Guidance for Flood Risk Analysis and Mapping

Vertical Datum Conversion

May 2014

FEMA

This guidance document supports effective and efficient implementation of flood risk analysis and mapping standards codified in the Federal Insurance and Mitigation Administration Policy FP 204-07801.

For more information, please visit the Federal Emergency Management Agency (FEMA) Guidelines and Standards for Flood Risk Analysis and Mapping webpage (http://www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping), which explains the policy, related guidance, technical references, and other information about the guidelines and standards process.

Nothing in this guidance document is mandatory other than standards codified separately in the aforementioned Policy. Alternate approaches that comply with FEMA standards that effectively and efficiently support program objectives are also acceptable.

Document History

Affected Section or Subsection	Date	Description
First Publication	May 2014	Initial version of new transformed guidance. The content was derived from the *Guidelines and Specifications for Flood Hazard Mapping Partners*, Procedure Memoranda, and/or Operating Guidance documents. It has been reorganized and is being published separately from the standards.

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1.0 Overview

This guidance document supports the nine vertical datum standards adopted by FEMA in the execution of vertical datum conversions from the National Geodetic Vertical Datum of 1929 (NGVD29) to the North American Vertical Datum of (NAVD88), and provides context and supporting guidance for the efficient implementation of those standards, as well as several scenario-based examples to facilitate a comprehensive understanding of associated vertical datum conversion considerations. This document contains the following information about conversion from the NGVD29 to NAVD88:

- General information about the two vertical datums most commonly used by FEMA for referencing 1% annual chance flood elevation information in Flood Insurance Rate Map (FIRM) databases, on FIRMs, and in Flood Insurance Studies (FISs)
- Information on publically available software for converting from NGVD29 to NAVD88
- Guidance on the analysis of vertical datum conversion options
- Guidance on the process of converting unrevised flood elevations to NAVD88
- Guidance on the coordination and documentation requirements associated with a vertical datum conversion

Every FIS and FIRM that contains the results of hydrologic and hydraulic flood hazard analyses is referenced to a specific vertical datum. NGVD29 was the vertical datum that most FISs and FIRMs utilized until the mid-1990s. After that time, NAVD88 became the vertical datum of choice for FIS/FIRM production. Because existing flooding hazard data referenced to NGVD29 may not be revised in the scope of an ongoing FIS/FIRM restudy, there is a need to enable efficient conversion of unrevised flood elevations to NAVD88. It is FEMA's goal to convert all flood maps in the Contiguous United States from NGVD29 to NAVD88 for the following reasons:

- NAVD88 is more compatible with modern surveying and mapping technologies like Global Positioning Systems and Light Detection and Ranging data and is more accurate than NGVD29.
- The old datum, NGVD29, is obsolete and no longer supported by the National Geodetic Survey (NGS).
- As time passes it will be substantially more difficult to obtain reliable elevations referenced to NGVD29, making it difficult for professional surveyors to certify elevations referencing NGVD29.
- Previously published NGVD29 heights on NGS benchmarks will not be updated or maintained, and become less reliable as they age.
- As reference marks are disturbed or destroyed, there will be fewer and fewer NGVD29 reference points available.

1.1 National Geodetic Vertical Datum of 1929

Historically, the most common vertical datum used by FEMA has been NGVD29. NGVD29 assumed that 26 tide gages in the United States and Canada all represented the same zero elevation, which was mean sea level. As survey technologies became more accurate, it became increasingly apparent that NGVD29 constraints were incorrectly forcing surveys to fit different tide stations (all zero elevation or mean sea level) that actually had different elevations relative to each other. NGVD29 essentially

warped the geoid, which represents an equipotential surface where gravity and elevations should be the same. Fortunately, the maximum warp anywhere in the United States, caused by forced constraints of NGVD29 at 26 tidal stations, is no more than 1.5 meters. Although there are exceptions, the warping found over smaller geographic areas, such as the area within any given county, is small.

