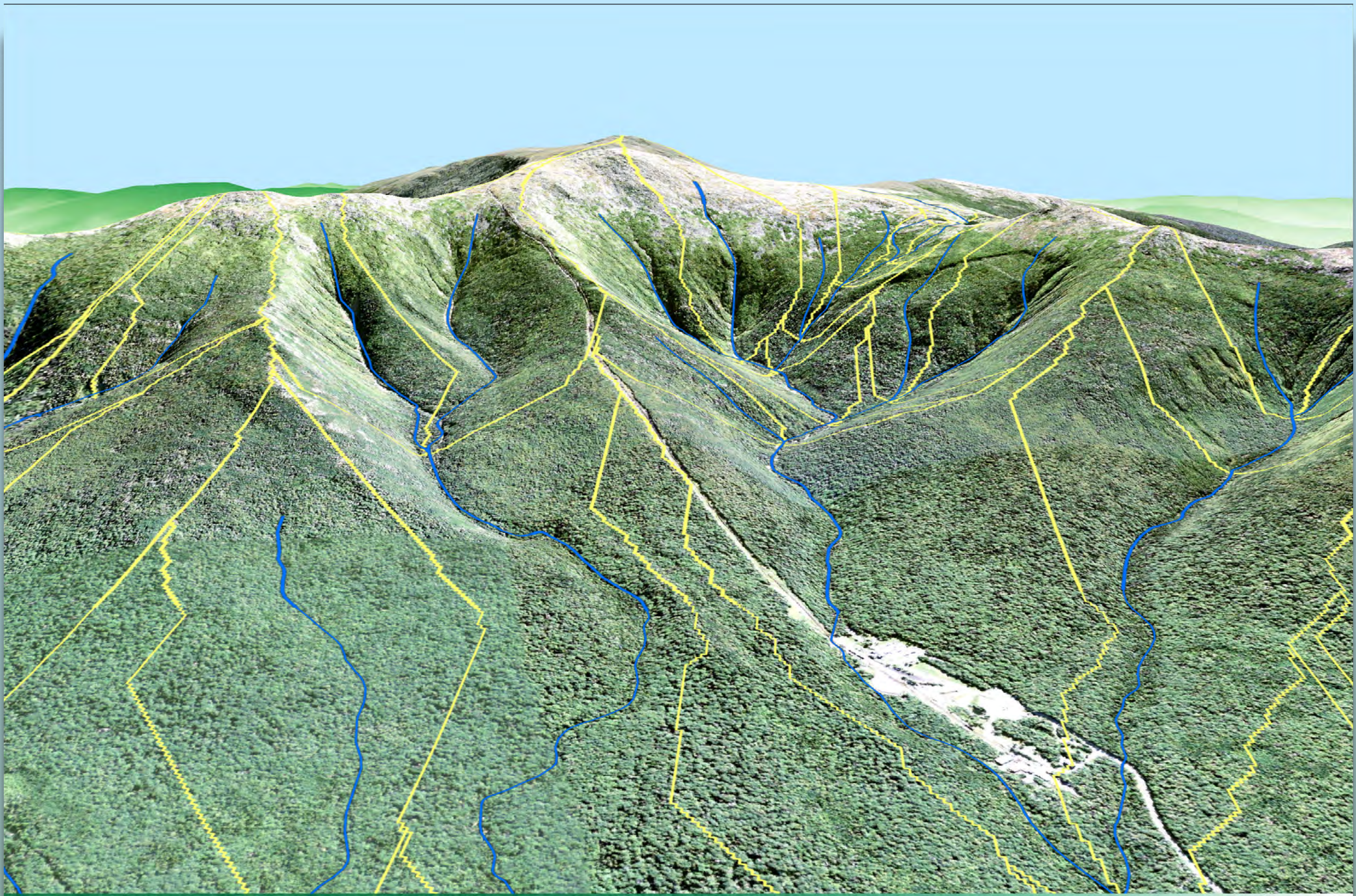
USGS
science for a changing world

EPA
United States Environmental Protection Agency

National Geospatial Program

User's Guide for the National Hydrography Dataset Plus (NHDPlus) High Resolution



Mt. Washington, New Hampshire - NHDPlus High Resolution (NHDPlus HR) streams in blue, catchments in yellow. The NHDPlus HR is created from the high resolution National Hydrography Dataset, Watershed Boundary Dataset and 3D Elevation Program data. (Data sources: NHDPlus HR Beta HU4-0108 2017, USGS 3DEP (NED) 1/3 arc-second 2017, NAIP Sept 2014)

USGS
science for a changing world

Open-File Report 2019–1096

U.S. Department of the Interior
U.S. Geological Survey

Cover. Mount Washington, New Hampshire, as shown in the National Hydrography Dataset Plus (NHDPlus) High Resolution; streams are shown as blue lines, and the catchments are in yellow.

User's Guide for the National Hydrography Dataset Plus (NHDPlus) High Resolution

By Richard B. Moore, Lucinda D. McKay, Alan H. Rea, Timothy R. Bondelid, Curtis V. Price, Thomas G. Dewald, and Craig M. Johnston

National Geospatial Program

Prepared in cooperation with the U.S. Environmental Protection Agency

Open-File Report 2019–1096

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2019

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit https://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit https://store.usgs.gov.

Suggested citation:
Moore, R.B., McKay, L.D., Rea, A.H., Bondelid, T.R., Price, C.V., Dewald, T.G., and Johnston, C.M., 2019, User's guide for the national hydrography dataset plus (NHDPlus) high resolution: U.S. Geological Survey Open-File Report 2019–1096, 66 p., https://doi.org/10.3133/ofr20191096.

ISSN 2331-1258 (online)

Contents

Figures

Tables

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square centimeter (cm^2)	0.1550	square inch (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second per square kilometer ($[m^3/s]/km^2$)	91.49	cubic foot per second per square mile ($[ft^3/s]/mi^2$)
	Acceleration	
meter per second squared (m/s^2)	3.2808	foot per second squared (ft/s^2)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

3DEP	3D Elevation Program
DEM	digital elevation model
EPA	U.S. Environmental Protection Agency
EROM	Enhanced Unit Runoff method
ET	evapotranspiration
HUC4	4-digit hydrologic unit code
HUC12	12-digit hydrologic unit code
NAD83	North American Datum of 1983
NAVD	North American Vertical Datum
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NHDPlus HR	National Hydrography Dataset Plus High Resolution
NWIS	National Water Information System
PET	potential evapotranspiration
PRISM	Parameter-Elevation Regressions on Independent Slopes Model
USGS	U.S. Geological Survey
VAA	value-added attributes
WBD	National Watershed Boundary Dataset

User's Guide for the National Hydrography Dataset Plus (NHDPlus) High Resolution

By Richard B. Moore,[1] Lucinda D. McKay,[2] Alan H. Rea,[1] Timothy R. Bondelid,[3] Curtis V. Price,[1] Thomas G. Dewald,[4] and Craig M. Johnston[5]

Introduction

The National Hydrography Dataset Plus (NHDPlus) High Resolution (NHDPlus HR) is a scalable geospatial hydrography framework built from the high-resolution (1:24,000-scale or better) **National Hydrography Dataset**[6] (NHD), nationally complete **Watershed Boundary Dataset** (WBD), and ⅓-arc-second (10-meter [m] ground spacing) **3D Elevation Program** (3DEP) **digital elevation model** (DEM) data. The NHDPlus HR brings modeling and assessment to a local neighborhood level while nesting seamlessly into the national context.

The NHDPlus HR (U.S. Geological Survey, 2018a) is modeled after the highly successful NHDPlus version 2 (NHDPlus V2; Dewald, 2015; Moore and Dewald, 2016). Like the NHDPlus V2, the NHDPlus HR includes data for a nationally seamless network of stream reaches, elevation-based **catchment** areas, flow surfaces, and value-added attributes that enhance stream-network navigation, analysis, and data display (Viger and others, 2016). Users will find that the NHDPlus HR, however, which increases the number of features nationally from about 2.6 million in the NHDPlus V2 to more than 30 million, provides richer, more current content that also can be used at a variety of scales.

NHDPlus HR is built from static versions of the high-resolution (1:24,000-scale or better) NHD, the 10-m 3DEP DEM, and the hydrologic-unit boundaries in the WBD. These three datasets are periodically updated by the U.S. Geological Survey (USGS), States, and other organizations who are active stewards of the datasets. These snapshots of the data are not intended to be directly updated by users for inclusions in these national databases. Requests for updates should be directed to the respective USGS national stewardship programs (Arnold, 2014). The snapshots of the NHD, 3DEP DEM, and WBD used to construct NHDPlus HR are included with the NHDPlus HR data.

NHDPlus HR consists of vector and **raster** data layers and includes the following components:

- a set of value-added attributes, in addition to the standard NHD attributes, that enhance stream-network navigation, analysis, and display;
- an elevation-based catchment area for each **flowline** in the stream network;
- catchment characteristics including mean annual precipitation, mean annual temperature, mean annual runoff, and mean latitude;
- **cumulative drainage-area** characteristics;
- mean annual flow values (from 1971 to 2000) and velocity estimates for each flowline in the stream network;
- flow direction and accumulation, elevation, catchment, and **hydroenforced** DEM rasters;
- headwater-node areas; and
- minimum and maximum elevations and slopes of flowlines.

The NHDPlus HR elevation-derived catchments are produced by using a drainage- enforcement technique first applied by the **Spatially Referenced Regression on Watershed Attributes (SPARROW)** model for New England. This technique involves forcing the high-resolution NHD drainage network onto the 3DEP data through trenching (or canyonizing) the DEM at streams, and enforcing the WBD hydrologic divides with walls, which are lines of raster cells with greatly increased elevation values (Moore and others, 2004). The WBD is also used to apply sinks (areas of no external drainage) in noncontributing areas. The resulting hydrologically conditioned DEM is used to produce catchments and other hydrologic derivatives that closely agree with the NHD and the WBD (fig. 1).

---

[1]U.S. Geological Survey.

[2]Horizon Systems Corp., under contract with the U.S. Geological Survey and U.S. Environmental Protection Agency.

[3]Private consultant, under contract with the U.S. Geological Survey and U.S. Environmental Protection Agency.

[4]U.S. Environmental Protection Agency, retired.

[5]U.S. Geological Survey, deceased.

[6]Terms in bold typeface the first time they appear in the report are defined in the Glossary. Press the Alt key followed by the left arrow key to return to the original page in the document after following the hyperlink.

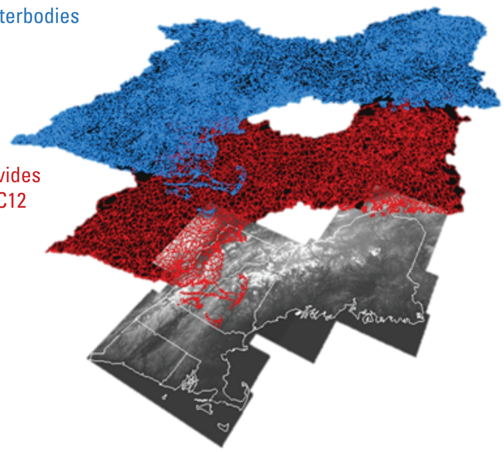


Figure 1. Major input datasets for the process of creating a hydrologically conditioned digital elevation model to create catchments in the National Hydrography Dataset Plus (NHDPlus) High Resolution. NHD, National Hydrography Dataset; WBD, Watershed Boundary Dataset; HUC12, 12-digit hydrologic unit code; 3DEP, 3D Elevation Program.

The data are provided by a variety of map projections because the raster data (.tifs) in the NHDPlus HR cover different parts of the Earth's surface (for example, the contiguous United States, Alaska, and Hawaii). Specific map projections centered on these respective areas provide the best representation of the rasterized 10-meter data. Feature class data (lines and polygons), on the other hand, can be represented worldwide in a single geographic coordinate system. Table 1 lists the projections for each type of data.

Downloading and Organizing NHDPlus HR Data

NHDPlus HR data are distributed as compressed files with a ".zip" or ".7z" extension (U.S. Geological Survey, undated). After downloading the NHDPlus HR data, install the data as follows:

1. Create a folder called "NHDPlusHRData" for the NHDPlus HR data. For the best performance, install the data on a local drive.

2. The compressed data files are named as follows, where "vpuid" is the identifier of each vector processing unit followed by the HU level such as "_HU4" or "_HU8":

    - For vector layers and attributes: NHDPlus_H_<vpuid>_GDB.zip
    - For raster layers: NHDPlus_H_<vpuid>_RASTER.7z

    Each NHDPlus HR compressed file should be uncompressed into the folder created in step 1. When using the unzip utility, choose the option that automatically preserves or creates the folder structure that is included inside the compressed files. Do not unzip into a folder named for the compressed file.

3. When completely installed, the uncompressed data should look as shown in figure 2.

NHDPlus HR Versioning

The initial release of NHDPlus HR is called "Beta." This label was selected to indicate that:

- input datasets (NHD, WBD, and 3DEP elevation) are as they were prior to building the initial release of NHDPlus HR. The building of NHDPlus HR will likely show the need for more editing, and

- the process and software for building NHDPlus HR are evolving as new hydrological conditions are discovered across the United States, and as software issues are discovered and corrected.

The plan of the release of NHDPlus HR includes incorporating feedback from the stewards of the data, quality-control, and assurance teams; updates to the input dataset; and software enhancements in a release named "Refresh." The plan also includes a periodic refresh of the NHDPlus HR when there are changes to NHD, WBD, and 3DEP elevations; corrections to released versions; or enhancements with additional NHDPlus attributes, feature classes, and raster datasets. Under the existing plan, refreshed data will contain version information to help users determine if they have the most recently published version of the data.

Structure of the NHDPlus HR Data

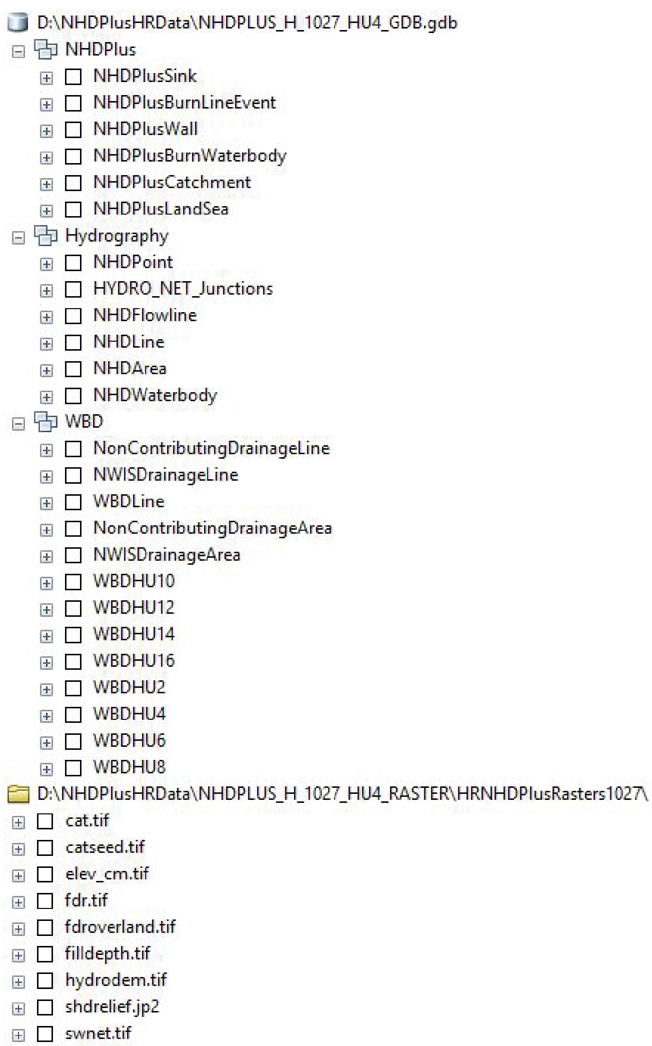
The NHDPlus HR vector feature classes and attribute tables are distributed in file geodatabases, with the file names following the format NHDPlus_H_<vpuid>HU<level>.GDB.gdb, where vpuid is the identification number of the vector processing unit (VPU). Each file geodatabase (GDB) contains the data for a single four-digit **hydrologic unit** (HU4) currently within the contiguous United States and eight-digit hydrologic unit (HU8) for parts of Alaska [2019]; however, the data are designed to fit together seamlessly to allow distribution by differently sized hydrologic units. The seamless design is made possible by using NHDPlus identification numbers (IDs), hydrosequence numbers, and origin and terminus nodes that are nationally unique. There are approximately 220 HU4s

Table 1. Map-projection information of the NHDPlus HR data.

Type of data	Projection/coordinate system
All vector data (feature classes)	Projection: geographic Datum: NAD83 Zunits: NO (none) Units: DD (decimal degrees) Spheroid: GRS1980 Xshift: 0.0 Yshift: 0.0
All .tif datasets within the contiguous United States (48 States) (cat, fac, fdr, elev_cm, ext_fac, ext_fdr)	Projection: Albers equal-area conical projection Datum: NAD83 Zunits: 100 cm for elev_cm, otherwise “NO” Units: meters Spheroid: GRS1980 Xshift: 0.0 Yshift: 0.0 Parameters: First standard parallel: 29°30’0.000” Second standard parallel: 45°30’0.000” Central meridian: -96°0’0.000” Latitude of projection’s origin: 23°0’0.000” False easting (meters): 0.0 False northing (meters): 0.0
All .tif datasets for Hawaii	NAD_1983_UTM_Zone_4N Projection: UTM Zone: 4N Datum: NAD83 Spheroid: GRS1980 Unit: meters
All .tif datasets for Alaska	NAD83_Alaska_Albers_2011 Projection: Albers equal-area conical projection False easting (meters): 0.0 False northing (meters): 0.0 Central meridian: -154.0 First standard parallel: 55.0 Second standard parallel: 65.0 Latitude of origin: 50.0 Linear unit: meter Datum: NAD 83 (2011) Spheroid: GRS 1980
All .tif datasets for Puerto Rico and the U.S. Virgin Islands	NAD_1983_Lambert_Conformal_Conic Projection: Lambert conformal conic False easting: 200000.0 False northing: 200000.0 Central meridian: -66.43333333333334 First standard parallel: 18.03333333333334 Second standard parallel: 18.43333333333333 Latitude of origin: 17.83333333333333 Linear units: meters
All .tif datasets for American Samoa	WGS_1984_UTM_Zone_2S Projection: Universal Transverse Mercator Zone: 2S Datum: WGS84 Spheroid: WGS84 Units: meters

Table 1. Map-projection information of the NHDPlus HR data.—Continued

Type of data	Projection/coordinate system
All .tif datasets for Guam	WGS_1984_UTM_Zone_55N Projection: Universal Transverse Mercator Zone: 55N Datum: WGS84 Spheroid: WGS84 Units: meters
All .tif datasets for Northern Mariana Islands	WGS_1984_UTM_Zone_55N Projection: Universal Transverse Mercator Zone: 55N Datum: WGS84 Spheroid: WGS84 Units: meters



Notes:
\HRNHDPlusRasters<vpuid>—Contains one folder per VPU
\NHDPlus_H_<vpuid>_GDB.gdb—Contains one geodatabase file for each VPU
\NHDPlusHRGlobalData—Contains national data such as the boundaries of the VPUs and gage data; not shown in this example

Figure 2. How the National Hydrography Dataset Plus High Resolution file structure should look in ArcCatalog once the compressed data files are uncompressed. For this example, vpuid = “1027 HU4” was selected.

in the United States and territories. Each HU4 is referred to as a VPU in NHDPlus HR terms. The NHDPlus HR raster data are distributed as a set of tagged image files (extension .tif). As of June 2019, all VPUs contained only a single raster-processing unit (RPU); however, the structure of NHDPlus HR could allow for the subdivision of large VPUs into multiple RPUs if necessary. Alaskan VPUs are being developed as HU8s rather than HU4s.

In addition to the three original datasets that were used to create NHDPlus (NHD, 3DEP DEM, and WBD), NHDPlus HR contains NHDPlus catchments, burn components (feature classes used to create the catchments), and multiple tables (table 2). In addition to the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, each VPU includes a folder that is named following the format HRNHDPlusRasters<vpuid> and contains the raster .tif images (table 3).
NHDPlus HR includes the following components:

- Hydrography—Original NHD data (input data to NHDPlus) are stored in the feature dataset called Hydrography. Feature classes within this feature dataset are as follows:
  - Hydro Net (lines) and Hydro Net Junction (points) depict the geometric network for the Hydrography Dataset with flow direction assigned for flow-line features. Hydro Net Junction contains points for flowline start and end nodes. These are produced when the NHD is extracted from the national database, and the network is given the name Hydro Net.
  - NHDArea—Polygons representing river area in the NHD
  - NHDFlowline—Lines representing the flowlines of the NHD network
  - NHDLine—Lines representing NHD hydrographic landmark features used for cartographic representation
  - NHDPoint—Points representing NHD hydrographic landmark features
  - NHDWaterbody—Polygons representing water bodies in the NHD

Table 2. Feature classes, tables, and other data used in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[National Hydrography Dataset (NHD) and Watershed Boundary Dataset (WBD) documentation is available at U.S. Geological Survey (2018b); complete 3D Elevation Program (3DEP) documentation is available at U.S. Geological Survey (2019a)]

Feature class	Comment
NHD Hydrography	Original NHD data (input data to NHDPlus)
NHDFlowline	Lines representing the flow lines of the NHD network
NHDWaterbody	Polygons representing water bodies in the NHD
NHDPoint	Points representing NHD hydrographic landmark features
NHDLine	Lines representing NHD hydrographic landmark features used for cartographic representation
NHDArea	Polygons representing river area in the NHD
NHDPlus	
NHDPlusCatchment	Polygon feature class for NHDPlus **catchment** polygons
NHDPlus Burn Components	NHDPlus feature classes used to create catchments; described in the “Main Data Components of the NHDPlus HR” section of this report:
NHDPlusBurnLineEvent	Line feature class
NHDPlusBurnWaterbody	Polygon feature class
NHDPlusLandSea	Polygon feature class
NHDPlusSink	Point feature class
NHDPlusWall	Line feature class
3DEP digital elevation model (DEM)	Digital elevation program (digital elevation model)
WBD	Watershed Boundary Dataset (original watershed data input to NHDPlus)
WBDHU_x	Where x is the numeric identifier for each level (2, 4, 6, 8, 10, and 12) of hydrologic units
WBDLine	Watershed Boundary Dataset line
NonContributingDrainageArea	Does not flow to the outlet of a hydrologic unit
NonContributingDrainageLine	Edge of noncontributing area
NWISDrainageArea	Drainage-area polygons for streamgages from the **National Water Information System** (NWIS)
NWISDrainageLine	Edge of area draining to streamgages

Table 3. Structure of tables and rasters in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

Table or raster	Comment
NHDPlus tables in NHDPlusHR_<vpuid>_GDB.gdb	
ExternalCrosswalk	
FeatureToMetadata	
HUMod	
MetaProcessDetail	
MetaSourceDetail	
NHDFcode	
NHDFeatureToMetadata	
NHDMetadata	
NHDPlusDivFracMP	Alias: NHDPlusDivergenceFractMainPath
NHDPlusEROMMA	
NHDPlusEROMQAMA	
NHDPlusEROMQARPT	
NHDPlusFlow	
NHDPlusFlowlineVAA	
NHDPlusIncrLat	
NHDPlusIncrPrecipMA	Alias: NHDPlusIncrPrecipitationMA
NHDPlusIncrPrecipMM_x	Mean monthly precipitation, where x is the month of the year Alias: NHDPlusIncrPrecipitationMMxx
NHDPlusIncrROMA	
NHDPlusIncrTempMA	
NHDPlusIncrTempMM_x	Mean monthly temperature, where x is the month of the year
NHDPlusMegaDiv	Alias: NHDPlusMultipleDivergence
NHDPlusNHDPlusIDGridCode	
NHDProcessingParameters	
NHDReachCodeMaintenance	
NHDReachCrossReference	
NHDSourceCitation	
NHDVerticalRelationship	
ProcessingParameters	
Rasters in NHDPlus HRRasters<vpuid>	
elev_source.gdb	
cat.tif	
catseed.tif	
elev_cm.tif	
fac.tif	
fdr.tif	
fdroverland.tif	
filldepth.tif	
hydrodem.tif	
shdrelief.jp2	
swnet.tif	

- NHDPlus feature classes stored in the feature dataset NHDPlus are as follows:
  - **NHDPlusCatchment**—Polygon feature class for NHDPlus **catchment** polygons
  - NHDPlus Burn Components—These NHDPlus feature classes were used to create catchments as described in the “Main Data Components of the NHDPlus HR” section of this report:
    - NHDPlusBurnLineEvent—Line feature class
    - NHDPlusBurnWaterbody—Polygon feature class
    - NHDPlusCatchment—Polygon feature class
    - NHDPlusLandSea—Polygon feature class
    - NHDPlusSink—Point feature class
    - NHDPlusWall—Line feature class
- These feature classes are defined in the WBD original watershed data (input data to NHDPlus):
  - NonContributingDrainageArea—Does not flow to the outlet of a hydrologic unit
  - NonContributingDrainageLine—Edge of noncontributing area
  - NWISDrainageArea—Drainage-area polygons for streamgages listed in the USGS **National Water Information System** (NWIS) database
- NWISDrainageLine—Edge of area draining to streamgages
  - WBDHU_x—x is the numerical identifier for the level (2, 4, 6, 8, 10, and 12) of each hydrologic unit
  - WBDLine—Edge of WBDHU_x area
- NHDPlus tables in NHDPlus_H_<vpuid>_GDB.gdb:
  - ExternalCrosswalk
  - FeatureToMetadata
  - HUMod
  - MetaProcessDetail
  - MetaSourceDetail
  - NHDFcode
  - NHDFeatureToMetadata
  - NHDMetadata
  - NHDPlusDivFracMP
  - NHDPlusEROMMA
  - NHDPlusEROMQAMA
  - NHDPlusEROMQARPT
  - NHDPlusFlow
  - NHDPlusFlowlineVAA
  - NHDPlusIncrLat
  - NHDPlusIncrPrecipMA
  - NHDPlusIncrPrecipMM_x—Mean monthly precipitation, where x is the month of the year
  - NHDPlusIncrROMA
  - NHDPlusIncrTempMA
  - NHDPlusIncrTempMM_x—Mean monthly temperature, where x is the month of the year
  - NHDPlusMegaDiv
  - NHDPlusNHDPlusIDGridCode
  - NHDProcessingParameters
  - NHDReachCodeMaintenance
  - NHDReachCrossReference
  - NHDSourceCitation
  - NHDVerticalRelationship
  - ProcessingParameters
- NHDPlus HRRasters<vpuid>
  - elev_source.gdb
  - cat.tif
  - catseed.tif
  - elev_cm.tif
  - fac.tif
  - fdr.tif
  - fdroverland.tif
  - filldepth.tif
  - hydrodem.tif
  - shdrelief.jp2
  - swnet.tif

Complete NHD and WBD documentation is available at U.S. Geological Survey (2019b). Complete 3DEP documentation is available at U.S. Geological Survey (2019a).

Main Data Components of the NHDPlus HR and How They Fit Together

This section describes the main data components of NHDPlus HR and how they fit together, including specific table attributes. The schematic diagram showing how the feature classes, tables, and rasters all fit together within NHDPlus is shown in figure 3 and is followed by descriptions of each feature class, table, raster, and their components.

Feature Classes of the NHDPlus HR

NHDPlusCatchment,—Contains a catchment polygon for either a NHDFlowline feature or a NHDPlusSink feature (table 4). Some polygons may be multipart polygons.

Burn Components

Catchments are created by a separate raster process that requires six additional feature classes created specifically for the purpose of producing catchments. These data, which are in the folder called BurnComponents, are included because they were used to create the catchments.

NHDPlusBurnLineEvent Line Feature Class

Description: Events that describe the parts of the NHDFlowline features used for hydroenforcement (table 5). The

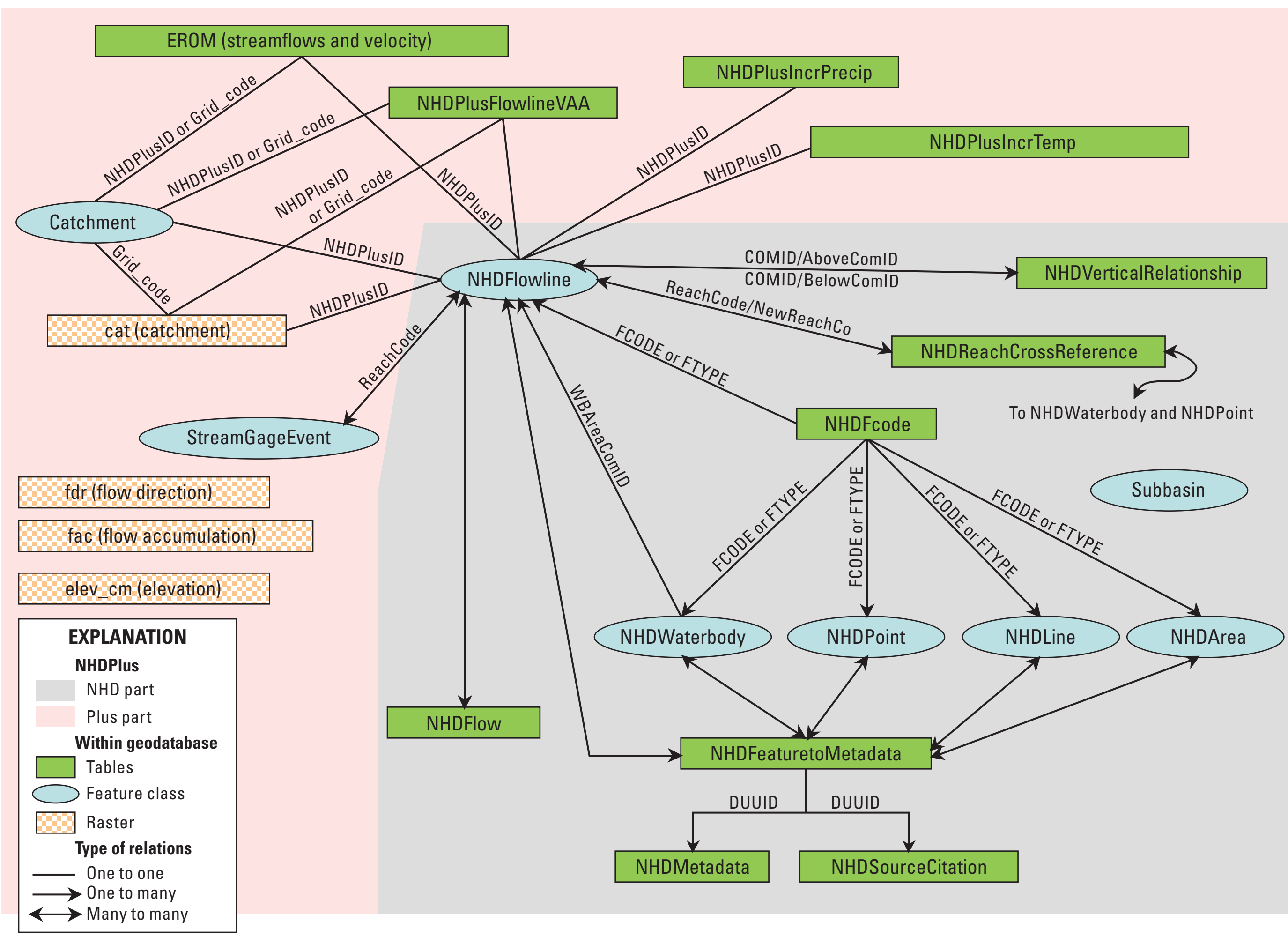


Figure 3. Relations among feature classes, tables, and rasters in the National Hydrography Dataset Plus (NHDPlus) High Resolution (NHDPlus HR). The section enclosed in the gray box is the National Hydrography Dataset (NHD), which is part of the NHDPlus structure. EROM, Enhanced [Unit] RunOff Method.

