# Elevation-Derived Hydrography Data Acquisition Specifications 2024 Revision A3

## Tables

# Revision History

## Version 2024 revision A3

- Added “GTRasterTypeGeoKey shall be RasterPixelIsArea” to Raster Product Characteristics.
- Updated **Figure 24** (Topologic relationships between elevation-derived hydrographic features) example 7 for clarity.
- Corrected Connector Capture Conditions information in Appendix 1. Representation, Extraction, Attribution, and Delineation Rules to maintain connectivity between any network features.
- Corrected Appendix 1. Representation, Extraction, Attribution, and Delineation Rules for Sink Attribute Information to remove Rise information.
- Added disclaimer to Appendix 2. Hydrologically Conditioned and Enforced DEM.
- Corrected Appendix 2. Hydrologically Conditioned and Enforced DEM by removing requirement to end all isolated networks with a Sink feature.

## Version 2024 revision A2

- User-Defined Features with FCode=0 in **Table 11** corrected so FClass=9.

## Version 2024 revision A

- Updated horizontal and vertical Coordinate Reference System (CRS)s for different regions.
- Ice Mass feature type (FCode: 37800) removed.
- Dam feature type (FCode: 34300) removed.
- Updated Sea/ocean island size criteria.
- Added Final Deliverable Project Area (FDPA) requirement to be submitted a single polygon or multipart polygon.
- Added User-defined feature attribute information to **Table 8**, **Table 11**, and Additional User-defined Features section.
- Added valid field combination to Connector: Indefinite Surface, FClass=1 and EClass=0 to **Table 11**.
- Added valid field combination to Connector, FClass=1 and EClass=0 to **Table 11**.
- Added a description and definition field to **Table 10**. Domain values for EClass feature attributes. Removed the Feature Attribute column. Clarified several definitions.
- Updated Delivered Products and Formats section, to include requiring spatial metadata and omitted NHD features to be delivered in geopackage format.
- Updated **Table 9**
    - Removed requirement to use EClass=0 from FClass domain values 1 and 9.
    - Made domain value 1 the default value.
- Updated Vertical Alignment section with requirements for overlapping polygons.
- Topology Changes
    - Added line feature valency limit of five features to Topology Rules section.

- Change feature edge matching requirement from exactly to within 0.001 meters.
- Removed outdated Topology Rule that Connector: Culvert features may split other features but must use the same FCode.
- Added Topological Relationships Between Elevation-Derived Hydrographic features section.
- Added requirement to snap inlet and outlet features at FDPA.

- Guideline Integration
    - Added Inclusion or Omission of National Hydrography Dataset (NHD) Waterbody Features version 2 guideline contents to Special Cases.
    - Added the Connector through Infrastructure Areas version 2 guideline contents to Special Cases.
        - Updated **Table 11** to include the associated Connector feature type EClass=0 and FClass=2 combination.
        - Clarified Connector feature type definition to accommodate usage in infrastructure areas.
        - Updated EClass and FClass value combinations to incorporate new FlowClass attribute.
        - Added subsurface stormwater system considerations.
    - Added the Network Connectivity through Ice Masses version 1 guideline contents to Special Cases.
    - Added the Sea/ocean version 3 guideline contents to the Sea/ocean READ Rules Delineation section.
    - Added Delineation of Features within areas with Digital Elevation Model (DEM) Limitations version 3 guideline contents to the Positional Assessment section.
    - Added Vertical Integration of Linear Features through Depressions version 4 guideline content to the Depression and Terrain Breach sections of Special Cases and Indefinite Surface Connector READ Rules. For Connector: Indefinite Surface features:
        - Added FlowClass value (2) requirement.
        - Changed EClass from 0 to 2. Updated **Table 11**.
    - Added Low Relief Areas to Special Cases from the Guidance for Stream Channel Delineation and Capture Conditions in Alaska guideline.
    - Updated Stream/river and Canal/ditch feature Special Conditions for lidar and IfSAR based collection and simplified thresholds for determining if the feature is captured as a line or polygon feature.
    - Added X, Y, and Z Coordinate Precision version 5 guideline content to the horizontal and vertical alignment sections.
    - Added additional contents from the Stream/river Special Condition- Complex Interlacing Channel version 3 guideline content to the Complex Interlacing Channels Special Case section.
    - Added Elevation Source Spatial Metadata Requirements version 1 guideline content to the Delivered Products and Formats section and tables section.
    - Added the Source Raster and Vector Data Requirements version 2 guideline content to the Coordinate Reference Section and Delivered Products and Formats section.

  - Added the Hydrologically Enforced DEM version 1 and Hydrologically Conditioned DEM version 1 guideline contents to Appendix 2.
  - Added the Waterbodies and Islands guideline contents.
    - Artificial path features around Islands to the Artificial Path READ Rules.
    - Island representation information to the Additional Elevation-Derived Hydrography Treatment and Elevation Specific Features.
    - Updated Lake/pond Capture Conditions and Source Interpolation Guidelines with new size criteria.
  - Added Elevation-Derived Hydrography Lines Crossing Ridges guideline content to Lines Crossing Ridges Special Case.
  - Added and updated Geomorphic Indicator guideline contents to Appendix 3.
  - Added Difference DEM instructions to Appendix 4.
  - Added Raster Spatial Reference Requirements to Appendix 5.
- Special Cases
  - Moved content from Connector: Indefinite Surface; Connector: Non-NHD Dataset; Canals and Ditches; and Drainageway Special Cases to Appendix 1.
  - Renamed Stream/river Special Case Complex Interlacing Channels.
  - Renamed Culvert Special Case to Bridge Locations.
  - Clarifies that a Connector: Culvert feature is not required for a continuous water feature when a bridge is removed in Culvert Special Case.
- READ Rules
  - Canal/ditch
    - Removed outdated Source Interpretation Guidelines from Canal/ditch READ Rules.
    - Change Canal/ditch in agricultural fields exception from User Defined Feature to Canal/ditch FCode with FlowClass=2.
  - Removed transportation size threshold for determining whether to use a Pipeline or Connector: Culvert feature.
  - Clarified that Connector: Culvert feature type must be underneath a transportation feature.
- Administrative changes to document.
  - Added “Data” to the title of this document.
  - Added specification versioning, guideline, and requirements terminology information to the introduction.
  - Removed Collection Concurrent with Elevation section.
  - Removed NHD references from FCode description.
  - Removed 3DEP Lidar Base Specification (LBS) Required Hydroflattening Collection section.
  - Removed reference to NHD specifications and 3DEP LBS from the Positional Assessment section.
  - Removed references to accuracy standards.
  - Change Lake/pond feature definition to include features formally collected as Reservoir features.
  - Removed reservoir information from Lake/pond Source Interpolation Guidelines.
  - Added contents of Elevation-Derived Hydrography Representation, Extraction, Attribution, and Delineation (READ) Rules to Appendix 1.

- Added READ Rule explanations to Appendix 1.
- Changed international boundary source to US Census Bureau data.

### Version 2023 revision A2

- Corrected Indefinite Surface Connector channelized segment length special case to include a length for the contiguous United States and Alaska.

### Version 2023 revision A

- The Low Confidence Area features are removed from the elevation-derived hydrography feature types.
- The reservoir feature type is removed from the elevation-derived hydrography feature types.
- Stream/river special condition added for complex interlacing channels.
- Changed or added additional EClass Domain Codes.
- Updated the Feature Type Description, Associated Geometry, and Use Classification Table with new EClass and FClass combinations as needed. This resulted in changes to some feature attribution information in the Elevation-Derived Hydrography Representation, Extraction, Attribution, and Delineation (READ) Rules 2023 rev. A.
- Added FlowClass field to line feature class attributes.
- Add Limitation field to point, line, and polygon feature class attributes.
- Changed name of Sink/rise feature to sink.
- Removed references to the National Hydrography Dataset (NHD) and replaced with elevation-derived hydrography or 3D Hydrography Program (3DHP) where appropriate.
- Ice Mass, Pipeline, and Non-NHD Connector FClass changed from 1 to 2.
- Removed the Feature type description, associated geometry, and use classification table from the Elevation-Derived Hydrography READ Rules 2023 rev. A. and referred the reader to the Elevation-Derived Hydrography Acquisition Specifications 2023 rev. A.
- Reformatted tables and in some case separated information into new tables for easier understanding.
- Changed geoid model to require GEOID18 specifically, instead of most recent.
- Clarified that Sink features may overlap a Playa feature.

### Version 2022 revision A

- Removal of AOCCs from Elevation-Derived Hydrography Specifications and from Task Orders.

### Version 2021 revision A

- Drainageway Definition Updated
    - Old Definition: A drainageway is a watercourse that conveys or is likely to convey water but lacks a clearly defined channel or banks differentiating it from an ephemeral Stream/river. Drainageways typically convey water for limited

periods of time and do not carry perennial flow. Drainageways may follow natural topographic flow paths or constructed or human-made flow paths.
  - New Definition: Drainageway features are flowlines delineated where terrain modelling indicates potential headwater drainage, but no channel is detectable. The drainageway code must only be applied at the initiation of flowlines or confluence of other drainageway features. The drainageway code must not be applied downstream of other non-drainageway NHD flowlines or waterbody features.

- Four New Elevation-Derived Hydrography Connector FCodes added to Connector Type
  - Culvert (FCode: 33401)—A subsurface feature connecting upstream and downstream hydrography features under a constructed feature (Exception: See READ Rules “Connector” for Dam Features). Typically constructed of formed concrete or corrugated metal and surrounded on all sides; top, and bottom by earth or soil. The hydrographic features defined by this specification are intended to be suitable for elevation surface treatments such as hydrologic-enforcement. Culvert features are used to maintain connectivity of hydrographic network features, while providing attribution allowing the Connector: Culvert to be easily identified for elevation surface treatments such as hydrologic-enforcement.
  - Indefinite Surface (FCode: 33404)—Indefinite Surface Connectors are used where evidence of channelization is not present in the digital elevation model surface but connectivity between an upstream and downstream channel is necessary to represent the network. Situations where Indefinite Surface Connectors may be used include low confidence areas in the DEM or heavy vegetative cover in which the channel cannot be resolved. Indefinite surface connector features may also be used to connect through areas having conservation treatments such as grassed waterways, which are designed to prevent soil erosion and the formation of channels. This FCode is recommended for use in situations where streams sink into the ground under low or normal flow conditions but would flow over the surface during high flow or flood conditions and connect to downslope hydrographic features.
  - Terrain Breach (FCode: 33405)—Used to breach terrain (or elevation) features that block the flow in a drainage network, such as a small rise in elevation, landslides, moraines, glacial till, or berms. This connector is used to breach flow blockages on the elevation surface; with no known manmade feature such as a pipeline or culvert connecting upstream and downstream flow. Do not use the Terrain Breach to represent underground flowpaths in known karst, permafrost or thermokarst terrain (See READ Rules for “Underground conduit”).
  - Non-NHD Dataset (FCode: 33410)— Used to provide network connectivity to or through a polygon feature that is represented in an external dataset maintained by another agency such as the National Wetlands Inventory, the Randolph Glacier Inventory, or other datasets related to hydrography. This connector will be used to traverse areas with no obvious network connections. Linear and polygon features that represent Stream/river or Canal/ditch flowpaths through the non-NHD dataset areas will be mapped as separate elevation-derived hydrography

features. This connector shall be used with a dataset recognized by the USGS for these purposes.

## Version 2020 revision A

- Underground Conduit FCode
    - "Positional Accuracy Indefinite" (FCode 42002) — The underground conduit allows network connectivity through areas where there is some evidence the water flows underground in karst and thermokarst regions.

- UniqueID Field
    - The UniqueID field is meant to be populated by the contractor prior to delivery of data to the USGS. Unique IDs allow communication with contractors by providing a tracking system for individual features.

## Introduction

This document is a copy of the Elevation-Derived Hydrography Data Acquisition Specifications 2024 rev. A3 as found on the US Geological Survey (USGS) National Geospatial Program (NGP) Standards and Specifications website. For the latest version of the specification, please visit the site: https://www.usgs.gov/ngp-standards-and-specifications/elevation-derived-hydrography-specifications.

Elevation-derived hydrography is collected by the USGS 3D Hydrography Program (3DHP) to refresh the geospatial representation of the Nation's surface waters. Elevation-derived hydrography data will replace the legacy National Hydrography Dataset (NHD) linework in the 3DHP dataset, creating an improved, spatially accurate, and three-dimensional network collected using these specifications. Data collected and accepted using the Elevation-Derived Hydrography Data Acquisition Specifications 2024 rev. A3 will be published as 3DHP data by the USGS.

This specification is primarily for lidar-derived hydrography data, but IfSAR-derived hydrography data specifications are listed when different from lidar-derived hydrography requirements.

### Schema

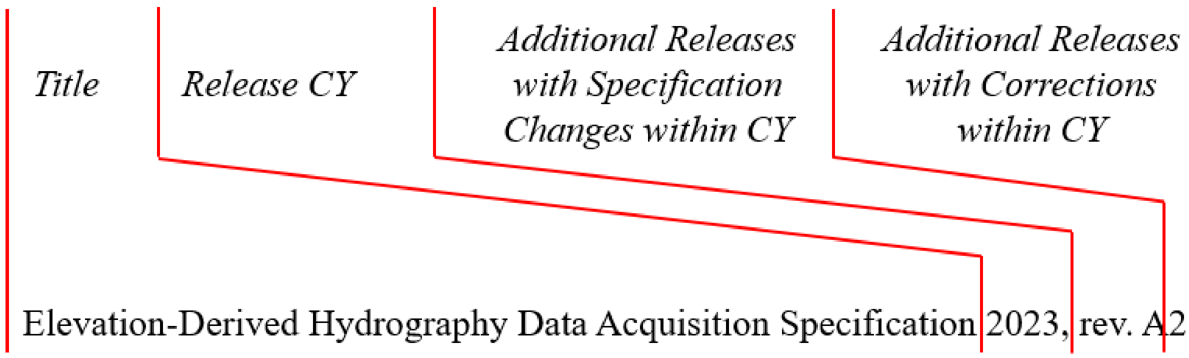
This specification reflects information in Elevation-Derived Hydrography schema 1.5. Please see previous versions of the Elevation-Derived Hydrography Data Acquisition Specifications; Representation, Extraction, Attribution, and Delineation (READ) Rules; and guidelines for earlier schema versions.

### Release Date

4/8/25.

### Elevation-Derived Hydrography Data Acquisition Specification Versioning

The USGS uses a calendar year-based versioning for Elevation-Derived Hydrography Data Acquisition Specifications. The revision represented by a letter indicates the version of the specification released within a calendar year that includes changes to the specification, such as additional, changed, or removed requirements. The number after the revision letter represents versions of the specification where corrections were made to the specification but are not updated requirements (**Figure 1**).




CY= Calendar Year
*Additional Releases with Corrections within CY omitted until needed.

**Figure 1.** USGS Elevation-Derived Hydrography Data Acquisition Specification versioning.

### Guidelines

The USGS Hydrography Specification Review Board (HSRB) reviews proposals to add, change, or remove requirements for elevation-derived hydrography throughout the year. The upcoming draft specification is modified when a proposal is approved. Pending that specification's release, the USGS may publish a guideline with updated requirements in the interim.

### National Hydrography Dataset

All references to the NHD in these specifications refer to the USGS hydrography data acquired prior to 2023 using methods different from this specification. The NHD was produced to a 1:24,000-scale or larger and will generally appear to be less dense and detailed than the data collected according to these specifications.

### Requirement Terminology

Individual requirements defined in this report use "shall" or "will" statements, which have a specific meaning in the context of a specification requirement:

- A "shall" statement means the requirement must be met.
- A "will" statement indicates the requirement is expected to be met wherever possible, but exceptions to implementation may exist.

## Collection Area

The collection area (or defined project area [DPA]) refers to the geographic extent where the elevation source exists and from which hydrography will be derived. Hydrographic features shall be derived from existing 3DEP elevation data (see "Source Raster Data Requirements").

Hydrographic features shall be collected within watersheds, as defined by the Watershed Boundary Dataset (WBD). A 10-digit hydrologic unit is the minimum unit size recommended for collection. A 12-digit hydrologic unit may be considered if collection restrictions exist due to political boundaries or elevation data availability.

- Hydrographic features shall be collected within the hydrologic unit area. A buffered area around each hydrologic unit shall be used to review and delineate the hydrographic features.
- Features in the DPA need to snap to elevation-derived hydrography source 3DHP data in x, y, and z coordinates.
- If less accurate hydrographic features are the only data that exist outside of a hydrologic unit, features shall not be snapped or adjusted to match those adjacent features.

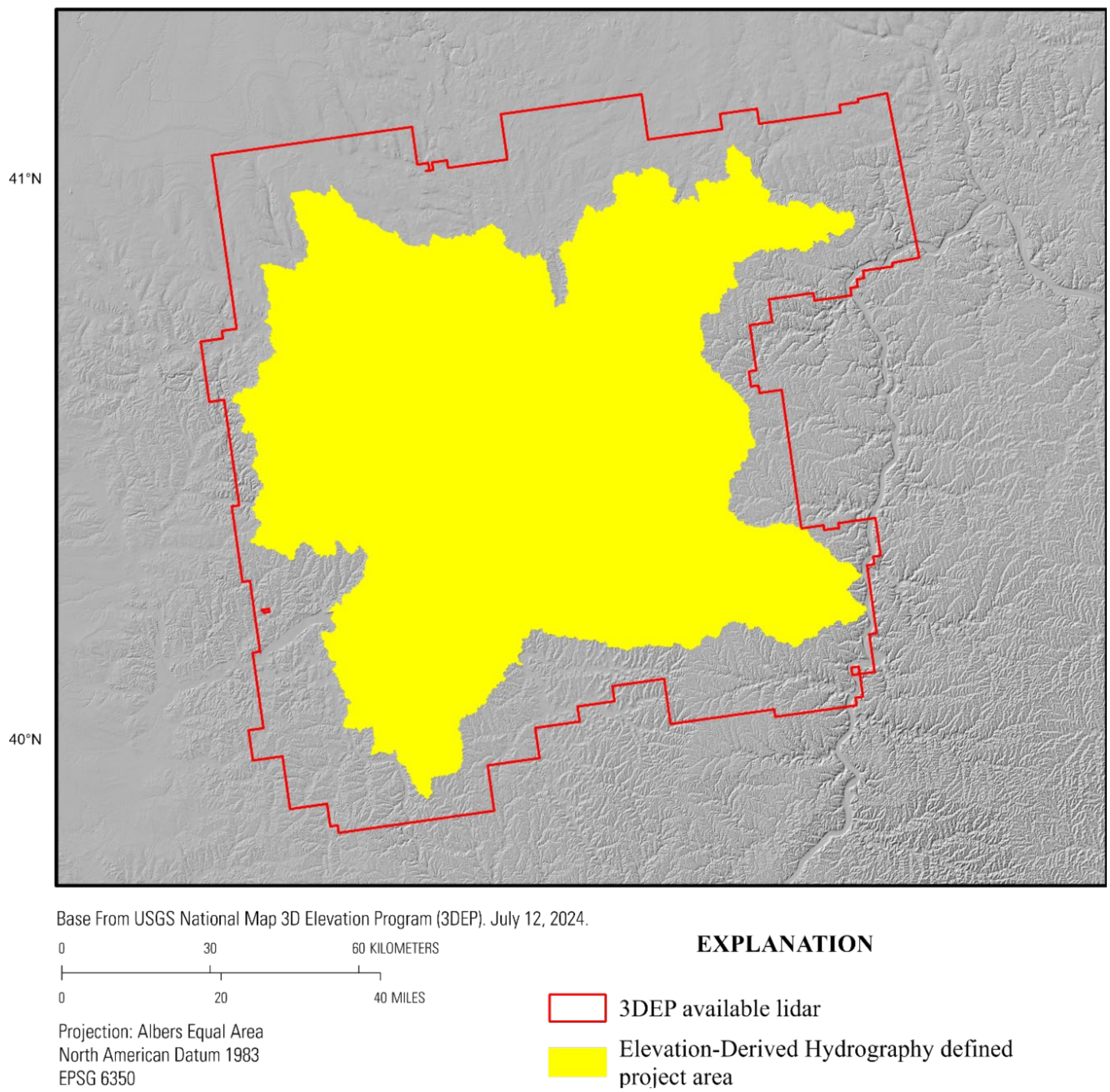



**Figure 2.** Hydrography collection from lidar.

### Final Deliverable Project Area

The Final Deliverable Project Area (FDPA) is the boundary of the DPA (**Figure 2**) plus any additional areas of hydrography that were not accounted for by the original DPA (**Figure 3** and **Table 15**).

**Figure 3.** Final Deliverable Project Area (FDPA) (in magenta) encompassing additional elevation-derived hydrography contributing flow to the original Defined Project Area (DPA) (in gray).

## Coordinate Reference System

Final products shall be in the coordinate reference systems (CRS) defined in **Table 1** and **Table 2**. If a collection area is composed of multiple elevation data collections, all elevation data shall be processed to one common CRS prior to elevation-derived hydrography compilation.

All geospatial products must meet the following requirements:

**Table 1.** Horizonal CRS

| Region | Datum | Coordinate System | GEOID | EPSG | Comments |
|---|---|---|---|---|---|
| Alaska (AK) | NAD83(2011) Epoch 2010.00 | Alaska Albers | 12B | 6393 | For lidar-based elevation-derived hydrography collection. |
| AK | NAD83 | Alaska Albers | 12B | 3338 | For IfSAR-based elevation-derived hydrography collection. |
| Contiguous United States (CONUS) | NAD83(2011) Epoch 2010.00 | Contiguous USA Albers | 18 | 6350 | - |
| Puerto Rico/Virgin Islands | NAD83(2011) Epoch 2010.00 | UTM Zone 19N | 18 | 6348 | Puerto Rico split between UTM zones 19N and 20N but should be delivered in zone 19N. |
| Hawaii (HI) - big island | NAD83(PA11) Epoch 2010.00 | UTM Zone 5N | 12B | 6635 | - |
| HI - others | NAD83(PA11) Epoch 2010.00 | UTM Zone 4N | 12B | 6634 | - |
| American Samoa | NAD83(PA11) Epoch 2010.00 | UTM Zone 2S | 12B | 6636 | - |
| Guam/Saipan North Marianas | NAD83(MA11) Epoch 2010.00 | UTM Zone 55N | 12B | 8693 | - |

**Table 2.** Vertical CRS

| Region | Datum | Coordinate System | GEOID | EPSG | Comments |
|---|---|---|---|---|---|
| Alaska (AK) | NAVD88 | NAVD88 | 12B | 5703 | For lidar-based elevation-derived hydrography collection. |
| AK | NAVD88 | NAVD88 | 12B | 5703 | For IfSAR-based elevation-derived hydrography collection. |
| Contiguous United States (CONUS) | NAVD88 | NAVD88 | 18 | 5703 | - |
| Puerto Rico | Onshore | Puerto Rico Vertical Datum of 2002 | 18 | 1123 | - |
| Hawaii | LMSL | - | 12B | - | Each island has its own based local tide datum for vertical reference, no EPSG equivalent. |
| American Samoa | Onshore | American Samoa Vertical Datum of 2002 (ASVD02) | 12B | 1125 | Revised/superseded in 2020. |
| Guam | Onshore | NAD83(2011) + Guam Vertical Datum of 2004 | 12B | 1126 | Revised/superseded in 2020 |
| North Marianas | Onshore | NAD83(2011) + Northern Marianas Vertical Datum of 2003 | 12B | 1119 | Revised/superseded in 2020. |
| Virgin Islands | Onshore | NAD83(2011) + Virgin Islands Vertical Datum of 2009 | 12B | 1124 | Revised/superseded in 2020 |

## Source Raster Data Requirements

The DEM used to create the lidar-derived hydrography shall be:

- Comprised of the best available 3DEP lidar source data or other accepted lidar source data.
- Seamless within the FDPA boundary.
- Completely encompassing the FDPA, plus at least 250 meters outside the FDPA, as needed to derive hydrography.

Associated DEM deliverables:

- If 3DEP hydroflattening breaklines are available for the selected elevation datasets, they shall be provided with the elevation-derived hydrography delivery as one polygon dataset in a geopackage.
- A spatial metadata layer that describes the source lidar data used. See the Elevation Source Spatial Metadata section for more information.

## Preparation of Elevation

The DEM used to derive hydrography shall be generated from 3DEP-compliant 1-meter resolution or better Original Product Resolution (OPR) DEMs unless the USGS has approved an alternate DEM source. The DEM shall be in the specified regional CRS (**Table 1** and **Table 2**). It is also acceptable to create the hydro-derivation surface from the 3DEP-compliant lidar point cloud and breaklines.

## Source Data

### Use of a DEM Source

1. The 3DEP OPR DEM rasters shall be used as the source DEM if available.
2. If the 3DEP OPR DEM rasters are not available, the 3DEP 1-meter DEM shall be used pending USGS approval.
3. If no 3DEP source is available, a USGS approved DEM source may be used.
4. DEM source requirements
    a. DEMs shall be mosaicked and projected from the source CRS to the regional CRS (to include Geoid transformation) listed in (**Table 1** and **Table 2**).
    b. A bilinear interpolation method shall be used to spatially transform and resample the DEM rasters to the required CRS and a spatial resolution of 1 meter.
    c. All units (x, y, and z) shall be in meters.
    d. Tiles shall not have NODATA cells between them in the final DEM deliverable.
    e. The final DEM shall include a 250-meter buffer, at minimum, around the entire FDPA. See Appendix 2 of this document for more information.
        i. If sufficient elevation data is not available to complete a 250-meter buffer, complete a DEM to the extent of the available elevation data and note the reason for the variation from the buffer requirement in the collection report.
        ii. The DEM bounding extent shall be clipped to the extent of the FDPA.
    f. NODATA areas shall not exist in the final DEM product.
        i. Consult with the USGS if gaps exist or areas are unavailable from 3DEP.

### Use of a 3DEP Lidar Point Cloud to Create the Project Area DEM

1. Requirements outlined in "Deliverables, Bare-Earth Surface (Raster DEM), in the latest version of the USGS 3DEP Lidar Base Specification (LBS) shall be followed when creating a mosaicked DEM from lidar sources.
2. Lidar point clouds and corresponding hydroflattening breaklines shall be spatially transformed from the source CRS to the regional CRS (to include Geoid transformation) listed in the CRS section (**Table 1** and **Table 2**).
3. Hydrographic breaklines that correspond to the project area shall be used to hydroflatten the waterbodies.
4. Hydrographic breaklines from multiple projects shall be merged into one feature class and used to hydroflatten waterbodies in the composite DEM.
5. Lidar Point Cloud source requirements
    a. The final DEM shall include a 250-meter buffer, at minimum, around the entire FDPA. If sufficient elevation data is not available to complete a 250-meter buffer, complete a buffer with the elevation data available and note the missing buffer in the collection report.
    b. NODATA areas shall not exist in the final DEM product.
        i. Consult with the USGS if gaps exist or areas are unavailable from 3DEP.

### Raster Product Characteristics

Raster products shall have the following characteristics:

1. Number of bands: 1
2. Cellsize: 1 x 1 meter
3. Format: GeoTIFF version 1.1 or Cloud Optimized GeoTIFF (COG as GeoTIFF version 1.1).
4. Pixel type: floating point
5. Pixel depth: 32 bit
6. NODATA value: -999999
7. Lossless Compression: DEFLATE, LERC, LZ77, or LZW
8. GTRasterTypeGeoKey shall be RasterPixelIsArea
9. Bounding extents of raster shall be minimized to fit the extent of the 250-meter minimum buffered area.
10. Pixel alignment shall conform to a grid in the defined CRS based on a model tie point of (0,0) and origin coordinates evenly divisible by the cell size.
11. Include spatial reference information. See Appendix 5 for additional information.

## Overlapping 3DEP Project Data

The choice of which source lidar elevation datasets to mosaic into a project-area elevation surface shall be based on characteristics of the source elevation data. Important criteria to consider when creating mosaicked 1-meter bare-earth DEM for deriving hydrography from two or more overlapping 3DEP projects are listed below.

1. The elevation source meets 3DEP requirements, in particular:
    a. The lidar point cloud (LPC) is available and coded as “Meets 3DEP” or meets with variance (MwV) in the 3DEP Work Unit Extent Spatial Metadata (WESM),
    b. The Original Product Resolution (OPR) DEM is available and coded as “Meets 3DEP” or “MwV” in the 3DEP WESM.
2. The data is from the most recent acquisition.
3. Exceptions may be made for 3DEP lidar projects where individual work units in a project have been published and are “expected to meet” 3DEP requirements but the final vertical accuracy testing cannot be performed until all work units are validated and published.

Other considerations include:

- Known variances or limitations (low confidence polygons).
- Vegetation (leaf-off is preferred) or ground cover (for example snow or ice) at time of collection.
- Soil saturation.
- Flooding.
- Ground detection quality and density.
- Presence or lack of tidal coordination.
- Vertical accuracy of the source data.
- Significant vertical offsets in DEM difference rasters.

Overlap areas shall be resolved based on the characteristics listed in the critical and other considerations above. The USGS will provide further guidance by request if determining the best project area to use within overlapping areas is ambiguous.

If blending between collection areas is necessary, blending shall be restricted to a small overlap area using a distance weighted algorithm. The USGS recommends a 10-meter blend width for lidar-source tiles, and 50-meter blend width if one-third arc-second seamless DEM data must be used to cover areas with restrictions on high-resolution elevation data publication (for example, on military and tribal lands). If significant vertical or horizontal offsets between collection areas are present, request guidance from the USGS for the recommended method to mosaic the datasets.

The seamless DEM for the project area shall be buffered by at least 250 meters outside the FDPA. The buffer area should be extended beyond 250 meters in areas of uncertainty where the watershed boundary is likely to change, such as in flat terrain. Any missing elevation data within the FDPA, including the 250-meter buffer, shall be reported to the USGS.

All methods used to create the mosaicked 1-meter bare-earth DEM shall be documented in the collection report. The collection report should also include a statement indicating whether the mosaicked 1-meter bare-earth DEM, used for the generation of elevation-derived hydrography features, was government furnished or not.

Seamless IfSAR-derived, 5-meter resolution, elevation surfaces are available from the USGS for derivation of hydrography in Alaska.

## Attribute Table Structure

The attribute table structure is described in **Table 4** and **Table 5**. An important component of the elevation-derived hydrographic features is that they have three-dimensional (3D) geometry (**Table 3**). Each feature type must be z-enabled, with z-values assigned to each point, vertex, and node. The feature classes use 3D geometry, pointZ, polylineZ, and polygonZ.

- Feature class (FClass)—A one-digit short integer code describing the hydrographic use of a feature (**Table 9**).
    - A “1” is used when a feature is collected to meet the elevation-derived hydrography acquisition specifications. An example of a feature with an FClass = 1 is a point feature defined as a sink. An example of a line feature with an FClass = 1 is a stream that is too narrow to be represented as a polygon. An example of a polygon feature with an FClass = 1 is a wide river, or a lake/pond.
    - A “2” is used when a feature is outside of the collection criteria. An example is when the features add too much complexity and will not be used for network connectivity. A line representing a drainage ditch in a neighborhood may be collected, but not used for network connectivity.
    - A “9” is used when a feature is not a hydrographic feature and is outside the 3DHP collection requirements. A line representing a levee is an example of a feature that may be useful for elevation processing but is not part of the hydrography network.
- Feature class for elevation (EClass)—A short integer code describing how the features are used in elevation surface treatments (**Table 10**).
- Feature code (FCode)—A long integer field containing a coded value for the type of hydrographic feature represented (**Table 8**). For instance, a Lake/pond has an FCode of 39000, and a Stream/river has an FCode of 46000.
- Description (Desc)—A 250-character free-text field with a text description of FCode, or it can be used for user-defined features not included in the domain list. Not required.
- Elevation source data (Source)—A 128-character free-text field with a text description of the source data used for deriving hydrography. For most features ‘Lidar’ or ‘IfSAR’ can be specified. If a source other than elevation is used, it should be noted. This may be required in areas of DEM limitations (see Digital Elevation Model (DEM) Limitation section for definition), or where ancillary data is used (**Table 14**).
- Hydrography delineation method (Method)—A 250-character free-text field with a text description of the method used for deriving hydrography. Examples are software, models, or digitizing techniques. Ancillary datasets can also be noted here.
- User-defined code (UserCode)—A 25-character free-text field with a code designated by the acquisition entity to identify features collected outside the scope of features described in this specification. It is intended to be used as a key to join tables with attributes outside of this specification. Not required.
- Free-text space used for comments (Comments)—A 250-character free-text field for user comments. Not required.

- User-defined code (UniqueID)—A 50-character free-text field that stores a unique identifier for each feature in the dataset. The UniqueID is intended to be stable throughout multiple deliveries of a dataset within a project area. The UniqueID field shall be populated by the data producer prior to delivery of data to the USGS. UniqueIDs allow communication with data producers by providing a tracking system for individual features.
- DEM Limitation (Limitation)— A short integer one-digit code that indicates when hydrographic features do not meet vertical or horizontal requirements because of elevation source data limitations (**Table 7**).
- Flow Direction Determination (FlowClass)— A short integer one-digit code used in the line feature class to describe whether a feature's flow direction can be determined (**Table 6**). In most cases, features shall be digitized in the direction of flow and shall flow downslope (FlowClass = 1). In very flat, wetland, or tidal areas, it is often impossible to determine the direction of flow (FlowClass = 0). Water may occasionally flow uphill, such as when a pump is used or in rare natural situations. A segment's z-values may flow in an upslope direction in cases where water enters a depression on the landscape and must rise to exit the depression. When flow is known to initiate from a lower elevation and discharge to a higher elevation, FlowClass = 2.

# Feature Codes and Values

Feature codes indicate hydrography types and how the features integrate with the elevation surface from which they were derived. The complete set of domain values required for this specification is provided in **Table 6**, **Table 7**, **Table 8**, **Table 9**, and **Table 10**. The fields, domains, and minimum feature collection requirements for each required feature are further defined in Appendix 1.

## 3DEP Light Detection and Ranging Base Specification Hydroflattening Features

The hydroflattening breaklines collected for lidar source data projects (U.S. Geological Survey, 2024b) can be used directly for waterbody polygon delineations. The FCodes corresponding to hydroflattening features are cross-referenced in **Table 11**.

## Additional User-Defined Features

Additional user-defined features may be added to elevation-derived hydrography collections. User-defined features may include features with FCodes in **Table 8** (other than 0) that are outside on the collection criteria. For example, canals in agricultural areas and outside the stream network may be in this category. User-defined features may also include features not listed with FCodes in **Table 8** other than (0). An example may be a levee or waterfall.

- If the feature is a valid feature type, but outside the collection criteria of this specification, the following guidelines apply:
  - FClass shall be coded as 2,
  - EClass shall be coded as 0,

    - FCode shall be a valid feature from **Table 8** and follow the attribute table structure from **Table 4** and **Table 5**. The Desc field may be used to describe the additional feature.
    - A code per feature type may be added to the UserCode field.
- Additional user-defined features outside of those collected for this specification (listed in **Table 8**), shall be coded as follows:
    - FClass shall be assigned a code of 9.
    - EClass shall be assigned a code of 0.
    - FCode shall be assigned a code of 0.
    - A code per feature type may be added to the UserCode field.
    - User-defined codes shall not duplicate FCodes defined in this specification.

## Delineation of Hydrographic Features

Hydrographic features shall be captured with either 3D point, line, or polygon geometry (**Table 11**). Some features may be collected as either 3D lines or 3D polygons, determined by the minimum area or length of shortest axis (Appendix 1). EClass indicates how features are used in elevation surface treatments. FClass indicates how the features are used in hydrography products.

### Elevation-Derived Hydrography Feature Collection

- The correct geometry shall be used to capture each feature type.
- At minimum, a hydrographic feature collection shall do the following (**Figure 4**):
    - Capture all features that a have a feature type in **Table 8** present in the National Hydrography Dataset (NHD) and detectable on the elevation surface.
    - Capture any additional features meeting capture conditions described in Appendix 1.
- New Hydrographic features shall be collected for the following reasons (**Figure 5**):
    - If there is clear evidence of the feature on the elevation surface, such as
        - Contour lines derived from the elevation surface.
        - Geomorphic derivates as defined in Appendix 3.
    - If there is clear evidence of the feature using an appropriate ancillary data source (**Table 14**).
    - If a method has given good results for delineation of stream channels or other features and is quality assured using lidar data and high-quality ancillary datasets.
    - If it is necessary to connect a hydrographic network.
- All criteria described in the following special cases shall be met.

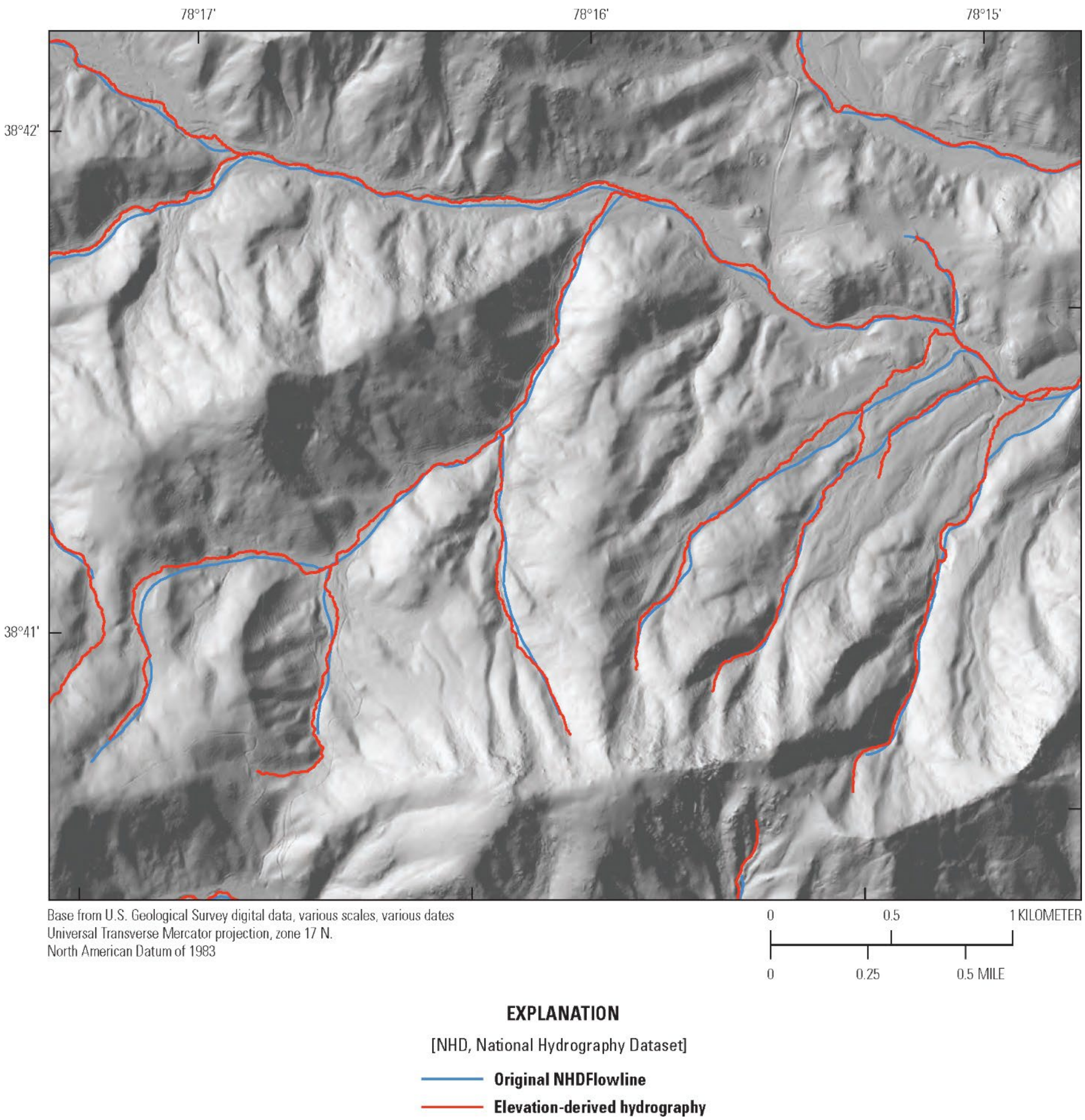



**Figure 4.** Minimum set of hydrographic features compared to the original NHD.

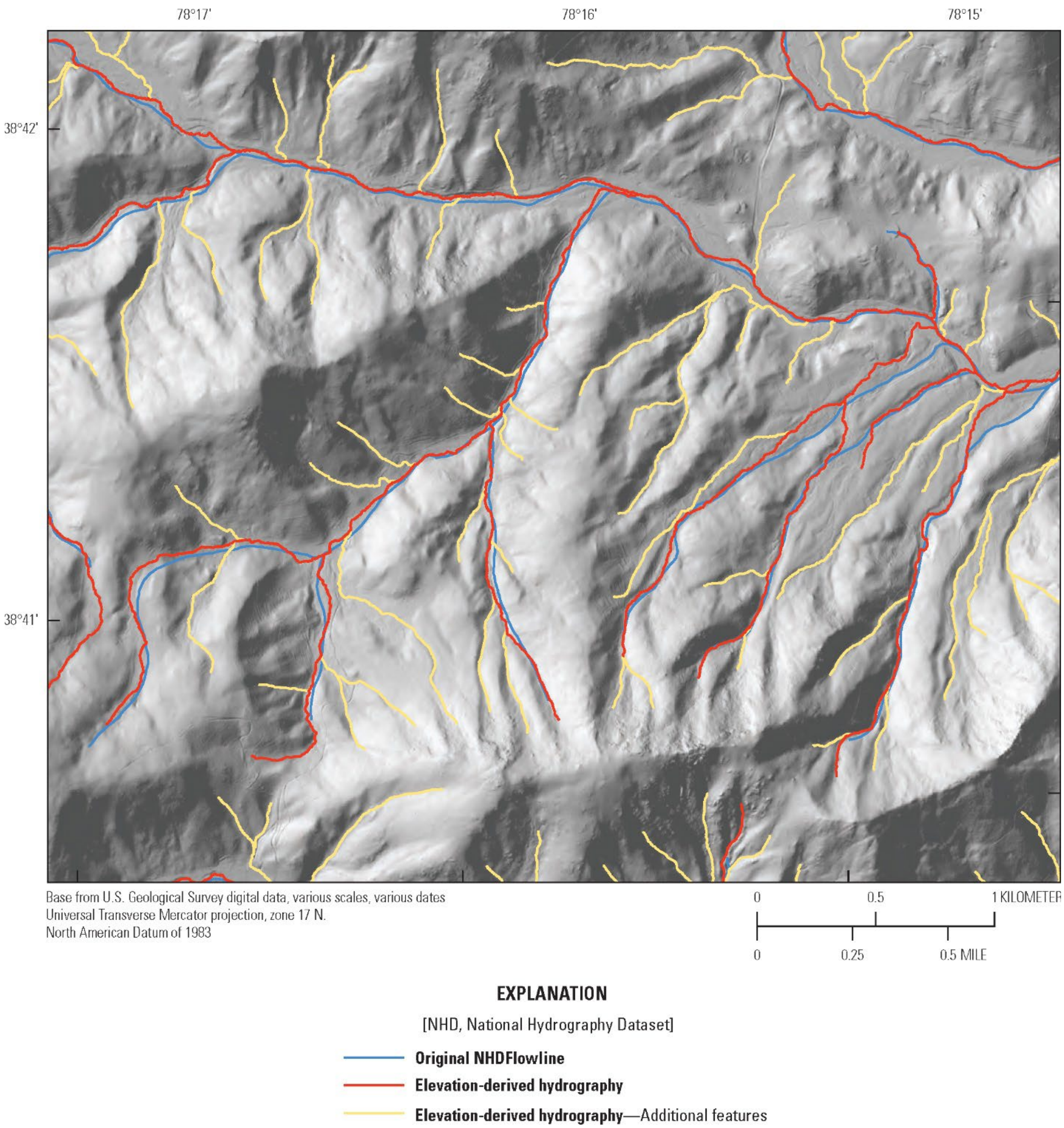



**Figure 5.** Additional features with visible channels captured from the light detection and ranging-derived elevation surface.

## Special Cases

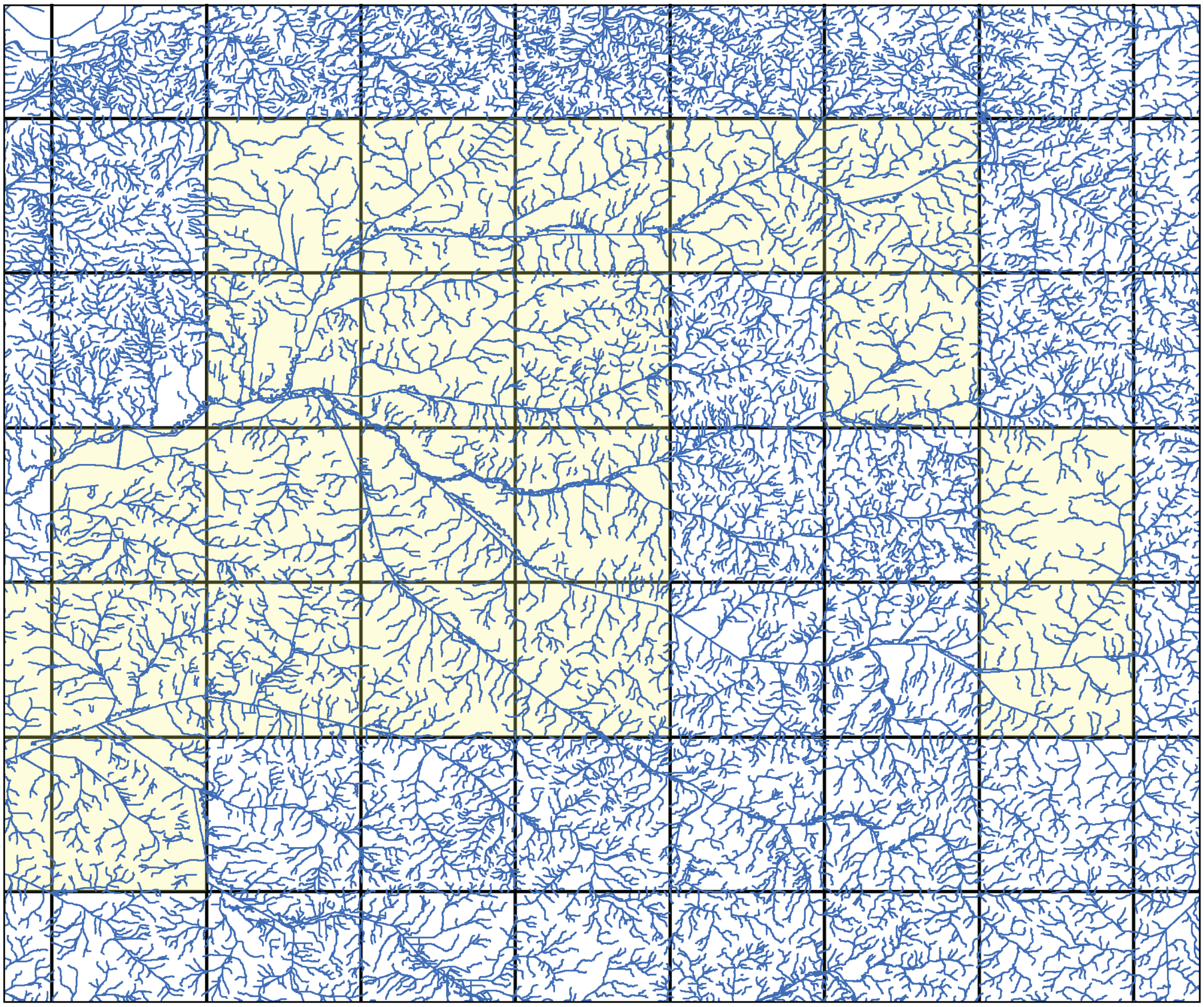
### 12-Digit Hydrologic Unit Consistency

The original NHD was digitized from individual 7.5-minute quadrangle map sheets compiled at different times, by many individuals, using varied sources; therefore, some areas of the country have hydrography represented at different densities. These discrepancies are due to differing source material or standards and procedures and are not due to differences in geomorphology or hydrologic conditions (**Figure 6**). To create a more consistent and representative depiction of national hydrography, new features shall be collected within 12-digit hydrologic unit boundaries and areas with line density inconsistencies shall be made consistent with the most densely collected part of the 12-digit hydrologic unit (**Figure 7**).

