Guidance for Flood Risk Analysis and Mapping

Vertical Datum Conversion

November 2023

FEMA

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Requirements for the FEMA Risk Mapping, Assessment, and Planning (Risk MAP) Program are specified separately by statute, regulation, or FEMA policy (primarily the Standards for Flood Risk Analysis and Mapping). This document provides guidance to support the requirements and recommends approaches for effective and efficient implementation. Alternate approaches that comply with all requirements are acceptable.

For more information, please visit the FEMA Guidelines and Standards for Flood Risk Analysis and Mapping webpage (https://www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping). Copies of the Standards for Flood Risk Analysis and Mapping policy, related guidance, technical references, and other information about the guidelines and standards development process are all available here. You can also search directly by document title at https://www.fema.gov/resource-document-library.

Table of Revisions

The following summary of changes details revisions to this document subsequent to its most recent version in May 2014.

Affected Section or Subsection	Date	Description
2	Nov. 2023	Updated to reference the National Geodetic Survey (NGS) Coordinate Conversion and Transformation Tool (NCAT), which supersedes the legacy Vertical Datum Conversion Program (VERTCON).
All	Nov. 2023	Various minor updates to correct outdated references and ensure consistent terminology as used by NGS.

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1. Overview

This guidance document supports the nine vertical datum standards adopted by FEMA for vertical datum conversions from the National Geodetic Vertical Datum of 1929 (NGVD 29) to the North American Vertical Datum of 1988 (NAVD 88). It 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 NGVD 29 to NAVD 88:

- General information about the two vertical datums most commonly used by FEMA for referencing 1-percent-annual-chance flood elevation information in Flood Insurance Rate Map (FIRM) databases, on FIRMs, and in Flood Insurance Studies (FISs).
- Information on publicly available software for converting from NGVD 29 to NAVD 88.
- Guidance on the analysis of vertical datum conversion options.
- Guidance on the process of converting unrevised flood elevations to NAVD 88.
- 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. NGVD 29 was the vertical datum used in most FISs and FIRMs until the mid-1990s. After that time, NAVD 88 became the vertical datum of choice for FIS/FIRM production. Because existing flooding hazard data referenced to NGVD 29 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 NAVD 88. It is FEMA's goal to convert all flood maps in the conterminous United States from NGVD 29 to NAVD 88 for the following reasons:

- NAVD 88 is more compatible with modern surveying and mapping technologies, like Global Positioning Systems (GPS) and Light Detection and Ranging (lidar) data and is more accurate than NGVD 29.
- The old datum, NGVD 29, 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 NGVD 29. This will make it difficult for professional surveyors to certify elevations referencing NGVD 29.
- Previously published NGVD 29 heights on NGS benchmarks will not be updated or maintained and become less reliable as they age.

- As reference marks are disturbed or destroyed, fewer NGVD 29 reference points will be available.

1.1. National Geodetic Vertical Datum of 1929

Historically, the most common vertical datum used by FEMA has been NGVD 29. NGVD 29 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 NGVD 29 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. NGVD 29 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 NGVD 29 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 its 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, NAVD 88, was completed in June 1991. It is now the only official vertical datum in the United States. NAVD 88 was created by adding 625,000 kilometers of leveling, performed after NGVD 29 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 benchmark at Father Point/Rimouski in Quebec, Canada, was held fixed as the constraint, enabling NAVD 88 and the International Great Lakes Datum of 1985 to be one and the same.

Now, other tide stations may have elevations other than zero. Since the establishment of NAVD 88, the preference has been for new flood hazard studies to be referenced to NAVD 88.

1.3. Other Vertical Datums

There are some limitations to NAVD 88 outside of the conterminous United States. NAVD 88 benchmarks are limited in Alaska. Many islands do not have any NAVD 88 benchmarks, have limited access to NAVD 88, 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. They will need to make project-specific decisions about the datum in which to publish the maps, and how to complete any necessary conversions between datums. Similarly, in a few cases within the conterminous United States, older maps may be referenced to a different local datum than NGVD 29. In these cases, the standard vertical datum conversion software discussed below is not applicable. However, users can still apply the general principles for defining areas and for applying a uniform conversion factor by testing a sampling of points and limiting maximum variation from the average conversion factor to 0.25 ft.