Table 4. NHDPlusCatchment polygon feature class in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusCatchment polygon catchment feature-class table in the NHDPlus_H_<vpuid>_GDB_gdb file. The table describes attributes for catchment polygons for NHDFlowline or sink features. The geometric shape of the features is polygonal; the feature class does not include measures of distances (M) nor elevation (Z) values. [GDB, geodatabase; VPU, vector-processing unit; VPUID, vector-processing unit identifier; NHD, National Hydrography Dataset; NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	1	NA	NA	Database attribute (not part of NHDPlus)
SHAPE	Geometry	Yes	NA	NA	NA	NA	NA	Database attribute (not part of NHDPlus)
NHDPlusID	Double	Yes	NA	NA	0	0	NA	Unique identifier of catchment
SourceFC	String	Yes	SourceFeatureClass	NA	NA	NA	20	Source: FeatureClass
GridCode	Long integer	Yes	NA	NA	0	NA	NA	Compacted identifier of catchment, unique for each VPU
AreaSqKm	Double	Yes	NA	NA	0	0	NA	Catchment area, in square kilometers
VPUID	String	Yes	NA	NA			8	Vector processing-unit identifier
SHAPE_Length	Double	Yes	NA	NA	0	0	NA	Database attribute (not part of NHDPlus)
SHAPE_Area	Double	Yes	NA	NA	0	0	NA	Database attribute (not part of NHDPlus)

Table 5. Fields used in hydroenforcement in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusBurnLineEvent line feature class in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. Lists events describing the parts of NHDFlowline features used for hydroenforcement. The geometry of the feature class is polylines; the feature class does not contain measure (M) or elevation (Z) values. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	1	NA	NA	
SHAPE	Geometry	Yes	NA	NA	1	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	NHDPlus identifier for a flowline feature
GridCode	Long integer	Yes	NA	NA	0	NA	NA	Compacted identifier of catchment, unique for each VPU
ReachCode	String	Yes	NA	NA	1	NA	14	Unique reach identifier
FromMeas	Double	Yes	FromMeasure	NA	0	0	NA	ReachCode measure at top of flowline
ToMeas	Double	Yes	ToMeasure	NA	0	0	NA	ReachCode measure at bottom of flowline
BurnLenKm	Double	Yes	BurnLengthKm	NA	0	0	NA	Length of BurnLineEvent feature, in kilometers
RPUID	String	Yes	NA	NA	1	NA	8	Raster processing-unit identifier
StatusFlag	String	Yes	NA	StatusFlag	1	NA	1	Flag reserved for Build/Refresh process
Catchment	Short integer	Yes	NA	NoYes	0	NA	NA	Will feature receive catchment? 0=no, 1=yes
Burn	Short integer	Yes	NA	NoYes	0	NA	NA	Will feature be hydroenforced? 0=no, 1=yes
VPUID	String	Yes	NA	NA	1	NA	8	Vector processing-unit identifier
SHAPE_Length	Double	Yes	NA	NA	0	0	NA	

term "hydroenforcement" refers to aligning the streams in the high-resolution NHDPlus drainage network onto the 3DEP DEM data; this alignment is achieved through overlaying the mapped stream network onto the 3DEP DEM (creating virtual trenches at the locations of the streams) and enforcing the WBD hydrologic divides through "walls" (lines of raster cells with greatly exaggerated elevation values). Other features used in the hydroenforcement process are sinks in noncontributing areas, oceanic water bodies, and estuaries. The resulting modified DEM is used to produce catchments and other hydrologic derivatives that closely agree with the NHD (streams and water bodies), WBD (divides), sinks, ocean, and estuary features.

NHDPlusBurnWaterbody Polygon Feature Class

Description: NHDWaterbody and NHDArea features used for hydroenforcement (table 6).

Table 6. Fields used for hydroenforcement for water bodies in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[This table refers to the NHDPlusBurnWaterbody polygon feature class in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. Lists details of the NHDWaterbody and NHDArea polygon features used for hydroenforcement. The geometry of the feature class is polygon; the feature class does not contain measure (M) nor elevation (Z) values. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
SHAPE	Geometry	Yes	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	NHDPlus identifier for a flowline feature
SourceFC	String	Yes	SourceFeatureClass	NA	NA	NA	20	Source "NHDWaterbody" of "NHDArea"
OnOffNet	Short integer	Yes	OnNetwork	NoYes	0	NA	NA	On/Off network flag, 1=on, 0=off
PurpCode	String	Yes	PurposeCode	PurposeCode	NA	NA	2	Code describing purpose of feature
Burn	Short integer	Yes	NA	NoYes	0	NA	NA	Will feature be hydroenforced? 0=no, 1=yes
VPUID	String	Yes	NA	NA	NA	NA	8	Vector processing-unit identifier
SHAPE_Length	Double	Yes	NA	NA	0	0	NA	
SHAPE_Area	Double	Yes	NA	NA	0	0	NA	

NHDPlusLandSea Polygon Feature Class

Description: Polygons used for hydroenforcement along coastlines in the NHDPlus (table 7).

Table 7. Fields used for hydroenforcement along coastlines in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusLandSea polygon feature class in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, in which VPUID is the identifier of each vector-processing unit. Describes polygons used for hydroenforcement along coastlines. The geometry of the feature class is polygon; the feature class does not contain measures (M) along the features nor elevation (Z) values. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
SHAPE	Geometry	Yes	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	Unique identifier of Land/Sea polygon
Land	Short integer	Yes	NA	LandSea	0	NA	NA	Numeric code for land (1), estuary (-1), or ocean (-2)
VPUID	String	Yes	NA	NA	NA	NA	8	Vector processing-unit identifier
SHAPE_Length	Double	Yes	NA	NA	0	0	NA	
SHAPE_Area	Double	Yes	NA	NA	0	0	NA	

NHDPlusSink Point Feature Class

Description: Point locations of sinks used for hydroenforcement (table 8).

Table 8. Fields used for sink-point locations in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusSink point feature class in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID (vpuid) is the identifier of each vector-processing unit and RPUID (rpuid) is the identifier of each raster-processing unit. Point locations of sinks used for hydroenforcement. The geometry of the feature class is point; the feature class does not contain measures (M) nor elevation (Z) values. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
SHAPE	Geometry	Yes	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	Unique identifier of sink point
GridCode	Long integer	Yes	NA	NA	0	NA	NA	Compacted numeric identifier of catchment, unique for each VPU
PurpCode	String	Yes	PurposeCode	PurposeCode	NA	NA	2	Code describing purpose of sink
FeatureID	Double	Yes	NA	NA	0	0	NA	Identifier of feature in another related feature
SourceFC	String	Yes	SourceFeatureClass	NA	NA	NA	20	Feature class referenced by FeatureID
RPUID	String	Yes	NA	NA	NA	NA	8	Raster processing-unit identifier
StatusFlag	String	Yes	NA	StatusFlag	NA	NA	1	Flag reserved for Build/Refresh process
Catchment	Short integer	Yes	NA	NoYes	0	NA	NA	Will feature receive catchment? 0=no, 1=yes
Burn	Short integer	Yes	NA	NoYes	0	NA	NA	Will feature be hydroenforced? 0=no, 1=yes
VPUID	String	Yes	NA	NA	NA	NA	8	Vector processing-unit identifier

NHDPlusWall Line Feature Class

Description: Lines used as walls in hydroenforcement (table 9).

Table 9. Fields used for walls in hydroenforcement in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusWall line feature class in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. Details specifications of lines used as walls in hydroenforcement. The geometry of the feature class is polyline; the feature class does not contain measures (M) nor elevation (Z) values. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
SHAPE	Geometry	Yes	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	Unique identifier of wall line
WallSource	String	Yes	NA	NA	NA	NA	30	
VPUID	String	Yes	NA	NA	NA	NA	8	Vector processing-unit identifier
Burn	Short integer	Yes	NA	NoYes	0	NA	NA	Will feature be hydroenforced? 0=no, 1=yes
SHAPE_Length	Double	Yes	NA	NA	0	0	NA	

Raster Layers

This section includes descriptions of the attributes of the rasters in the NHDPlus HR. The rasters are in the \HRNHDPlusRasters<vpuid> folder. A raster-attribute table is required and included for the catchment raster (abbreviated in the table as "cat"). The other rasters, however, are not required to have attribute tables because no other information is stored in these rasters except for the cell value itself. The software inconsistently creates attribute tables for these rasters where it is not necessary (for example, for catseed, elev_cm, fac, filldepth, and hydrodem).

cat.tif

Description: Rasters of catchments. Each catchment has a unique GridCode value with a one-to-one match to the NHDPlusID field code values (table 10).

Table 10. Attributes of catchment rasters in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the \HRNHDPlusRasters<vpuid>\cat.tif rasters, where VPUID is the identifier of each vector-processing unit]

Field name	Description	Format
Value	GridCode of each catchment	Integer
Count	Number of cells with each specific GridCode value	Integer
NHDPlusID	Identifier of an NHDPlusBurnLineEvent or NHDPlusSink feature	Double

catseed.tif

Description: Seed raster is used to produce the NHDPlus HR catchments by using the fdr.tif raster with the ArcGIS Watershed tool. Each cell value in the raster is the GridCode for the corresponding catchment seed.

elev_cm.tif

Description: Elevation raster projected to raster-coordinate system. Elevation values are represented as integers in centimeters relative to the North American Vertical Datum of 1988 (NAVD 88). An attribute table is not created for this raster. Information about projections for various levels of data is listed in table 1.

hydrodem.tif

Description: A raster of integer values of the hydrologically conditioned digital elevation model (HydroDEM), with the NHDPlusBurn components integrated into the digital elevation model, and then filled. This raster is used to generate the flow-direction raster (fdr.tif) from which the flow-accumulation (fac.tif) and catchment (cat.tif) rasters are generated. The elevations measured with respect to the NAVD 88 are in centimeters.

fac.tif

Description: Flow-accumulation values based on the HydroDEM, where the cell values of the raster are defined as the number of cells within the RPU draining to each cell within the RPU. Further information is available in the ArcGIS documentation of the Flow Accumulation tool.

fdr.tif

Description: Integer flow-direction raster that contains the codes that show the direction water would flow from each raster cell within the RPU based on the HydroDEM. The raster is saved as 8-bit unsigned. Cell values of the raster indicate downward direction of flow to a neighboring cell or zero if the cell is a sink (end of flow). Directions are assigned according to the values in table 11.

Table 11. Attributes of the flow-direction raster in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the \HRNHDPlusRasters<vpuid>\fdr.tif rasters, where VPUID is the identifier of each vector-processing unit]

Field name	Description	Format
Value	The value for the raster cell. Can be assigned one of nine possible values: 0 Flow ends (sink) 1 Flow is to the east 2 Flow is to the southeast 4 Flow is to the south 8 Flow is to the southwest 16 Flow is to the west 32 Flow is to the northwest 64 Flow is to the north 128 Flow is to the northeast	Integer
Count	Number of cells with each value	Integer

fdroverland.tif

Description: Overland flow-direction raster. This raster is the same as fdr.tif, except with cells coincident with flow network or water bodies, and flow-network (swnet.tif) data cells being set to NoData. The raster is saved as 8-bit unsigned (values are all positive).

filldepth.tif

Description: Raster image showing the difference between the HydroDEM raster just before filling in imperfections in the data (filling in isolated topographic lows) and the final HydroDEM raster hydrodem.tif. Cell values of the raster are the fill-depth values, in centimeters. This raster is useful for examining the results of the hydrological-conditioning process. The burned and walled elevation raster before filling can be recreated by subtracting this raster from hydrodem.tif. Elevations in this raster are in centimeters (NAVD 88); note that some elevations are very large because of the burn-and-wall values used in the processing.

shdrelief.jp2

Description: Shaded-relief raster built from the elevation raster in the raster coordinate system (elev_cm.tif). Cell values of shaded-relief brightness are scaled from 0 to 255. More details are available in the ArcGIS documentation for the Hill Shade tool. The raster is saved as 8-bit unsigned.

swnet.tif

Description: Raster that includes all cells on the flowline network or waterbodies. Cell values are assigned 1 if the cell represents a flowline location, or 2 if it is a waterbody cell (table 12). All cells not on the flowline network nor on waterbodies are assigned values of NoData. The raster is saved as 8-bit unsigned.

Table 12. Attributes of the flow-network rasters in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the \HRNHDPlusRasters<vpuid>\swnet.tif rasters, where VPUID is the identifier of each vector-processing unit]

Field name	Description	Format
Value	Can be assigned one of three possible values: 1 Network flow cell 2 Waterbody cell NoData Cell not on flow network	Integer
Count	Number of cells with value	Integer

NHDPlus HR Tables

NHDPlusFlow Table

Description: The **NHDPlusFlow table** describes flowing and nonflowing connections among NHDFlowline features (table 13). The table contains data for headwater and terminal NHDFlowline features, pairs of NHDFlowline features that exchange water, NHDFlowline features that connect to coastline NHDFlowline features, and coastline NHDFlowline features that connect to each other.

The original NHD includes a table called NHDFlow with flow connections that comprise only geometric connections among NHDFlowline features. The NHDPlusFlow table, on the other hand, may include nongeometric as well as geometric connections. Nongeometric connections are used to represent situations such as return flows along an international border or underground connections in karst topography (fig. 4).

Table 13. Flow connections among flow-line features in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusFlow table in the in the NHDPlus_H_<vpuid>_GDB_gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
FromNHDPID	Double	Yes	FromNHDPlusID	NA	0	0	NA	NHDPlusID for the upstream flowline
ToNHDPID	Double	Yes	ToNHDPlusID	NA	0	0	NA	NHDPlusID for the downstream flowline
NodeNumber	Double	Yes	NA	NA	0	0	NA	Identifier of node between FromNHDPID and ToNHDPID
DeltaLevel	Short integer	Yes	FromStreamLevMinusToStreamLev	NA	0	NA	NA	Numerical difference in stream levels
Direction	Short integer	Yes	FlowRelationshipType	NA	0	NA	NA	Flow-relationship type
GapDistKm	Double	Yes	GapDistanceKm	NA	0	0	NA	Distance between flowlines in kilometers (if a gap exists)
HasGeo	Short integer	Yes	IsGeometricConnection	NoYes	0	NA	NA	Flag if a gap exists, 0=no, 1=yes
FromVPUID	String	Yes	NA	NA	NA	NA	8	VPUID of upstream flowline
ToVPUID	String	Yes	NA	NA	NA	NA	8	VPUID of downstream flowline
FromPermID	String	Yes	FromPermanentIdentifier	NA	NA	NA	40	Permanent identifier of upstream flowline
ToPermID	String	Yes	ToPermanentIdentifier	NA	NA	NA	40	Permanent identifier of downstream flowline

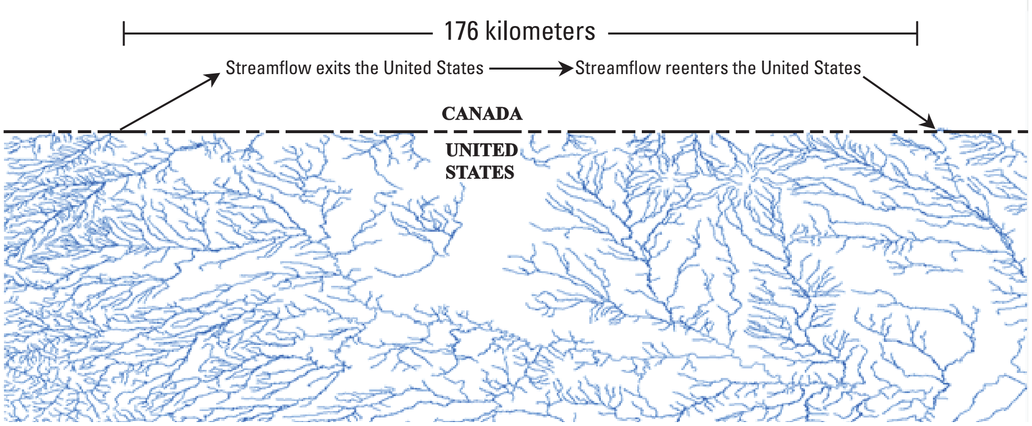


Figure 4. A nongeometric connection used to represent return flows of rivers along international borders in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

NHDPlusDivFracMP Table

Description: Specifications about the fraction of a cumulative attribute to be routed through each path in a divergence (table 14). The NHDPlusIDs in this table represent NHDFlowline surface-water features that, based on the NHDPlusFlow table (table 13), form a network divergence (a flow split). All the paths in a given divergence are identified in this table by unique node-identification numbers (NodeNumber).

All divergences are represented in this table. If DivFracMP.DivFrac values are specified, then they are used in the Divergence Routing method of all NHDPlus accumulated attributes, such as drainage area. [DivFrac is an attribute in the DivFracMP table.] Divergences for which no information is known about the fractional split are assigned DivFracMP.DivFrac = “-9998” for all paths in the divergence. In this case, the Divergence Routing method uses the PlusFlowlineVAA.Divergence field and routes a fraction of 1 to the main path (Divergence = 1) and a fraction of 0 to all other paths (Divergence = 2). When not set to “-9998”, the sum of the DivFrac values for all paths in a divergence (all records with the same NodeNumber) must equal 1.

Table 14. Fraction of flow or other cumulative attribute routed through a path in divergence features in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusDivFracMP table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit; table lists flow values for divergent paths. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	NHDPlus identifier for a flowline feature
NodeNumber	Double	Yes	NA	NA	0	0	NA	Unique identifier for point at top of flowline
DivFrac	Double	Yes	DivergenceFraction	NA	0	0	NA	Fraction for routing cumulative attribute
StatusFlag	String	Yes	NA	StatusFlag	NA	NA	1	
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

NHDPlusMegaDiv Table

Description: Table containing the NHDPlusFlow records for divergences that have more than two outflow paths (table 15). The NHDPlusMegaDiv table has an alias name of NHDPlusMultipleDivergence.

Table 15. Flow paths routed through divergence features that have more than two outflow paths in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusMegaDiv table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each VPU (vector-processing unit). Includes value-added attributes for each NHDFlowline feature in the NHDPlusFlow table; updated by using the NHDPlus Build/Refresh process. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
FromNHDPID	Double	Yes	FromNHDPlusID	NA	0	0	NA	NHDPlusID of the upstream flowline
ToNHDPID	Double	Yes	ToNHDPlusID	NA	0	0	NA	NHDPlusID of the downstream flowline
VPUID	String	Yes	NA	NA	NA	NA	8 characters	Vector-processing-unit identifier

NHDPlusFlowlineVAA Table

Description: Value-added attributes for each NHD-Flowline class feature that appears in the PlusFlow table (or where NHDFlowline.FlowDir = "With Digitized"). The NHD-Plus HR Build/Refresh process populates the NHD-PlusFlowlineVAA table (table 16). The NHDPlusFlowline-VAA table differs from the NHDFlowlineVAA table because the NHDFlowlineVAA table is an official table in the NHD schema that contains all value-added attribute values that are stored in the NHD central database but is not populated by the NHDPlus HR Build/Refresh process. Additional information on value-added attributes can be found in steps C, F, Q, and R in the "NHDPlus HR Build/Refresh Process Description" section of this report.

Table 16. Value-added attributes for features in the NHDFlowline class in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusFlowlineVAA table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. Describes flowing and nonflowing connections between NHDFlowline features. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	NHDPlus identifier for a flowline feature
StreamLeve	Short integer	Yes	StreamLevel	NA	0	NA	NA	Stream level
StreamOrde	Short integer	Yes	StreamOrder	NA	0	NA	NA	Modified Strahler stream order
StreamCalc	Short integer	Yes	StreamCalculator	NA	0	NA	NA	Further modification of stream order
FromNode	Double	Yes	NA	NA	0	0	NA	NHDPlusID of the upstream flowline
ToNode	Double	Yes	NA	NA	0	0	NA	NHDPlusID of the downstream flowline
HydroSeq	Double	Yes	HydrologicSequence	NA	0	0	NA	Hydrosequence number, in ascending order
LevelPathI	Double	Yes	LevelPathIdentifier	NA	0	0	NA	Level-path identifier
PathLength	Double	Yes	PathLength	NA	0	0	NA	Distance downstream to network end
TerminalPa	Double	Yes	TerminalPathIdentifier	NA	0	0	NA	Terminal-path identifier
ArbolateSu	Double	Yes	UpstreamCumulativeStreamKm	NA	0	0	NA	Arbolate sum, the sum of the lengths of all digitized flowlines upstream from the downstream end of the immediate flowline, in kilometers
Divergence	Short integer	Yes	DivergenceCode	Divergence	0	NA	NA	0 = no divergence, 1 = major path, 2 = minor path
StartFlag	Short integer	Yes	IsHeadwater	NoYes	0	NA	NA	Start flag (1 = headwater start)
TerminalFl	Short integer	Yes	IsNetworkEnd	NoYes	0	NA	NA	Terminal flag
UpLevelPat	Double	Yes	UpstreamMainPathLevelPathI	NA	0	0	NA	Upstream main-path levelpath identifier
UpHydroSeq	Double	Yes	UpstreamMainPathHydroSeq	NA	0	0	NA	Upstream main-path hydrosequence identifier
DnLevel	Short integer	Yes	DownstreamMainPathStreamLevel	NA	0	NA	NA	Stream level of downstream flowline
DnLevelPat	Double	Yes	DownstreamMainPathLevelPathID	NA	0	0	NA	Downstream mainstem level-path identifier
DnHydroSeq	Double	Yes	DownstreamMainPathHydroSeq	NA	0	0	NA	Downstream mainstem hydrosequence identifier

Table 16. Value-added attributes for features in the NHDFlowline class in the National Hydrography Dataset Plus (NHDPlus) High Resolution.—Continued

[Refers to the NHDPlusFlowlineVAA table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. Describes flowing and nonflowing connections between NHDFlowline features. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
DnMinorHyd	Double	Yes	DownstreamMinorHydroSequence	NA	0	0	NA	Downstream minor hydrosequence identifier
DnDrainCou	Short integer	Yes	DownstreamDrainageCount	NA	0	NA	NA	Count of flowlines immediately downstream
FromMeas	Double	Yes	FromMeasure	NA	0	0	NA	ReachCode measure at top of flowline
ToMeas	Double	Yes	ToMeasure	NA	0	0	NA	ReachCode measure at bottom of flowline
ReachCode	String	Yes	NA	NA	NA	NA	14	Unique reach identifier
RtnDiv	Short integer	Yes	HasReturningDivergence	NoYes	0	NA	NA	Returning-divergence flag
Thinner	Short integer	Yes	ThinnerCode	NA	0	NA	NA	Code for thinning the network; not in use
VPUIn	Short integer	Yes	NA	NoYes	0	NA	NA	Are there VPU inflows? 0=no, 1=yes
VPUOut	Short integer	Yes	NA	NoYes	0	NA	NA	Are there VPU outflows? 0=no, 1=yes
AreaSqKm	Double	Yes	NA	NA	0	0	NA	Catchment area, in square kilometers
TotDASqKm	Double	Yes	TotalDrainageAreaSqKm	NA	0	0	NA	Total cumulative area, in square kilometers
DivDASqKm	Double	Yes	DivergenceRoutedDrainAreaSqKm	NA	0	0	NA	Divergence-routed cumulative area, in square kilometers
MaxElevRaw	Double	Yes	MaximumElevationRaw	NA	0	0	NA	Maximum elevation raw (not smoothed), in centimeters
MinElevRaw	Double	Yes	MinimumElevationRaw	NA	0	0	NA	Minimum elevation raw, in centimeters
MaxElevSmo	Double	Yes	MaximumElevationSmoothed	NA	0	0	NA	Maximum elevation smoothed, in centimeters
MinElevSmo	Double	Yes	MinimumElevationSmoothed	NA	0	0	NA	Minimum elevation smoothed, in centimeters
Slope	Double	Yes	NA	NA	0	0	NA	Slope of the flowline from smoothed elevation (unitless)
SlopeLenKm	Double	Yes	SlopeLengthKm	NA	0	0	NA	Flow-line length used to calculate slope, in kilometers
ElevFixed	Short integer	Yes	IsElevationFixed	NoYes	0	NA	NA	Flag indicating if downstream elevation is fixed
HWType	Short integer	Yes	HeadwaterType	HeadwaterType	0	NA	NA	Headwater type, 0=real, 1=artificial
HWNodeSqKm	Double	Yes	HeadwaterNodeDrainageAreaSqKm	NA	0	0	NA	Area that drains to the headwater node in square kilometers
StatusFlag	String	Yes	NA	StatusFlag	NA	NA	1	Flag reserved for Build/Refresh process
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

NHDPlusEROMMA Table

Description: Enhanced Unit Runoff method (EROM) mean annual flow estimates from 1971 to 2000 for NHDFlowline features in the NHDPlus HR network (table 17). All flow estimates are in cubic feet per second and represent the flow at the downstream end of the NHDFlowline feature. All velocity computations, based on the Jobson (1996) method, are in feet per second and represent the velocity at the downstream end of the NHDFlowline feature.

EROM uses a six-step flow-estimation procedure and populates the NHDPlusEROM and NHDPlusEROMQA tables. The steps are as follows:

1. Step 1, the unit runoff step, uses a raster produced by a flow-balance model (McCabe and Wolock, 2011) to compute the initial estimates for the mean annual **streamflow** (QAMA) values.
2. Step 2 computes estimates of losses caused by excessive evapotranspiration. EROM incorporates a "losing streams" methodology (loss in streamflow that can be caused by excessive evapotranspiration from the stream channels). Estimates of this loss made in this step are subtracted from the QAMA flow estimates and are stored in the mean annual streamflow modification-B (QBMA) attribute.

Steps 1 and 2 are designed to estimate what is called "natural flow." Step 1 uses the flow-balance-runoff catchment values, which reflect what is called "natural runoff." Step 2, "Excess Evapotranspiration (ET)," is designed to take instream losses caused by natural hydrologic processes into account. This loss of instream flow is an important observed phenomenon, especially in areas west of the Mississippi River.

3. Step 3 is a log-log regression step that uses reference gages to provide an additional adjustment to the flow estimates. Reference gages (Falcone and others, 2010) are gages considered to be largely unaffected by human activities. This regression improves the mean annual flow estimates. Estimates made in this step are applied to the QBMA flow estimates and are stored in the mean annual streamflow modification-C (QCMA) attribute.
4. Step 4 adjusts the streamflow for flow transfers, withdrawals, and augmentations by using the NHDPlusAdditionRemoval table. Estimates made in this step are applied to the QCMA flow estimates and are stored in the mean annual streamflow modification-D (QDMA) attribute.
5. Step 5 is the gage-adjustment step, which is based on the observed flow at the gage. Only gages that meet certain criteria are used to perform gage adjustment. The gage-adjusted flow estimates should be considered the "best" NHDPlus HR flow estimates for use in models and analyses. Estimates made in this step are applied to the QDMA flow estimates and are stored in the mean annual streamflow modification-E (QEMA) attribute.
6. In step 6, a proportion (typically 20 percent) of the gages are randomly removed from the gage-adjustment process, which then provides a basis for an estimate of the accuracy of the flow estimates created in step 5. Step 6 is also referred to as the Gage Sequestration Step. The streamflow estimates from this step are similar to the step 5 flows, except a random 20 percent of the gages are not used. This step is only useful as an approximate error estimate for the step 5 flows. The Gage Sequestration flows (QFMA and QFIncrMA) are included in the NHDPlusEROMMA results table for possible quality assurance uses. The QFMA flows should not be used in applications, because these flows are less accurate than the QEMA flows.

The best EROM streamflow and stream-velocity estimates are the gage-adjusted values, from streamflow calculation step E (NHDPlusEROMMA.QEMA, where QEMA is an attribute within the table NHDPlusEROMMA) and stream-velocity calculation step E (NHDPlusEROMMA.VEMA, where VEMA is an attribute within the table NHDPlusEROMMA).