In cases where prior local resolution or lidar-derived projects exist, discontinuity between feature density can occur. These discrepancies are often along county or other political boundaries (**Figure 8**). The same rules apply as those with quadrangle-line differences: linework shall match the densest representation of hydrography within a 12-digit hydrologic unit, unless channelization is not detectable within the elevation surface. Where geomorphology, geology, or other terrain features create actual differences in stream density, the natural representation of features that depicts the disparity in density should be captured.

### Summary Guidance for Consistency

- New features collected within 12-digit hydrologic unit boundaries shall be evaluated for line density inconsistencies (**Figure 6**). New features shall be collected to be consistent with the most densely collected part of the 12-digit hydrologic unit (**Figure 7**).
- Where geomorphology, geology, or other terrain features create actual differences in stream density within the FDPA, the natural representation of these features shall reflect the density disparity.
- If a geographic area has an extremely dense stream network collected to meet local needs, a less detailed depiction of adjacent areas should be corrected when elevation-derived hydrography is collected. (**Figure 8**).



**EXPLANATION**

[USGS, U.S. Geological Survey; NHD, National Hydrography Dataset]

**Density disparity by quadrangle boundary**

**USGS 1:24,000-scale topographic map boundary**

**NHDFlowline**

**Figure 6.** Artifacts within NHD density inherited from original quadrangle map delineation of hydrography.

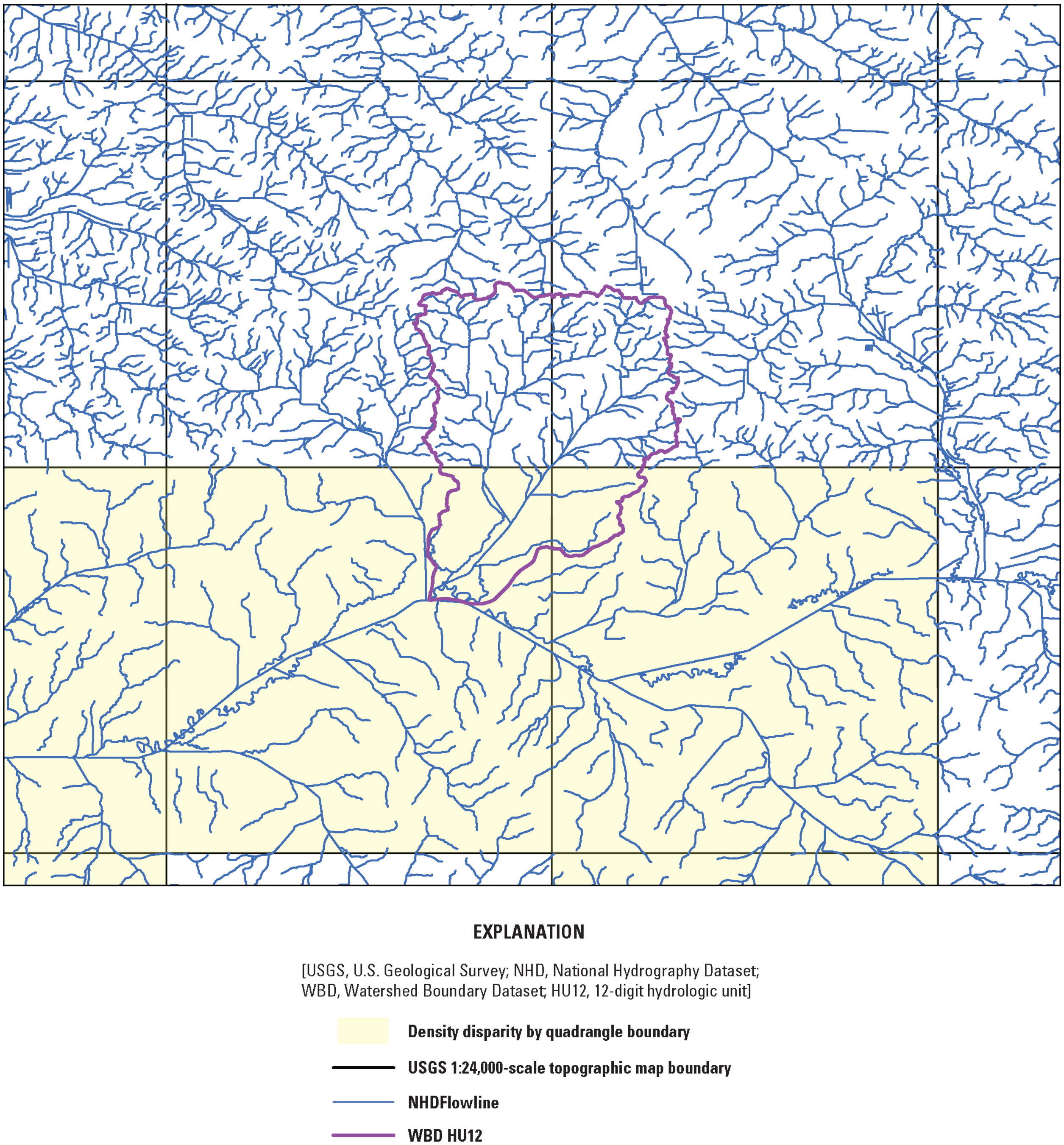



**Figure 7.** The hydrography within the southern quadrangles of this 12-digit hydrologic unit must be densified to be consistent with the northern quadrangles.

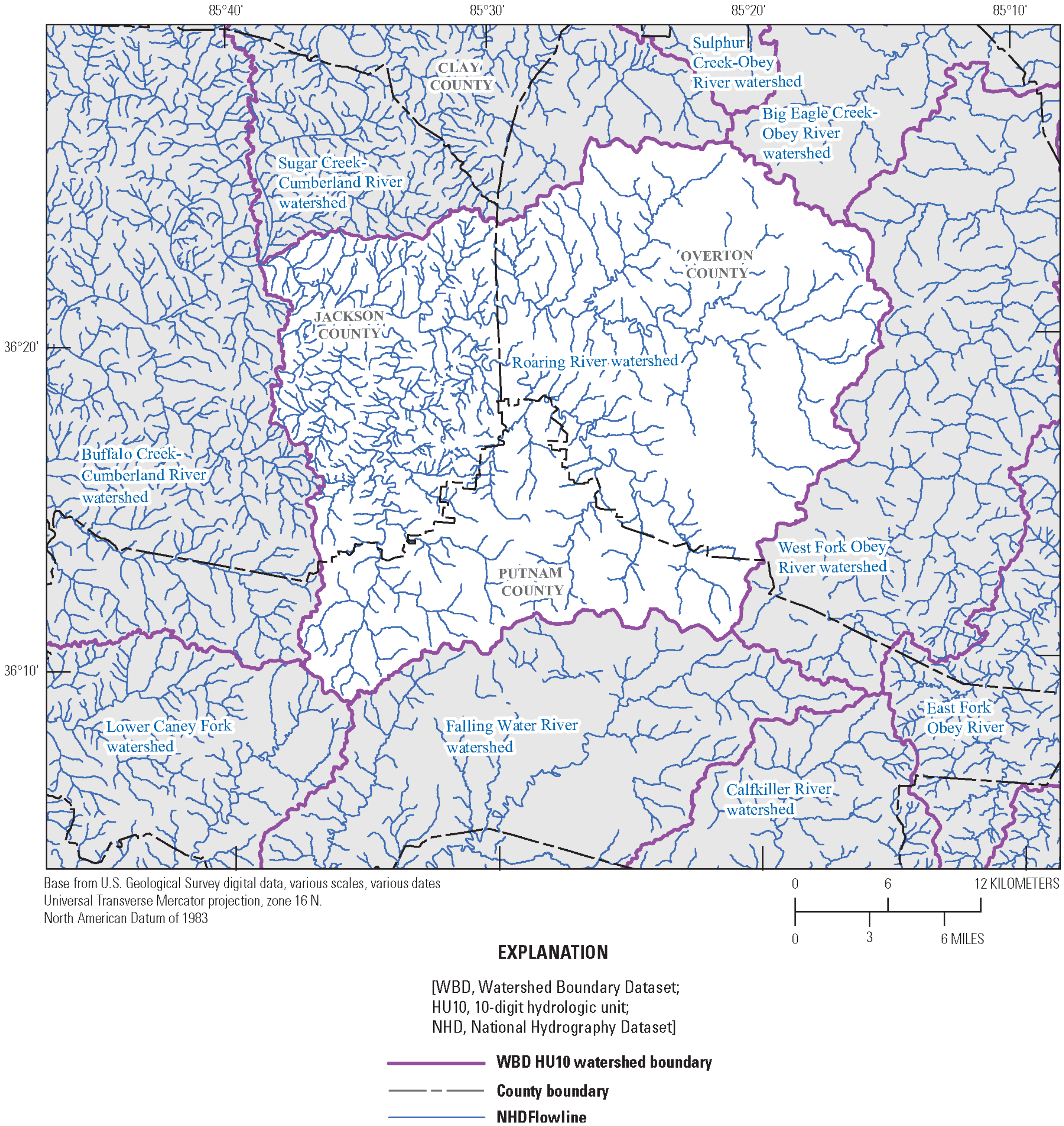



**Figure 8.** Streams within the Roaring River watershed indicate density disparity because of the collection differences between Jackson, Overton, and Putnam Counties, Tennessee. Updates to this area should correct density disparities by making the densities of Overton and Putnam Counties match the density of Jackson County within the DPA.

## Bridge Locations

- Surface points at bridges are removed from the bare-earth elevation surface to ensure continuity of water features beneath and that shorelines are followed (**Figure 9**). No connector feature is required if the bare-earth elevation shows a continuous water feature where a bridge was removed.

- If a bridge is not removed, a hydrographic feature below a transportation feature shall be regarded as a Connector: Culvert (FCode: 33401).
- A culvert must be a separate feature, with nodes matched (snapped) to the up and downstream hydrographic features at each end.
- Elevation attribution (EClass=3) shall identify the culvert separately (**Figure 10**).
- If a polygon feature contains a culvert, the polygon shall not be split. The culvert feature shall be delineated on the Artificial path feature within the polygon feature.
- See the Connector: Culvert section of Appendix 1. for more information.
- See Connector: Terrain Breach if artifacts causing obstructions are present on the elevation surface.


**Figure 9.** Bridge treatment in the bare-earth DEM. The bridge deck is removed, and water surface is interpolated beneath the bridge to maintain a monotonic, continuous water feature.

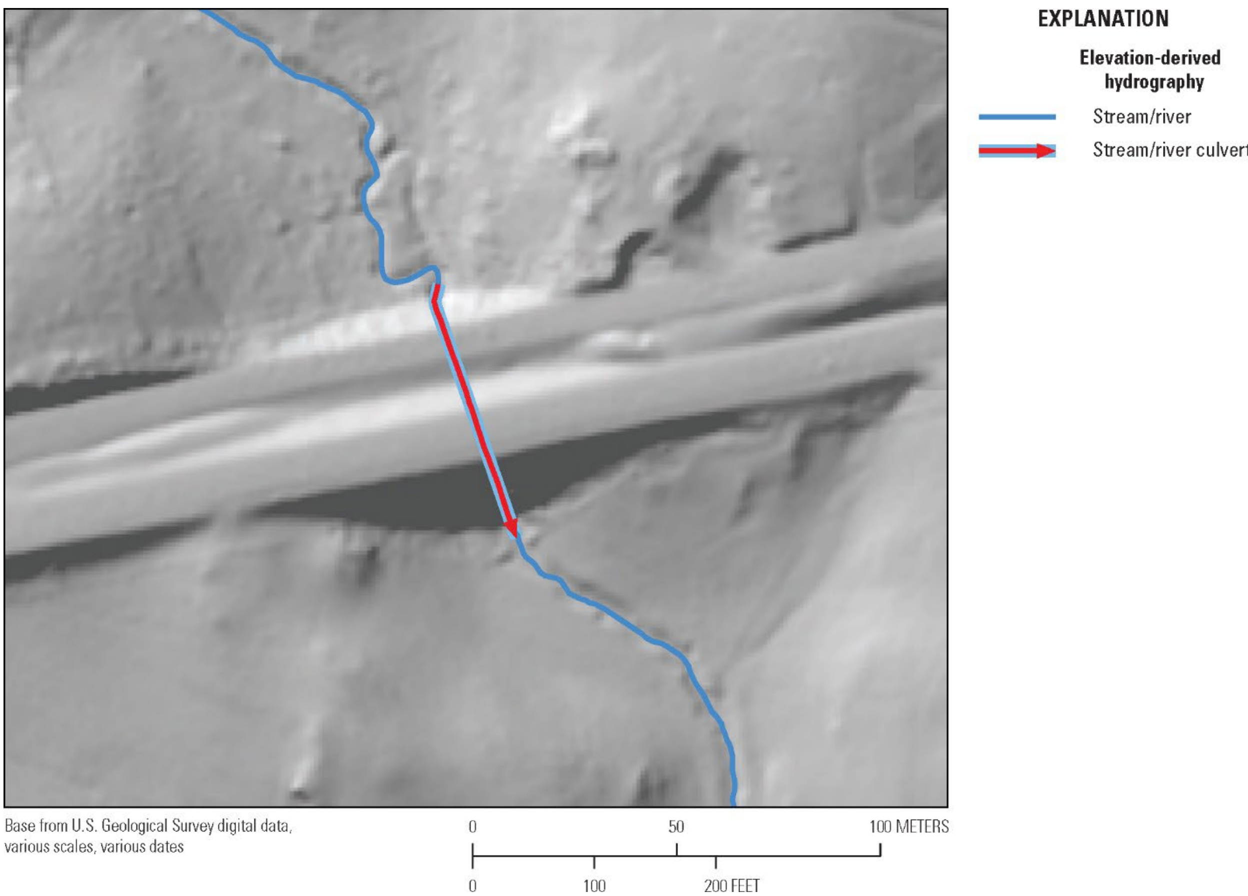



**Figure 10.** Proper delineation of a culvert feature within a stream segment.

## Headwaters at Roads

- Identify streams with an initiation (headwater) point within 100 feet (ft) or 30 m of a road (**Figure 11**).
- If a stream channel is visible (in imagery or a DEM) upstream from a road, extend the Stream/river through the road using the rules described for delineation of Connector: Culvert features, and extend the Stream/river at least 100 ft or 30 m upstream from the road intersection.
- If a stream channel is not visible upstream from a road, but there are other indications that a culvert is present at the intersection of the road allowing flow to continue into the Stream/river, extend the Stream/river to the road and add a culvert feature through the road. It is not necessary to extend the Stream/river upstream from the culvert if no channel visible.
- If a stream channel is not visible upstream from the road, and no other indication of a connection between the upstream area and the headwater exist, no action is required.
- See the Stream/river section of Appendix 1 for more information.

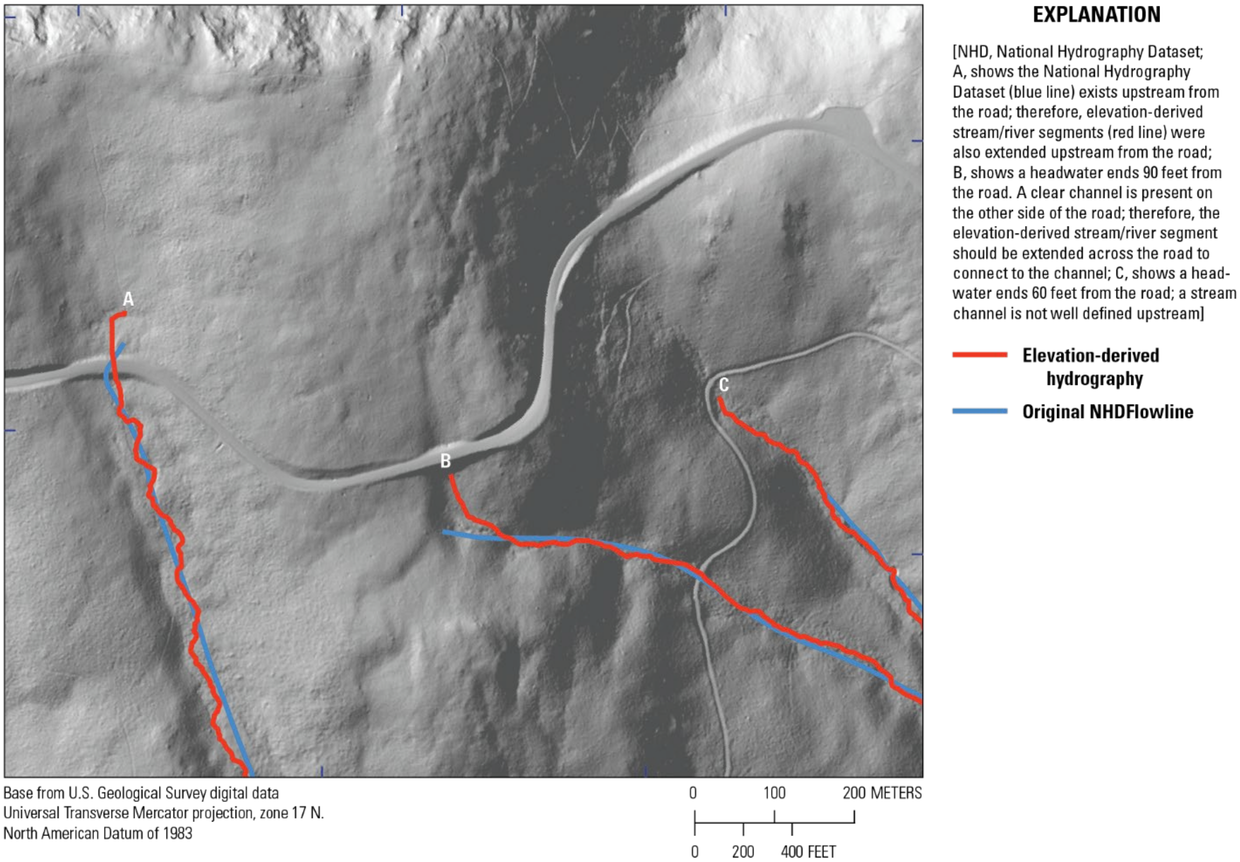



**Figure 11.** Correcting headwater stream delineation at roads.

## Depressions

The following applies to linear features that need to rise from a depression greater than the vertical threshold (2-meter deep in IfSAR, 1-meter deep in lidar), have a channel downstream, and are outside of karst or thermokarst areas (**Figure 12**).

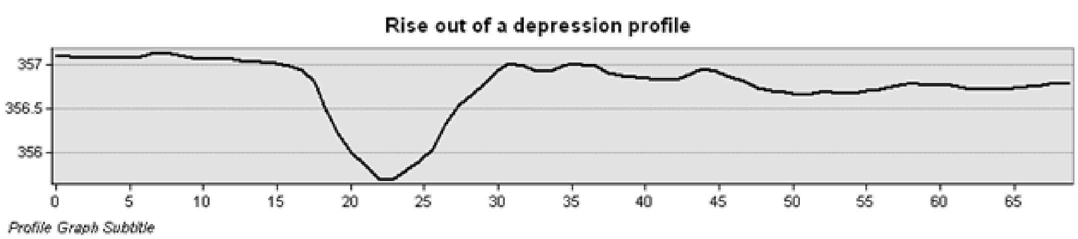



**Figure 12.** Depression where rise exists because of the depressed landform.

- Linear features exiting a depression shall be split at the point where the depression ceases to rise, and downstream monotonicity is possible.
- The segment from the lowest point of the depression to the high point at the edge of the depression shall be coded as a Connector: Indefinite Surface feature (**Figure 13** and **Figure 14**).
- If the z-values of Connector: Indefinite Surface feature’s vertices cannot be downstream enforced,

- Add a comment to the feature stating, “Downstream monotonicity cannot be enforced through depressions in the surface.”
- Assign FlowClass = 2
- Assign EClass = 2
- The segment downstream of the split shall be coded as the appropriate feature class and downstream monotonicity shall be enforced.

- Indefinite surface downstream of a depression
  - If a Connector: Indefinite Surface feature is required downstream of a depression, the portion of the feature *inside* of the depression shall have a comment stating, “Downstream monotonicity cannot be enforced through depressions in the surface.”
  - The Connector: Indefinite Surface feature shall be split at the highest point out of the depression and the *downstream* Connector: Indefinite Surface feature shall be monotonic with no comment added (**Figure 14**).

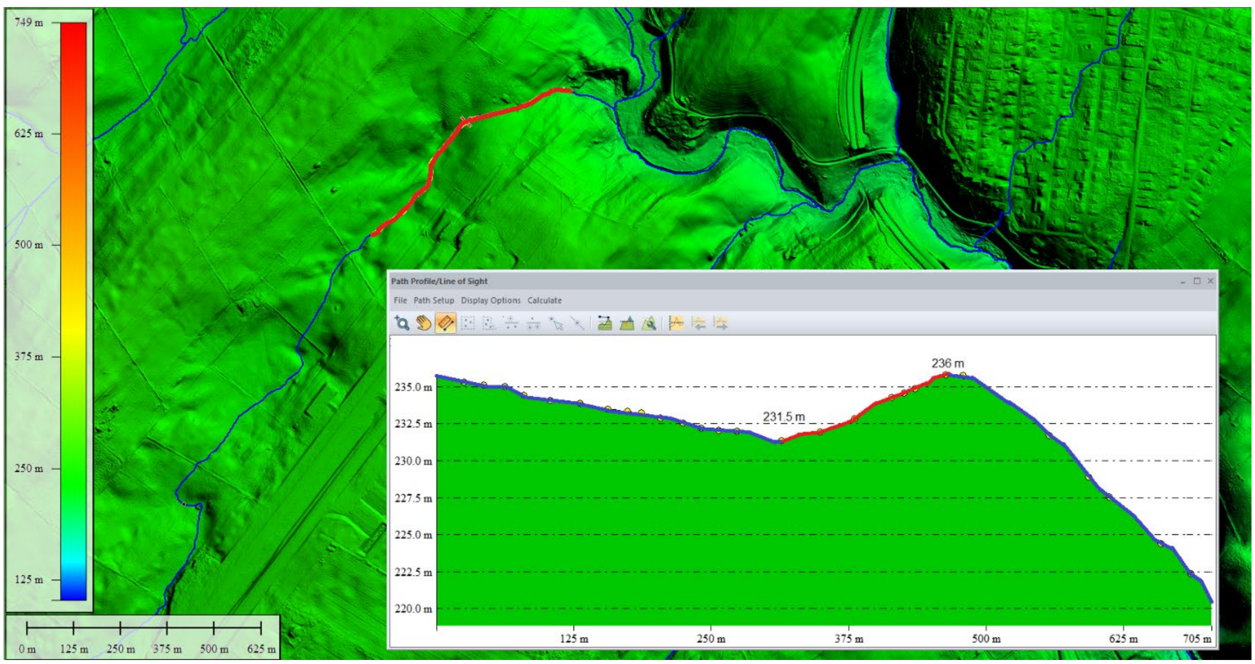



**Figure 13.** Example of where a Connector: Indefinite Surface feature (red) is placed from the lowest point in a depression to the outlet point in the depression.

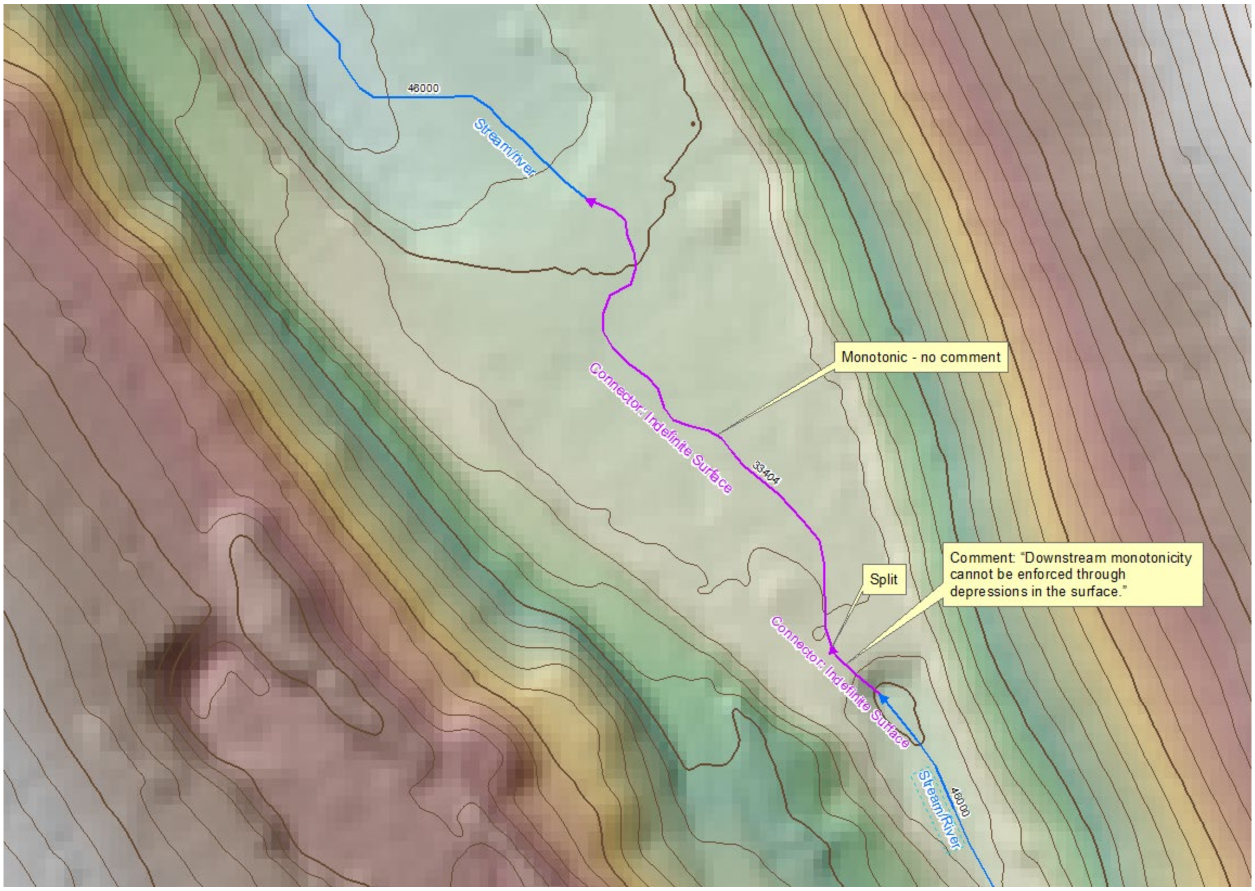



**Figure 14.** Example of a depression with a Connector: Indefinite Surface feature placed from the lowest point in the depression to the downstream outlet point followed by a second Connector: Indefinite Surface feature representing the lack of a discernible channel downstream of the depression. The Connector: Indefinite Surface feature within the depression requires the Comments field to be coded with "Downstream monotonicity cannot be enforced through depressions on the surface." While the downstream Connector: Indefinite Surface feature does not require a comment in the Comments field.

When deciding whether to use a Connector: Indefinite Surface or a Connector: Terrain Breach feature, note that a Connector: Terrain Breach feature will not have a depression before the rise (**Figure 51**). Connector: Terrain Breaches are used when there is steady flow across the surface before encountering an obstacle blocking the flow. Connector: Terrain Breach features provide a method to bypass a typically short obstacle rising from the surface. A Connector: Indefinite Surface feature typically connects upstream and downstream features in channels over terrain with no detectable channels on the elevation surface but can also be used to navigate out of a depression (**Figure 12**).

## Complex Interlacing Channels

- An area of complex channels is an area where a stream or river flows in an intricate network of interlacing channels with no permanent, primary channel.

- The Area of Complex Channels polygon feature type (FCode 53700) defined in the NHD is not included in the acquisition of elevation-derived hydrography.
- Hydrographic features falling within the previously defined area of complex channels shall be collected as Stream/river features (FCode 46000), Connector: Indefinite Surface (FCode 33404), Connector: Terrain Breach (FCode 33405), or other feature types as appropriate.
- No loops shall be present (see Topology Rules).
- Areas of complex channels previously identified in the NHD can identify areas where these guidelines shall be followed.
    - Ancillary sources may also help identify areas of complex channels. Their use shall be noted in the Comment field and in the metadata.
- In areas of complex interlaced or braided channels, at least five channels present in the elevation surface shall be delineated.
    - Appendix 1shall be followed to determine if streams are represented as line or polygon features.
        - Intersecting features shall not have a valency/confluence greater than five.
    - Channels delineated shall be the most prominent either in width or depth (**Figure 15**).
        - In IfSAR-based hydrography derivation, channels deeper than 2 meters and longer than 2000 meters are considered prominent.
        - In lidar-based hydrography derivation, channels deeper than 0.5 meters and longer than 1000 meters are considered prominent.
    - If multiple smaller channels are present, delineate channels that are evenly distributed throughout the entire braidplain to ensure the entire area is represented.
    - If more than five channels are present efforts should be made to match the channel feature density delineated in the NHD.
        - If the elevation does not include evidence of channelization to meet past NHD delineations, add an explanation to the collection report in the final delivery.
- Dynamic mid-channel bar deposits found in braided channels shall not be considered islands or follow island depiction guidelines. Multiple small mid-channel bars may be combined to appear as one area, but it is most important to maintain the characteristics of the braided channel being depicted.
    - Large mid-channel bars or collections of bar deposits should typically have flowpaths on both sides. Large mid-channel bars or bar deposits are:
        - Ten acres or more for IfSAR-based delineations.
        - Four acres or more for lidar-based delineations

An example of an area with multiple, interlacing channels is shown in **Figure 16**. The complex braided system is difficult to capture in its entirety and can be captured with a representative subset of channels, evenly spaced through the area. At least five major channels must be captured. Any features that have been hydroflattened or meet the 2-dimensional (2D) feature capture conditions (Appendix 1) shall be delineated as polygons, with Artificial path features. Narrower channels shall be captured that represent the complex nature of the area, but it is not necessary to include every channel. Both densities represented in **Figure 17** and **Figure 18** are acceptable for the represented area of complex braided stream features.

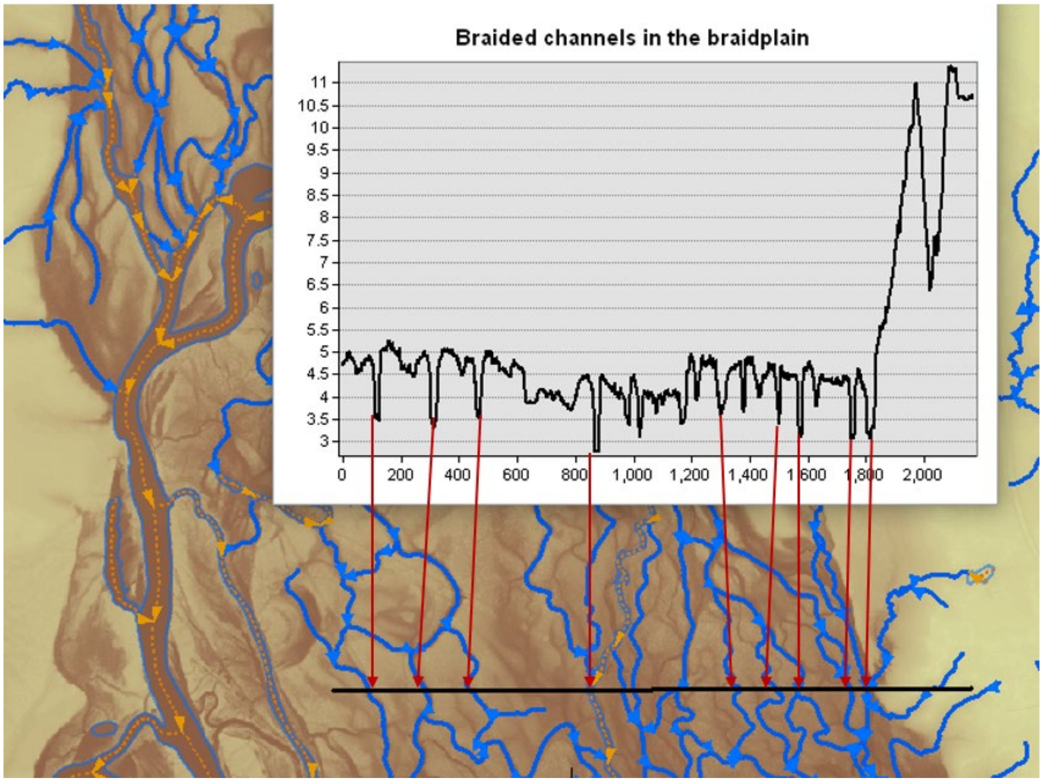



**Figure 15**. Determining major channels based on depth of channelization from a lidar-derived elevation source. At least five of the most prominent channels shall be included, spaced throughout the braidplain.

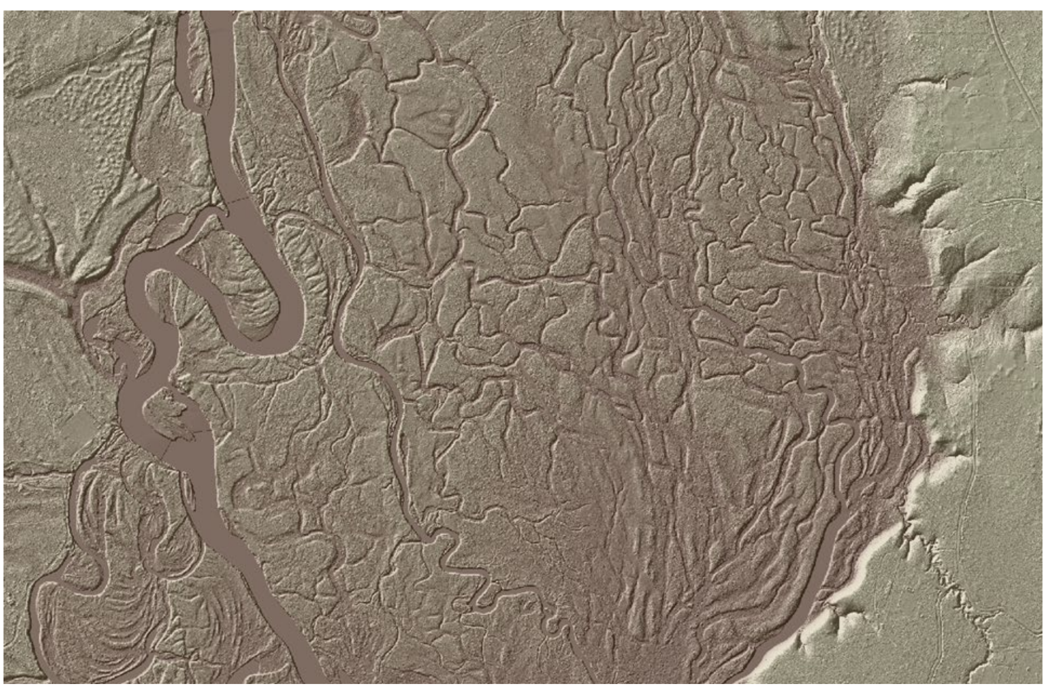


**Figure 16.** An area with multiple braided channels visible in the elevation surface.

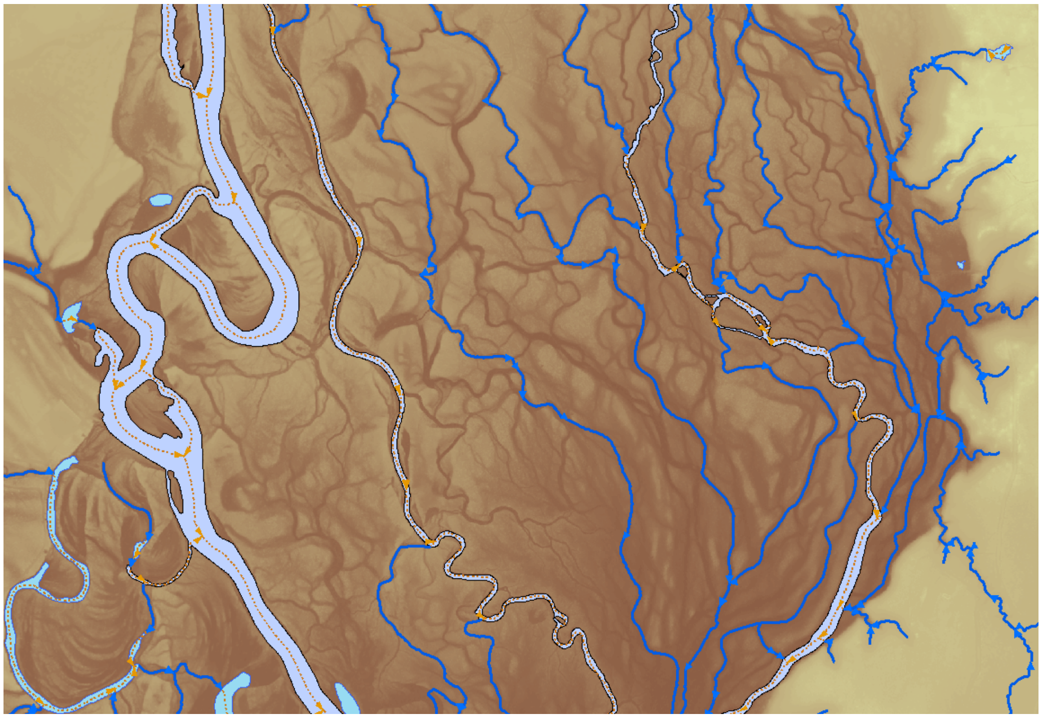


**Figure 17.** The minimum number of Stream/river features delineated to represent a braided channel system.

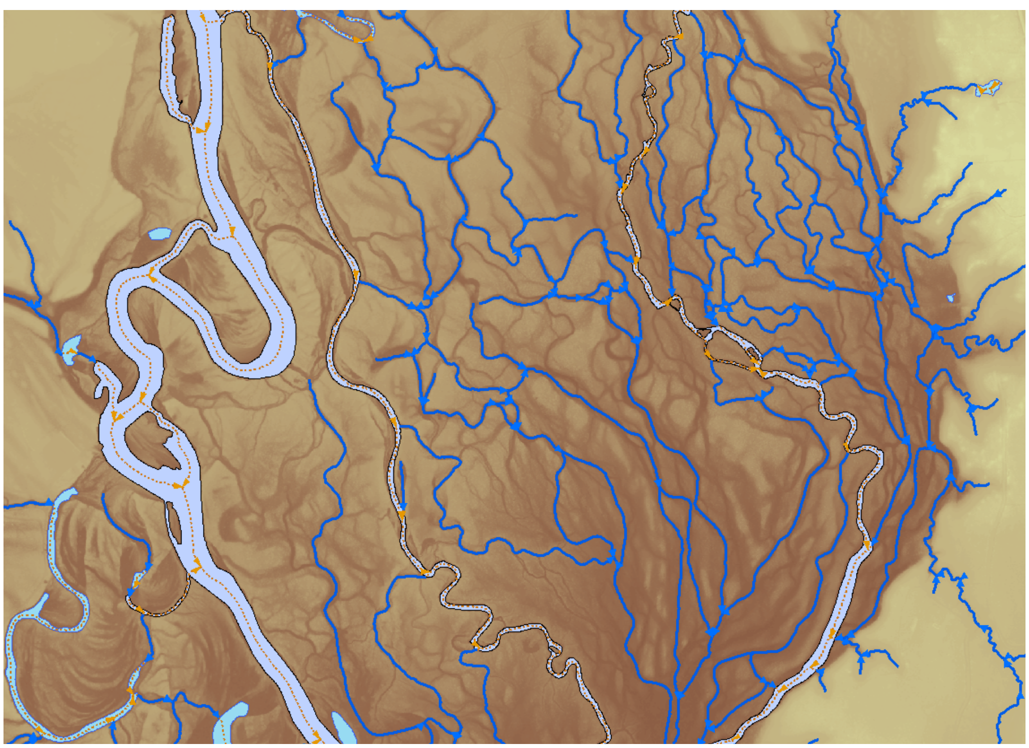


**Figure 18.** A denser representation of stream features within a braided channel system.

## Low Relief Areas

In areas with no channel deeper than one meter in lidar or two meters in IfSAR below the surrounding DEM surface for 500 (lidar) and 1000 (IfSAR) meters, geomorphic derivatives indicate may indicate a channel is present, in such cases connector and Stream/river features may be placed to maintain the network but are otherwise not required (**Figure 19**). See Connector: Indefinite Surface Connector in Appendix 1 and Appendix 3 for information about connecting channelized features through un-channelized terrain.

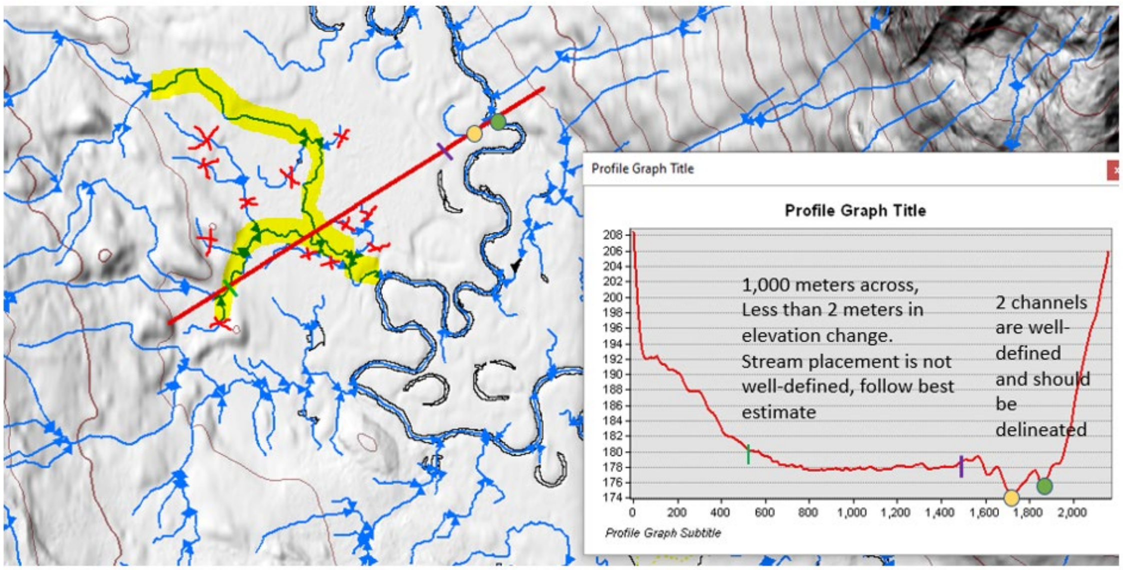



**Figure 19.** Example of multiple possible channels in a floodplain greater than 1000 meters across in a IfSAR source DEM. Channels less than 2 meters deep are not required (indicated by red Xs) unless they provide network connectivity (highlighted in yellow), but well-defined channels shall be placed (yellow and green dots).

## Inclusion or Omission of NHD Waterbody Features

When developing elevation-derived hydrography for delivery to the USGS, waterbody features from the NHD shall be represented in the final hydrography network (**Figure 20** and **Figure 21**. All updated features included for delivery shall be delineated in accordance with elevation-derived hydrography specifications and requirements.

Additional waterbody features not present in the NHD may be captured if they are a) present in the hydroflattening breaklines and meet the minimum size requirements, or b) present in the elevation surface and meet the minimum size requirements for capture of that feature type. (Appendix 1).

- All NHD Waterbody features that are:
  - Greater than 2 acres in a DPA using IfSAR-source DEMs, or 0.25 acres in a DPA using lidar-source DEMs and are also found in the hydroflattening breaklines shall be included in the final delivery to the USGS.

    - Greater than 2 acres in a DPA using IfSAR-source DEMs and were not found in the hydroflattening breaklines shall be exported to a NHD waterbody omission geopackage with a comment explaining their omission.
        - In a DPA using IfSAR-source DEMs, if a waterbody is hydroflattened or otherwise discernible, and does not contain a breakline, it may be added to the elevation-derived hydrography delivery but is not required.
    - Greater than 0.25 acre in lidar-source DEMs that were not found in the hydroflattening breaklines and:
        - Detectable on the elevation surface shall be appropriately delineated and included in the final delivery to the USGS, or
        - Not detectable shall be exported to a NHD waterbody omission geopackage with a column explaining their omission.
- NHD Waterbody features less than 2 acres in IfSAR-source DEMs or 0.25 acre in lidar-source DEMs are not required to be included in the final delivery. Some projects may have special capture conditions approved by the USGS.
- Add notes to the exported NHD waterbody features, in a text field named "Comment," 255 characters in length, explaining why the NHD waterbody features are excluded, including in the following cases:
    - If the NHD Waterbody feature in a different, non-overlapping location, it shall be noted that the feature is in present but in a new location.
        - Comment: "NHD waterbody included in updated location."
    - If the NHD Waterbody feature is no longer present on the DEM it shall be noted that the feature no longer exists.
        - Comment: "NHD Feature not present on elevation surface."
    - If the hydroflattening breakline overlapping the NHD Waterbody feature is less than 2 acres in IfSAR-source DEMs or 0.25 acre in lidar-source DEMs, it shall be noted that the corresponding breakline does not meet the minimum size capture conditions.
        - Comment: "The breakline corresponding to this NHD Waterbody does not meet the minimum size capture conditions."
    - If the NHD Waterbody feature is less than 2 acres in IfSAR-source DEMs or 0.25 acre in lidar-source DEMs, it does not meet the minimum size capture conditions and does not need to be exported or documented.
    - Other reasons not listed here shall be noted and explained in detail in the collection report.
        - Use a standardized comment throughout delivery if the condition occurs more than once.

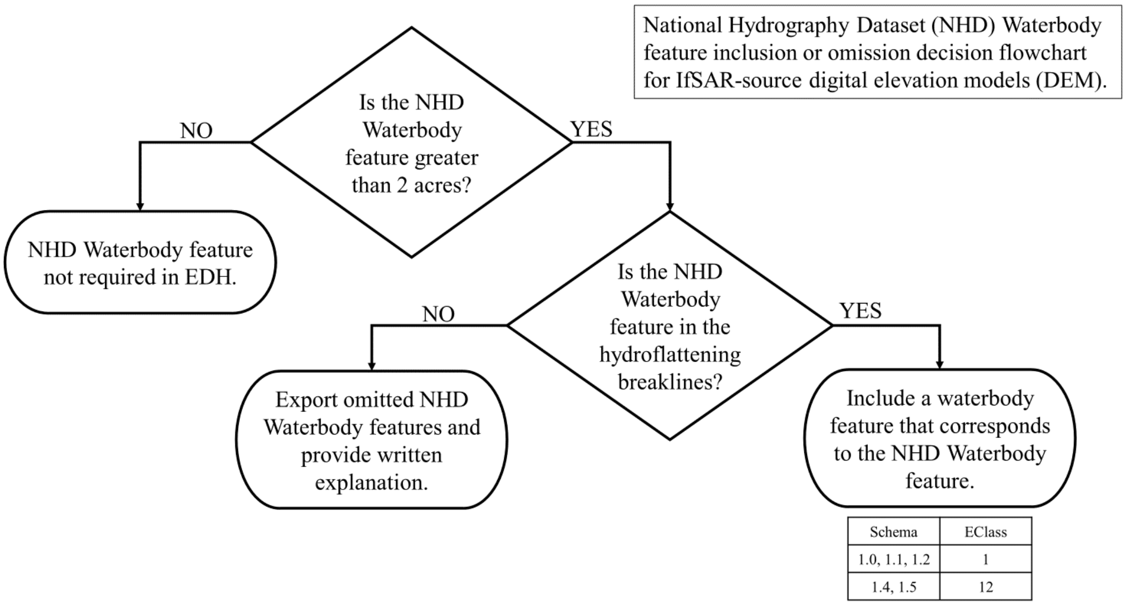



**Figure 20.** NHD Waterbody feature inclusion or omission decision flow chart for IfSAR-source DEMs. EClass coding included.

