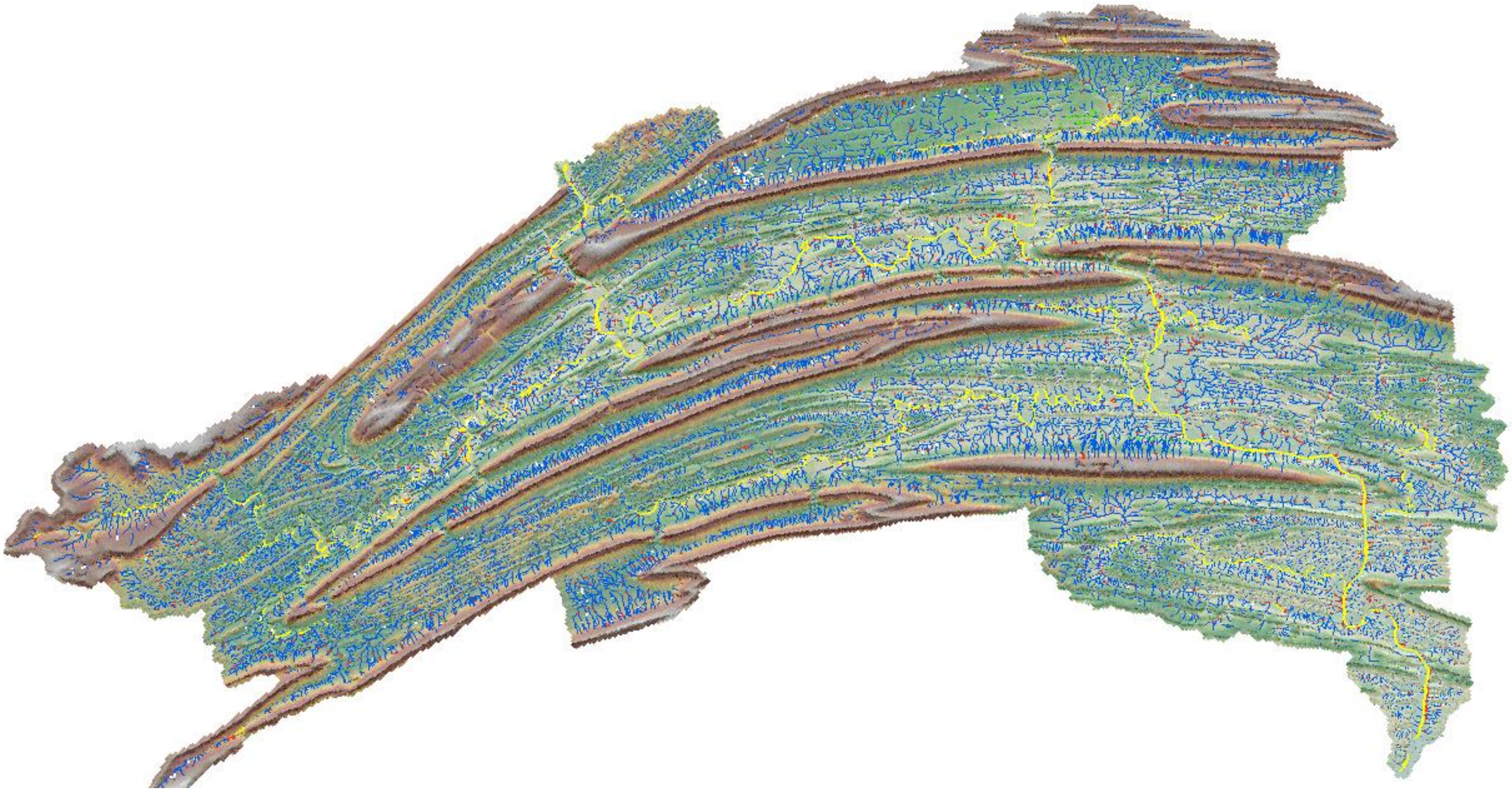
August 2, 2023



PA Raystown EDH Collection and Positional Accuracy Report - 02050304

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Cover Photo: An overhead view of the Lower Juniata Watershed displaying the unique Ridge-and-Valley Appalachian topography

Introduction

In June2021, NV5 Geospatial (NV5) was contracted by the United State Geologic Survey (USGS) to collect elevation-derived hydrography (EDH) from 1m 3DEP standard lidar bare earth DEM products for three 8-digit hydrologic units in south central Pennsylvania covering an area of 3,403 square miles. Data were collected to meet standards laid out in the Elevation-Derived Hydrography Acquisition Specification and the Elevation-Derived Hydrography Read Rules. This report covers HU 02050304 - Lower Juniata Watershed and documents processing methods along with landscape specific considerations and approaches for the PA Raystown EDH area of interest (AOI). Figure 1 shows the extent of the total project area and identifies HU 02050304. Additional reports will be generated for the remaining 8-digit hydrologic units.