Table 17. Fields used to calculate mean annual flow estimates in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusEROMMA table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. All flow rates are in cubic feet per second, and all velocity values are in feet per second. ET, evapotranspiration; NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	NHDPlus identifier for a flowline feature
QAMA	Double	Yes	FlowEstARunoffMA	NA	0	0	NA	Mean annual flow from runoff
VAMA	Double	Yes	VelocityARunoffMA	NA	0	0	NA	Velocity for QAMA
QIncrAMA	Double	Yes	IncrFlowEstARunoffMA	NA	0	0	NA	Incremental flow from the catchment runoff

Table 17. Fields used to calculate mean annual flow estimates in the National Hydrography Dataset Plus (NHDPlus) High Resolution.—Continued

[Refers to the NHDPlusEROMMA table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. All flow rates are in cubic feet per second, and all velocity values are in feet per second. ET, evapotranspiration; NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
QBMA	Double	Yes	FlowEstBExcessETMA	NA	0	0	NA	Mean annual flow from excess ET
VBMA	Double	Yes	VelocityBExcessETMA	NA	0	0	NA	Velocity for QBMA
QIncrBMA	Double	Yes	IncrFlowEstBExcessETMA	NA	0	0	NA	Incremental flow with excess ET
QCMA	Double	Yes	FlowEstCRefGageRegressMA	NA	0	0	NA	Mean annual flow with reference-gage regression
VCMA	Double	Yes	VelocityCRefGageRegressMA	NA	0	0	NA	Velocity for QCMA
QIncrCMA	Double	Yes	IncrFlowEstCRefGageRegressMA	NA	0	0	NA	Incremental flow by subtracting upstream QCMA
QDMA	Double	Yes	FlowEstDAdditionRemovalMA	NA	0	0	NA	Mean annual flow with NHDPlusAdditionRemoval
VDMA	Double	Yes	VelocityDAdditionRemovalMA	NA	0	0	NA	Velocity for QCMA
QIncrDMA	Double	Yes	IncrFlowEstDAdditionRemovalMA	NA	0	0	NA	Incremental flow with NHDPlusAdditionRemoval
QEMA	Double	Yes	FlowEstEGageAdjustedMA	NA	0	0	NA	Mean annual flow from gage adjustment
VEMA	Double	Yes	VelocityEGageAdjustedMA	NA	0	0	NA	Velocity from gage adjustment
QIncrEMA	Double	Yes	IncrFlowEstEGageAdjustedMA	NA	0	0	NA	Incremental flow from gage adjustment
QFMA	Double	Yes	FlowEstFGageSequesterMA	NA	0	0	NA	Mean annual flow from gage sequestration step (EROM Step6, below) in cubic feet per second
QIncrFMA	Double	Yes	IncrFlowEstFGageSequesterMA	NA	0	0	NA	Incremental flow from gage sequestration
ArQNavMA	Double	Yes	AddRemoveFlowNotAvailableMA	NA	0	0	NA	NHDPlusFlowAR mean annual flow not available on flowline
PETMA	Double	Yes	CatchmentPotentialETMA	NA	0	0	NA	Potential evapotranspiration for mean annual conditions in catchment
QLossMA	Double	Yes	FlowLossFromPotentialETMA	NA	0	0	NA	Mean annual flow loss from excess ET in catchment
QGAdjMA	Double	Yes	GageFlowAdjustmentMA	NA	0	0	NA	Flows adjusted to match flows measured by an appropriate gage, in cubic feet per second
QGNavMA	Double	Yes	GageAdjustmentNotAvailableMA	NA	0	0	NA	Mean annual flow adjustment not available for this gage
GageAdjMA	Short integer	Yes	IsGageAdjustedMA	NoYes	0	NA	NA	Are the mean annual flows gage-adjusted? 0=no, 1=yes
AvgQAdjDMA	Double	Yes	GageFlowFlowlineBottomMA	NA	0	0	NA	Gage flow adjusted for downstream end (bottom) of flowline
GageIDMA	String	Yes	NWISGageIDMA	NA	NA	NA	16	Identifier of the gage
GageQMA	Double	Yes	GageFlowMA	NA	0	0	NA	Mean annual flow calculated from flows measured by gage on flowline
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

NHDPlusEROMQAMA Table

Description: Statistical descriptions of initial estimates of streamflow from runoff for the EROM mean annual flow estimates are listed in the NHDPlusEROMQAMA table (table 18). The layout of the NHDPlusEROMQAMA table is designed to facilitate graphical and statistical analyses. All data values are adjusted for the downstream end of the flowline. The data in the table are sorted by GageRef; thus, all the reference gages are listed at the top of the table. This feature is useful for users who want to look at graphs or additional statistics for only the reference gages representing more natural conditions.

Note: The NHDPlusEROMQAMA table will be empty if no gages within the VPU meet the criteria for selection. To be selected for use in the EROM flow estimations, the streamflow gage must be within the VPU being processed and have collected 10 years of continuous streamflow data within the years 1970-2000, and the gage drainage area reported in the NWIS database must be within 25 percent of the drainage area provided with the associated NHDPlus flowline.

Table 18. Fields used to calculate flow statistics in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusEROMQAMA table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. NA, not available; NWIS, National Water Information System; ET, evapotranspiration]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0		NHDPlus identifier of a NHDFlowline
GageID	String	Yes	NWISGageID	NA	NA	NA	16	NWIS GageID value
GageRef	Short integer	Yes	IsReferenceGage	NoYes	0	NA	NA	Identifies whether gage is measuring a stream considered to be representing “natural reference conditions”
QE	Double	Yes	FlowEstEGageAdjusted	NA	0	0	NA	Gage flow, in cubic feet per second
QA	Double	Yes	FlowEstARunoff	NA	0	0	NA	Cumulative runoff, in cubic feet per second
QB	Double	Yes	FlowEstBExcessET	NA	0	0	NA	= QA – Excess ET (EET), in cubic feet per second
QC	Double	Yes	FlowEstCRefGageRegression	NA	0	0	NA	= QB +/- RefGage regression adjustment
QD	Double	Yes	FlowEstDAdditionalRemoval	NA	0	0	NA	= QC +/- NHDPlusAdditionRemoval, in cubic feet per second
QEUnitRo	Double	Yes	UnitFlowEPerSqKm	NA	0	0	NA	QE / DivDASqKm, in cubic feet per second per square kilometer
QAUnitRo	Double	Yes	UnitFlowAPerSqKm	NA	0	0	NA	QA / DivDASqKm, in cubic feet per second per square kilometer
QBUnitRo	Double	Yes	UnitFlowBPerSqKm	NA	0	0	NA	QB / DivDASqKm, in cubic feet per second per square kilometer
QCUnitRo	Double	Yes	UnitFlowCPerSqKm	NA	0	0	NA	QC / DivDASqKm, in cubic feet per second per square kilometer
QDUnitRo	Double	Yes	UnitFlowDPerSqKm	NA	0	0	NA	QD / DivDASqKm, in cubic feet per second per square kilometer
QADelta	Double	Yes	FlowEstEMinusFlowEstA	NA	0	0	NA	QE – QA, in cubic feet per second
QBDelta	Double	Yes	FlowEstEMinusFlowEstB	NA	0	0	NA	QE – QB, in cubic feet per second
QCDelta	Double	Yes	FlowEstEMinusFlowEstC	NA	0	0	NA	QE – QC, in cubic feet per second
QDDelta	Double	Yes	FlowEstEMinusFlowEstD	NA	0	0	NA	QE – QD, in cubic feet per second
QAURoDelt	Double	Yes	UnitFlowEMinusUnitFlowA	NA	0	0	NA	Q_EUnitRo – Q_AUnitRo, in cubic feet per second per square kilometer
QBURoDelt	Double	Yes	UnitFlowEMinusUnitFlowB	NA	0	0	NA	Q_EUnitRo – Q_BUnitRo, in cubic feet per second per square kilometer
QCURoDelt	Double	Yes	UnitFlowEMinusUnitFlowC	NA	0	0	NA	Q_EUnitRo – Q_CUnitRo, in cubic feet per second per square kilometer
QDURoDelt	Double	Yes	UnitFlowEMinusUnitFlowD	NA	0	0	NA	Q_EUnitRo – Q_DUnitRo, in cubic feet per second per square kilometer
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

NHDPlusEROMQARpt Table

Description: The EROM cumulative-runoff report contains comparisons of the EROM flow estimates and the observed streamgage flows (table 19). The report is stored in the form of a table.

Table 19. Fields used to calculate cumulative runoff statistics for each vector-processing unit in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusEROMQARpt table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where vpuid is the identifier of each vector-processing unit. RptLine, report text up to 120 characters; NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
RptLine	String	Yes	NA	NA	NA	NA	120	

NHDPlusIncrROMA Table

Description: Mean annual runoff averaged over the area of each NHDPlus HR catchment. Mean annual-runoff values were used in computing EROM mean annual-flow estimates. The runoff values are for the period from 1971 to 2000. If a catchment extends beyond the geographic extent of the runoff data, the value will be the runoff over the part of the catchment from which data were collected. In those cases, the MissRMA value (table 20) will apply to the area of the catchment from which data were not available.

Table 20. Fields used for mean annual runoff averaged over the area of each catchment in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusIncrROMA table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	NHDPlus identifier of a catchment
MissRMA	Double	Yes	MissingDataAreaRunoffMA	NA	0	0	NA	Area of catchment with no data, in square kilometers
RunOffMA	Double	Yes	CatchmentMeanRunoffMA	NA	0	0	NA	Mean annual incremental runoff, in millimeters per year
HydroSeq	Double	Yes	HydrologicSequence	NA	0	0	NA	Hydrologic-sequence number
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

NHDPlusIncrLat Table

Description: Mean latitude of each NHDPlus HR catchment (table 21). The mean latitude is needed for the potential-evapotranspiration calculation, which is a part of the streamflow-estimation process.

Table 21. Fields used for the mean latitude of each catchment in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusIncrLat table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	Unique identifier of NHDPlus catchments
MissLat	Double	Yes	CatchmentAreaNoDataLatitude	NA	0	0	NA	Area of catchment with no data, in square kilometers
MeanLat	Double	Yes	CatchmentMeanLatitude	NA	0	0	NA	Mean latitude, in degrees
HydroSeq	Double	Yes	HydrologicSequence	NA	0	0	NA	Hydrologic sequence
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

Annual and Monthly Precipitation

NHDPlusIncrPrecipMA and NHDPlusIncrPrecipMMmm tables.—Description: Mean annual and mean monthly precipitation, respectively, averaged over the area of each NHDPlus catchment. The NHDPlusIncrPrecipMA table contains the mean annual precipitation, and each of the 12 NHDPlusIncrPrecipMMmm tables contains the mean monthly precipitation for each catchment; in NHDPlusIncrPrecipMMmm, mm is substituted in the file name with the values 01 through 12 for January through December. Precipitation values were computed by using a raster that combined the data from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) for the conterminous United States (PRISM Climate Group, 2006) with data from a set of 1-kilometer (km) rasters for areas in Canada and Mexico (data from McKenney and others, 2006). Mean annual precipitation values were used in computing EROM mean annual flow estimates. The mean monthly precipitation values are used for estimating excess evapotranspiration in EROM. The precipitation data are for the period from 1971 to 2000.

If a catchment extends beyond the extent covered by the precipitation data, the value will be the average for the part of the catchment for which data were collected. The variables MissPMA and MissPMMmm (tables 22 and 23, respectively) will add the precipitation data for areas in the catchment for which data were not available.

The value for NHDPlusIncrPrecipMA (mean annual as opposed to mean monthly) is not needed when estimating streamflow with EROM and may be intentionally left blank.

Table 22. Fields used for the mean annual precipitation averaged over the area of each catchment in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusIncrPrecipMA table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector processing unit. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	NHDPlus identifier of a catchment
MissPMA	Double	Yes	MissingDataAreaPrecipitationMA	NA	0	0	NA	Area of catchment with no data, in square kilometers
PrecipMA	Double	Yes	CatchmentMeanPrecipitationMA	NA	0	0	NA	Mean annual precipitation, in inches
HydroSeq	Double	Yes	HydrologicSequence	NA	0	0	NA	Hydrologic-sequence number
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

Table 23. Fields used for the mean monthly precipitation averaged over the area of each catchment in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusIncrPrecipMMmm tables in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where mm is the identifier for each month (with values of 01 to 12), and VPUID is the identifier of each vector-processing unit. NA, not available]

Field name	Data type	Allow nulls	Alias name	Do-main	Preci-sion	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	NHDPlus identifier of a catchment
MissPMMmm	Double	Yes	MissingDataAreaPrecipMMmm	NA	0	0	NA	Area of catchment with no data, in square kilometers
PrecipMMmm	Double	Yes	CatchmentMeanPrecipitationMMmm	NA	0	0	NA	Mean monthly precipita-tion, in inches
HydroSeq	Double	Yes	HydrologicSequence	NA	0	0	NA	Hydrologic-sequence number
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

Annual and Monthly Temperature

NHDPlusIncrTempMA and NHDPlusIncrTempMMmm Tables

Description: Mean annual and mean monthly temperatures (in degrees Celsius) averaged over the area of each NHDPlus catchment. The NHDPlusIncrTempMA table contains the mean annual temperature values (table 24), and the 12 NHDPlusIncrTempMMmm tables contain the mean monthly temperature values (table 25). In NHDPlusIncrTempMMmm, mm is substituted in the file name with the values 01 through 12 for January through December.

The temperature values were computed by using a raster that combined data from PRISM for the conterminous United States (PRISM Climate Group, 2006) with data arranged in a set of 1-km rasters provided for areas in Canada and Mexico by McKenney and others (2006). The temperature data are for the period from 1971 to 2000.

If a catchment extends beyond the area from which the temperature data were provided, the average temperature applies only to the area of the catchment that provided the data. The variables MissTMA and MissTMMmm (tables 24 and 25) give the total areas in the catchments from which data were not available.

The value for NHDPlusIncrTempMA (mean annual as opposed to mean monthly) is not needed when estimating streamflow with EROM and may be left blank.

Table 24. Field names used for the mean annual temperature averaged over the area of each catchment in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusIncrTempMMmm table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. NA, not available]

Field name	Data type	Allow nulls	Alias name	Do-main	Preci-sion	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	Unique identifier of a NHDPlus catchment
MissTMA	Double	Yes	MissingDataAreaTemperatureMA	NA	0	0	NA	Area of catchment with no data, in square kilometers
TempMA	Double	Yes	CatchmentMeanTemperatureMA	NA	0	0	NA	Mean monthly temperature, in de-grees Celsius multiplied by 100
HydroSeq	Double	Yes	HydrologicSequence	NA	0	0	NA	Hydrologic-sequence number
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

Table 25. Fields used for the mean monthly temperature averaged over the area of each catchment in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusIncrTempMMmm tables in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where mm is the identifier for each month (with values of 01 to 12), and VPUID is the identifier of each vector-processing unit. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	
NHDPlusID	Double	Yes	NA	NA	0	0	NA	Unique identifier of a NHDPlus catchment
MissTMMmm	Double	Yes	MissingDataAreaTemperatureMMmm	NA	0	0	NA	Area of catchment with no data, in square kilometers
TempMMmm	Double	Yes	CatchmentMeanTemperatureMMmm	NA	0	0	NA	Mean monthly (MM) temperature of catchment, in degrees Celsius
HydroSeq	Double	Yes	HydrologicSequence	NA	0	0	NA	Hydrologic sequence
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

NHDPlusNHDPlusIDGridCode Table

Description: A crosswalk table, to cross-reference, between NHDPlusIDs and grid codes assigned during raster processing (table 26).

Table 26. Fields used to cross-reference the catchment-feature identifiers and grid codes in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the NHDPlusNHDPlusIDGridCode table in the NHDPlus_H_<vpuid>_GDB.gdb file geodatabase, where VPUID is the identifier of each vector-processing unit. NA, not available]

Field name	Data type	Allow nulls	Alias name	Domain	Precision	Scale	Length	Comments
OBJECTID	Object identifier	No	NA	NA	NA	NA	NA	Unique identifier of a NHDPlus catchment
NHDPlusID	Double	Yes	NA	NA	0	0	NA	Source feature class: NHDFlowline or NHDPlusSink
SourceFC	String	Yes	SourceFeatureClass	NA	NA	NA	20	Source: FeatureClass
GridCode	Long integer	Yes	NA	NA	0	NA	NA	Unique, compact identifier for a catchment for a given VPU
VPUID	String	Yes	NA	NA	NA	NA	8	Vector-processing-unit identifier

National Datasets

The NHDPlus HR also includes several national datasets within the HRNHDPlusGlobalData.gdb file geodatabase (table 27). The major feature classes of the file geodatabase are described in this section.

Table 27. Feature classes and tables of national datasets used in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

Feature class name	Description
NHDPlusBoundaryUnit	Polygon feature class of vector- and raster-processing unit boundaries
NHDPlusGage	Point feature class of streamgage locations and characteristics
NHDPlusConnect	Table showing flowline connections between vector-processing units
NHDPlusGageSmooth	Point-event table of additions or removal of streamflow
NHDPlusAdditionRemoval	Table of streamflow transfers, withdrawals, and returns. Not populated in the NHDPlusHR beta release.

NHDPlusHRGlobalData.gdb\ NHDPlusBoundaryUnit Feature Class

Description: Polygon boundary for each geographic unit used to build NHDPlus HR (table 28). The unit types are VPU (vector-processing unit) and RPU (raster-processing unit). For the contiguous United States, the boundaries were constructed from WBD HU4 polygons available during the production phase of the project.

Table 28. Description of the polygon boundary for each geographic unit used in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[Refers to the \NHDPlusHRGlobalData.gdb\BoundaryUnit feature class; Char, number of characters; Double, double precision real number]

Field name	Description	Format
DrainageID	Drainage-area identifier	Char(2)
DrainSeqNo	Drainage-sequence number	Integer
VPUID	Vector-processing-unit (VPU) unique identifier	Char(8)
VPUName	VPU name	Char(100)
VPUSeqNo	VPU sequence number	Integer
RPUID	Raster-processing-unit (RPU) identifier	Char(9)
UnitType	Boundary-unit type [VPU, RPU]	Char(3)
AreaSqKM	Area of the VPU or RPU, in square kilometers	Double

NHDPlusHRGlobalData.gdb\NHDPlusGage Feature Class

Description: Locations of streamflow gages on the NHDFlowline features. This table (table 29) is used for streamflow estimation.

Table 29. NHDPlusHRGlobalData.gdb\NHDPlusGage (feature class).

[Char, number of characters; Double, double precision real number]

Field name	Description	Format
HydroAddressID	Unique NHD identifier for feature	Char(40)
AddressDate	Date feature was created	Date
Reachcode	Identifier of reach on which the streamgage is located	Char(14)
ReachSMDate	Reach version date	Date
OnNetwork	On/Off network flag, 1=on, 0=off	Integer
NHDPlusID	Unique identifier for NHD gage feature	Double
FeatureClassRef	NHD feature class containing the gage	Integer
SourceAgency	Originator of event	Char(130)
SourceDataset	Data source where gage is maintained	Char(100)
SourceID	Gage identifier/U.S. Geological Survey site number	Char(100)
SourceFeatureURL	URL to website where detailed gage data can be found	Char(255)
Measure	Measure along reach where streamgage is (in percent from downstream end of the one or more NHDFlowline features that are assigned to the ReachCode)	Double
Station_NM	Station name	Char(254)
FeatureType	Set to "StreamGage"	Char(100)
HU	Hydrologic unit	Char(12)
State	State	Char(2)
State_CD		Char(2)
LatSite	Latitude	Double
LonSite	Longitude	Double
DaSQMi	Drainage area, in square miles	Double

NHDPlus Data Domains

The data in the NHDPlus HR are described by purpose codes (table 30). Other domains are also used (table 31).

Table 30. Purpose codes and descriptions for domains used in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

[The field type for the purpose-code domain is string; NHD, National Hydrography Dataset; VPU, vector-processing unit]

Code	Description	Applicable feature classes					
		NHDPlus-BurnLineEvent	NHDPlus-BurnWaterbody	NHDPlus-BurnAddLine	NHDPlus BurnAddWaterbody	NHDPlus Sink	WBD HU12
SE	Network end	X	X	X	X	X	
SN	BurnLineEvent nonspatial connection	X	X	X	X	X	
SP	NHDWaterbody playa		X	X	X	X	
SC	NHDWaterbody closed lake		X	X	X	X	
SH	12-digit hydrologic unit (HU12) polygon minimum point or centroid					X	X
SK	Karst sinkhole					X	
SD	Topographic depression					X	
SO	Other sink					X	
AC	Coastline from adjacent vector-processing unit (VPU)			X			
AF	Added feature from adjacent VPU, not upstream			X	X		
AU	Added feature from adjacent VPU, upstream			X	X		
AI	Inflow connecting feature from upstream VPU			X	X		
AO	Outflow flowlines to elevation-clip boundary (boundary of the raster processing)			X	X		
UF	Unused feature, FCode or by feature			X	X		
DO	Digitized outlow path			X			
DC	Digitized connector flowline			X			
OC	NHDWaterbody sea, bay, estuary		X				
IM	Ice mass or glacier		X				
WB	NHD Waterbody		X		X		

Table 31. Description of other domains used in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

Domain name	Type	Description
Yes/No	Short integer	1 = yes 2 = no
Headwater type	Short integer	1 = artificial headwater 2 = real headwater
Land/sea	Short integer	0 = estuary 1 = land 2 = sea
Divergence	Short integer	0 = feature that is not part of a divergence 1 = feature that is the main path of a divergence 2 = feature that is a minor path of a divergence

Concepts for Understanding and Using NHDPlus HR

Concepts discussed in this section include the following:

- Unique Feature Identifiers in NHDPlusID.
- Divergences in NHDPlus HR network with complex hydrography.
- Total upstream and divergence-routed accumulation to aggregate upstream incremental values.
- Stream slope in the NHDPlusFlowlineVAA table.
- Finding the upstream inflows to an NHDPlus VPU: navigation of the stream network, if necessary, into upstream or downstream NHDPlus HR VPU workspaces.
- Finding all the flowlines immediately tributary to a reach of river.
- Isolated Networks: NHDPlus contains many isolated networks throughout the United States. An isolated network appears to terminate into the ground or has no outflow.
- Why NHDPlus catchment boundaries may differ from WBD HUC12 boundaries.
- Why some NHDFlowline features do not have matching catchments.
- Using the NHDPlus value-added attributes for tasks other than navigation:
  - Example 1: Using LevelPathID to generalize the stream network based on stream length.
  - Example 2: Using TerminalPathID to select the river and its drainage area.
  - Example 3: Stream profile plots.
  - Example 4: Stream Order.
  - Example 5: Stream Level.
  - Why flows estimated by the Enhanced Unit Runoff Method may differ from gage-reported streamflow.

NHDPlus HR Unique Feature Identifiers

The unique identifier for all NHDPlus HR spatial objects is the NHDPlusID. It is a 14-digit number stored in a field whose type is defined as "double."
Caution: Do not export the NHDPlus HR tables to .dbf format or the feature classes to shapefiles for use in ArcGIS, which cannot translate all the significant digits of the field to the target format if the data are stored in a .dbf table or in a shapefile. Low-order digits are lost along with the ability to link NHDPlus HR components to each other.

NHDPlus HR and Divergences

The NHDPlus HR network includes complex hydrography (network components), including convergent, divergent, and complex flow paths (). A convergent junction is the simplest type of junction for downstream routing and accumulating attributes, such as drainage area. Divergent and other types of complex junctions complicate computing cumulative values.

The DIVERGENCE field in the NHDPlus_H_<vpuid>.gdb\NHDPlusFlowlineVAA table defines "main" and "minor" paths at divergences. One path is designated as the main path and is given a DIVERGENCE attribute value of "1." All other paths in the divergence are designated as minor paths and are given a DIVERGENCE attribute value of "2" (fig. 6).

In many cases, the divergences are "local" (fig. 7) because the divergence returns to the main network at the next downstream confluence. In figure 7, the red flowline represents the local divergence. The blue line represents the main path or flowlines not affected by these divergences because the divergent streams rejoin the network.

NHDPlus HR can represent many complex networks – for example, nested divergences, braided streams, coastal drainage patterns, complex irrigation-channel systems, and divergences where the divergent flowlines never rejoin the network downstream. Some complex divergences do not immediately rejoin the main network (fig. 8), may flow into additional divergences, return to the main network many miles downstream and can thus effect multiple flowlines. When attribute values are routed and accumulated, cumulative values will be affected by these divergences.

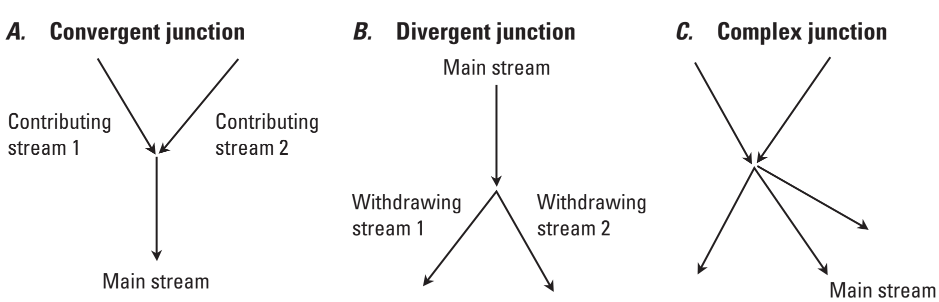


Figure 5. Complex hydrography with *A*, convergent, *B*, divergent, and *C*, complex flow paths in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

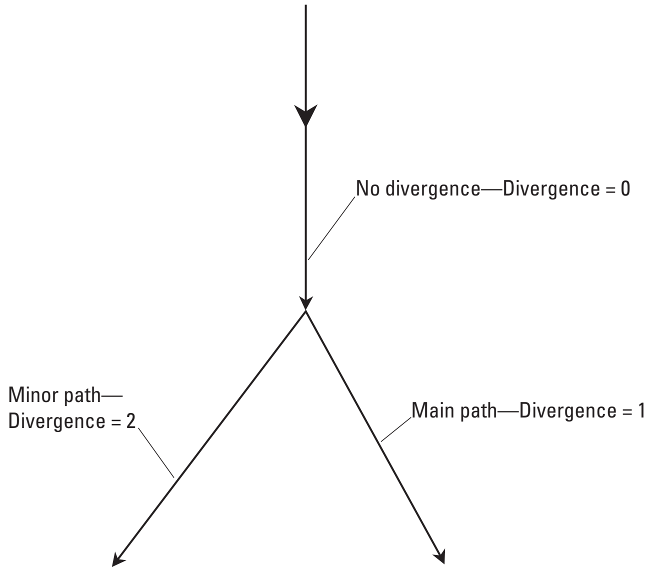


Figure 6. Main and minor paths of divergent junctions of hydrography in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

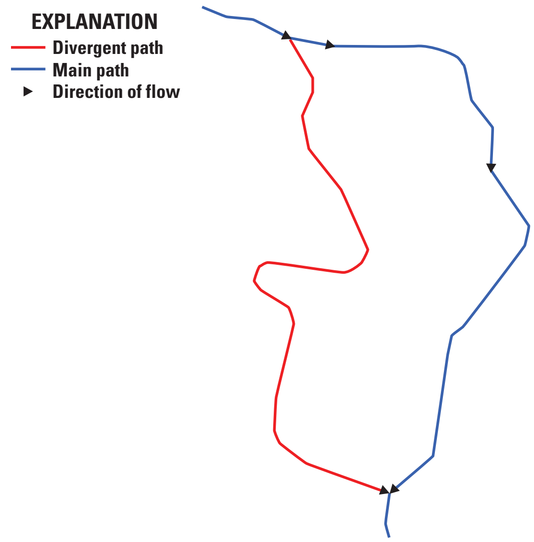


Figure 7. A local divergence of streamflow within the National Hydrography Dataset Plus (NHDPlus) High Resolution.

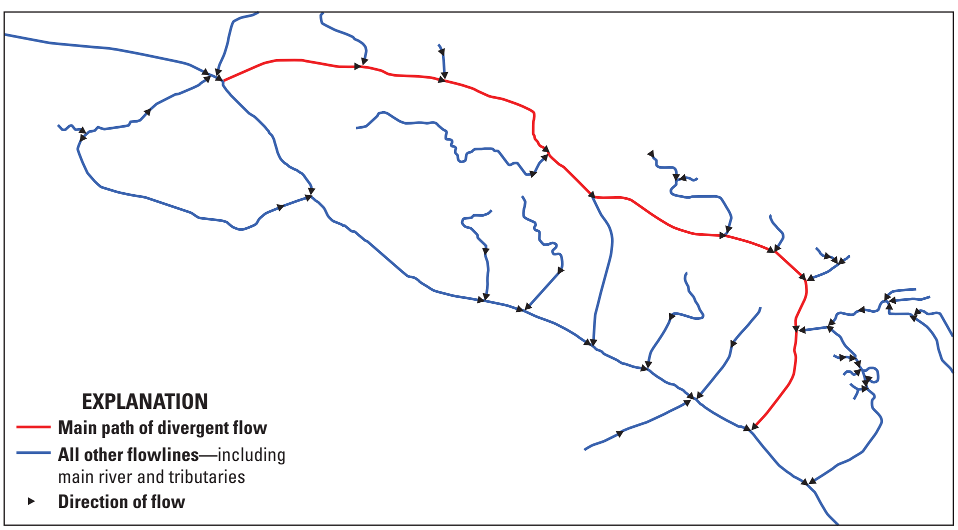


Figure 8. A complex divergent junction in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

Total Upstream Accumulation and Divergence-Routed Accumulation

The objective of accumulation is to aggregate the incremental values of features so that, at any NHDFlowline feature or catchment in the network, the cumulative attribute value for the area upstream of the feature or catchment can be computed. NHDPlus HR has implemented two methods for accumulating attributes along the NHDPlus HR network. The first method, Total Upstream Accumulation, accumulates the attribute for each NHDFlowline feature along the network that represents the total value of the attribute upstream of the most downstream (bottom) node of the NHDFlowline feature. The second approach, Divergence-Routed Accumulation, apportions the attribute value at each divergence. A part of the accumulation is routed down each path of the divergence so that the sum of the divergence parts is 100 percent of the accumulated value at that point in the network. For each NHDFlowline feature along the network, the divergence-routed accumulation values for an attribute do not include amounts routed down minor divergent paths that have not returned to the main network.

For the vast majority of divergences, it is not known how to appropriately apportion to the paths in the divergence. Where there is no specific information, NHDPlus HR uses defaults that route 100 percent of the attribute down main paths (NHDPlusFlowlineVAA.Divergence = 1) and 0 percent down minor paths (NHDPlusFlowlineVAA.Divergence = 2). The NHDPlus HR table NHDPlusDivFracMP documents known proportions for main and minor paths and thus provides information that is used in the Divergence-Routed Accumulation method. This method does not include minor divergent flowlines, and the flowlines downstream of the minor divergences do not include the cumulative values upstream of the divergence (fig. 9) until the divergence rejoins the main path.

Attribute accumulation can be done for specific sites or for the entire network. Site-specific accumulation can be easily completed with upstream navigation followed by the aggregation of any attributes assigned to NHDFlowline features (or their associated catchments) by using the navigation results. When an entire-network accumulation method is implemented, the desired attributes are accumulated for each NHDFlowline feature and saved in an attribute table for future use. Entire-network accumulations require a program or script to complete the task. Different mathematical operations are chosen based on the attribute being aggregated. For example, the attribute named "drainage area" is additive, whereas categorical land-use attributes are computed by using an area-weighted average.

As previously discussed, the two techniques used for accumulating attributes for every flowline in the network are **Total Upstream Accumulation** and Divergence-Routed Accumulation.

For the Total Upstream Accumulation method, the accumulation for each NHDFlowline feature is the aggregation of all the incremental upstream values that are being accumulated. The advantage of this method is divergence classifications that are less sensitive to error because the accumulated values represent the total accumulation upstream of each NHDFlowline.

The Divergence-Routed Accumulation method starts at the top of the network and moves downstream, aggregating the incremental values for features or catchments. As each feature or catchment is processed, the cumulative values are saved. The advantage of this method is that values can be computed quickly; however, the Divergence-Routed Accumulation method is sensitive to errors in divergence classifications. When the wrong path is designated as the major path, accumulated values will be routed down the wrong path. In addition, NHDFlowline features downstream of divergences that have not returned to the major network path will not receive the full

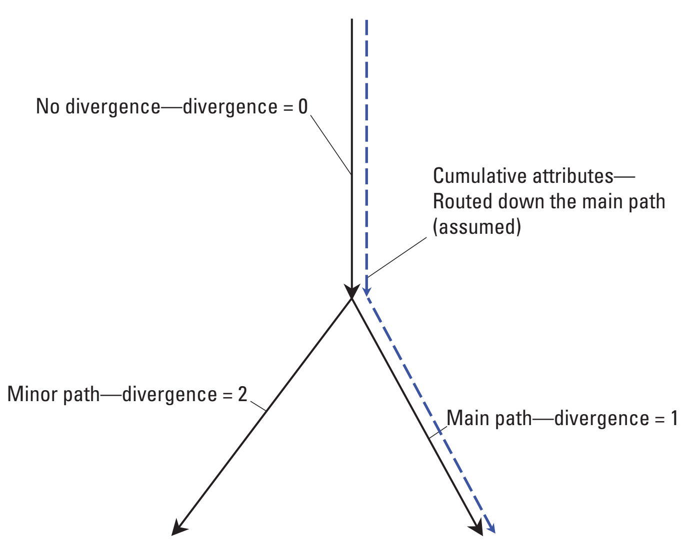


Figure 9. The Divergence-Routed Accumulation method of aggregating the incremental values of features in the National Hydrography Dataset Plus (NHDPlus) High Resolution. In this method, attributes are routed down the main path for aggregation.

accumulated value from features upstream of the divergence. Divergence-routed accumulation may be appropriate for some attributes but not for others, and the user should be aware of these distinctions.