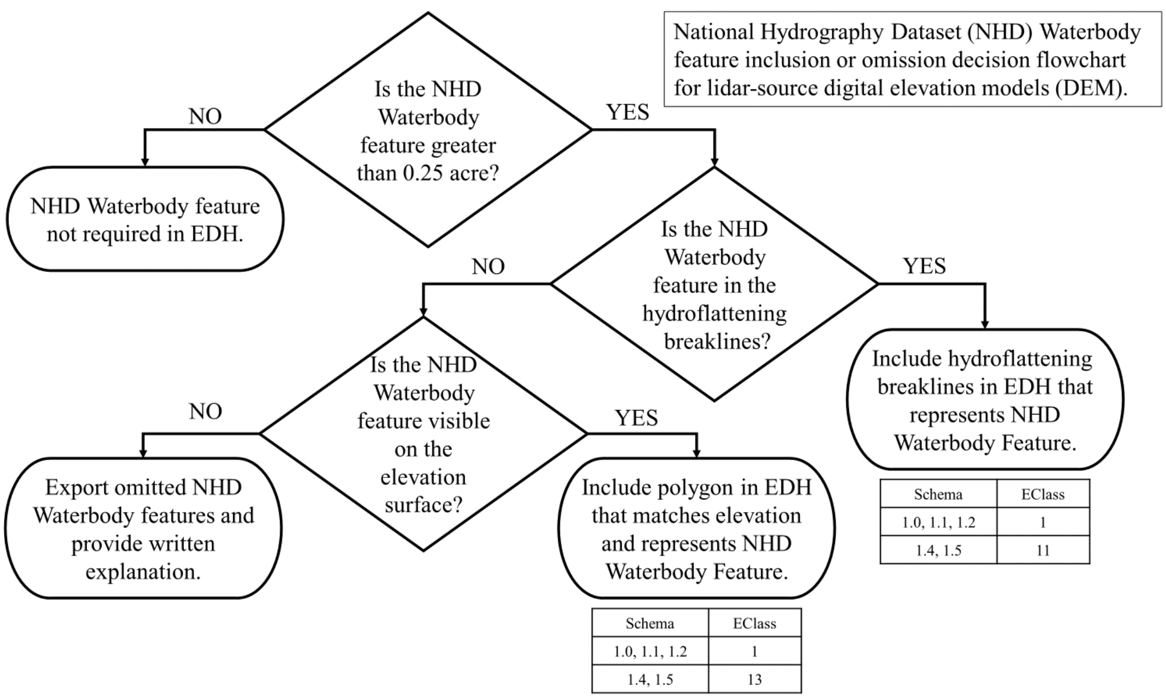



**Figure 21.** NHD Waterbody inclusion or omission decision flow chart for lidar-source DEMs. EClass coding included.

## Infrastructure Areas

Connector (33400) features shall be used to connect hydrographic features in areas where there is no clear channelization or flowpaths and evidence of built environments on the elevation surface (**Figure 22**). These Connector features shall be used where subsurface stormwater systems or long pipes are used to divert water underground for short to relatively long distances. In developed or urban landscapes Connector features to traverse areas where subsurface paths and connections are unknown. A Connector feature provides the approximate location of subsurface infrastructure connectivity so that the hydrography network can be continuous between upstream and downstream visible channels.

- If subsurface stormwater systems are available, the primary path through subsurface infrastructure can be included as the infrastructure connector.
    - Secondary or minor subsurface connections should not be coded as part of the network and shall be coded as FClass = 2, EClass = 0.
- The Connector feature shall pass through a developed area likely containing a subsurface pipe and/or stormwater system where the subsurface connections are not known.
    - Comment field shall contain "Infrastructure - unknown subsurface connection."
    - FClass field shall equal 1 (Hydrographic feature defined within the collection criteria of the elevation-derived hydrography specifications.)
    - EClass field shall equal 3 (Linear feature used for breaching.).
- If subsurface connections are mapped and available as ancillary data, the primary path between features within channels on the elevation surface should be used.
    - Comment field shall contain "Infrastructure - subsurface connection."
    - FClass field shall equal 1 (Hydrographic feature defined within the collection criteria of the elevation-derived hydrography specifications.)
    - EClass field shall equal 3 (Linear feature used for breaching.).
- The elevation of the downstream end node shall be at or below that of the upstream start node within the network to maintain downstream monotonicity (FlowClass = 1).
- Any surface channelization shall be captured as the appropriate FCode, with limited use of Connector features to provide network connectivity.
- If prominent ditches or canals are on the elevation surface and divert water around obstructions, capture those as Canal/ditch features rather than placing connector features used for infrastructure through a developed area. Canal/ditch features can connect to Connector features used to traverse infrastructure to create flow connectivity.
- Connector features used to connect flow infrastructure through areas with infrastructure:
    - May connect features with channelization at an upstream point, through developed areas with no channelization, to downstream features within channels on the elevation surface.
    - May be used to connect through large buildings or parking areas.
    - Shall not be used if it is unlikely that the connection has underground stormwater pipes.

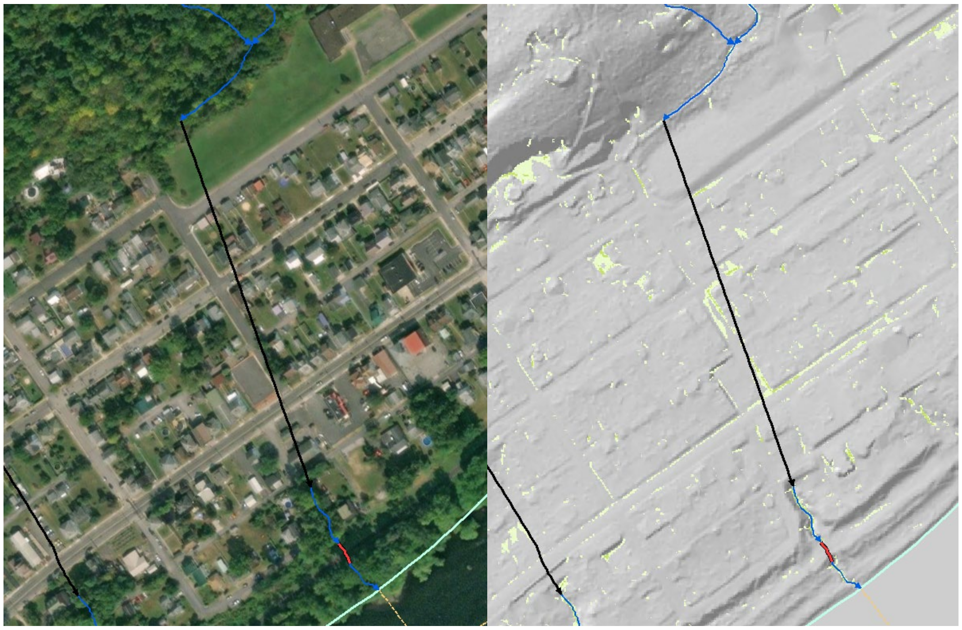


**Figure 22.** Example of a Connector used to connect infrastructure through an area with little channelization and developed landcover. Blue lines represent stream features, black lines represent infrastructure Connector features, and red segments represent Connector: Culvert features.

The Connector feature used to connect flow through infrastructure is not used:

- To traverse transportation features (see Connector: Culvert) unless the transportation features are within a densely developed area. See **Figure 22** for an example of roads traversed by an Infrastructure Connector.
- To bypass evident natural channelization in a developed area or urban setting. This connector type can link the network through large buildings, parking areas, or through urbanized areas.

## Ice Masses

A drainage network may need to be delineated in areas with ice masses (glaciers). In most cases, a channel will not be detectable through an ice mass, so a Connector: Indefinite Surface (FCode 33404) feature shall be used to for connectivity (**Figure 23**). If a Connector: Indefinite Surface feature is used, include a comment stating, “Ice Mass Connectivity.”

If a channel is detectable, a Stream/river feature (FCode 46000) shall be used following the standard requirements for Stream/river features specified in Appendix 1.

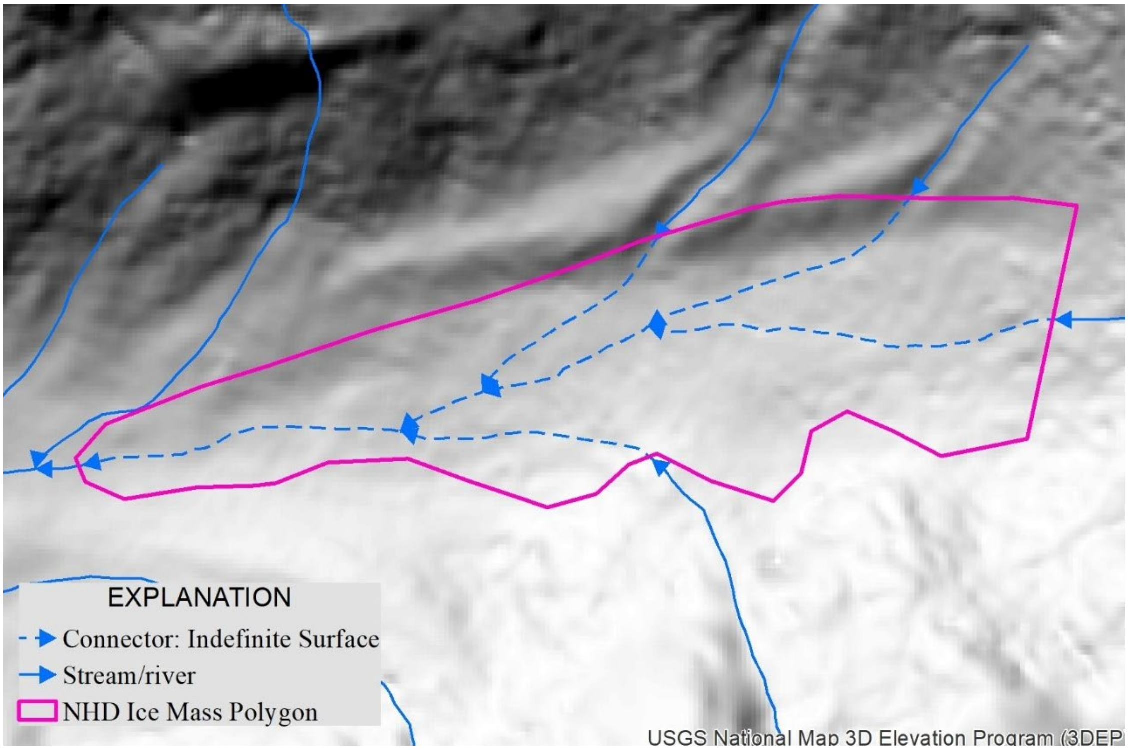



**Figure 23.** Example of Connector: Indefinite Surface (FCode 33404) features delineated through an NHD ice mass.

If the ice mass creates a rise in elevation and it is necessary to connect upstream and downstream features through the ice mass area, use a Connector: Indefinite Surface feature from the base of the rise to the point where flow begins to go downhill again. If a Connector: Indefinite Surface feature is used in this manner, include a comment stating, "Ice Mass Connectivity. Monotonicity cannot be enforced."

The presence of ice masses in a collection area shall be documented in the collection report, including the source used to identify ice mass and the imagery date or the date the source was accessed. The recommended ancillary data source for glaciers and ice masses is the Randolph Glacier Inventory, A Dataset of Global Glacier Outlines, Version 7, National Snow and Ice Data Center (nsidc.org). Current imagery or NHD may also be used to identify ice mass areas.

## Lines Crossing Ridges

Delineated elevation-derived hydrography shall not cross areas where the surface elevation is higher than surrounding cells. Elevation-derived hydrography shall follow channels and flow paths lower than surrounding terrain.

Elevation-derived hydrography lines crossing over ridges can create watershed delineation issues. To avoid this, ridges should be identified using geomorphic derivatives and intersected with elevation-derived hydrography lines to see if the lines cross ridges (Appendix 3).

In some cases, a line crossing a 'ridge' may require a Connector: Terrain Breach features. In other cases, it may indicate a misaligned line and delineated on an adjacent slope. In the most serious case, it shows a line has been derived crossing a ridge and flowing into an adjacent channel. Ideally these ridge areas will be identified and avoided as hydrography lines are generated, and algorithms can be optimized to avoid placing lines that cross over ridges.

Caution should be used in calling these 'errors'; IfSAR and lidar surfaces contain many artifacts and scattered 'ridge' cells may be anomalies in the surface that are not necessary to avoid.

If streams are crossing ridges, as indicated by geomorphic derivatives, they should be evaluated to determine if they are a problem. Removing single or small clusters of or two or three 'ridge' cells from the geomorphic derivatives will help reduce probable artifacts.

## Coordinate Precision

Coordinate precision is used to define the cluster tolerance for the dataset's x, y, and z domains. The coordinate precision for elevation-derived hydrography shall be 0.001 meters.

## Topology

Topology is a set of rules and behaviors defining the spatial relationships between features in a geospatial dataset. The 3DHP relies on the topology of features in the hydrographic network to maintain a continuous network and support functions such as network navigation.

### Topology Rules

- Remove vertices that are less than 1.5 m apart.
    - Do not compromise correct feature placement on to the elevation surface by removing more vertices than necessary.
    - All features shall have a smooth, non-rasterized appearance while maintaining correct horizontal and vertical position relative to the elevation surface.
- Split all line features at polygon boundaries.
    - Code flowlines within a waterbody polygon as Artificial path (FCode: 55800)
    - Artificial path features must be completely within the waterbody polygon, starting and ending at the nodes that are coincident with inflowing and outflowing features.
- All line features shall be one segment, with no breaks within the feature.
- All interacting features shall have a node (a start/beginning, or end/terminating, vertex) at any intersection or confluence of more than one feature.
    - Features that change FCodes within a flowline segment shall be split at that point.
    - Intersecting line features shall be split at that intersection, unless there is evidence the features do not interact (for example, where a pipeline crosses a Stream/river feature).

  - Lines meeting polygons shall be split at the polygon intersection point. The start and end nodes shall exist on the polygon boundary at the connection. Avoid splitting the polygon feature.
  - Artificial path features within a polygon shall have an end or start node snapped to incoming linework. The start and end nodes shall exist on the polygon boundary at the connection. Avoid splitting the polygon feature.
  - No lines shall have self-intersections or cutbacks.
  - Polygon features shall not overlap but may share edges.
- Linear features of the dataset shall create a complete network.
  - Flow shall move from upstream to downstream.
    - Elevation values shall descend from upstream to downstream.
  - All hydrographic features within the DPA shall be collected, regardless of their outflow location. This may create isolated network features.
  - Isolated pieces of the network may be present if a sink or other known break in the hydrologic network exists.
    - A Sink point shall be used to identify these locations.
  - If a full network cannot be delineated, a comment is required in the collection report.
  - No network loops are allowed.
  - At the inlet and outlet of the FDPA
    - Lines shall be snapped to the FDPA.
    - Polygons shall be coincident with the FDPA.
- Line features smaller than 1.5 m shall be removed or merged with a longer feature.
- All features shall have a complete set of attributes associated with them.
- Line features shall not have a valency greater than five at junctions.

## Topological Relationships Between Elevation-Derived Hydrographic Features

Elevation-derived hydrographic features must be ordered to ensure correct topological relationships, and the order can be determined by the coincidence of start and end nodes, as well as polygons and lines. The following is a list of common required topological relationships but is not exhaustive of all relationships (**Figure 24**).

Correct Feature Relationships:

1. The end node for a Drainageway feature must be coincident with a start node of a downstream linear feature excluding Connector: Indefinite Surface.
2. A Drainageway feature must be a headwater or connected to a headwater drainageway feature, and end where a channel is detectable on the elevation surface. Headwater Drainageway features may have an end node coincident with another Drainageway feature’s end node or start node.
3. A Connector: Culvert may split a Drainageway feature. Headwater Drainageway features may have a start or end node coincident with a culvert start node, and the Drainageway may continue downstream of the culvert, having a start node coincident with the upstream culvert end node.

4. A culvert connector is not considered a feature within a channel that would signal the end of an indefinite surface connector classification. Stream/river, Connector: Indefinite Surface, and Connector: Culvert features may have start and end nodes coincident with other Stream/river, Connector: Indefinite Surface, and Connector: Culvert features start and end nodes.
5. Waterbody polygon features must be coincident with Artificial path features if part of the stream network. Artificial path features must have a start and/or end node coincident with another linear feature. Headwater and outflow waterbodies must have Artificial path features starting in the middle of the waterbody feature.
6. Waterbody polygon features may be isolated from the stream network and are not coincident with any other features or nodes. Isolated waterbodies shall not have an Artificial path.
7. Waterbody features may be situated as the outlet of a network with no outflow from the waterbody. For such terminal waterbodies, the upstream Stream/river feature's end node coincident with an Artificial path start node within the waterbody. The Artificial path end node would be situated in the middle of the water body and would be coincident with a Sink point.

Incorrect feature relationships:

8. Drainageway features may not have end nodes coincident with Connector: Indefinite Surface start nodes. A Drainageway becomes another feature type when it encounters a detectable channel on the elevation surface.
9. Stream/river features may not have an end node coincident with a Drainageway start node. A Drainageway is always a headwater feature. A Connector: Indefinite Surface should be used downstream of a channelized feature.
10. Waterbody polygon features must contain Artificial path features to connect to downstream features, unless isolated from the stream network.
11. Drainageway end nodes may not connect to the start node of a culvert that has an end node connecting to the start node of a Connector: Indefinite Surface. A culvert does not signal a change in feature type (see topological relationship 3 above).
12. If a Stream/river feature and a Drainageway have coincident end nodes, there cannot be a Drainageway downstream. Once a Drainageway encounters a channelized feature (Stream/river or Canal/ditch), any unchannelized feature downstream must be coded as a Connector: Indefinite Surface.

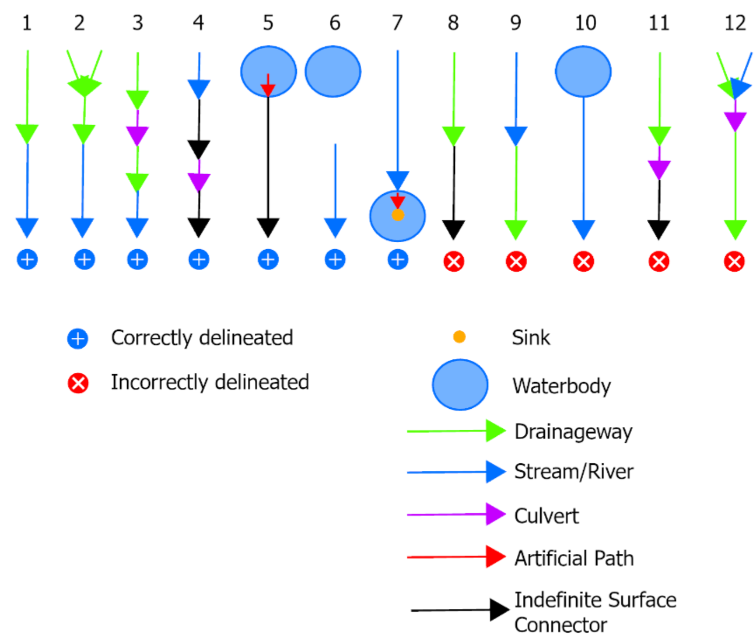



**Figure 24.** Topologic relationships between elevation-derived hydrographic features.

### Z-Values

- Features shall be delivered in file geodatabase, format as pointZ, polylineZ, or polygonZ feature classes.
- All features shall conform to the georeferenced information defined in the "Spatial Reference System" section of this specification.
  - A file with appropriate projection information shall accompany all hydrographic feature deliveries.
- At all intersections, regardless of feature type, the geometry of intersecting vertices shall match with 0.001 meters in x, y, and z, unless there is no evidence of interaction between the features (for example, pipelines).
- Features used to breach surface terrain features (EClass = 3) shall have the elevation values of the connecting features at the end points. The elevation values of the surface above the Connector: Culvert, Connector: Terrain breach, Connector, or Pipeline shall not be used.

## Positional Assessment

The goal of the positional assessment is to create a hydrography product that is vertically and horizontally integrated with the 3DEP bare-earth DEM. The elevation-derived hydrography's positional assessment is always measured against the bare-earth DEM source.

### Elevation-Derived Hydrography Positional Evaluation and Reporting

Ideally, all features, or as many features as possible, should be visually inspected to make sure that they meet the requirements described in this specification. If a complete review is not feasible, a stratified random sample may be used to select a subset of features to evaluate the accuracy of the dataset.

For a holistic review of the dataset, the features reviewed should be:

- Representative of all features in the dataset, so they should contain at least one feature for each EClass and FCode present in the dataset.
- Representative of the complete geographic area of the dataset,
- Representative of special cases that make up features, including, but not limited to:
  - Headwaters
  - Confluences between Stream/river reaches.
  - Intersections with polygons and stream features
  - Canal/ditch features
  - Isolated networks
  - Drainageways
  - Intersections near roads
  - Culverts
  - Islands within polygon features
- Representative of land cover and geologic types or geo-physical regions, including but not limited to:
  - Urban areas
  - Low slope areas

## Positional Assessment and Reporting

Positional assessment results shall be reported for vertical and horizontal geometry of the hydrographic features relative to the 3DEP bare-earth DEM (see hydroflattening exception below).

- Positional assessment indicates how accurately vector hydrographic features are positioned relative to the feature as represented on the DEM.
- This measure is always represented as meters (plus or minus).

## Hydroflattening Polygon Exception

- An exception to the reporting requirement is for vertices that have been adjusted to maintain monotonicity for hydroflattening.
- Vector features used for hydroflattening must follow the requirements of the LBS.
- Vector features used for hydroflattening shall be integrated into the elevation-derived hydrography dataset and follow the Elevation-Derived Hydrography Acquisition Specifications except for positional assessment and reporting requirements.

## Vertical Positional Assessment of Hydrographic Features Relative to the DEM

- All lines and water-surface edges shall be at or just below the elevation value of the immediately surrounding terrain, within the vertical tolerance (**Figure 25**).
    - Exceptions to this requirement are features that are used to breach surface terrain (Connector: Culvert, Connector: Terrain breach and Connector features), Underground Conduits, and overland pipelines (Pipeline features).

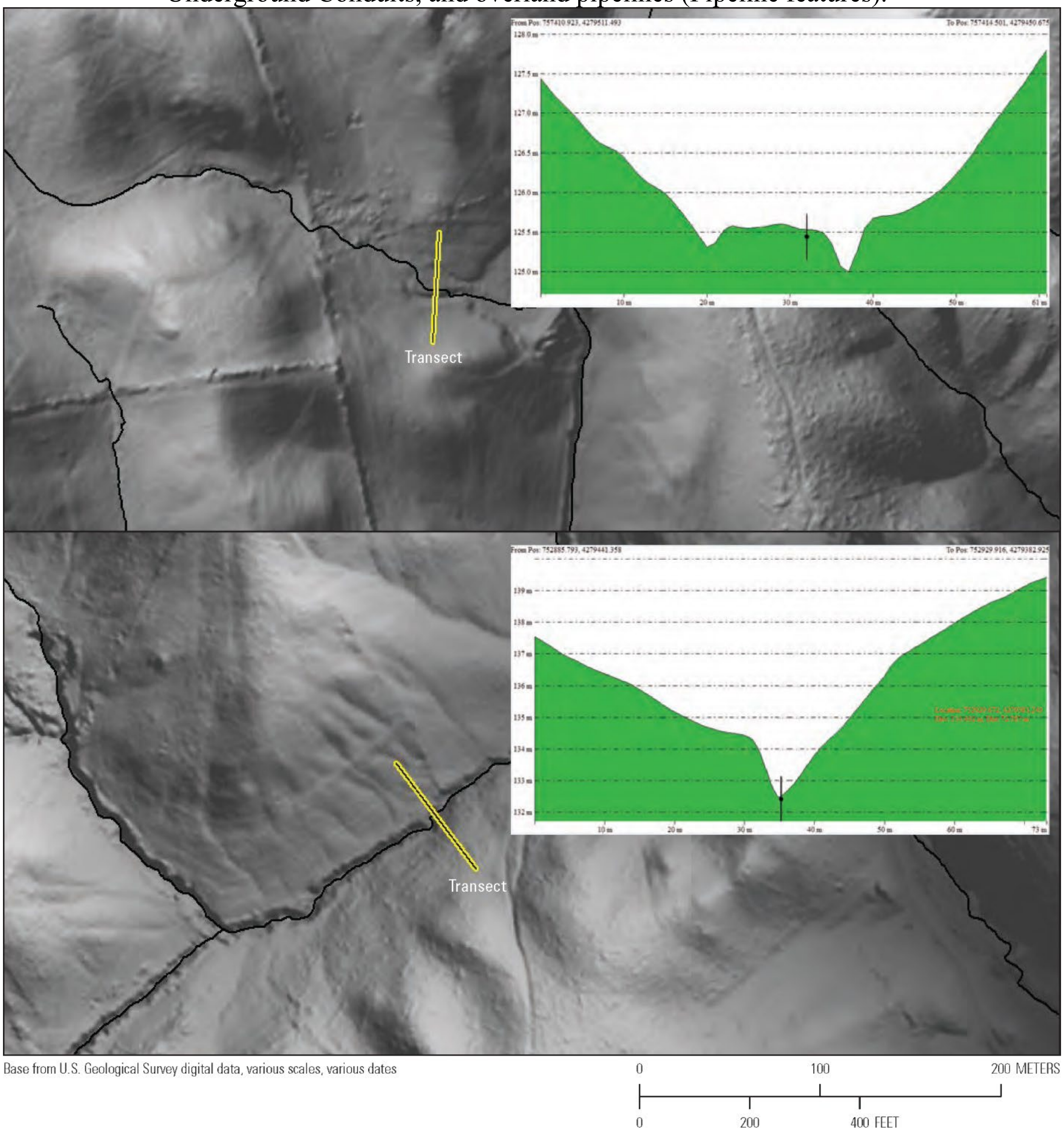



**Figure 25.** Two cross-sectional views of transects intersecting two Stream/river segments. A. This Stream/river segment has deviated horizontally from the main channel but is still vertically integrated with the elevation surface. B. This segment is well integrated vertically and horizontally with the lidar-derived surface. Both segments' elevation values are within 0.1 meter of the surface elevation values.

## Horizontal Positional Assessment of Elevation-Derived Hydrography

The horizontal positional assessment evaluates the placement of vector hydrographic features against the bare-earth DEM from which they were derived. Linear, polygonal and point features shall be within the specified tolerances for the feature type as detected on the elevation surface, as follows.

### Linear Features

Stream and other linear channel features shall stay within the apparent channels in the elevation data and shall not leave the channel.

### Polygonal Features

Lake/pond and other polygonal features shall match the apparent boundary of the feature in the elevation data and shall not vary from the boundary of the feature.

### Point Features

Point features shall remain within 3 meters of the apparent location of the feature in the elevation data.

## Digital Elevation Model (DEM) Limitation

Elevation data may contain limitations that make it unsuitable for deriving hydrographic data, making it difficult or impossible to accurately portray hydrography that aligns with the elevation surface and reflects true ground conditions. If portions of the DEM are unsuitable for the derivation of hydrography, a polygon surrounding the area shall be provided to the USGS. The polygon shall be accompanied by written justification explaining why hydrography could not be derived in that area.

Note, that the DEM Limitation polygon is intended to identify areas where the DEM is unsuitable for deriving hydrographic feature. It is not intended to be used for individual stream segments with small surface obstructions.

General characteristics of areas with DEM limitations include:

- High degree of roughness (degree of irregularity of the surface) rendering channels indiscernible.
- Channels that cannot be discerned over continuous areas.
- Channels visible in imagery or orthorectified radar intensity (ORI) images but cannot be modeled with geomorphic derivatives or similar analysis of the elevation surface.
- A continuous drainage network that cannot be modeled over the area.

If DEM Limitation polygons must be used, the NHD may be compared against the elevation-derived linework to help determine the extent of the DEM Limitation area and appropriate representation of flow through the area. In cases of significant discrepancies between the elevation-derived linework and NHD, the linework shall be reviewed against the source DEM and high-resolution imagery. The imagery shall be acquired within 10 years of the date of the elevation collection and its resolution must be within three times the resolution of the source elevation. Contact the USGS for further guidance if imagery with an appropriate resolution is not available. This review is intended to verify that the elevation data is of inadequate quality to derive linework and that the NHD or imagery better represents the flow path.

### Delineating Features in Areas with DEM Limitations

Two methods are available for delineating hydrographic features in an area with DEM Limitations: by incorporating the NHD data into the elevation-derived hydrography network, or by using a current imagery source to delineate the stream network. The choice of method shall depend on the date and accuracy of the NHD or imagery (ORI), as well as the level of effort involved. Consult the USGS if further guidance is required.

### Delineating the DEM Limitation Polygon

For both methods of hydrography delineation within a DEM limitation polygon:

- A DEM Limitation polygon shall be:
  - Delineated around areas where the drainage network is difficult to derive given the quality of the elevation data source.
  - Stored as a feature class in the spatial metadata geopackage deliverable.
- DEM Limitation polygons shall not be delineated around a single feature or small number of features. They are meant to report areas where alternate hydrography delineation methods are necessary due to significant issues with bare-earth classification or surface artifacts in the DEM.

### Features within the DEM Limitation Polygon

- Follow all topology rules and relationships in this specification.
- Monotonicity shall be maintained to ensure the inlet and outlet features inside the DEM Limitation polygon have z-values appropriate to maintain monotonicity through the rest of the hydrographic network.
  - Vertical tolerance will not be enforced within a DEM limitation area.
  - End points of features flowing into and out of the DEM limitation polygon must match in x, y, and z values.
- Document the source and method in the metadata and collection report.
- Assign Limitation field a value of 1.
- Add appropriate description in Methods field.

### Use of NHD to Capture Hydrographic Features in Areas with DEM Limitations

- Evaluate the NHD in areas where the DEM Limitation polygon is being used and if the NHD is better than what could be produced using standard drainage network derivation methods, use it in place of derived linework.
- Add “NHD” as the Source field.
- Apply z-values to NHD feature vertices using guidance from section above.

#### Use of Imagery to Capture Hydrographic Features in Areas with DEM Limitations

- Identify a suitable imagery source for delineating hydrographic features.
    - Imagery resolution shall be within three times the cell size of source elevation.
    - Imagery shall be collected within 10 years of the elevation capture date.
- Add “xxx Imagery” as the Source field, where xxx refers to the name of the imagery product used to define hydrographic features.
- Apply z-values to vertices using guidance from section above.

#### Density in Areas with DEM Limitations

If DEM Limitations affect the ability to reach the predicted density for the area, document the issue in the collection report.

## Alignment

Alignment specifications describe the geometry and placement of features. It is important that all features collected shall be logically and spatially consistent with the elevation data both horizontally and vertically. Features shall also be spatially consistent with NHD features, where appropriate (if an existing feature is spatially correct and will remain unchanged).

### Horizontal Alignment

- New features shall align appropriately with NHD features outside of the collection area, for instance, if a stream is added to an existing channel, it shall be as close as possible to the stream network nodes. See Collection Area.
- Features shall be aligned according to topology rules.
- Features shall be snapped within 0.001 meters across elevation tile and project boundaries in horizontal and vertical (x, y, and z) spatial dimensions (see coordinate precision). Data shall be sufficient to pass all USGS validation tests against these specifications.
- Lines
    - Lines shall generally be oriented from upstream to downstream, although some exceptions exist (see Special Cases).
    - No lines shall have pseudo nodes (other than headwater beginning nodes) or breaks within reaches.
    - Intersections with other features shall be within 0.001 meters of each feature’s vertices.

    - At all intersections, regardless of feature type, the geometry of all coincident start and end nodes shall match within 0.001 meters in x, y, and z (see coordinate precision).
    - Features shall align horizontally with the bare-earth DEM they were derived from, within the positional assessment limits described in the "Horizontal Positional Assessment" section (**Figure 26**).
- Polygon
    - If a polygon is incomplete because it is on the boundary of the collection area, it shall be coincident with the outer extent of the FDPA.
    - Where Lake/pond and Stream/river boundaries coincide with a hydroflattened surface, the 3DEP hydroflattening breaklines can be used directly as waterbody polygons.
        - The boundary shall represent the hydroflattened surface cartographically and be smoothed to remove a rasterized appearance, while maintaining a representation of the hydroflattened surface.
        - Vertices do not need to be placed on hydroflattened cells but should closely represent the hydroflattened shoreline.
    - Horizontal discontinuities along a waterbody shoreline resulting from tidal variations during elevation data collection are retained in 3DEP final DEMs and will be reflected in the placement of Stream/river vertices.
- Points
    - The x and y coordinates of points coded as sinks placed at the end of an isolated network shall be within 0.001 meters of the x and y vertex coordinates of the end-node of the associated isolated network.

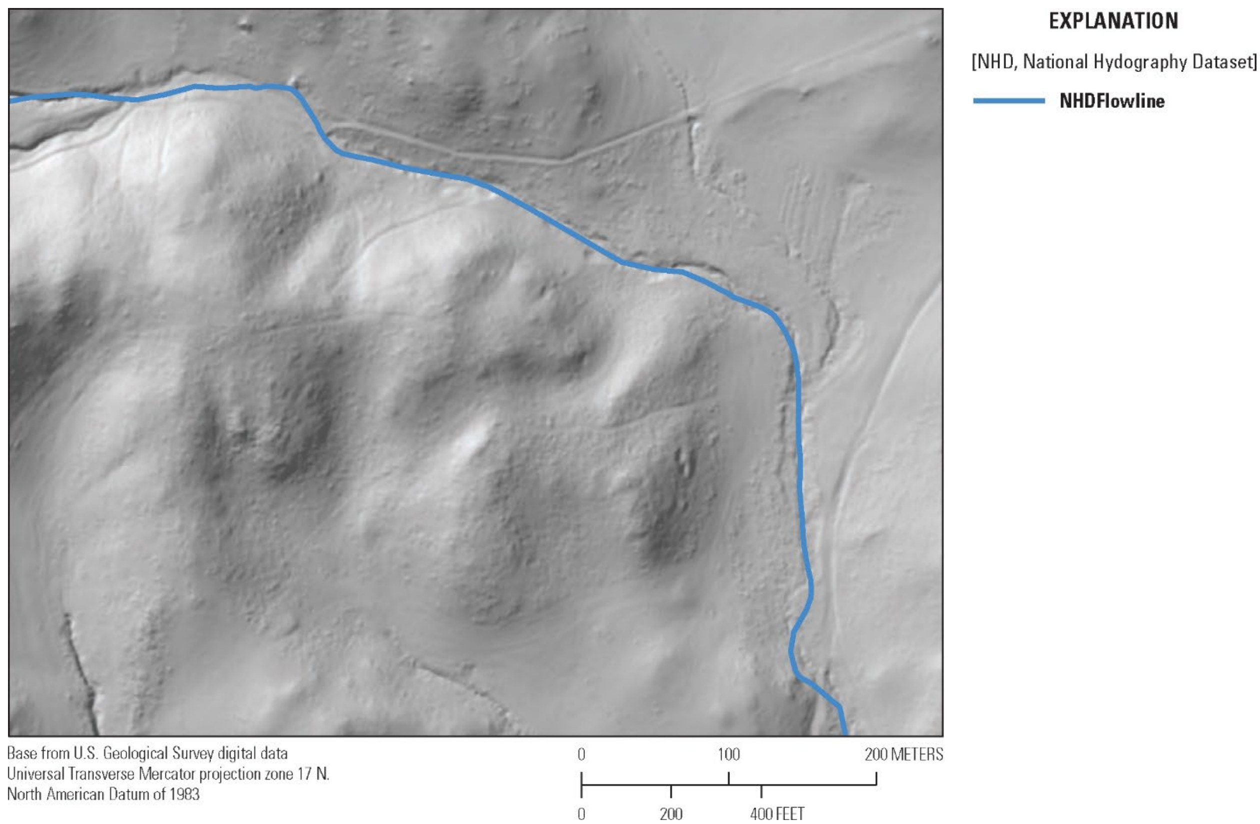



**Figure 26.** An example of poor horizontal alignment. There are many instances in which the streams (in blue) fall outside the apparent channel of the elevation-derived surface.

## Vertical Alignment

- Features shall edge match within 0.001 meters across tile and project boundaries in the vertical (z) spatial dimensions.
- Data shall be sufficient to pass all USGS validation tests against these specifications.
- Features shall align vertically with the bare-earth DEM they were derived from, within the positional assessment limits described in the "Vertical Positional Assessment" section.
- At all intersections, regardless of feature type, the geometry of all intersection vertices shall match within 0.001 meters in x, y, and z, unless there is evidence of no interaction between features. For example, pipelines over a stream may not interact.
- Lines
    - Streams must flow monotonically from upstream to downstream, with no rise in elevation. Exceptions must be identified with a valid FlowClass attribute that exempts the feature from downstream monotonicity. A comment explaining why monotonicity is not possible may be included.
        - Each vertex in a line shall be at the same or a lower elevation value than the preceding vertex in the direction of flow from upstream to downstream.

        - Change in z-values are determined by subtracting a vertex's z-value from the adjacent, connected upstream vertex's z-value.
    - The z-value assigned to vertices on linear features shall be precise to 0.001 meters. (See coordinate precision)
        - Vertical Tolerance: When the vertex's z-value is subtracted from the corresponding DEM pixel value, the absolute difference shall be:
            - Within 0.001 meters above the elevation surface, and
            - Within 1.001 meters (lidar) or 2.001 meters (IfSAR) below the elevation surface.
        - Exceptions to the vertical tolerance requirement are features that are used to breach surface terrain (Connector: Culvert, Connector: Terrain breach and Connector features), Underground Conduit feature, or overland pipelines (Pipeline features).
    - Above-ground pipelines visible on the elevation surface shall use the elevation of that surface (See Pipelines in Appendix 1).
- Polygons
    - If a polygon is incomplete because it is on the boundary of the collection area, the water surface shall be flat and level, as appropriate for the type of waterbody (level for lakes, gradient for rivers).
    - All landward water surface edges shall be at or below the immediately surrounding terrain.
    - Differences in the location of the land/sea interface caused by discontinuities from tidal variations during elevation data collection and found in 3DEP DEMs will be reflected in placement of waterbody vertices.
    - Lake/pond and Playa
        - Where Lake/pond feature boundaries coincide with a hydroflattened surface, 3DEP hydroflattening breaklines can be used directly as waterbody polygons. The z-values of the boundary vertices shall match the elevation value of the hydroflattened surface within 0.001 meters, even if not placed on the hydroflattened surface (see Supplemental Information for Polygon Vertical Alignment section).
        - If Lake/pond boundaries do not coincide with a hydroflattened surface but are within the capture conditions required for the hydrography of an area, they shall be collected. Best judgment must be used to portray the boundary relative to the Lake/pond extent on the elevation surface.
            - The z-values of the boundary vertices shall be equal to the elevation of the downstream segment's start node.
            - If the waterbody is isolated, an elevation value representative of the waterbody surface shall be applied to all the waterbody polygon's vertices. EClass shall equal 13.
        - Flattened waterbodies shall have a flat and level water surface (a single elevation for every bank vertex defining the waterbody's perimeter).
        - The entire water surface edge shall be at or below the immediately surrounding terrain (the presence of floating waterbodies will be cause for rejection of the deliverable).

        - If a polygon overlaps elevation-source boundaries that have a vertical offset, an elevation value that is equal to the lowest portion of the waterbody can be used.
            - Limitation field for the waterbody shall equal 1.
            - Artificial paths passing through the waterbody shall maintain downstream monotonicity but are not required to match the waterbody elevation value.
        - Long narrow Lake/pond features, with decreasing water surface elevations downstream shall:
            - Present a gradient downhill,
            - Follow the immediately surrounding terrain,
            - Have z-values that correspondingly decrease downstream.
    - Stream/river and Canal/ditch:
        - Boundary vertex z-values shall match the corresponding DEM pixel value within 0.001 meters.
        - Downstream monotonicity is enforced on the corresponding Artificial path feature.
        - The entire water surface edge shall be at or below the immediately surrounding terrain.
- Points
    - The z coordinate of points coded as sinks placed at the end of an isolated network shall be within 0.001 meters of the z-value of the end-node of the associated isolated network.

## Supplement Information for Polygon Vertical Alignment

### Hydroflattening Breaklines – IfSAR

Hydroflattening breaklines from the Alaska 3DEP IfSAR collection can be used directly as waterbody boundaries but must be smoothed to remove the rasterized appearance. An initial check should be performed to ensure the breaklines are spatially and temporally representative of the hydroflattened surface, particularly on borders between tiles that were merged to create the elevation surface. The polygon boundary must be an accurate representation of the hydroflattened surface. If IfSAR breaklines do not match the hydroflattened area within the elevation surface, adjustments to the breakline to better represent the lake surface are permissible. Add a comment within the ‘Comments’ field to note that the boundary was adjusted beyond smoothing any rasterized appearance. Z-values assigned to vertices shall match the hydroflattened surface elevation. EClass shall equal12.

In this example (**Figure 27**) the IfSAR breakline polygon (shown in red) was smoothed but remains an accurate representation of the hydroflattened surface. The hydroflattened surface (shown in blue) has an elevation value of 735.599 meters. The vertices of the smoothed polygon (shown in black) should also equal 735.599 meters.

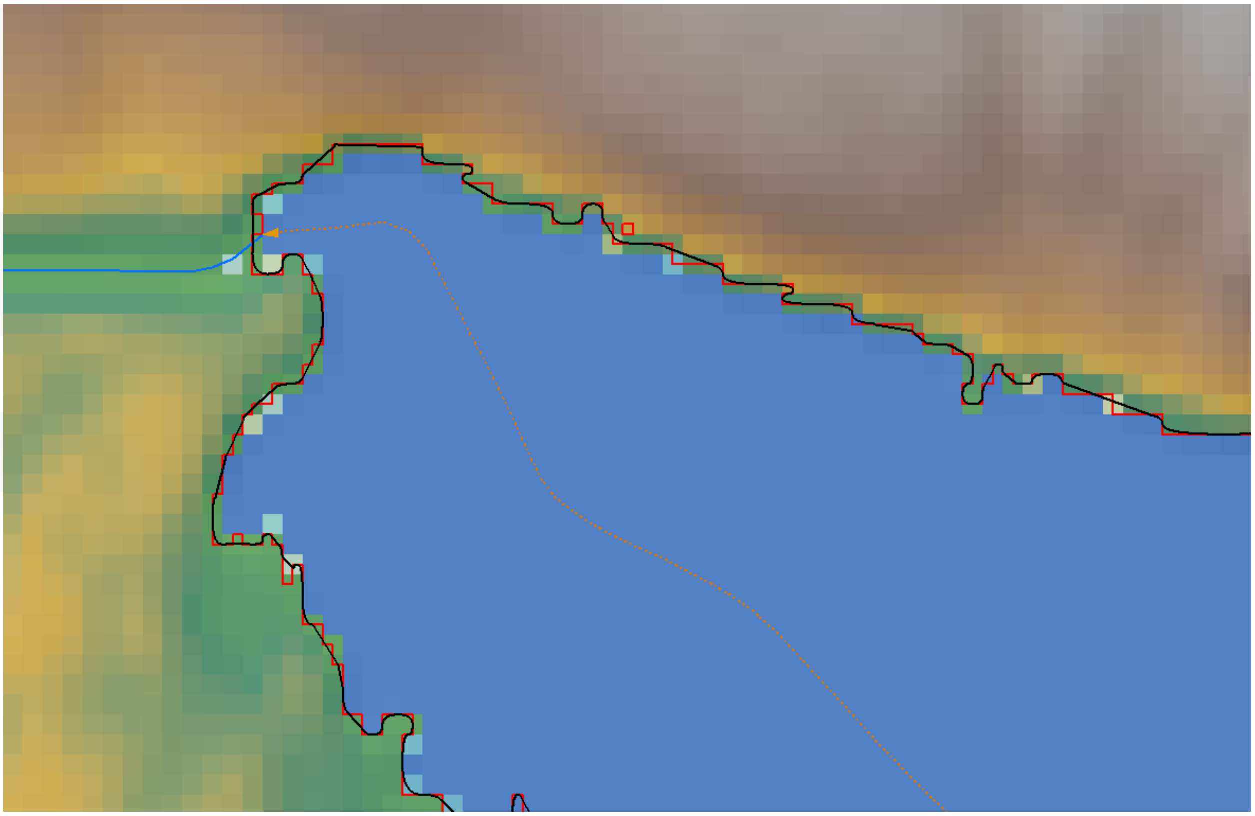


**Figure 27.** Smoothed IfSAR breaklines in black with the original breaklines shown in red.

### Hydroflattening Breaklines– Lidar Collections

Hydroflattening breaklines from a lidar collection can be used directly as waterbody boundaries. No editing or horizontal adjustments are needed if the hydroflattening breakline polygon was collected with the source 3DEP DEM and was used to hydroflatten the DEM surface. EClass shall equal 11. An initial check shall be performed to ensure the breaklines are spatially and temporally representative of the hydroflattened surface, particularly on borders between lidar projects that were merged to create the elevation surface (**Figure 28**).

If the lidar hydroflattening breaklines do not match the hydroflattened area within the elevation surface, adjustments to the outline to better represent the lake surface are permissible. EClass shall equal 12. Z-values assigned to vertices shall match the elevation of the hydroflattened surface (**Figure 28**).

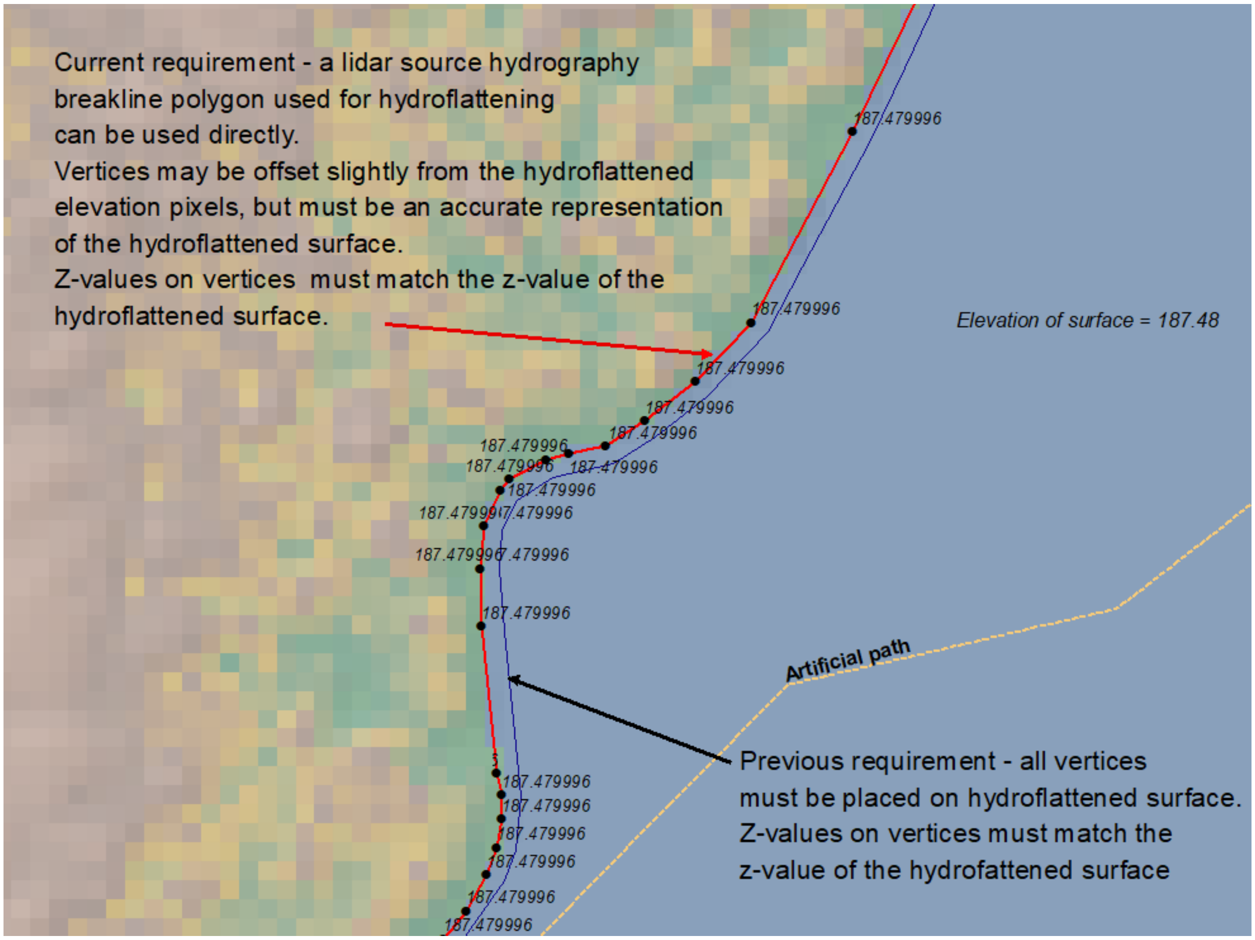


**Figure 28.** Difference between current and previous requirements to delineate polygons.

## Waterbody is Not Hydroflattened – Lidar and IfSAR

All polygon outlines for waterbodies not on the hydroflattened surface must approximate the waterbody outline based on the elevation surface. Z-values assigned to vertices shall match the start node of the downstream segment exiting the waterbody. EClass shall equal 13.