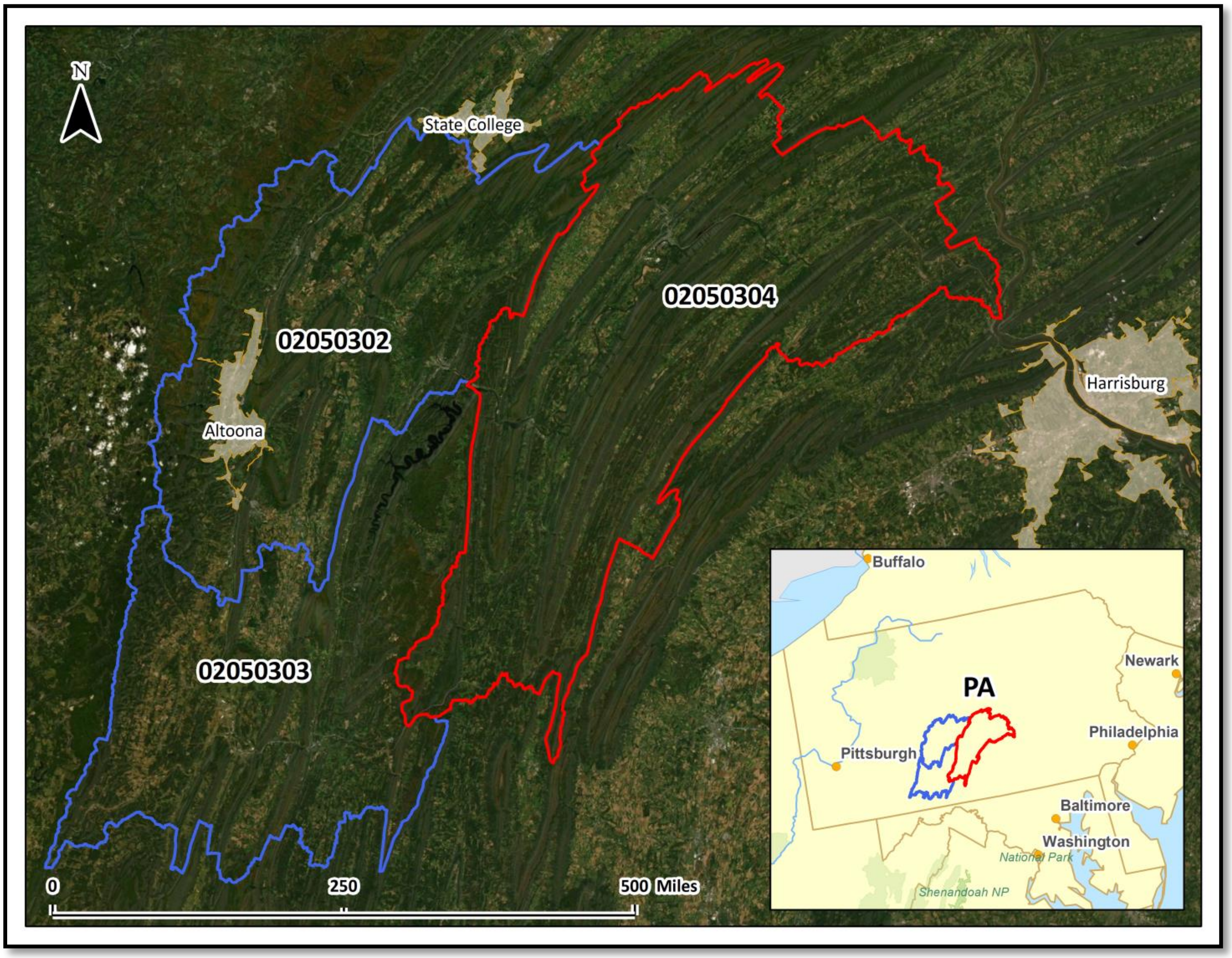

Figure 1: PA Raystown Elevation Derived Hydrography AOI

Source Data

The PA Raystown EDH data was derived using a combination of 3 different lidar datasets. Previously collected breaklines delineating stream/rivers ~30m wide and 2 acre ponds used in hydroflattening of these lidar datasets were also used. The PA_South_Central_2017 and PA_Western_2019 projects had original coordinate reference systems of NAD83(2011), UTM Zone 17N meters, Geoid 12b . In order to produce the dataset in the desired coordinate reference system NAD83(2011) Contiguous USA Albers meters, Geoisd12b, the las files associated with these projects were reprojected and the bare earth DEMs remade from the point cloud. The third project, PA_North_Central_2019, was already in the desired coordinate reference system and did not require regeneration of the DEM.
In addition to the elevation data, the US census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) road lines, USGS digital Karts map, National Agriculture Imagery Program (NAIP) Imagery, and Google Earth Imagery and Street View were all used to aid hydrographic delineation and accuracy. Table 1 provides acquisition dates, lidar quality level, and vertical accuracy of the elevation data while Figure 2 illustrates the geographic breakdown of the source elevation data.