1.2 North American Vertical Datum of 1988

During the 1970s, the NGS, and counterpart agencies in Mexico and Canada, adopted a vertical datum based on a surface that would closely approximate the Earth's geoid. The new adjustment, NAVD88, was completed in June 1991 and is now the only official vertical datum in the United States. NAVD88 was created by adding 625,000 kilometers of leveling, performed since NGVD29 was established, and by performing a major least squares adjustment that constrained only a single tide station at zero elevation. The height of the primary tidal bench mark at Father Point/Rimouski in Quebec, Canada, was held fixed as the constraint, enabling NAVD88 and the International Great Lakes Datum of 1985 to be one and the same.

Now, other tide stations may have elevations other than zero. Subsequent to the establishment of NAVD88, new flood hazard studies are preferably referenced to NAVD88.

1.3 Other Vertical Datums

There are some limitations to NAVD88 outside of the Contiguous United States. NAVD88 benchmarks are limited in Alaska and many islands may not have any NAVD88 benchmarks, limited access to NAVD88, or have other limitations with the geodetic control available. Projects in Alaska, Hawaii, Puerto Rico, the Pacific Islands, and even smaller island communities need to research the local datums and available geodetic control and make project specific decisions about what datum to publish the maps in and how to complete any necessary conversions between datums. Similarly, in a few cases within the Contiguous United States, older maps may be referenced to a different local datum than NGVD29. In these cases, the standard Vertical Datum Conversion Program (VERTCON) conversion software discussed here is not applicable, but the general principles for defining areas for applying a uniform conversion factor by testing a sampling of points and limiting maximum variation from the average conversion factor to 0.25ft can still be applied.

2.0 Vertical Datum Conversion Software

In order to effect a conversion from NGVD29 to NAVD88, specific conversion software must be used. The NGS and the U.S. Army Corps of Engineers (USACE) have developed software, which may be obtained free of charge, for performing conversions between NGVD29 and NAVD88.

Mapping Partners may download the PC-compatible NGS VERTCON software from the NGS webpage at http://www.ngs.noaa.gov/ by selecting the Geodetic Tool Kit option. Similarly, Mapping Partners may download the USACE CORPSCON software from the same location. Both programs compute the modeled differences in orthometric heights (elevations) between NGVD29 and NAVD88 for a given location specified by geographic coordinates (latitude and longitude). Using CORPSCON, Mapping Partners can also enter Universal Transverse Mercator or State Plane coordinates in lieu of geographic coordinates. Identical results are obtained using either the VERTCON or CORPSCON software.

3.0 Vertical Datum Conversion Considerations

As stated earlier, one of the goals of FEMA's Risk Mapping, Assessment, and Planning Program (Risk MAP) is to convert all flood maps from NGVD29 to NAVD88. Accordingly, FEMA Standard 118 mandates that "for areas within the continental United States, all new flood maps and updates must be referenced to NAVD88". To assist with this goal, this document provides guidance that supports the vertical datum conversion standards, including scenario-based guidance to assist with the conversions.

When coordinating with communities during the Discovery process, FEMA staff and mapping partners should explain the national vertical datum conversion goals and benefits to community officials. If a community opposes conversion to NAVD88, FEMA staff should coordinate with NGS State Geodetic Advisor and leverage their expertise and influence to engage the community regarding the benefits of NAVD88 and the limitations of NGVD29. The NGS State Geodetic Advisors can be found at http://www.ngs.noaa.gov/ADVISORS/AdvisorsIndex.shtml.

4.0 Vertical Datum Conversion Process Overview

The process of executing a conversion of otherwise unrevised flood elevations that are currently referenced to NGVD29 should normally begin during the post-Discovery process in consideration of the decisions that a datum conversion may have on the project scope and project setup. More information on this is available in other FEMA guidance focused on Discovery and project setup.

Per Standard 118, all new flood maps must be referenced to NAVD88. If the Flood Risk Project is updating an existing FIRM that is referenced to NGVD29, any unrevised flood elevations within the project footprint will need to be converted to NAVD88.