2. Vertical Datum Conversion Software

The NGS Coordinate Conversion and Transformation Tool (NCAT) may be used for conversions between NGVD 29 and NAVD 88. Mapping Partners may use the web-based tool or download the NCAT software (free of charge) at https://www.ngs.noaa.gov/NCAT/. NCAT, which supersedes the legacy Vertical Datum Conversion Program (VERTCON), incorporates the capabilities of several other NGS computer programs.

NCAT includes options for converting single or multiple points. Below are the basic steps and inputs for computing the modeled difference in orthometric heights (elevations) between NGVD 29 and NAVD 88 for a given location using latitude and longitude coordinates:

1. **Convert/transform from:** Horizontal+height
2. **Select the type of horizontal coordinate:** Geodetic lat-long
3. **Select a height:** Orthometric
4. **Latitude/longitude:** Enter values or move the location of the pin on the map
5. **Input/output reference frame (horizontal datum):** NAD83(2011)
6. **Orthometric height:** 0.000
7. **Units of height:** International Feet
8. **Input geopotential datum (vertical datum):** NGVD29
9. **Output geopotential datum (vertical datum):** NAVD88
10. **SPC zone:** Auto Pick (default zone)
11. Click “Submit” and review the “Transformed Coordinate” section to confirm input and output coordinate attributes. The “Orthometric Height” field in the “Total Change + Uncertainty” column corresponds to the datum adjustment from NGVD 29 to NAVD 88.

3. Vertical Datum Conversion Considerations

As stated earlier, one goal of FEMA’s Risk Mapping, Assessment, and Planning (Risk MAP) program is to convert all flood maps from NGVD 29 to NAVD 88. Accordingly, FEMA Standard Identification Number (SID) 118 mandates that for areas within the continental United States, all new flood maps and updates must be referenced to NAVD 88. To support this goal, this document provides guidance related to 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 NAVD 88, FEMA staff should coordinate with the NGS Regional Geodetic Advisor and leverage their expertise and influence to engage the community regarding the benefits of NAVD 88 and the limitations of NGVD 29. Find contact information for the NGS Regional Geodetic Advisors at https://geodesy.noaa.gov/ADVISORS/.

4. Vertical Datum Conversion Process Overview

The process of converting otherwise unrevised flood elevations that are currently referenced to NGVD 29 should normally begin during the post-Discovery process. This is because of a datum conversion's potential effects on the project scope and project setup. More information on this is available in the FEMA guidance focused on Discovery and project setup.

Per SID 118, all new flood maps must be referenced to NAVD 88. If the Flood Risk Project is updating an existing FIRM that is referenced to NGVD 29, any unrevised flood elevations within the project footprint will need to be converted to NAVD 88.

Per SID 120, 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. This may result in occasional situations in which a countywide FIS and FIRM will contain some communities referenced to NGVD 29 and some referenced to NAVD 88. Having multiple vertical datums on the same maps or in the same FIS can be confusing to end users, so it is generally desirable to minimize this situation. However, when revisions only affect some communities that share an existing countywide FIS and FIRM, this option may be preferable to converting many other unrevised products to NAVD 88.

As SID 121 states, the vertical datum conversion must be applied to flood elevations reported on the FIRM, in the Flood Profiles of the FIS Report, and in 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 use a single conversion factor for an entire county, it is not always possible. There may be variations in the difference between the two vertical datums in that 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, it is generally desirable to define a small number of stream groupings for the project and maintain the maximum variance in each grouping. In the most challenging situations, some individual streams or portions of an individual stream 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. Section 5 of this document provides additional details about each option and its associated process.

Table 1: Vertical Datum Conversion Options

Option	Name	Description
1	Passive Conversion	This option is used when the difference between NGVD 29 and NAVD 88 is negligible. When this option is used, no changes are made to flood elevations on the FIRM or in the FIS Report. See Section 5.1 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 5.2 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 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 5.3 for more information.

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.