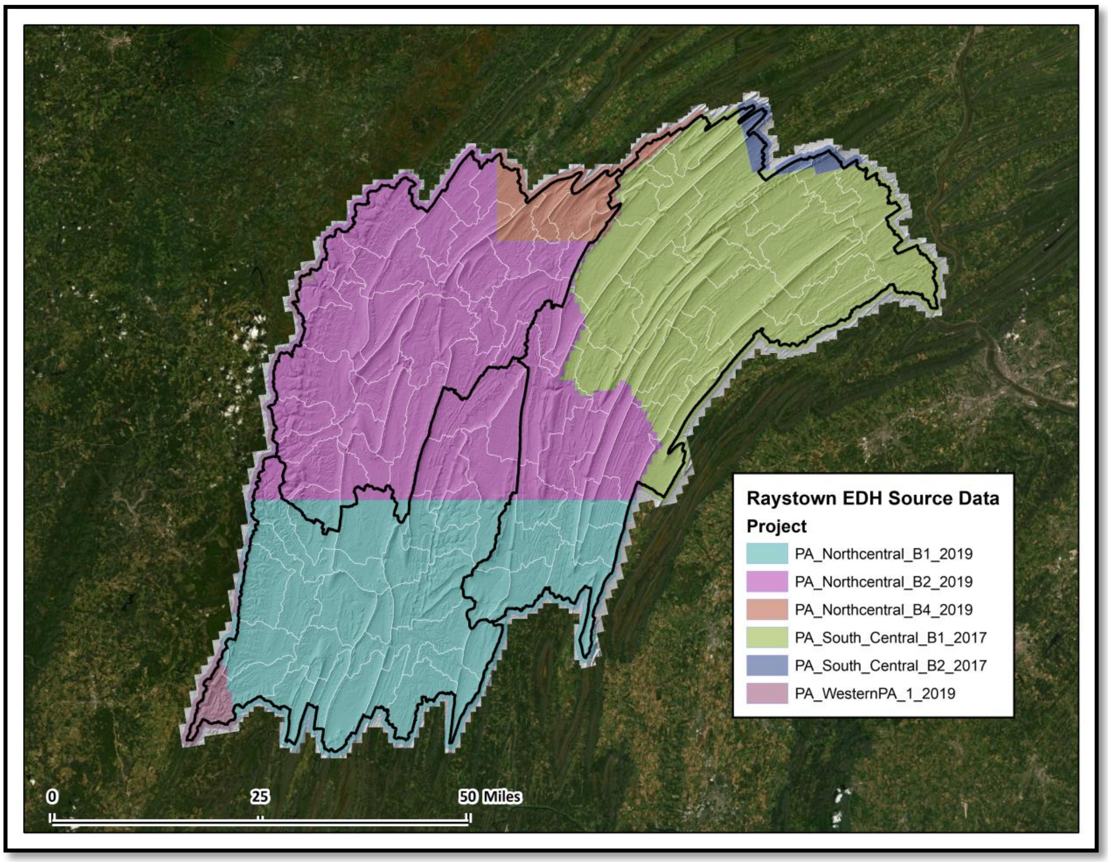

Figure 2: Geographic breakdown of the PA Raystown EDH lidar data sources

Table 1: PA Raystown EDH lidar data sources

Dataset	Acquisition dates	Quality level 2	Vertical Accuracy (95% CI)
PA_South_Central_B2_2017	11/21/17 – 12/21/17	QL2	0.122 m
PA_South_Central_B1_2017	11/21/17 – 12/21/17	QL2	0.122 m
PA_Northcentral_B1_2019	3/20/19 – 3/28/19	QL2	0.098 m
PA_Northcentral_B2_2019	3/26/19 – 4/11/19	QL2	0.098 m
PA_Northcentral_B4_2019	3/26/19 -11/16/19	QL2	0.098 m
PA_WesternPA_1_2019	11/18/19 – 3/9/20	QL2	0.065 m

Landscape Description

The PA Raystown area of interest (AOI) is located south central Pennsylvania. The area is part of the Ridge-and-Valley Appalachians with approximately half of the study area comprised of carbonate karst (Figure 3). The area is predominately deciduous forest with smaller developed areas and areas of farming and agriculture. Table 2 breaks down the approximate land cover classes of the study area according to the National Land Cover Database and Figure 4 displays the geographic breakdown.

Figure 3: Approximately 50% of the PA Raystown area is comprised of Carbonate Karst according to USGS published digital karst data[1].

[1] Weary, D.J., and Doctor, D.H., 2014, Karst in the United States: A digital map compilation and database: U.S. Geological Survey Open-File Report 2014–1156, 23 p., https://dx.doi.org/10.3133/ofr20141156.

Table 2: National Land Cover Dataset (NLCD) breakdown of land cover types in the PA Raystown AOI

NLCD Landscape Classification	Approximate % of the PA Raystown AOI
Water	0.86%
Developed	7.09%
Barren	0.29%
Deciduous Forrest	59.68%
Evergreen Forest	1.84%
Mixed Forest	7.59%
Shrub/Scrub	0.52%
Grassland/Herbaceous	0.54%
Pasture/Hay	10.62%
Cultivated Crops	10.67%
Wetlands	0.28%

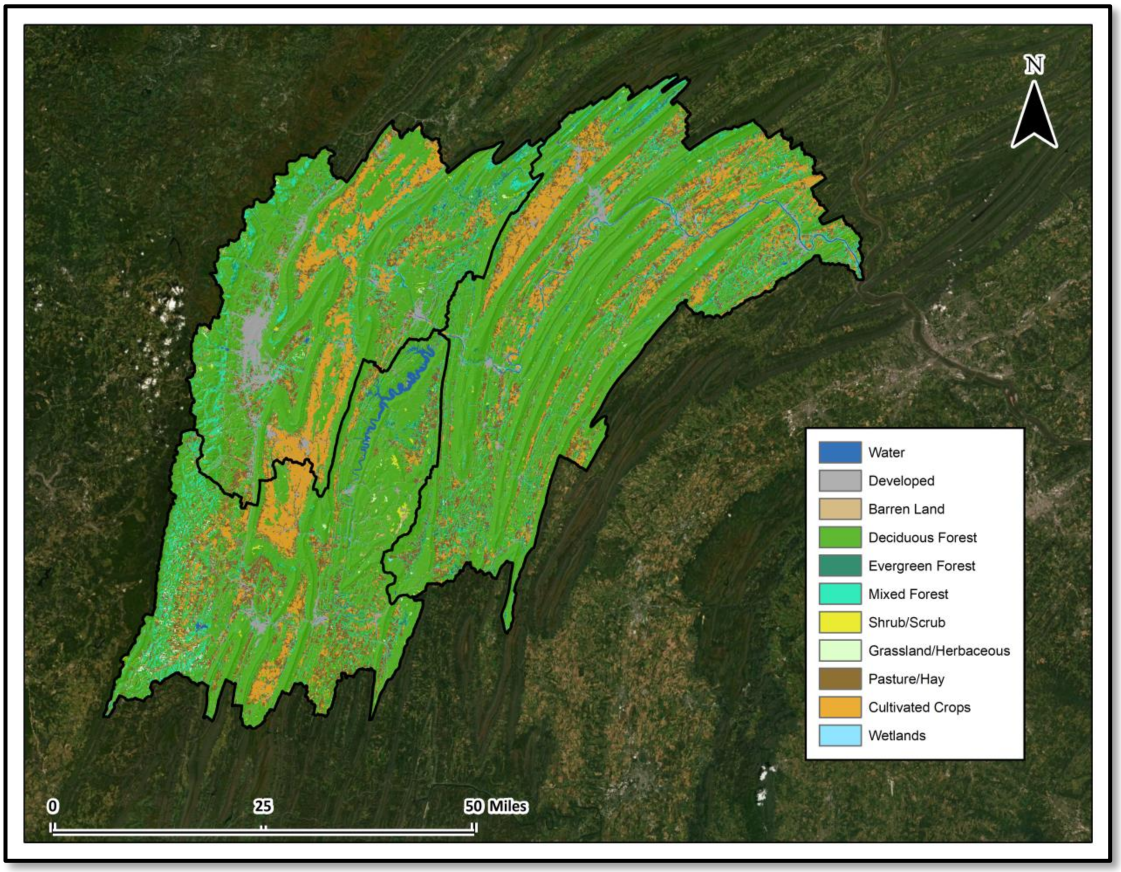

Figure 4: Geographic breakdown of land cover types in the PA Raystown EDH AOI

2D Delineation

The first step in the EDH delineation process is to create and finalize all 2-dimensional (2D) polygon features within the study area. It is prudent for these to be the first features analyzed, updated, and finalized when deriving hydrography from elevation data due to the subsequent necessary integration with the 1-dimensional (1D) polyline features.