Additionally, to eliminate possible confusion and misuse of flood elevation information, all published flood elevations within a given community must be referenced to the same datum per Standard 120. This may result in occasional situations whereby a countywide FIS and FIRM will contain some communities referenced to NGVD29 and some that will be referenced to NAVD88. Because having multiple vertical datums on the same maps or in the same FIS can be confusing to end users, it is generally desirable to minimize this situation. However, when revisions only affect some communities within an existing countywide FIS and FIRM, this option may be preferable to converting many other unrevised products to NAVD88.

As stated in Standard 121, the vertical datum conversion shall be applied to flood elevations reported on the FIRM, Flood Profiles shown in the FIS Report, and all data tables in the FIS Report that document flood elevations. The primary guiding principle in executing vertical datum conversions for unrevised flood elevations is to ensure that no more than a 0.25 foot variance from the average conversion factor exists at any point.

While it is desirable to execute a single conversion factor for an entire county, sometimes it is not possible due to variations in the difference between the two vertical datums in that particular geographic location. The first step in a typical datum conversion is to perform calculations to see if a single countywide vertical datum conversion factor can be applied to all unrevised flooding sources. If a countywide conversion is not possible, then it is generally desirable to define a small number of stream groupings for the project where the maximum variance is maintained with each grouping. In

the most challenging situations, some individual streams or portions of individual streams must have a separate conversion factor calculated to keep below the maximum variance.

Table 1 provides a high level summary of the different vertical datum conversion options. Additional details about each option and its associated process details are provided in Section 5 of this document.

Table 1: Vertical Datum Conversion Options

Option	Name	Description
1	**Passive Conversion**	This option is used when the difference between NGVD29 and NAVD88 is negligible. When this option is used, there are no changes made to flood elevations on the FIRM or in the FIS Report. See Section 5.1 of this guidance for more information.
2	**Countywide Conversion**	This option may be used when an average conversion factor for the entire county (computed using standardized techniques) falls within arithmetic tolerances. See Section 5.1.1 of this guidance for more information.
3	**Stream - Based Conversion**	This option is used when Options 1 and 2 are not possible or when Option 2 is not appropriate due to potential mismatches that could occur in adjacent counties. When this option is used, individual streams or stream segments may be grouped to carry one common conversion factor, or individual streams and/or stream segments may each carry their own conversion factors. See Section 5.1.2 of this guidance for more information.

The process of executing a vertical datum conversion for unrevised flood elevations involves answering questions in an iterative fashion to make a datum conversion decision as shown in Figure 1.

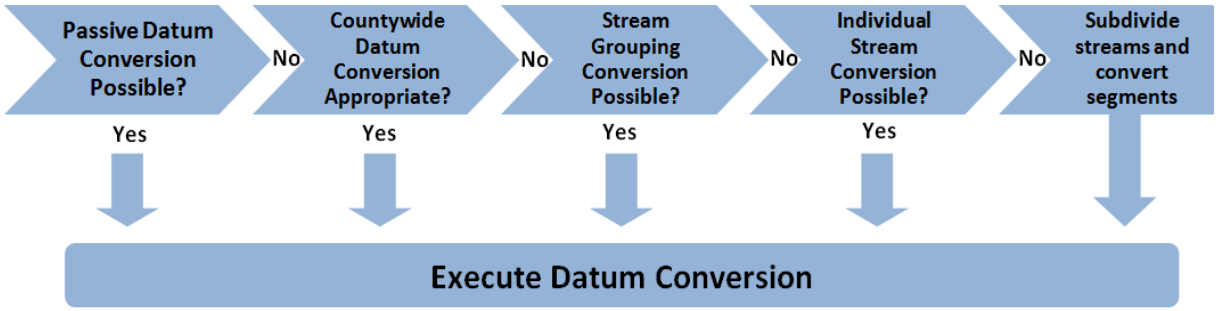

Figure 1: Iterative Vertical Datum Conversion Decisions

Looking at the datum conversion decision process a little closer provides more insight as demonstrated by Figure 2. These decisions will be based on a variety of criteria, ranging from the geographic layout and extent of the existing FIRM to the variations in datum conversion factors between NGVD29 and NAVD88. Details on the vertical datum conversion process are provided in Section 5 of this document.