Understanding NHDPlus Slope

NHDPlus slope is unitless. Slope is found in the NHDPlusFlowlineVAA table. Minimum (Min*ElevSmo*) and maximum (Max*ElevSmo*) smoothed elevations for flowlines are expressed in meters. The elevations are smoothed in step Q from the raw minimum elevations created in step O for each catchment and the maximum raw elevation, also created in step O, at the headwaters. The length of NHDPlusBurnLineEvent features (BurnLenKM) is in kilometers. Therefore, when slope is calculated with these fields, the result is slope in meters per kilometer:

$$Slope = \frac{\max elev_{smo} - \min elev_{smo}}{BurnLenKM}. \quad (1)$$

To calculate the true (unitless) slope provided in NHDPlusFlowlineVAA.Slope, the units must be divided by 1,000 meters per kilometer (m/km). NHDPlus slopes are constrained to be ≥0.00001. Note: the smoothing technique is described in the section “Step Q—Smooth Raw Elevations” of this report.

Finding the Upstream Inflows to an NHDPlus HR VPU

All NHDPlus HR VPU workspaces are hydrologically connected drainage areas with inflows from other VPUs and outflows to other VPUs. Before navigating the stream network within a VPU, determine whether the navigation should be continued into upstream or downstream NHDPlus HR VPU workspaces.

The existence of upstream and downstream VPUs is noted in the NHDPlusFlowlineVAA VPUIn and VPUOut attributes. When these attributes are set to “1” (“Yes”), there are one or more upstream or downstream VPUs, respectively. To find the NHDPlusIDs of the flowlines that receive water from an upstream VPU or discharge water to a downstream VPU, search the NHDPlusHRGlobalData.gdb\NHDPlusConnect table for DnVPUID or UpVPUID, respectively, to be equal to this VPU. The NHDPlusConnect tables found in this manner also provide the NHDPlusIDs of the flowlines in the upstream and downstream VPUs.

Finding All Flowlines That Are Immediately Tributary to a Reach of River

First, find the reach of interest along the main river by using the following method:

1. Navigate upstream on the mainstem of the major river from the desired starting flowline for the desired distance. To do this, first find the NHDPlusID of the starting flowline. Then determine the following:
   A. LPI. Find NHDPlusFlowlineVAA.LevelPathI for this NHDPlusID. Set LPI = LevelPathI.
   B. MinPL. Find NHDPlusFlowlineVAA.Pathlength for this NHDPlusID. Set MinPL = Pathlength.
   C. MaxPL. Set MaxPL = desired distance to navigate upstream (for example, PL+150 km)
   D. Select NHDPlusFlowlineVAA where LevelPathI = LPI, Pathlength< = MaxPL, and Pathlength > = MinPL
   E. The NHDPlusIDs of the selected records identify the reach of the main river.
2. Find the tributaries to the reach: Join the NHDPlusFlow.ToNHDPlusID (using ToNHDPlusID as the join field) to the list of NHDPlusIDs from step 1 above. All the NHDPlusflow.FromNHDPlusIDs in the joined records are the NHDPlusIDs of the tributaries to the desired reach of the river.

Working With Main Networks and Isolated Networks

Most of the features in the NHDPlus surface-water network drain to the Atlantic Ocean, Pacific Ocean, Gulf of Mexico, land masses in Canada and Mexico, or to one of the Great Lakes. These features compose the “main” flowline network in NHDPlus. In addition, NHDPlus HR includes many isolated networks throughout the United States. An isolated network appears to terminate into the ground or has no outflow. Many isolated networks either seep into the ground or end because of excessive evaporation. These are often called “noncontributing” networks (fig. 10) and although they can develop in any part of the country, they develop primarily in the Southwest and in the southeastern parts of the Pacific Northwest (hydrologic region 17). Some isolated networks are mapping errors (fig. 11); these networks should be connected to the main NHDPlus network or removed. “Noncontributing” here refers to networks that include no surface-water connections. The absence of surface-water connections does not rule out the presence of groundwater connections that can and do exist in many places but are beyond the present [2019] scope of NHDPlus HR.

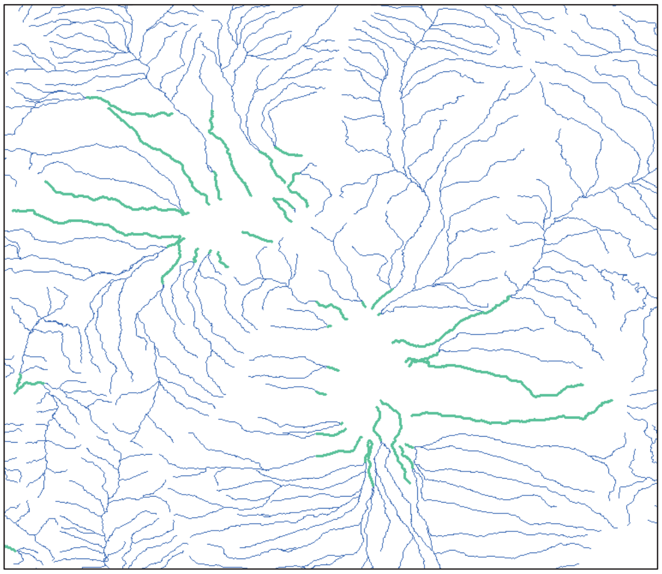


Figure 10. Noncontributing isolated networks in the National Hydrography Dataset Plus (NHDPlus) High Resolution. Teal lines are terminal segments of isolated networks.

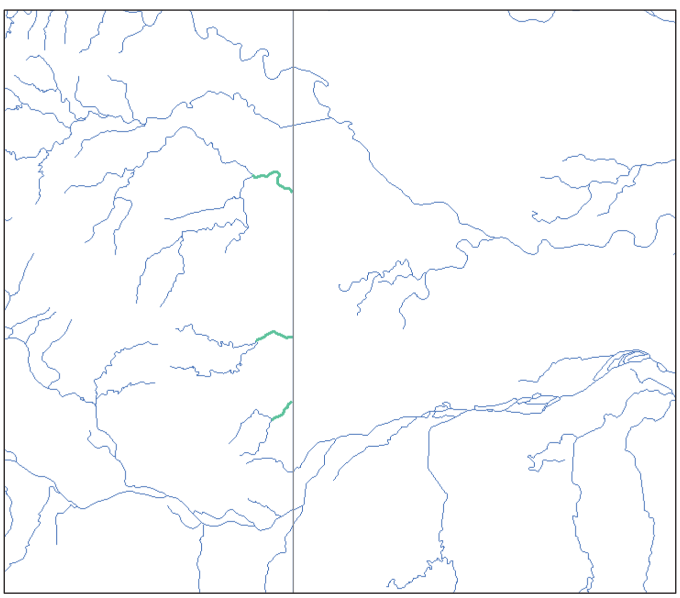


Figure 11. Three isolated networks in the National Hydrography Dataset Plus (NHDPlus) High Resolution that include mapping errors indicated by the truncated lines in the center of the figure. The north-south line in the middle of the map area represent the boundary between two U.S. Geological Survey topographic quadrangle maps.

Isolated networks may exist in any NHDPlus HR drainage area. To find the terminal flowlines of isolated networks, join the NHDPlusFlowlineVAA attribute table to the NHDFlowline feature class by using the NHDPlusID field in each. Then select all flowlines with NHDPlusFlowlineVAA.TerminalFl = 1. The flowlines selected are considered by the NHDPlus to be terminal flowlines. Flowlines selected inside the VPU are the terminal flowlines of isolated networks.

Differences Between Catchment Boundaries and WBD Boundaries for 12-Digit Hydrologic Unit Codes

The WBD is a baseline hydrologic drainage-boundary framework that accounts for all land and surface areas of the United States; it was developed jointly by State and Federal agencies. A hydrologic unit is defined as a drainage area delineated to nest in a multilevel, hierarchical drainage system. Its boundaries are defined by hydrographic and topographic criteria that delineate an area of land upstream from a specific point on a river, stream, or similar surface-water feature.

A common goal of the NHD and WBD programs is to minimize the differences between NHDPlus catchment boundaries and WBD HUC12 boundaries. The objective is to nest NHDPlus HR catchments within WBD 12-digit hydrologic (HUC12) areas. This, in turn, would make it possible for catchment attributes to be aggregated up to any hydrologic-code level.

NHDPlus HR catchments are constructed by using a snapshot of the WBD. The HUC12 **drainage-area divide** lines from the WBD are incorporated into the NHDPlus HR hydroenforced DEM as walls so that DEM-derived flow-direction cells (the NHDPlus HR fdr.tif raster) conform to the drainage divides in the WBD. Catchments for NHDFlowline features and sink features are created by using the NHDPlus HR fdr.tif raster and should conform to the WBD boundaries within the 10-m-cell resolution except at pour points, where streams cross from one HUC12 to the next downstream HUC12. In practice, however, catchments and WBD boundaries are not always closely aligned. At present, the catchment boundaries correspond well at ridge lines, but differences are common at the WBD pour points. Common data conditions that could result in differences between the catchment and WBD boundaries are as follows:

- The pour point of the catchment is upstream or downstream of the pour point of the WBD. This misalignment between the NHD and the WBD can occur at HUC12 stream outlets where the segmentation of the NHD does not match outlets in the WBD. The result is a catchment, for example, extending into a part of the next downstream or upstream HUC12 (fig. 12).

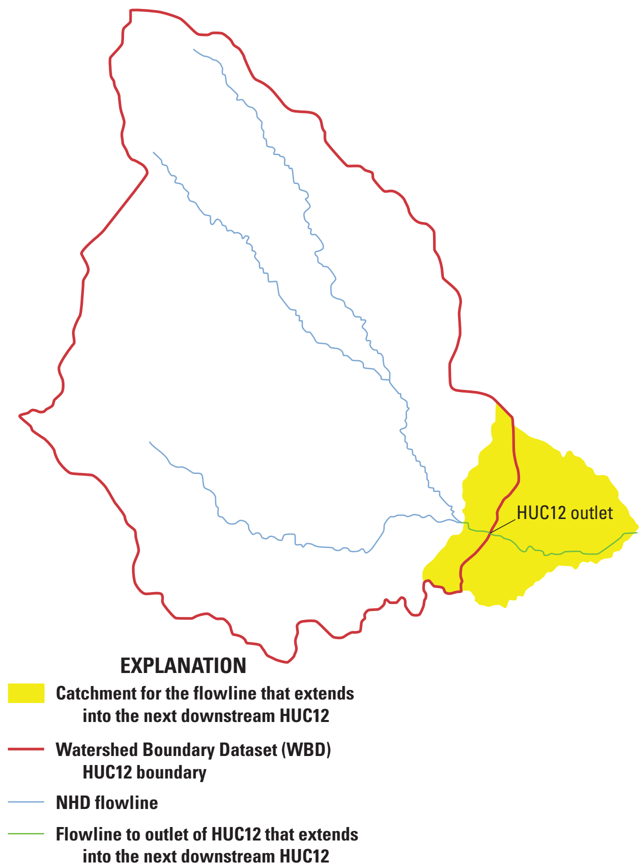


Figure 12. A catchment in one 12-digit hydrologic unit code (HUC12) extending into a part of the next downstream HUC12 in the National Hydrography Dataset Plus (NHDPlus) High Resolution. NHD, National Hydrography Dataset.

- The 10-m cell resolution can be a limiting factor for spatial correspondence between the NHDPlus HR catchments and WBD divides; this is true where an NHDFlowline feature is within one cell width of a WBD divide. This situation can result in the NHDFlowline feature incorrectly breaching the WBD wall feature in the hydroenforced DEM, where a breach is not appropriate. This processing artifact can cause the catchment for the NHDFlowline feature to extend beyond the WBD divide. An example of this is shown in figure 13, where the 10-m cell-size rasterization causes a series of NHDFlowline features to breach nearby WBD wall features.

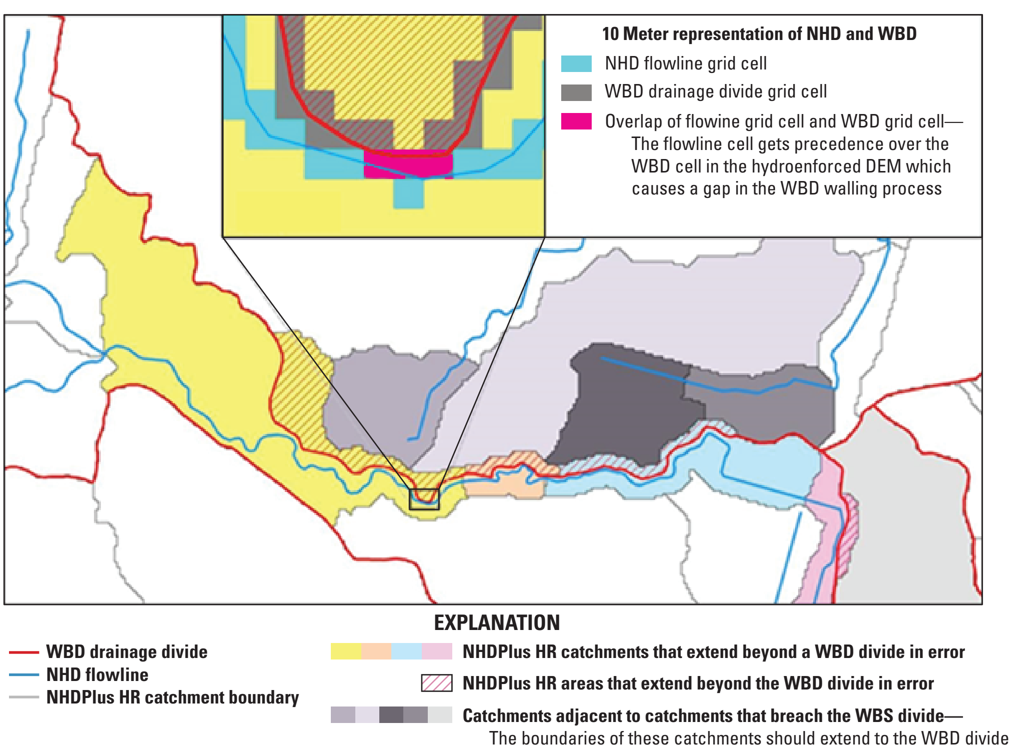


Figure 13. An example of flowlines from the National Hydrography Dataset (NHD), watersheds from the Watershed Boundary Dataset (WBD), and catchments in the National Hydrography Dataset Plus (NHDPlus) High Resolution (NHDPlus HR) to illustrate the limitation of a 10-meter-cell representation of the correspondence of NHD and WBD data in the NHDPlus HR.

- Where lake shorelines are used to define WBD boundaries (fig. 14), the NHDPlus HR catchments associated with **artificial paths** within the lakes will not match the WBD boundary. The representation of the artificial-path catchment features in the lake from the NHD includes contributing drainage from the surrounding HUC12s.

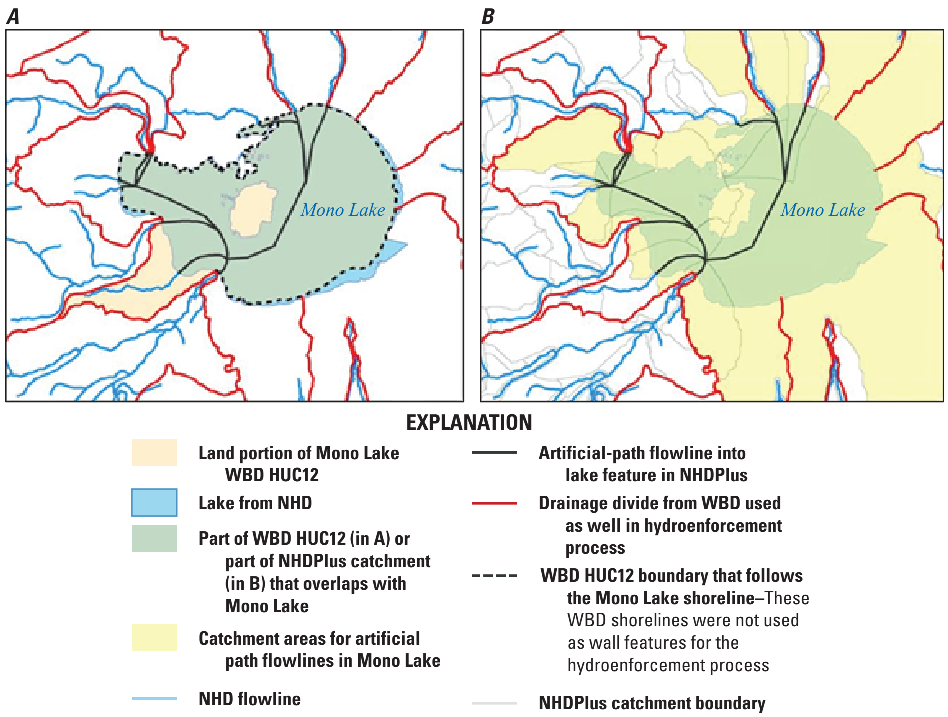


Figure 14. An example of a lake shoreline used to define the Watershed Boundary Dataset (WBD) boundary. *A*, The shoreline WBD boundaries are not used in the National Hydrography Dataset Plus (NHDPlus) catchment delineation process and thus do not match *B*, the catchment boundaries in the High Resolution (NHDPlus HR).

- In arid areas, some HUC12s may be “empty” (may not contain any NHDFlowline features or other water features). If the HUC12 was not identified in WBD as a **closed basin**, the wall between the HUC12 and the downstream HUC12 was removed during the NHDPlus HR production process. In these cases, the catchments may not agree with the HUC12 boundaries, such as the example in figure 15*A*, which shows two empty HUC12s. A part of the boundary of each empty HUC12 is removed from the Wall feature, hydrologically connecting the empty HUC12 to the next downstream drainage. One empty HUC12 flows into the next downstream empty HUC12, which in turn drains to the next downstream HUC12 that contains an NHDFlowline feature. The resultant catchment for the NHDFlowline feature is the area of the HUC12 that includes the feature and the two upstream empty HUC12s (fig. 15).

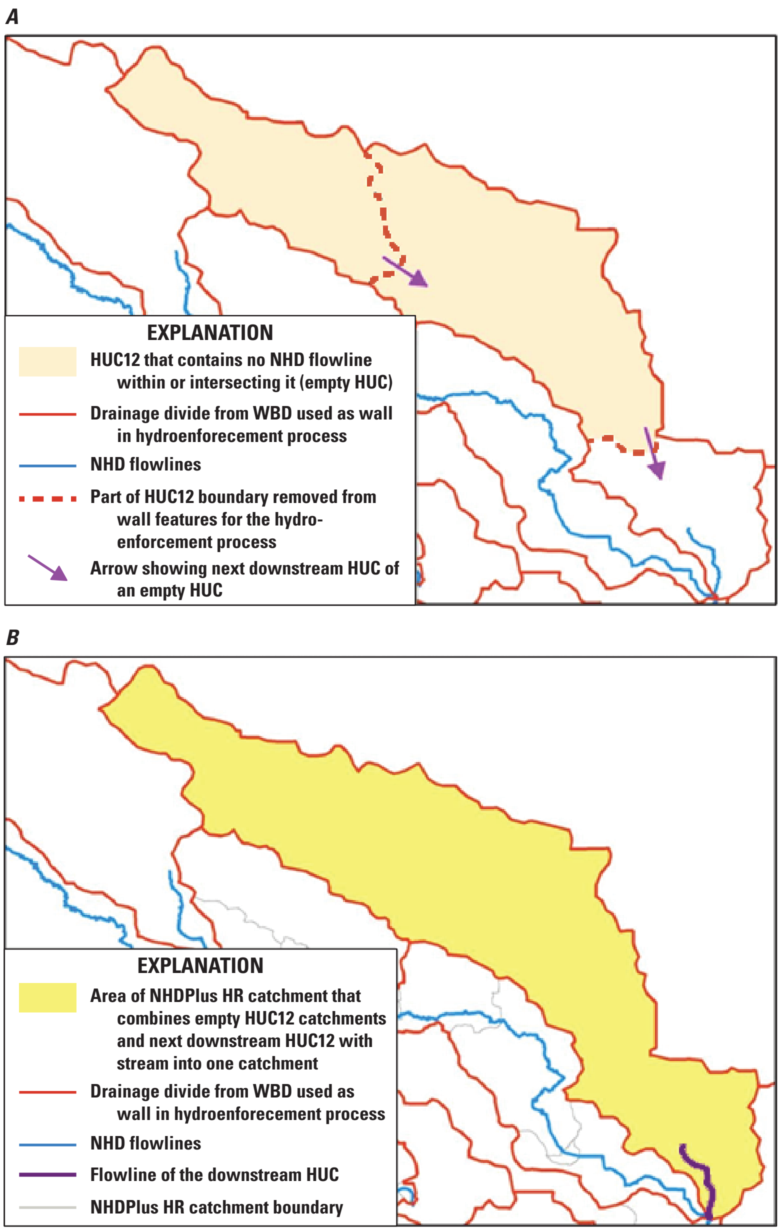


Figure 15. *A*, Two adjacent 12-digit hydrologic unit code (HUC12) drainage areas that do not contain flowline features in the National Hydrography Dataset (NHD) and *B*, a single catchment created from the three merged areas in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

- Arid areas can present isolated NHDFlowline networks within a HUC12 with a sink at the downstream end of each isolated network. Within a HUC12, there may exist an area downhill of the sink with no flowline connecting the area to an adjacent HUC12 (fig. 16). If the HUC12 is not identified as a closed basin in the WBD and has a downstream HUC12 identified, then a section of the wall can be removed during NHDPlus HR processing. By removing the wall section, the downhill part of the HUC12 drains to the downstream HUC12. In these cases, the areas downhill of the sink will be assigned to a catchment in the downstream HUC12. Figure 16 shows a catchment for an NHDWaterbody playa feature (dried lake bed of a temporary lake); the catchment is a sink labeled with a map identifier 1 and includes the entire area for an upslope empty HUC12 and a large part of another upstream HUC12 that is otherwise partially allocated to catchments for an isolated network.

All NHDFlowline headwater features are trimmed back by a small distance to reduce possible breaches of ridge lines in the HydroDEM.

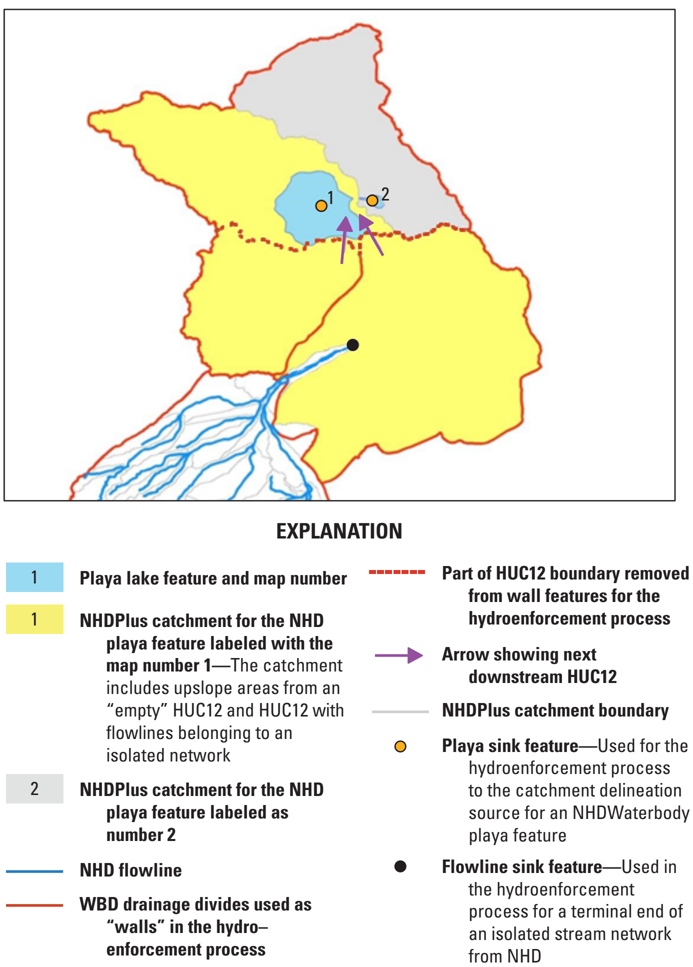


Figure 16. The catchment for a playa-lake NHDWaterbody feature (map identifier [ID] 1) originally from the National Hydrography Dataset (NHD) displayed in the National Hydrography Dataset Plus High Resolution so that it includes most of the area for an upslope empty 12-digit hydrologic unit code (HUC12) area (map ID 2). This adjustment was done through hydroenforcement of the NHDPlus HR catchment with the boundaries of the HUC12 from the Watershed Boundary Dataset (WBD).

In figure 17, a headwater NHDFlowline feature extends into an adjacent WBD HUC12 in a manner that appears to contradict how the drainage should be as defined by the WBD. This situation may represent an error either in the NHD or in the WBD. Visual review of this example with high-resolution oblique aerial photography (fig. 17 inset) indicated that the headwater feature does extend into the adjacent HUC12 through culvert and pipeline features.

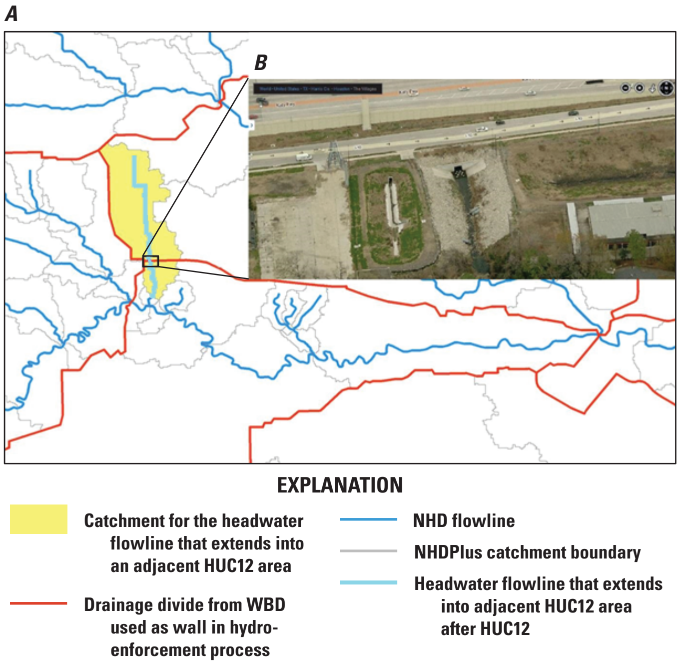


Figure 17. *A*, A headwater NHDFlowline feature in the National Hydrography Dataset Plus (NHDPlus) High Resolution that extends into an adjacent Watershed Boundary Dataset (WBD) 12-digit hydrologic unit code (HUC12) area. *B*, Aerial photograph (from The National Map) showing the culverted connection between the two areas that were shown in the WBD as two separate HUC12 areas. Correcting errors like this should be addressed through the stewardship program sponsored by the U.S. Geological Survey (https://doi.org/10.3133/fs20143084).

NHDFlowline Features With and Without Catchments

In general, catchments are generated for networked NHD flowlines (InNetwork = “Yes”). However, in NHDPlus HR, some networked flowlines were intentionally removed from the set of features used for catchment generation. Examples included pipelines, elevated canals, headwater flowlines that conflicted with the WBD, and some other limited data conditions. The “Catchment” field in the NHDPlusBurnLineEvent feature class identifies the flowlines, which were designated as “N” for “not used for catchment generation” or “Y” for “used in catchment generation.”

A common cause of flowlines without catchments is the resolution of the 3DEP DEM data. The fine 10-m resolution of the DEM used to create NHDPlus HR greatly reduces this condition: for example, only 0.05 percent of the flowlines in VPU 0602 in NHDPlus HR lacked catchments, compared with 1.4 percent in VPU 0602 in NHDPlus (30-m medium resolution) and with 1.1 percent in NHDPlus (30-m medium resolution), nationally. Catchments were not generated for many very short flowlines, whose lengths were defined as approximately 14 m or less (14 m is the diagonal distance across a 10-m raster cell). When flowlines longer than 14 m are within the same raster cells as a very short flowline, the raster cells are typically assigned to the longer flowlines unless another field has been used to give priority to the shorter flowlines, and no catchment has been delineated for the very short flowline.

In rare circumstances depending on the spatial configurations of multiple surrounding flowlines, flowlines longer than 14 m may not have been assigned a catchment. For example, flowlines may be parallel to each other within a given raster cell and may continue this way through additional raster cells that encompass the entire length of one of the flowlines. In this case, cells used as seeds to delineate the catchments may be assigned to the longer flowline within each cell, and it is possible for the shorter flowline to not be designated a seed for any cell.

Using the NHDPlus Value-Added Attributes for Nonnavigation Tasks

The attributes in the NHDPlusFlowlineVAA table provide several easily used and powerful capabilities. Below are examples of the use of the NHDPlusFlowlineVAA for non-navigation tasks.

Example 1. Using LevelPathI To Generalize the Stream Network Based on Stream Length

The mainstem of each stream is assigned a unique identifier as a value-added attribute called "LevelPathI." LevelPathI is set equal to the HydroSeq value of the most downstream flowline on that river. LevelPathI can be used in conjunction with the NHDFlowline feature LengthKM (defined in the NHDFlowline table) to build a table of the total lengths of all mainstems of all networked streams and rivers. In ArcMap, follow these steps:

1. Join NHDPlusFlowlineVAA.NHDPlusID and NHDFlowline.NHDPlusID.
2. Summarize by NHDPlusFlowlineVAA.LevelPathI with sum (NHDFlowline.LengthKM).

The output table from the summary will contain each LevelPathI and the sum of the lengths of all the flowlines in the level path. Figure 18 highlights the main rivers whose lengths are equal to or greater than 100 km in length. A threshold criterion of any length can be used as desired.