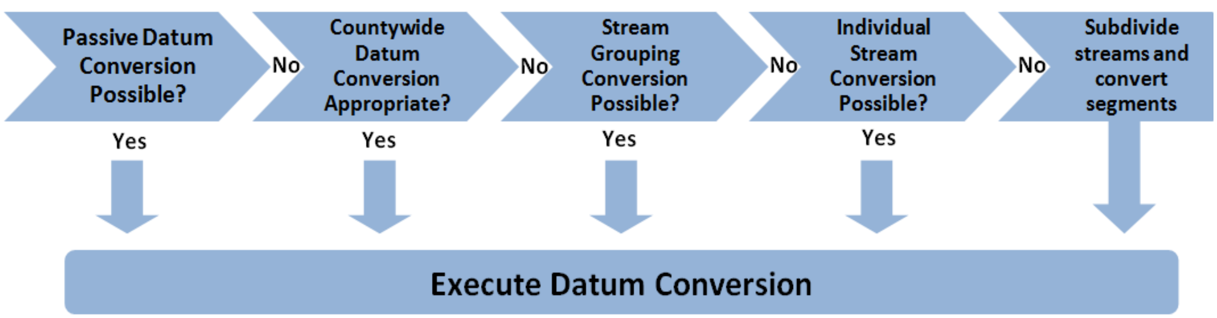

Figure 1: Iterative Vertical Datum Conversion Decisions

Looking at the datum conversion decision process a little more closely 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 NGVD 29 and NAVD 88. Details on the vertical datum conversion process are provided in Section 5 of this document.

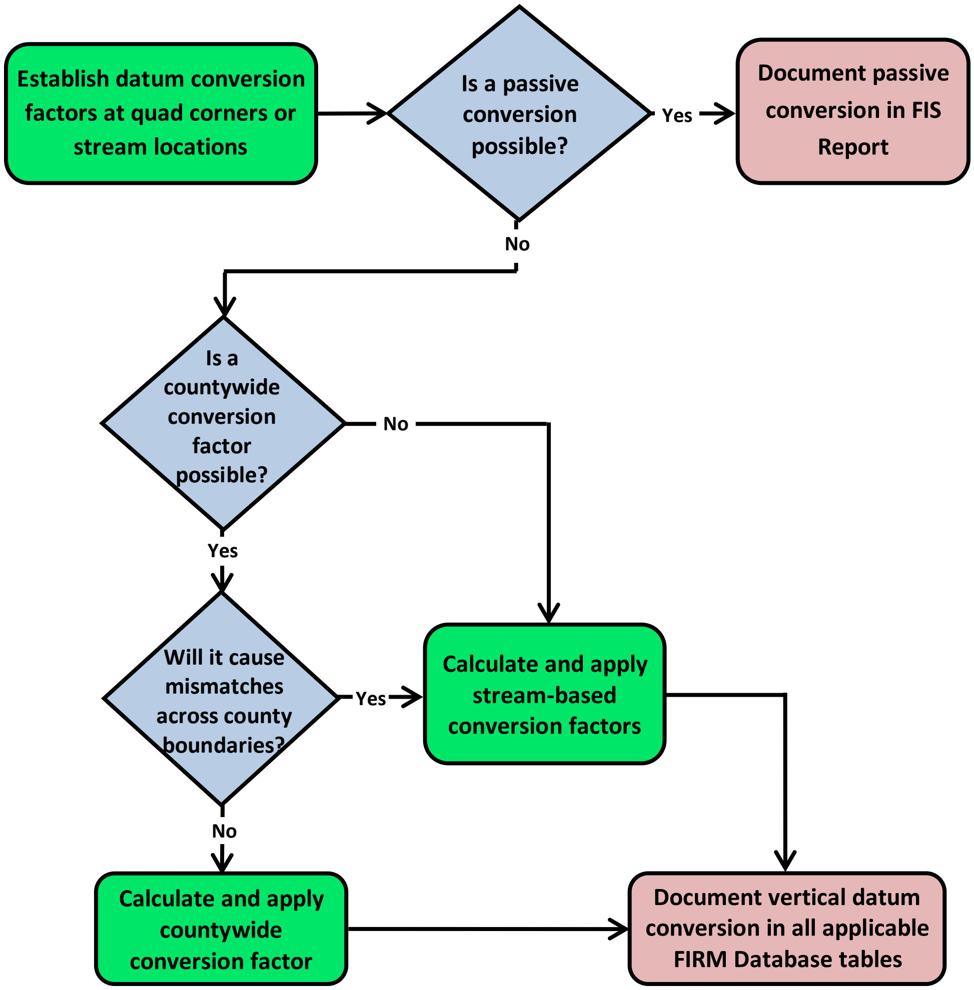

Figure 2: Detailed Vertical Datum Conversion Decision Process

5. Calculation and Application of Vertical Datum Conversion Factors

To enable a consistent and objective conversion of unrevised NGVD 29 flood elevations to NAVD 88, three options are available. These are outlined in Table 1 and detailed below. Before selecting the proper option, determine the average vertical datum conversion factor and individual variations from the average for the area of interest.