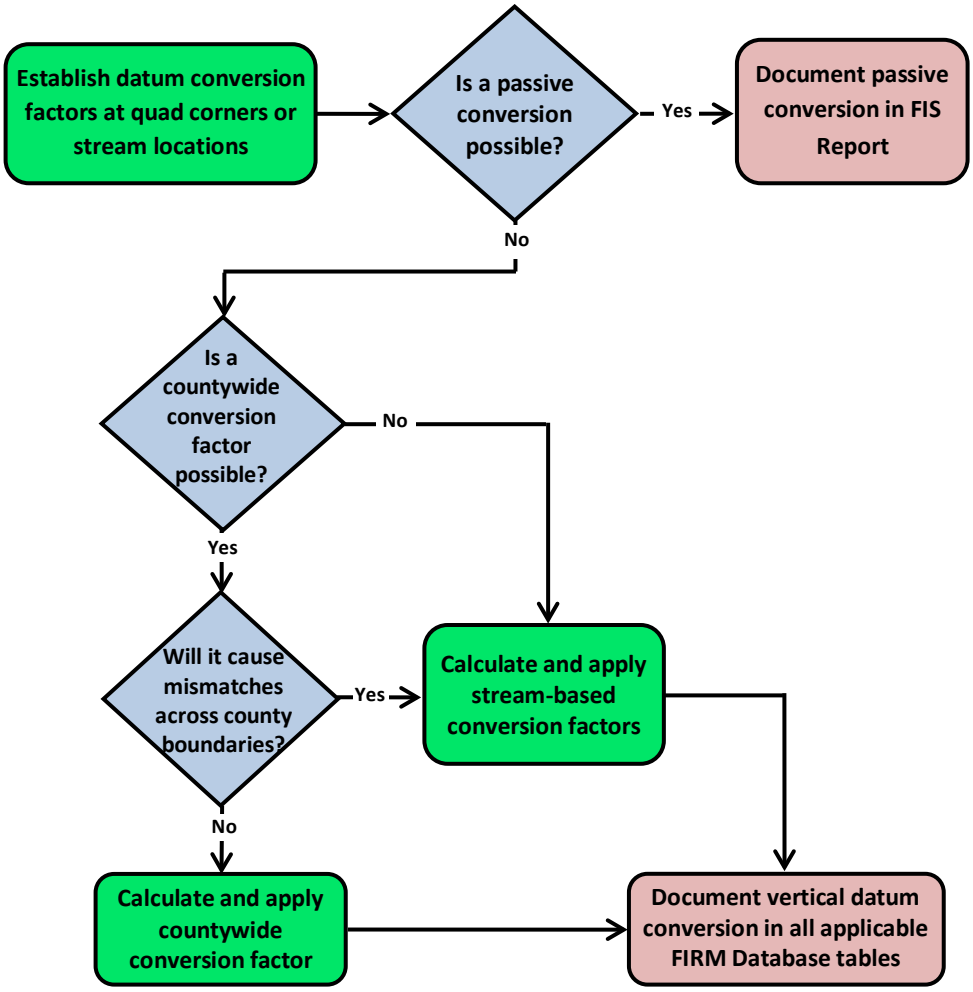

Figure 2: Detailed Vertical Datum Conversion Decision Process

5.0 Calculation and Application of Vertical Datum Conversion Factors

To enable a consistent and objective conversion of unrevised NGVD29 flood elevations to NAVD88, there are 3 options available as outlined in Table 1 above and as detailed in Section 5 below. Before the proper option may be selected, the average vertical datum conversion factor and individual variations from the average must be determined for the area of interest.