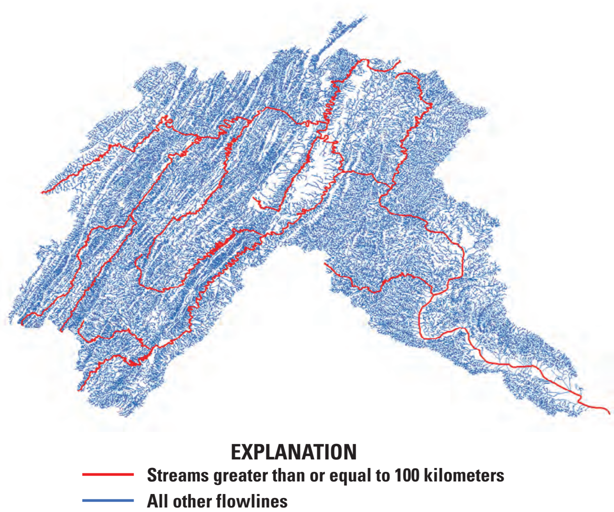


Figure 18. Streams with lengths greater than or equal to 100 kilometers for the Potomac River watershed within the mid-Atlantic region of the United States, in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

Example 2. Selecting an Individual River or Terminal River Basin

TerminalPathID is a value-added attribute that contains the same value for each of the NHDFlowline features in an entire drainage area. TerminalPathID is set to the HydroSeq value-added attribute of the terminal NHDFlowline feature in the drainage. For example, if the terminal feature of a river has a HydroSeq represented by a value A, then the LevelPathI for the river's mainstem is assigned the value A (fig. 19) and, if this river ends in a network terminus, the TerminalPathID for the river and its drainage area is assigned the value A.

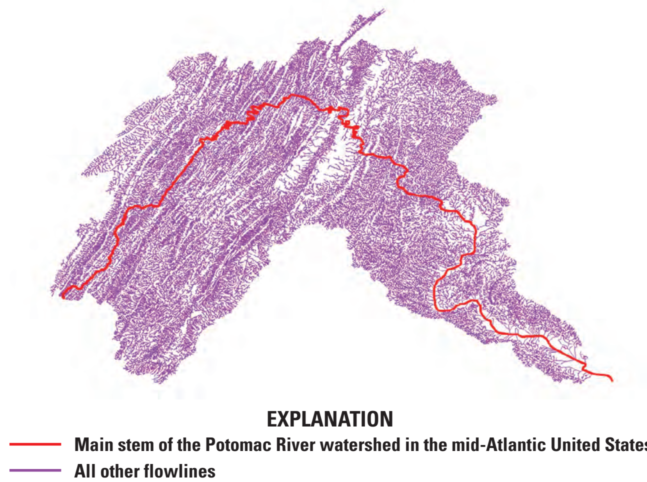


Figure 19. The Potomac River watershed as represented in the National Hydrography Dataset Plus (NHDPlus) High Resolution where the mainstem of a river has been set to LevelPathI=A; the main stem of the river is highlighted in red, and the tributary drainages of the selected river (TerminalPathID=B) are shown in purple. In this example, the value selected for A= is the hydrosequence number (HydroSeq field) of the terminal flowline of the Potomac River within the mid-Atlantic region and B = is the hydrosequence number (HydroSeq field) of the terminal flowline of Chesapeake Bay in a VPU downstream of the Potomac River.

Example 3. Profile Plots

Plots of elevation data along a river where the x axis is the river mile (or river kilometer) can be used for showing data and modeling results (fig. 20). The NHDPlus HR value-added attributes contain the basic information to readily develop such profile plots. In addition to the LevelPathI that can be used to identify every flowline on a river, the PathLength value-added attribute can be used to show the length from the downstream end (bottom) of the NHDFlowline feature to the end of the network. For instance, every flowline in the Missouri River drainage basin has a PathLength value that describes how far away the endpoint of the flowline is from the point for the mouth of the Mississippi River.

In accordance with basic profile-plotting procedure, select the NHDFlowline features by using the LevelPathI for the river of interest, and assign a data value (for example, a modeling result) by using the NHDPlusIDs as the join item of the selected NHDFlowline features and the model data. By including the value-added attribute PathLength in the dataset, the PathLength data can be used as the x-axis values, and elevation data values (MinElevSmo) as the y-axis values, to plot the profile of the river.

Figure 20 uses the NHDPlusFlowlineVAA.PathLength (distance to network terminus) attribute of the main stem of a river as the x-axis and the NHDPlusFlowlineVAA.MinElev Smooth (minimum smoothed elevation) attribute as the y-axis. The elevation-change point near PathLength 180 is where the selected river changes from free-flowing to estuarine.

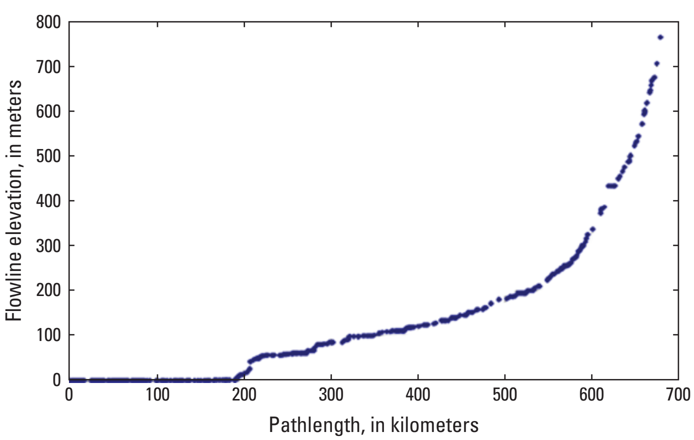


Figure 20. An elevation-profile plot of the main stem of a hypothetical river in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

Example 4. Stream Order

The NHDPlus HR stream order is based on a modification of the Strahler method (Strahler, 1957). Stream order is used to rank streams according to relative size or position in the network. Mapping or classifying NHDFlowline features based on stream order can assist with ranking features by relative size within the network, selecting streams of only certain orders, or aggregating data by stream order.

Figure 21 shows the use of different color shades for each stream order for a selected area (in this example, the Potomac River watershed). The use of shades of blue may show how stream order can help rank streams by relative size. Figure 22 shows the same area but with streams of stream-order 1 removed. This is one method to "thin" the network based on the criterion of hydrologic stream order.

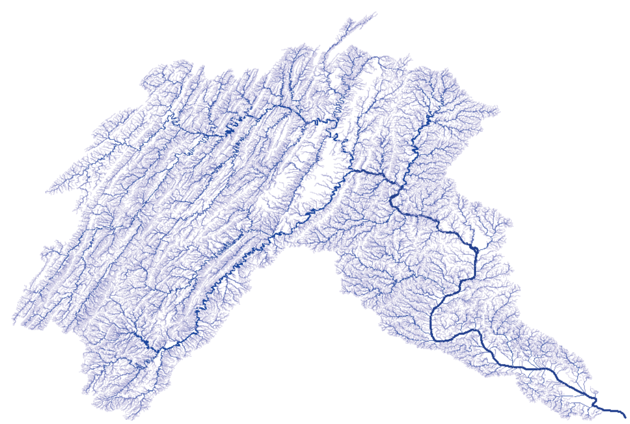


Figure 21. Streams of different stream orders shown in the National Hydrography Dataset Plus (NHDPlus) High Resolution for the Potomac River watershed in the mid-Atlantic region of the United States. The rankings of streams are symbolized by the thicknesses and shades of blue, with the streams of higher order represented by dark blue.

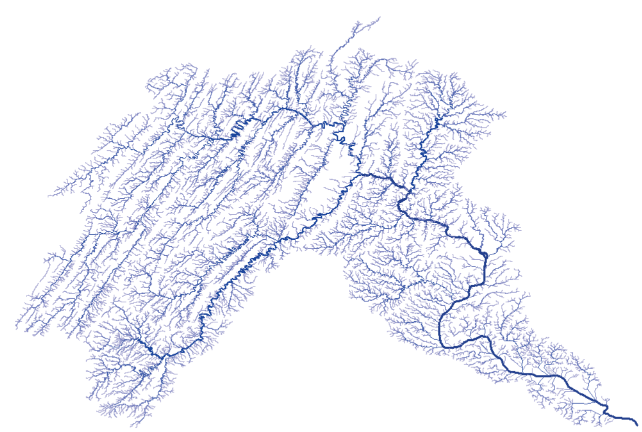


Figure 22. Streams of different stream orders in the Potomac River watershed in the mid-Atlantic region of the United States as depicted in the National Hydrography Dataset Plus (NHDPlus) High Resolution with streams of stream order 1 removed.

Example 5. Stream Level

The StreamLevel value-added attribute is often misunderstood or misused by users. Users commonly think of stream level "as the opposite of stream order", which is incorrect. Stream level has nothing to do with relative stream size.

The primary use of stream level is to distinguish the main stem from the tributary streams based on the inflows immediately upstream from the selected stream segment (fig. 23). The stream level assigned the lowest value is the main stem, and the higher stream-level values are assigned to the tributaries. For example, StreamLevel 1 would apply to the Mississippi River main stem but also to every stream, regardless of length or volumetric flow rate, that terminates on a coastline. In figure 23, the flowlines are labeled with the StreamLevel values. The NHDFlowline feature in the north-south direction is StreamLevel 2, and the feature coming in from the west is StreamLevel 3. Therefore, the north-south feature is the main stem, and the feature coming in from the west is the tributary.

Differences Between Flow Estimates from EROM and Gage-Reported Streamflow

EROM is a technique for computing mean streamflows. (Computation of mean annual flow estimates by EROM is included in "Step T—EROM Flow Estimation, Flow QAQC, and Jobson Velocity Estimation" in the "NHDPlus HR Build/Refresh Process Description" section of this report.) This discussion is intended to address why the EROM gage-adjusted flow estimates (NHDPlusEROMMA.QE) may not match the flow reported at a given gage location.

To adjust the flow based on gage flows, EROM screens gages based on the number of years of record, the period of record, and a comparison of the NWIS-reported drainage area with the NHDPlus-calculated drainage area. Only gages that pass the screening are used in the gage-adjustment process of EROM. Consequently, if a gage does not pass the screening criteria, the EROM flow estimate may differ from the gage flow measurement.

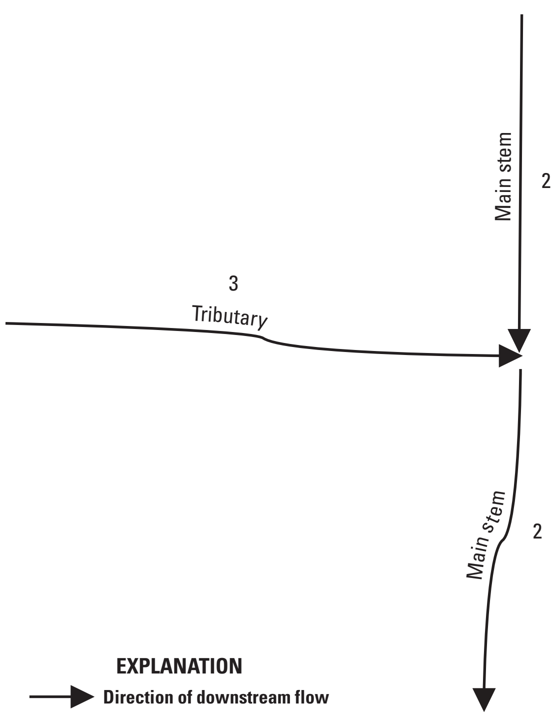


Figure 23. The StreamLevel values in the National Hydrography Dataset Plus (NHDPlus) High Resolution at a flowline junction where the main stem of a stream converges with a tributary flowing in from the west. In StreamLevel values, the lowest values refer to the main-stem rivers and the higher values to the tributaries.

NHDPlus HR Build/Refresh Process Description

This section of this report is intended for NHDPlus users who require more detailed information on the inner workings of the database to see how NHDPlus HR data are created and gain a greater understanding of NHDPlus HR and its strengths and capabilities. The Build/Refresh process (fig. 24) consists of a single application, called HRNHDPlusBuildRefresh, which creates and manages the workflow of steps necessary to execute the Build/Refresh process. Additional setup and help tools are implemented by using an ArcGIS toolbox. Each run of the Build/Refresh process produces one VPU of NHDPlus HR data.

Step A—Prepare the NHD and WBD Data

This step builds a workspace that contains the appropriate NHD and WBD data. The data are put into a structure suitable for NHDPlus processing. If this is the first VPU to be processed in the drainage area, the HRNHDPlusGlobalData.gdb is configured for a drainage area. For this step, a script creates a file-geodatabase (.gdb extension) step to contain the spatial definition of the drainage area and the divisions of the drainage area that define the VPU. The created geodatabase file also contains the overall hydrologic sequence of VPUs (upstream to downstream) and the specifics of how and where the VPUs connect to each other. During this step, a final quality-assurance and quality-control (QAQC) check is done on the NHD data and, if necessary, minor edits are made to the NHD data.

Step B—Prepare the NHDPlus-HR Workspace

In this step, the workspace created in step A is modified. The initial geodatabase created from the NHD and WBD data is transformed into the NHDPlus HR geodatabase. NHDPlusIDs are assigned as needed. The upstream and downstream VPU connections are stored in the NHDPlusGlobalData table.

Step C—Build Network Value-Added Attributes (Part 1)

This step partially populates the NHDPlusFlowlineVAA table. The first 10 value-added attributes are calculated. The value-added attributes are populated from the contents of the NHDPlusFlow table and the NHDFlowline feature class.

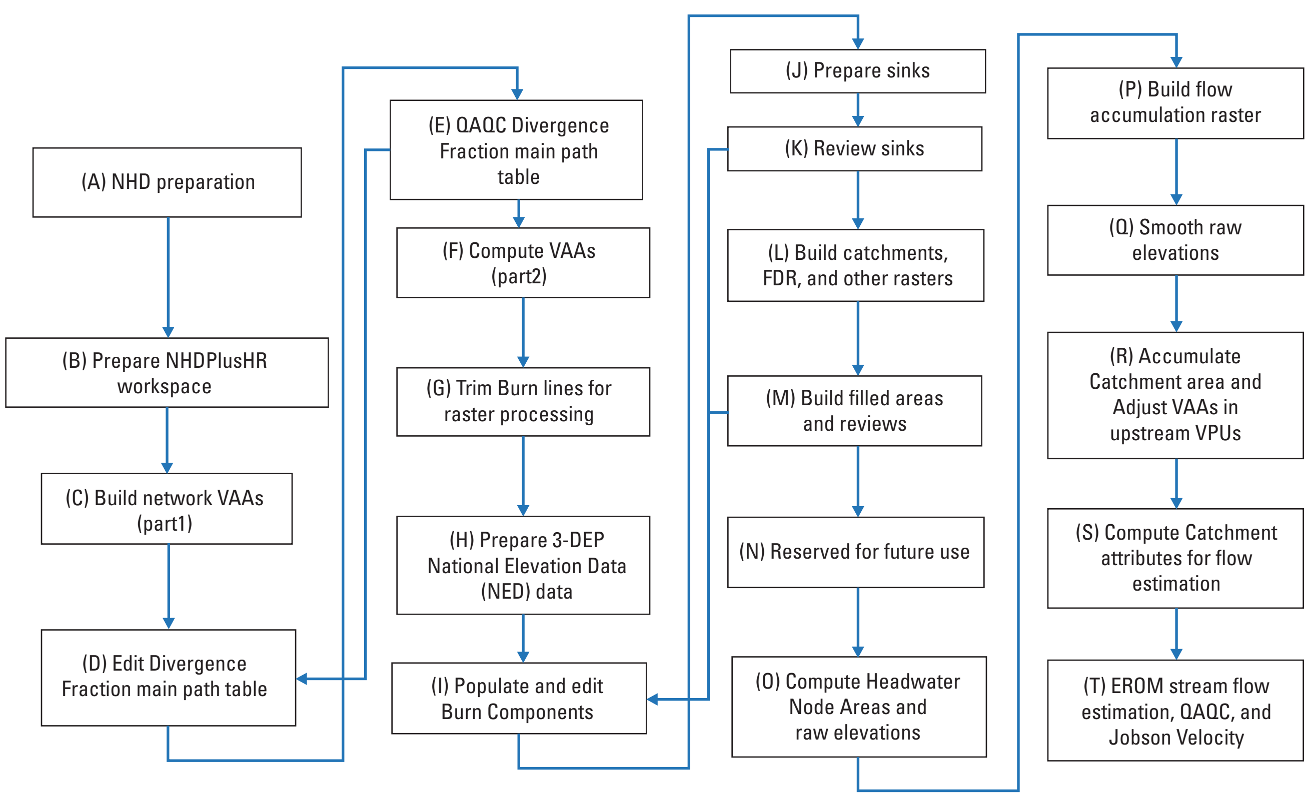


Figure 24. The workflow for the Build/Refresh process of the National Hydrography Dataset Plus (NHDPlus) High Resolution (NHDPlusHR). VAAs, value added attributes; QAQC, quality assurance and quality control; 3DEP, 3-Dimensional Elevation Program; NED, National Elevation Dataset; FDR, flow-direction raster; EROM, enhanced unit runoff method.

The value-added attributes are calculated only for NHDFlowline features with NHDFlowline.InNetwork = "Yes". The following value-added attributes are populated in this step:

- Frommeasure: Set to the m-values at the bottom (downstream end) of the NHDFlowline feature.
- Tomeasure: Set to the m-values at the top (upstream end) of the NHDFlowline feature.
- Fromnode/Tonode: The Fromnode is the top (upstream end) of the NHDFlowline feature; the Tonode is the bottom (downstream end) of the NHDFlowline feature. A node is defined as one of the following:
  - One type of Fromnode is the top of an NHDFlowline feature that has a flow-table record with Direction = 712 (a headwater node).
  - One type of Tonode is the bottom of an NHDFlowline feature that has a flow-table record with Direction = 713 (a terminal node).
  - Other points serve both as a FromNode and a ToNode: The "point" of flow exchange represented by a flow-table record with Direction = 709 (a node between two or more NHDFlowline features). The node ID is stored as a ToNode for the upstream flowline and as a FromNode for the downstream flowline. Coastal flowlines also receive FromNode and ToNode values even though they do not pass streamflow.
  - Each node is given a nationally unique number (table 32).

Table 32. Values used for network nodes in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

Direction value	Network type
709	Within network
712	Network start
713	Network end
714	Nonflowing

- StartFlag: Set to 1 if the NHDFlowline feature has a NHDPlusVAA table record with Direction = 712 (headwater flowline), or if the Direction = 714 and the FromNHDPlusID = 0.
- TerminalFlag: Set to 1 if the NHDFlowline feature has a NHDPlusVAA table record with Direction = 713, or if the Direction = 714 (nonflowing) and the ToNHDPlusID = 0.
- VPUIn: Set to 1 if the NHDFlowline feature has a NHDPlusVAA table record with Direction = 709 or 714, and the FromNHDPlusID is not in the VPU.
- VPUout: Set to 1 if the NHDFlowline feature has a NHDPlusVAA table record with Direction = 709 or 714 and the ToNHDPlusID is not in the VPU.
- DnDrainCount: Set to the number of NHDPlusVAA table records where the NHDFlowline feature is the FromNHDPlusID and Direction = 709.
- ReachCode: Set to NHDFlowline.ReachCode of the NHDFlowline feature.

Step D—Edit Divergence-Fraction Main Path Table

During step D, the DivFracMP table is edited (manually, in ArcMap, when necessary) to specify main paths at points of flow divergence. If gaged-streamflow data are available, the DivFracMP table may also be manually entered to specify the percentage of streamflow that flows down each of the divergent paths.

Step E—QAQC Divergence-Fraction Main Path Table

Step E is an automated QAQC process that confirms that the sum of the divergence fractions for a given divergence (the set of DivFracMP records with the same NodeNumber) is 1.0.

Step F—Compute Value-Added Attributes (Part 2)

Step F completes the value-added-attribute computation task started in step C. Each value-added attribute is computed and compared with other value-added attributes to confirm that the value-added attributes are internally consistent. For step F to be considered successfully completed, all value-added attributes must pass their respective comparison checks. For the remainder of this section, only NHDFlowline features with InNetwork = "Yes" are assigned value-added attribute values. The following value-added attributes are populated:

- *Divergence*: Divergence is a flag that distinguishes between the main and minor paths at a network-flow split. At a network split, one NHDFlowline feature is designated as the major path (Divergence = 1), and all other paths in the split are designated as minor paths (Divergence = 2). All features that are not included in a flow split have Divergence = 0. Divergence always agrees with StreamLevel. This agreement ensures that upstream and downstream movements along the main path give the same navigation results. The main path at a flow split is selected from the outflowing NHDFlowline features that include these attributes:

  1. an NHDFlowline feature that is part of a series of consecutive flowlines that share the same name and ultimately flows to a coast and has an FType (feature type) of StreamRiver, Artificial Path, or Connector; otherwise,

2. an NHDFlowline feature that is part of a series of consecutive flowlines that does not ultimately flow to a coast and has an FType of StreamRiver, Artificial Path, or Connector; otherwise,
3. an NHDFlowline feature in the DivFracMP table that has a positive Divfrac value that is the maximum such value at the divergent node; otherwise,
4. any named stream, river, artificial path, or connector that ultimately flows to a coast; otherwise,
5. any unnamed stream, river, artificial path, or connector that does not ultimately flow to a coast; otherwise,
6. any named canal, ditch, or pipeline that ultimately flows to a coast; otherwise,
7. any NHDflowline feature that ultimately flows to a coast; otherwise,
8. any named stream or river, artificial path, or connector that does not ultimately flow to a coast; otherwise,
9. any unnamed stream or river, artificial path, or connector that does not ultimately flow to a coast; otherwise,
10. any named canal, ditch, or pipeline that does not ultimately flow to a coast; otherwise,
11. any flowline that does not ultimately flow to a coast.

If there is more than one NHDFlowline feature that matches the criterion or the rule, the one with the lowest NHDPlusID value is selected.

- *ArbolateSum*: The computation of ArbolateSum starts at the headwaters of the NHDFlowline network. The NHDFlowline.LengthKM is added along the network, so that each feature has an ArbolateSum of its length plus the length of every upstream feature.
- *StreamLevel*: StreamLevel is a numeric code that traces main paths of water flow upstream through the drainage network. The determination of StreamLevel starts at the terminus of a drainage network. If the terminus stops at a coastline NHDFlowline feature (at the Atlantic Ocean, the Pacific Ocean, or the Gulf of Mexico), a stream level of 1 is assigned to the terminus and all the NHDFlowline features in the main path upstream to the headwater of the stream. If the terminus drains into the ground or stops at the Canadian or Mexican border, a stream level of 4 is assigned to the terminus and all the NHDFlowline features in the main path upstream to the headwater of the stream. After the initial stream level of 1 or 4 is assigned to the terminus and its upstream path, all tributaries to that path are assigned a stream level equal to 1 plus the stream-level number assigned to the path of the stream into which it flows (the terminus and its upstream path). Then the tributaries to those stream paths are assigned a stream level incremented by 1. This continues until the entire stream network has been assigned stream levels. If possible, StreamLevel follows a named path. In other words, at any confluence, if there is an NHDFlowline feature immediately upstream with the same name, that feature is selected as the main path. If there is no matching name immediately upstream, the NHDFlowline feature with the maximum ArbolateSum value is selected. To ensure agreement with Divergence, StreamLevel assignment does not follow a minor path at or downstream of an NHDFlowline feature with Divergence equal to 2.
- *HydroSeq*: HydroSeq is a nationally unique sequence number that places the flowline in hydrologic sequence. HydroSeq is calculated by assigning temporary sequential numbers from the headwaters of the NHDFlowline network to the downstream end of the network. To begin, each headwater is assigned a value. Next, all outflows from the headwater streams are assigned values. Then all outflows of the headwater streams are assigned values. This process continues until all network features have values. The features are sorted by descending values from the lowest values for upstream locations to the highest values for downstream locations, and the final HydroSeq values are reassigned in the reversed order (from downstream to upstream) sequence. The final HydroSeq values are smallest at the downstream end of the network and largest at the upstream end of the network (fig. 25). The primary characteristic of the HydroSeq value is that, if the features are processed by descending

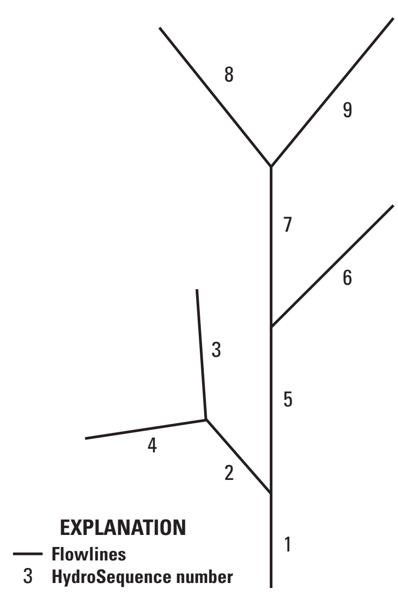


Figure 25. The order of assigning HydroSequence values in the National Hydrography Dataset Plus (NHDPlus) High Resolution. At any flowline, all upstream flowlines have higher hydrologic-sequence numbers, and all downstream flowlines have lower hydrologic-sequence numbers.

HydroSeq values (upstream to downstream), when any one feature is processed, all the features upstream of that feature have already been processed. Following this sequence is important for modeling purposes.

- *DnLevel*: DnLevel is the value of StreamLevel of the main path NHDFlowline feature immediately downstream of an NHDFlowline feature. If DnLevel ≠ StreamLevel, the stream is about to discharge into another stream pathway.
- *LevelPathI*: LevelPathI is set to the HydroSeq value of the most downstream feature on the river (fig. 26). For example, all the features along the Mississippi River have the same value for LevelPathI.

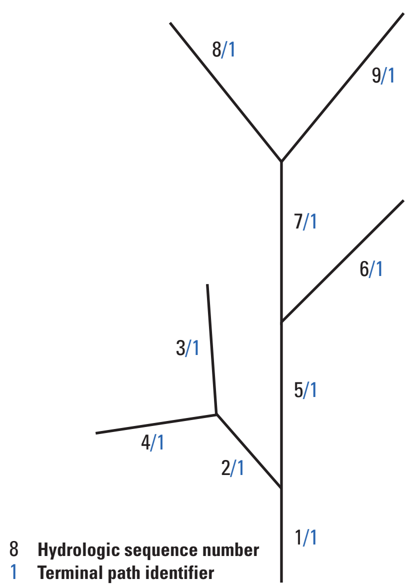


Figure 26. Ordering of level-path identifiers and their relations to level paths and hydrologic-sequence numbers in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

- *TerminalPathID*: TerminalPathID is set to the HydroSeq value of the most downstream feature in the drainage system; in other words, the HydroSeq of the network terminus will become the TerminalPathID of all the features that flow to that terminus (fig. 27). [Note: A drainage system can contain multiple VPUs.] For example, all the features that flow to the mouth of the Delaware River will have the same value for TerminalPathID.
- *UpLevelPathID*: UpLevelPathID is the LevelPathI of the main path NHDFlowline feature immediately upstream of an NHDFlowline feature.
- *UpHydroSeq*: UpHydroSeq is the HydroSeq value of the main path NHDFlowline feature immediately upstream of an NHDFlowline feature.
- *DnMinorHydroSeq*: When there is a flow split at the downstream end of a feature, DnMinorHydroSeq is the HydroSeq value of a minor path in that divergence. If there is more than one minor path in the divergence, DnMinorHydroSeq is set to the HydroSeq value of the path with the lowest NHDPlusID value.

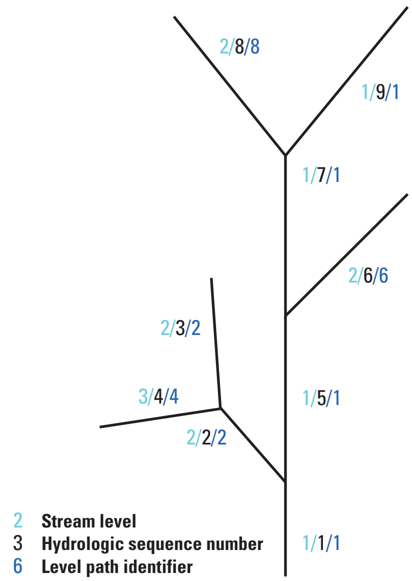


Figure 27. The ordering of terminal-path identifiers and relation to hydrologic-sequence numbers in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

- *PathLength*: PathLength is the sum of the NHDFlowline.LengthKM downstream values for each flowline along the main path to the terminus of the network. For example, the PathLength of the mouth of the Missouri River will be the distance to the mouth of the Mississippi River.
- *RTNDivergence*: RTNDivergence is the returning divergence and is set to 1 when one or more of the paths from a split in an upstream flow return to the network at the upstream end of the NHDFlowline feature.
- *StreamOrder and StreamCalculator*: StreamOrder (fig. 28) in NHDPlus and NHDPlus HR is a modified version of stream order as defined by Strahler (1957). The Strahler stream-order algorithm does not account for flow splits in the network, whereas the algorithm used in NHDPlus and NHDPlus HR for stream order takes flow splits into consideration. The StreamCalculator value-added attribute is a modification of the StreamOrder value-added attribute. StreamCalculator is a variable created to assist with tracking divergences and is computed with StreamOrder. These value-added attributes are computed from upstream to downstream. The method used for assigning StreamOrder and StreamCalculator is as follows:
  - All headwater or "start" reaches are assigned a Strahler order of "1."
  - StreamCalculator is assigned the same value as StreamOrder for all headwater flowlines.
  - If there are no divergences, then StreamOrder and StreamCalculator have the same value; both values are increased in the manner defined for calculating the Strahler order.

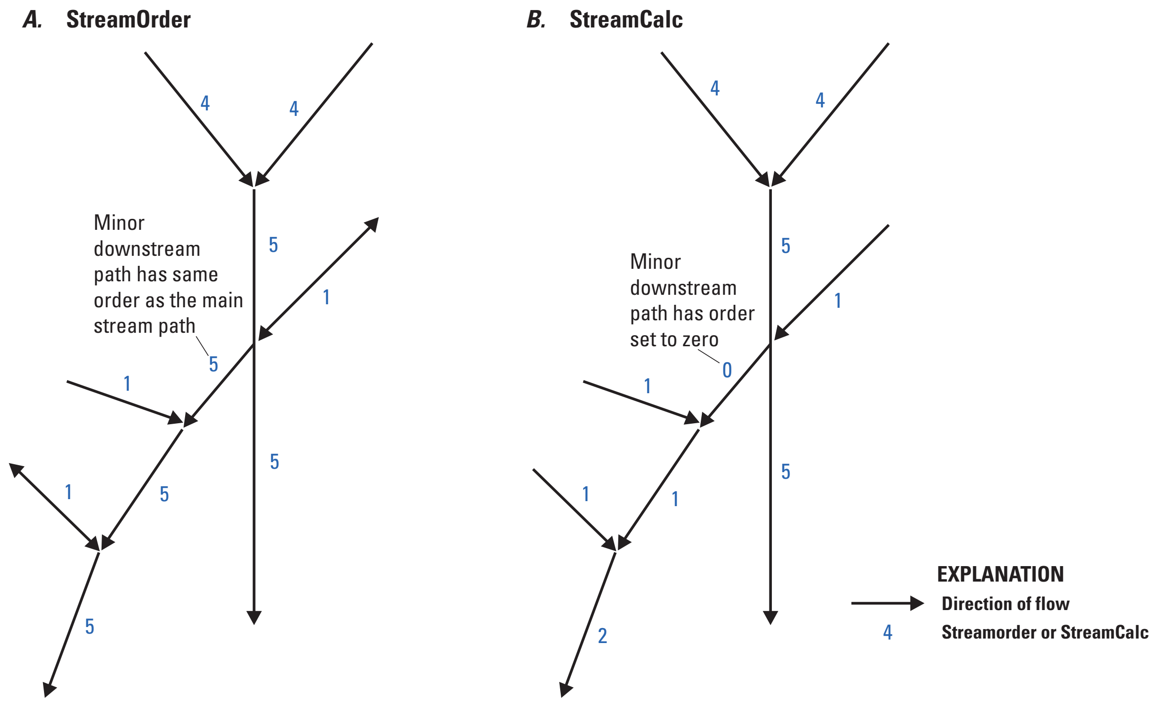


Figure 28. Ordering of the *A*, StreamOrder and *B*, StreamCalculator (StreamCalc) values in the National Hydrography Dataset Plus (NHDPlus) High Resolution. The StreamOrder value of a minor downstream path is the same as that of the main-stream path, whereas the StreamCalculator value of a minor downstream path is set to zero.

