin and Illinois.

Relationship between Memphis Datum, Mean Gulf Level and NAVD88.

Because each vertical datum has its own unique adjustment procedures, each is warped in a complex way with respect to NAVD88. Local shifts between the datum surfaces can be estimated by identifying benchmarks that have heights determined in both systems and comparing them. Using this technique, McKibbin and Schmidt (1954) developed relationships between these surfaces and NGVD29 using USACE data. However no published datum shifts between the legacy datums and NAVD88 exist. In order to determine these relationships we went through McKibbin and Schmidt (1954) and identified all of the benchmarks in their study that have valid NAVD88 heights in the National Geodetic Survey (NGS) database (www.ngs.noaa.gov/cgi-bin/datasheet.prl).
Using this data and the legacy elevations provided by McKibbin and Schmidt (1954) we were able to determine height differences between these legacy datums and NAVD88. Figure 1 shows the benchmarks in Illinois where heights are available for one or more of these legacy datums and NAVD88. Note that our study is restricted to narrow corridors along the Illinois and Mississippi River Valleys. Because of this limited geometry, our study is unable to fully define the complex relationship or the tilts between these two datum surfaces. We were able to measure height differences between the legacy datums and NAVD88 for specific points along these corridors. Figure 2 shows the vertical shift between NAVD88 and Memphis Datum for points along the Illinois River. There appears to be no clear trend. All that can be said is that the shift is 7.7 +- 0.1 ft at the 95% level of confidence.

McKibbin and Schmidt (1954) do not list any individual benchmarks with heights in the Mean Gulf Level datum however they do list datum shifts between Mean Gulf Level and NGVD29 for specific localities along the Mississippi from Cairo, IL, to Prairie Du Chen, WI. We developed approximate datum shifts between Mean Gulf Level and NAVD88 by applying shifts calculated using the NGS program vertcon (www.ngs.noaa.gov/PC_PROD/pc_prod.shtml#VERTCON) for the appropriate locality to the NGVD29 values. The height differences as a function of Mississippi River miles are shown in figure 3. It should be noted that the NGVD29 heights used by McKibbin and Schmidt (1954) will not reflect any post 1954 adjustments to NGVD29. Because the vertcon shifts applies to post 1954 adjustment values, it has the potential to introduce a slight bias into the height difference shown in figure 3. In order to estimate the effect that post any post 1954 adjustment of NGVD29 might have had on the height differences shown in figure 3, we compared NGVD29 heights from for 11 benchmarks along the Mississippi Valley from McKibbin and Schmidt (1954) located between river mile 209-513 with NGVD29 heights from superseded heights from the NGS database. Since, in every case but one, the two values agree within a hundredth of a foot, we feel that post 1954 adjustments to NGVD29 are unlikely to have significantly affected the height differences shown in figure 3. Note that the height difference between Mean Gulf Level and NAVD88 starts out as slightly negative near Cairo IL (mile 0) then reaches a fairly constant value of 0.2 ft over most of the northern part of the Mississippi River Valley in IL and southern WI.

Fourth General Adjustment of 1912

The Fourth General Adjustment of 1912 included 46,462 km of level lines and about 11,000 benchmarks (Berry 1976). Mean sea level was held at nine tide gages located on the East, West and Gulf coasts holding elevations referenced to local mean sea level (LMSL) fixed at nine tide stations (Boston MA, Sandy Hook NJ, Baltimore MD, Morehead City NC, Brunswick GA, Biloxi, MS, Galveston TX, San Diego CA and Seattle WA). Adjusted heights for benchmarks are reported in Bowie and Avers (1914).