It is important that users of this guidance document understand that "area of interest" may be an entire county, a group of streams within the county (e.g. a sub-watershed), a stream, or even a stream segment. It is also important to understand that the area of interest normally starts at a large scale, such as an entire county FIRM, and may progressively become narrower in focus as a decision is reached regarding the appropriate datum conversion protocol to apply. Accordingly, the process described below begins with an analysis of quad corner conversion values to determine if a passive or countywide conversion is possible (within allowable arithmetic constraints) and may then progress into

a more detailed analysis of conversions for grouped streams, conversions for individual streams, or conversions for stream-segments.

Whenever possible, a countywide datum conversion factor is preferred, even if only a portion of the county contains elevations that need a datum conversion or only some communities within the county are being updated. The first step is to use VERTCON or CORPSCON to determine the conversion factor at each land-based quad corner within the county. As shown in Figure 3, where quad corners outside the county (represented by a circle containing an "**x**") are not used, using only quad corners that fall within the county could skew the calculation. In this case, additional quad corners falling within 2.5 miles of the county may be used on a discretionary basis to calculate the datum conversion factor provided that all land-based quad corners within the county are included as demonstrated in Figure 4.

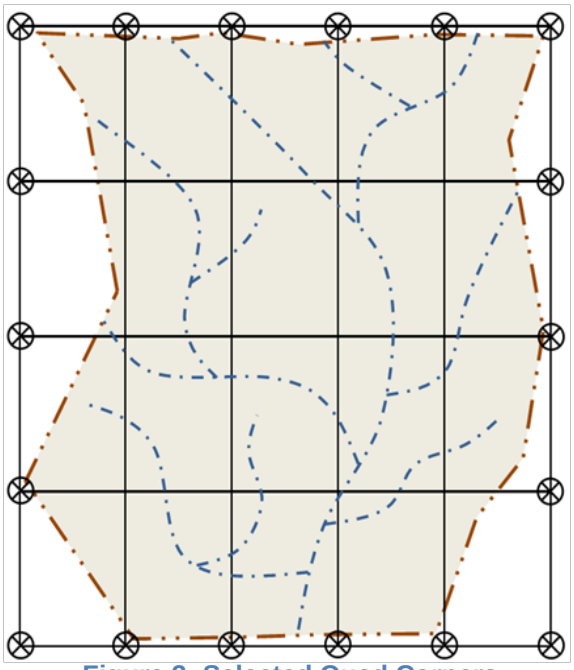

Figure 3: Selected Quad Corners (Inside county only)

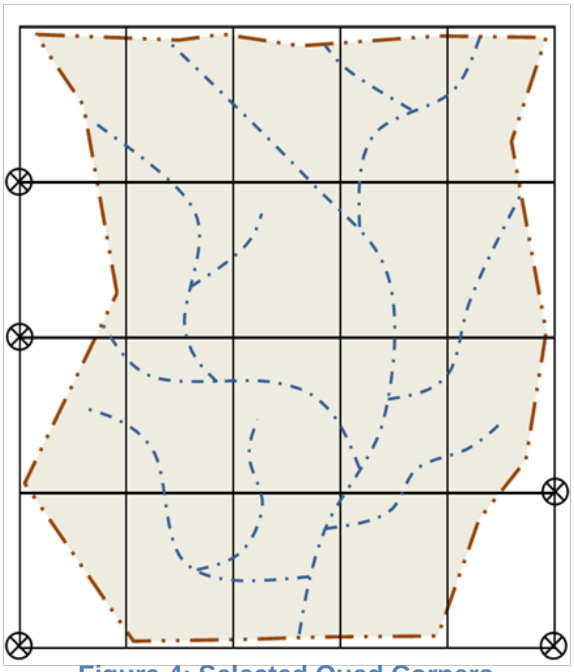

Figure 4: Selected Quad Corners (With discretionary additions)

Once conversion factors for all eligible quadrangle corners have been established, an average conversion factor should be determined by calculating a simple, unweighted arithmetic mean of all selected quad corners (or all selected stream locations if a quadrangle-based conversion is not appropriate).