The lidar breaklines from the 3 lidar source datasets were collected for all lake ponds >2 acres and stream >30m nominal width in accordance with the USGS lidar base specification (LBS). These breaklines were utilized for the EDH by applying a small negative buffer to ensure all vertices were placed directly on the hydroflattened surface. Vertices were then removed as necessary to ensure the required minimum vertex spacing of 1.5 meters.

While the lidar breaklines served to capture all major water features in the study area, EDH specifications call for higher resolution capture thresholds than the LBS. Per EDH specifications, lake/ponds > ~.4 hectares and stream/rivers or canal/ditches >15m require 2D delineation. Additionally, there is a requirement to collect all previous legacy NHD polygon features regardless of size, assuming there is still evidence of the feature in the elevation data. Additional capture to EDH specifications was done manually. The legacy NHDWaterbody and NHDArea polygons were used as reference during this process.

Once all 2D polygons were delineated, Z values were assigned from the lidar DEM. The previously captured lakes, ponds, and reservoirs were assigned a consistent elevation for the entire polygon while rivers were assigned consistent elevations on opposing banks and smoothed to ensure downstream flow through the entire river channel. The newly delineated polygons also had elevation values extracted from the DEM, but no hydroflattening was performed resulting in variable Z values for these features.

1D Delineation

Hydroenforcement

Hydroenforcement is a prerequisite for hydrography development and is the process of removing false obstructions such as culverts not visible in lidar and other spurious barriers to flow. Hydroenforcement is performed through a combination of automated and manual techniques. Automation of hydroenforcement is primarily performed through sink/depression identification (indicative of a barrier to flow) and least cost path analysis to find the barrier outlet based on DEM elevation. While this method can and does successfully breach many barriers, it is often not comprehensive enough and the accuracy of the breach outlet can vary in undesirable ways, specifically in built-up terrain. The critical nature of hydroenforcement to successful stream extraction necessitates manual review and often additional enforcement performed by trained analyst using ancillary raster layers and supplemental data to help draw focus to areas where flow is not being correctly modeled.

Once the hydroenforcement lines have been finalized, elevations from the DEM are extracted to line, monotonicity is enforced, and the elevations of the lines replace those of the original DEM to breach the false obstruction.

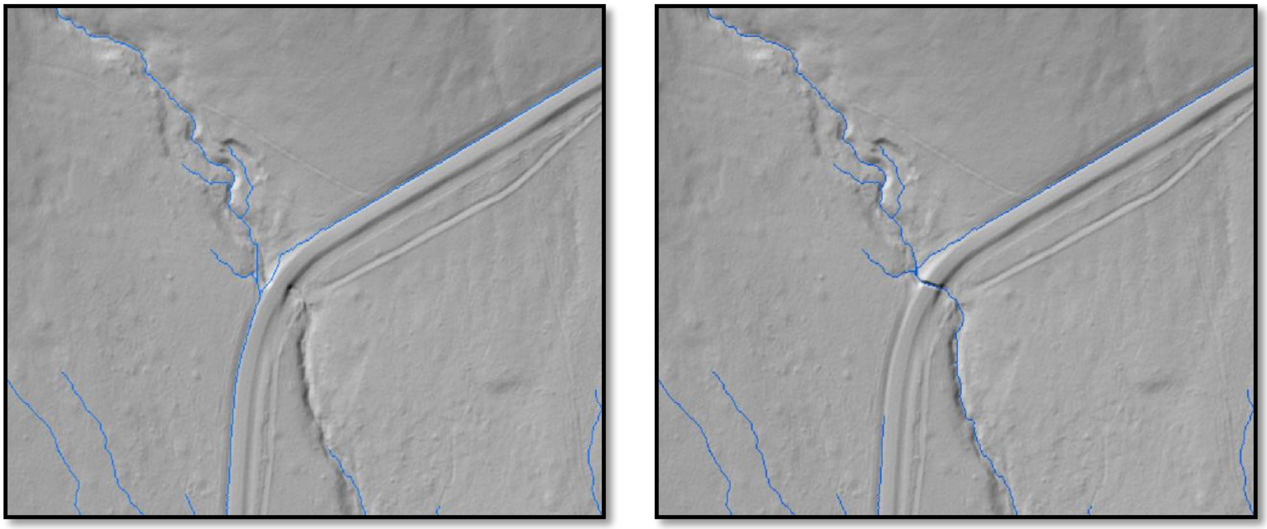

Figure 5: Example of a flowline path before and after DEM enforcement.

Flow Direction & Flow Accumulation

After hydroenforcement, the remaining small micro sinks and depressions are filled to allow for continuous flow across the landscape. The flow direction for each individual cell is then calculated using the D8 method. This process assigns a standard numeric integer to each cell indicating which of the surrounding 8 neighbors contains the lowest elevation value and thus the direction of flow. The flow direction raster is then run through a flow accumulation routine which sums the number of upstream cells for all cells in the raster. The value of the flow accumulation raster represents the upstream drainage area for every cell in the analysis area.

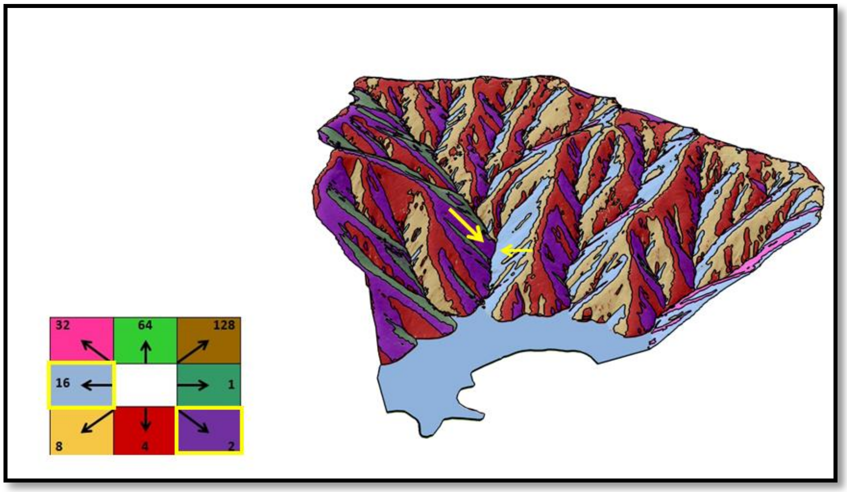

Figure 6: Flow direction coding used to determine the flow accumulation of a given raster cell

Flowline Delineation

The next step in the process requires determining a flow accumulation threshold at which to initiate stream delineation. Cells with high flow accumulation are highly likely to represent stream flow paths, however there are many smaller streams on the landscape that only drain small areas, but are nevertheless true streams that should be mapped. If too high a stream threshold is selected many smaller ephemeral streams will be missed and many headwaters will be downstream of their true location. The net result of selecting too high a flow accumulation/stream initiation threshold is an abundance of omission errors. If too low a stream threshold is selected there will be many false-positive streams mapped (commission errors) where there is no evidence of channelization in the ground model. A balance therefore must be struck between selecting a low enough flow accumulation to map all visible stream channels while avoiding the generation of an abundance of false-positive streams that will need to be filtered out. An initial flow accumulation threshold of 2 acres was used to generate the initial flowlines.