In the example below (**Figure 29**), the vertices are assigned the z-value of the downstream segment's start node, 187.1 meters. The Artificial path feature must be downstream monotonic and may slope downwards or be flat.

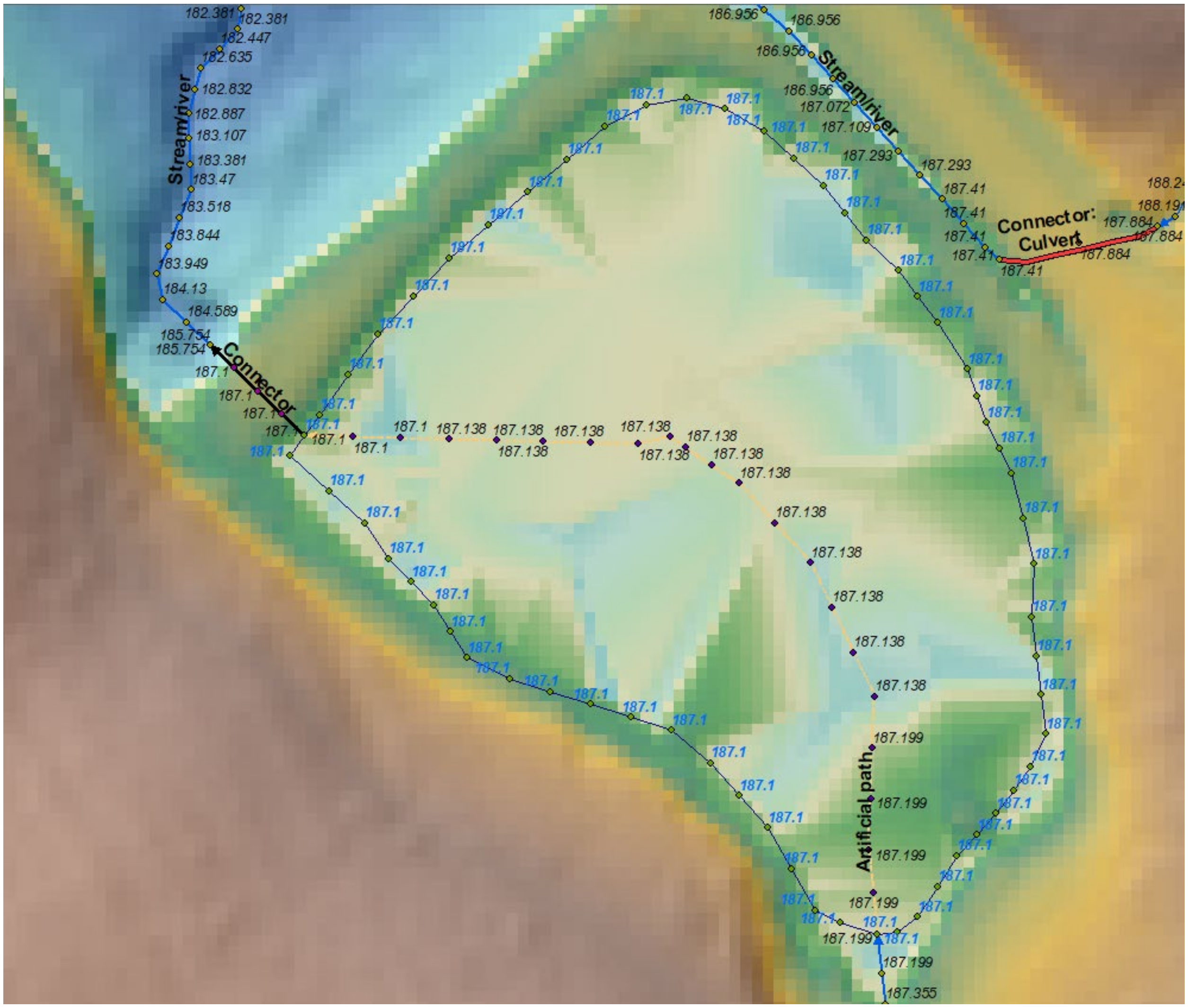



**Figure 29.** An example of an Artificial path feature maintaining downstream monotonicity. Z-values assigned to waterbody vertices are equal to the start node of the Connector feature at the outlet of the waterbody.

### Completeness

- All features shall be collected to form a complete stream network without breaks, unless there is evidence a break should occur (for example, isolated waterbodies or subterranean streamflow). All topology rules shall be followed.
- Features shall be coded with the appropriate UniqueID, FClass, EClass, FCode, Desc, source, method, FlowClass and Limitation.
- UserCodes shall be used where applicable.
- Domains shall match those specified in the Tables section and Appendix 1.

## Metadata

Two forms of metadata are required for elevation-derived hydrography deliveries.

## Elevation-Derived Hydrography File Geodatabase Metadata

- Metadata for the elevation-derived hydrography file geodatabase shall be provided in Extensible Markup Language (XML) formatted files (Bray and others, 2008) compliant with the Federal Geographic Data Committee Content Standard for Digital Geospatial Metadata (Federal Geographic Data Committee, 1998a). The USGS may offer additional or alternative metadata formats in the future.
- Metadata shall document the following:
  - Methods used to delineate features,
  - Minimum feature length,
  - Format of source elevation data (lidar or IfSAR),
  - Source of elevation data (where the data were acquired),
  - Date of source elevation data,
  - Quality level of source elevation data,
  - Ancillary datasets used, including source, date, and resolution,
  - Spatial reference system, including horizontal and vertical units, and horizontal and vertical datum used,
  - Results of relative accuracy assessment of hydrographic data,
  - Method for relative accuracy assessment,
  - Field definitions for tables associated with geospatial data (explanation of what type of information the field contains); and
  - Contact information for data collector.

## Elevation Source Spatial Metadata Requirements

The 3DEP WESM is a USGS-maintained dataset of current lidar data availability and project information, including lidar quality level, data acquisition dates, and links to project-level metadata. Information about the source elevation data shall be stored in the template provided (**Table 16**). Overlapping portions of the 3DEP polygons shall be excluded based on the methods applied to resolve overlapping elevation source data. See the Source Data Section for guidance on selecting the appropriate overlapping lidar collection (**Figure 30**). The selected 3DEP WESM polygons provided as spatial metadata shall not include portions of the polygons that were not used in the final mosaicked DEM.

The FDPA shall be used to select and incorporate polygons from the 3DEP Work-Unit Extent Spatial Metadata (U.S. Geological Survey, 2024a) and shall be used as spatial metadata to document the portions of datasets used to create the DEM mosaic for elevation-derived hydrography deliverables (**Figure 31**). The 3DHP Service should be used when creating the FDPA to avoid including any portion of features from neighboring watersheds (U.S. Geological Survey, 2023).

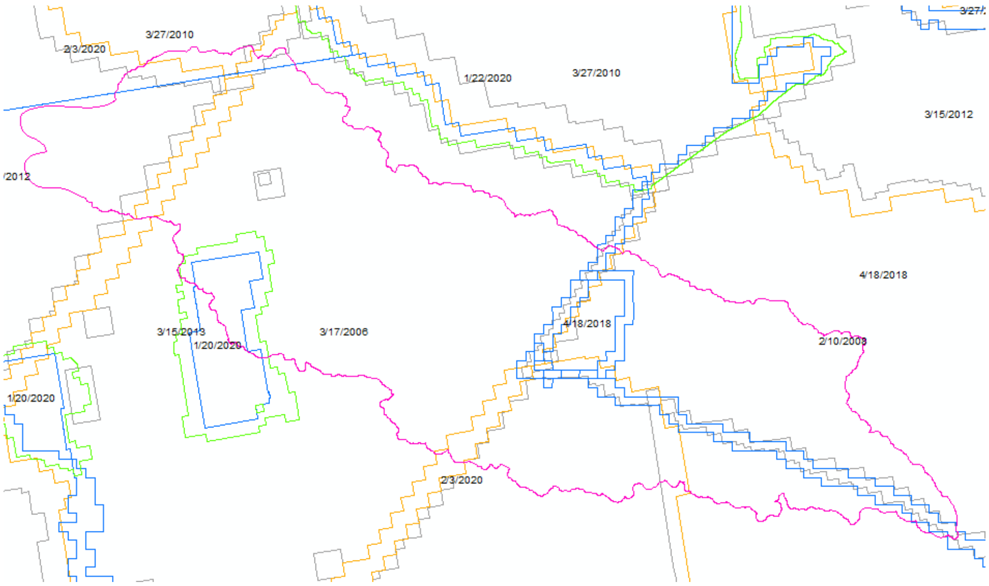



**Figure 30.** Example showing all possible 3DEP WESM Polygons available within FDPA, prior to selection.

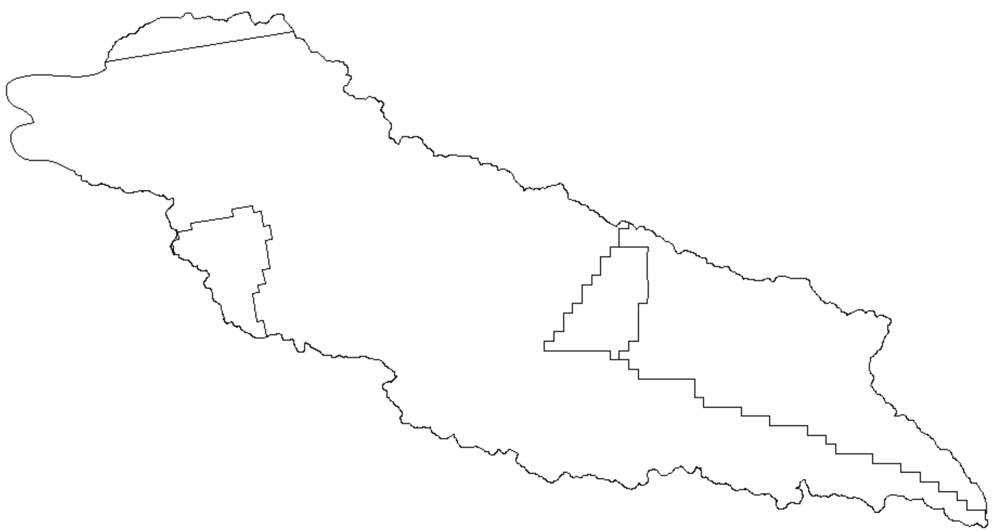


**Figure 31.** Example of selected 3DEP WESM Polygons clipped to the FDPA, with no overlap included.

If any portion of the elevation data used to derive the hydrographic data is not from a 3DEP source, provide information about the additional source in the collection report. If any portions of the DEM were found to be unsuitable for deriving hydrography, a polygon shall be drawn around the area and provide an explanation in the attribute table describing the issue (**Table 17**, **Figure 32**). See Delineating Features in Areas with DEM Limitations.

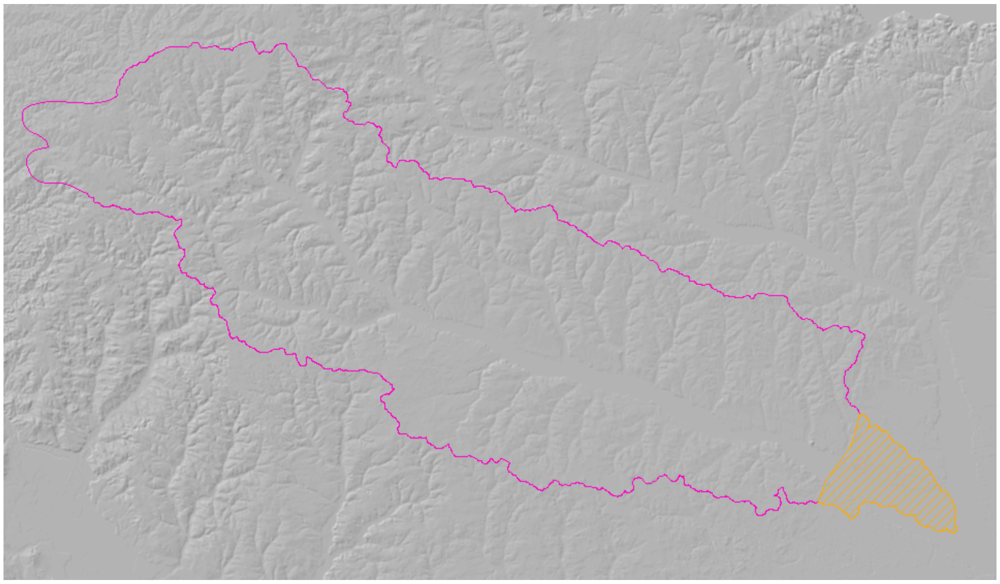


**Figure 32.** Example of a DEM Limitation polygon (orange hatched area). Explanation for use of the dataset limitation polygon would be provided in the attribute table for the feature class.

The schema name shall include the work unit name of the project for which the DPA was created.

## Delivered Products and Formats

Delivered products shall include the following:

- A geopackage containing all NHD features not captured in the elevation-derived hydrography dataset, particularly named features, as along with omitted 3DEP breaklines.
- A spatial metadata containing four layers, in geopackage format:
    - DPA: The original DPA provided to the data producers as the area to be delineated with elevation-derived hydrography.
    - FDPA: The extent of data being submitted as a deliverable. Shall be submitted as a single polygon, or multipart polygon only in cases where work unit areas are discontinuous such as islands or noncontiguous hydrologic units.
    - Elevation Project Polygons: 3DEP WESM polygons representing the 3DEP DEMs used for elevation-derived hydrography, or polygon extents for sources other than 3DEP.
    - DEM_Limitation: Boundaries of areas where there are limitations such that the DEM is unsuitable for deriving hydrographic data.
- An elevation-derived hydrography dataset shall be delivered in a current version of the file geodatabase template provided by the USGS.
- A seamless DEM from which the hydrography was derived, in GeoTIFF or GeoTIFF (COG) format.
- If available, 3DEP hydroflattening breaklines for the source elevation datasets shall be provided with the elevation-derived hydrography delivery as one polygon dataset in a geopackage.

- An XML metadata file for the elevation-derived hydrography file geodatabase, in FGDC format.
- A collection report summarizing the product, processing steps, project area, and any unusual conditions for the project area.
- A summary of any accuracy assessments completed on the data. This may be a section within the collection report.

# Tables

**Table 3.** Geometry of elevation-derived hydrographic feature types.

| Feature type | Format | Geometry |
|---|---|---|
| Point | Vector shape | 3D point, pointZ |
| Line | Vector shape | 3D line, polylineZ |
| Polygon | Vector shape | 3D polygon, polygonZ |

**Table 4.** Attribute table structure for line hydrographic features.

| Attribute description | Item name | Item | Item type | Domain | Item precision |
|---|---|---|---|---|---|
| Feature class (hydrography) | FClass | Integer | Short | FClass | 4 |
| Feature class (elevation) | EClass | Integer | Short | EClass | 4 |
| Feature code | FCode | Integer | Long | FCode | 5 |
| Description | Desc | Text | Text | -- | 250 |
| Elevation source data | Source | Text | Text | -- | 128 |
| Hydrography delineation method | Method | Text | Text | -- | 250 |
| User-defined code | UserCode | Text | Text | -- | 25 |
| Free-text space for user comments | Comments | Text | Text | -- | 250 |
| User-defined code | UniqueID | Text | Text | -- | 50 |
| Digital Elevation Model (DEM) Limitation | Limitation | Integer | Short | Limitation | 1 |
| Flow Direction Determination | FlowClass | Integer | Short | FlowClass | 1 |

**Table 5.** Attribute table structure for area and point hydrographic features.

| Attribute description | Item name | Item | Item type | Domain | Item precision |
|---|---|---|---|---|---|
| Feature class (hydrography) | FClass | Integer | Short | FClass | 4 |
| Feature class (elevation) | EClass | Integer | Short | EClass | 4 |
| Feature code | FCode | Integer | Long | FCode | 5 |
| Description | Desc | Text | Text | -- | 250 |
| Elevation source data | Source | Text | Text | -- | 128 |
| Hydrography delineation method | Method | Text | Text | -- | 250 |
| User-defined code | UserCode | Text | Text | -- | 25 |
| Free-text space for user comments | Comments | Text | Text | -- | 250 |
| User-defined code | UniqueID | Text | Text | -- | 50 |
| Digital Elevation Model (DEM) Limitation | Limitation | Integer | Short | Limitation | 1 |

**Table 6.** Domain values for FlowClass feature attributes.

| Domain value | Feature attributes |
|---|---|
| 0 | Flow direction is unable to be determined from elevation surface. |
| 1* | Flow direction is in digitized direction, and z-values on vertices flow downslope. |
| 2 | Flow direction is in digitized direction, and z-values on vertices flow upslope. |

*This is the default value.

**Table 7**. Domain values for Limitation feature attributes.

| Domain value | Feature attributes |
|---|---|

| | |
|---|---|
| 0* | No elevation dataset limitation. |
| 1 | Elevation dataset limitation. |

*This is the default value.

**Table 8.** Feature Code (FCode) values and descriptions.

| FCode | Desc |
|---|---|
| 0 | User-defined feature |
| 33400 | Connector |
| 33401 | Connector: Culvert |
| 33404 | Connector: Indefinite Surface |
| 33405 | Connector: Terrain Breach |
| 33410 | Connector: Non-NHD Dataset |
| 33600 | Canal/ditch |
| 36100 | Playa |
| 39000 | Lake/pond |
| 42002 | Underground Conduit |
| 42800 | Pipeline |
| 44500 | Sea/ocean |
| 45000 | Sink |
| 46000 | Stream/river |
| 46800 | Drainageway |
| 55800 | Artificial path |

**Table 9.** Domain values for Feature Class (FClass) feature attributes.

| Domain value | Feature attributes |
|---|---|
| 1* | Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications. |
| 2 | Hydrography feature captured outside the collection criteria of the elevation-derived hydrography specifications. |
| 9 | Nonhydrography feature. |

*This is the default value.

**Table 10**. Domain values for Elevation Class (EClass) feature attributes.

| Domain value | Description | Definition |
|---|---|---|
| 0 | Not used to create elevation derivatives. | Not used for elevation derivative. Includes features that are above the surface (such as pipelines), on the surface, or below the surface but should not be hydro-enforced (such as underground conduits). |
| 2* | Linear feature that follows elevation surface. | Linear hydrographic features that follow the elevation surface. |
| 3 | Linear feature used for breaching. | Linear features below ground level used for breaching—Examples include connectors through dams, culvert connectors, and terrain breach connectors. Used for elevation derivatives. |
| 11 | Polygon created using a lidar source hydroflattening breakline. | For use with lidar source elevation, where an unmodified hydroflattening elevation breakline was used to make a waterbody. |
| 12 | Polygon created using a smoothed IfSAR source hydroflattening breakline. | For use with IfSAR source elevation, where the hydroflattening elevation breakline was smoothed to make the waterbody boundary. The waterbody boundary should match the hydroflattened surface within 2 pixels after smoothing. |
| 13 | Polygon created where no hydroflattening breakline is suitable or available. | For use where there is no hydroflattening elevation breakline or the hydroflattening elevation breakline is unsuitable for creating waterbodies. If a hydroflattening elevation breakline is available, extensive editing must be done to use it as a waterbody boundary. |

*This is the default value.

**Table 11.** Feature type description, associated geometry, and use classification.

| Desc | FCode | Geometry type | FClass Domain value | EClass Domain value |
|---|---|---|---|---|
| Artificial path | 55800 | 3D line, polylineZ (creates network connectivity) | 1 | 2 |

| Desc | FCode | Geometry type | FClass Domain value | EClass Domain value |
|---|---|---|---|---|
| Canal/ditch | 33600 | 3D line, polylineZ (does not connect primary network features) | 2 | 0 |
| Canal/ditch | 33600 | 3D line, polylineZ (creates network connectivity) | 1 | 2 |
| Canal/ditch | 33600 | 3D polygon, polygonZ (polygon matches hydroflattening breaklines, breakline used) | 1 | 11 |
| Canal/ditch | 33600 | 3D polygon, polygonZ (polygon based on hydroflattened surface, breakline edits required) | 1 | 12 |
| Canal/ditch | 33600 | 3D polygon, polygonZ (no hydroflattening breakline available, polygon newly captured) | 1 | 13 |
| Connector | 33400 | 3D line, polylineZ | 1 | 3 |
| Connector | 33400 | 3D line, polylineZ | 1 | 0 |
| Connector | 33400 | 3D line, polylineZ | 2 | 0 |
| Connector: Culvert | 33401 | 3D line, polylineZ | 1 | 3 |
| Connector: Indefinite surface | 33404 | 3D line, polylineZ (creates network connectivity) | 1 | 2 |
| Connector: Indefinite surface | 33404 | 3D line, polylineZ (creates network connectivity) | 1 | 0 |
| Connector: Non-NHD Dataset | 33410 | 3D line, polylineZ (does not connect primary network features) | 2 | 0 |
| Connector: Terrain breach | 33405 | 3D line, polylineZ | 1 | 3 |
| Drainageway | 46800 | 3D line, polylineZ (creates network connectivity) | 1 | 2 |
| Lake/pond | 39000 | 3D polygon, polygonZ (polygon matches hydroflattening breaklines, breakline used) | 1 | 11 |
| Lake/pond | 39000 | 3D polygon, polygonZ (polygon based on hydroflattened surface, breakline edits required) | 1 | 12 |
| Lake/pond | 39000 | 3D polygon, polygonZ (no hydroflattening breakline available, polygon newly captured) | 1 | 13 |
| Pipeline | 42800 | 3D line, polylineZ (does not connect primary network features) | 2 | 0 |
| Pipeline | 42800 | 3D line, polylineZ (creates network connectivity) | 1 | 2 |
| Pipeline | 42800 | 3D line, polylineZ (creates network connectivity) | 1 | 3 |
| Playa | 36100 | 3D polygon, polygonZ | 1 | 0 |
| Sea/ocean | 44500 | 3D polygon, polygonZ (polygon matches hydroflattening breaklines, breakline used) | 1 | 11 |
| Sea/ocean | 44500 | 3D polygon, polygonZ (polygon based on hydroflattened surface, breakline edits required) | 1 | 12 |
| Sea/ocean | 44500 | 3D polygon, polygonZ (no hydroflattening breakline available, polygon newly captured) | 1 | 13 |
| Sink | 45000 | 3D point, pointZ | 1 | 0 |
| Stream/river | 46000 | 3D line, polylineZ (creates network connectivity) | 1 | 2 |
| Stream/river | 46000 | 3D polygon, polygonZ (polygon matches hydroflattening breaklines, breakline used) | 1 | 11 |
| Stream/river | 46000 | 3D polygon, polygonZ (polygon based on hydroflattened surface, breakline edits required) | 1 | 12 |
| Stream/river | 46000 | 3D polygon, polygonZ (no hydroflattening breakline available, polygon newly captured) | 1 | 13 |
| Underground Conduit | 42002 | 3D line, polylineZ (creates network connectivity) | 1 | 0 |
| User Defined Feature | 0 | 3D line, polylineZ (does not connect primary network features) | 9 | 0 |

**Table 12.** Polygon features used for hydroflattening an elevation surface.

| Desc | FCode |
|---|---|
| Canal/ditch | 33600 |
| Lake/pond | 39000 |
| Sea/ocean | 44500 |
| Stream/river | 46000 |

**Table 13.** Hydroflattening feature and updated code.

| Hydroflattening feature | Hydroflattening short description (see LBS for all cases) | Elevation-derived hydrographic feature | FCode | Elevation-derived hydrographic feature 2D (polygon) description |
|---|---|---|---|---|
| Inland ponds and lakes | Waterbodies with a surface area of 0.8 ha (2 acres) or greater (approximately equal to a round pond 100 m in diameter) at the time of collection shall be flattened. | Lake/pond | 39000 | A standing body of water with a predominantly natural shoreline surrounded by land. |
| Inland streams and rivers | Streams and rivers of a 30 m or greater nominal width shall be flattened. | Stream/river | 46000 | A body of flowing water. |
| Tidal waterbodies | Tidal waterbodies are defined as any waterbody that is affected by tidal variations, including oceans, seas, gulfs, bays, inlets, salt marshes, and large lakes. | Sea/ocean | 44500 | The great body of saltwater that covers much of the Earth. |
| Nontidal boundary waterbodies | Boundary waterbodies are waterbodies that contain some or all of the DPA. Boundary waterbodies may be any type of waterbody but are virtually always large in area or width. A boundary waterbody shall be represented as a polygon that follows the shore throughout the project and is then closed using arbitrary line segments as needed across the waterbody. Boundary waterbodies do not include the natural far shoreline. | Any large 2D features at the edge of the DPA. Exceptions are tidal waterbodies: Sea/ocean. | 39000, 43600, 46000 | A 2D feature that is not wholly contained within the DPA and is therefore only partially delineated. |

**Table 14.** Examples of acceptable ancillary datasets.

| Required/ recommended | Source | Resolution | Comments | Use |
|---|---|---|---|---|
| Required | Subset of NHD features required for capture in the elevation-derived hydrography | 1:24,000 or better | Download most recent version from The National Map | Use as a guide for minimum features that must be collected. |
| Required | Elevation surfaces, bare-earth DEM | 1 meter | Should be created from bare-earth lidar points. | All features collected must match the surface of the lidar bare-earth surface. |
| Required | Watershed Boundary Dataset, 12-digit hydrologic units | 1:24,000 or better | Download most recent version from The National Map | Use as a guide for minimum density of features that must be collected. Buffer the watershed areas to capture a complete network. |
| Recommended | Subset of NHD features not required for capture in the elevation-derived hydrography | 1:24,000 or better | Download most recent version from The National Map, or use web feature service | Use as a reference for features within the NHD with FCodes not required by elevation-derived hydrography, but potentially useful for understanding the hydrology of the area. |
| Recommended | Intensity images from same source as lidar surfaces | 1 meter | Should be created from bare-earth intensity values | From the same source as the elevation surface. Can be used as imagery. Water and wet areas are often visible. |
| Recommended | Leaf-off orthoimagery | ≤1 meter | Image date should be as close to the lidar collection date as possible | Visible features below tree canopy. Helpful to identify roads and stream intersections. |
| Recommended | Leaf-on orthoimagery | ≤1 meter | Image date should be as close to the lidar collection date as possible | Riparian zones are often obvious in imagery. |

| Required/ recommended | Source | Resolution | Comments | Use |
|---|---|---|---|---|
| Recommended | Near infrared band for vegetation | ≤1 meter | Image date should be as close to the lidar collection date as possible | Helpful for vegetation identification. |
| Recommended | Transportation layer | 1:24,000 or better | State or local government data tends to be higher resolution and more current than Federal road and highway datasets | Used for identification of culvert features, and for delineation of headwater streams near roads or railroads (see “Culverts” and “Headwaters at Roads” subsections of “Special Cases” in the “Delineation of Hydrographic Features” section). |
| Recommended | Bridge and culvert datasets from DOT or others | 1:24,000 or better | May be difficult to find for many States. Often coarser resolution but useful as a guide. National datasets exist (National Bridge Inventory, Federal Highway Administration, U.S. Department of Transportation) but are coarse | Use as a guide for culvert identification. |
| Recommended | Dam locations | 1:24,000 or better | National dataset coarser than lidar; for example, National Inventory of Dams | Use as a guide for dam identification. |
| Recommended | Lidar full point cloud | 1 meter | Should be from the same lidar collection | Helpful to distinguish features, or buildings that may be in flowpaths. |
| Recommended | Storm sewer systems and underground systems in urban areas | 1:24,000 or better | Source date should be as close to the lidar collection date as possible | Use to identify subsurface connections, pipelines, culverts. |
| Recommended | Building footprints | 1:24,000 or better | Source data should be as close to the lidar collection date as possible. Microsoft building footprints are available nationally but may be several years old. Local or State agencies may have more recently updated building footprints. | Use to route hydrography around buildings. Can be useful in areas where buildings were removed in the bare-earth surface, but a pit was created as an artifact of the filtering. |
| Recommended | Randolph Glacier Inventory | NA | Download most recent version from GLIMS: Global Land Ice Measurements from Space | Use to find glacier locations. See section on “Ice Masses” |
| Recommended | National Wetlands Inventory | NA | Download most current version from the Fish and Wildlife Service. | Use to identify open water. |

**Table 15.** Data dictionary for EDH_Spatial_Metadata.gpkg Final_Deliverable_Project_Area feature class.

| Field | Type | Length | Definition |
|---|---|---|---|
| OBJECTID | Object ID | -- | Automatically generated sequential unique whole numbers. |
| geometry | Geometry | -- | The type of geometry—point, line, polygon, multipoint, or multipatch that the table stores. |
| producer | Text | 100 | Name of organization submitting elevation-derived hydrography |
| ptsid | Long | -- | USGS Product Tracking System ID for 3DHP Project |
| workunitid | Long | -- | USGS Product Tracking System ID for 3DHP Project |
| edhspecversion | Text | 10 | Name and version of specification used |
| edhschemaversion | Text | 10 | Name and version of schema used |

**Table 16.** Data dictionary for EDH_Spatial_Metadata.gpkg, Elevation_Project_Polygons feature class.

| Field | Type | Length | Definition |
|---|---|---|---|
| OBJECTID | Object ID | -- | Automatically generated sequential unique whole numbers. |
| shape | Geometry | -- | The type of geometry—point, line, polygon, multipoint, or multipatch that the table stores. |
| ptsid | Long | -- | USGS Product Tracking System ID for 3DEP Project |
| source | Text | 200 | Free text description of elevation data source. |
| workunit | Text | 500 | USGS Product Tracking System work-unit name for 3DEP Project |
| workunitid | long | -- | USGS Product Tracking System work-unit identifier for 3DEP Project |
| dldate | date | -- | date the data were downloaded from source. |
| html | text | 100 | URL for source data |
| collectstart | date | -- | USGS 3DEP WESM elevation source data collection start date. |
| collectend | date | -- | USGS 3DEP WESM elevation source data collection end date. |
| otherdate | text | 100 | Free text description of dates associated with other elevation source data. |
| ql | text | 50 | ASPRS quality level of data. https://www.asprs.org/a/society/divisions/pad/Accuracy/Draft_ASPRS_Accuracy_Standards_for_Digital_Geospatial_Data_PE&RS.pdf |

**Table 17.** Data dictionary for EDH_Spatial_Metadata.gpkg, DEM_Limitation feature class.

| Field | Type | Length | Definition |
|---|---|---|---|
| OBJECTID | Object ID | -- | Automatically generated sequential unique whole numbers. |
| geometry | Geometry | -- | The type of geometry—point, line, polygon, multipoint, or multipatch that the table stores. |
| workunitid | Long | -- | USGS Product Tracking System ID for 3DHP Project |
| Explanation | Text | 250 | Explanation describing why the area of the DEM is unsuitable for deriving hydrography. |

**Table 18.** Data dictionary for EDH_Spatial_Metadata.gpkg, DPA feature class.

| Field | Type | Length | Definition |
|---|---|---|---|
| OBJECTID | Object ID | -- | Automatically generated sequential unique whole numbers. |
| geometry | Geometry | -- | The type of geometry—point, line, polygon, multipoint, or multipatch that the table stores. |
| workunitid | Long | -- | USGS Product Tracking System ID for 3DHP Project |
| hu8 | Text | 8 | HU8 number |
| todate | Date | -- | Date of contract or agreement to work on elevation-derived hydrography project |

**Table 19.** Standard Comments

| Reference | Comment |
|---|---|
| Depression Special Case | Downstream monotonicity cannot be enforced through depressions in the surface. |
| Inclusion or Omission of NHD Waterbody Special Case | NHD waterbody included in updated location. |
| Inclusion or Omission of NHD Waterbody Special Case | NHD Feature not present on elevation surface. |
| Inclusion or Omission of NHD Waterbody Special Case | The breakline corresponding to this NHD Waterbody does not meet the minimum size capture conditions. |
| Infrastructure Special Case | Infrastructure - unknown subsurface connection |
| Infrastructure Special Case | Infrastructure - subsurface connection. |
| Ice Masses Special Case | Ice Mass Connectivity. |
| Ice Masses Special Case | Ice Mass Connectivity. Monotonicity cannot be enforced. |

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# Appendix 1. Representation, Extraction, Attribution, and Delineation (READ) Rules

The READ rules are structured in the following way.

- Feature definition—The official definition of the hydrographic feature.
- Attribute/attribute value list—Lists specific codes required to populate the attribute table for each feature type. See READ Rules Notes below.
- Delineation—Describes the limit or extent of a feature that should be delineated.
- Representation rules—Explains how to represent features depending on various factors.
- Representation conditions—Explains when a feature should be delineated as a point, line, or polygon.
- Data extraction—Rules for when a feature should be extracted, what attributes are applied, and how to understand different special-case scenarios based on the source and ancillary datasets. See READ Rules Notes below.
    - Capture conditions—Defines the limits for the size of feature that should be captured or delineated for a specific feature type.
    - Attribute information—Definitions for codes applied during data extraction.
    - Source interpretation guidelines—Explains different potential scenarios to consider and how to address them when looking at complex situations in the source or ancillary datasets.

## READ Rule Notes

### Attribute/Attribute Value

Each feature requires domain codes entered into the attribute table for the feature class (**Table 11**.). See “Field Definitions and Domain Values for Attributes” section for -Derived Hydrography code definitions.

### Data Extraction Rules

Data Extraction Rules are divided into three categories: capture conditions, attribute information, and source interpretation guidelines. Capture conditions explain the requirements for a feature to be collected, and other pertinent information about acquisition. Attribute information explains the definitions of the codes and attributes that must be applied if the feature is acquired. Source interpretation guidelines give additional information for special circumstances that help determine whether a feature should be acquired or not. Not all features have source interpretation guidelines, and if this is the case, this will be indicated with “None.”

## Artificial Path

An abstraction to facilitate hydrologic modeling through open waterbodies (**Figure 33** and **Figure 34**).

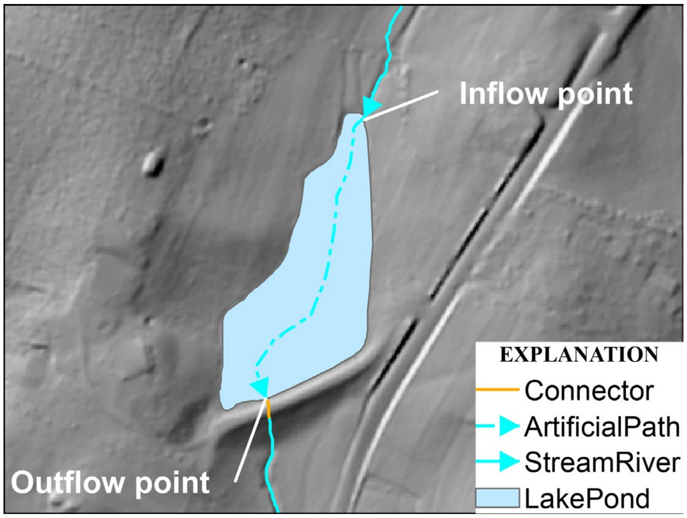


**Figure 33.** Diagram showing inflow and outflow points of a Lake/pond feature.

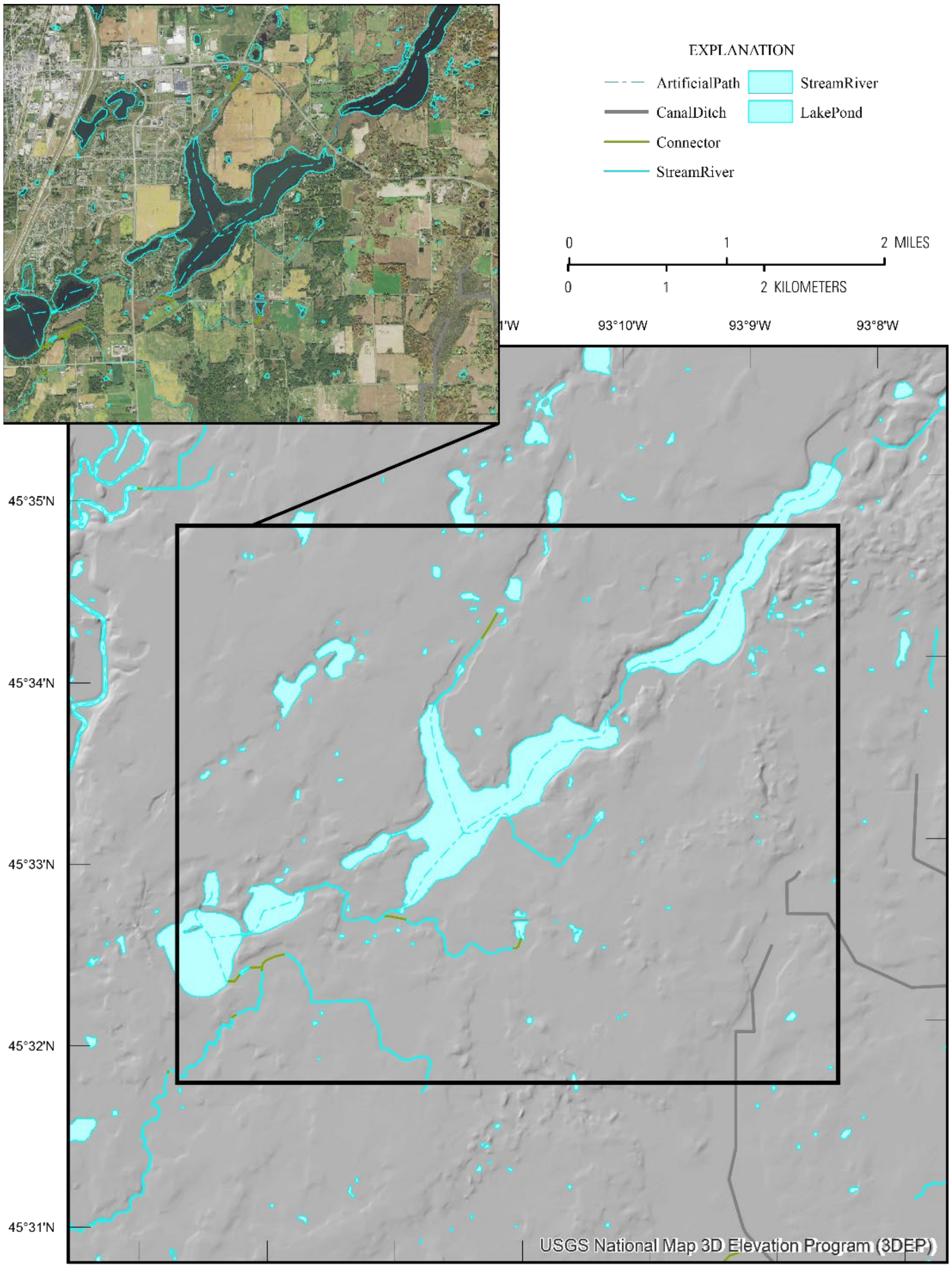


**Figure 34.** Example of Artificial path features in Lake Fannie, Minnesota. Source data are from the NHD (U.S. Geological Survey, 2020), which is used to provide examples of hydrographic feature types but may differ in density and other characteristics of elevation-derived hydrography.

## Delineation

The limit of an Artificial path feature is defined as the connection between the inflow and outflow points of an in-line polygon, the line through a head or terminal open waterbody connecting to the inflow (for terminal) or the outflow point (for head) (**Figure 34**).

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 20**).

**Table 20.** Artificial Path representation rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | greater than 0 | -- |
| 2-dimensional (polygon) | -- | -- | -- |

## Special Conditions

### *Artificial Path Features Around Islands*

- Islands smaller than 1 acre shall not be delineated unless they were in the original breaklines used for hydroflattening the DEM.
- Group small islands into large "island areas".
    - IfSAR
        - If islands smaller than 1 acre are present in the original breaklines, are no more than 30 meters apart, and cover more than an acre combined within the channel, treat the combined islands as an "island area" and only place Artificial path features around the group, not within them. The "island area" follows the same rules as an individual "island area".
    - Lidar
        - If islands smaller than 1 acre are no more than 16 meters apart and cover more than a tenth of an acre combined within the channel, treat the combined islands as an "island area" and only place Artificial path features around the group and not within them. The island area would follow the same rules as an individual island area.
    - Avoid tracing Artificial path features around all the islands (**Figure 35**). Artificial path features through waterbodies shall follow the shortest path while connecting to all inputs and outflowing channels (**Figure 36**).
    - Artificial path features represent the direction of flow and shall not loop back causing some flow to go upstream around islands (**Figure 37**).

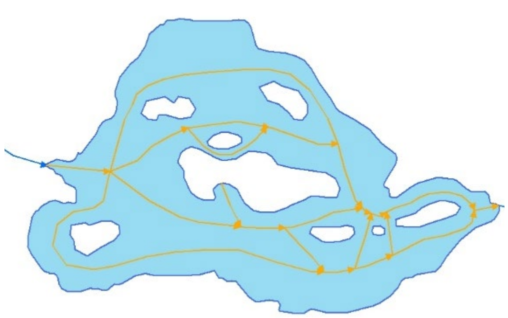

**Figure 35.** Too many Artificial path features around small islands in waterways.

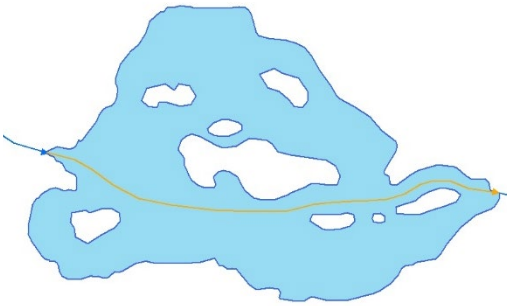

**Figure 36.** Correct placement of Artificial path following shortest distance through waterbody, not looping around small islands, and not crossing over any islands.

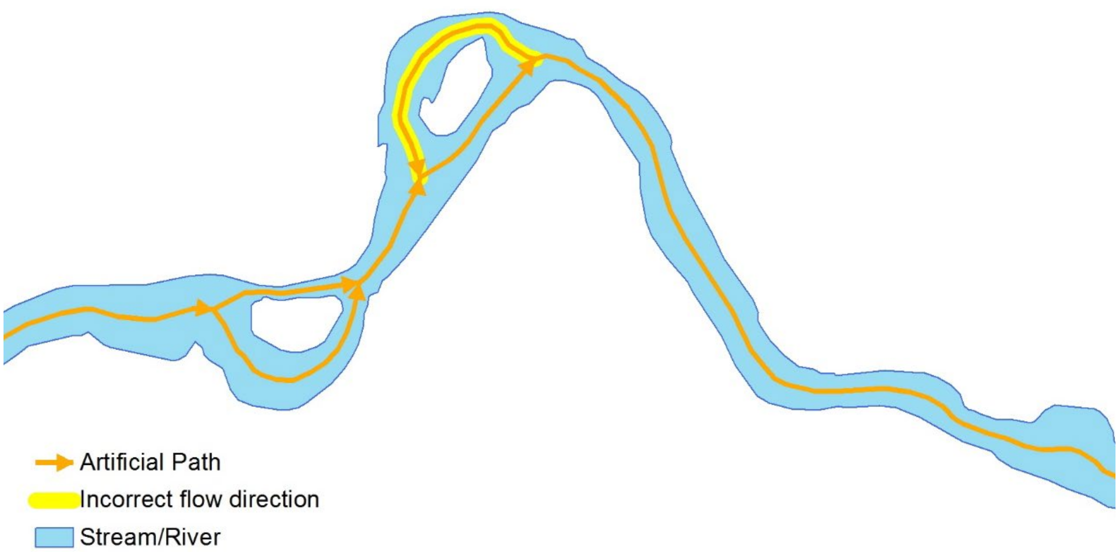


**Figure 37.** Lines shall always flow downstream monotonically. This example shows an incorrectly placed segment flowing upstream.

## Data Extraction

## Capture Conditions

Artificial path features shall be placed in all polygons except isolated Lake/pond features. Artificial path features shall represent the shortest path from the inflow to the outflow without crossing through banks or islands.

## Attribute Information

FClass 1— Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.

FCode 55800—Artificial path (abstraction to facilitate hydrologic modeling through open waterbodies).
EClass 2— Linear feature that follows elevation surface.

## Source Interpretation Guidelines

None.

## Canal/ditch

An artificial open waterway constructed to transport water, irrigate or drain land, connect two or more bodies of water, or serve as a waterway for watercraft (**Figure 38**, **Figure 39**, and **Figure 40**).

**Figure 38.** Shadroe Canal Weir, Cape Coral, Florida, as an example of a canal. Photograph by Shane Prorok, U.S. Geological Survey.