After this is done a range of conversion factors from all selected points (minimum and maximum offsets from the average calculated above) should be established for the county from the values calculated at quad corners. This information will then be used to determine the maximum offset for the county with an understanding that the maximum offset from the average may not exceed 0.25 foot for any of the selected quadrangle corners if a countywide conversion factor is to be used.

5.1 Passive Conversion (Option 1)

Per Standard ID 119, if the average countywide conversion value is less than +/- 0.1 foot, Option 1 may be used and the datum conversion shall be considered to be executed passively. In those cases, the flood elevations on the FIRM, Flood Profiles, and in the FIS Report tables shall not be

adjusted and the passive conversion must be documented in the FIS report and should be documented in the metadata file.

An average conversion of 0.1 foot or less could be deceiving in areas that contain conversions to NAVD88 that show large plus and minus variances. To illustrate this point, Table 2 shows a hypothetical datum conversion analysis where the average conversion to NAVD88 was calculated as -0.09 foot. However, Table 2 also reveals that the there was at least one quadrangle corner that did not pass the arithmetic delta analysis thereby rendering a passive-conversion inappropriate.

Table 2: Conversion Values for Hypothetical Flood Risk Project Area

Vertical Datum Conversion Data	VDC Values
Range of conversion values	- 0.38 through + 0.24
Average conversion factor	- 0.09
Maximum offset from the average conversion value	**+ 0.33**

5.2 Countywide Conversion (Option 2)

If it is determined that a passive conversion is not possible a single countywide vertical datum conversion factor may be applied if the maximum offset from the average conversion factor does not exceed 0.25 foot. As stated in Standard 123, a full FIRM conversion using a single countywide conversion factor derived from the average of selected quadrangle corners is only allowed when the maximum offset from the calculated average does not exceed 0.25 foot. This datum conversion option is normally only possible in areas of minor variations and for areas of smaller geographic extent. The countywide conversion factor will be used to adjust flood elevations on the FIRM, Flood Profiles and FIS Report data tables and will be addressed in the FIRM database per the *FIRM Database Technical Reference*. The conversion factor shall then be documented in the FIS report per the *FIS Report Technical Reference* and should be documented in the metadata file.

Once the countywide conversion option is determined to be appropriate, the FIRM Database S_Datum_Conv_Pt table will be populated with the datum conversion factor and all unrevised flood elevations on the FIRM and in the FIS and the FIRM Database will be adjusted and documented accordingly. When Option 2 is selected, a table shall be added to the FIS report that provides the quadrangle corner conversion data used for the datum conversion calculation. That table is shown as "Table 20" in the *FIS Report Technical Reference*.

If a countywide conversion factor is not possible, the Mapping Partner must either convert the flooding sources by grouping them and sharing a conversion factor; by calculating a conversion factor for individual flooding sources; or by stream segments as detailed in Section 5.2 below.

5.3 Stream-Based Conversion (Option 3)

When a countywide conversion (Option 2) is not possible due to at least one quadrangle corner having an offset of more than 0.25 foot from the calculated average, a stream-based datum conversion will need to be processed. To accomplish this, each stream or stream segment being converted should have at least three points selected; one at the downstream end; one at the midway point; and one at the upstream end as shown in Figure 5, where the datum conversion points are represented by black circles with yellow shading. The conversion points for each stream will then be

used as a dataset to make decisions regarding the appropriate groupings of streams or stream segments or conversion of individual streams or stream segments. The final result will then be represented in the S_Datum_Conv_Pt table in the FIRM database.

When Option 3 is used, a table shall be added to the FIS report that provides the stream conversion data represented as stream groupings, individual streams, and/or stream segments. That table is shown as "Table 21" in the *FIS Report Technical Reference*.

For Option 3, the calculation of an average conversion value for a grouping of streams, or stream segments, should use all points for the selected group to calculate the average and should not double count points at stream confluences. If all points in the selected group have less than a 0.25 foot offset from the average of those points, then those streams may be grouped to carry one vertical datum conversion factor.