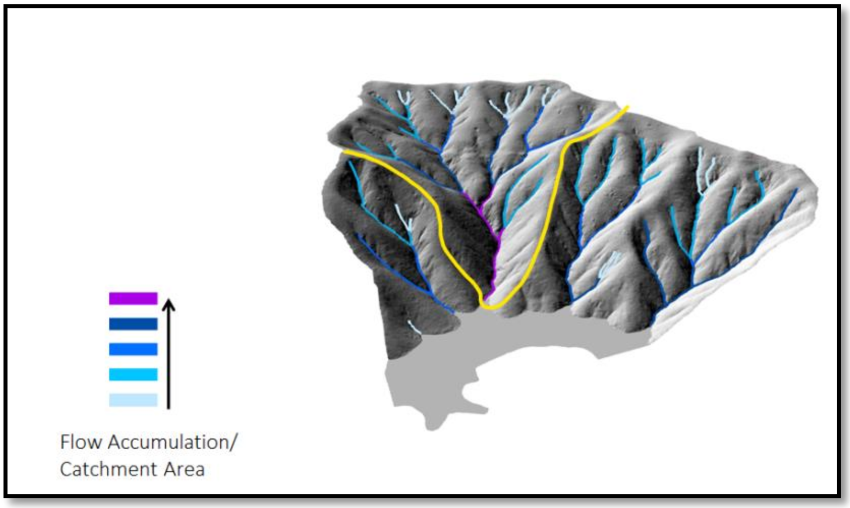

Figure 7: Flow accumulation values increase from upstream to downstream

Smoothing

After automated stream generation, the network must be smoothed to remove the rasterization of the flow lines. The automated flowlines are run through a custom XY smoothing routine that removes the rasterization while maintaining alignment with the stream channels of the DEM.

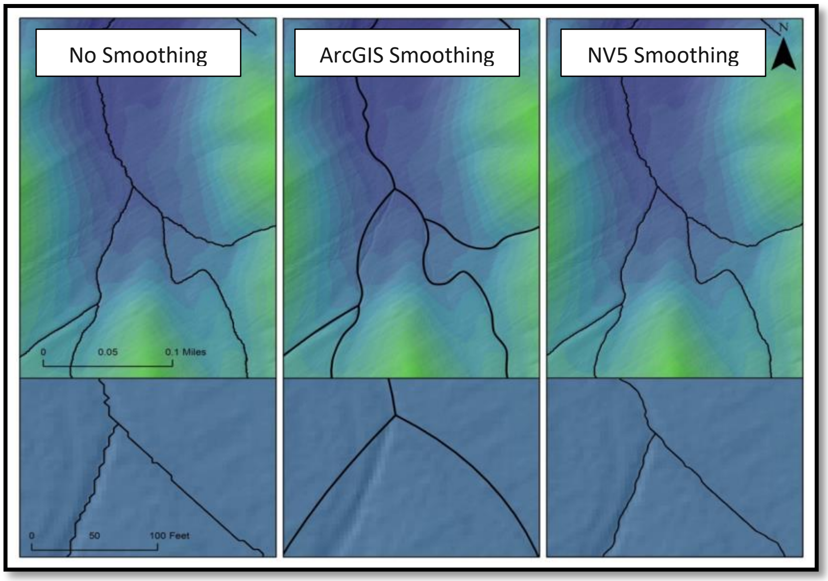

Figure 8: NV5's custom XY smoothing removes rasterization while maintaining spatial accuracy.

Network Integration

Once the stream lines have been cartographically smoothed, they must be incorporated with the updated 2D polygons. The previously discussed flow direction and flow accumulation routines do not perform well on hydroflattened surfaces. In these areas flowlines are often incorrectly delineated as parallel lines running toward the outer edges of the waterbody feature rather than representing the centerline of the 2D polygon. In order to avoid excess artificial paths within polygons and create true centerlines, the data is run through a custom network integration routine that removes all automatically generated streamlines within the polygons and replaces them with true centerlines. The integration process then creates artificial path lines to join all inflowing streams to the main centerline of the feature. (Figure 9)