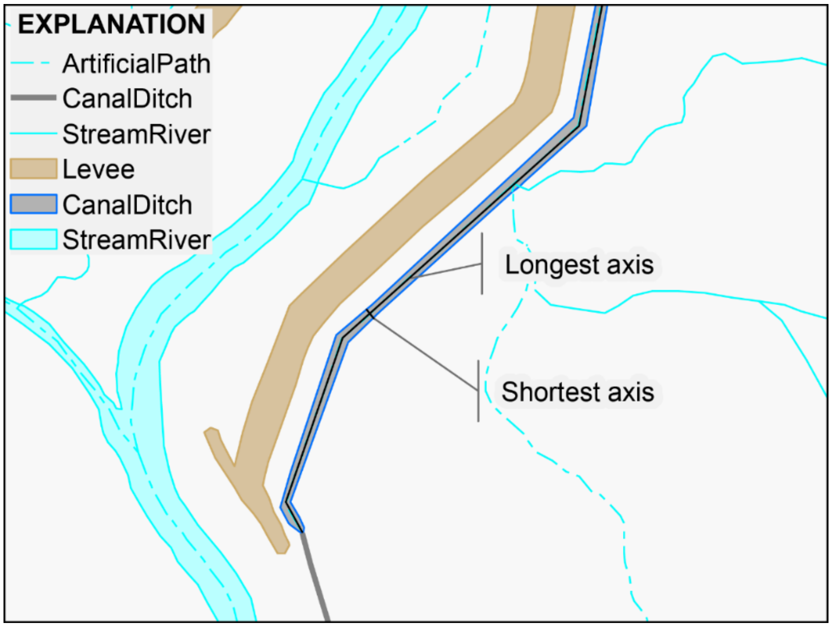


**Figure 39.** Diagram showing shortest and longest axes of a Canal/ditch feature.

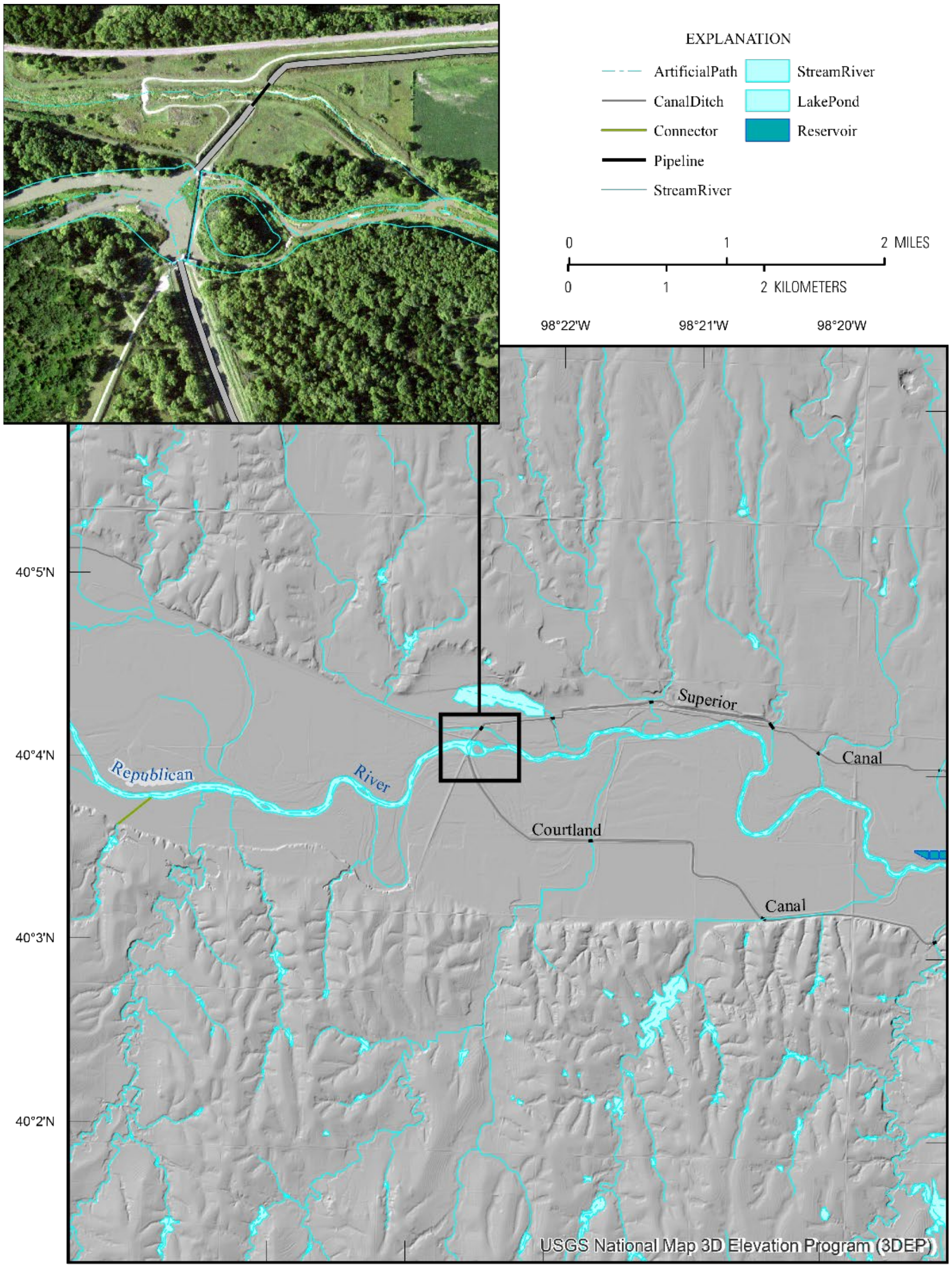


**Figure 40.** Courtland and Superior Canals near the Nebraska-Kansas state line, shown as examples of canal/ditch features. Source data from the NHD (U.S. Geological Survey, 2020), provide examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

## Delineation

The limit of Canal/ditch is the top of the banks of the artificial waterway.

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 21**).

**Table 21.** Canal/ditch Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | less than 50 ft (15 m) in lidar; less than 98 ft (30 m) in IfSAR | -- |
| 2-dimensional (polygon) | -- | greater than 50 ft (15 m) in lidar; greater than 98 ft (30 m) in IfSAR | -- |

## Special Conditions

To accommodate variations in the shortest axis of Canal/ditch:

- For lidar-based hydrography
  - The 3DEP breaklines used for hydroflattening canal and ditch locations on the elevation surface may be used as Canal/ditch polygon features in elevation-derived hydrography.
  - Canal/ditch features greater than 15 meters across should be delineated as 2D (polygon) features, while those less than 15 meters across should be delineated as line (1D) features. Occasionally, the Canal/ditch may narrow or expand beyond these thresholds and adjustments shall be made based on the following guidelines:
    - If a narrowed section in a Canal/ditch polygon is less than 15 meters wide for less than 1000 meters, keep it as a polygon.
    - If a narrowed section in a Canal/ditch polygon is less than 15 meters wide for more than 1000 meters, convert it to a line feature.
    - If a widened section of a Canal/ditch line is greater than or equal to 15 meters for less than 1000 meters, keep as a line feature.
    - If a widened section in a Canal/ditch line is greater than or equal to 15 meters for more than 1000 meters, convert it to a polygon feature.
- For IfSAR based hydrography
  - Smoothed 3DEP breaklines used for hydroflattening canal and ditch features on the elevation surface in IfSAR may be used as Canal/ditch polygon features in elevation-derived hydrography.
    - If a narrowed section in a Canal/ditch polygon is less than 30 meters wide for less than 2000 meters, keep it as a polygon feature.
    - If a narrowed section in a Canal/ditch polygon is less than 30 meters wide for more than 2000 meters, convert it to a line feature.
    - If a widened section in a Canal/ditch line is greater than or equal to 30 meters for less than 2000 meters, keep as a line feature.
    - If a widened section in a Canal/ditch line is greater than or equal to 30 meters for more than 2000 meters, convert it to a polygon feature.

## Data Extraction

Canals and ditches can be an important aspect of a hydrologic network, particularly in low relief areas. The problem with many interconnected canals as a part of a hydrologic network is that it becomes difficult to navigate the stream network. The direction of flow in canals and ditches is not always apparent and may vary based on weather or season. Creating a network that flows in a downstream direction, with z-values descending from upstream to downstream, is challenging in areas when many low-slope segments. Additionally, culverts can be difficult to identify in smaller canal systems, leading to isolated networks. An area in the Coastal Plain of North Carolina with many visible canals in orthoimagery and in the lidar surface is shown in **Figure 41**.


**Figure 41.** An area with an abundance of Canal/ditch features. A, orthoimagery; B, lidar.

**Figure 42** shows an example of features present in the NHD (delineated in black) and additional Canal/ditch features added to an elevation-derived stream network (represented in purple). Features tagged as “A” are canals that extend existing canal networks, help guide drainage patterns around a built environment, and are therefore substantial additions to the network. The features tagged as “B” are less than 300 meters long, are within a field that is agricultural, and do not add a substantial amount of information about drainage patterns because the Canals/ditch features are flowing into larger Canals/ditch features that are part of the hydrologic network. These two canals/ditches (B) do not meet the current criteria for capture as an elevation-derived hydrography feature and will not be added to the NHD. However, if local/project needs require, these features may still be collected and identified using the UserCode attribute as described previously.

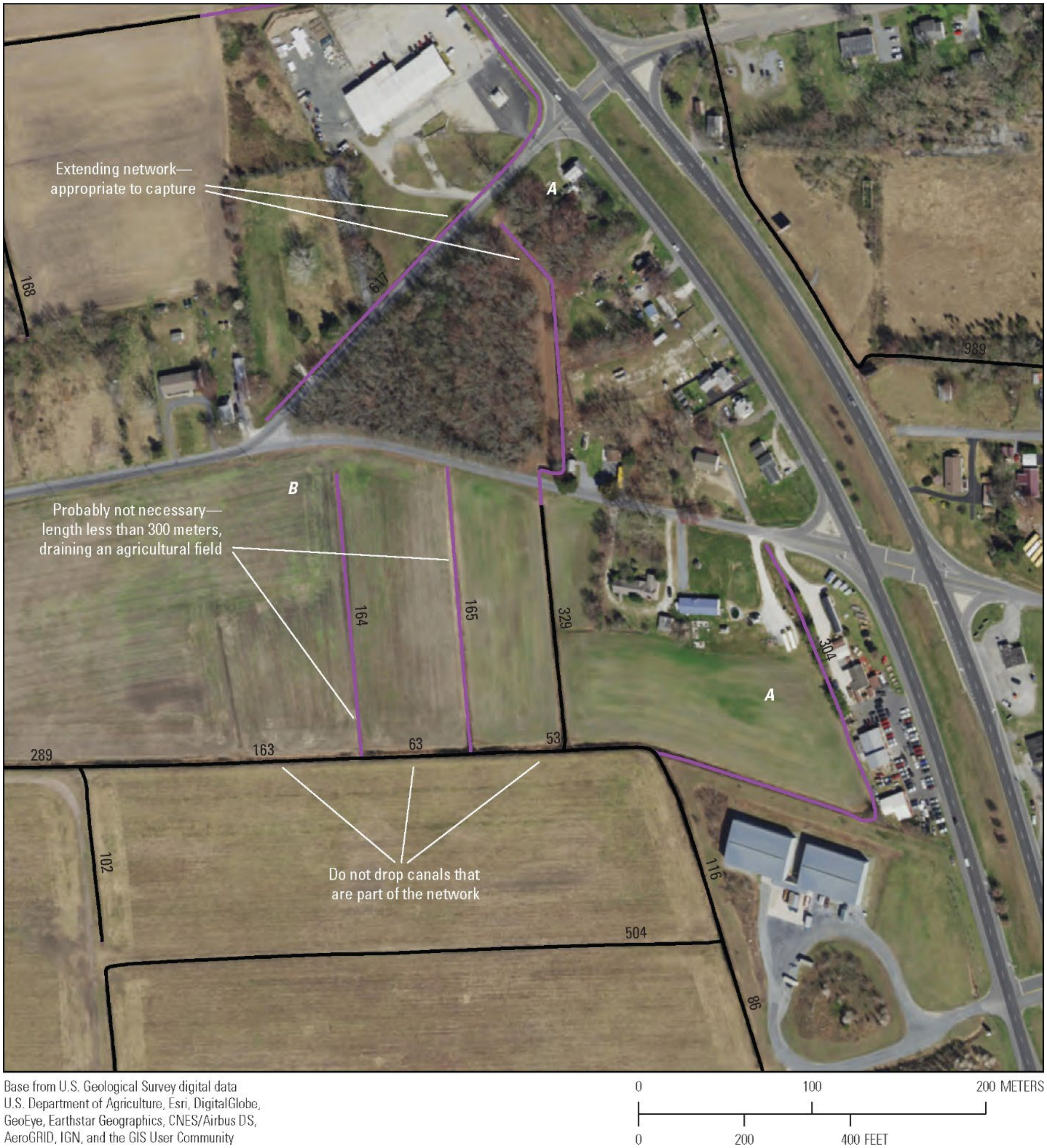


**Figure 42.** Canal/ditch features as part of a hydrographic network. "A" denotes features in purple that should be included in the network. "B" denotes features in purple that should be removed from the network.

## Capture Conditions

If Canal/ditch is named, or

if Canal/ditch is greater than or equal to 984 feet (300 meters) along the longest axis, then capture.

If Canal/ditch is needed to provide network connectivity,

then capture.

If Canal/ditch is within agricultural fields and drains to another Canal/ditch or other hydrographic features,

then do not capture (see following exception).

The exception is if a project has a special need for canals and ditch features that are within agricultural fields and drain to another Canal/ditch or other hydrographic feature, then these features shall be coded with an FClass=2 to indicate that the hydrographic feature is captured outside the collection criteria of the elevation-derived hydrography specifications.

Note that a hydrographic network shall not be broken if features are excluded.

### Attribute Information

FClass 1— Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 33600—Canal/ditch (an artificial open waterway constructed to transport water, irrigate or drain land, connect two or more bodies of water, or serve as a waterway for watercraft).
EClass 2— Linear feature that follows elevation surface.

OR

FClass 2— Hydrography feature captured outside the collection criteria of the elevation-derived hydrography specifications.
FCode 33600—Canal/ditch (an artificial open waterway constructed to transport water, irrigate or drain land, connect two or more bodies of water, or serve as a waterway for watercraft).
EClass 0—Not used to create elevation derivatives.

OR

FClass 1— Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 33600—Canal/ditch (an artificial open waterway constructed to transport water, irrigate or drain land, connect two or more bodies of water, or serve as a waterway for watercraft).
EClass 11—Polygon created using a hydroflattening breakline.

OR

FClass 1— Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 33600—Canal/ditch (an artificial open waterway constructed to transport water, irrigate or drain land, connect two or more bodies of water, or serve as a waterway for watercraft).
EClass 12—Polygon created from edited hydroflattening breakline on flattened elevation surface.

OR

FClass 1— Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 33600—Canal/ditch (an artificial open waterway constructed to transport water, irrigate or drain land, connect two or more bodies of water, or serve as a waterway for watercraft).
EClass 13—Polygon created for non-flattened waterbody features in the DEM.

### Source Interpretation Guidelines

Do not capture rivers that have been channelized to control flooding or erosion, or to maintain flow for navigation as Canal/ditch. See “Stream/river” section (for example, Los Angeles River is a large, channelized river, and coded as Stream/river).

## Connector

A known, but nonspecific, connection between two non-adjacent network segments. Connector feature types are used when two surface-water features appear to interact through a constructed feature but there is no discernable evidence of the interaction on the surface. For example, a Connector feature may be used to show the connection between the lake and the stream output through a dam (**Figure 43** and **Figure 44**).

**Figure 43.** The New Libby Dam, on the Kootenai River, Libby, Montana, is an example of where a Connector feature could be used to connect the flow of the river from the bottom left side of the image to the lake on the top right side of the image. Photograph by U.S. Army Corps of Engineers.

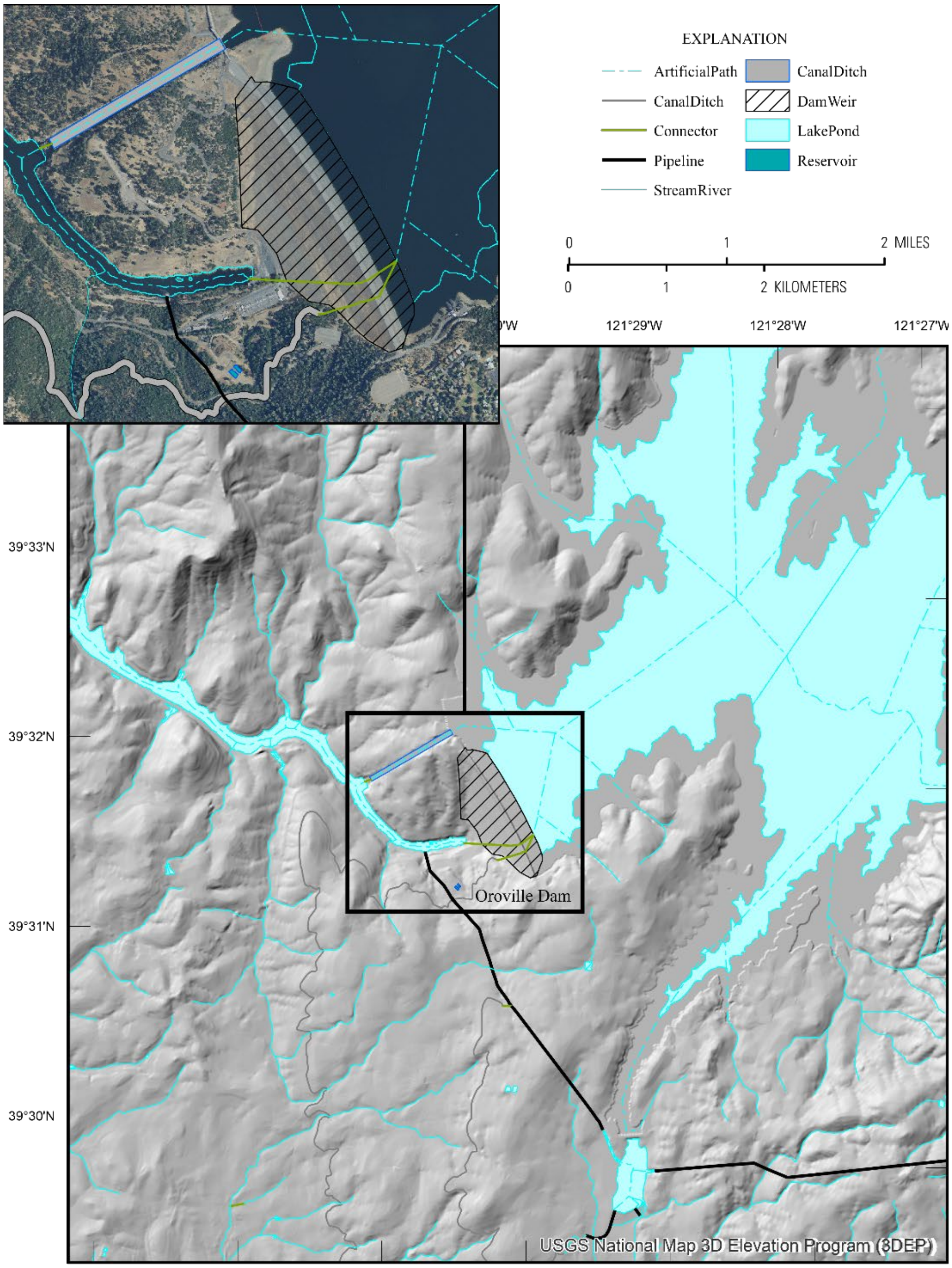


**Figure 44.** Oroville Dam, California, is an example of a Connector hydrographic feature. Source data are from the NHD (U.S. Geological Survey, 2020), which is used to provide examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

## Delineation

The limit of Connector features is the virtual line connecting two nonadjacent network segments.

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 22**).

**Table 22.** Connector Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | greater than 0 | -- |
| 2-dimensional (polygon) | -- | -- | -- |

## Special Conditions

If using the Connector feature for the purpose of connecting upstream and downstream networks through an area with development or infrastructure, please see the Infrastructure Areas Special Case.

## Data Extraction

## Capture Conditions

If connector is required to maintain connectivity between two network feature objects,

then capture.

## Attribute Information

FClass 1— Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 33400—Connector (a known, but nonspecific, invisible connection between two nonadjacent network segments).
EClass 3— Linear feature used for breaching.

OR

FClass 1— Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 33400—Connector (a known, but nonspecific, invisible connection between two nonadjacent network segments).
EClass 0— Not used to create elevation derivatives.

OR

FClass 2— Hydrography feature captured outside the collection criteria of the elevation-derived hydrography specifications.
FCode 33400—Connector (a known, but nonspecific, invisible connection between two nonadjacent network segments).

EClass 0— Not used to create elevation derivatives.

## Source Interpretation Guidelines

The following conditions indicate when and why the capture of a Connector is required:

- When a Connector is part of a connected network.
- When there is a gap between network features for example, at a dam that causes a gap between an upstream Lake/pond and a downstream Stream/river.
- When infrastructure or development is present and surface water connections are below ground or unable to be detected (see Special Case, Infrastructure Areas).
- When two hydrographic features cross each other, but do not share water, a Connector shall be used to identify the smaller feature.

## Connector: Culvert

Subsurface water conveyances under a transportation feature (**Figure 45** and **Figure 46**).


**Figure 45.** Examples of culverts, which can be many shapes and sizes and found in a variety of locations. Example A is a very large box culvert running underneath an interstate. Example B shows a much smaller culvert running under a two-lane residential road. (Photo credit: Christy-Ann Archuleta).

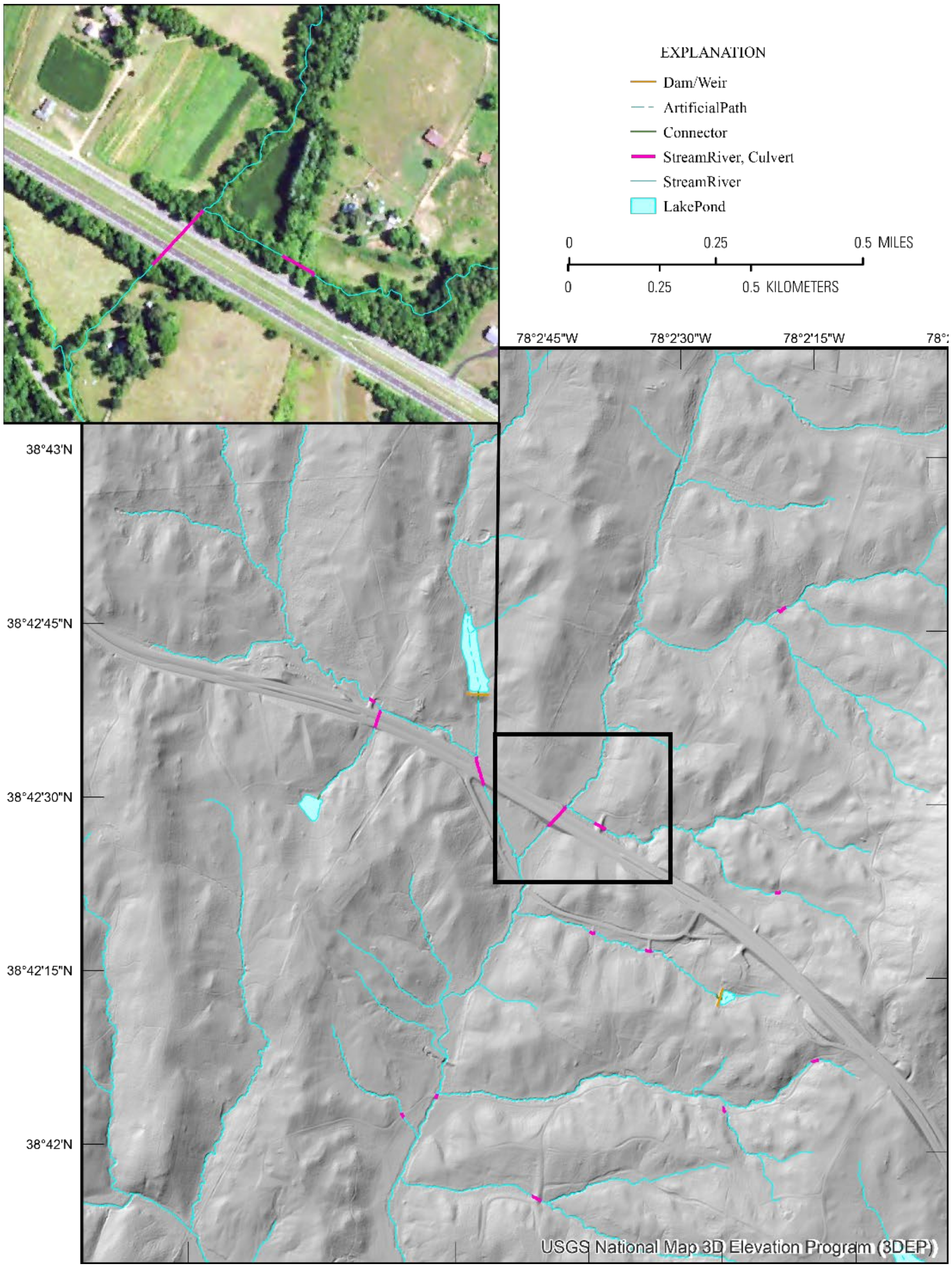


**Figure 46.** Highway 211 in Virginia crosses unnamed streams with culvert hydrographic features. Source data from the NHD (U.S. Geological Survey, 2020), provides examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

## Delineation

The limit of culvert is the edges of the water conveyance structure.

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 23**).

**Table 23.** Culvert Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | greater than 0 | greater than 5 feet (1.5 meters) |
| 2-dimensional (polygon) | -- | -- | -- |

## Special Conditions

Culvert water conveyances may take many forms, for example, a corrugated metal pipe running under a driveway, a massive concrete box under a superhighway, or a platform suspended over flowing water. The purpose of the Connector: Culvert feature in the stream network is to connect the water flowing through a conveyance to the water flowing downstream, without breaking the downstream flow in the network. Connector: Culvert features shall be delineated as (1D) lines connecting the upstream and downstream segments of single-line streams or Artificial path features.

## Data Extraction

## Capture Conditions

If the culvert is greater than 5 feet (1.5 meters) along the longest axis,

then capture.

## Attribute Information

FClass 1— Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 33401— Connector: Culvert (Subsurface water conveyances under a transportation feature).
EClass 3— Linear feature used for breaching.

### *Special Conditions*

Connector: Culvert feature type shall only be used when the feature is underneath a transportation feature. Other hydrographic feature running under other hydrographic features shall use the Connector (33400) feature type.

## Source Interpretation Guidelines

If a structure cannot be definitive identified as a bridge or culvert on the bare earth elevation surface, the feature shall be regarded as a culvert.

Culvert features shall cross transportation features. If a transportation dataset is used to help determine the location of transportation features, it shall be at least as dense as The National Map Transportation Theme layer. If a road is detectable on the elevation surface but not found in the transportation dataset, a Culvert feature must still be placed.

## Connector: Indefinite Surface

A connector feature used where evidence of channelization is not present in the DEM surface but connectivity between an upstream and downstream channel is indicated by terrain modelling (**Figure 47**). Connector: Indefinite Surface features may be used include where the DEM is limited or where the channel is obscured in the DEM due to heavy vegetative cover (see the Delineating Features in Areas with DEM Limitation section). Connector: Indefinite Surface features can also be used to connect through areas having conservation treatments such as grassed waterways, which are designed to prevent soil erosion and the formation of channels. This FCode is recommended for use in situations where streams sink into the ground under low or normal flow conditions but would flow over the surface during high flow or flood conditions and connect to downslope hydrographic features. Connector: Indefinite Surface may also be used to maintain the linear network through depressions in non-karst or thermokarst terrain (see Depressions under Special Cases).

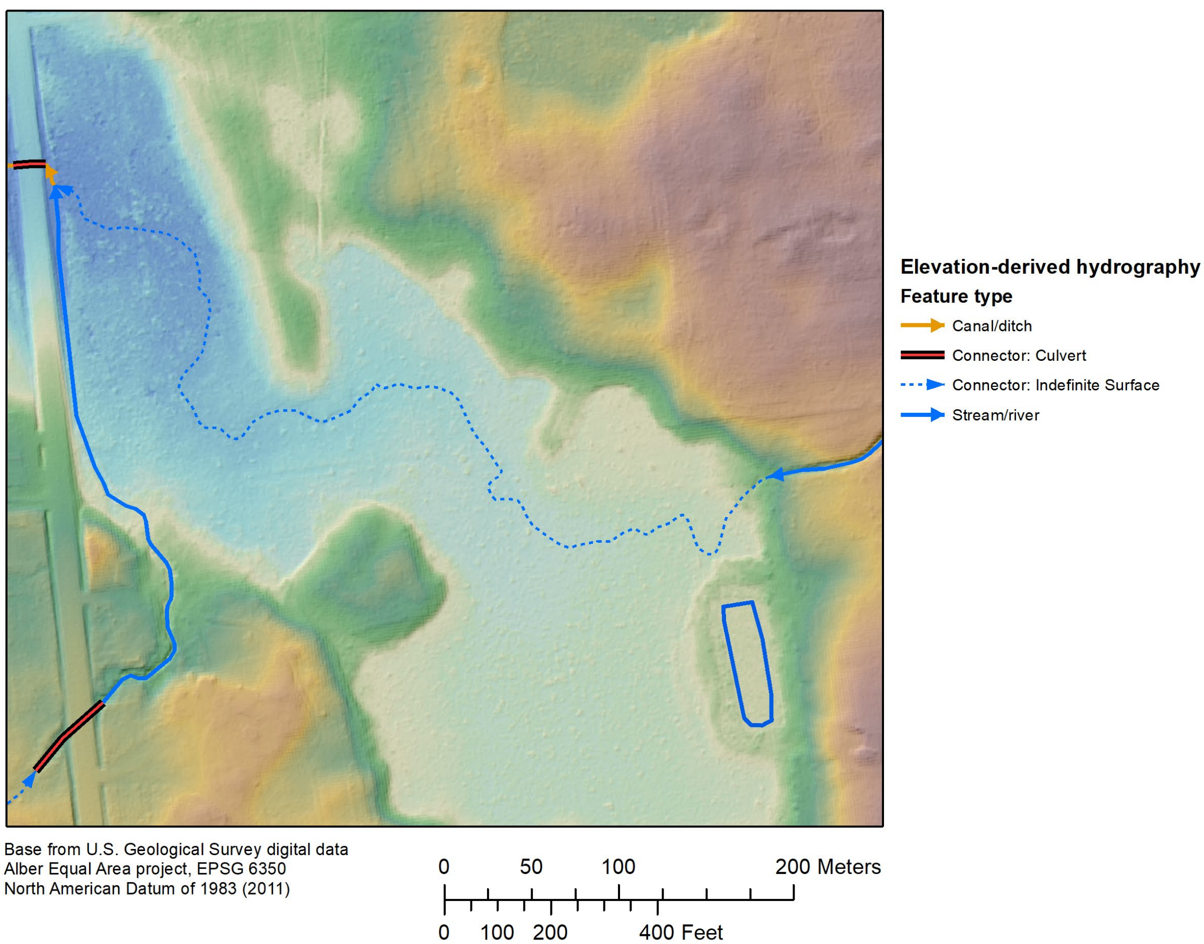


**Figure 47.** Example of Connector: Indefinite Surface features providing network connectivity through an area without clear channelization.

## Delineation

The limit of a Connector: Indefinite Surface is the space needed for connectivity between an upstream segment of a natural topographic flow-path and the downstream portion of that flowpath, where the channel becomes indiscernible over a distance but resumes downstream. May be determined by modelling techniques, but a clearly defined channel shall not be found in locations where a Connector: Indefinite Surface is used. Connector: Indefinite Surface shall never be used in headwater locations. For indiscernible channels in headwater locations, see Drainageway.

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 24**).

**Table 24.** Connector: Indefinite Surface Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | greater than 0 | -- |
| 2-dimensional (polygon) | -- | -- | -- |

## Special Conditions

None.

## Data Extraction

## Capture Conditions

Connector: Indefinite Surface features bridge gaps where a clearly defined channel is lost on the topographic surface but resumes downstream. Connector: Indefinite Surface features shall only be captured in locations with clearly defined channels upstream and downstream and shall have no discernible channel in between.

- A Connector: Indefinite Surface feature is used where a channel is not detectable (Appendix 3).

- If a section within a Connector: Indefinite Surface segment is within a channel on the elevation surface for more than 100 meters lidar (200 meters IfSAR), it shall be split and the section that is within a channel on the elevation surface shall be coded as a Stream/river, Canal/ditch, or other hydrographic features that may be within a channel on the elevation surface.

- Examples where Connector: Indefinite Surface features may be used include, but are not limited to:

  - Areas with DEM Limitations or heavy vegetative cover where the channel cannot be resolved.
  - Connector: Indefinite Surface features may also be used to connect through areas having conservation treatments such as grassed waterways, which are designed to prevent soil erosion and the formation of channels.
  - The Connector: Indefinite Surface feature type is recommended for use in situations where streams sink into the ground under low or normal flow conditions but would flow over the surface during high flow or flood conditions and connect to downslope hydrographic features.

- If a feature does not have evidence of channelization, and is a headwater, the Drainageway feature type (FCode: 46800) shall be used.

- The Connector: Indefinite Surface feature type is recommended for use in situations where streams sink into the ground under low or normal flow conditions but would flow over the surface during high flow or flood conditions and connect to downslope hydrographic features.

- Avoid using the Connector: Indefinite Surface feature type if karst terrain indicates underground flow is predominant and year-round (see Appendix 1 for Underground Conduit).

### Attribute Information

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 33404— Connector: Indefinite Surface (a connector feature used where evidence of channelization is not present in the DEM surface but connectivity between an upstream and downstream channel is indicated by terrain modelling).
EClass 2— Linear feature that follows elevation surface.

OR

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 33404— Connector: Indefinite Surface (a connector feature used where evidence of channelization is not present in the DEM surface but connectivity between an upstream and downstream channel is indicated by terrain modelling).
EClass 0— Not used to create elevation derivatives.

### Source Interpretation Guidelines

None.

## Connector: Non-NHD Dataset

Used to provide network connectivity to or through a polygon feature that is represented in an external dataset maintained by another agency such as the National Wetlands Inventory, the Randolph Glacier Inventory, or other datasets related to hydrography. This connector shall be used with a dataset recognized by the USGS for these purposes. Currently there are no Non-NHD datasets approved for use with this connector.

### Attribute/Attribute Value

### Delineation

### Representation Rules

### Special Conditions

### Data Extraction

### Capture Conditions

### Attribute Information

### Source Interpretation Guidelines

## Connector: Terrain Breach

Used to breach terrain (or elevation) features that block the flow in a drainage network, such as a small rise in elevation, landslides, moraines, glacial till, or naturally formed berms. A Connector: Terrain Breach feature is used to breach flow blockages on the elevation surface; with no known built feature connecting upstream and downstream flow (**Figure 48** and **Figure 49**).

In contrast, the Underground Conduit (FCode 42002) is used to represent an underground flowpath in known karst, permafrost, and thermokarst terrain; the culvert connector (FCode 33401) is used to connect upstream and downstream flow through a transportation feature; and connector (FCode 33400) is used to connect underground flow from upstream to downstream through built environments such as a dam.

**Figure 48.** A large tree obstructing South Hominy Creek, in Candler, Buncombe County, North Carolina. Image courtesy of Roger Ehrlich. A Connector: Terrain Breach feature would be used to bypass this tree, which has a diameter over 2 meters.

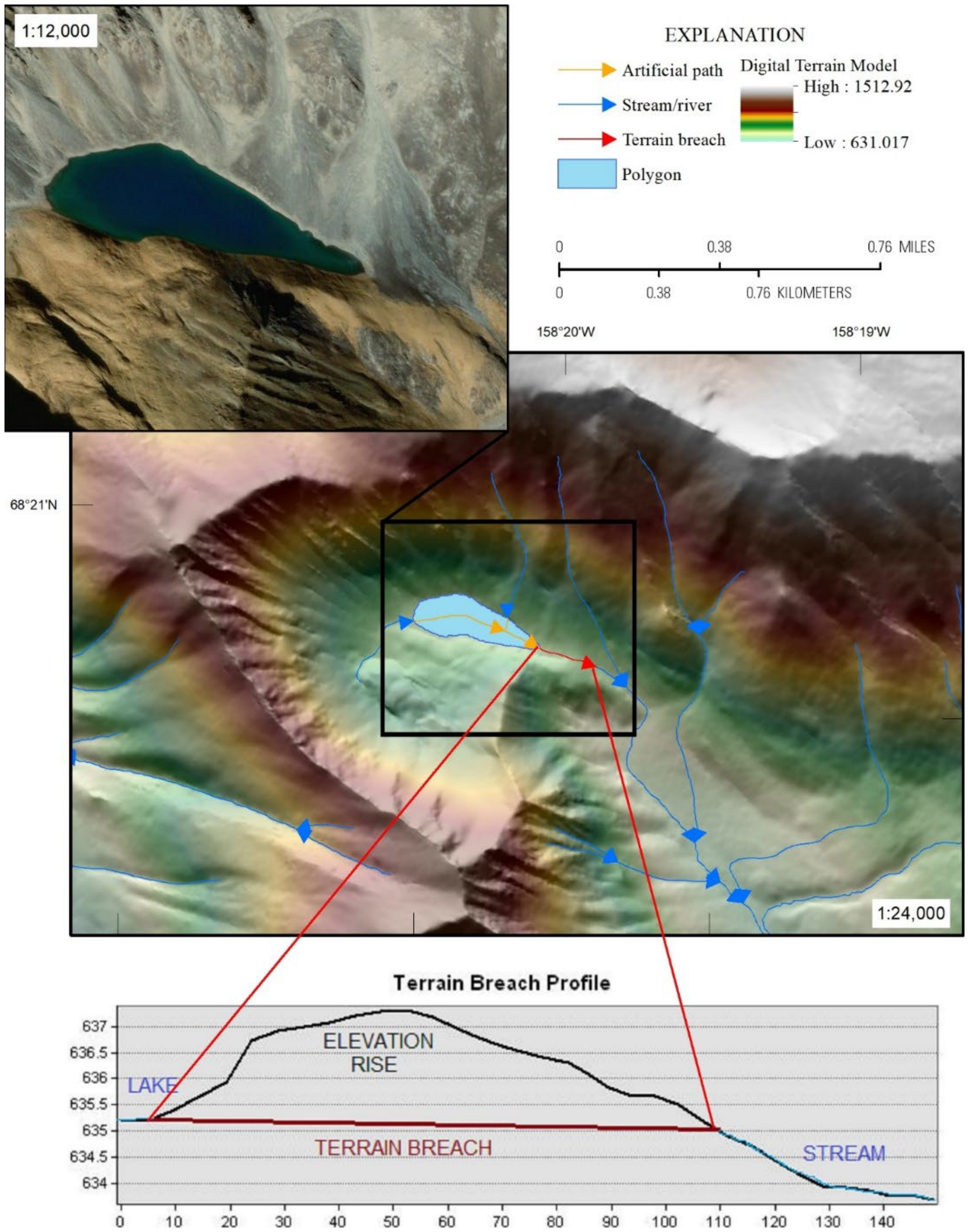


**Figure 49.** A high-altitude mountain lake formed by a natural berm, provides an example of a Connector: Terrain Breach feature. Source data for elevation is 3DEP IfSAR, and the imagery is from the State of Alaska Open Data Geoportal.

## Delineation

The limit of Connector: Terrain Breech is the virtual line connecting two nonadjacent network segments, extending from the lowest point on one side of the obstruction to a point at or below the starting point on the other side of the obstruction.

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 25**).

**Table 25.** Connector: Terrain Breach Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | greater than 0 | -- |
| 2-dimensional (polygon) | -- | -- | -- |

## Special Conditions

None.

## Data Extraction

## Capture Conditions

If Connector: Terrain Breach is required to maintain connectivity through a rise in elevation between two network feature objects,

then capture.

If Connector: Terrain Breach with a rise in elevation extends in length for three pixels or more than the source resolution (3 meters for lidar, 15 meters for IfSAR) within the terrain,

then capture.

## Attribute Information

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 33405—Connector: Terrain Breach (Used to breach terrain (or elevation) features that lock the flow in a drainage network, such as a small rise in elevation, landslides, moraines, glacial till, or naturally formed berms).
EClass 3— Linear feature used for breaching.

## Source Interpretation Guidelines

The following conditions indicate when and why the capture of Connector: Terrain Breach is required (**Figure 50**):

- When Connector: Terrain Breach is part of a network that is represented as connected.

- When there is a gap caused by a rise in elevation greater than or equal to 1 meter in lidar and greater than or equal to 2 meters in IfSAR.

Do not use the Connector: Terrain Breach feature type to represent underground flowpaths in known karst, permafrost or thermokarst terrain, see Underground Conduit in Appendix 1.

A Connector: Terrain Breach feature is not necessary:

- If the rise in elevation requires z-values along the linear feature to be less than 1 meter below the surface for lidar (**Figure 51**), or 2 meters below the surface for IfSAR source elevation, or
- If the rise in elevation extends in length for three pixels or less than the source resolution (3 meter for lidar, 15 meters for IfSAR) within the terrain.

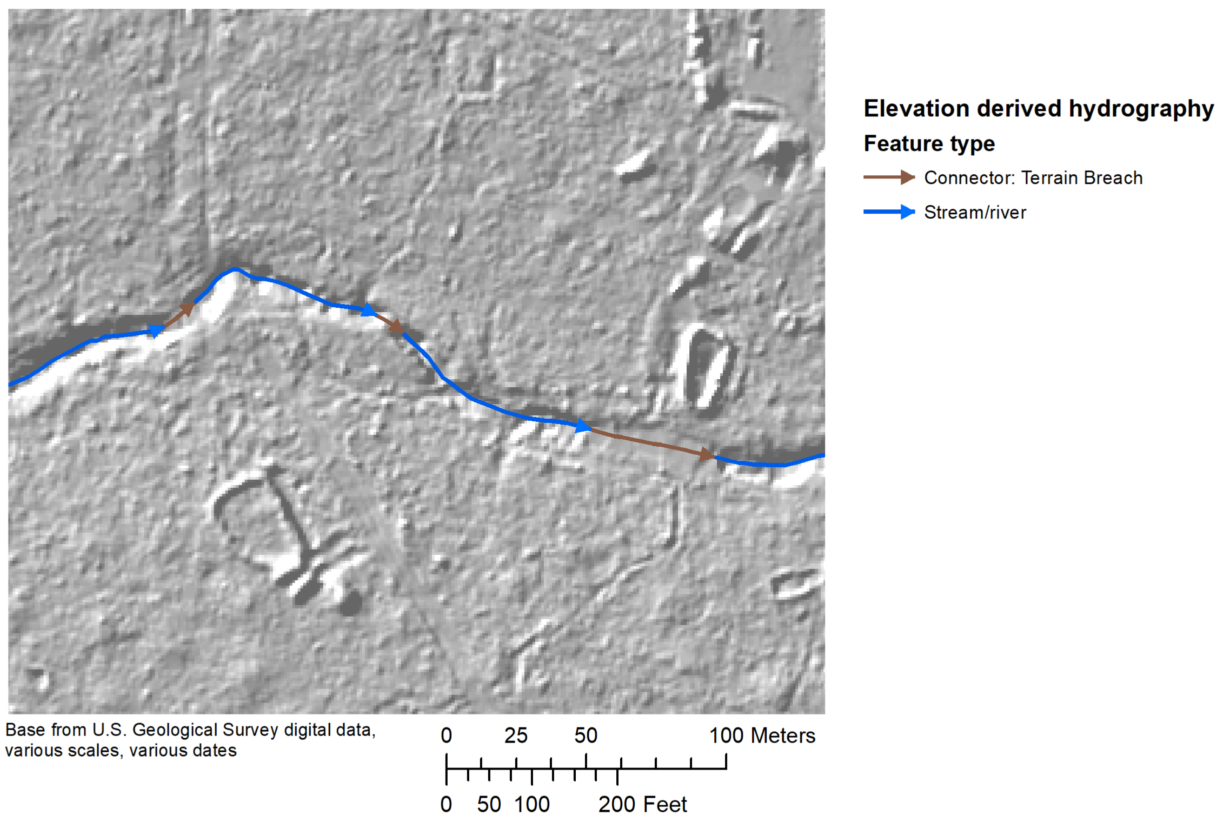


**Figure 50.** Example map of Connector: Terrain Breach.

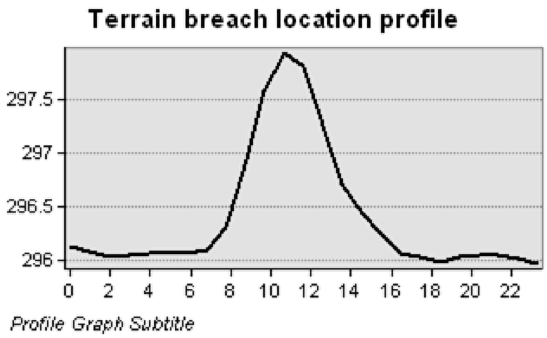


**Figure 51.** Example of rise in elevation of one meter or greater, requiring a terrain breach.

*Special Conditions*

None.

## Drainageway

Flowlines delineated where terrain modelling indicates potential headwater drainage, but no detectable channel exists (Appendix 3). The Drainageway code must only be applied at the initiation of flowlines or confluence of other Drainageway features. The Drainageway feature code must not be applied downstream of other non-drainageway flowlines or waterbody features (see Topological Relationships Between Elevation-Derived Hydrographic features).

- When a high degree of uncertainty exists for headwater features, the Drainageway feature type (FCode: 46800) shall be used. This code indicates further investigation is necessary to determine if a hydrographic feature exists on the ground.

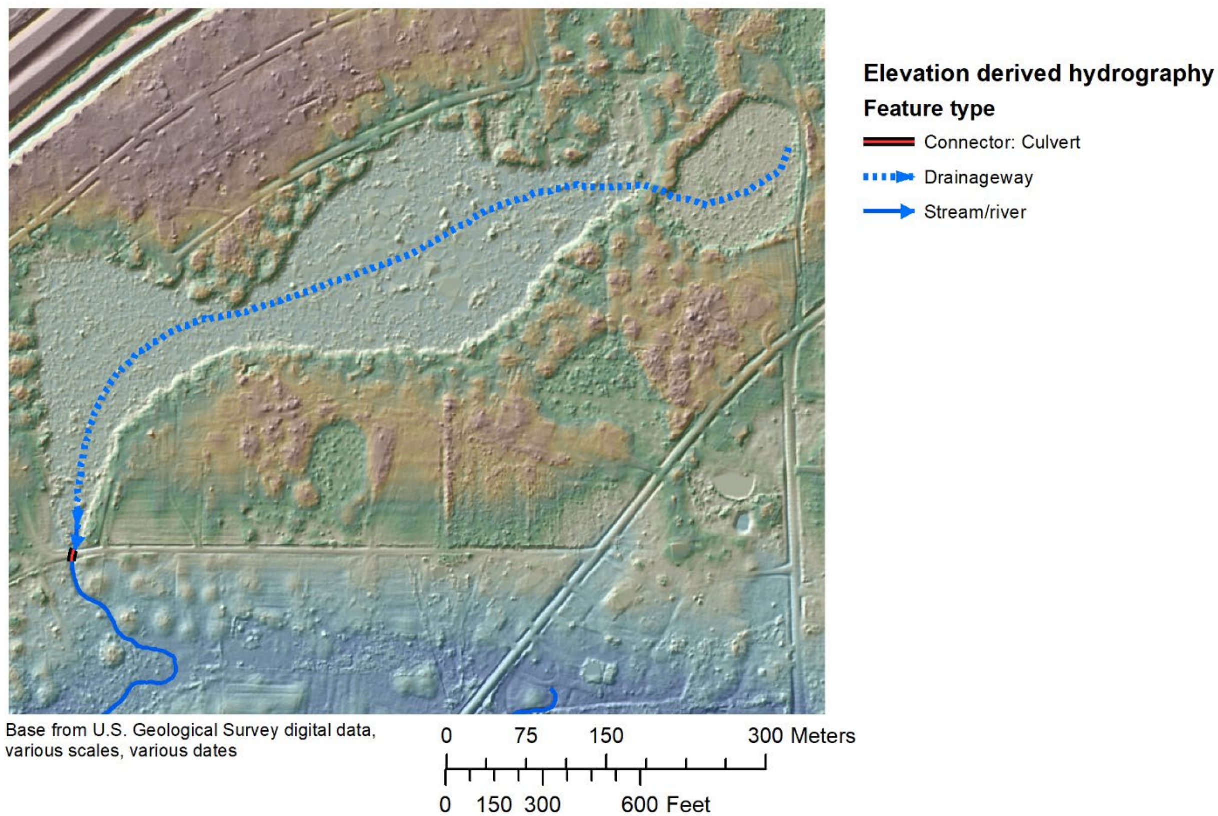


**Figure 52.** Example map of Drainageway.

### Delineation

The limit of a drainageway is the topographic flowpath or the approximate overland flow path between two disconnected drainage network features. A drainageway may be determined by modelling techniques indicating potential headwater drainage, but no channel will be detectable on the elevation surface.

- The Drainageway feature code must only be applied at the initiation of flowlines or confluence of other Drainageway features. The Drainageway feature code must not be applied downstream of other non-drainageway flowlines or waterbody features).

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 26**).

**Table 26.** Drainageway Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | greater than 0 | -- |
| 2-dimensional (polygon) | -- | -- | -- |

## Special Conditions

To accommodate variations in the shortest axis of drainageway:

FOR elevation-derived hydrography: If shortest axis of drainageway is

less than 20 feet (6 meters) regardless of distance, and is connected at the downstream end to a 2-dimensional (polygon) Stream/river,

then drainageway is represented as a 1-dimensional (line) basic feature object.