Figure 5 shows a hypothetical county where two streams in the southwest corner of the county (shown in red and symbolized with a dotted line as opposed to blue with dashed lines) are being revised with the remainder of the streams being converted to NAVD88. Decisions on stream groupings for Option 3 will be based on an analysis of the datum conversion values at each data point (indicated as black circles with yellow fill).

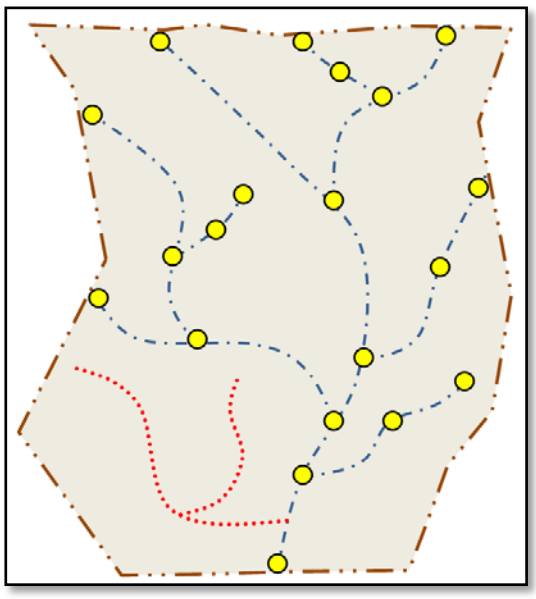

Figure 5: Stream-Based Datum Conversions

A key point is that larger streams may need to be subdivided into two or more different groupings of stream segments. For example, if a county is divided into a north and south half, any streams that crossed between the north and the south may be broken into stream segments with a segment included in each of the two conversion groups. Any group might consist of complete streams and stream segments.

If, however, streams cannot be grouped, they may each carry their own datum conversion factor, and in extreme cases, individual streams may need to be subdivided and converted as individual segments in order to pass the arithmetic conversion parameters.

5.4 Execution of the Selected Conversion Method

The Mapping Partner will need to enter the results of the final datum conversion values into the S_Datum_Conv_Pt table of the FIRM database and in datum conversion tables in the FIS report that are shown in the *FIS Report Technical Reference*. The unrevised flood elevations on the FIRM, FIRM Database, Flood Profiles, Floodway Data tables, and any other tabular listing in the FIS report of 1% annual chance flood elevations should reflect the converted elevations information.

6.0 Other Considerations and Scenarios

This section provides guidance for other situations such as coastal, lacustrine and community-based vertical datum conversions, as well as guidance for ensuring that differences in datum conversion values for individual flooding sources across county boundaries are not occurring

6.1 Coastal Datum Conversion and Zone Boundary Considerations

In consideration of how the coastal floodplain boundaries (gutters) separating elevation zones are mapped, the results of the datum conversion analysis may require re-plotting those boundaries if the conversion factor isn't close to a whole foot value (e.g., 0.95 – 1.05). If the conversion factor was -1.54 for example, it would create the potential for more than a half foot delta between the NAVD88 value and the original NGVD29 value at any given location due to the fact that the Wave Height Analysis for Flood Insurance Studies (WHAFIS) model calculates the gutter at the half-foot value.

If needed, it is recommended that the FEMA Project Monitor be consulted to determine which of the following options (or others if warranted) should be applied:

- Remap the gutters based on where the half-foot location now falls
- Show one decimal for all coastal flood elevations
- Leave the gutters as-is and convert the coastal flood elevations only in FIS tables and in the appropriate tables of the FIRM Database as noted in the *FIRM Database Technical Reference*.

Note also that there are no prescribed protocols for spacing or selection of coastal datum conversion points when it is determined that the quad corner method does not yield compliant results. It is recommended that points be distributed at regular intervals between the shoreline and the spatial extent of the landward floodplains. These intervals should not be at a greater distance than would be realized if quad corners were used, which is roughly 10 miles in distance in consideration of an average U.S. Geological Survey quad being approximately 8 miles wide x 10 miles high.