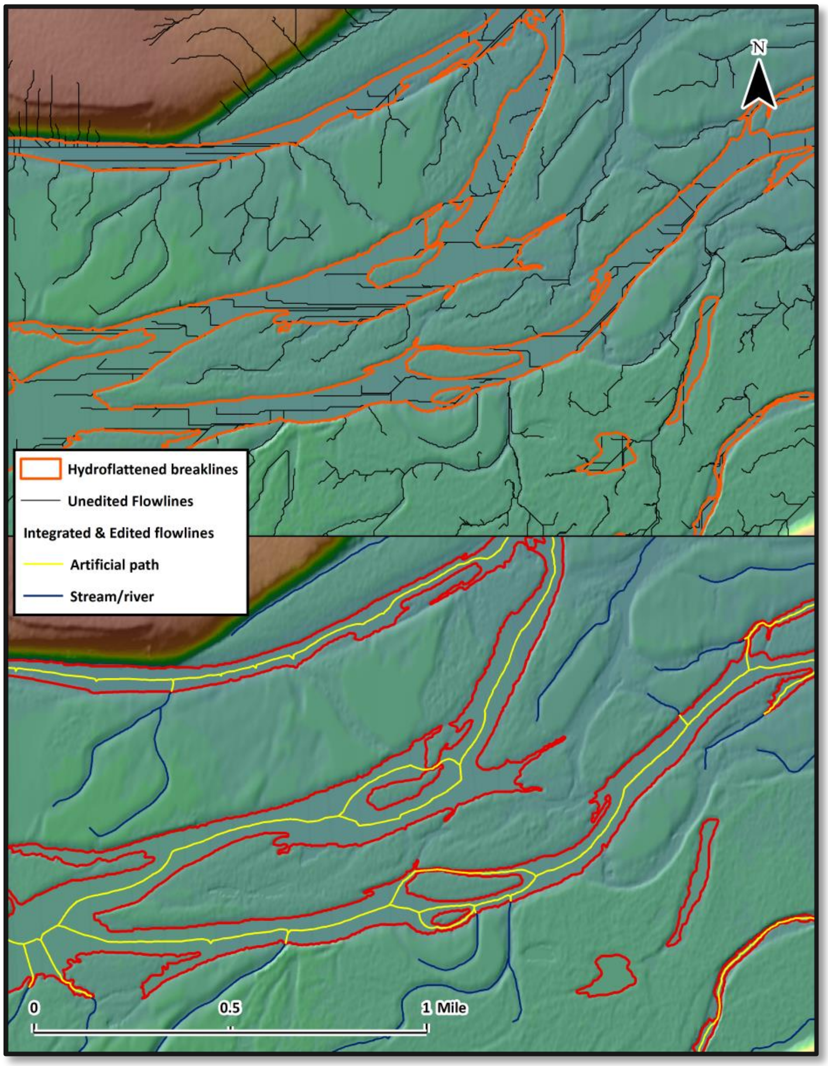

Figure 9: The top image shows the model-derived flowlines on the hydroflattened river surface. The bottom image shows NV5's automated custom integration process resulting in clean centerlines linking surface flow through waterbodies.

Omission/Commission

Omission and specifically commission identification are particularly important in creating high accuracy hydrography. In order to aid in omission and commission identification, several derivative rasters recommended by the USGS were generated and used for both automated and manual omission and commission. These include raster calculations of geomorphons, openness, curvature, and Bothat filtering. Geomorphons is a method for delineating the landscape into discrete geomorphic classes such as pit, valley, peak, etc. from which the landform types associated with streams (footslope, valley, and depression) are extracted. Openness and curvature help identify degree of channelization, while Bothat filtering helps identify low relief channels. These data layers were used to aid in the automated commission filtering by comparing the auto generated stream lines to these indicator layers. Likewise, channels signature locations without associated streamlines can also be identified during manual review and investigated for inclusion in the network.

All streams that are found to have good correlation with the geomorphic indicators are retained. These flowlines are then used with network tracing routines to identify additional stream lines that do not necessarily display channelization in the ground model, but are necessary to retain for network connectivity.

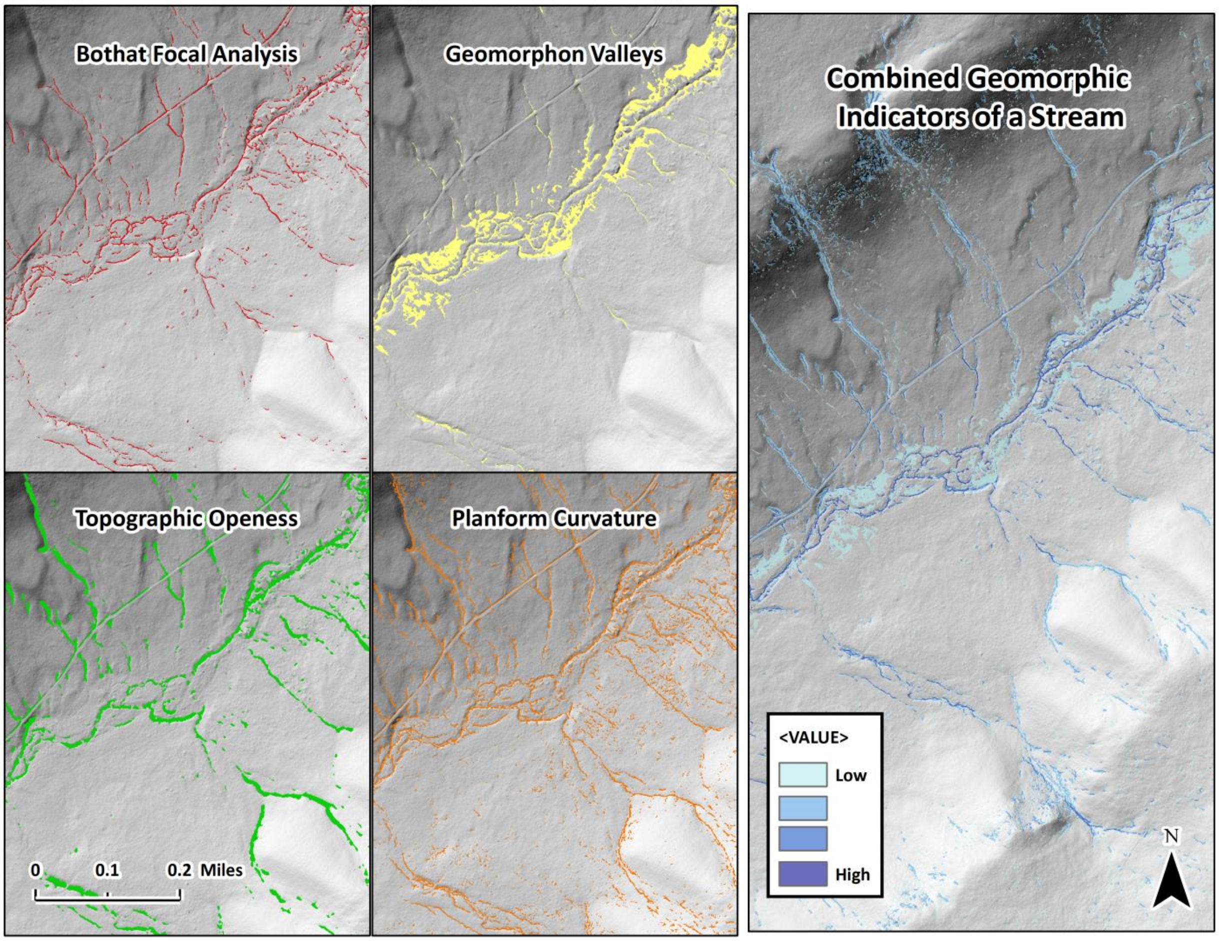

Figure 10: Multiple ancillary layers can be derived from the lidar DEM to describe the landscape and aid in automated streamline detection.