If shortest axis of drainageway is greater than or equal to 50 feet (15 meters) and does not meet drainageway criteria, collect as appropriate feature for capture conditions (Stream/ river, playa, and others as needed).

## Data Extraction

## Capture Conditions

Drainageway features have no clearly defined capture conditions. Modelling techniques (such as flow models, elevation surface models, and logistic regression models) expose features and, therefore, require further investigation to determine their status and classification as hydrographic features.

## Attribute Information

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 46800—Drainageway (flowlines delineated where terrain modelling indicates potential headwater drainage, but no channel is detectable).

EClass 2— Linear feature that follows elevation surface.

### Source Interpretation Guidelines

None.

## Lake/pond

A standing body of water surrounded by land (**Figure 53**, **Figure 54**, and **Figure 55**).

**Figure 53.** Crater Lake, Oregon, is an example of a Lake/pond feature. Photograph by Willie Scott, U.S. Geological Survey.

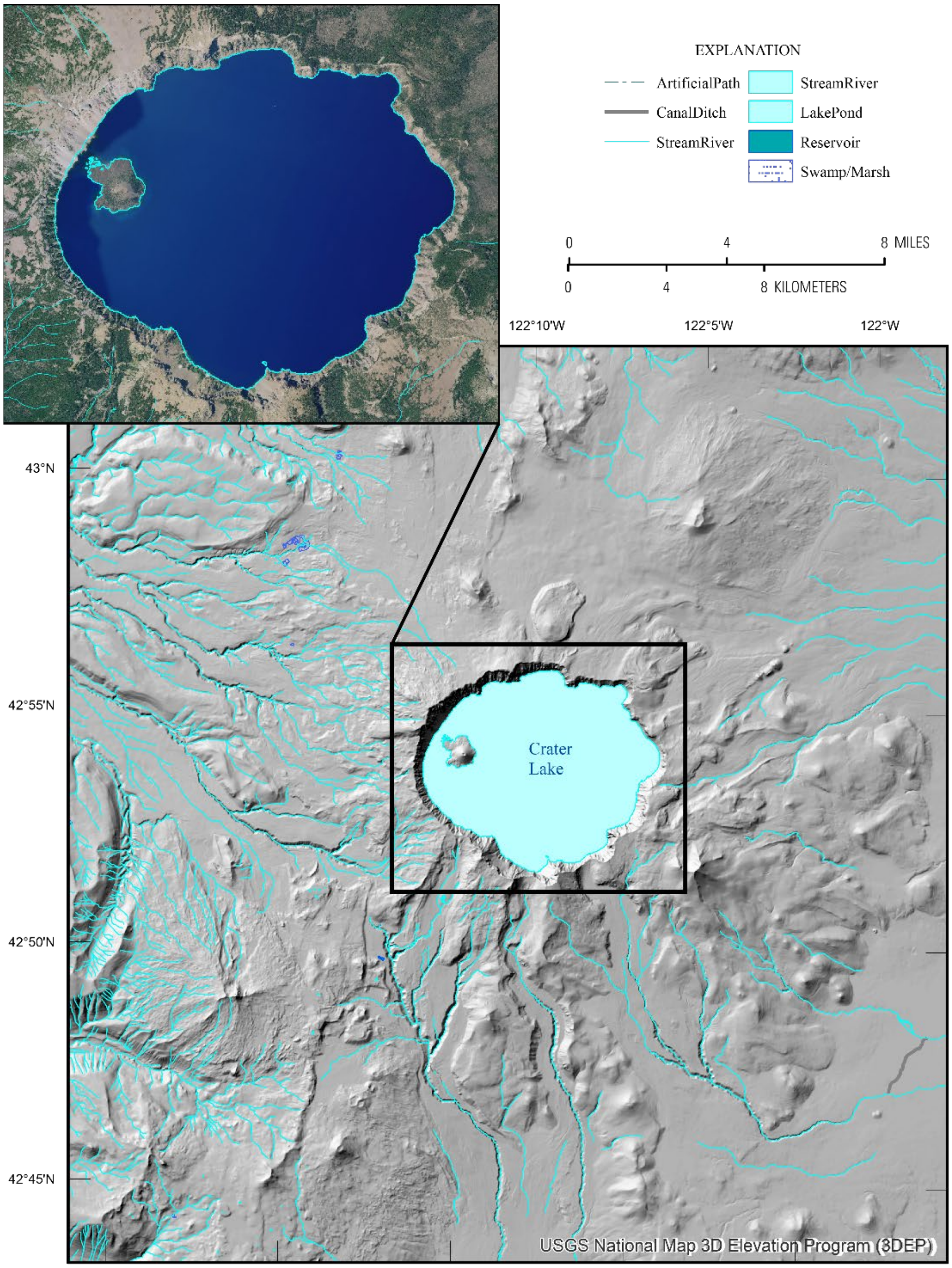


**Figure 54.** Crater Lake on Mount Mazama, Oregon, is an example of natural Lake/pond feature.

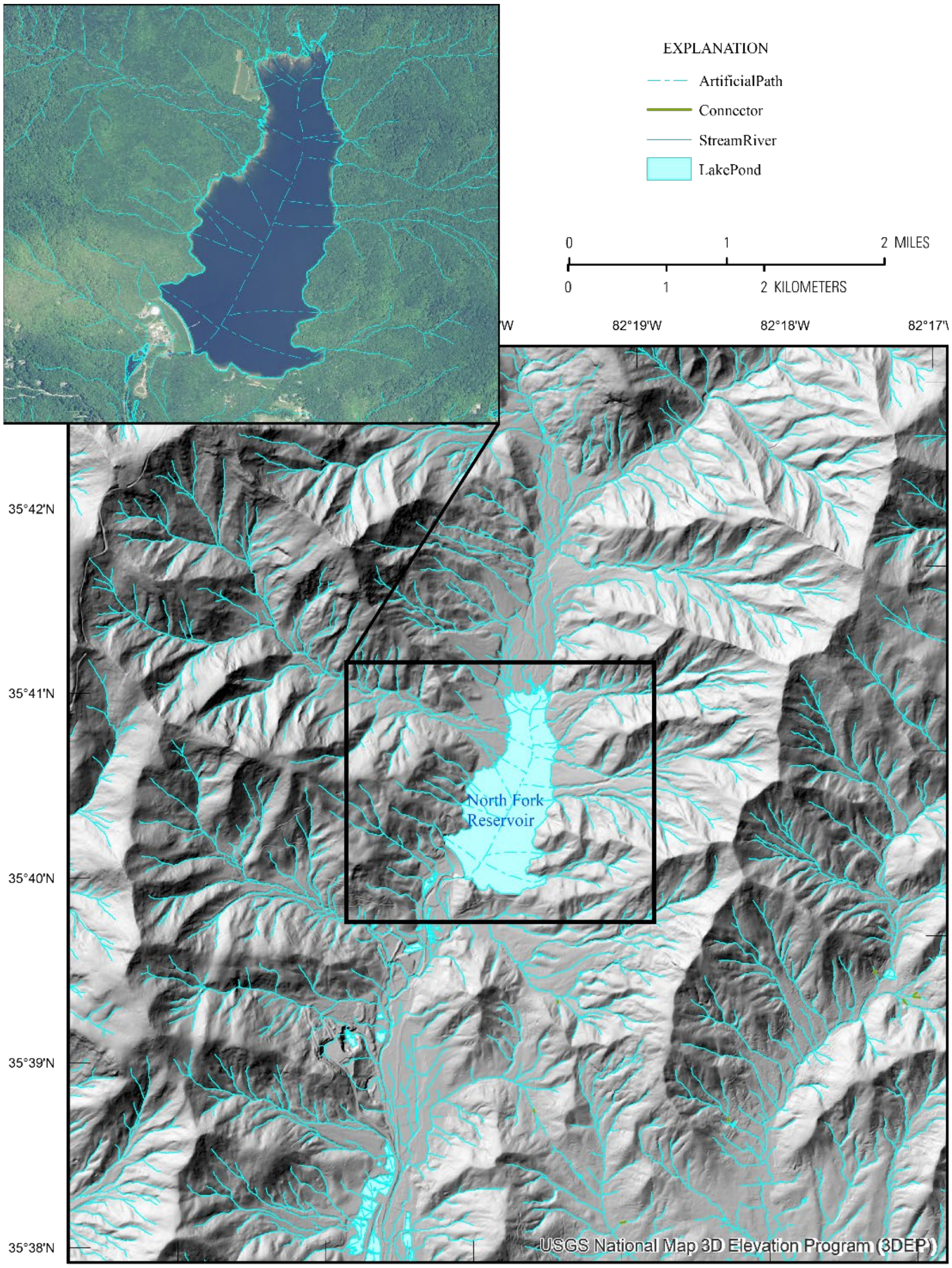


**Figure 55.** North Fork Reservoir, North Carolina, is an example of constructed Lake/pond feature. Source data are from the NHD (U.S. Geological Survey, 2020), which is used to provide examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

## Delineation

The limit of Lake/pond where Stream/river enters, or leaves is determined by the conformation of the land.

The limit of Lake/pond is the position of the visible edge of the waterbody (date of lidar collection).

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 27**).

**Table 27.** Lake/pond Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | -- | -- |
| 2-dimensional (polygon) | greater than 0 | -- | -- |

## Special Conditions

None.

## Data Extraction

## Capture Conditions

For Elevation-Derived Hydrography feature collection, if Lake/pond is greater than or equal to 0.25 acres (1,000 square meters),

then capture.

## Attribute Information

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 39000—Lake/pond (a standing body of surrounded by land).
EClass 11— Polygon created using a hydroflattening breakline.

OR

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 39000— Lake/pond (a standing body of water surrounded by land).
EClass 12— Polygon created from edited hydroflattening breakline on flattened elevation surface.

OR

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 39000— Lake/pond (a standing body of water surrounded by land).
EClass 13— Polygon created for non-flattened waterbody features in the DEM.

### Source Interpretation Guidelines

Do not capture dry lakes as Lake/pond (see Playa feature type, Appendix 1).

The minimum size for islands within Lake/pond is 0.12 acres (approximately 500 square meters).

For examples of islands and intermittently submerged islands that may be apparent on the elevation surface, see “Additional Elevation-Derived Hydrography Treatments and Elevation Specific Features” section.

## Pipeline

A surface or subsurface, closed, constructed conduit for conveying water (**Figure 56** and **Figure 57**).

**Figure 56.** A pipeline crossing the Colorado River near Dotsero, CO (U.S. Geological Survey).

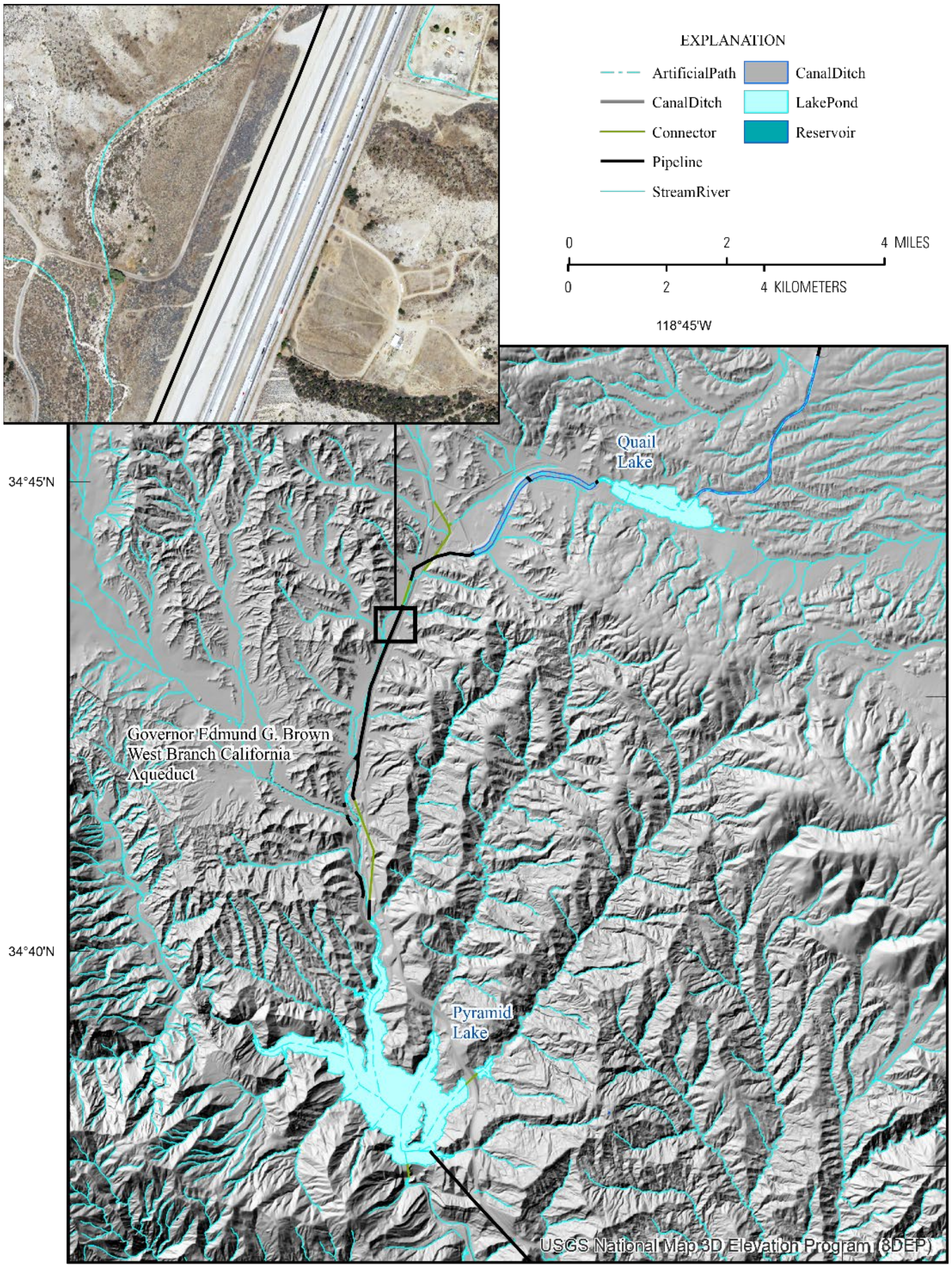


**Figure 57.** The various pipelines that form the Governor Edmund G. Brown West Branch California Aqueduct are shown as an example of Pipeline features. Source data are from the NHD (U.S. Geological Survey, 2020), which is used to provide examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

## Delineation

The limit of an underground Pipeline is the edge of the ground scars or linear clearings, or other above ground artifacts that can be detected from ancillary data or other methods.

The limit of a near-ground or elevated Pipeline is the extent of the structure.

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 28**).

**Table 28.** Pipeline Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | greater than 0 | greater than 5 feet (1.5 meters) above ground or 50 feet (~15 meters) underground |
| 2-dimensional (polygon) | -- | -- | -- |

## Special Conditions

None.

## Data Extraction

## Capture Conditions

### *Above Ground*

If Pipeline conveys water between natural water features such as Stream/river or Lake/pond features, is above ground, is not underwater, and is greater than or equal to 5 feet (1.5 meters) along the longest axis,

then capture with EClass of 0 and FClass of 2.

Note: The Pipeline must connect to existing water features or water conveyance on both ends.

### *Underground*

If Pipeline conveys water underground, is in NHD, or the Pipeline is greater than 50 feet in length from other ancillary sources,

then capture.

Note: Only above ground pipelines are required to be captured, but if an ancillary source is used, an underground pipeline can be added to connect above ground features. Source of the ancillary data must be cited.

### *Through Transportation Feature*

If Pipeline conveys water under a road or other transportation feature, then capture as a Connector: Culvert with EClass of 3, (see Connector: Culvert description for FCode), and not as Pipeline.

### Attribute Information

FClass 2— Hydrography feature captured outside the collection criteria of the elevation-derived hydrography specifications.
FCode 42800—Pipeline (A surface or subsurface, closed, constructed conduit for conveying water).
EClass 0— Not used to create elevation derivatives.

OR

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 42800—Pipeline (A surface or subsurface, closed, constructed conduit for conveying water).
EClass 2— Linear feature that follows elevation surface.

OR

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 42800—Pipeline (A surface or subsurface, closed, constructed conduit for conveying water).
EClass 3— Linear feature used for breaching.

### Source Interpretation Guidelines

None.

## Playa

The flat area at the lowest part of an undrained desert basin, generally devoid of vegetation (**Figure 58** and **Figure 59**).

**Figure 58.** Clayton Valley Playa, Nevada, is an example of a Playa feature. Photograph by Lisa Stillings, U.S. Geological Survey.

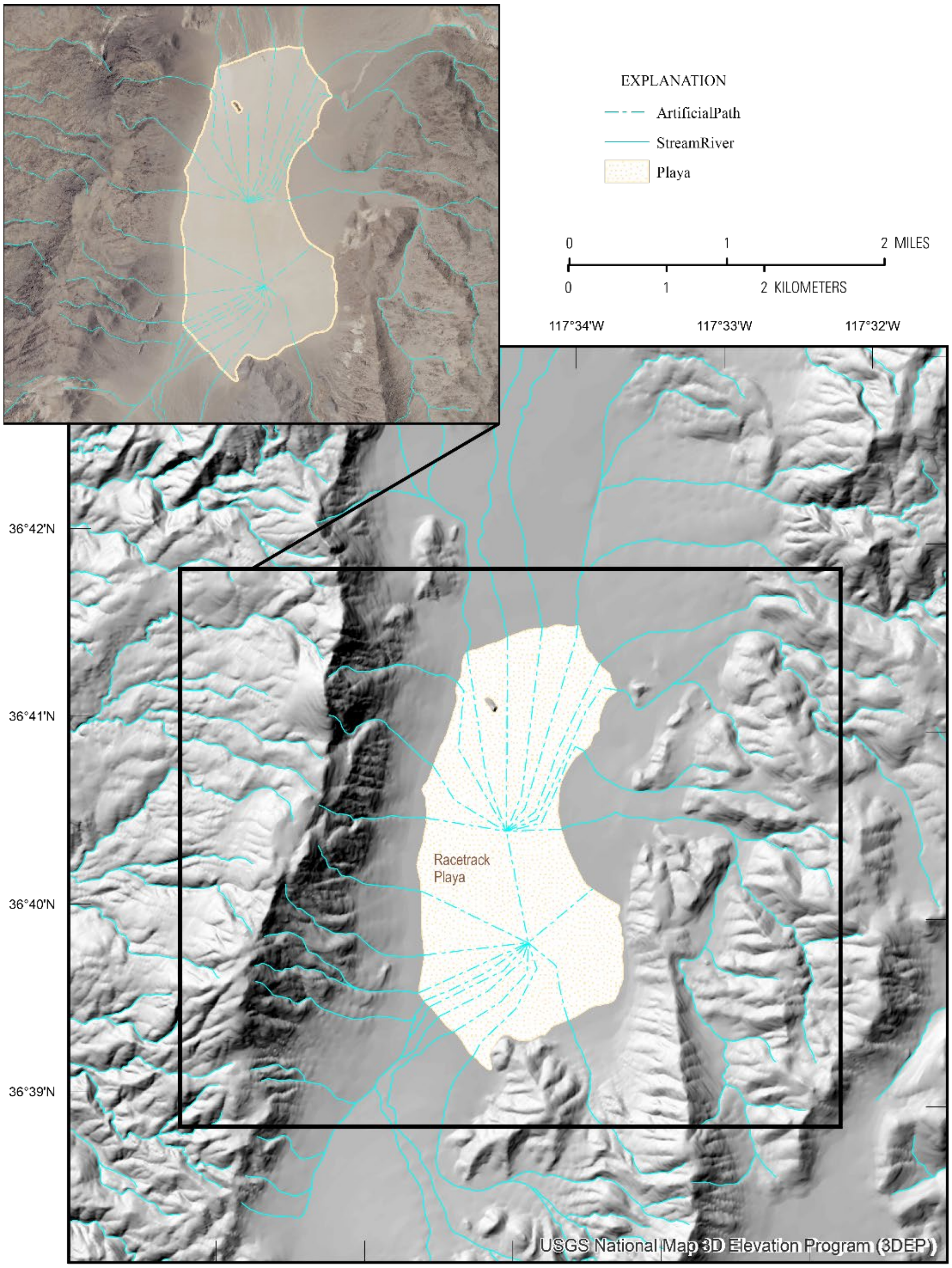


**Figure 59.** Racetrack Playa in Death Valley, California, is an example of Playa feature. Source data are from the NHD (U.S. Geological Survey, 2020), which is used to provide examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

## Delineation

The limit of Playa is the extent of the lowest part of the basin.

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 29**).

**Table 29.** Playa Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | -- | -- |
| 2-dimensional (polygon) | greater than 0 | -- | -- |

## Special Conditions

None.

## Data Extraction

## Capture Conditions

If Playa is greater than or equal to 1 acre (4,000 square meters),

then capture.

## Attribute Information

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 36100—Playa (the flat area at the lowest part of an undrained desert basin, generally devoid of vegetation).
EClass 0— Not used to create elevation derivatives.

## Source Interpretation Guidelines

A Sink feature shall be placed at the lowest point of elevation in a Playa feature.

## Sea/ocean

The great body of saltwater covering most of the Earth's surface (**Figure 60** and **Figure 61**).

**Figure 60.** Photograph of an ocean wave (Photograph by S. Lee, National Park Service, 2015).

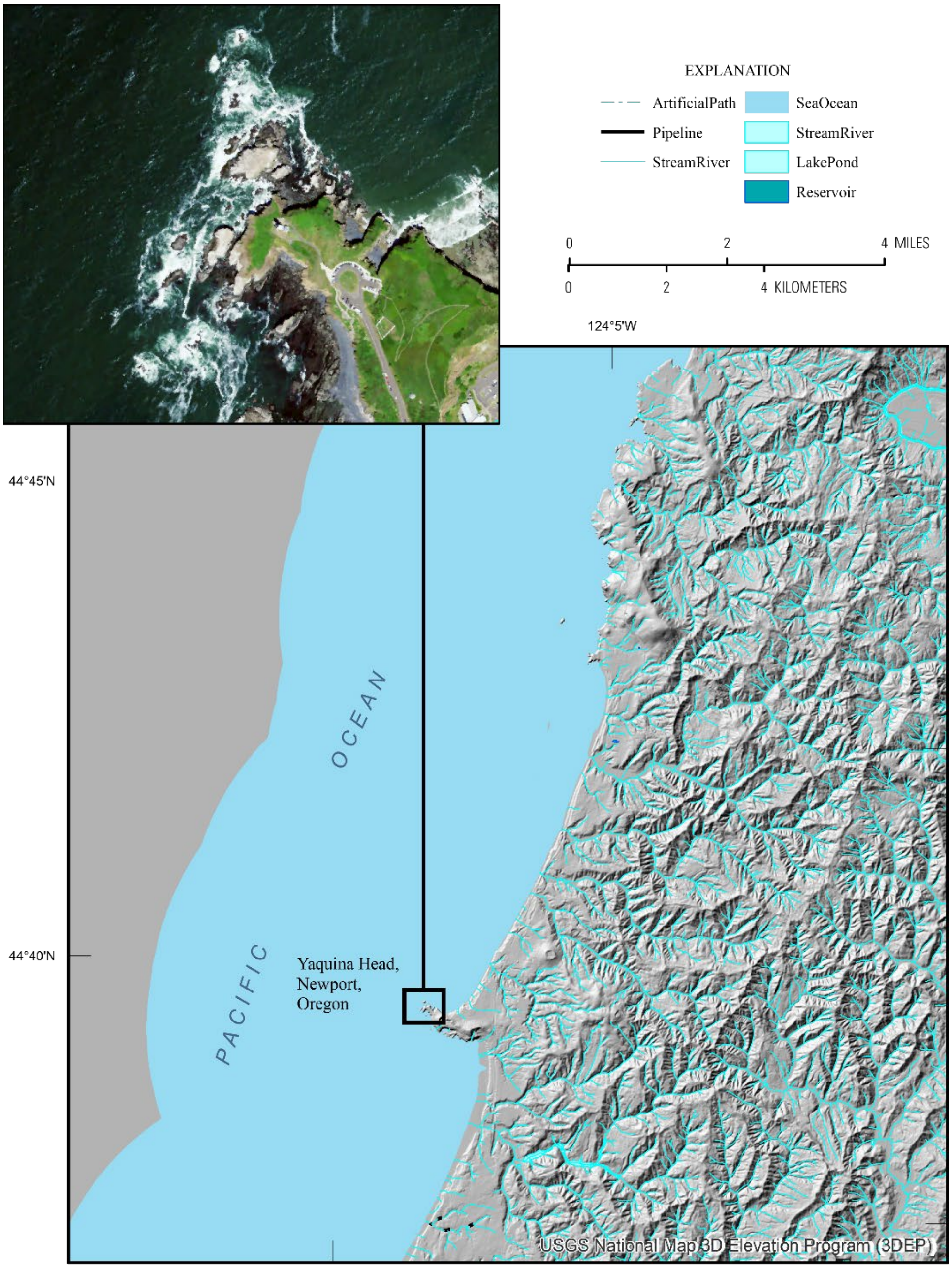


**Figure 61.** The Pacific Ocean near Yaquina Head, Newport, Oregon, is an example of a Sea/ocean hydrographic feature. Source data are from the NHD (U.S. Geological Survey, 2020), which is used to provide examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

### Delineation

The land/sea interface of a Sea/ocean polygon feature shall match the Sea/ocean hydroflattened breakline polygon created from the source elevation data, except in locations where the hydroflattened breakline polygon is intersected by the NHD coastline feature, in which case, it shall terminate at the NHD coastline location (**Figure 62**). The basic method for determining the Sea/ocean extent shall include the following:

- Use the hydroflattened polygon collected with the elevation data as the Sea/ocean landward extent or land/sea interface.
    - Use the NHD to determine if an NHD coastline feature overlaps the hydroflattened breakline polygon.
    - If the hydroflattened breakline polygon extends inland beyond the NHD coastline feature:
        - In CONUS, the Sea/ocean polygon shall terminate at the NHD coastline feature.
        - In Alaska, the Sea/ocean polygon may terminate up to 100 meters inland beyond the NHD coastline feature.
    - If portions of the hydroflattened area are excluded by the NHD coastline feature, they shall be coded as Lake/pond (FCode 39000) or Stream/river (FCode 46000) as appropriate.
- The seaward extent of the Sea/ocean polygon shall be the current WBD boundary.
- In international waters, the seaward Sea/ocean polygon extent shall be the international border as defined in by the International Boundaries TIGER/Line Shapefile from the US Census Bureau.
- The Sea/ocean polygon shall be split at major inlets where the distance between headlands is at least a width of 1 nautical mile, which is approximately 2 kilometers (**Figure 63**).
    - Inlets shall be treated as entire features. The primary outlet point downstream of where the inlet reaches 2 kilometers in width shall be used as the split point.
    - Space between islands shall not be split where it narrows to 2 kilometers or less. All water between and around islands shall be considered Sea/ocean.
- Sea/ocean polygons shall not contain Artificial path features, nor shall Artificial path features extend into the Sea/ocean polygon from the inland stream network. All inland Artificial path features shall end and snap at the landward edge of the Sea/ocean polygon. All lines and polygons that terminate at the Sea/ocean, shall end and snap at the Sea/ocean polygon boundary.
- The Sea/ocean polygon between the United States and other countries shall be delineated to the international border (**Figure 64**).

In areas where rivers enter Sea/ocean, the limit is where the conformation of the land and water makes the division obvious, or, if the land and water do not suggest an obvious limit, the limit is where the river reaches a width of 1 nautical mile (approximately 2 kilometers) without further constrictions.

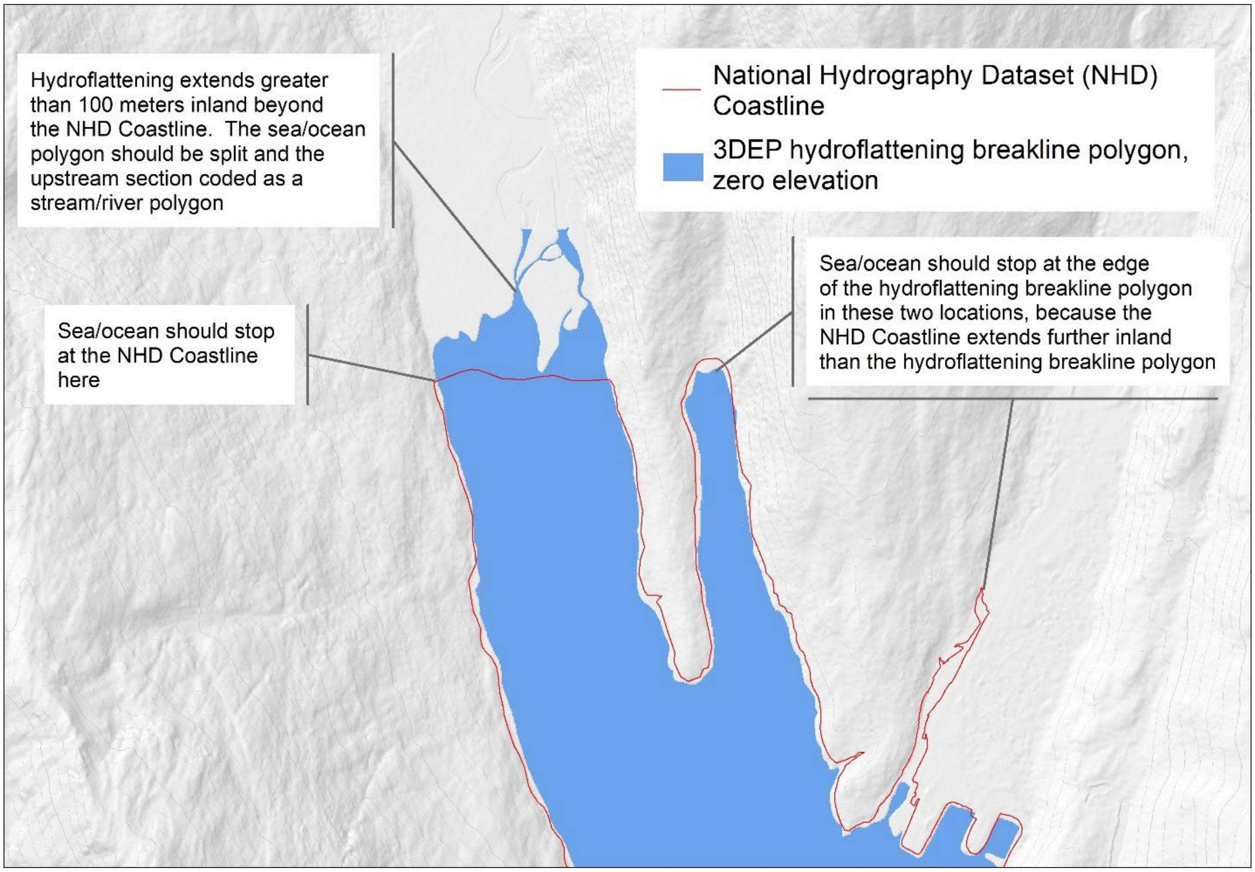


**Figure 62.** Example of where the Sea/ocean polygon shall end when the NHD coastline is used as a reference.

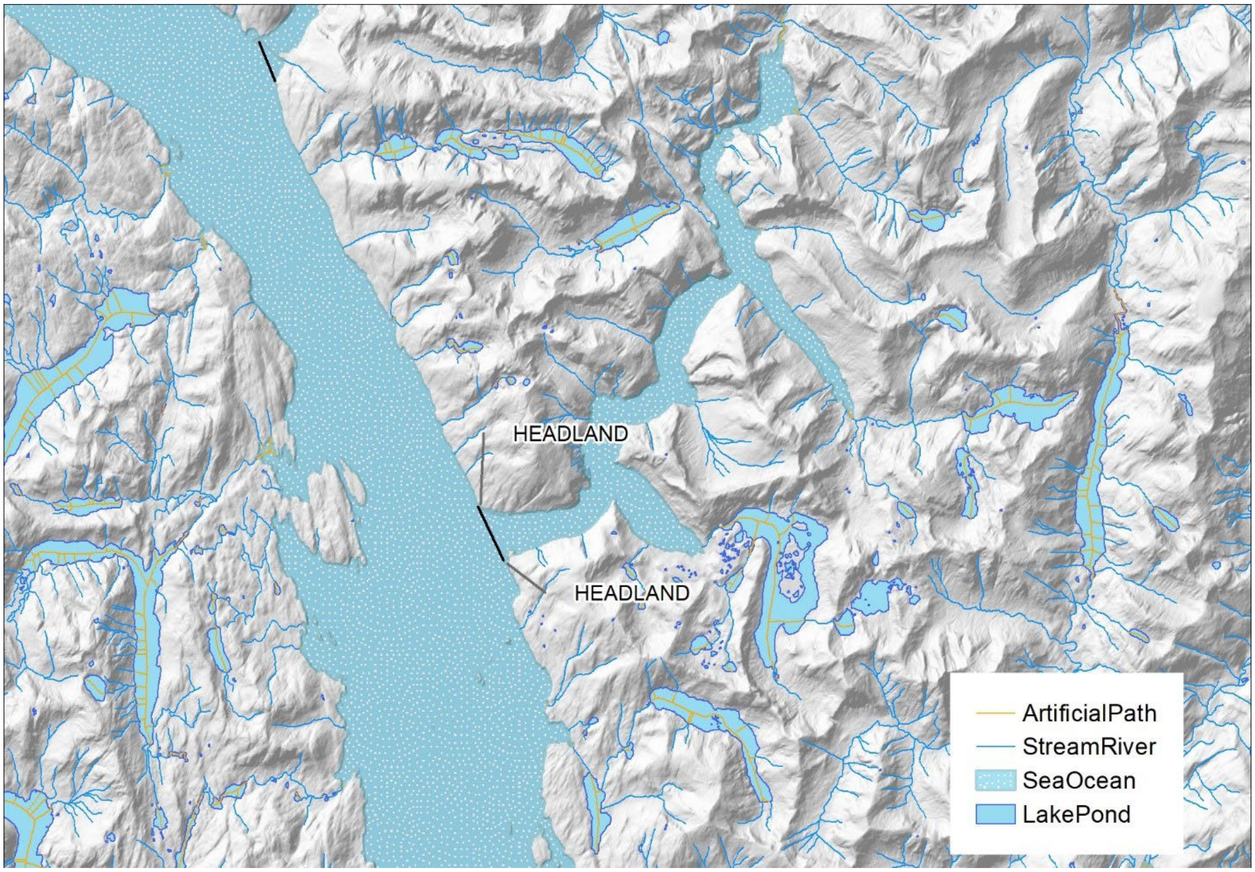


**Figure 63.** Example of where the Sea/ocean polygon shall end when the NHD coastline is used as a reference.

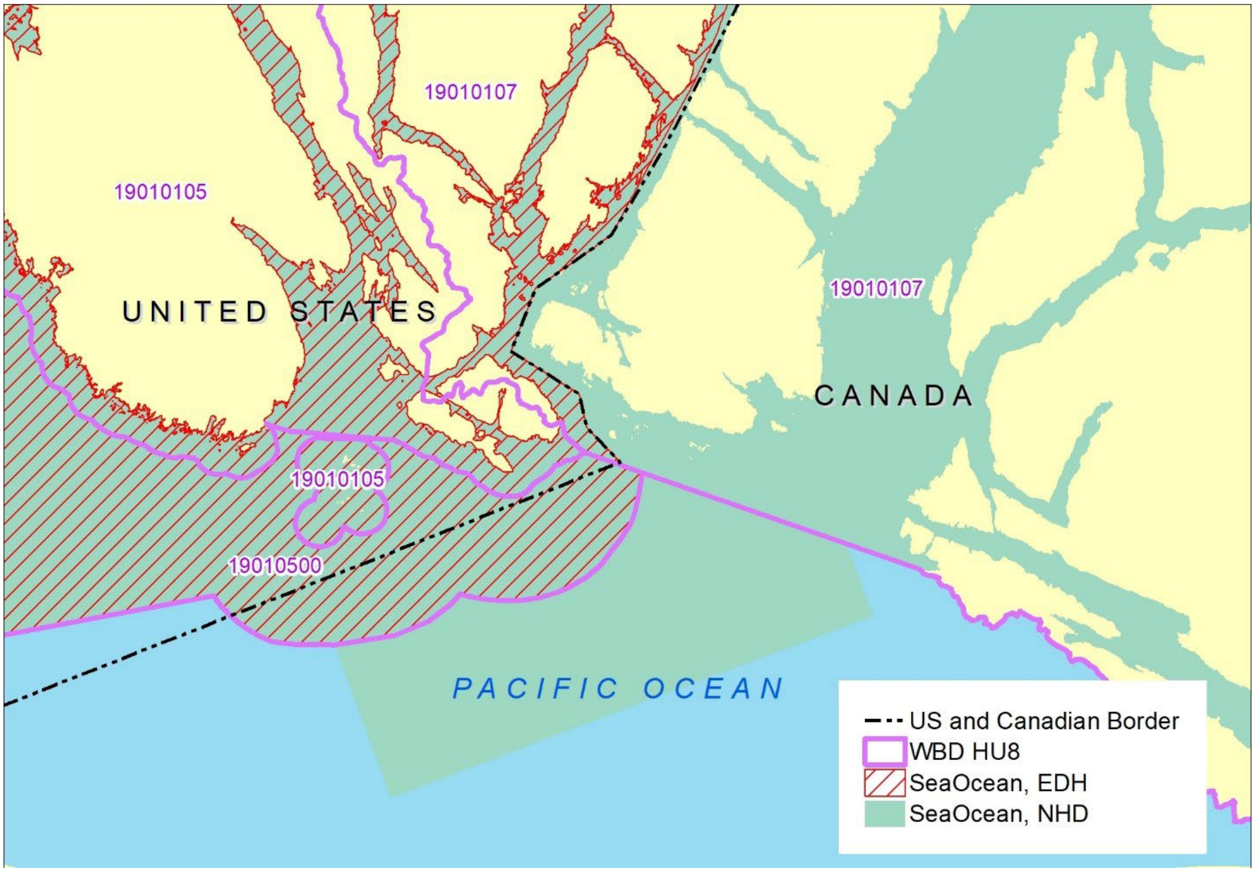


**Figure 64.** Example of where the Sea/ocean polygon should end when the NHD coastline is used as a reference.

A boundary waterbody is any waterbody that contains the boundary of the collection (meaning the opposite bank or shore is not being mapped). Boundary waterbodies may be a single water surface elevation (for example, lake) or gradient (for example, river). Boundary waterbodies shall contain either a centerline or the extent of the current WBD, depending on the circumstances.

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 30**).

**Table 30.** Sea/ocean Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | -- | -- |
| 2-dimensional (polygon) | greater than 0 | -- | -- |

## Special Conditions

None.

## Data Extraction

### Capture Conditions

If Sea/ocean is within the project area, capture all.

### Attribute Information

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 44500—Sea/ocean (the great body of saltwater that covers much of the Earth).
EClass 11— Polygon created using a hydroflattening breakline.

OR

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 44500—Sea/ocean (the great body of saltwater that covers much of the Earth).
EClass 12— Polygon created from edited hydroflattening breakline on flattened elevation surface.

OR

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 44500—Sea/ocean (the great body of saltwater that covers much of the Earth).
EClass 13—Polygon created for non-flattened waterbody features in the DEM.

### Source Interpretation Guidelines

The minimum size for islands within Sea/ocean is 1 acre (4,000 square meters).

For examples of islands and intermittently submerged islands, which may be apparent on the elevation surface, see the “Additional Elevation-Derived Hydrography Treatments and Elevation Specific Features” section.

## Sink

The place at which a stream disappears into an underground conduit or an isolated depression where the network ends (**Figure 65** and **Figure 66**).

**Figure 65.** Ephemeral sinking stream in Winchester, Virginia. Photograph by Benjamin V. Miller, U.S. Geological Survey.

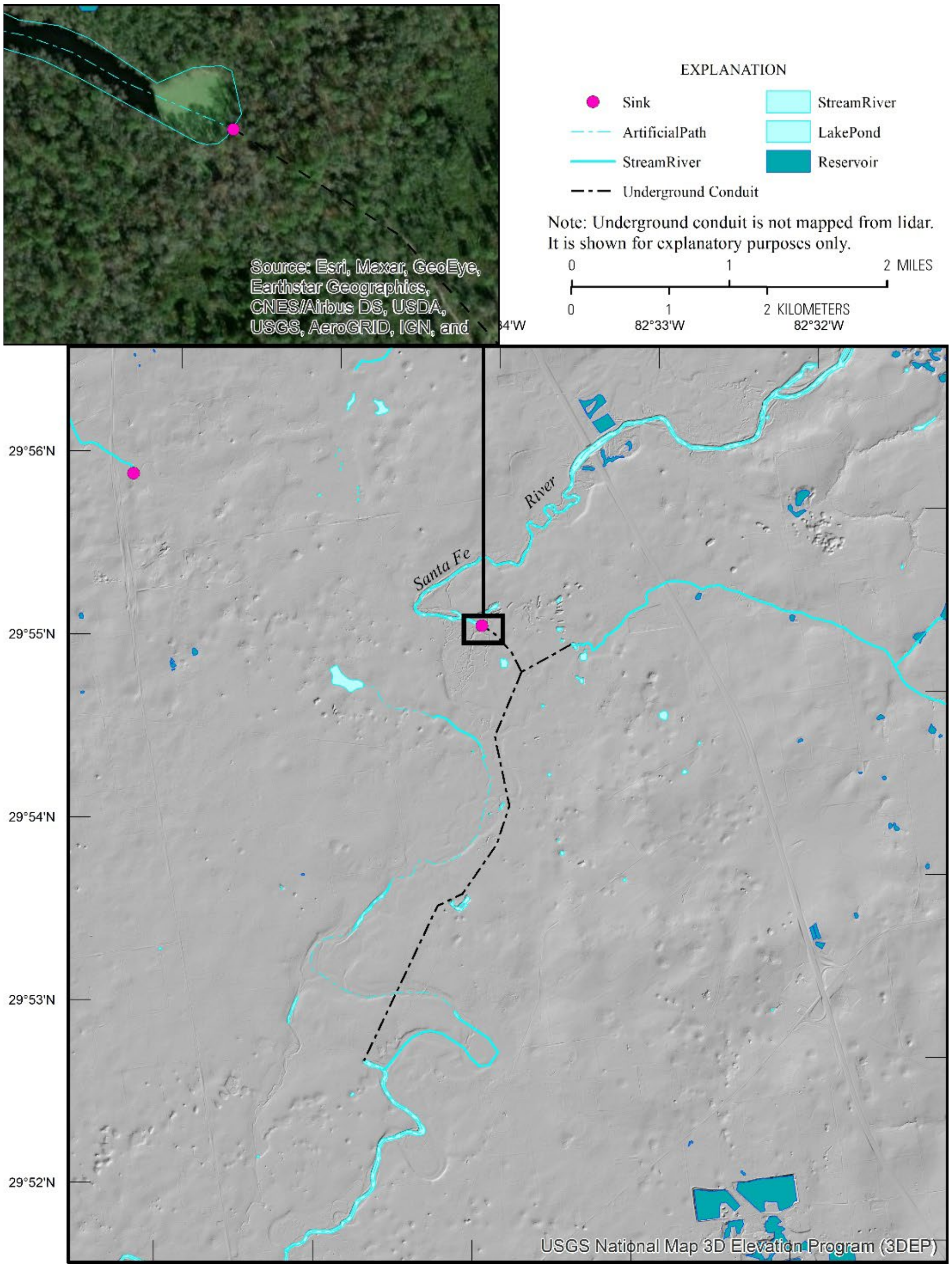


**Figure 66.** Sink features on the Santa Fe River, Florida, shown as examples of Sink hydrographic features. Source data are from the NHD (U.S. Geological Survey, 2020), which is used to provide examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

## Delineation

The limit of Sink is the place at which a stream disappears underground.

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 31**).

**Table 31.** Sink Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | greater than 0 | -- | -- |
| 1-dimensional (line) | -- | -- | -- |
| 2-dimensional (polygon) | -- | -- | -- |

## Special Conditions

None.

## Data Extraction

## Capture Conditions

If stream disappears,

then capture at the point of disappearance.

## Attribute Information

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 45000—Sink (the place at which a stream disappears into an underground conduit or an isolated depression where the network ends).
EClass 0— Not used to create elevation derivatives.

## Source Interpretation Guidelines

A Sink feature shall be used at the lowest point of elevation in a Playa feature.

## Stream/river

A body of flowing water (**Figure 67**, **Figure 68**, and **Figure 69**).

**Figure 67.** Eagle Creek at Zionsville, Indiana, shown as an example of a river. Photograph by U.S. Geological Survey.


**Figure 68.** Diagram showing the shortest and longest axes of a Stream/river feature.

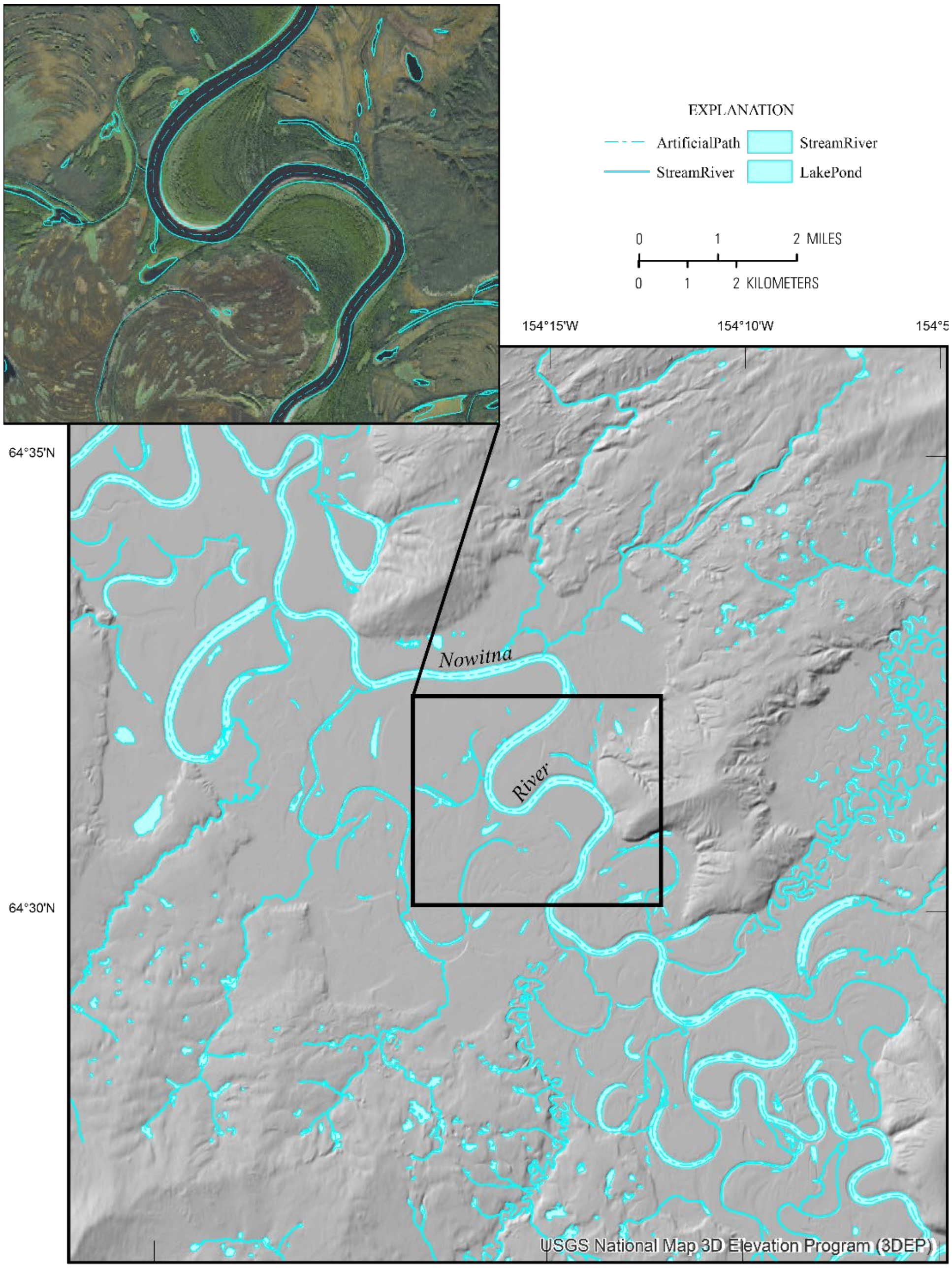


**Figure 69.** Nowitna River, Alaska, shown as an example of a Stream/river hydrographic feature. Source data are from the NHD (U.S. Geological Survey, 2020), which is used to provide examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

## Delineation

The delineation of Stream/river features shall adhere to the following rules, describing the boundary limits of the feature, and other delineation rules:

- The boundary limit of Stream/river:

  - Is determined by the position of the visible edge of the banks as depicted on the DEM (as of the lidar collection date).
  - Where it enters or leaves Lake/pond
    - Is determined by the conformation of the land.
  - Where it enters Sea/ocean
    - Is determined by the location where the conformation of the land and water makes the division obvious, or, if the land and water do not suggest an obvious limit, the limit is where the stream reaches a width of 1 nautical mile (approximately 2 kilometers) without further constrictions.
- Other delineation rules
  - The upper limit of Stream/river is where the feature first becomes evident as a channel.
  - In cases of sharp turns of rapidly moving water, where the natural water surface is notably not level bank-to-bank, the water surface shall be represented as it exists while maintaining an aesthetic cartographic appearance.
  - The entire water surface edge shall be at or below the immediately surrounding terrain.
  - Stream channels shall break at culvert locations leaving the roadway over the culvert intact.
  - Streams shall be continuous at bridge locations.

## Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 32**).

**Table 32.** Stream/river Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| 0-dimensional (point) | -- | -- | -- |
| 1-dimensional (line) | -- | less than 50 ft (15 m) in Lidar; less than 98 ft (30 m) in IfSAR | -- |
| 2-dimensional (polygon) | -- | greater than 50 ft (15 m) in Lidar; greater than 98 ft (30 m) in IfSAR | -- |

## Special Conditions

To accommodate variations in the shortest axis of Stream/river:

- For lidar based hydrography
  - The 3DEP breaklines used for hydroflattening streams and rivers on the elevation surface may be used as Stream/river polygon features in elevation-derived hydrography.
  - Streams greater than 15 meters across should be delineated as (2D) polygon streams, and streams less than 15 meters across should be delineated as (1D) line streams. On occasion, the stream may narrow or expand beyond these thresholds, and the following chart explains how to adjust the stream accordingly.

- If narrowed section is less than 15 meters wide in a polygon stream for less than 1000 meters, then keep the narrowed section as a polygon feature.
- If narrowed section is less than 15 meters wide in a polygon stream for more than 1000 meters, then convert narrowed section to a line feature.
- If widened section is greater than or equal to 15 meters in a line stream for less than 1000 meters, then keep as a line stream.
- If widened section is greater than or equal to 15 meters in a line stream for more than 1000 meters, then convert widened section to a polygon feature.

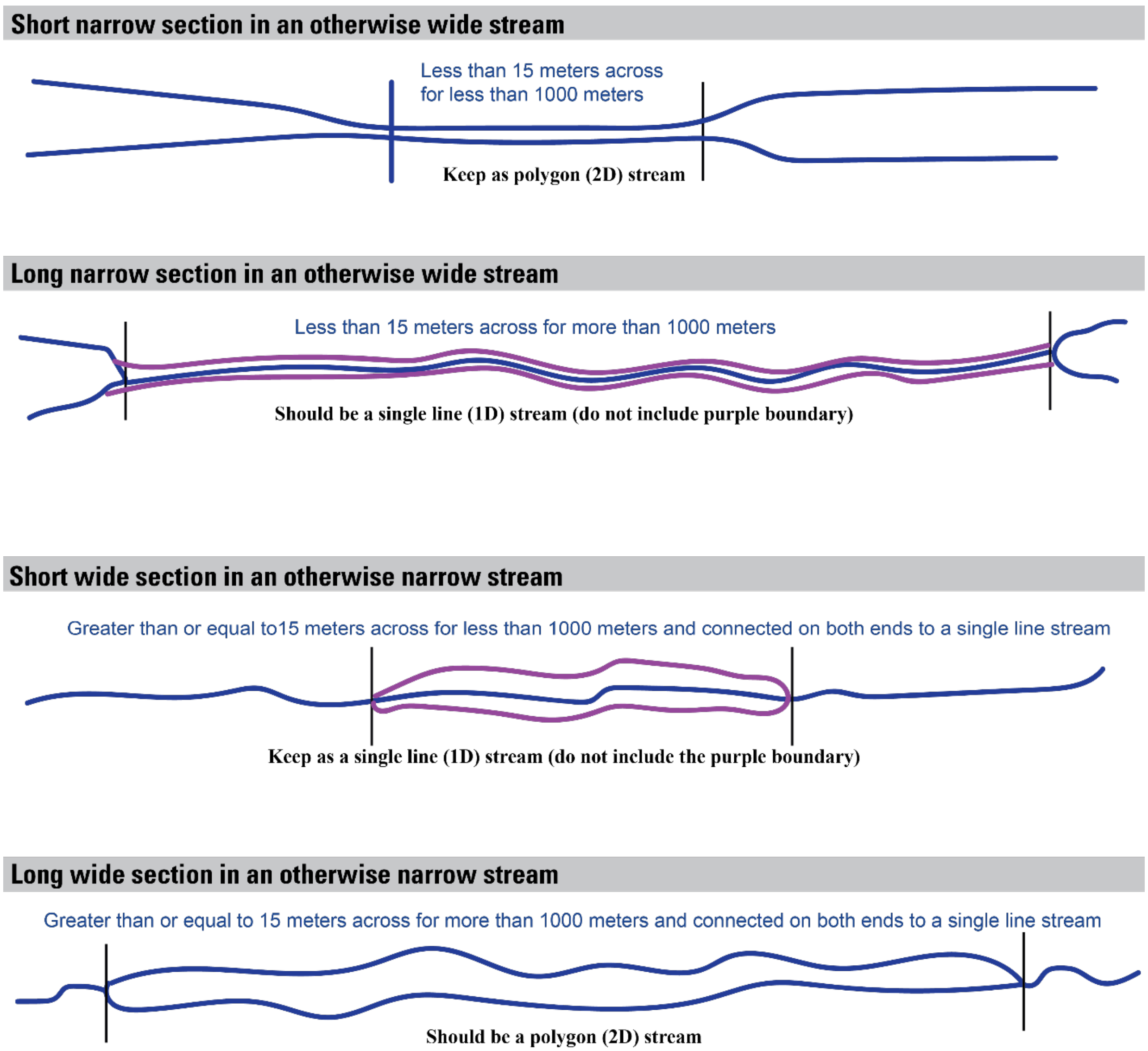


**Figure 70.** Stream/river feature special conditions for lidar based hydrography.

- For IfSAR based hydrography.

- Smoothed 3DEP breaklines used for hydroflattening streams and rivers on the IfSAR elevation surface may be used as Stream/river polygon features in elevation-derived hydrography.
    - If narrowed section is less than 30 meters wide in a polygon stream for less than 2000 meters, then keep the narrowed section as a polygon.
    - If narrowed section is less than 30 meters wide in a polygon stream for more than 2000 meters, then convert narrowed section to a line feature.
    - If widened section is greater than or equal to 30 meters in a line stream for less than 2000 meters, then keep as a line stream.
    - If widened section is greater than or equal to 30 meters in a line stream for more than 2000 meters, then convert widened section to a polygon feature.

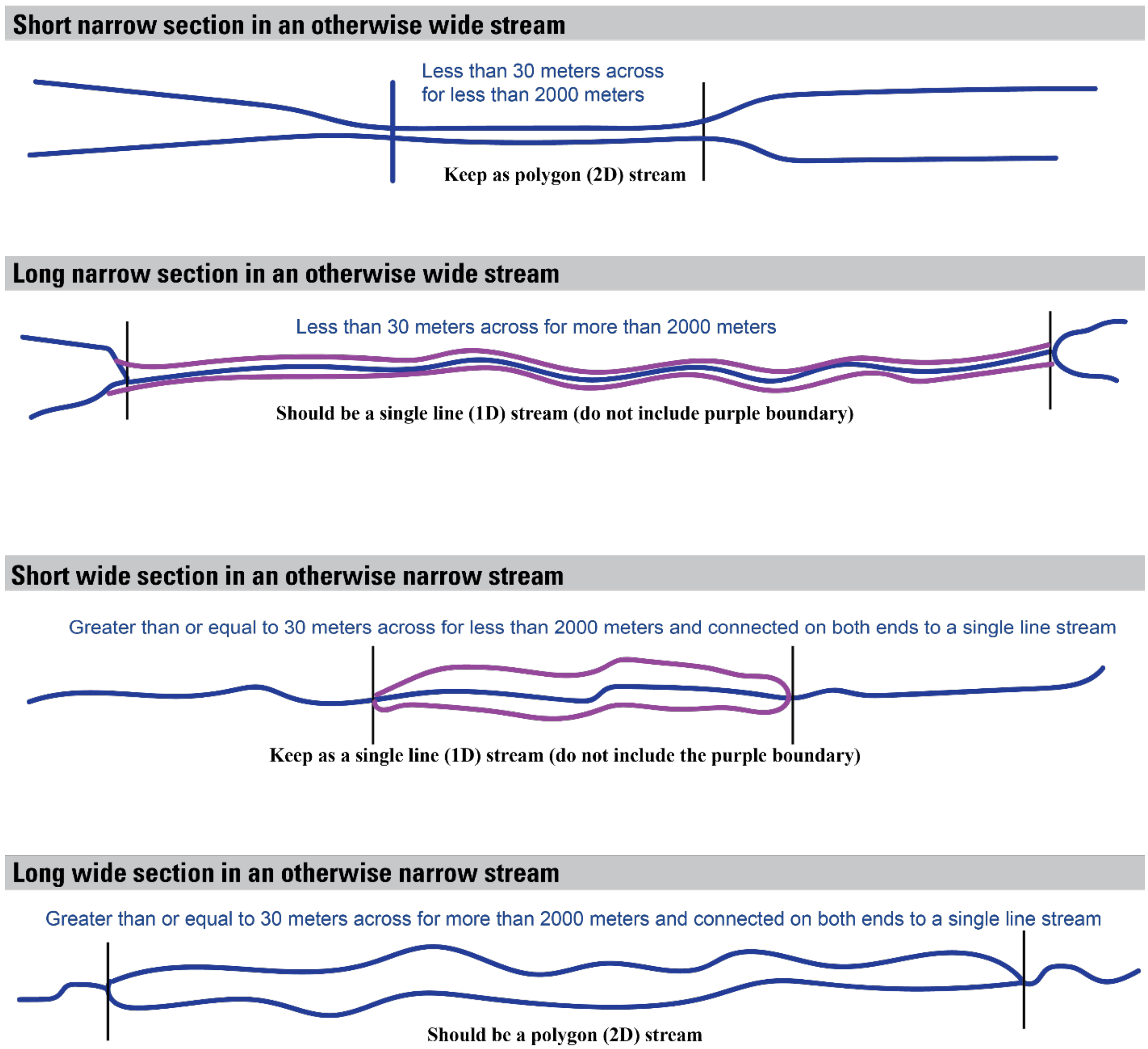


**Figure 71.** Stream/river feature special conditions for IfSAR based hydrography.

## Data Extraction

### Capture Conditions

If Stream/river" has a detectable channel on the elevation surface, then capture.,

then capture.

### Attribute Information

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 46000—Stream/river (a body of flowing water).
EClass 2— Linear feature that follows elevation surface.

OR

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 46000—Stream/river (a body of flowing water).
EClass 11— Polygon created using a hydroflattening breakline.

OR

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 46000—Stream/river (a body of flowing water).
EClass 12— Polygon created from edited hydroflattening breakline on flattened elevation surface.

OR

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 46000—Stream/river (a body of flowing water).
EClass 13— Polygon created for non-flattened waterbody features in the DEM.

### Source Interpretation Guidelines

See Stream/river section under the Island section of the Additional Elevation-Derived Hydrography Treatments and Elevation Specific Features for additional information about delineating islands in Stream/river polygons.

## Underground Conduit

A set of naturally occurring subsurface drainage channels formed from the dissolution of soluble rocks in karst terrain or in terrain similar to karst but formed in non-soluble rocks, as by melting of permafrost or ground ice, collapse after mining, and by outflow of liquid lava from beneath its solidified crust (**Figure 72** and **Figure 73**).

**Figure 72**. Ephemeral sinking stream in Minnesota, Rocky Spring, central Kentucky. Photograph by Charles J. Taylor, U.S. Geological Survey.

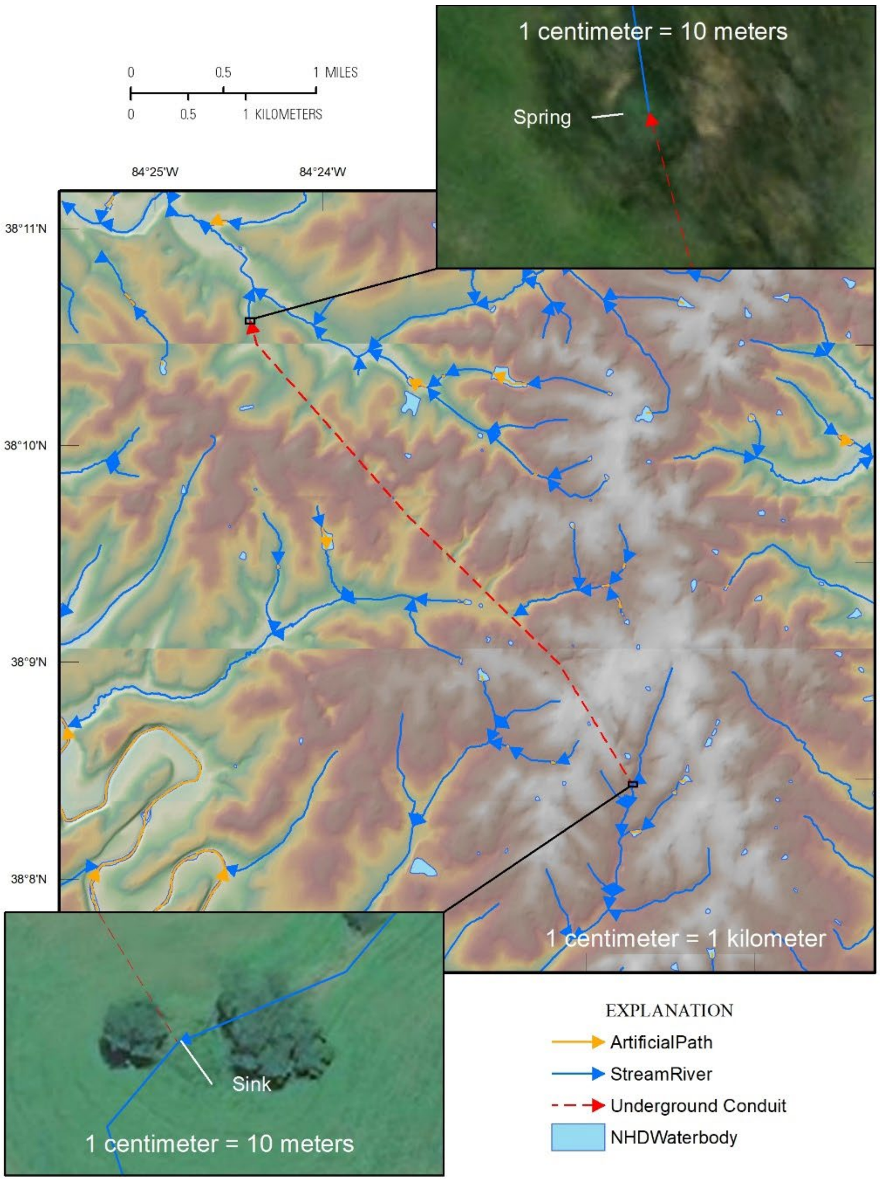


**Figure 73.** Example of an Underground Conduit feature, Fayette County, Kentucky. Note how the surface topography does not provide information or clues as to the direction of groundwater flow within the underground conduit. The flow direction was determined by dye-tracing and provided to the USGS Hydrography program.

## Delineation

The limit of Underground Conduit is the virtual line connecting two nonadjacent network segments where the NHD has previously placed an underground conduit, or other data sources have mapped the subsurface flowpath between surface water features in karst terrain.

Underground Conduit may also be placed in locations where there is evidence of subsurface flowpath between surface water features in thermokarst terrain.

NOTE: A Sink point feature must be placed at the start of an Underground Conduit.

### Representation Rules

Delineate features as points, lines, or polygons based on their area or length along different axes (**Table 33**).

**Table 33.** Underground Conduit Representation Rules.

| Kind of feature object | Area | Shortest Axis | Longest Axis |
|---|---|---|---|
| **0-dimensional (point)** | -- | -- | -- |
| **1-dimensional (line)** | -- | greater than 0 | -- |
| **2-dimensional (polygon)** | -- | -- | -- |

### Special Conditions

None.

### Data Extraction

### Capture Conditions

If Underground Conduit is required to identify a known or highly probable groundwater flowpath with verified outflow location,

then capture.

### Attribute Information

FClass 1—Hydrography feature defined within the collection criteria of the elevation-derived hydrography specifications.
FCode 42002—Underground Conduit: Indefinite (a set of naturally occurring subsurface drainage channels formed from the dissolution of soluble rocks in karst terrain or in terrain similar to karst but formed in non-soluble rocks, as by melting of permafrost or ground ice (thermokarst), collapse after mining, and by outflow of liquid lava from beneath its solidified crust).
EClass 0— Not used to create elevation derivatives.

### Source Interpretation Guidelines

The following conditions indicates when and why the capture of Underground Conduit is required:

- When Underground Conduit is part of a network that is represented as being connected.
- When there is a previously existing groundwater dataset, or other data indicating the presence of karst, thermokarst, mining systems, volcanic terrain, or similar groundwater terrain types disrupting the hydrographic network.

*Special Conditions*

None.

## Additional Elevation-Derived Hydrography Treatments and Elevation Specific Features

The following describes treatments and additional features that shall be applied during the acquisition of Sea/ocean, and other waterbody features and shall be taken into consideration as treatments for the depiction of waterbodies. The treatments and additional features can also be used to convey additional information about the level of confidence for elevation data in certain acquisition areas.

### Island

A permanent island is an area of exposed land, surrounded by water (**Figure 74** and **Figure 75**). Islands need to be erased from Lake/pond, Stream/river, and Sea/ocean features.

**Figure 74.** Image of Rikers Island, New York. The National Map Viewer, U.S. Geological Survey.

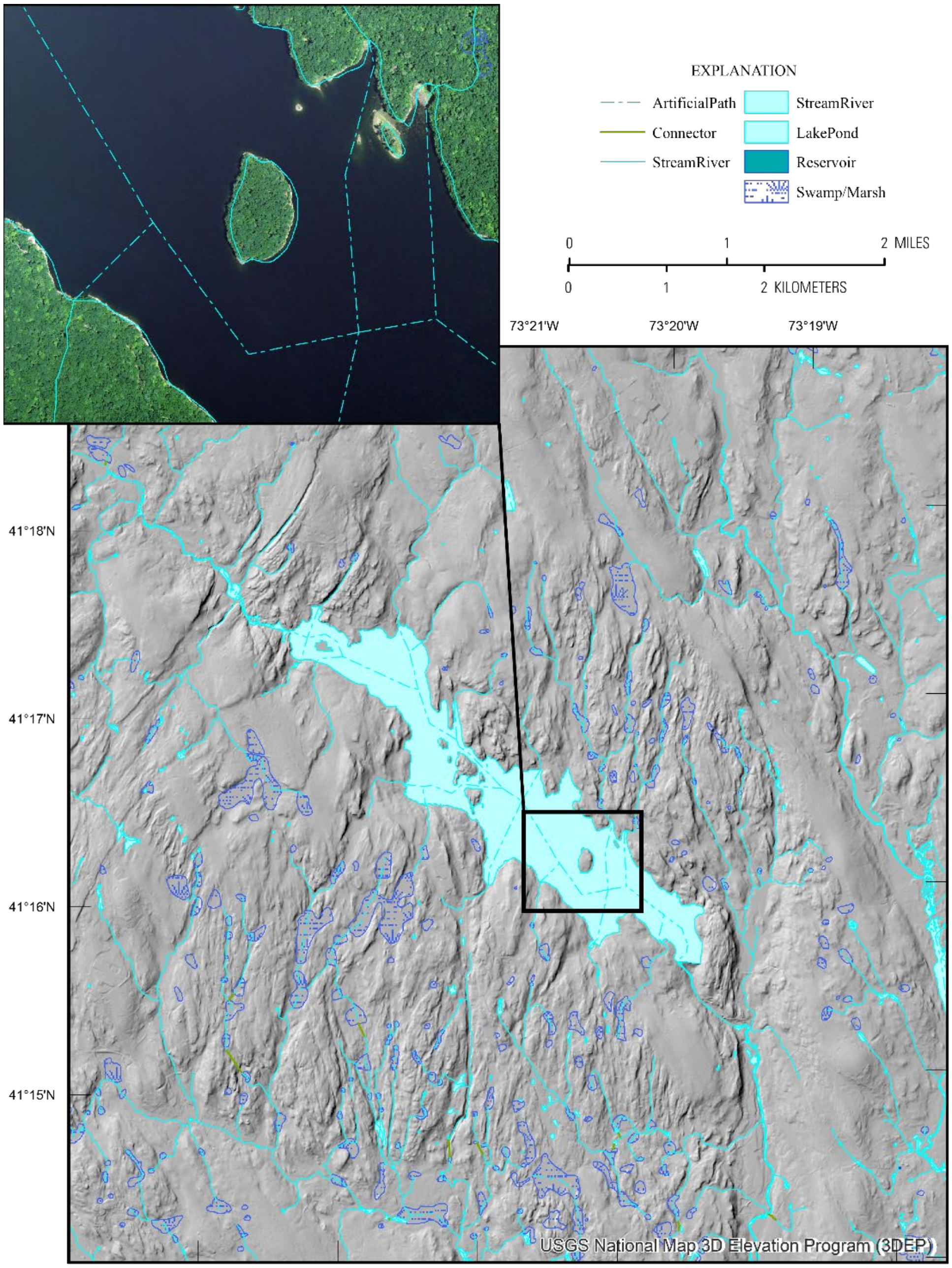


**Figure 75.** An island in the Saugatuck Reservoir in Connecticut shown as an example of treatment for Lake/pond features. Source data are from the NHD (U.S. Geological Survey, 2020), which is used to provide examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

## Delineation

### Lake/pond

The minimum size for islands within Lake/pond is 0.12 acres (500 square meters).

#### Sea/ocean

The minimum size for islands within Sea/ocean is 1 acre (4,000 square meters).

#### Stream/river

The minimum size for islands within Stream/river polygon is 0.12 acres (500 square meters) with the following exceptions:

- The island is present in the hydroflattening breaklines, in which case it may be included.
- There is a group of islands under the minimum size that are grouped close together. They may be added as one island.

See Artificial Path Representation Rules for information about adding Artificial path features in areas with islands.

#### Island/Sandbar

Intermittently/partially submerged islands or parts of islands are submerged at the time of collection (**Figure 76**) are most often found in coastal areas because of tidal variations during the collection, or in rivers collected while at a high flow. If island/sandbar is disconnected from the shore or is visible at the time of collection, then treat as an island (remove from Lake/pond or Sea/ocean feature). Otherwise, treat as shoreline.

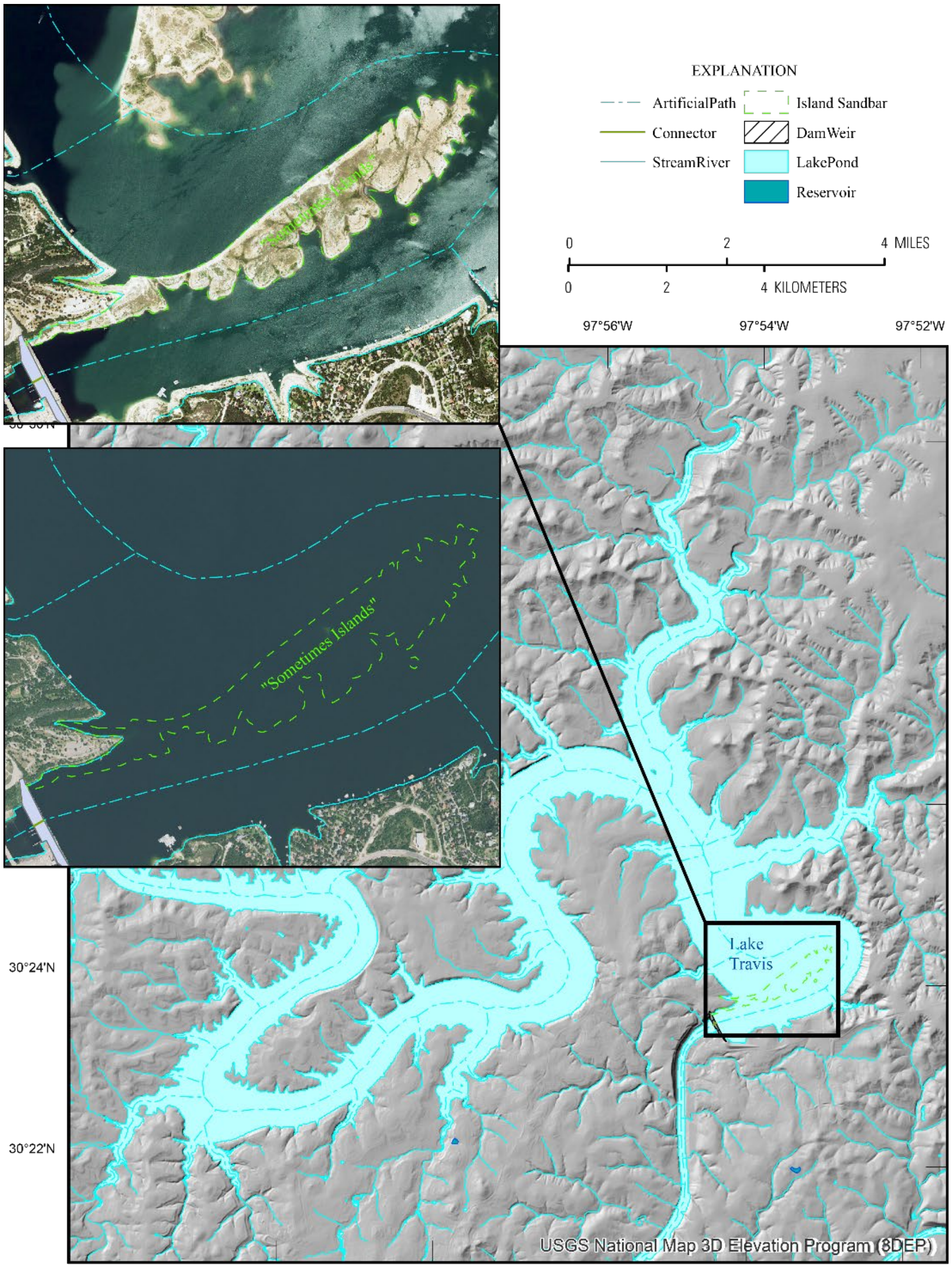


**Figure 76.** “Sometimes Islands” in Lake Travis, Texas, shown as an example of an intermittent island/sandbar. Source data are from the NHD (U.S. Geological Survey, 2020), which is used to provide examples of hydrographic feature types but may not have the same density and other characteristics of elevation-derived hydrography.

## Appendix 1 References

U.S. Census Bureau, 2023. TIGER/Line Shapefile, 2023, Nation, U.S., International Boundaries (national), accessed October 21, 2024, at https://catalog.data.gov/dataset/tiger-line-shapefile-2023-nation-u-s-international-boundaries-national

# Appendix 2. Hydrologically Conditioned and Enforced DEM

The Digital Elevation Models (DEMs) used to derive hydrography for the U. S. Geological Survey's (USGS) 3D Hydrography Program (3DHP) is typically constructed from multiple lidar data projects. Defined below are hydrologically conditioned and enforced DEMs. Note, these definitions may vary from the methods implemented for hydrologically conditioned or enforced products for 3D Hydrography Program (3DHP).

## Hydrologically Conditioned DEM

Hydrologic conditioning enables continuous water flow across an elevation surface and includes the removal of isolated sinks or pits, retaining only real sinks. Hydrologic enforcement, in contrast, adjusts the elevation surface coincident with the hydrological network. While hydrologic conditioning is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether the flow is in a stream channel or not.

A hydroconditioned elevation surface, for the purposes of the 3D National Topography Model, 3DHP data delivery, shall have the following characteristics:

- A Z-value corresponding to every vertex in a linear feature from the elevation–derived hydrography data shall replace a z-value of the corresponding cell in the source elevation DEM.
    - Exceptions are:
        - Any feature that is not used for elevation derivatives (EClass = 0),
            - Any feature that has uninitialized (undefined or indeterminate) flow associated with it,
            - Area of complex channels, dam/weir, ice mass, playa
        - Any feature that crosses above other hydrographic features (for example, pipelines)
- Any raster cell that is overlain by an elevation-derived linear feature, but does not have a vertex associated with it, must have a z-value that is at or below the upstream vertex value and at or above the downstream vertex value.
    - Linear interpolation between vertices is required for cells that represent the linear features to avoid stairstep appearance.
- Z-values corresponding to the linear feature from the elevation–derived hydrography data shall replace the z-values in the surface elevation DEM using the exact z-value or the z-value minus a constant value throughout the DPA.
    - The altered surface must minimally affect slopes along linear features and relative vertical relationship between linear hydrographic features.
- Downstream monotonicity shall be maintained for cells that correspond to the elevation-derived hydrographic features.
    - All Connector: Culvert, Connector, and Underground Conduit vertex z-values must be placed so that terrain that blocks flow has been replaced.
- Polygon features that were not hydroflattened in the source DEM are not required to be hydroflattened.

- All elevation values for cells that correspond to the elevation-derived hydrography linear features shall be connected and flow to an outlet point in the DPA, unless a sink is identified as the terminus of a network or as a true sink on the landscape.
  - If an isolated network flowline features ends at a sink point feature.
    - The Sink point feature z-value shall be equal to the end point of the isolated network z-value and the z-value within the hydro-conditioned DEM.
    - Raster cells that correspond to isolated portions of the network shall maintain downstream monotonicity and other rules defined here.
- All elevation values on the source elevation surface, other than those that correspond to the elevation-derived hydrography linear features, shall flow towards an elevation-derived hydrography cell, or the outlet point in the DPA, or an identified sink.
  - Sink areas that do not serve as the end point of an isolated network, true Sink feature, or outlet point shall be filled such that flow shall not end in the sink areas.
    - Sinks shall be filled using algorithms that cause minimum alteration to the elevation surface.
    - Large, filled sink areas within the hydroconditioned surface may be verified to ensure there are not missing breach features. The following criteria may be used to review filled sinks in the terrain.
      - A filled sink area in which the contiguous cells create a surface area greater than a quarter acre (1,011 square meters) for lidar-derived data, or greater than 1 acre (4050 square meters) for IfSAR-derived data, and
      - With depth that is ≥ 0.2 meters below the non-filled elevation surface for lidar-derived data, or a depth ≥1 meter for IfSAR-derived data.
- A flow direction raster generated from the hydro-conditioned surface must reflect and maintain the elevation-derived hydrography network and allow continuous flow across the surface except where true sinks exist.
- Expected Outcomes
  - Obstructions are removed from the elevation surface where manmade or natural anomalies impede the flow paths of water on the DEM surface.
  - Downstream monotonicity is enforced within cells that correspond to the stream network.
  - All cells on the DEM surface shall flow towards an outlet point or true sink in the elevation surface.
  - The hydro-conditioned DEM can be used to create accurate derivatives that reflect watershed boundaries, flow direction, or flow accumulation models.

## Hydrologically Enforced DEM

Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under structures, rather than appearing to be dammed by these structures in the computer model because of road deck elevations higher than the water levels. Hydro-enforcement also ensures downstream monotonicity at the cells that correspond to a stream network.

A hydro-enforced elevation surface, for the purposes of the 3D National Topography Model, 3DHP data delivery, shall have the following characteristics:

- The hydro-enforced elevation surface shall match the source DEM used to derive the elevation-derived hydrography data in z-values except where z-values have been replaced by the z-values assigned to the elevation-derived hydrographic features for downstream monotonicity.
    - Z-values for every vertex in every linear feature from the elevation–derived hydrography data shall replace the z-values of the corresponding cell in the source elevation DEM.
    - Exceptions are:
        - Any feature that is not used for elevation derivatives (EClass = 0),
            - Any feature that has uninitialized (undefined or indeterminate) flow associated with it,
            - Areas of complex channels, dam/weir, ice mass, playa
        - Any feature that crosses above other hydrographic features (for example, pipelines)
- Any raster cell that is overlain by an elevation-derived linear feature, but does not have a vertex associated with it, must have a z-value that is at or below the upstream vertex value and at or above the downstream vertex value.
    - Linear interpolation between vertices is required for cells that represent the linear features to avoid stairstep appearance.
- Downstream monotonicity shall be maintained for cells that correspond to the elevation-derived hydrographic features.
    - All Connector: Culvert, Connector, and Underground Conduit vertex z-values must be placed so that terrain that blocks flow is replaced.
- Polygon features that were not hydroflattened in the source DEM are not required to be hydroflattened.
    - Artificial path features that flow through polygon features must be enforced in the elevation surface following the rules defined above.
- In cases where polygon features were hydroflattened during abnormal flow conditions and create a condition where z-values for a stream network cannot both maintain downstream monotonicity, and match the elevation of the hydroflattened surface of a waterbody polygon:
    - The z-values of the stream network flowing into and out of the polygon, and the Artificial path features through the polygon, shall maintain downstream monotonicity independent of the hydroflattened polygon boundaries.
    - Features that do not match the z-values of a hydroflattened surface shall be included in the Collection Report. Comments shall also be included on individual features within the file geodatabase of delivered features.
- All elevation values for cells that correspond to the elevation-derived hydrography linear features shall be connected and flow to an outlet point in the DPA, unless a sink is identified as the terminus of a network or as a true sink on the landscape.
    - If an isolated network flowline features ends at a sink point feature.

        - The Sink point feature z-value shall be equal to the end point of the isolated network z-value and the z-value within the hydro-conditioned DEM.
        - Raster cells that correspond to isolated portions of the network shall maintain downstream monotonicity and other rules defined here.
- Expected Outcomes
    - Obstructions are removed from the elevation surface where manmade or natural anomalies impede the flow paths of water on the DEM surface.
    - Elevation values reflect the z-values of the vertices of the elevation-derived hydrography linear features used for hydro-enforcement.
    - Downstream monotonicity is enforced within cells that correspond to the stream network.
    - Cells along the network shall flow towards an outlet point or true sink in the elevation surface.

# Appendix 3. Using Geomorphic Derivatives to Validate the Position of Hydrographic Features

Elevation-derived hydrography must integrate both horizontally and vertically with 3DEP bare-earth elevation surfaces. Geomorphic derivatives of the elevation surface are used to determine if hydrographic features follow channels in the elevation surface. Geomorphic derivatives that depict channelization, low points in the terrain, or flow paths are generated and classified to identify the probable location of water on the landscape. The elevation-derived hydrography validation process uses a four-component index, known as the GeoMorphic Index (GMI), of classified geomorphologic derivatives to assess horizontal integration with the elevation surface.

Four components are used to create the GMI and identify the likely channel positions. Three of the four components (Geomorphons, BotHat, and Multiscale Elevation Percentile) identify channelization or relative low spots in the terrain and predict where water would flow or pool. These derivatives are calculated as neighborhood functions to identify channels based on surrounding terrain but are not computed on the elevation surface as a whole. This creates derivatives that are not overly influenced by extremes within a defined project area (DPA). The fourth component (D-infinity) identifies flowpaths based on flow accumulation rather than channelization. An index is created by combining the geomorphic components into a single index layer used to identify the presence of a stream channel. The index is ranked from 0 to 4, where 0 indicates that no components that may identify a channel are present and 4 indicates all components are present in the index layer. Comparing vector hydrography derived from an elevation source to derivatives from the same elevation source helps ensure hydrographic linework is aligned with surface characteristics likely to represent hydrographic channelization.

Elevation derivatives used in the GMI to identify hydrographic features are described below.

## Feature Preserving Smoothing

Lidar-derived elevation surfaces often capture extremely slight variations in elevation, and often contain artifacts or triangulation that increase roughness, depressions, or channels in the surface. These insignificant features or artifacts cause noise rather than help detect true channels in the surface. A filter is applied to the bare-earth DEM to remove small variations in the surface but maintain edges where changes in slope or direction occur (**Table 34**).

The USGS applies the Feature Preserving Smoothing (Lindsay et al, 2019) algorithm to de-noise the DEM prior to deriving the geomorphic components used in the GMI for data validation.

**Table 34.** Feature Preserving Smoothing Filter.

| Parameter | Values for Lidar | Values for IfSAR |
|---|---|---|
| Size of the filter kernel | 11 | 11 |
| Maximum difference in normal vectors, in degrees | 15 | 15 |
| Number of iterations | 3 | 3 |
| Maximum allowable absolute elevation change | 0.5 | 0.5 |
| Multiplier for when vertical and horizontal units differ | Not Applied | Not Applied |

## Geomorphons

The Geomorphon classification is a method of identifying landforms, typically summarized to 10 types (**Figure 77**). Flat, Peak (summit), Ridge, Shoulder, Spur (convex), Slope, Hollow (concave), Footslope, Valley and Pit (depression) (Jasiewicz and Stepinski, 2013). The algorithm uses a line-of-sight analysis within a search radius, to determine the appropriate landform classification for each cell within a DEM. The search radius controls the generalization of landform classes; the larger the search radius, the more generalized the characterization of the landscape, and the smaller the search radius, the more detailed the landforms that can be identified. Several software systems include a Geomorphon tool, notably GRASS, ArcGIS Pro, QGIS, and Whitebox Tools.

For use as an input geomorphic derivative layer, Valley and Depression classes to represent major river valleys are extracted (**Figure 78** and **Figure 79**). A second geomorphon layer with a smaller search radius to identify ridges is also created. Ridges are used to identify areas where streams cross high points in the terrain. Cells representing ridges are removed from the GMI if a ridge overlaps a potential channel area.

The process used to generate the Geomorphon derivatives is as follows:

- Geomorphons are created from the smoothed elevation surface with the wider search radius for finding valleys (**Table 35**).
- Classes 9 and 10 are extracted to represent stream valleys.
- Geomorphons are created from the smoothed elevation surface with the narrower search radius for finding ridges (**Table 36**).
- Classes 2, 3, and 5 are extracted to represent ridges.

**Table 35.** Geomorphon Valley

| Parameter | Values for Lidar | Values for IfSAR |
|---|---|---|
| Classes of Geomorphons | 9 (valley) and 10 (depressions) | 9 (valley) and 10 (depressions) |
| Search Radius (Meters) | 60 | 250 |
| Flatness Threshold Angle in Degrees | 1 | 0.5 |

**Table 36.** Geomorphon Ridges.

| Parameter | Values for Lidar | Values for IfSAR |
|---|---|---|
| Classes of Geomorphons | 2 (peak), 3 (ridge), and 5 (spur) | 2 (peak), 3 (ridge), and 5 (spur) |
| Search Radius (Meters) | 15 | 15 |
| Flatness Threshold Angle in Degrees | 1 | 0.5 |

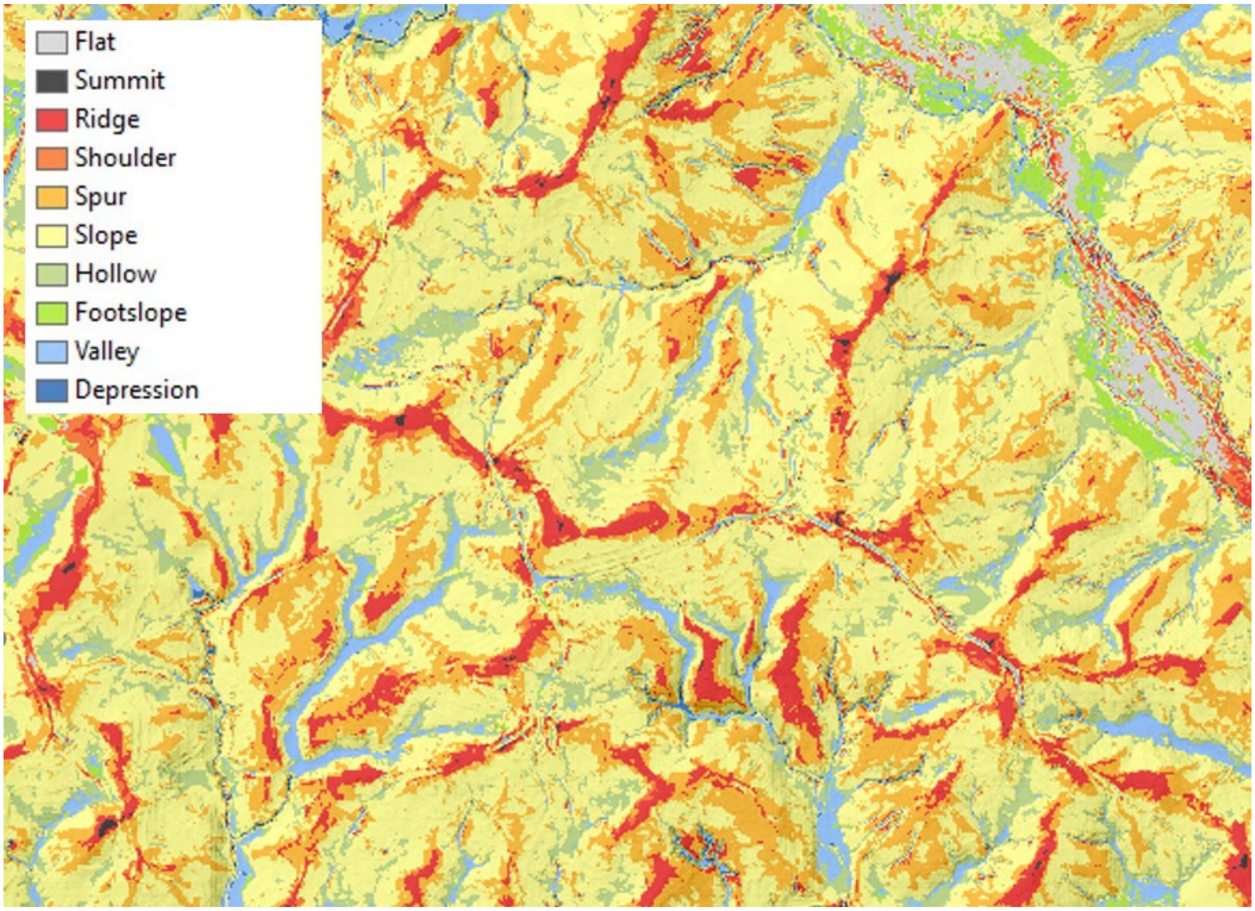

**Figure 77.** Example of the ten geomorphic classifications.

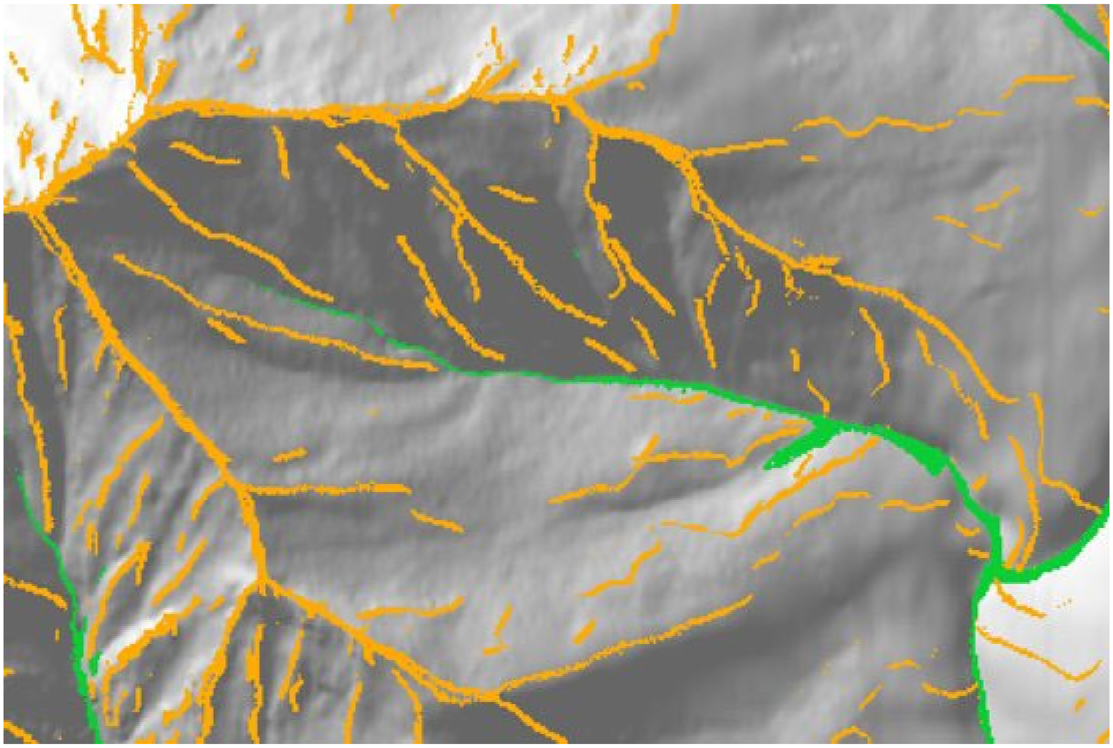

**Figure 78.** Example of a high slope area with Geomorphon valleys (green) and ridges (orange).

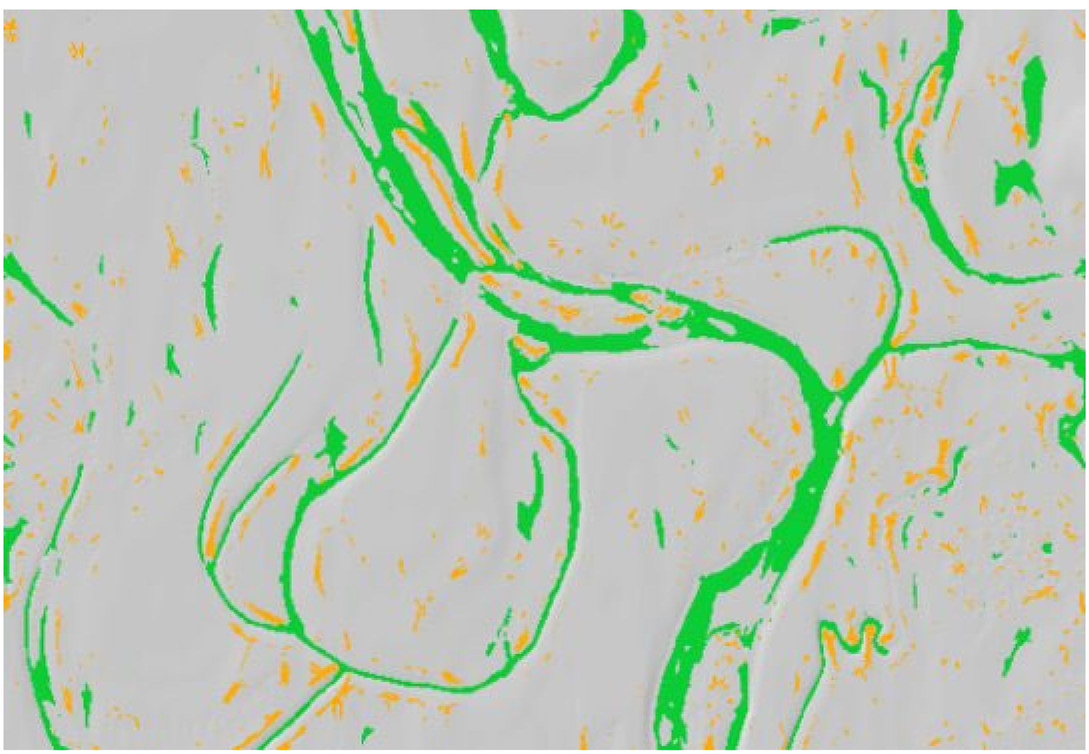

**Figure 79.** Example of a low slope area with Geomorphon valleys (green) and ridges (orange).

## BotHat

BotHat is an implementation of the black top-hat transform function that is used to remove noise and identify low points within an image, applied to an elevation surface. The BotHat function is performed at two neighborhood search radiuses, and cells with transformed values over the corresponding threshold in both iterations are included in the output derivative. (Rodriquez, et al., 2002).