It is important that users of this guidance document understand that an “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 the FIRM for an entire county, and may progressively become narrower in focus as decisions are reached regarding the appropriate datum conversion protocol to apply. Accordingly, the process described below begins with an analysis of quad corner conversion values. This will determine if a passive or countywide conversion is possible (within allowable arithmetic constraints). This may be followed by a more detailed analysis of conversions for grouped streams, for individual streams, or 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 NCAT to determine the conversion factor at each land-based quad corner within the county. As shown in Figure 4, 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 3.

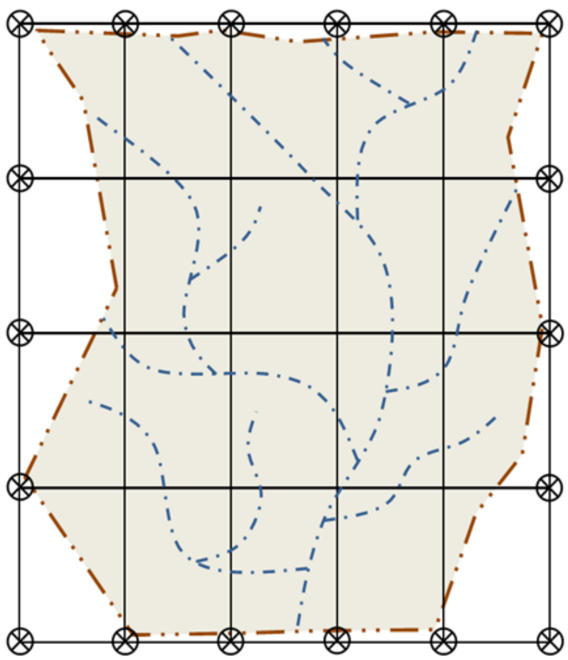

Figure 4: Selected Quad Corners (Inside county only)

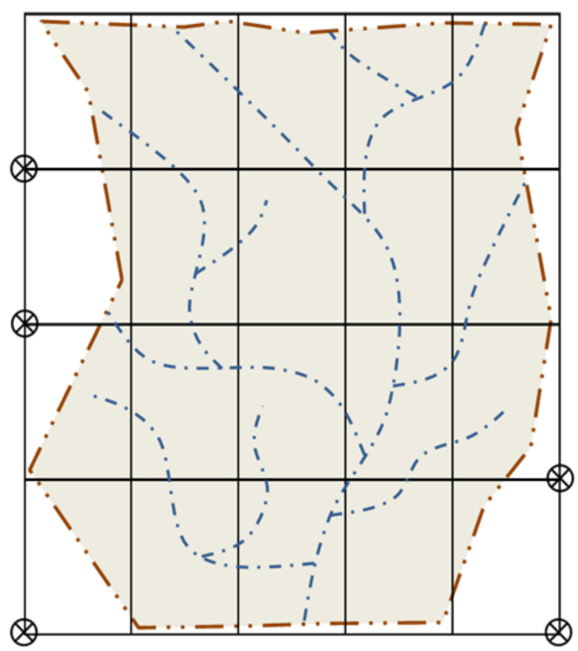

Figure 3: Selected Quad Corners (With discretionary additions)

Once conversion factors for all eligible quadrangle corners have been established, determine an average conversion factor 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, establish a range of conversion factors from all selected points (minimum and maximum offsets from the average calculated above) for the county from the values calculated at quad corners. This information will 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 SID 119, if the average countywide conversion value is less than +/- 0.1 foot, Option 1 may be used, and the datum conversion is considered to be executed passively. In those cases, the flood elevations on the FIRM and in the Flood Profiles and the FIS Report tables may not be adjusted. 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 NAVD 88 that show large plus and minus variances. To illustrate this point, Table 2 shows a hypothetical datum conversion analysis where the average conversion to NAVD 88 was calculated as -0.09 foot. Table 2 also reveals that at least one quadrangle corner 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 SID 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 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 will 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. All unrevised flood elevations on the FIRM and in the FIS Report and the FIRM Database will be adjusted and documented accordingly. When Option 2 is selected, add a table to the FIS Report that provides the quadrangle corner conversion data used for the datum conversion calculation. An example of that table is shown as Table 19 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, or calculate a conversion factor for individual flooding sources or for stream segments, as detailed in Section 5.3.