Manual Review

Once the automated filtering has been run, the data is passed to a trained analyst for review. Analyst are also provided the selected geomorphic indicator layers to aid in their manual review and ensure flowlines remain in the stream channel throughout the length of the line. If omission errors are identified, additional finer scale stream lines for the localized area can be generated using a lower flow accumulation threshold and are added to the stream network.

Quality assurance layers are provided to the editors to draw attention to things such as lines flowing across ridges, lines or line segments not corresponding to the GMI, and long unnaturally straight segments.

Z values

Post manual review, once all XY feature position was finalized, Z values were added to the line work and downstream monotonicity was enforced using custom scripting routines based on line direction. Monotonicity was strictly enforced for all features with and Eclass of 2 (Hydrographic feature used for elevation purposes) or 3 (Culvert – used for hydro-enforcement).

Culvert and Terrain Breach Segmentation

The elevation derived hydrography specification calls for the segmentation of culvert features to be used for hydroenforcement. Culvert features were identified by comparing the monotonically enforced elevation values to the elevation ground model. Area where vertices were significantly below the DEM surface as compared to adjacent vertices were identified and used to segment the derived flowline. This automated process was then manually reviewed and additional culverts identified as necessary. Sinks/depressions and headwater stream points within 30m of roads were used during manual review to aid in appropriate culvert capture.
Where the DEM misalignment was greater than 1m and did not appear to near a road or be a true culvert, the connector: terrain breach attribution was used. In some areas terrain breach features were necessary due to heavy vegetation obscuring the ground along reach sections resulting in incorrect TIN'ing and falsely high elevation values. Per USGS guidance, terrain breaches were not used in areas of karst topography.

Karst Terrain

As noted in the landscape description section, the area of interest contains many karst features[2] complicating the hydrography delineation process. Per USGS guidance, karst sinks greater then 3m were identified and used as the termination point for the upstream network in most cases. In areas where the sink was less then 3m and/or did not appear to have a hard wall stopping point where underground flow begins, indefinite surface connectors (Fcode 33404) were used to provide network connectivity. In most cases, enforcement of downhill Z values could not be maintained while preserving DEM alignment and therefore these features have been attributed with the comment "*Downstream monotonicity cannot be enforced through karst terrain depressions in the surface*." It should be noted that there were several areas of what appeared to be karst terrain existing outside of the official karst delineation. Indefinite surface features associated with this terrain have been distinguished with the comment "*Connection through karst-like area but not in official karst shape*."

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[2] Areas of karst for the purpose of this project were defined by the dataset Karst in the United States: A Digital Map Compilation and Database (Weary and Doctor, 2014).

Below are descriptions of each of the 2D and 1D feature codes (Fcodes) found within the PA Raystown elevation derived hydrography dataset. The possible combinations of Ftype, Eclass, and specific comments are provided for each Fcode along with further description where applicable.

2-D features

Lake/Pond

Lake/pond features were attributed based on the legacy NHDWaterbody polygons. Newly delineated lake/pond polygons were attributed based on their geometry characteristics and connection to 1D stream/river flowlines.

Ftype	Eclass	Fcode	Comment	Description	Number
1	1	39000	-	Lake/Pond	52
1	1	39000	Not hydroflattened, not original lidar breakline	Lake/Pond feature that met EDH capture specifications but did not meet Lidar base specifications and therefore has not been hydroflattened	952

Reservoir

Reservoir features were attributed based on the legacy NHDWaterbody polygons. Newly delineated reservoir polygons were attributed based on their geometry characteristics.

Ftype	Eclass	Fcode	Comment	Description	Number
1	0	43600	Not hydroflattened, not original lidar breakline	Reservoir feature that met EDH capture specifications but did not meet Lidar base specifications and therefore has not been hydroflattened	4

Stream/river

Stream/river features were attributed based on the legacy NHDArea polygons. Newly delineated Stream/river polygons were attributed based on their geometry characteristics and connection to 1D Stream/river flowlines.

Ftype	Eclass	Fcode	Comment	Description	Number
1	1	46000	-	Stream/River	12
1	1	46000	Not hydroflattened, not original lidar breakline	Stream/River feature that met EDH capture specification but did not meet Lidar base specifications and therefore has not been hydroflattened	1

Dam/Weir

Dam/Weir polygon features were delineated and attributed based on the legacy NHDArea polygons.

Ftype	Eclass	Fcode	Comment	Description	Number
1	0	34300	-	Dam/Weir polygon that existed as and NHD polygon	1

1-D Features

Connector

Connector features were utilized to maintain network connectivity where the exact connection was not visible in elevation or other reference data. Connectors used to represent unknown flowpaths through areas of infrastructure were differentiated from those providing connections through dam features.

Ftype	Eclass	Fcode	Comment	Description	Number
1	0	33400	Infrastructure Connection – unknown flowpath	Connector feature used to maintain network connectivity where the exact connection was not visible in the elevation data due to infrastructure	34
1	3	33400	Dam	Connector associated with a Dam	296

Connector: Culvert

Culverts were attributed using DEM alignment and supplemental TIGER roads shapefiles. Features proximate to roads that also displayed deviation from the DEM after enforcing downstream monotonicity were attributed as culverts.

Ftype	Eclass	Fcode	Comment	Description	Number
1	3	33401	-	Connector: Culvert	16,610

Connector: Indefinite Surface

Indefinite surface connectors were utilized in areas of karst terrain as well as in areas lacking channelization within the GMI. Areas lacking channelization were defined as any non-headwater flowpath >100m in contiguous length falling outside of the GMI or any line with a >40% of its total length falling outside of the GMI. Features less than 100m were excluded from this analysis.   The indefinite surface features associated with karst terrain have the previously discussed comments added to the feature and have not been downhill Z enforced. Features simply lacking channelization in the GMI but necessary for network connection have no associated comment and have monotonic elevations. Some indefinite surface connectors may appear to contain pseudo nodes however these are valid breaks where the comment field distinguishes between lines associated with karst and lines outside of the GMI.