- When a divergence is reached, the defined main path (DIVERGENCE = 1) is assigned the same values for StreamOrder and StreamCalculator on the basis of the inflows to the divergence.
- The defined minor-path divergence (DIVERGENCE = 2) is assigned the StreamOrder value based on the inflows to the divergence, but StreamCalculator is assigned the value “0.” As the minor-path divergence continues downstream, the StreamCalculator value remains “0,” and the StreamOrder value cannot increase until the flowline is combined with another flowline that has a StreamCalculator value greater than 0. This sequence allows multiple minor-path divergences to intertwine without increasing the StreamOrder of the minor path.
- When two minor-path flowlines with StreamCalculator values equal to 0 and different StreamOrder values join, the larger StreamOrder value is maintained, and StreamCalculator remains equal to 0.
- Because StreamOrder cannot increase if StreamCalculator is equal to 0, when a minor path rejoins the main path, the main path StreamOrder value is maintained.

Step G—Trim Burn Lines for Raster Processing

In step G, the lengths of some features in the NHDBurnLineEvent feature class are shortened to improve the hydroenforcement process. To avoid the possibility that headwater features will cut through the ridge lines in the elevation data, the headwater features are trimmed by 100 m. To ensure that the NHDPlus HR flow-direction rasters (more information in the “fdr.tif” section in this report) follow the main paths at flow divergences, the minor paths of divergences are also trimmed or shortened by 100 m.

Occasionally, a headwater feature or a minor divergent-path feature is shorter than 100 m; such features are removed entirely from the NHDPlusBurnLineEvent feature class. Features removed from the NHDPlusBurnLineEvent feature class are not included in NHDPlus HR raster processing, are consequently not hydroenforced into the DEM, and do not receive catchments. When these features are headwater features, they will not have values for the attributes that depend upon the raster processing, such as endpoint elevations, slope, headwater-node area, and flow estimates.

Step H—Prepare Elevation Data

The purpose of step H is to extract, project, and prepare elevation data from a snapshot of 3DEP DEM. The outputs of this tool are written to the NHDPlus HRRasters<vpuid> raster folder. They include elevation data (elev_cm.tif) in centimeters NAVD 88, a shaded relief raster (shdrelief.jp2), and a file geodatabase containing two polygon feature classes: the elevation- dataset clip extent (elev_clip) and metadata (source information; elev_meta) polygons.

Step I—Populate and Edit Burn Components

In step I, the vector ingredient datasets that will be used in hydrologic conditioning in step L are prepared. This step includes a series of batch processing tools and requires interactive editing and verification steps. New in NHDPlus HR, these tools are called "helper tools" because they assist the developer user in in the creation of NHDPlus data. The processes that make up step I are as follows:

Create workspace and prepare feature classes.—The first helper tool ("Create Features") is the starting point for the processing of step I. This tool creates a workspace for editing features in this step. Copies of the datasets to be used in hydroenforcement (NHDPlusWall, NHDPlusBurnLineEvent, NHDPlusBurnWaterbody, NHDPlusSink, NHDPlusAddLine, and NHDPlusAddWaterbody feature classes) are added to the workspace. The feature classes are prepared for later step I processing, and field values are assigned for later use in hydroenforcement (step L); for example, NHDPlusBurnLineEvent features are assigned Burn = "Y" for elevation burning and Catchment = "Y" for watershed seeding. Other field values are populated for use in the data review step ("Find and Resolve Stream-Wall Conflicts"). The NHDPlusBurnAddLine features that flow in and out of the VPU are identified. If the VPU is being refreshed from a previous run of the NHDPlus HR process, previous Burn and Catchment assignments are preserved, and NHDPlusSink assignments where flow ends (for example, karst sink holes) are copied from the previously processed workspace to the step I editing workspace. A map document that includes symbols and explanations is created to facilitate editing.

Tag exit walls for empty HUC12s.—In this step, HUC12 polygons in WBD_HUC12 that are not closed basins (as identified by the WBD ToHU field) and include no NHDPlusBurnLineEvent features are identified. HUC12s that meet these criteria are termed "empty HUCs" and lack any NHDFlowline connection to drain these areas correctly in the HydroDEM. These HUC12 polygons are automatically identified when the Create Features tool is run.

Once the empty HUC12s are identified, the WBD attribute ToHU in the polygon data is used to determine whether or not a downstream HUC12 is identified. If it is, then the NHDPlusWall line feature between the empty HUC12 and its identified downstream neighboring HUC12 has the Burn field set to "N" to prevent the empty HUC12s downstream wall line from being included in hydroenforcement, allowing the flow to pass from the empty HUC12 to the next one downstream (or locally the other way). The flow is defined in the flow-direction and flow-accumulation rasters (fdr.tif and fac.tif).

Find and resolve stream-wall conflicts.—The initial Create Features tool compares all NHDPlusBurnLineEvent features with the VPU boundary and finds and stream-wall conflicts, which can be interactively resolved. The tool also sets the value of the EDGE field to the following values:

- "Y" if the feature crosses the VPU wall and is a headwater flowline,
- "X" if the feature crosses the VPU wall but is not a headwater flowline,
- "O" if the feature is entirely outside the VPU, and
- "I" if the feature is entirely inside the VPU.

Based on these codes, Burn and Catchment values are assigned to each NHDPlusBurnLineEvent feature to eliminate conflicts. These automated choices may be reviewed interactively and modified if necessary.

In NHDPlus HR, most waterbodies used in hydroconditioning are treated as areas where the raster representation of the waterbody is assumed to pass water downstream; however, especially in karst or arid areas, some waterbodies are treated as "sinks" where surface-water flow stops. In step I, this is accomplished by using a feature-class attribute called PurpCode (purpose code). Waterbodies coded as playa features in the NHD are automatically tagged as playa sinks (PurpCode = "SP"). In addition, other waterbodies may be tagged PurpCode = "SC" (closed lakes) in step I. Many of the waterbodies tagged as closed lakes are in arid areas and are located over the internal drainage points of noncontributing (closed) HUC12 polygon areas. (Many of these closed HUC12 polygons are named for the waterbodies and playas that cover their internal drainage point.) In locations where a waterbody covers a HUC12 drainage point, assigning closed lakes prevents the entire HUC12 polygon from filling up in the hydroconditioning process.

Other sink-point locations are directly created in step I to stop flow in the hydroconditioning process. For example, a closed HUC12 that does not have a playa or lake waterbody at its internal drainage point may require that a topographic-depression sink be placed there. These sink points are tagged with PurpCode values designating what they represent (for example, SD for topographic depression or SK for karst sinkhole).

Create burn components for international areas (if applicable).—For VPUs along international borders, hydrographic data from Canadian or Mexican sources are included in the NHDPlus HR burn components NHDPlusBurnAddLine and NHDPlusBurnAddWaterbody. In some cases, these international data sources contribute part of harmonized (international) high-resolution NHD data, whereas other sources are datasets available from Canadian or Mexican agencies such as the National Hydrographic Network (NHN) of Canada (Government of Canada, undated). Additional hydrography is included in the NHDPlus HR to improve catchment delineations in locations where NHDFlowline features receive contributing drainage from international areas. In some noncontributing areas for which information is known, lake polygons in international areas are coded as closed lakes.

Add Burn Components at inter-VPU connections (if applicable).—Wherever VPUs are connected (whether as an inflow to or outflow from an adjacent VPU), the connecting NHDPlusBurnLineEvent features from the adjacent VPU are added to the NHDPlusBurnAddLine feature class of the VPU being processed; this addition ensures that catchment delineations for the VPU being processed are constrained by the adjacent VPU flowlines. In addition, flowlines are needed in the NHDPlusBurnAddLine feature from downstream-associated VPUs to ensure proper hydroenforcement of the DEM. All downstream VPU flowlines are selected to extend to the edge of the DEM. Waterbodies from the adjacent VPUs are integrated into NHDPlusBurnAddWaterbody if features are at or near the connection areas between the VPUs.

Create NHDPlusLandSea polygons (for a coastal VPU).—The NHDPlusLandSea feature class is created by using the NHD coastline features. A buffer polygon area is created for each side of the coastline: a polygon for the land side and a polygon for the ocean side. Estuary polygons are optional features that can be created where they are desired or needed to separate coastal bays from the ocean polygon areas. Separate polygons for each estuary would be useful for estuarine studies that use the NHDPlus HR network.

Prepare burn components.—This is a tool that is run to erase nonconnecting NHDPlusAddLine and NHDPlusAddWaterbody features and set required fields (Burn, Catchment, RPUID, VPUID) in the temporary-sink feature class. The prepared datasets are added to the map to verify that the process ran correctly.

Update VPU workspace.—Running this tool is the final step in the step I process. This tool copies NHDPlus HR data back to the production workspace so that the data can be used in the subsequent steps.

Step J—Prepare Sinks

Step J is an automated step that creates sink points from disconnected line features and polygon features (playas, closed HUC12 polygons with no sinks or flow features). This step also assigns a unique identifier (NHDPlusID) to all non-NHD-derived burn components (including point sinks created in step I).

Create NHDPlusIDs for new features.—This automated step populates NHDPlusIDs for all features lacking an identifier (ID). These features include NHDPlusAddLine and NHDPlusAddWaterbody features inside the VPU and any new manual sinks created in step I.

Populate OnOffNet for NHDPlusBurnWaterbody features.—To create more realistic catchments, waterbodies on and off the network are handled differently in the creation of the hydrologically conditioned DEM (HydroDEM). For this reason, the OnOffNet fields in the NHDPlusBurnWaterbody and NHDPlusBurnAddWaterbody feature-class tables are populated. OnOffNet is used to differentiate waterbodies that intersect a **burn line** from either the NHDPlusBurnLineEvent or the NHDPlusBurnAddLine feature class. Only features in NHDPlusBurnLineEvent feature class with a “Burn = Y” are used in the spatial-intersect selection. All features in the NHDPlusBurnAddLine feature class are used in the spatial-intersect selection with the NHDPlusBurnWaterbody and NHDPlusBurnAddWaterbody feature classes. Any waterbody that intersects a burn line or is a playa or lake is coded as “1” in the field OnOffNet. The hydroenforcement process for these features in step L is different from that for waterbody features that do not intersect burn lines or are identified as closed lakes or playas (OnOffNet = 0).

Create derived sink features.—Derived sink features are created for the following scenarios:

- *Ends of isolated networks.*—Network ends are identified by finding NHDPlusPlusFlow records that have Direction = 713 (tables 16 and 32). Sinks are created for the corresponding NHDPlusBurnLineEvent feature’s most downstream point. These NHDPlusSink features are assigned the following values:
  - PurpCode = “SE” (network end)
  - SourceFC = “NHDFlowline”
  - FeatureID = “NHDPlusID” of the “NHDPlusBurnLineEvent” feature
  - The value for the InRPU field of the network-end feature (identifying the RPU in which the feature is located) is carried over from the InRPU field of the NHDPlusBurnLineEvent feature.
- *Sinks near flowlines.*—Sinks are removed if they are within two cells (this is a parameter for step J) of an NHDPlusBurnLineEvent or NHDPlusBurnAddLine feature that is not associated with the isolated network.
- *Nonspatially connected network ends.*—These ends are identified from the NHDPlusFlowline table where the values in the field GapDistKM exceed 0.03 km. The InRPU value is carried over from the NHDPlusBurnLineEvent feature into the InRPU field in the NHDPlusSink feature class table. These NHDPlusSink features are assigned the following values:
  - PurpCode = “SN” (nonspatial connection)
  - SourceFC = “NHDFlowline”
  - FeatureID = “NHDPlusID” of the “NHDPlusBurnLineEvent” feature
- *BurnWaterbody playas.*—Create sinks at the centroids of polygon features in the NHDPlusBurnWaterbody

feature class that are classified as playas (36099<FCODE<36200). These playa-sink polygon features are assigned the following values:

- PurpCode = "SP" (playa)
- PurpDesc = "NHD Waterbody Playa"
- SourceFC = "NHDWaterbody"
- FeatureID = NHDPlusID of the NHDPlusWaterbody feature that the sink represents
- The value of the InRPU field is set by using a spatial-overlay intersect with the RPU polygons in the NHDPlusHRGlobalData\NHDPlusBoundaryUnit feature class

- *BurnWaterbody closed lakes.*—Create sinks at the centroids of polygon features in the NHDPlusBurnWaterbody feature class that were tagged as closed lakes in step I. These NHDPlusSink features are assigned the following values:
  - PurpCode = "SC" (closed lake)
  - PurpDesc = "NHD Waterbody closed lake"
  - SourceFC = "NHDWaterbody"
  - FeatureID = "NHDPlusID" of the "NHDPlusWaterbody" feature that the sink represents
  - The value of the InRPU field is set by using a spatial-overlay intersect with the RPU polygons in the HRNHDPlusGlobalData\NHDPlusBoundaryUnit feature class
- *NHDPlusBurnAddWaterbody playas.*—Create sinks at the centroids of polygon features in the NHDPlusBurnAddWaterbody feature class that are classified as playas (FCODE>36099 and FCODE<36200). These NHDPlusSink features are assigned the following values:
  - PurpCode = "SP" (playa)
  - PurpDesc = "NHDPlusBurnAddWaterbody playa"
  - SourceFC = "NHDPlusBurnAddWaterbody"
  - FeatureID = "PolyID" of the "NHDPlusBurn AddWaterbody" feature that the sink represents
  - The value of the InRPU field is set by using a spatial-overlay intersect with the HRNHDPlus GlobalData\NHDPlusBoundaryUnit feature class
- *NHDPlusBurnAddWaterbody closed lakes.*—Create sinks at the centroids of polygon features in NHDPlusBurnAddWaterbody that are classified as closed lakes in step I. These NHDPlusSink features are assigned the following values:
  - PurpCode = "SC" (closed lake)
  - PurpDesc = "BurnAddWaterbody closed lake"
  - SourceFC = "NHDPlusBurnAddWaterbody"
  - FeatureID = "PolyID" of the "NHDPlusBurnAddWaterbody" that the sink represents
  - The value of the InRPU field is set by intersecting a spatial overlay with the HRNHDPlusGlobalData\NHDPlusBoundaryUnit feature class
- *Create sinks in closed HUC12 polygons (if needed).*—Closed (noncontributing) HUC12 polygons are coded in WBD as ToHU = "C" or ToHU = "CLOSED BASIN." If no sinks have been placed in these closed HUC12 polygons, sinks are placed at the minimum elevation point(s) within the HUC12. The DEM created in step H (elev_cm.tif) is used to determine the minimum elevation within a given closed HUC12. These NHDPlusSink feature-class fields are assigned the following values:
  - PurpCode = "SH" (closed HUC12 centroid or point of minimum elevation)
  - PurpDesc = "WBD_Closed HUC12"
  - SourceFC = "WBD_Subwatershed"
  - FeatureID = "NHDPlusID" of HUC12 polygon
  - The value of the InRPU field is set by using a spatial intersect with the HRNHDPlusGlobalData\NHDPlusBoundaryUnit feature class

Step K—Review Sinks

Step K is an opportunity to review the contents of the production workspace at this point in the process; however, as the NHDPlus HR process has developed, more and more of the preparation has become automated, so this step has become less necessary. For example, manual sink preparation has been moved to step I, and many automated checks and workflows in step I usually resolve issues before the process reaches step K; however, Step K provides a good opportunity to be sure that the sinks are properly placed to prevent erroneous results.

Step L—Build Catchments, Flow Direction, and Other Rasters

Step L processes burn components (flowlines and sinks, for example) created by the previous steps to create the HydroDEM and build raster flow-derivative datasets, including catchments for features in the NHDPlusBurnLineEvent and NHDPlusSink feature classes and sink features that are marked for catchment delineation (Catchment = "Y"). Raster catchments are converted to polygon features and added to the NHDPlusCatchment feature class.

Building Catchments

The general steps in preparing the input vector data from the NHDPlusBurnComponents folder are as follows:

1. *Assign GridCode values*.—GridCode values are unique sequential numbers used to identify catchments for raster processing. Positive GridCode values have a 1:1 match with NHDPlusIDs. GridCode values are assigned to all flowlines in the NHDPlusBurnLineEvent feature class and all sink points in the NHDPlusSink feature class. Sequential negative GridCode values are assigned to all features in the NHDPlusBurnAddLine feature class that are outside the VPU. All positive GridCode values are recorded with their corresponding NHDPlusIDs in the NHDPlusIDGridCode table in the production workspace.
2. Extract features from the NHDPlusBurnLineEvent feature class where Burn = "Y." Write selected records to a temporary TmpBurnLineEvent feature class.
3. Append all features from the NHDPlusBurnAddLine feature class to the TmpBurnLineEvent feature class. The TmpBurnLineEvent feature class is used in the stream-burning process (described in the "Stream-Burning Using the AGREE Method" section in the hydroenforcement part of this step) for hydrologic enforcement of the NHD streams and additional features from the NHDPlusBurnAddLine feature class.
4. Extract features from the NHDPlusBurnLineEvent feature class where Catchment = "Y." Write selected records to a temporary TmpCatchLine feature class.
5. Select features from NHDPlusBurnAddLine with GridCode greater than 0. Append selected features to the TmpCatchLine feature class, which will be used to generate catchments.
6. Combine waterbodies from the NHDPlusBurnWaterbody and NHDPlusBurnAddWaterbody feature classes and assign them to a temporary feature class. This temporary feature class will be used for hydroenforcement of all waterbody features.
7. Select features from the NHDPlusBurnWaterbody and NHDPlusBurnAddWaterbody feature classes for which OnOffNet = "1" and assign them to the temporary TmpWBodyOn feature class, which will be used for the processing of waterbodies according to bathymetric gradient.
8. Select NHDPlusSink features with Burn = "Y" for hydroenforcement.
9. Calculate STEP values for each TmpBurnLineEvent feature for hydroenforcement. STEP values are based on the values of the NHDPlus value-added attribute HydroSeq field and act like stairsteps defining the elevation of the bottom of the burned-in canyon representing the stream. The riverbed is calculated to decrease in elevation when features are traced from upstream to downstream. The STEP value is used to enforce raster flow to follow the vector-network flow from upstream to downstream.

Hydroenforcement

The next part of the process is to build the rasters for the HydroDEM for each RPU. Following is a general overview of the main raster-processing steps in building the HydroDEM for each RPU. The step is intended for future versions of NHDPlus HR to be repeated for each RPU of the VPU being processed. At present [2019], however, there is only one RPU comprising the VPU. The steps for processing the primary rasters are as follows:

1. Clip the VPU vector data to the RPU buffer area.
2. Assign negative GridCode values to the TmpCatchLine features that are inside the VPU but do not belong to the RPU being processed.
3. Convert all flowlines (NHDPlusBurnLineEvent and NHDPlusBurnAddLine) to rasters. The StreamLevel field from the NHDPlusVAA table is used to prioritize the vector-to-raster processing so that main-stem flowlines take precedence at confluences in the merge operation. This conversion ensures correct representation of the flowline network in the raster-data model.
4. Assign negative GridCode values for non-negative sink features that do not belong to the RPU being processed.
5. Convert all sinks to a raster by using GridCode values as the cell values.
6. Merge the sink raster with the NHD raster; the merged raster is the catseed.tif raster ("Raster Layers" section of this report) and the seed raster that is used as the source raster for catchment delineation.

To create a flow-direction raster that can be used to create catchments, the raster DEM is altered to force alignment with streams, waterbodies, sinks, and watershed divides through hydroenforcement. The different input-data features are enforced in the following ways:

Waterbody enforcement.—Certain waterbody features from the NHD were used in the HydroDEM enforcement process; these features include the Lake/Pond, Playa, and Reservoir features from the NHDWaterbody feature class and the Stream/River polygon features from the NHDArea feature class. Step 6 of the NHDPlus Build/Refresh process selects these features from both NHD feature classes and writes them to the NHDPlusBurnWaterbody feature class. In addition to NHD features in the BurnWaterbody feature class, any other waterbodies collected in the NHDPlusBurnAddWaterbody feature class are also enforced. For this processing, the features from both the BurnWaterbody feature class and the BurnAddWaterbody feature class are combined into a temporary waterbody feature class.

The waterbody enforcement is a two-stage process that improves catchment delineations near waterbodies. In this process, all the waterbodies are enforced by determining the minimum DEM elevation and by setting the overlapping waterbody cells in the HydroDEM to the minimum DEM value for each waterbody. The elevations of these cells are then decreased (dropped) by subtracting 100 m from the previously set minimum elevation values. Decreasing the elevations of the waterbodies ensures that these cells are well below the surrounding terrain. When the Fill process is applied to the HydroDEM (in the "Final HydroDEM, Catchments, Flow Direction and Accumulation, and Other NHDPlus HR Outputs" section of this step), the waterbodies will fill and drain to one location, the result of which will lead to better agreement with the catchment delineations in relation to these features.

The second stage process of the waterbody enforcement, termed "applying a bathymetric gradient" is the same process used in NHDPlus versions 1 and 2. The bathymetric gradient ensures that the catchments generated for artificial path flowlines within waterbodies are based on a gradient directed toward the artificial path flowlines (fig. 29). This process involves enforcement of just the waterbodies that intersect the flowline network (OnOffNet = 1) or have a sink within them.

Stream burning using the AGREE method.—Modifications were applied to the source DEMs (elev_cm.tif) to produce the HydroDEM. These modifications were considered necessary because often the drainage path (flow path) defined by the 3DEP DEM surface does not exactly match the 1:100,000-scale NHD (fig. 30*A*). In many cases, the NHD streams and 3DEP DEM-derived streams are parallel or offset from each other. If this offset distance is greater than one raster-cell width, then some cells may not be identified as being upslope from the NHD stream segment and therefore could be excluded from the delineated catchment in error (fig. 30*B*).

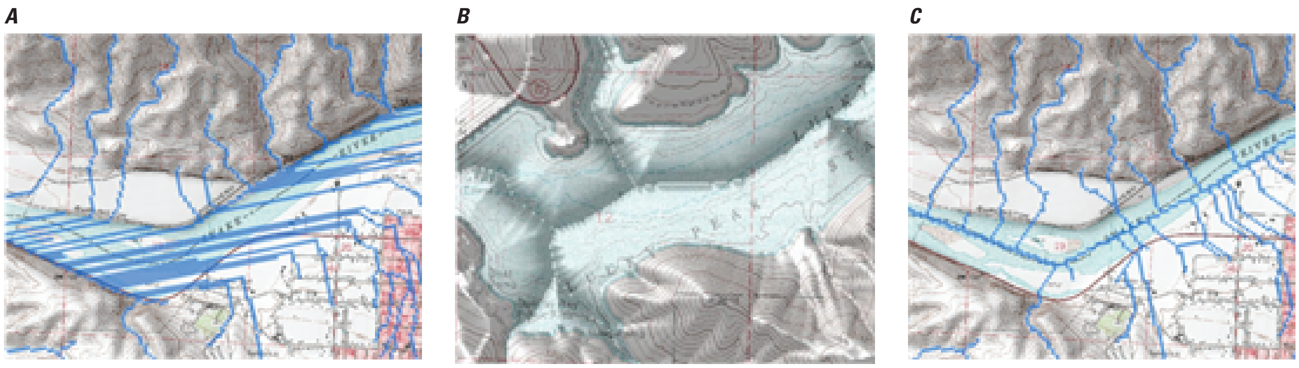


Figure 29. *A*, Flow-accumulation lines in a standard digital elevation model (DEM), *B*, bathymetric gradient of a waterbody, and bathymetry *C*, flow-accumulation lines determined based on bathymetric-gradient values in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

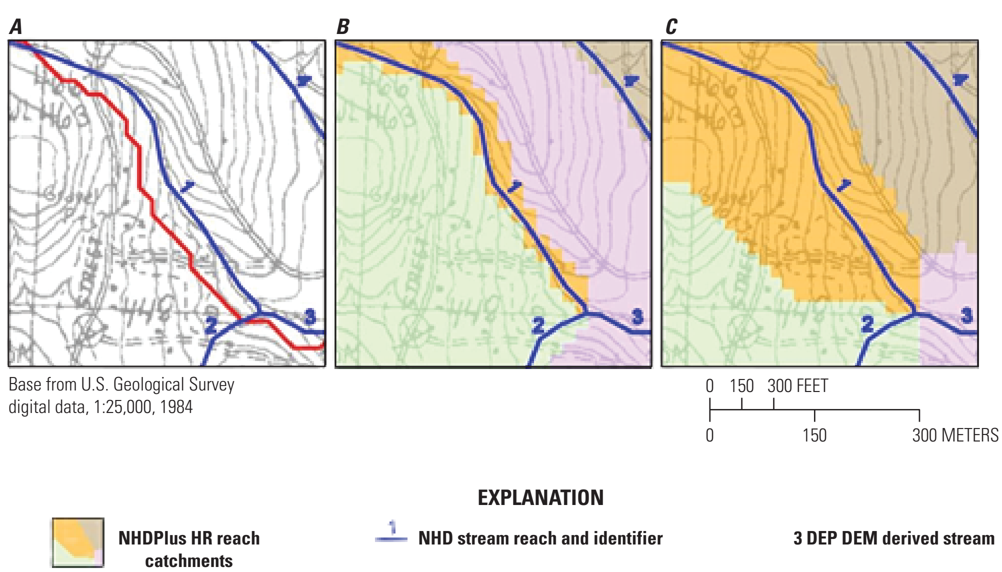


Figure 30. *A*, Displacement of a 3D-Elevation Program (3DEP) elevation model-derived stream from the National Hydrography Dataset (NHD)-delineated stream; *B*, errors in catchment delineations created by using unmodified 3DEP data, and *C*, NHD catchment delineations corrected by using AGREE-modified 3DEP data for the National Hydrography Dataset Plus (NHDPlus) High Resolution. AGREE is a program originally written in ARC Macro Language (AML), converted into Python, and incorporated into the NHDPlus catchment delineation process.

To mitigate this mismatch of stream locations, the NHD vector drainage was integrated into the raster 3DEP DEM data, often referred to as "**stream burning**" (Saunders, 2000). This process uses computer algorithms originally written in the AGREE Arc Macro Language (AML) program (Hellweger and Maidment, 1998). The algorithms are now run in Python using ArcGIS ArcPy commands. Figure 30*C* illustrates how the AGREE program corrects for DEM flow path displacement errors when delineating catchments.

AGREE follows a procedure called "burning a canyon" into the DEM created from the 3DEP-DEM-derived data by subtracting a specified vertical distance from the elevation of the NHD vector streamlines. AGREE was modified to control the elevation of the bottom of the canyon by the values determined from the HydroSequence field of the flowlines to ensure that the flow-direction raster points downstream. (Lower HydroSequence values equate to lower channel-bottom elevations.)

AGREE also smooths the elevations adjacent to NHD stream-cell locations in the DEM within a buffer distance specified by the user. Typically, the buffer distance is related to a common horizontal-displacement error between NHD and 3DEP-DEM-derived streams; this error is seldom exceeded. For HydroDEM production, the buffer distance was set to 60 m (six cell widths) on each side of the line of the NHD stream (fig. 31). The smoothing process changes the DEM raster-cell elevations within the buffer area to create a downward-sloping gradient toward the modeled canyon beneath the NHD streams. The steepness of the slope within the buffer is controlled by the AGREE "Smooth Drop/Raise Distance" option. For the HydroDEM, a smooth drop distance of 500 m was specified, with acceptable results.

The use of AGREE's 60-m-smoothing buffer distance of the NHD streams may cause potential problems at headwater flowlines because they begin at or near drainage divides in the DEM. The 60-m buffer distance at these headwater streams may extend across the DEM drainage divides and into the adjacent watershed, thereby including areas outside the actual catchment area.

To minimize the problem of extending headwater streams into adjacent watersheds, these headwater streams were trimmed back in step G of the NHDPlus Build/Refresh process ("Step G—Trim Burn Lines for Raster Processing" section of this report). In addition, headwater streams still in conflict with the divides of the WBD HUC12s in the NHDPlusWall feature class were trimmed back to remove 70 percent of their original length (during Step I of this NHDPlus Build/Refresh Process). The trimmed-back positions are noted in the ToMeas field of the NHDPlusBurnLineEvent table. These positions are retained in the NHDPlusBurnLineEvent feature class, whereas the NHDFlowline feature class remains unaltered.

Enforcement of WBD divides as walls.—A seamless nationwide network of the HUC12 drainage divides of the WBD are integrated into the HydroDEM as "walls" in the NHDPlusWall feature class. The process of conditioning DEM data to WBD drainage divides is called **walling**, which vertically

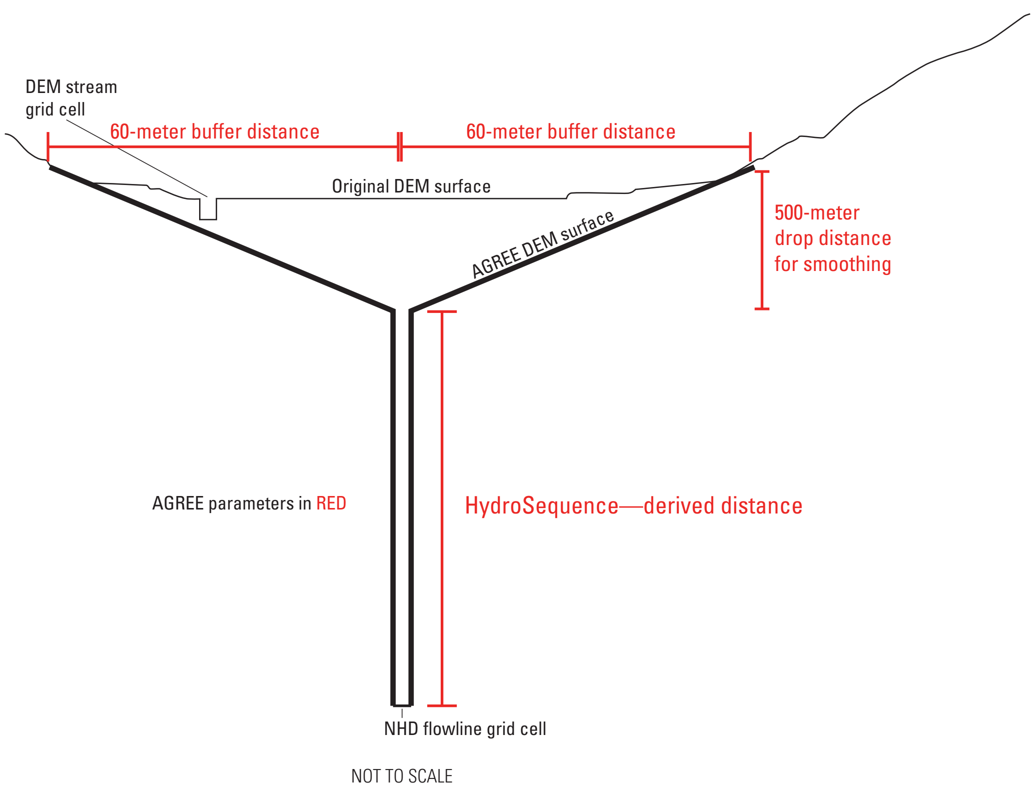


Figure 31. The modifications of a cross section of a digital elevation model (DEM) in the National Hydrography Dataset Plus (NHDPlus) High Resolution from the algorithms of the AGREE program for hydroenforcement. Modifications are shown in red. NHDPlusFlowline is the flowline feature class from the National Hydrography Dataset Plus.

exaggerates DEM elevations corresponding to the locations of WBD ridge lines (fig. 32). The vertical distance used to exaggerate the cells is a specified constant added to the elevation raster cells above the WBD. Breaks in the walls were created where the stream network crosses the WBD to ensure proper passage of water from one WBD HUC12 to another. A graphical three-dimensional (3D) representation of a hydrologically conditioned DEM with WBD walling and the NHD "burning" is shown in figure 32.