5.3. Stream-Based Conversion (Option 3)

When a countywide conversion (Option 2) is not possible because at least one quadrangle corner has an offset of more than 0.25 foot from the calculated average, a stream-based datum conversion is needed. To do this, select at least three points for each stream or stream segment being converted--one at the downstream end, one at the midway point, and one at the upstream end. In Figure 5, the datum conversion points are represented by black circles with yellow shading. The conversion points for each stream are used as a dataset to make decisions regarding the appropriate groupings of streams or stream segments or the conversion of individual streams or stream segments. The final result will be represented in the S_Datum_Conv_Pt table in the FIRM database.

When Option 3 is used, add a table 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 20 in the FIS Report Technical Reference.

For Option 3, the calculation of an average conversion value for a grouping of streams or stream segments, use all points for the selected group to calculate the average, and do 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, 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. The remainder of the streams are being converted to NAVD 88. 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).

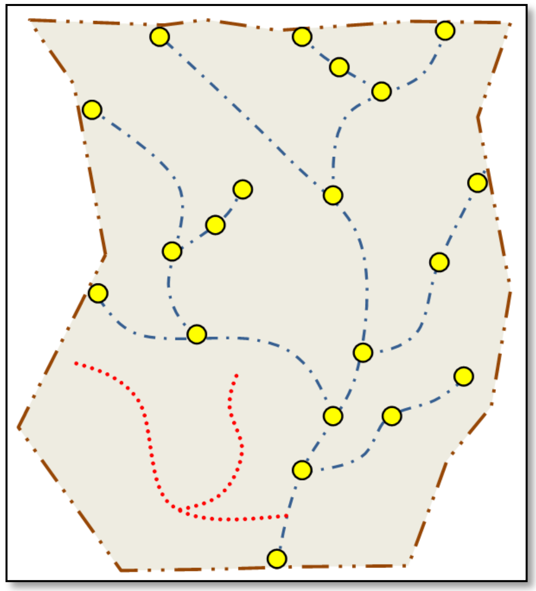

Figure 5: Stream-Based Datum Conversions

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 half and a south half, any streams that cross between the north and the south may be broken into stream segments. Include one segment in each of the two conversion groups. Any group might consist of both complete streams and stream segments.

If streams cannot be grouped, they may each carry their own datum conversion factor. In extreme cases, individual streams may need to be subdivided and converted to individual segments 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 into the S_Datum_Conv_Pt table of the FIRM database and in the datum conversion tables in the FIS Report (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-percent-annual-chance flood elevations should reflect the converted elevation information.

6. 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 do not occur.

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 is 1.54, for example, it would create the potential for more than a half-foot delta between the NAVD 88 value and the original NGVD 29 value at any given location. This is because the Wave Height Analysis for Flood Insurance Studies (WHAFIS) model calculates the gutter at the half-foot value.

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

- 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 the FIS tables and in the appropriate tables of the FIRM Database, as noted in the FIRM Database Technical Reference.

There are no prescribed protocols for spacing or the 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 result 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 and 10 miles high.

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

If a countywide conversion factor is not possible, each lacustrine and ponding area will need to be calculated, either in groups similar to the grouping of streams, or on the basis of each flooding source. 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 three points, with additional points added for very large water bodies (those 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, consult the FEMA Project Monitor to determine the best course of action. Regardless of the methodology chosen, document the conversion points and factors in S_Datum_Conv_Pt in the

FIRM database, in the FIS Report datum conversion tables shown in the FIS Report Technical Reference. They should also 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).

6.4. Partially Converting a Countywide FIRM to NAVD 88

In some cases, when not all of the communities shown on an existing FIRM are being revised, the communities where map panels are being revised must be converted to NAVD 88, 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 NGVD 29 to a community in NAVD 88 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 this type of situation, additional guidance will be posted to the FEMA Knowledge Sharing Site.

7. Other Information

The following sections provide information associated with the coordination and planning of FIS, FIRM, and FIRM database requirements, and the documentation of a vertical datum conversion.

7.1. General Coordination Considerations

Discussions on the conversion of unrevised flood elevations to NAVD 88 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. Details on this topic are available in other guidance.

7.2. FIS, FIRM, and FIRM Database Requirements

All Technical References may be viewed and/or downloaded at the link provided at the beginning of this document.

- 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 populating the S_Datum_Conv_Pt table of the FIRM database are provided in the FIRM Database Technical Reference.

7.3. Documentation Requirements

When the datum is converted for unrevised flood elevations, the Mapping Partner responsible for preparing the Technical Support Data Notebook (TSDN) must 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 must document the process used to determine the applied conversion factor. The TSDN must 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 that applies to any location within the conversion area.