The level data included in the adjustment of 1912 include a series of lines extending along the Mississippi river from Cairo, IL to St Paul MN. In order to determine a height difference between NAVD88 and the Fourth General Adjustment of 1912 along the Mississippi, we checked all of the points listed in Bowie and Avers (1914) and cross referenced these with the NGS database to identify marks with both NAVD88 and the Fourth General Adjustment heights. In all we investigated 563 marks from the list in Bowie and Avers (1914) and identified 119 in the NGS database. Of these 62 had adjusted NAVD88 heights and 57 had only VERTCON heights. Standard River miles for these benchmarks were determined using shape files supplied by the USACE (lagic.lsu.edu/metadata/losco/**river**_mile_mark_**usace**/navgeog3dxmmk.html) and ESRI's ArcInfo software. Using this data we developed a chart of the height differences as a function of river miles for all of the 62 points with adjusted NAVD88 heights. The results are shown in Figure 5. Figure 4 shows a the Fourth General Adjustment-NAVD88 height difference for the Illinois River Valley.

In the Mississippi Valley (above St Louis) the relationship between NAVD88 and the Fourth General Adjustment (see figure 5) shows significant variation with distance in the relationship between the Fourth General Adjustment – NAVD88 height difference and river miles. However a simple 2nd order polynomial regression line (see figure 6) produces an acceptable fit.

$$D = -0.055329148 + 0.00314407R - 3.25861084627033 \bullet 10^{-06} R^2$$

Where D is the the Fourth General Adjustment – NAVD88 height difference in ft and R is the position of the point in USACE River miles. The predicted datum conversion from this regression equation is shown in Figure 6 and the corresponding residuals are shown in figure 7.

Conclusion

Heights along the upper Mississippi River and its tributaries have been measured using many different vertical datums. While most of these are of historical interest, there are three that are still in active use, NAVD88, NGVD29 and the Fourth General Adjustment of 1912. Each vertical datum defines its own reference surface for heights. Each reference surface will produce a different height so as users of geographic data it is up to us to ensure that we know what reference surfaces all of our heights are referenced to. While surveyors are used to dealing with NAVD88 and NGVD29, few will be aware of the continued use of the Fourth General Adjustment or the existence of other legacy datums.

The difference between NAVD88 and NGVD29 are quite small in Illinois and indeed over most of the Mississippi River Valley, however the other legacy datums have much greater shifts. For example the height difference between the Fourth General Adjustment, (which is still in common use for recording river level heights) and NAVD88 is as much as 0.82 ft. The height difference for Memphis Datum, which is no longer used but which remains important due to

the large amount of legacy data within this system, is over 7.5 ft. As a result, correctly identifying the datum associated with each height measurement is particularly important for workers in this region.

Acknowledgements

This paper benefited greatly from reviews by Dave Doyle, Dave Conner, Ajit Singh, Dru Smith and ,Dave Zilkoski, all of the National Geodetic Survey.

References

Berry, R. M. 1976. "History of Geodetic Leveling in the United States." Surveying and Mapping, vol. 36 no. 2, pp. 137-153.

Bowie W. and H. G. Avers 1914. *Fourth General Adjustment of the Precise Level Net in the United States and the Resulting Standard Elevations*, Special Publication No. 18, U.S. Coast & Geodetic Survey, Government Printing Office Washington, D.C.

McKibbon J. C. and M. O. Schmidt (1954) Datum Planes in Illinois Civil engineering Studies Surveying Series #1 Department of Civil Engineering University of Illinois; Urbana Illinois

Zilkoski, David B., John H. Richards, and Gary M. Young Results of the General Adjustment of the North American Vertical Datum of 1988 American Congress on Surveying and Mapping *Surveying and Land Information Systems*, Vol. 52, No. 3, 1992, pp.133-149

- Figure 1 Map showing location of benchmarks with NAVD88 elevations and elevations in one or more legacy datums. Triangles shows points along the upper Mississippi which have heights from the Fourth General Adjustment of 1912 reported in Bowie and Avers (1914) and have valid NAVD88 heights. Crosses show benchmarks along the Illinois River Valley which McKibbin and Schmidt (1954) list heights in the Fourth General Adjustment of 1912 and Memphis Datum and which also have valid NAVD88 heights from the NGS database.