STEP elevations for flowlines.—Modified from the original AGREE process (Hellweger and Maidment, 1998), NHDPlus HR computes the values of the elevations of cells within the NHD stream channel by using the values of the NHDPlus value-added attribute HydroSeq to compute a unique elevation value for each flowline, thus creating a stepping sequence within the burned-in stream canyon from AGREE. This improvement enhances the ability of the HydroDEM flow path to follow the main-path navigation defined by NHDPlus and resolves issues that sometimes occurred with NHDPlus version 1 flow-direction rasters in which the Fill process forced uphill flow, into an adjacent RPU or VPU inflow connection. Although catchment delineations are unaffected by the flow directions of streams, the use of stepped values for the stream channels in NHDPlus HR greatly enhances the usability of the flow-direction raster for watershed delineations.

Enforcement along the NHD coastline.—Another feature of NHDPlus HR is the hydroenforcement of NHD coastline areas, which are in the NHDPlusLandSea feature class. In NHDPlus HR, the ocean areas within a buffer area of the NHD coastline have elevation values lower than any NHD feature on land. For coastal estuaries of interest, a two-tiered stepping process can be imposed in the HydroDEM to allow for DEM-based watershed delineation within an estuary to capture drainage to the estuary by selecting just one raster cell as the seed for the watershed delineation.

The new NHDPlusBurn component of the feature class NHDPlusLandSea is used for coastal enforcement. The enforcement is only applied for VPUs with NHD coastline. NHDPlusLandSea is a polygon feature class that typically contains two or three unique polygon categories coded in the field named "Land." The polygon coded as Land = 1 is used to resolve any disparity of landward elevations in the HydroDEM between the NHD coastline and the coastline defined by the 3DEP DEM. The ocean polygon (Land = -2) in the NHDPlusLandSea feature class is used to drop the surface elevation of ocean cells in the HydroDEM below the imposed elevations of the NHD coastline. Estuary polygons (Land = -1) are optional features along the coast for those bays where it is preferable to have the estuary polygons differentiated from the ocean cells. In the final HydroDEM, the estuary cells are 1 centimeter (cm) higher than the ocean cells and 1 cm lower than the lowest NHD coastline in the VPU. By using the NHDPlusBurnAddLine feature class, flow paths can be imposed onto the estuary- and ocean-elevation cells in the form of burned-in canyons to direct the drainage paths of these flows.

Enforcement of sink points.—For VPUs with sinks, the points are converted to a raster wherein a sink is represented by one raster cell. These sink cells are set to NoData in the HydroDEM so that drainage from the sinks flows to these points. Later, when the NHDPlusFlow direction raster is created, these NoData cell values are replaced with 0 (zero) values in the flow-direction raster to ensure their usability with point-based watershed delineation.

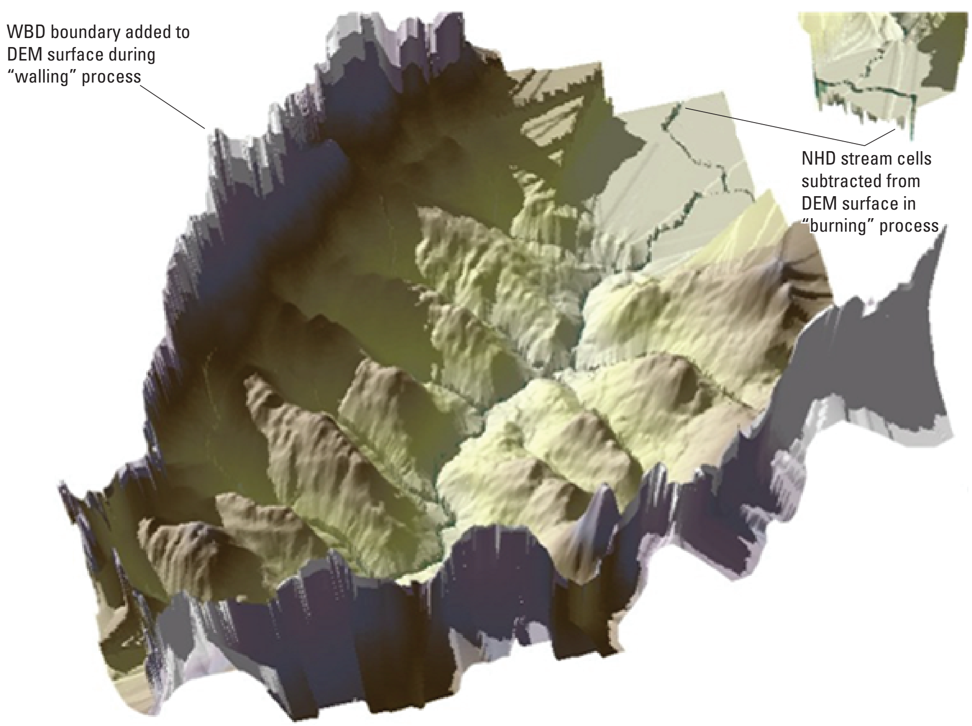


Figure 32. Perspective view of a modified digital elevation model (DEM) with "walling" of existing Watershed Boundary Dataset (WBD) boundaries and "burning" of National Hydrography Dataset (NHD) streams from hydroenforcement in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

Final HydroDEM, Catchments, Flow Direction, Flow Accumulation, and Other NHDPlus HR Outputs

After the NHDPlusBurn components are processed through the various hydrological- conditioning steps, the HydroDEM for each RPU is finalized by applying the Fill process. Fill is used to resolve any depressions in the DEM by “filling” these areas so that the cells drain to the lowest surrounding raster cells. All low points are filled except for those areas designated in the HydroDEM as “NoData” cell sinks. The HRNHDPlusRaster filldepth.tif shows cells raised by the Fill process and is available along with the HydroDEM data (hydrodem.tif) for each RPU.

From the final filled HydroDEM, the flow-direction and flow-accumulation rasters are written to each HRNHDPlusRasters<vpuid> folder. Flow-direction and flow-accumulation rasters represent cells and cell counts only within the RPU (or VPU since there is only one RPU per VPU at present [2019]); they do not include cells in upstream production units or buffer areas.

Another feature of NHDPlus HR is that there is a second version of this flow direction where the burned-in surface-water features (streams and waterbodies within the network) are replaced by NoData cells. This variant flow-direction raster is named fdroverland and is also written to the HRNHDPlusRasters<vpuid> folder. The fdroverland.tif raster can be used with the FlowLength function in the ArcGIS Spatial Analyst Toolbox to determine the overland flow-path length from each raster cell to a NoData stream, waterbody, or coastline. Flow-length rasters are useful for a variety of applications, including determining buffer areas on the banks of rivers or lakes.

The standard NHDPlus HR flow-direction raster (pointing to just one downstream direction) is used in conjunction with the NHDPlus HR catseed.tif raster to determine the catchments for the NHD flowlines and NHDPlus sinks. Catchments generated for flowlines or sinks can be determined by the FeatureID and SourceFC fields of the NHDPlusCatchment feature class. Positive values in the FeatureID field indicate catchments delineated for NHDFlowlines, whereas negative FeatureID values indicate sink-related catchments.

The data on catchments are available in raster format (cat.tif) and as a vector-polygon feature class (catchment). The vector polygon was created in Python by using ArcGIS’s Raster to Polygon tool. It is important to note that catchment features in a feature class may be made up of one or more vector-polygon features. Multiple polygon features occur because of the 10-m raster-cell resolution of the source and the raster-to-vector conversion process. In these situations, one or more cells with directional flow traveling diagonally into an adjacent cell along a catchment boundary may create a separate polygon in the vector-data model if these data are converted from a raster (fig. 33). These multiple polygons are merged, however, into a single multipart polygon, for each catchment.

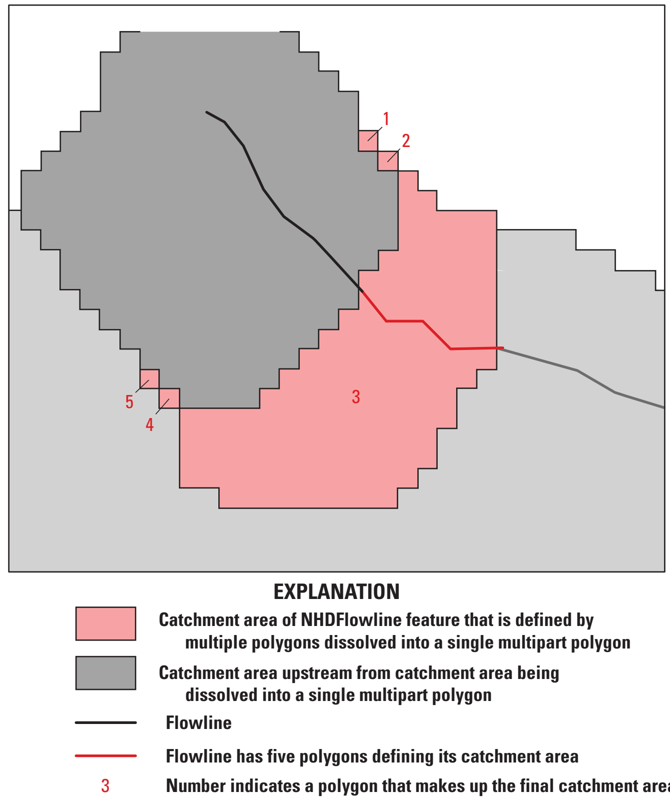


Figure 33. A multipart feature in pink defining a catchment area in the National Hydrography Dataset Plus (NHDPlus) High Resolution. The final catchment is represented by a single multipart polygon.

Step L also determines the minimum elevations in the NED (elev_cm.tif) for each catchment and writes out the values to the NHDPlusElevSlope table found in the NHDPlusAttributes folder. The minimum elevation of the catchment is assumed to be at the outlet of the catchment and thus is also the value used for the minimum elevation of the stream or river represented by the flowline. These minimum elevations are recorded as the flowlines’ minimum raw elevations in field MinElevRaw; smoothed elevations are created later in the process and recorded in the field MinElevSmo.

Step M—Build Filled Areas and Review

The output from the processing in step L is checked in an automated manner to verify the results:

- Verify that GridCode values were assigned for all burn components. This is a check for unanticipated data or software problems.
- Check for gaps in the catchment mask, area defining the catchments, ensuring that the catchments between RPUs are seamless. This is also a check for unanticipated data or software problems.

- Report any large filled areas to the user. If these are found, they usually indicate that a sink may have to be added, or changes to the burn components may have to be made. Large filled areas are not unusual and do not indicate a software problem; the user can fix the problem by going back to step I (to edit burn components, for example, by breaching walls) and rerunning steps J through L.

Running the Step M Checks tool generates a log file and a map document showing the results of these checks. In addition, the Step M Flow Trace tool can be run by the user to verify that the raster flow directions are consistent with the hydrography.

Step N—Reserved

Step O—Compute Headwater-Node Areas and Raw Elevations

In this step, the catchment area of the upstream end (called the "headwater node") of each headwater flowline and the "raw" (unsmoothed) elevations for the downstream end of each headwater flowline are determined. First, the part of the total catchment area that drains into the headwater node is determined. The minimum elevation within each headwater-node catchment is obtained from the elev_cm.tif and then used as the maximum raw elevation for the corresponding headwater flowline. Upstream and downstream flowlines are interpolated to assign elevations to flowlines that do not have catchments due to discretization (flowlines too small to receive a catchment), which is done in step G. The results of step O are stored in the NHDPlusVAA table in the HWNodeSqKm (headwater-node catchment area), MaxElevRaw (maximum elevations of headwater-node catchments [generated from the upstream end of the headwater stream]), and MinElevRaw (minimum elevations) for all flowlines that are missing catchments. The values of the MaxElevRaw and MinElevRaw fields are inputs to step Q.

Step P—Build Flow-Accumulation Raster

The flow-direction raster built in step L is used to calculate a flow-accumulation raster for each RPU in the VPU. The flow-accumulation raster records a count of all cells that flow into each cell across the dataset; the product of the cell size and the cell count is the raster drainage area to every cell within the RPU (assuming dendritic conditions).

Step Q—Smooth Raw Elevations

The raw flowline elevations developed in step O provide upstream elevations for most headwater flowlines and downstream elevations for most flowlines. [The situations where upstream and downstream elevations are not available are described in the "Special Consideration" part of this section.] Raw elevation values from steps O and P may result in negative slopes where elevations decrease as the flowlines are traversed from downstream to upstream. This problem is not uncommon when using DEMs for estimating flowline slopes. To develop nonnegative slope estimates for all flowlines and consistent elevations at nodes, several steps are performed in elevation smoothing. The postprocessing and elevation smoothing take advantage of advanced NHDPlus network traversal capabilities.

- First, because the minimum elevations for flowlines joining at a downstream node are independently developed in step O and thus may not be equal, the elevations at such nodes are made equal by using the minimum elevation of the one (or more) flowlines that are immediately upstream of the node.
- Second, the node elevations are also assigned as the maximum elevation for each flowline that is immediately downstream of the node.

These two processes result in consistent node elevations for flowlines with catchments. When all the flowlines immediately upstream of a node are too short to generate catchments, the node will have an elevation equal to the downstream smoothed elevation.

- Third, elevations are projected between upstream and downstream MinElevRaw elevations to assign MinElevRaw elevations to the flowlines that have negative slopes. The result of the smoothing is that all the flowlines will have a positive ("downhill") or zero slope. NHDPlus HR slopes are constrained ≥0.00001 meter per meter (m/m) even when the elevation smoothing process produces equal upstream and downstream elevations on a flowline. Another important reason to perform smoothing is to ensure that all networked flowlines have elevations and slopes. For nodes with missing elevations, the smoothing process fills in these elevations and slopes based on the elevation values of the flowlines upstream and downstream. There are some cases where the smoothed elevations produce a zero slope, but the slope is set to missing (-9998), which is described under the "Special Consideration" heading of this section.
- Fourth, because "raw" elevations are based on the values determined in the catchment building process, many flowlines are trimmed in step G, which leads to these elevations being computed based on the trimmed flowline. Therefore, the elevation smoothing length used for calculating slope (SlopeLenKM) uses the flowline lengths from the NHDPlusBurnLineEvent features.

The results of the elevation smoothing processing are stored in the MinElevSmo and MaxElevSmo fields in the

NHDPlusFlowlineVAA table. One of the powerful features of NHDPlus HR is the ability to extract all the flowlines for a stream path and sort in an upstream or downstream order. This capability permits smoothing to be completed on a stream level path basis (for example, the Ohio River main stem). Also, the elevation smoothing is done sequentially, going from the mainstem to the tributaries.

Smoothed elevations and slopes for NHDPlus.—An upstream smoothing approach is employed to smooth flowline elevations at end nodes (fig. 34). The approach interpolates in the upstream direction and forms the upper envelope of the elevation profile.

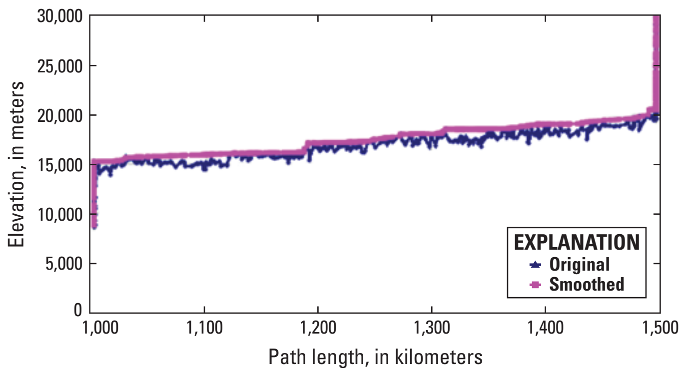


Figure 34. Upstream elevation smoothing in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

A relatively small number of flowline connections exist where elevations of all flowlines at a node are not consistent. These elevation inconsistencies occur only where some level paths meet, particularly in areas with complex divergences. As a result of elevation smoothing, most (>99 percent) flowlines in the network receive a slope ≥0.00001 m/m.

Special consideration.— Sometimes, headwater flowlines or minor path flowlines are trimmed back to the point where a catchment cannot be built. In these cases, both upstream and downstream raw elevations are missing (-9998). Also, where Catchment or Burn fields are set to "N", the actual slope cannot be determined but should not be considered to be zero; in such cases, the slope is set to missing (-9998). In addition, in some cases where the downstream junction is a simple junction, the downstream flowline also has a slope set to missing; this is because there is no way to determine an upstream elevation, but there is no reason to expect it to be zero. The elevation smoothing process does assign elevations in these situations, but the upstream and downstream elevations are equal. In cases where the slope is missing, the streamflow velocity (discussed in the velocity computation section) is computed with the Jobson unknown slope regression equation (Jobson, 1996, eq. 14, p. 15).

Step R—Accumulate Catchment Area and Adjust Value-Added Attributes in Upstream VPUs

Step R uses accumulation processes to establish the cumulative upstream catchment areas for each NHDFlowline feature in the current VPU where some of that upstream area comes from another VPU. Step R adjusts the upstream area for NHDFlowline features where NHDFlowline.InNetwork = "Y" and NHDFlowline.FType ≠ "Coastline". Cumulative catchment areas are stored in the NHDPlusFlowlineVAA table. Step R also adjusts value-added attribute values for TerminalPathID, LevelPathI, and StreamLevel where these values involve multiple VPUs.

Step S—Compute Catchment Attributes for Flow Estimation

Step S overlays NHDPlusCatchments on various attribute rasters to compute mean values of the attribute for each catchment. The attributes computed are:

- mean annual and mean monthly temperature
- mean annual and mean monthly precipitation
- mean latitude
- mean annual runoff

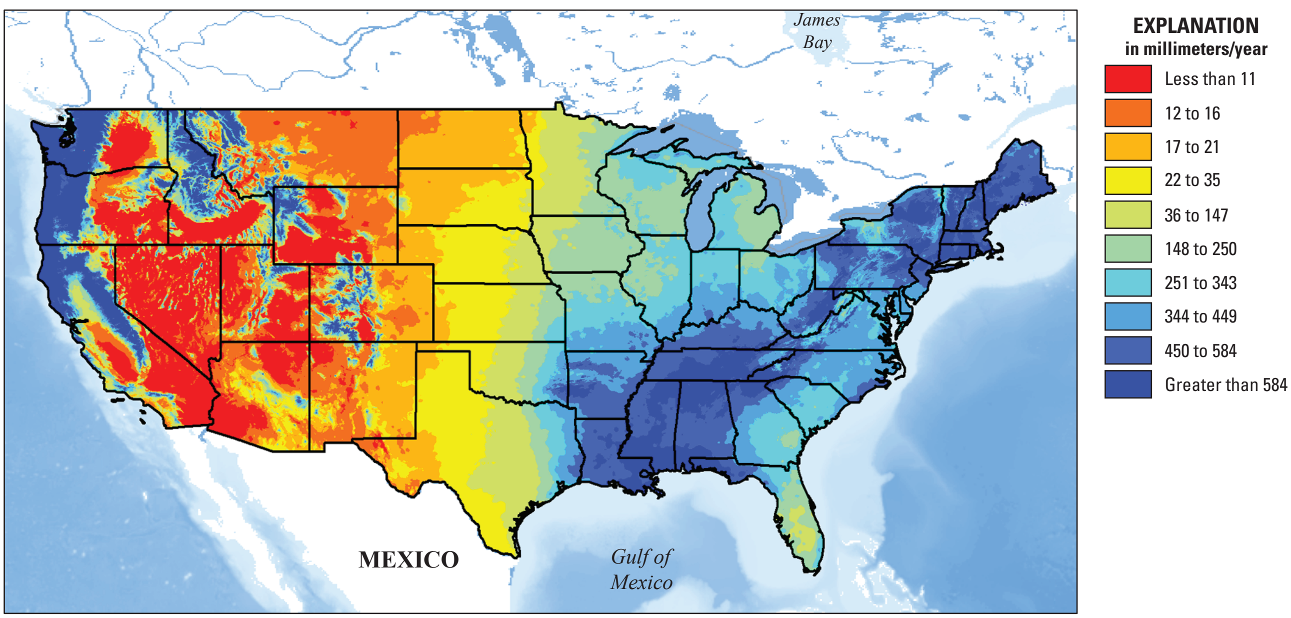
Step T—EROM Flow Estimation, Flow QAQC, and Jobson Velocity Estimation

Generally, step T is run for a VPU and all upstream VPUs that are within the same hydrologic region (two-digit hydrologic unit code [HUC2]). In very large HUC2s, it is likely that processing all VPUs in a single run of step T may not be appropriate. This can be determined by reviewing the EROMQARpt table. When that is the case, a determination is made about which VPUs have similar characteristics, and these are combined into single step T run. The group of VPUs must form a contiguous drainage but need not reach to the headwaters.

EROM Step 1—Unit Runoff Calculations

Step 1 uses the mean annual runoff produced by the U.S. Global Change Research Program (USGCRP) where a water balance approach was used to estimate runoff. The water balance approach takes precipitation, potential evapotranspiration (PET), evapotranspiration (ET), and soil moisture storage into account. In this process, ET losses are not allowed to exceed precipitation. In step S, the mean annual runoff raster (fig. 35) is overlain with the NHDPlus HR catchments to compute runoff within each catchment. The catchment runoff values are conservatively routed downstream to arrive at the first estimate of streamflows for each networked NHDFlowline feature. For use in NHDPlus HR, the runoff raster was expanded to include areas of Canada and Mexico.

Incremental runoff flows for each network NHDFlowline feature are stored in the QIncrAMA field. The QIncrAMA flows are routed and accumulated to produce the step 1 flow estimates that are labeled QAMA.



Base map from U.S. Geological Survey The National Map digital data, 2018

Figure 35. The mean annual-runoff raster image used in the National Hydrography Dataset Plus (NHDPlus) High Resolution and in step 1 of the EROM process.

EROM Step 2—Excess Evapotranspiration Adjustment

Step 2 implements a method that takes "excess ET" into account. This method, developed by Dave Wolock of the USGS (G.J. McCabe and D.M. Wolock, U.S. Geological Survey, written commun., 2017), considers the total available water in a given catchment to compute additional losses due to ET. The ET losses can exceed the total water available in a catchment, resulting in a net loss in streamflow.

As streamflow is routed through the NHDFlowline network, some part of the flow can be "lost" in a downstream catchment through ET. The quantity of loss in streamflow is assumed to be a function, in part, of excess potential ET (PET), which is defined as the PET that is in excess of actual ET (AET). The model assumes that the excess PET within the river corridor itself places a demand on water entering the catchment from upstream flow and that the river corridor is 30 percent of the total catchment area (Fract1 variable in the model). Furthermore, it is assumed that the amount of upstream flow that can be lost to satisfy excess PET is limited to 50 percent of the total upstream flow (Fract2). These percentages were determined by subjective calibration of the model to measured streamflow in arid regions that clearly lose water in the downstream direction. Runoff consumption in a catchment occurs when locally generated streamflow computed from the water-balance model is less than streamflow loss due to excess potential evapotranspiration.

There are situations, such as temperate areas east of the Mississippi, where this step is not run and the step 2 flows are set equal to the step 1 flows. For mean annual flows, there is an option to not run this step. If the NHDPlusEROMQARpt error statistics for a VPU show that step 2 greatly increases the error terms, EROM can be rerun with the option to skip step 2. Input data are as follows:

- PrecipMA: mean annual precipitation in the catchment from PRISM
- TempMA: mean monthly temperature of the catchment
- LatMean: average latitude of the catchment for the NHDFlowline feature class
- QIncrAMA: incremental flow in the catchment from step 1
- Julian Day: for each month, the Julian calendar day for the middle of the month
- Fract1, Fract2: input parameters to step T; default values are 0.3 and 0.5, respectively

The calculation is performed with the Hamon method (Hamon, 1961), by deriving total PET from the sum of the monthly PET values and then using the following equations:

$$AET = max(PrecipMA - PET, 0), \quad (2)$$

$$ExtraPET = max(PET - AET, 0), \quad (3)$$

$$QBMA = QAMAUS + QIncrAMA - min(QAMAUS \times Fract2, ExtraPET \times Fract1), \text{ and} \quad (4)$$

$$QIncrBMA = QBMA - QAMAUS, \quad (5)$$

where

QAMAUS is the sum of QAMA flows that enter the catchment

ExtraPET is the extra potential evapotranspiration beyond the actual.

QIncrBMA is contribution of the QBMA flow supplied by the individual catchment.

For headwater NHDFlowline features, *QIncrBMA* = *QBMA*.

EROM Step 3—Reference Gage Regression Flow Adjustment

A log-log regression step using reference gages provides a further adjustment to the flow estimates. This regression improves the mean annual flow estimates that are intended to represent natural conditions. Through log-log regression analysis, the measured flow at the reference gages is evaluated compared with flow estimates from step 2. Based on the regression predictions, step 3 uses the results of the analysis to adjust the step 2 flows.

The regression step has been found to improve EROM flow estimates in some areas of the country based on VPUs, whereas in other areas, it has a marginal effect. To review the effects the regression step has on improving EROM flow estimates, refer to the EROMQAMARpt table.

The reference gage regression applies a regression-based adjustment to the QBMA flow, which is then referred to as QCMA. The regression is determined as follows:

- The reference gages are screened based on two criteria. First, the NHDPlus HR drainage area for the gage must be within, plus or minus, a certain percentage of the NWIS-reported drainage area. Second, the gage must have a required minimum number of years or months of complete record from 1971 to 2000. The criteria used for each VPU are listed in the EROMQAMARpt table.

- The screened reference gages are used to develop a log-log regression that compares the gage flow to the QBMA flow. The regression is of the form:

$$\log_{10}(QCMA) = a + b \times \log_{10}(QBMA), \quad (6A)$$

The log-log regression is transformed to calculate QCMA:

$$QCMA = 10^a \times QBMA^b \times BCF, \quad (6B)$$

where

a and *b* are regression coefficients (defined in eqs. 13 and 14, respectively), and

BCF is a bias correction factor (defined in eq. 16).

Equation 6 is then applied in prediction mode to all networked NHDFlowline features.

- The regression uses the following variables and equations:

$$Y_i = \log_{10}(Q\_Fi), \tag{7}$$

$$X_i = \log_{10}(QBMA_i), \tag{8}$$

$$X_{bar} = \sum \frac{X_i}{N}, \tag{9}$$

$$Y_{bar} = \sum \frac{Y_i}{N}, \tag{10}$$

$$x_i = X_i - X_{bar}, \tag{11}$$

$$y_i = Y_i - Y_{bar}, \tag{12}$$

$$a = (Y_{bar} - b \times X_{bar}), \text{ and} \tag{13}$$

$$b = \frac{\sum x_i \times y_i}{\sum x_i^2}, \tag{14}$$

$$r^2 = b \times \frac{\sum x_i \times y_i}{\sum y_i^2}. \tag{15}$$

where

- Y is the log-transformed value of the Falcone reference gage mean annual flow,
- X is the log-transformed value of the EROM QB mean annual flow,
- i is the gage being used, from 1 to n,
- N is the number of reference gages being used [summations are for all N reference gages],
- Q_F_i is the streamflow (Q) for the Falcone reference gage i adjusted to the bottom of the stream segment, and
- $QBMA_i$ is the QBMA flow for the NHDFlowline feature containing gage i.

To determine the BCF coefficient, the regression uses a "smearing" approach from Duan (1983), as follows:

$$BCF = \sum \frac{10e_i}{N}, \tag{16}$$

where

$$e_i = Y_i - 10a \times X_i b. \tag{17}$$

To illustrate the process, the simplified features in figure 36 are used in this discussion. The calculations are performed for NHDFlowline features 1 and 2 and all networked features above 1 and 2 (not shown on fig. 36). Also, all flows are ≥0; no negative flows are allowed. Incremental flows may be negative.

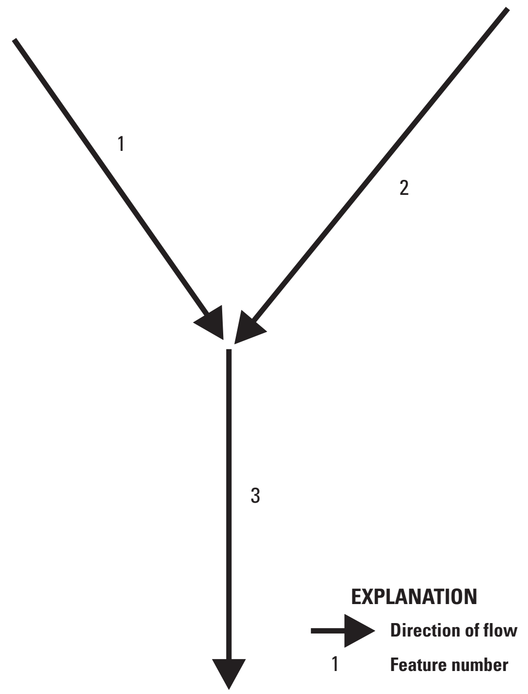


Figure 36. A simple junction with network features numbered 1, 2, and 3 in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

$$QCMA_1 = 10^a \times QBMA_1^{\,b} \times BCF, \tag{18}$$

$$QCMA_2 = 10^a \times QBMA_2^{\,b} \times BCF, \text{ and} \tag{19}$$

$$QCMA_3 = 10^a \times QBMA_3^{\,b} \times BCF. \tag{20}$$

The incremental flow is calculated as the mean annual flow on the given flowline minus the upstream flows. This incremental flow adjustment is shown for flowline 3:

$$QIncrCMA_3 = QCMA_3 - (Divfrac_3 \times (QCMA_1 + QCMA_2)), \tag{21}$$

where

- $QCMA_n$ is the flow on NHDFlowline feature n with the reference gage equation applied,
- n is the number of the feature; in figure 36, which is our example, this is feature 1, 2, and 3,
- $QBMA_n$ is the flow on NHDFlowline feature n from step 2 "Excess Evapotranspiration Adjustment" of the EROM processing,
- $QIncrCMA_n$ is the incremental flow on NHDFlowline feature,
- $Divfrac_n$ is the fraction of the upstream flow that would be routed to NHDFlowline feature n if feature n were part of a divergence.