Ftype	Eclass	Fcode	Comment	Description	Number
1	0	33404	Connection through karst-like area but not in official karst shape	Flowpath through what appears to karst terrain where monotonicity cannot be maintained however not located within an officially designated karst area.	15
1	0	33404	Downstream monotonicity cannot be enforced through karst terrain depressions in the surface	Flowpath through karst terrain where downstream monotonicity cannot be enforced while maintaining alignment with the DEM	84
1	2	33404	-	Flowpath used to provide network connectivity through areas lacking channelization as indicated by the GMI layer	736

Connector: Terrain Breach

Terrain breaches were attributed in areas where line placement was verified, but enforcement of monotonicity resulted in vertices greater than 1m below the surface for short reaches, most often due to TIN'ing artifacts in the DEM due to heavy vegetation and a lack of ground classified points. No terrain breaches exceed 100m in length.

Ftype	Eclass	Fcode	Comment	Description	Number
1	3	33405	-	Terrain Breach	152

Canal/Ditch

Canal/Ditches were classified in urban areas where hydrography runs along roads or in clearly defined, man-made channels.

Ftype	Eclass	Fcode	Comment	Description	Number
1	2	33600	-	Canal/Ditch	28

Dam/Weir

Dam/Weir lines were based on legacy NHD Dam/Weir Lines. Lines were manually digitized where the ground model indicated dam presence.

Ftype	Eclass	Fcode	Comment	Description	
1	0	34300	-	Dam/Weir location	9

Stream/river

Stream River features were attributed based on the legacy NHD attribution.

Ftype	Eclass	Fcode	Comment	Description	Number
1	2	46000	-	Stream/river feature	58,453

Drainageway

Drainageways represent upstream/headwater reaches of the network where channelization was less pronounced in the GMI layer resulting in >40% of the line falling outside of the GMI layer.

Ftype	Eclass	Fcode	Comment	Description	Number
1	2	46800	-	Headwater flowpaths in low slope areas lacking distinct channelization in the elevation data	23

Artificial Paths

Artificial Paths represent all flowpaths delineated through 2D polygon features. Some artificial paths may appear to contain pseudo nodes however these are valid breaks where 2D stream/river polygons transition from smaller non hydroflattened stream/rivers to the larger hydroflattened stream/rivers. There are also select artificial paths within the non-flattened polygons that contain vertices that do not align with the DEM. These were manually reviewed and are the result of TIN'ing artifacts in the DEM.

Ftype	Eclass	Fcode	Comment	Description	Number
1	2	55800	-	Flowpath connecting 1D stream through a 2D polygon	4,701
1	2	55800	Contains vertices > 1m below the surface due to TIN'ing	Flowpath connecting 1D stream through a 2D polygon	8

Point features

User-defined feature

The user-defined feature represents the outlet point for the HU8 watershed. It is not part of the EDH capture specifications but represents the drainage point of the mapped hydrography.

Ftype	Eclass	Fcode	Comment	Description	Number
2	0	0	Network End - HU8 02050304 Outlet	Outlet	1

Sink/Rise

The existing NHD contained 9 SinkRise points. These areas were individually reviewed using the lidar DEM and 4 of the locations were delineated in the updated hydrography. An additional 165 Sink/Rise points were captured based on the attribution of the linework. Of the total 171 points captured from the updated hydrography, 72 of these represent sink bottoms >3m deep where the line network terminates. The other 99 Sink/Rise features captured represent sinks between 1 and 3m where the network does not terminate, but downhill monotonicity could not be maintained on the lines exiting the sink.

Ftype	Eclass	Fcode	Comment	Description	Number
2	0	45000	Karst Sink	Sink/Rise location	99
2	0	45000	Network End - Karst Sink	Sink/Rise location	72

XY Alignment

Feature alignment was assessed using the previous mentioned geomorphic indicator layers and minimum elevation percentile raster. Alignment was measure for only those features attributed as streams, which are expected to align with the geomorphic indicator layers. When alignment was measured, 91.11% of all stream-classified lines corresponded to these layers.

Z alignment

Z alignment was assessed by comparing the final feature vertex Z values to the final hydroflattened DEM. All polygon vertices are placed on the hydroflattened surface and therefore have no significant deviation from the DEM. The below table summarize the results for polyline vertices compared to the DEM, broken out by Eclass and Fcode.

Table 3: Average deviation from elevation data by Feature Type

Eclass	Feature Type	Number of features	Average deviation from the elevation data
2	Artificial Path	4,709	0.04 m
2	Canal/Ditch	28	0.07 m
0	Connector	34	0.12 m
3	Connector	296	0.47 m
3	Connector: Culvert	16,610	0.5 m
0	Connector: Indefinite Surface Connection	99	0.00 m
2	Connector: Indefinite Surface Connection	736	0.01 m
3	Connector: Terrain Breach	152	0.97 m
2	Drainageway	23	0.00 m
2	Stream/river	58,452	0.02 m

Density

The legacy NHD for HU 02050304 - Lower Juniata Watershed area of interest contained ~ 2,684 miles of hydrography flowlines. The elevation derived hydrography contains ~ 7,410 miles, representing a 2.76 density increase of mapped flowlines.

Legacy NHD Comparison

Polygons

Of the previously existing 881 NHD waterbody lake/pond polygons 658 were captured in the update. The remaining 239 were omitted due to lack of evidence to the lidar DEM. Of the omitted waterbodies, two had official GNIS names and IDs in the legacy NHD data: Minehart Reservoir (01201561) & Bear Pond (01168901).

Polylines

The NHD was used as an aid in flowline delineation to ensure previously delineated features were captured if supported by the elevation data. All 148 named streams within the AOI were specifically reviewed to ensure capture and connectivity.

When comparing the legacy NHD to the updated elevation-derived hydrography, 85.69% of legacy lines representing 97.87% of the total length of the legacy NHD intersected the updated hydrography. When the search radius is expanded to 10m 95.66% of legacy lines representing 99.42% of the total length of the legacy NHD were represented.

Points

The existing NHD contained 9 SinkRise points. These areas were individually reviewed using the lidar DEM and 4 of the locations were delineated in the updated hydrography. The other points were not supported as sinks based on the lidar DEM.