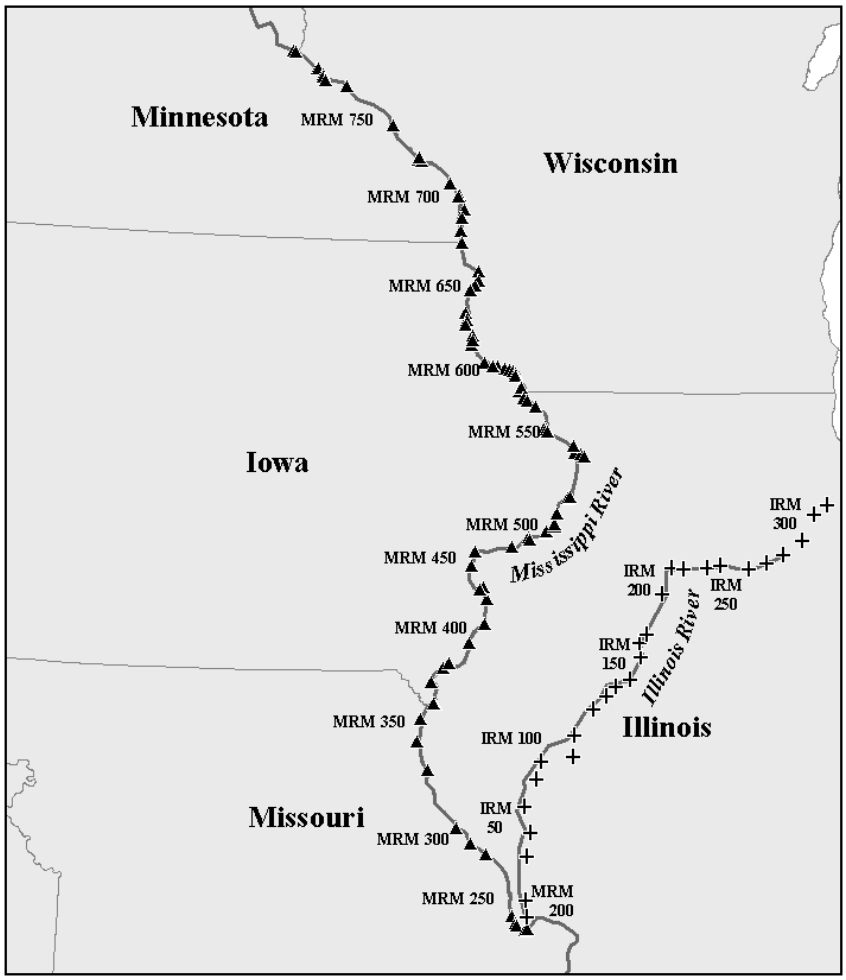

Figure 2 Height difference between Memphis Datum and NAVD88 for points along the Illinois River vs. standard river miles from the confluence with the Mississippi.

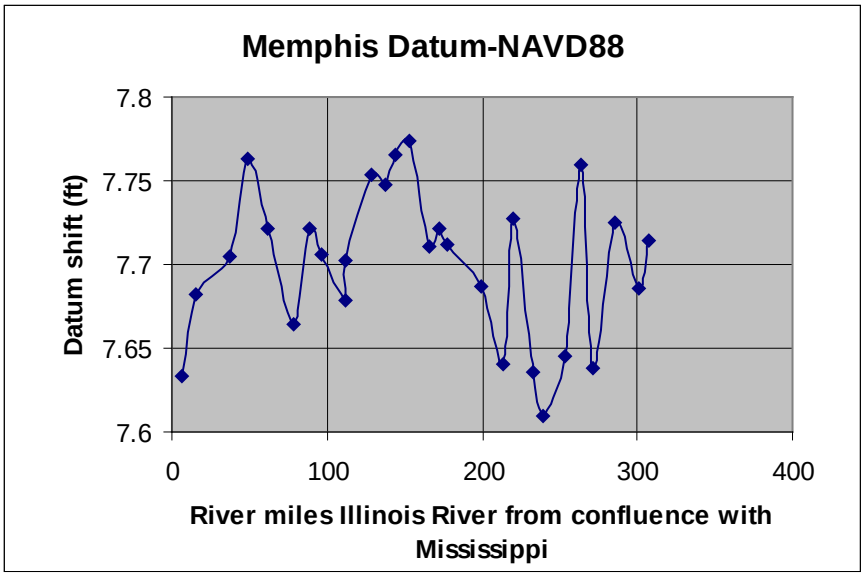

Figure 3 Approximate height difference between Mean Gulf Level and NAVD88 for points along the Mississippi River