6.2 Conversion of Lacustrine, Ponding, and other Static Flood Elevations

If a countywide conversion factor is not possible, each area of lacustrine and ponding will need to be calculated either in groups similar to the grouping of streams, or on a flooding source by flooding source basis. The process of establishing conversion values for individual lakes and ponding areas with relatively static elevations is similar to the stream-by-stream approach. The only difference is in the distribution of points to be used to calculate the average conversion. For larger water bodies such as lakes, it would be prudent to select a minimum of 3 points, with additional points added for very large water bodies (those that are more than 10 miles across for example). If analysis of the selected points indicates that a single datum conversion value is not feasible due to an excessive offset from the average, then the FEMA Project Monitor be consulted to determine the best course if this situation arises. Regardless of the methodology chosen, conversion points and factors must be documented in S_Datum_Conv_Pt in the FIRM database, in the FIS report datum conversion tables shown in the *FIS Report Technical Reference*, and should be documented in the metadata file.

6.3 Avoiding Vertical Datum Differences Across County Boundaries

There may be cases where a countywide datum conversion is arithmetically possible, but not appropriate, due to the introduction of mismatches across county boundaries for flooding sources shared by adjacent counties. In those cases, it may be more appropriate to convert the vertical datum using Option 3 (Stream-Based) to avoid differences in datum conversion values across county boundaries.

6.4 Partially Converting a Countywide FIRM to NAVD88

In some cases, when only some communities shown on an existing FIRM are being revised, the communities where map panels are being revised must be converted to NAVD88, but communities that are not being revised, are not required to have the elevations converted. In these cases, it is important to label the maps and elevations clearly to minimize confusion for map users. It is also important to document the vertical datum used for each community within the FIRM Database and to document the use of two vertical datums within the metadata file.

Additionally, care should be exercised to ensure that unrevised streams forming community boundaries or that cross from a community in NGVD29 to a community in NAVD88 be properly converted and clearly represented on the Flood Profiles and in the data tables within the FIS report.

As new best practices become available for situations where the vertical datum is converted for select communities within an existing countywide FIRM, additional guidance will be posted to the FEMA Knowledge Sharing Site.

7.0 Other Information

The following sections provide information associated with coordination and planning FIS; FIRM, and FIRM database requirements; vertical datum conversion documentation; and a Vertical Datum Conversion Tool option.

7.1 General Coordination Considerations

Discussions on the conversion of unrevised flood elevations to NAVD88 should begin during the Discovery Phase of the Flood Risk Project. Decisions made at this point may have an impact on how the subsequent Project Setup is conducted and how information associated with the datum conversion is presented at the Discovery and Flood Risk Review Meetings. Additional guidance on this topic is available in other guidance.

7.2 FIS, FIRM, and FIRM Database Requirements

- The *FIS Report Technical Reference* provides information on how the FIS should address the vertical datum conversion and associated documentation.
- The *FIRM Panel Technical Reference* provides information on the vertical datum as it relates to the FIRM panel marginalia.
- Instructions and requirements associated with population of the S_Datum_Conv_Pt table of the FIRM database are provided in the *FIRM Database Technical Reference*.

All Technical References may be viewed and/or downloaded at http://www.fema.gov/media-library/assets/documents/34519

7.3 Documentation Requirements

When a datum conversion is conducted on unrevised flood elevations, the Mapping Partner responsible for preparing the Technical Support Data Notebook (TSDN) shall ensure that all unrevised hydraulic models and supporting backup information are clearly labeled to indicate that the FIRM and FIS report reflect a datum conversion. In addition, the Mapping Partner converting the

elevations to the new vertical datum shall document the process used to determine the applied conversion factor. Additionally, the TSDN shall clearly document the datum conversion factor applied to the Flood Risk Project, whether it is at a full jurisdiction level, at a granular stream-segment by stream-segment level, or somewhere in between. Users must be able to determine the specific datum conversion factor applicable to any location within the conversion area.