The process used to generate the BotHat derivative is as follows:

- A black top-hat transform is performed on the smoothed elevation surface with an 11x11 square kernel to characterize whether cells are in a wider valley.
- Another black top-hat transform is performed on the smoothed elevation surface with a 3x3 square kernel to characterize whether cells are in a narrower channel.
- Cells where the transformed value is greater than the corresponding threshold (**Table 37**) in both iterations are extracted to the output derivative.

Black top-hat transform is available within a number of software systems: Whitebox, ArcGIS Pro, SciPy, QGIS, and Open-cv. **Figure 80** and **Figure 81** show examples of BotHat channel results in conjunction with Geomorphon valleys and ridges.

**Table 37.** Black Top Hat transform (or BotHat)

| Parameter | Value |
|---|---|
| Cells greater than this value in the 3x3 BotHat raster will be included in the output. | 0.025 |
| Cells greater than this value in the 11x11 BotHat raster will be included in the output | 0.1 |

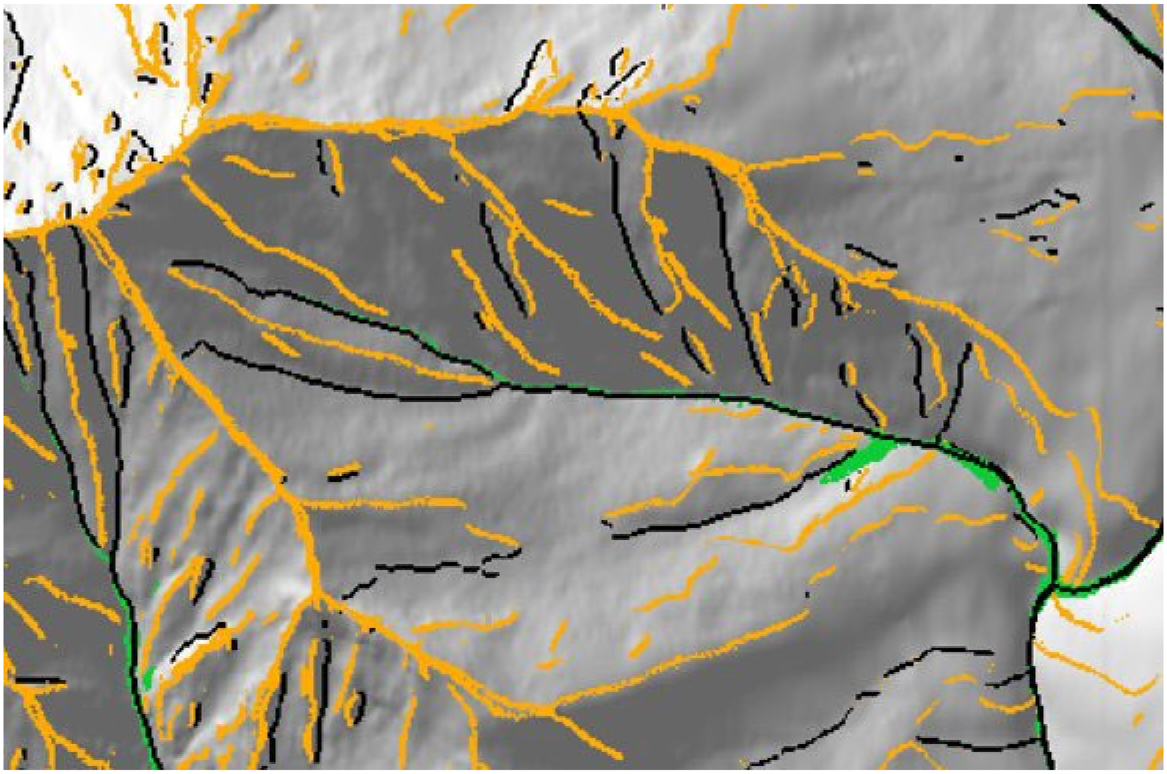

**Figure 80.** Example of a high slope area with Geomorphon valleys (green) and ridges (orange) and BotHat channel bottom results (black).

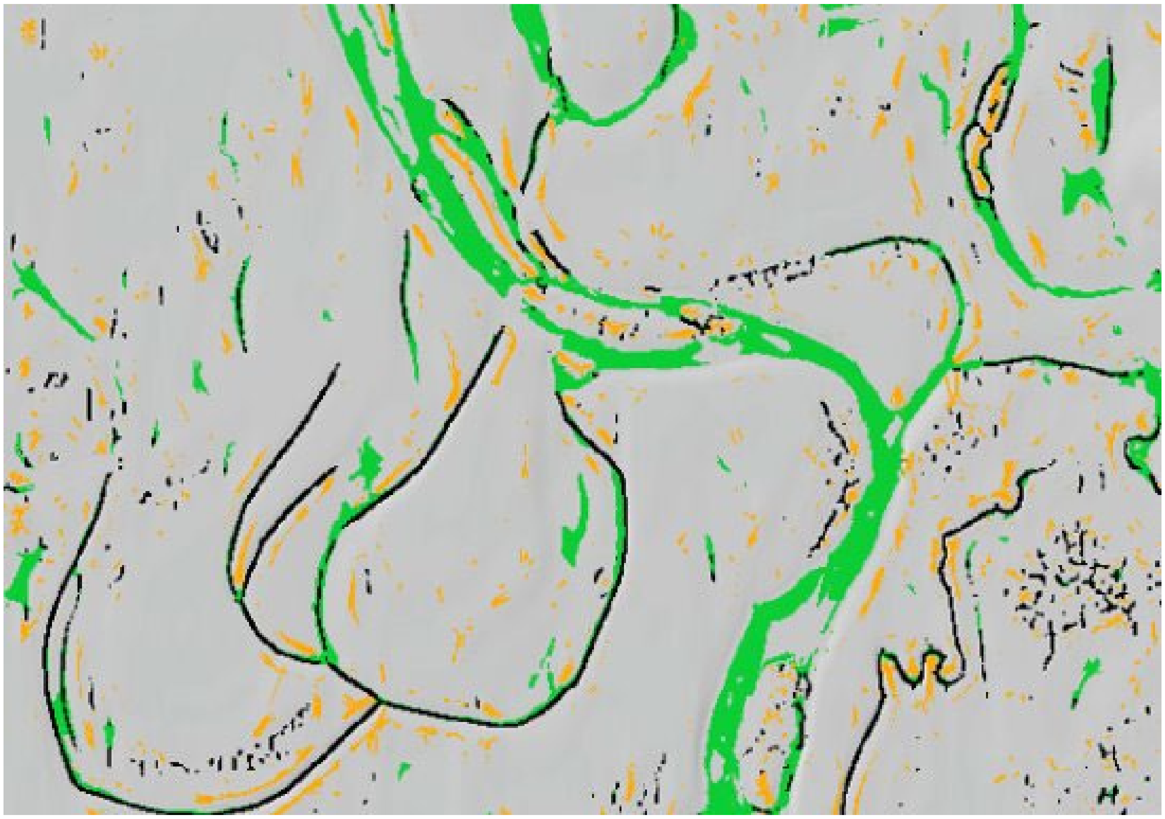

**Figure 81.** Example of a low slope area with Geomorphon valleys (green) and ridges (orange) and BotHat channel bottom results (black).

## D-Infinity Flow Accumulation

The flow paths generated from a D-Infinity flow accumulation are used to create the only component used in the GMI that is based on flow direction. All other components are geomorphic derivatives of a defined neighborhood on the surface. The D-Infinity algorithm assigns a flow direction to every cell based on the steepest slope of a triangular facet (Tarboton, 1997). The model allows for flow to diverge onto more than one downslope cell. Diverging paths characterize a relatively natural flow regime that does not force flow into one path across a surface.

The D-infinity flow accumulation is created on an unfilled DEM surface to produce flow paths that would naturally flow across the surface. Filling the DEM removes sinks and low points in the terrain to create continuous flow across the entire watershed, but it raises some terrain values to create flat areas that are not truly present in the surface. The flow accumulation created on an unfilled DEM will be regularly interrupted, but it can be used to detect areas within the hydrography network that do not have channels on the elevation surface. The results can help connect sections of the flow paths within channels on the elevation surface with sections that are not within channels on the elevation surface. This works well in areas of moderate to high relief. This derivative does not increase connectivity in flat terrain or in places with many depressions.

The process used to produce the d-infinity flow accumulation derivative is as follows:

- A d-infinity flow direction analysis is performed on the smoothed elevation surface.
- A flow accumulation analysis is completed using the flow direction surface.

The flow accumulation threshold value (**Table 38**) is applied to produce the output derivative. **Figure 82** and **Figure 83** show examples of D-Infinity flowpaths in conjunction with the previously described geomorphic indices.

D-infinity flow accumulation analysis is available in most GIS Software systems.

**Table 38.** D-Infinity Flow Path.

| Parameter | Values for Lidar | Values for IfSAR |
|---|---|---|
| D-infinity flow accumulation threshold for inclusion in GMI | 12500 | 500 |

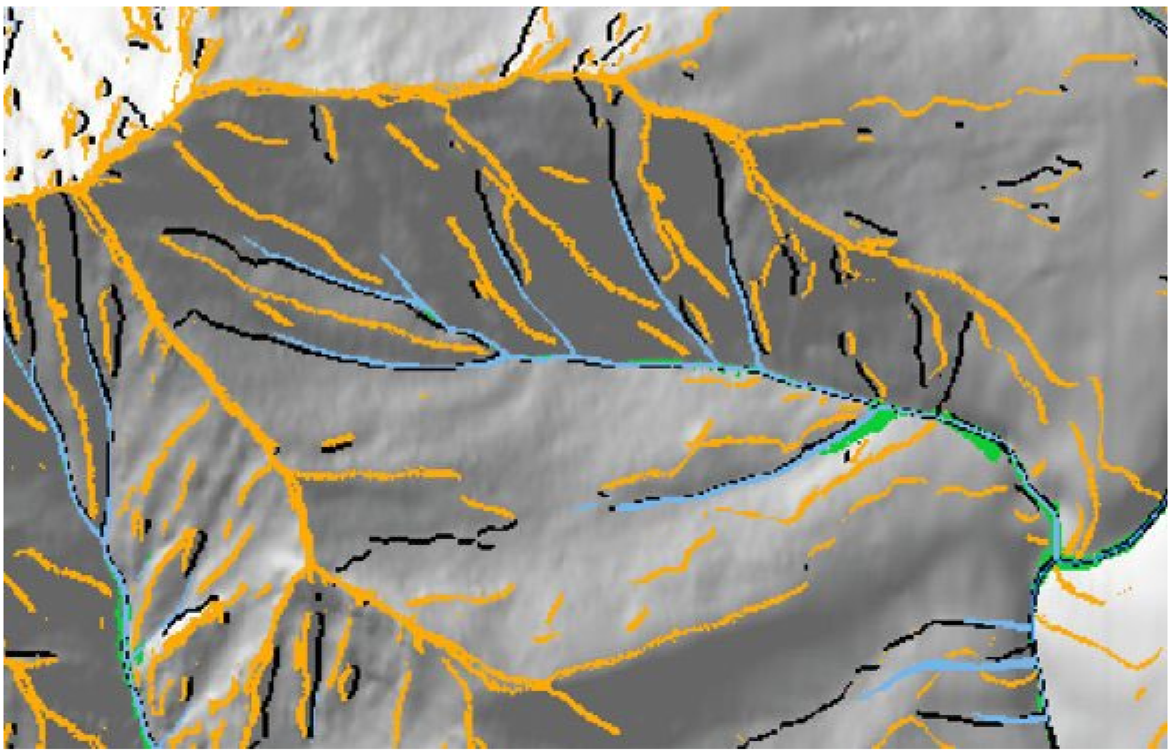

**Figure 82.** Example of a high relief area with Geomorphon valleys (green) and ridges (orange), BotHat channel bottom results (black), and D-infinity flowpaths (blue).

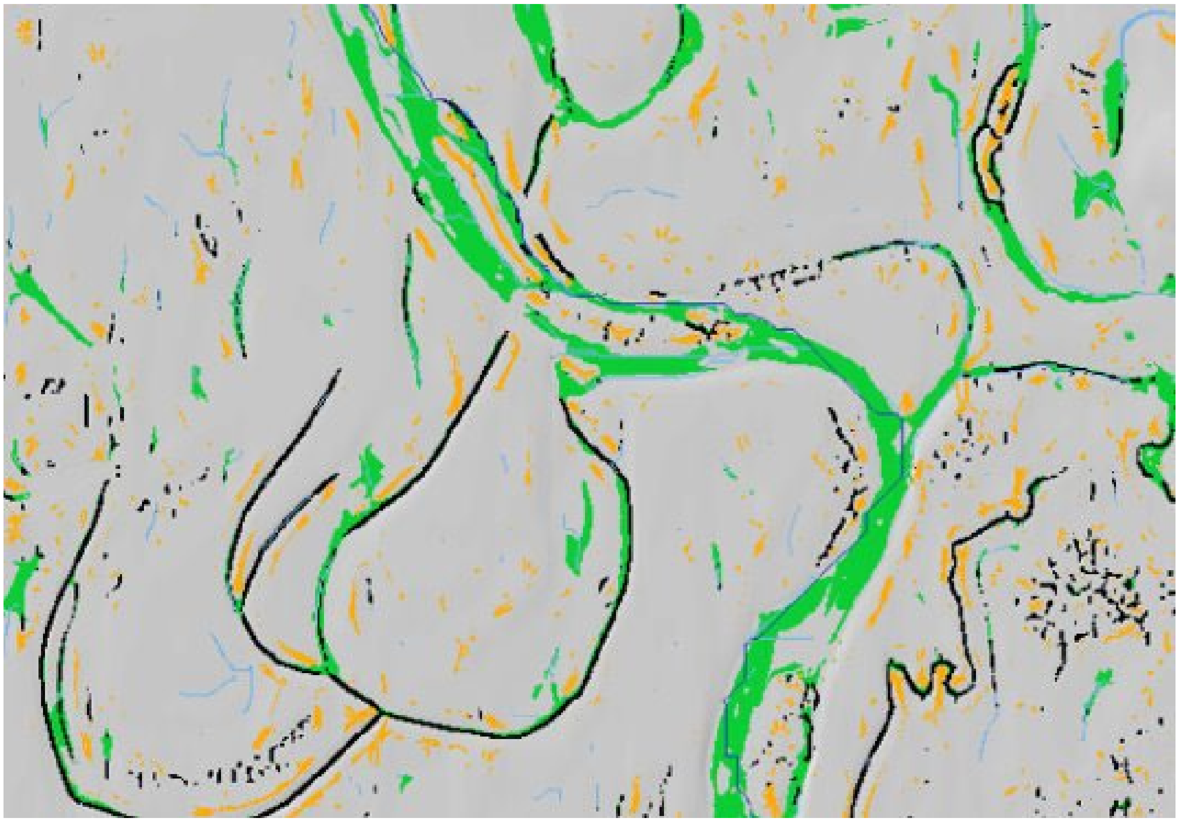

**Figure 83.** Example of a low relief area with Geomorphon valleys (green) and ridges (orange), BotHat channel bottom results (black), and D-infinity flowpaths (blue).

## Multiscale Elevation Percentile

Multiscale elevation percentile derivative (MEP) is a measure of local topographic position (Lindsay, 2018). It is a neighborhood-based algorithm that characterizes the relative vertical position of a cell as a percentile of the local elevation distribution within a range of neighborhood sizes. The 0 percentile is the lowest relative point in the window and 100 percentile is the highest.

The process used to produce the multiscale elevation percentile derivative is as follows:

- Multiscale elevation percentile is performed on the smoothed elevation surface.
- Cells with values less than the maximum percentile (**Table 39**) are extracted to produce the output derivative. **Figure 84** and **Figure 85** show examples of MEP in conjunction with the previously described geomorphic indices.

**Table 39.** Multiscale Elevation Percentile.

| Parameter | Value |
|---|---|
| Number of significant digits used while binning elevation values | 3 |
| Minimum search neighborhood radius in grid cells | 1 |
| Step size as any positive non-zero integer | 1 |
| Number of steps | 10 |
| Step nonlinearity factor | 1 |
| Maximum percentile to include in GMI | 10 |

Multiscale elevation percentile is available in Whitebox tools.

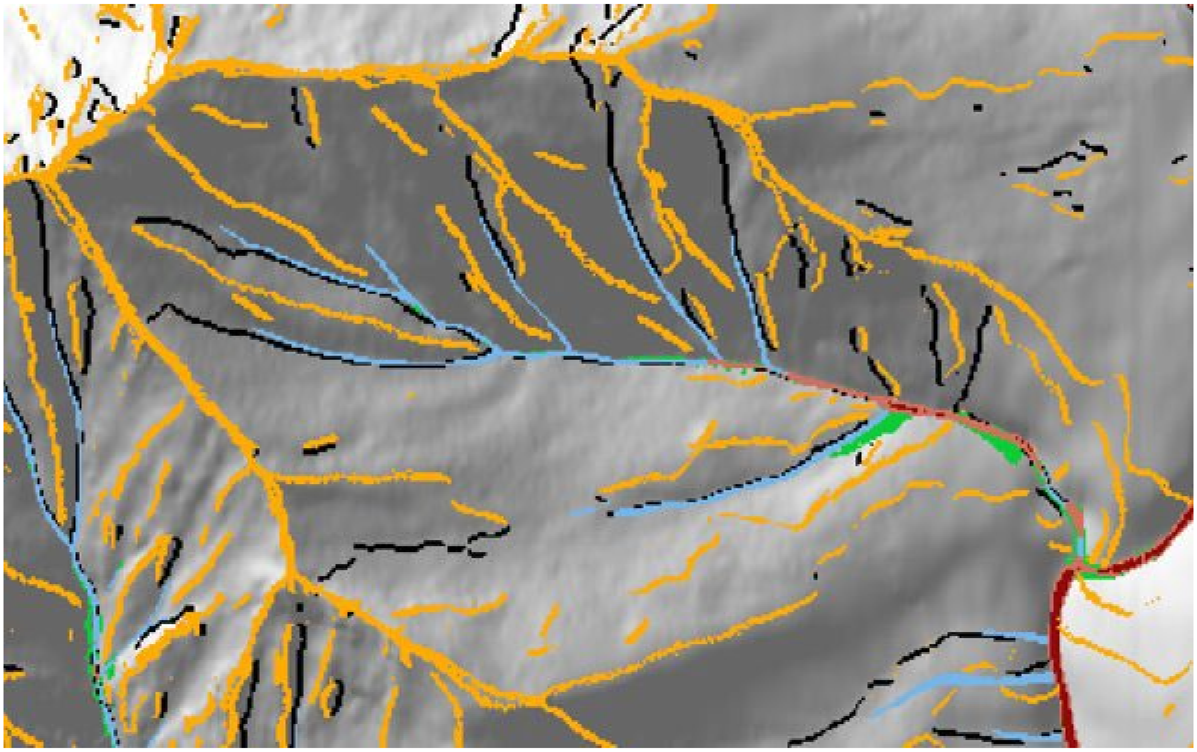

**Figure 84.** Example of a high slope area with Geomorphon valleys (green) and ridges (orange) and BotHat results (black) and D-infinity flow accumulation (blue) and Multiscale Elevation Percentile relative low points (reds).

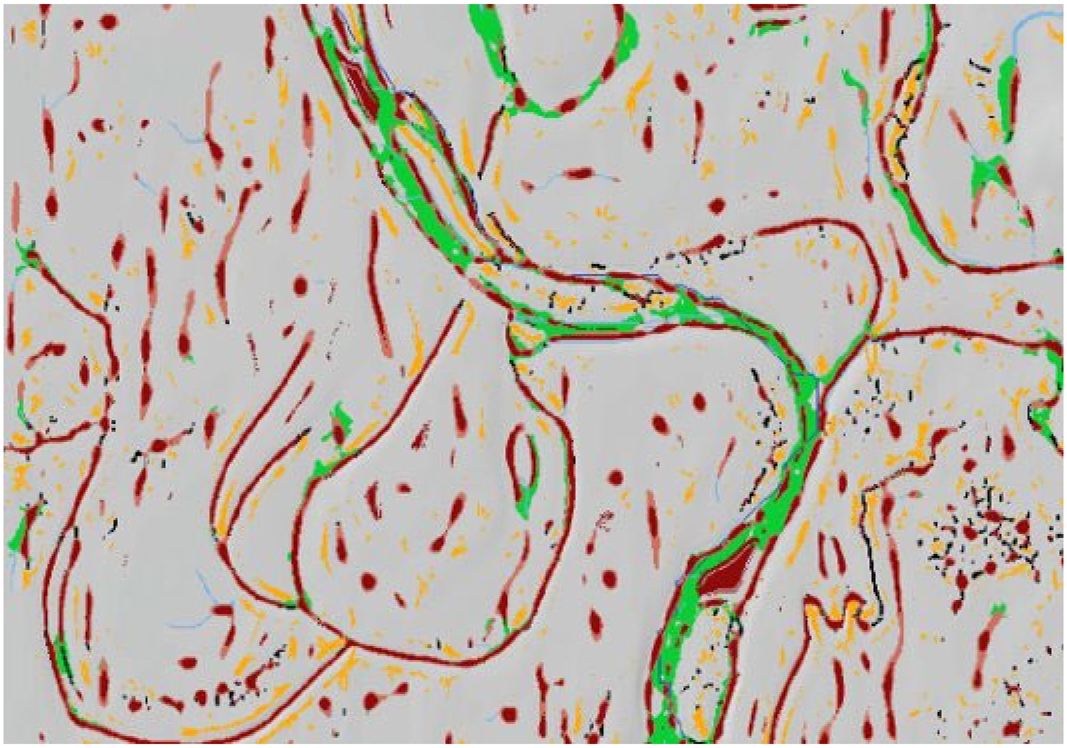

**Figure 85.** Example of a low slope area with Geomorphon valleys (green) and ridges (orange) and BotHat results (black) and D-infinity flow accumulation (blue) and Multiscale Elevation Percentile relative low points (reds).

## Geomorphic Index (GMI)

The GMI is created by combining the elevation derivative components into a single value that is more comprehensive than any one technique alone for identifying channelization in an elevation surface.

The process used to produce the GMI is as follows:

1. The binary outputs from Multiscale Elevation Percentile, BotHat, valley Geomorphons, and D-infinity flow accumulation are added together.
2. Any cells overlapping the binary output from ridge Geomorphons are removed to exclude rises in elevation that may have been captured erroneously by other derivatives.
3. If the GMI output contains many isolated sinks or artifacts because of a particularly rough terrain, a de-noise step can be run. This step removes isolated regions of GMI that have a maximum GMI value of 1 (only one geomorphic derivative present) and are less than 1,000 square meters in area.

The resulting GMI contains values from 1 to 4, where 1 represents areas where only 1 derivative component identified potential channelization or conditions that would support hydrography; and 4 represents areas where all 4 derivative components identify potential channelization. **Figure 86** and **Figure 87** show the output of the GMI process.

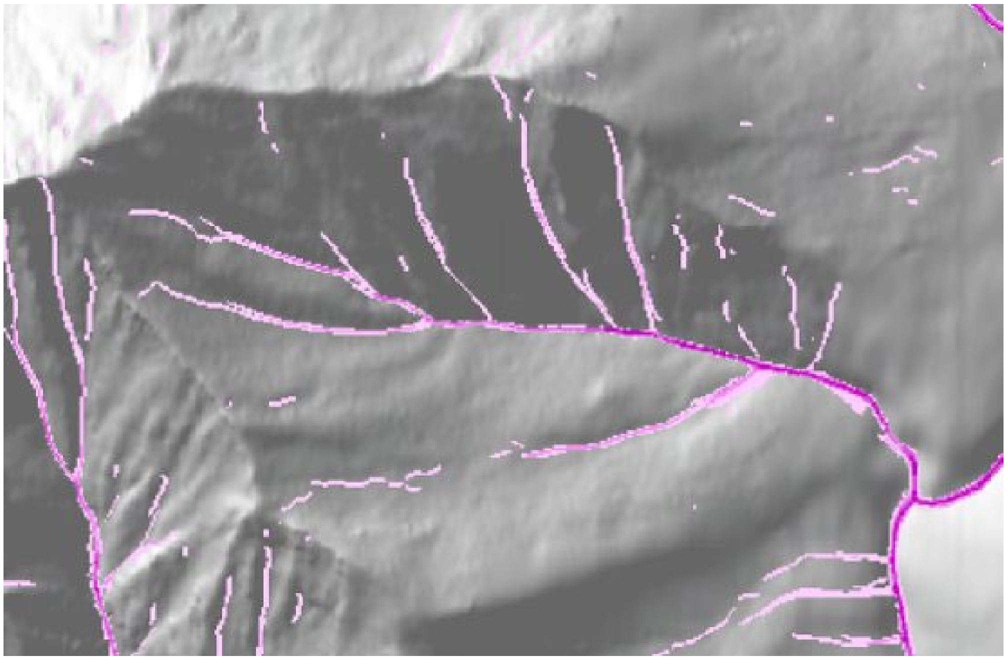

**Figure 86.** The combined GMI for a high area. GMI scores range from 1 to 4 with low GMI scores in lighter colors and high GMI scores in darker colors.

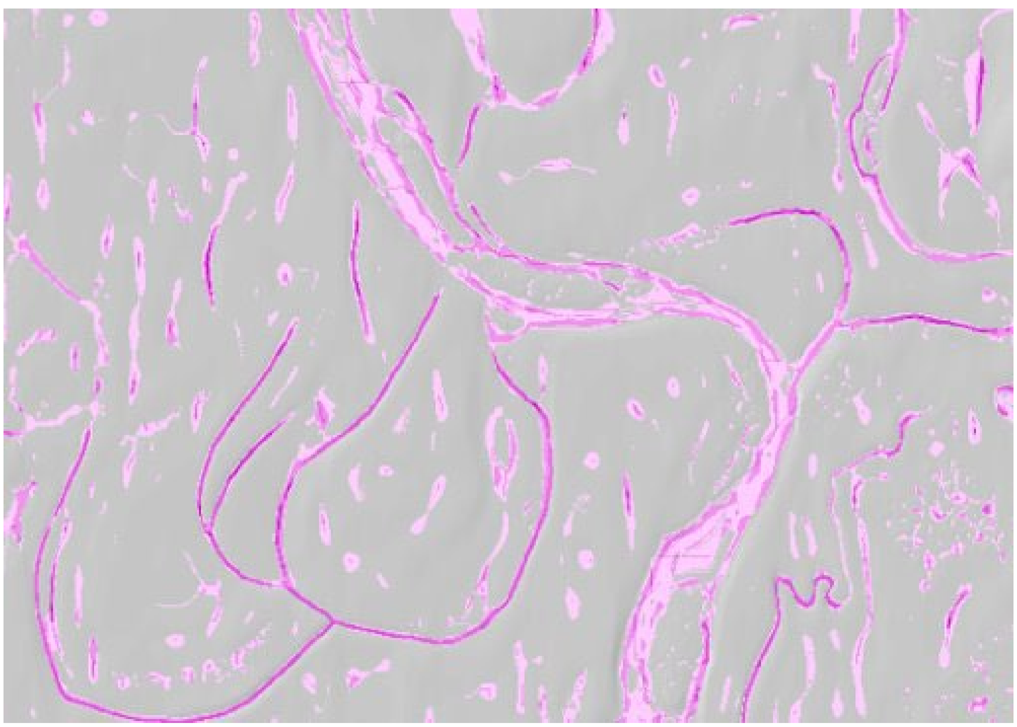

**Figure 87.** The combined GMI for a low slope area GMI scores range from 1 to 4 with low GMI scores in lighter colors to high GMI scores in darker colors.

## Validation Using Geomorphic Index (GMI).

Non-breaching and surface-flowing linear features in the elevation-derived hydrography specifications are defined based on whether the flow path is within a channel (Stream/river and Canal/ditch) or outside of a channel (drainageway or indefinite surface connector). The GMI is used to validate the classification of features and to determine whether the horizontal placement of features within channels on the elevation surface is accurate. It is also helpful in identifying areas of potential network omission and proper culvert placement.

The stream network is rasterized and compared to the GMI raster layer during data validation. A feature within a channel (Stream/river or Canal/ditch) is flagged as a potential error if more than 25% of the feature is outside of the GMI. This could indicate that the feature was delineated outside of the channel, or that the feature, or a section of the feature, was misclassified as a Stream/river or Canal/ditch and should be classified as a feature that is not within a channel on the elevation surface. It may also be a commission error; in which case the feature should be removed. An FCode indicating a feature should not be within a channel on the elevation surface is flagged as a potential error if more than 40% of the feature is within GMI values greater than 1. This may indicate that the feature or part of its length was misclassified as a feature within a channel on the elevation surface. **Figure 88** shows examples of potentially misaligned vector features identified by analysis against the GMI. **Figure 89** shows different scenarios interpreting line features using GMI.

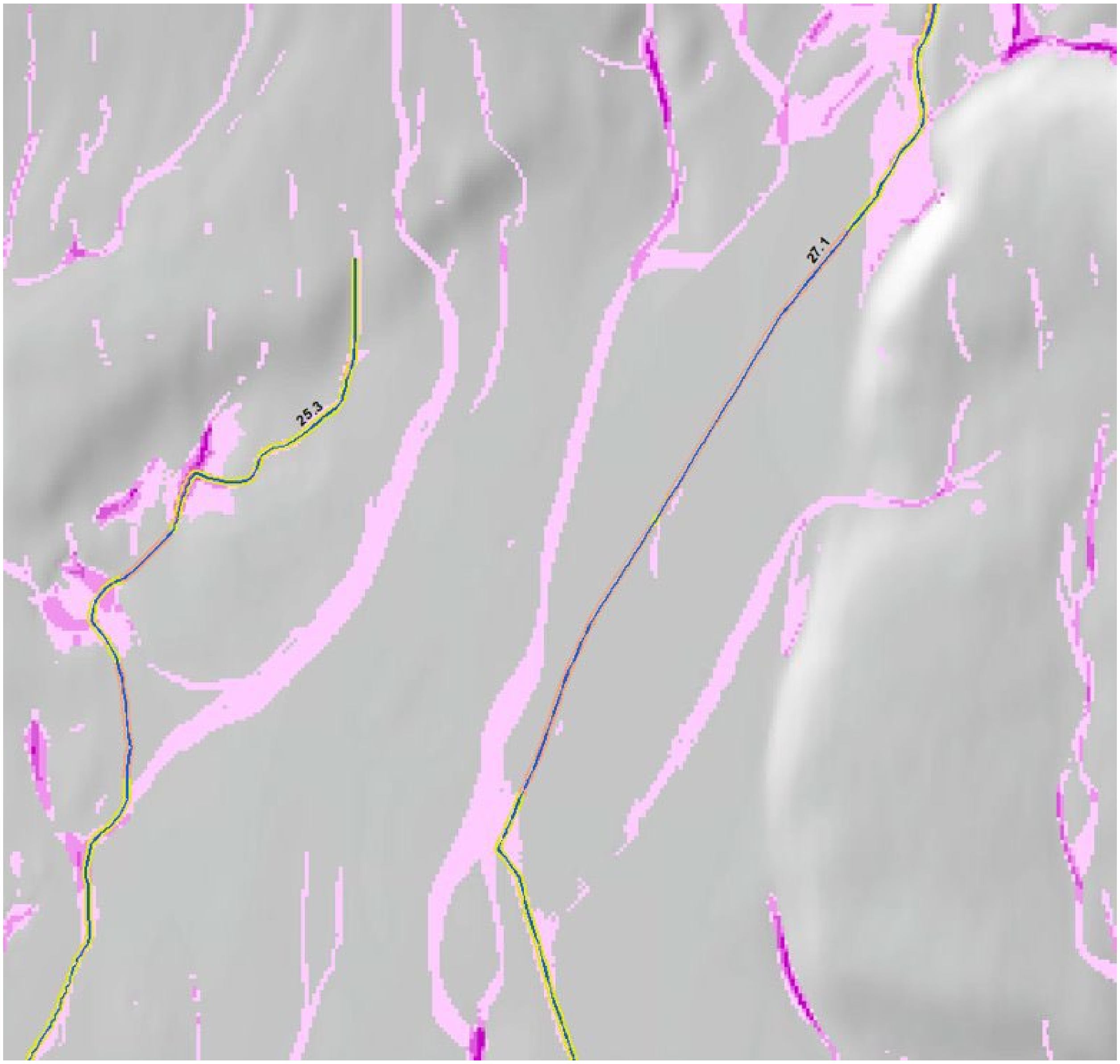


**Figure 88.** Example showing two vector features that are may be misaligned on the surface. Over 25% of their length is outside of the GMI. With closer inspection, other channels present in the GMI are more likely paths for the features.

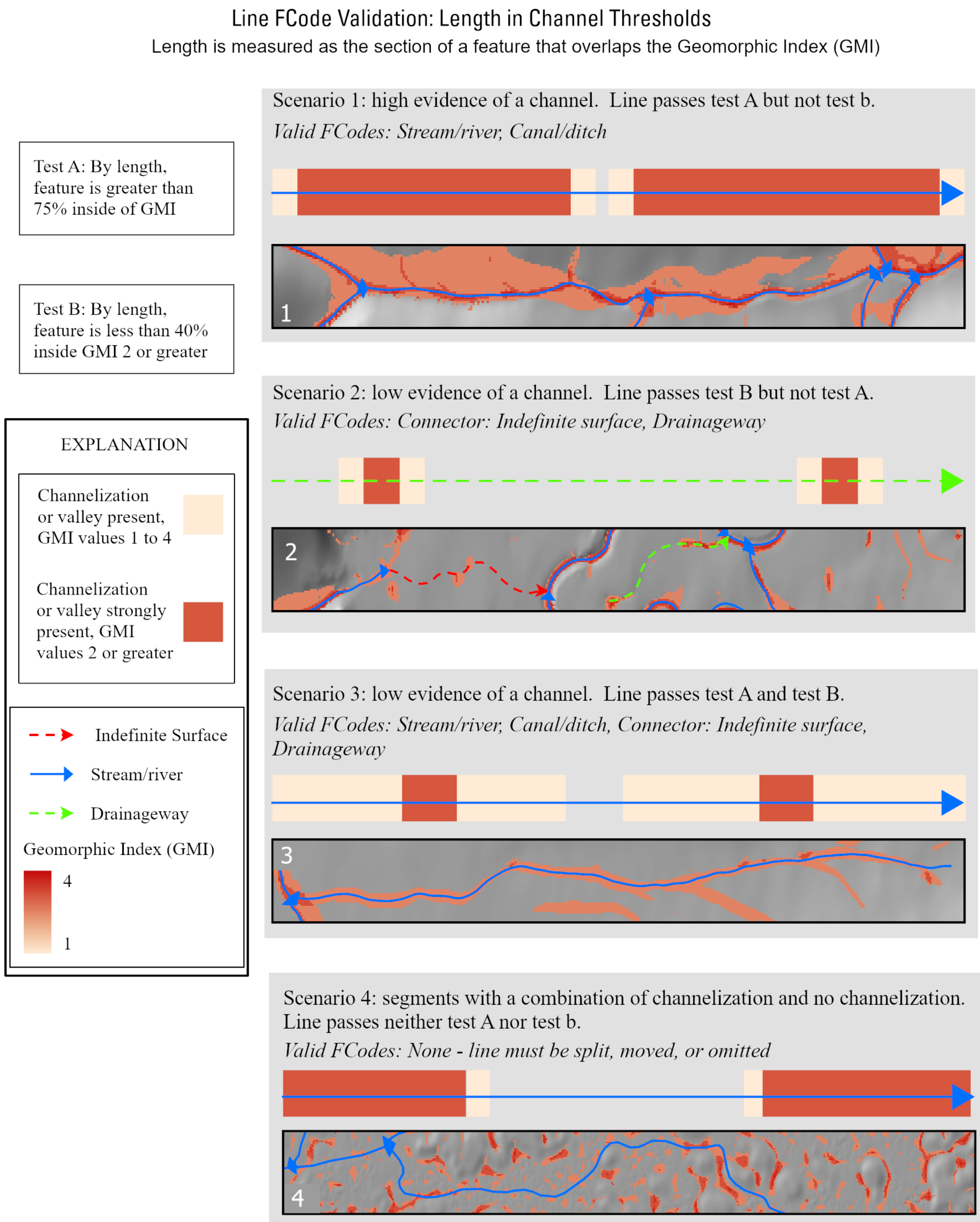


**Figure 89:** Elevation-derived hydrography line feature channel validation thresholds.

The test for potential omission errors removes the areas in the GMI that contain hydrographic features. Large areas that have a GMI with a value of 2 or more but no vector hydrographic features within them are flagged as potential omission areas. Omission areas that are close to roads are removed to avoid overcollection of ditch networks along transportation features.

## Appendix 3 References

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Tarboton, D. G., (1997), "A New Method for the Determination of Flow Directions and Contributing Areas in Grid Digital Elevation Models," Water Resources Research, 33(2): 309-319

U.S. Geological Survey, 2024, 3DEP Spatial Metadata: U.S. Geological Survey webpage, accessed July 2024 at https://www.usgs.gov/3d-elevation-program/3dep-spatial-metadata.

Lindsay, John. (2020). Whitebox User Manual accessed July 2024 at https://www.whiteboxgeo.com/manual/wbt_book/intro.html.

# Appendix 4. Difference DEM

The DEM used to derive hydrography for the U. S. Geological Survey's (USGS) 3D Hydrography Program (3DHP) is typically created from multiple lidar data projects. The lidar data, primarily collected by the USGS 3D Elevation Program (3DEP), must meet the USGS Lidar Base Specifications (LBS) that were current at the time of collection. Lidar has been collected as part of 3DEP since 2012, and several revisions to the specifications have been implemented. to the LBS. The technology used to collect airborne terrestrial lidar data has also improved dramatically over time, making positional accuracy, point density, and algorithms for classification of the point clouds considerably different over the years. The DEM difference raster shall document the differences between the source bare-earth DEMs used for deriving hydrography.

The difference raster will be used to identify the location and magnitude where source bare-earth DEMs differ. Because the source bare-earth DEMs are most likely in different coordinate reference systems, there will be slight differences between the rasters throughout the project area. Difference rasters shall be created by subtracting each overlapping source bare-earth DEM from the most recent source bare-earth DEM with a collection area.

- A difference raster for each source bare-earth DEM overlapping the most recent source bare-earth DEM shall be created (**Figure 90**). Please reference the latest Source Raster and Vector Data Requirements for critical consideration to determine source bare-earth DEM quality.
    - The difference raster(s) shall be created by subtracting the overlapping source bare-earth DEM from the source bare-earth DEM determined to be the most recent (**Figure 90**).
    - If the source bare-earth DEMs are in a projection other than EPSG:6350 or EPSG:5703/GEOID18, they shall be transformed to EPSG:6350 and/or EPSG:5703/GEOID18 prior to creating the difference raster.
    - The geoid name shall be appended to the VERT_CS[] name field in the spatial reference string. For example: VERT_CS["NAVD88 height (meter) – GEOID18"].
- Naming convention shall follow the example in **Figure 91** or **Figure 92**. All comparisons shall be identified in the raster output name.
    - Difference rasters shall be named with the following naming convention: Diff_OPR1_X.tif.
        - Diff refers to the product being a difference raster.
        - OPR1 is the short name of the most recent source bare-earth DEM.
        - X (and so on) is the short name of the source bare-earth DEM overlapping OPR1. See examples below.

*OPR_1.tif – OPR_2.tif = Diff_OPR1_2.tif*

*OPR_1.tif – OPR_3.tif = Diff_OPR1_3.tif*

- A polygon feature class shall be included to indicate Source DEM extents and overlap areas. A simplified name shall be used for each source DEM to identify products being analyzed as difference rasters. See example in Supporting Information.

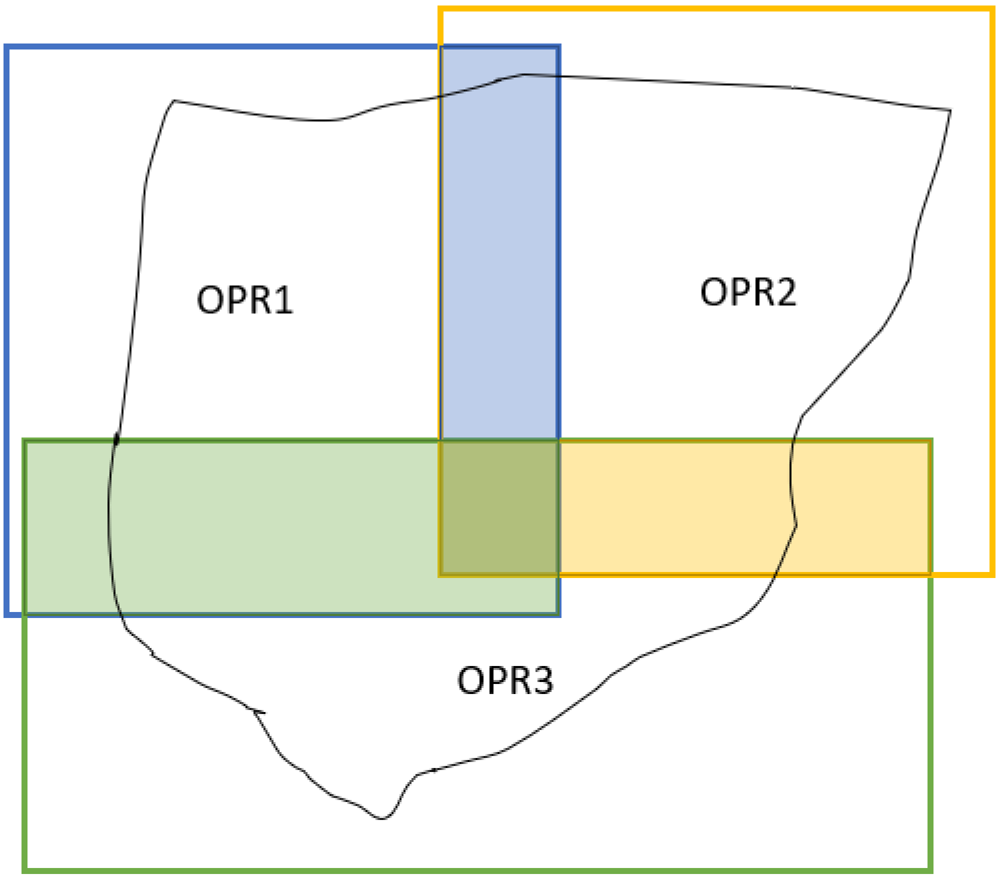


**Figure 90.** An elevation-derived hydrography project area shown in black outline with three lidar sources used to create the DEM mosaic. The short names of the source bare earth DEMs are shown. Overlap areas are shown as shaded areas.

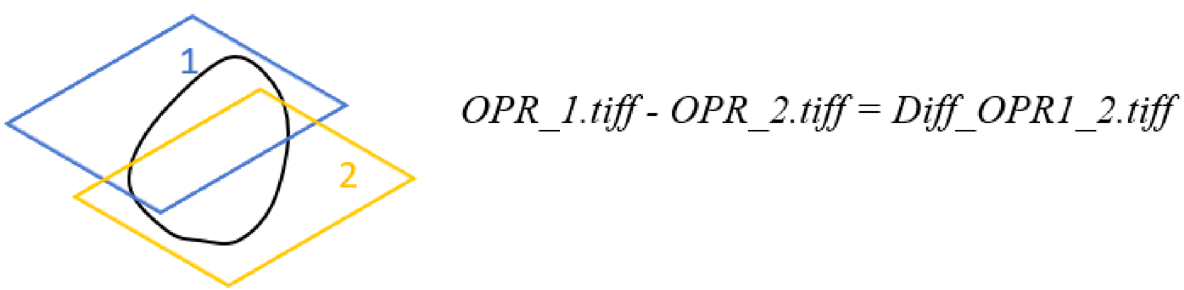


**Figure 91.** An elevation-derived hydrography project area shown in black with two overlapping source bare earth DEMs, OPR1 and OPR2. OPR1 has the most recent data, so OPR2 is subtracted from OPR1 to create the difference DEM, Diff_OPR1_2.tiff.

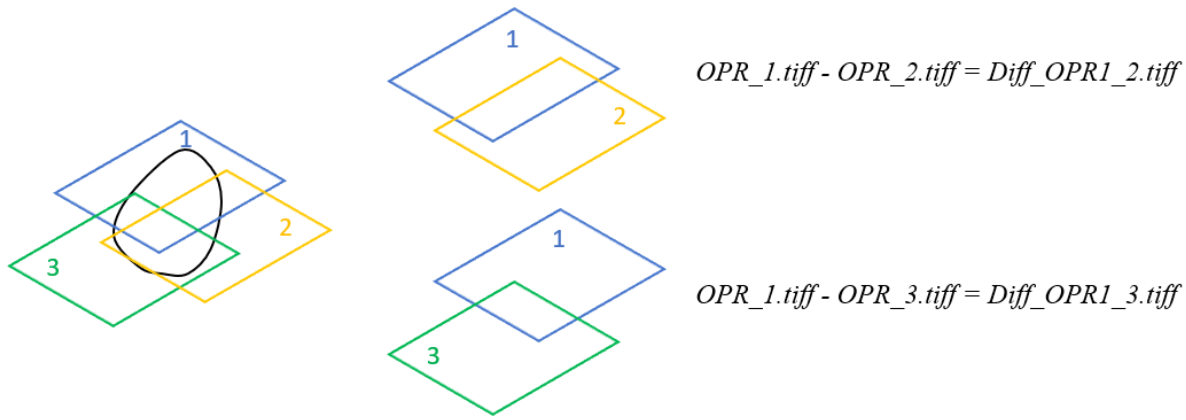


**Figure 92.** An elevation-derived hydrography project area shown in black with three overlapping source bare earth DEMs, OPR1, OPR2, and OPR3. OPR1 has the most recent data, so OPR2 is subtracted from OPR1 to create the first difference DEM, Diff_OPR1_2.tiff. Then OPR3 is subtracted from OPR1 to create the second difference DEM, Dirr_OPR1_3.tiff.

## Appendix 5. Raster Spatial Reference Requirements

To generate a properly formatted spatial reference, the USGS recommends adding spatial reference information into the GeoTIFF or GeoTIFF (COG) after completing all other processing using a GDAL version greater than 3.1.0.

While the USGS recognizes that the GDAL tool is not a rigorous standards-based solution, it serves as a mutually convenient open-source tool suitable for 3DHP purposes at this time.

Following are examples to improve readability of the spatial reference including other commercial software standard GeoTIFF file generation:

*gdal_translate -a_srs EPSG:6350+5703 -co TILED=YES -co BIGTIFF=IF_SAFER -co COMPRESS=DEFLATE -co GEOTIFF_KEYS_FLAVOR=ESRI_PE <source_dataset> <destination_dataset>*

for generation of a COG formatted GeoTIFF file:

*gdal_translate -a_srs EPSG:6350+5703 -of COG -co BIGTIFF=IF_SAFER -co COMPRESS=DEFLATE -co GEOTIFF_KEYS_FLAVOR=ESRI_PE <source_dataset> <destination_dataset>*