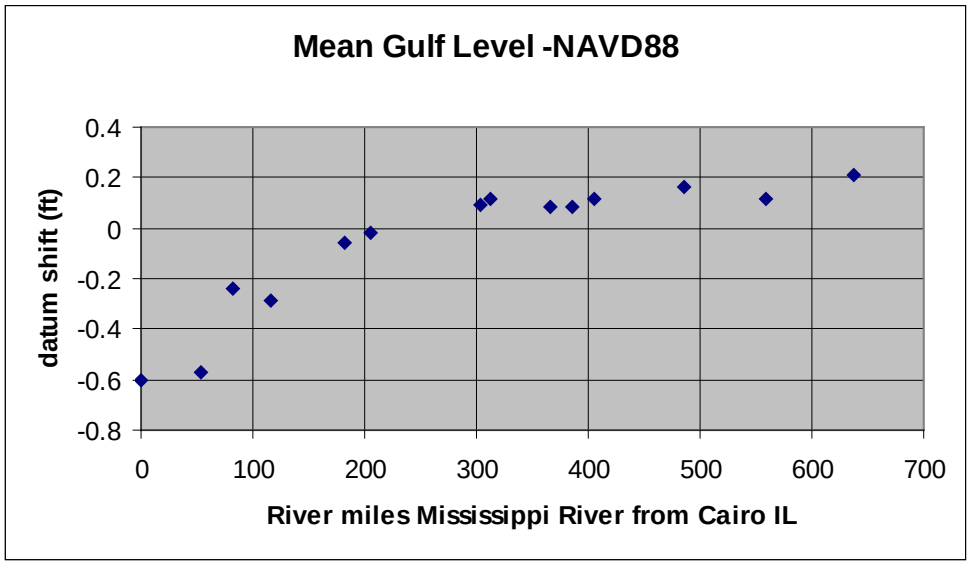

Figure 4 Shift between the 4th General adjustment and NAVD88 in the Illinois River Valley from the confluence with the Mississippi River to Willow Springs in suburban Chicago.

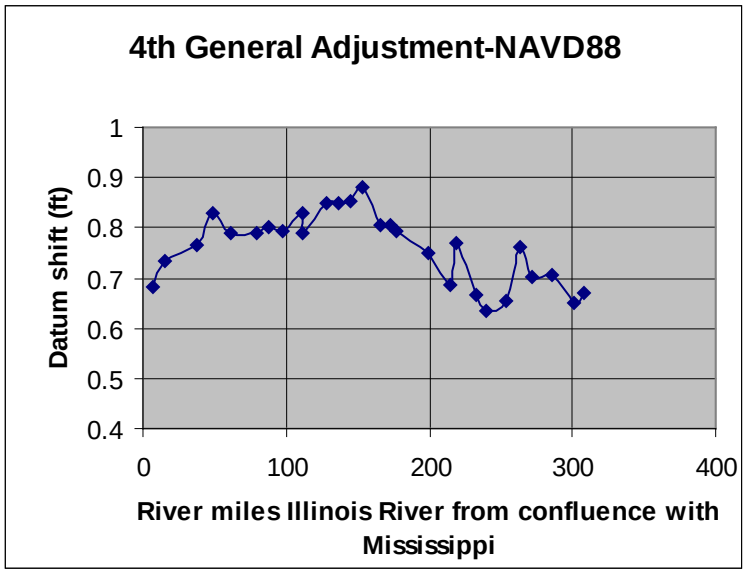

Figure 5

Shift between 4th General adjustment and NAVD88 in the Mississippi River valley between St. Louis and St Paul.