Flow balance is preserved because accumulated flows are a sum of incremental flows. The reference gage regression is, in effect, equal to incremental flows in cases where the network feature is a headwater or a minor path of a divergence without flow split values (DivFrac = 0 for the minor path).

EROM Step 4—Manmade Addition and Removal Adjustments

Manmade additions, removals, and transfers are found in the NHDPlusAdditionRemoval table; flow removals, additions, and transfers include irrigation and drinking water withdrawals, karst areas flows, and losses or gains from groundwater from outside of the catchment. This table is being built over time, based largely on user input.

During step 4, these additions and removals are applied to step 3 flows. This table can hold, for instance, values of flow transfers from the Colorado River to other basins or locales (for example, Phoenix, Ariz., or California), flows withdrawn for irrigation, and irrigation return flows. As the EROM process steps route down the NHDFlowline network, flows are added and removed based on the addition and removal points and quantities in the NHDPlusAdditionRemoval table. The $QIncrCMA_n$ values are modified and saved as $QIncrDMA_n$.

Situations arise where the total available flow is less than the flow that is to be transferred from a given NHDFlowline feature. In this case, all QDMA flow will be transferred or withdrawn, resulting in a zero flow at that NHDFlowline feature.

The cumulative and incremental flows after the NHDPlusAdditionRemoval adjustments are referred to as QDMA and QIncrDMA, respectively. QDMA and QIncrDMA are computed as follows:

$$QDMA_n = QCMA_n \pm NHDPlusAdditionRemoval, \quad (22)$$

$$QIncrDMA_3 = QDMA_3 - (\text{DivFrac}_3 \times (QDMA_1 + QDMA_2)) \quad (23)$$

EROM Step 5—Gage-Based Flow Adjustment

In step 5, NHDPlus HR network features that are upstream from the gages are adjusted for gage-based flow. Step 5 is a way to provide much better flow estimates upstream from gages and adjust flow estimates downstream from gages to better reflect flow alterations not taken into account in the first four steps. The processing in step 5 adjusts streamflow estimates based on observed gaging station data. Only gaging stations linked to the NHDPlus HR network are used to adjust flows. The adjustment process includes the following steps:

- Only gages where the drainage area of the NHDPlus HR gage is within ±20 percent of the drainage area of the NWIS-reported gage are used for gage adjustment. The drainage area comparison removes gages that are incorrectly located on the minor path of a divergence or on a tributary rather than on a main stem (fig. 37; the gage points along the x axis of the graph are gages that would be removed in this process). The gage flows are computed from 1971 to 2000, and there needs to be a record of at least 10 complete years (for mean annual) of flow data in this period for the gage to be used in gage adjustment.

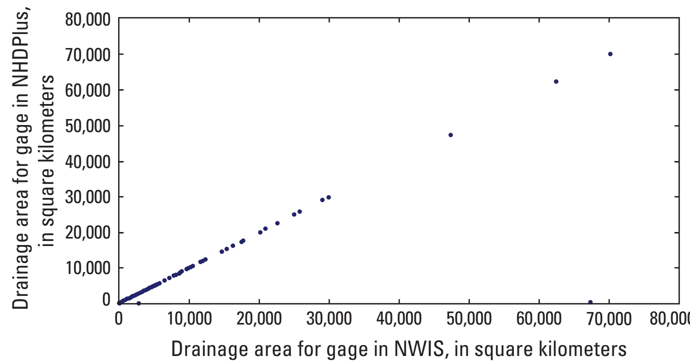


Figure 37. A comparison of drainage areas for gages in the National Hydrography Dataset Plus (NHDPlus) High-Resolution (NHDPlus HR) and the National Water Information System (NWIS) to illustrate gage-mismatch exclusion for gage-flow adjustment in the NHDPlus HR. Data points past the 0,0 point on the x-axis represent gages that would be excluded from the gage-flow adjustment process.

- The gage flows and drainage areas are adjusted to reflect values at the downstream end of the NHDFlowline feature. Drainage area is adjusted by adding the catchment area downstream from (below) the gage to the gage drainage area. The gage flow is adjusted by taking the catchment unit runoff from step 1 (in cubic feet per second per square kilometer) and adding that incremental flow based on the part of the catchment area that is below the gage.
- Incremental flows are adjusted as follows:
  - For upstream gages (no other gages upstream).
    - The adjustment is apportioned in the incremental streamflows (QDMA) so that the NHDFlowline features that are closer to the gage receive more of the adjustments than NHDFlowline features farther away from the gage. The adjustment is apportioned based on the ratio of the drainage area of an NHDFlowline feature to the drainage area of the gage.
    - Streamflow adjustment is made only where the cumulative drainage area of the NHDFlowline feature is ≥50 percent of the NHDPlus HR gage drainage area.
    - A “flow balance” will usually be maintained so that the incremental flows from step 5 can be summed to get the step 5 streamflows.

- For a gage that is downstream from another gage on the same mainstem:
  - Main stems can be identified by the values of the LevelPathI field in NHDPlus HR (see NHDPlus-FlowlineVAA.LevelPathI).
  - The adjustments are apportioned to incremental flow so that the NHDFlowline features that are closest to the gage receive more of the adjustments than NHDFlowline features farther away from gage.
  - The flows will be adjusted for all NHDFlowline features between the two gages regardless of the gage drainage ratios.
- Gage-adjusted flows upstream from gages are routed downstream of the gages so that the gage adjustments will affect NHDFlowline features downstream from gages. This helps to improve flow estimates on all NHDFlowline features downstream from gages.
- The gage flow adjustments are computed as follows:
  - Where there is no gage upstream:
    - The change in flow (ΔQ) necessary for the step 4 flow and the gage flow (Q_{gage}) to match is calculated as follows:

$$\Delta Q = Q_{gage} - QDMA. \tag{24}$$

    - The NHDFlowline features to which ΔQ must be apportioned is found by navigating upstream from the gage and flagging all NHDFlowline features with a cumulative drainage area ≥0.5 time the gage drainage area. The cumulative drainage area for each NHDFlowline feature is referred to as "CumDA."
    - The sum of the cumulative drainage areas for the NHDFlowline features to be adjusted is computed. This will be referred to as "CumCumDA."
    - The incremental flow adjustment $\Delta IncQ$ for each of the NHDFlowline features from equation 2 is calculated as follows:

$$\Delta IncQ = \frac{\Delta Q}{CumCumDA} \times CumDA \text{ and} \tag{25}$$

$$QIncrEMA = QIncrDMA + \Delta IncQ. \tag{26}$$

    - All the NHDFlowline features that are adjusted are flagged so that no further flow adjustments can be made to them.
  - Where the gage is downstream from another gage on the same LevelPathI:
    - The revised flow at the upstream gage(s) is routed and accumulated from the upstream gage down to this gage. The accumulation is based on the QIncrDMA values on the NHDFlowline features between the gages. At this gage, the ΔQ (eq. 24) is based on the downstream gage values.
    - The NHDFlowline features are navigated from this gage to the next upstream gage(s). This routing includes all NHDFlowline features between the two gages as well as any tributary NHDFlowline features that have not already been flagged as being adjusted and tributary NHDFlowline features where the cumulative drainage area is ≥0.5 time the downstream gage drainage area.
    - The drainage area criterion is not used for NHDFlowline features on the same LevelPathI between the gages. This ensures there are no "gaps" in the gage flow adjustments between gages on the same mainstem, which is defined by the LevelPathI.
    - The flow adjustment method described in equations 25 and 26 is used, where CumCumDA is the cumulative drainage area for all NHDFlowline features being adjusted. These adjustments include all NHDFlowline features between the gages on the LevelPathI and any tributary NHDFlowline features where the drainage area of the feature is ≥0.5 time the downstream gage drainage area.
    - Large rivers will have adjustments on most of NHDFlowline features, with adjustments probably occurring on large tributaries.
    - Where there are no gages downstream on the LevelPathI, flows are accumulated to the bottom of the LevelPathI using the QIncrEMA values on the main stem and tributaries.

EROM Step 6—Gage Sequestration Computations

Because step 5 uses all gages, the flow estimates at the gages will always match the gaged flow values. This means that any statistical analyses on the step 5 flows compared with gage flows will always be a perfect match. Step 6 is designed to provide a measure of the accuracy of gage adjustment flow estimates on ungaged NHDFlowline features. The first step is to sequester (remove) a random set of gages, typically 20 percent, and repeat the gage adjustment process using the unsequestered gages (the remaining 80 percent). The EROM QEMA streamflow values are then used to compute the streamflow statistics for the sequestered gages (the 20 percent not used for gage adjustment).

This gage sequestration step is performed once, so the results are a snapshot of potential benefits of the gage adjustment step. The gage sequestration could be performed multiple times, each time sequestering a different random set of gages. Averaging the streamflow results over these multiple runs would be a refinement of this streamflow process.

Summary of Processing Steps

- Taken together, steps 1 and 2 are designed to provide the best consideration of the water balance components that is currently feasible on a national scale.
- In step 3, the reference gage regression adjustment takes into account factors not incorporated in the water balance, such as broad regional-scale groundwater effects.
- In step 4, the NHDPlusAdditionRemoval adjustment has great potential to be able to take any water-use factors into account, including groundwater, drinking water withdrawals, sewerage discharges, and irrigation.
- In step 5, gage adjustment takes into account any factors not covered in the first four steps, such as consumptive use from dammed reservoirs and flow augmentations not accounted for the NHDPlusAdditionRemoval tables.
- In step 6, the accuracy of gage flow adjustments from step 5 are evaluated.

EROM Incremental Flows

EROM provides estimated flows and incremental flows for each networked flowline. The flow is equal to the sum of the incremental flows upstream from each NHDFlowline and on the flowline.

EROM Flow Estimation QAQC

The EROM QAQC step produces two outputs: a tabular EROMQARpt (fig. 38) report and the EROMQAMA table.

```
OBJECTID      RptLine (Report Line)
1       EROM QA Report For VPUs used in this run = 0105 0104 0103 0102 0106 0109 0107
2       -
3       ETFRACT1 = 0.3 ETFRACT2 = 0.5
4       Statistics used in the QA Report:
5       N = Number of Gages
6       SEE = Standard Error of the Estimate in percent;
7
8
9       Table 1: Statistics For All Gages:
10      Gage Runoff Excess ET RefGage Reg PlusFlowAR
11      MA | 109 | 2.2731 | 2.2368 | 14.698 | 2.2368 | 14.698 | 2.2809 | 12.367 | 2.2809 | 12.367 |
12
13
14      Table 2: Statistics For Sequestered Gages:
15      Gage Seq. Gages
16      Period N Qbar Qbar SEE
17
18
19      Table 3: Statistics For Reference Gages:
20      Period N Qbar Qbar SEE Qbar SEE Qbar SEE Qbar SEE
21      MA | 21 | 1.9161| 1.8679 | 17.577 | 1.8679 | 17.577 | 1.9196 | 13.493 | 1.9196 | 13.493 |
22
23
24      Period N a b BCF R2 SER
25      MA | 21 | 0.0625| 0.9922 | 1.0087 | 0.9938 | 0.0612 |
26      Gage Sequestration Proportion = 0.2
27      Qbar = Log10 Mean Flow (cfs)
28      2/3 of the Flow Estimates will have errors that are within one SEE
29      Period N Qbar Qbar SEE Qbar SEE Qbar SEE Qbar SEE
30      MA | 22 | 2.3528 | 2.3694 | 11.846 |
31
32      Gage Runoff Excess ET RefGage Reg PlusFlowAR
33      Table 4: Reference Gage Log-Log Regression Statistics:
```

Figure 38. Example EROMQARpt used in the National Hydrography Dataset Plus (NHDPlus) High Resolution.

The EROMQARpt report contains comparisons of the EROM flow estimates and the observed gage flows. Two statistics are used for measuring how well the different flow estimates performed in relation to the gage flows:

1. The log10 mean flow at the gage as compared to the log10 of the EROM mean flow estimate.
2. The standard error of the estimate (SEE) in percent; two-thirds of the flow estimates will be within 1 SEE.

There are four internal tables within the EROMQARpt (fig. 38):

1. Table 1 reports statistics for all gages for flow values A, B, C, and D (described in the first part of the "Step T—EROM Flow Estimation, Flow QAQC, and Jobson Velocity Estimation" section of this report).
2. Table 2 reports the statistics for only the sequestered gages.
3. Table 3 reports the statistics for only the reference gages.
4. Table 4 lists the statistics used in the reference gage regression step (flow value QCMA); these values are the log-log regression coefficients, the coefficient of determination (R^2), and the standard error of the regression.

The best EROM flow and velocity estimates are the gage adjusted values, QEMA. For natural flows, the best estimates are the reference gage regression values, QCMA.

Figure 39 shows a graph of gage flows versus EROM flows with gage flows on the x axis and EROM flow estimates for runoff and the reference gage regression on the y axis. The graph is in log-log coordinates to best show the range of flows. The blue circles are the runoff flow estimates and the magenta circles are the flows adjusted with the reference gage regression. The red line is where the gage and EROM flows would be equal. Note how the runoff estimates consistently underestimate the (true) gage flows. The reference gage regression shifts the flows up to better match the gage flows.

Velocity Computation

Velocities are estimated for EROM mean annual flow using the work of Jobson (1996). This method uses regression analyses on hydraulic variables from more than 980 time-of-travel studies, which represent about 90 different rivers in the United States. These rivers represent a range of sizes, slopes, and channel geometries. Four principal variables are used in the Jobson method: drainage area, flowline slope, flow for which velocity is calculated, and mean annual flow. Since we are calculating the velocity for mean annual flow, the two flow variables have the same value. Based on analyses using the Jobson method, regression equations were developed to relate velocity (in meters per second) to drainage area, a dimensionless drainage area, slope, flow, and a dimensionless relative flow.

The slope smoothing process does not permit zero slopes on NHDFlowline features. If the elevation smoothing produces a zero slope, the slope is set to a value of 0.00001. There are situations where the slope is set to "missing" (-9998), in which case the Jobson unknown slope method is used for the velocity calculation. For all NHDFlowline features with slope, velocities are calculated using the Jobson slope method.

The dimensionless relative discharge (Q'_a ; from Jobson, 1996) is expressed as follows:

$$Q'_a = \frac{Q}{Q_a}\ , \qquad (27)$$

where

Q is the flow (in cubic meters per second) and
Q_a is the mean annual flow (in cubic meters per second).

The dimensionless drainage area (D'_a ; from Jobson, 1996) is expressed as follows:

$$D'_a = \frac{D_a^{1.25} \times 0.5g}{Q_a}\ , \qquad (28)$$

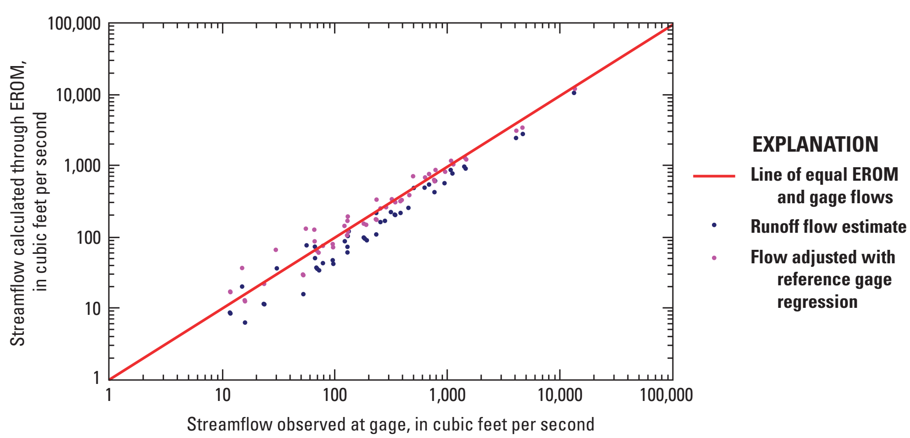


Figure 39. An example of a comparison of flows estimated by the Enhanced Unit Runoff method (EROM) in the National Hydrography Dataset Plus (NHDPlus) High-Resolution and flow data collected at streamgages.

where

D_a is the drainage area (in square meters),

g is the acceleration of gravity (9.8 meters per second squared), and

Q_a is the mean annual flow (in cubic meters per second).

The NHDFlowline feature velocity (v_s) based on the Jobson slope equation (Jobson, 1996) is calculated as follows:

$$v_s = 0.094 + \left(0.0143 \times \left(0.919 D'_a\right) \times \left(Q'_a - 0.469\right) \times \left(0.159 slope\right) \times \left(\frac{Q}{D_a}\right)\right). \quad (29)$$

The NHDFlowline feature velocity (v) based on the unknown slope equation (Jobson, 1996) is calculated as follows:

$$v_{us} = 0.02 + \left(0.051 \times \left(0.821 D'_a\right) \times \left(Q'_a - 0.465\right) \times \left(\frac{Q}{D_a}\right)\right). \quad (30)$$

To convert velocity from meters per second to feet per second, multiply the value in meters per second by 3.2808. Note: The intercept term is defined when the flow or drainage area is zero. For the slope method, $v_s = 0.094 \times 3.2808 = 0.3084$ foot per second; for the unknown slope method, $v_{us} = 0.02 \times 3.2808 = 0.0656$ foot per second.

Selected References

Arnold, D.E., 2014, The National Map hydrography data stewardship—What is it and why is it important? U.S. Geological Survey Fact Sheet 2014–3084, 2 p. [Also available at https://doi.org/10.3133/fs20143084.]

Dewald, T., 2015, Making the digital water flow (revised June 2017): USEPA, 8 p., accessed January 27, 2019, at https://www.epa.gov/waterdata/learn-more

Duan, N., 1983, Smearing estimate—A nonparametric retransformation method: Journal of the American Statistical Association, v. 78, no. 383, p. 605–610. [Also available at https://doi.org/10.2307/2288126.]

Falcone, J.A., Carlisle, D.M., Wolock, D.M., and Meador, M.R., 2010, GAGES—A stream gage database for evaluating natural and altered flow conditions in the conterminous United States: Ecology, v. 91, no. 2, p. 621. [Also available at https://doi.org/10.1890/09-0889.1.]

Fontaine, R.A., Wong, M.F., and Matsuoka, I., 1992, Estimation of median streamflows at perennial stream sites in Hawaii: U.S. Geological Survey Water-Resources Investigations Report 92–4099, 37 p. [Also available at https://doi.org/10.3133/wri924099.]

Government of Canada, [undated], National hydro network—NHN—GeoBase series: Government of Canada website, accessed October 18, 2018, at https://open.canada.ca/data/en/dataset/a4b190fe-e090-4e6d-881e-b87956c07977.

Hamon, W.R., 1961, Estimating potential evapotranspiration: Journal of the Hydraulics Division, v. 87, no. 3, p. 107–120.

Hellweger, F., and Maidment, D., 1997, AGREE–DEM surface reconditioning system: University of Texas database, accessed March 23, 2016, at http://www.crwr.utexas.edu/gis/gishyd98/quality/agree/agree.htm. [At time of publication, database has been moved to http://www.ce.utexas.edu/prof/maidment/gishydro/ferdi/research/agree/agree.html.]

Horizon Systems Corp., [undated]a, NHDPlus version 1 (archive): Horizon Systems Corp. NHDPlus website, accessed October 12, 2018, at http://www.horizon-systems.com/NHDPlus/NHDPlusV1_home.php.

Horizon Systems Corp., [undated]b, NHDPlusV2 documentation: Horizon Systems Corp. NHDPlus website, accessed October 12, 2018, at http://www.horizon-systems.com/NHDPlus/NHDPlusV2_documentation.php.

Horton, R.E., 1945, Erosional development of streams and their drainage basins—Hydrophysical approach to quantitative morphology: Bulletin of the Geological Society of America, v. 56, p. 275–370. [Also available at https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2.]

Instituto Nacional de Estadística y Geografía, [undated], Red Hidrográfica escala 1:50,000 edición 2.0: Instituto Nacional de Estadística y Geografía natural resources database, accessed 2018, at http://www.inegi.org.mx/geo/contenidos/recnat/hidrologia/regiones_hidrograficas.aspx.

Jobson, H.E., 1996, Prediction of travel time and longitudinal dispersion in rivers and streams: U.S. Geological Survey Water-Resources Investigations Report 96–4013, 69 p. [Also available at https://pubs.er.usgs.gov/publication/wri964013.]

McCabe, G.J., and Wolock, D.M., 2011, Independent effects of temperature and precipitation on modeled runoff in the conterminous United States: Water Resources Research, v. 47, no. 11, W11522, 11 p., accessed 2018 at https://doi.org/10.1029/2011WR010630.

McKenney, D.W., Papadopol, P., Campbell, K.L., Lawrence, K.M., and Hutchinson, M.F., 2006, Spatial models of Canada- and North America-wide 1971/2000 minimum and maximum temperature, total precipitation and derived bioclimatic variables: Natural Resources Canada Frontline Technical Notes 106, 9 p. [Also available at https://cfs.nrcan.gc.ca/publications/download-pdf/26775.]

Moore, R.B., and Dewald, T.G., 2016, The road to NHDPlus—Advancements in digital stream networks and associated catchments: Journal of the American Water Resources Association, v. 52, no. 4, p. 890–900. [Also available at https://doi.org/10.1111/1752-1688.12389.]

Moore, R.B., Johnston, C.M., Robinson, K.W., and Deacon, J.R., 2004, Estimation of total nitrogen and phosphorus in New England streams using spatially referenced regression models: U.S. Geological Survey Scientific Investigations Report 2004–5012, 42 p. [Also available at https://doi.org/10.3133/sir20045012.]

Natural Resources Canada, 2008, Hydrology—Drainage areas (version 6.0): Natural Resource Canada Atlas of Canada 1,000,000 National Frameworks Data, accessed 2008 at http://geogratis.gc.ca/geogratis/en/option/select.do?id = 87B4BE8F-C67C-5545-80B5-AB6FC056149E. [At the time of this publication, website has been moved; updated data are available at http://lwbin-datahub.ad.umanitoba.ca/dataset/atlca-funddra.]

Natural Resources Canada, 2016, Canadian digital elevation data: Natural Resources Canada GeoBase Series web page, accessed March 23, 2016, at http://www.geobase.ca/geobase/en/data/cded/description.html. [At the time of this publication, database has been moved; a digital elevation model that uses these data is available at https://open.canada.ca/data/en/dataset/7f245e4d-76c2-4caa-951a-45d1d2051333.]

Natural Resources Canada, 2017, National hydro network: Natural Resources Canada GeoBase Series web page, accessed August 16, 2017, at http://www.geobase.ca/geobase/en/data/nhn/description.html. [At the time of this publication, database has been moved and can be accessed at https://open.canada.ca/data/en/dataset/a4b190fe-e090-4e6d-881e-b87956c07977.]

North Pacific LCC Data Coordinator, 2014, Canadian national hydro network (NHN)—GeoBase web mapping service (WMS): Data Basin dataset, accessed October 18, 2018, at https://databasin.org/datasets/dda81e7c146049259097c1e7aade60ba.

PRISM Climate Group, 2006, PRISM climate data: PRISM Climate Group database, accessed 2006 at http://www.prismclimate.org. [At the time of this publication, website had been moved to http://prism.oregonstate.edu/.]

Saunders, W., 2000, Preparation of DEMs for use in environmental modeling analysis, *in* Maidment, D., and Djokic, D., eds., Hydrologic and hydraulic modeling support with geographic information systems: Redlands, Calif., Environmental Systems Research Institute, Inc., p. 29–51.

Strahler, A.N., 1957, Quantitative analysis of watershed geomorphology: Eos, Transactions American Geophysical Union, v. 38, no. 6, p. 913–920. [Also available at https://doi.org/10.1029/TR038i006p00913.]

U.S. Environmental Protection Agency, [undated], NHDPlus (national hydrography plus dataset): U.S. Environmental Protection Agency and U.S. Geological Survey database, accessed June 18, 2018, at https://www.epa.gov/waterdata/nhdplus-national-hydrography-dataset-plus.

U.S. Geological Survey, 2018a, NHDPlus high resolution: U.S. Geological Survey The National Map website, accessed October 12, 2018, at https://nhd.usgs.gov/NHDPlus_HR.html. [At the time of this publication, website had been moved to https://www.usgs.gov/core-science-systems/ngp/national-hydrography/nhdplus-High Resolution.]

U.S. Geological Survey, 2018b, Watershed boundary dataset: U.S. Geological Survey National Hydrography website, accessed October 12, 2018, at https://nhd.usgs.gov/wbd.html.

U.S. Geological Survey, 2019a, 3D elevation program: U.S. Geological Survey website, accessed September 20, 2019, at https://www.usgs.gov/core-science-systems/ngp/3dep.

U.S. Geological Survey, 2019b, National hydrography: U.S. Geological Survey website, accessed September 20, 2019, at https://www.usgs.gov/core-science-systems/ngp/national-hydrography.

U.S. Geological Survey, [undated], National hydrography: U.S. Geological Survey website, accessed September 20, 2019, at https://nhd.usgs.gov/data.html.

Viger, R.J., Rea, A., Simley, J.D., and Hanson, K.M., 2016, NHDPlusHR—A national geospatial framework for surface-water information: Journal of the American Water Resources Association, v. 52, no. 4, p. 901–905. [Also available at https://doi.org/10.1111/1752-1688.12429.]

Glossary

3D Elevation Program *See* National Elevation Dataset; *see also* digital elevation model.

artificial path A National Hydrography Dataset (NHD) flowline feature type that represents a flow path through a waterbody in the surface water network of the NHD.

burn line A line used to perform hydroenforcement of the digital elevation model (DEM) during step L of the NHDPlus HR Build/Refresh production process. Burn lines are stored in the NHDPlusBurnlineEvent feature class if they are NHDFlowline features within the VPU or in NHDPlusBurnAddLine if they are additional lines that are not NHDFlowline features within the VPU.

catchment The land surface area that flows directly to an NHDPlus or NHDPlus HR feature. For most networked surface-water linear features, the catchment represents the incremental area that drains directly to each feature or stream segment. Exceptions include coastline features, where the catchments represent the total drainage area to each individual coastline segment. For off-network sink features, the catchment represents the total drainage area to the sink because there are no upstream features. Similarly, because there are no upstream features, the catchments for headwater linear features represent the total drainage area as well as the incremental drainage area.

cumulative drainage area The total upstream or upslope area that flows to an NHDPlus feature. For surface water network linear features, this is the catchment area for a specific flowline combined with the catchment areas for all upstream flowlines.

closed basin A watershed or basin where there are no surface water outlets.

digital elevation model A raster dataset (a raster of squares) representing elevation.

divergence-routed accumulation A method of accumulating attributes downstream along the surface-water network features where the attribute is divided into parts at each flow split in the network and where the total of the parts equals 100 percent.

drainage-area divide The boundary line between two different drainage areas along a topographic ridge or divide.

flow table *See* NHDPlusFlow table.

flow-path displacement The horizontal positional offset between a mapped stream in the NHD and that of a synthetic stream derived from a DEM.

flowline A mapped stream segment or a path through a waterbody in the surface-water network of the NHD; this is the basic unit of the NHD linear surface-water network.

hydroenforcement A process of altering a DEM to force alignment with streams, waterbodies, sinks, and watershed divides for the creation of a flow-direction raster.

hydrologic unit A standardized classification system for streams and rivers in the United States developed by the U.S. Geological Survey. Hydrologic units are watershed areas organized in a nested hierarchy by size. The largest subdivisions are assigned a two-digit code from 01 through 22. Four-digit codes are assigned to subdivisions of the two-digit code areas; six-digit codes, to the four-digit code areas; and so on into 8, 10, and 12-digit code areas.

National Elevation Dataset (NED) Seamless elevation coverage of the conterminous United States, Hawaii, Alaska, and the island territories; *see also* 3D Elevation Program *and* digital elevation model.

National Hydrography Dataset (NHD) A comprehensive set of digital spatial data that represent the surface waters of the United States using common features such as lakes, ponds, streams, rivers, canals, and oceans.

National Water Information System A principal U.S. Geological Survey repository of national water resources data.

NHD reach A uniquely identified linear feature that consists of one or more flowlines; *see also* reach.

NHDPlus An integrated suite of application-ready geospatial datasets that incorporate many of the best features of the NHD, the

NED, and the Watershed Boundary Dataset. NHDPlus is currently [2019] distributed at a medium (NHDPlus version 2) and high (NHDPlus HR) resolution.

NHDPlusFlow table A database table that contains the interconnections between flowlines in the NHD.

raster A matrix of cells organized into rows and columns, where each cell contains a value such as land surface elevation, mean annual temperature, or mean annual precipitation. In geographic information system (GIS) applications the cells represent mapped locations on the earth surface.

reach A uniquely identified linear feature that consists of one or more flowlines; *see also* NHD reach.

reach code A unique, permanent identifier in the NHD associated with an NHD reach.

Spatially Referenced Regressions on Watershed Attributes (SPARROW) A modeling tool for the regional interpretation of water-quality monitoring data. The model relates in-stream water-quality measurements to spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and aquatic transport. SPARROW empirically estimates the origin and fate of contaminants in river networks and quantifies uncertainties in model predictions.

stream burning A process of overlaying a mapped stream network onto a DEM, creating "trenches" where the stream network exists. Stream burning improves how accurately the resulting DEM flow paths match the streams to ensure DEM-derived catchment boundaries fit the stream network.

stream segment Part of a stream, often extending between tributary confluences; *see also* flowline.

streamflow The volume of water flowing past a fixed point in a fixed unit of time.

total upstream accumulation A method of accumulating attributes downstream along the surface water network features where the accumulated value at any NHDFlowline feature is the total amount of the attribute that is upstream of the network feature.

walling Using a representation of the known drainage boundaries to build up or mathematically modify a DEM to more accurately represent the locations of the known drainage boundaries. First developed for the New England SPARROW model.

Watershed Boundary Dataset A baseline hydrologic drainage boundary framework that accounts for all land and surface areas in the United States. Watersheds are organized by hydrologic unit (see hydrologic unit).

For more information, contact
National Geospatial Program
Core Science Systems
U.S. Geological Survey
12201 Sunrise Valley Dr., MS 511
Reston, VA 20192
https://www.usgs.gov/core-science-systems/national-geospatial-program

Publishing support provided by the
Pembroke Publishing Service Center

Moore and others—**User's Guide for the National Hydrography Dataset Plus (NHDPlus) High Resolution**—Open-File Report 2019–1096

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20191096