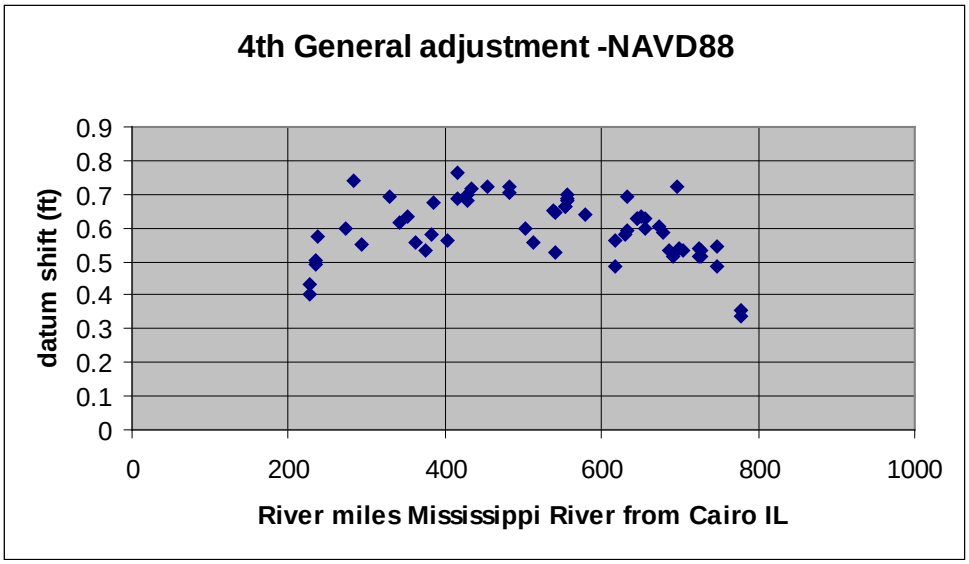

Figure 6

Order 2 regression for Mississippi Valley benchmarks between the 4th General adjustment - NAVD88 height difference vs. River Miles.

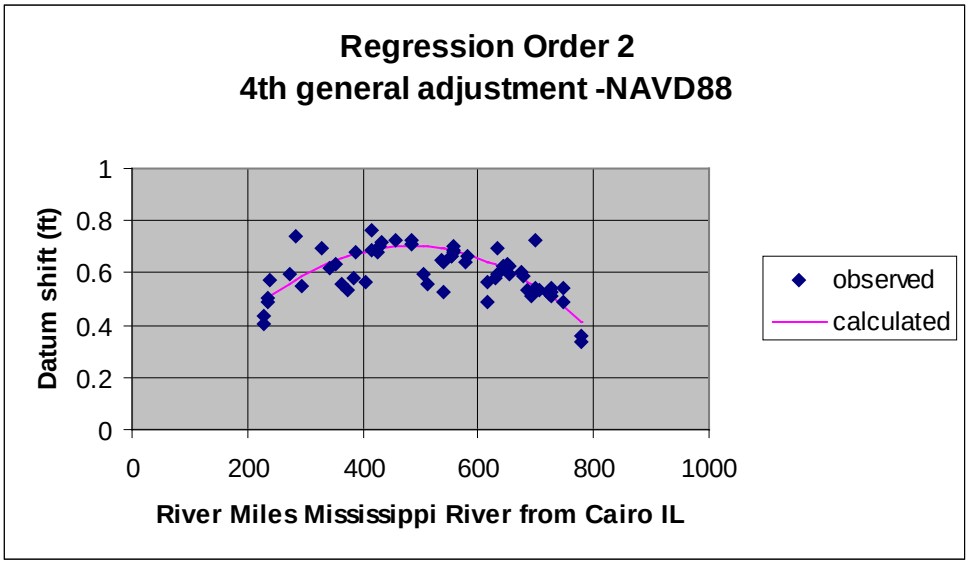

Figure 7

Residuals after removing Second-order regression