

Creating a Hydro-enhanced Elevation Surface Using the Fully Integrated Elevation and Hydrography 3DHP Product

NSGIC 3DHP FTN Forum

March 15, 2023

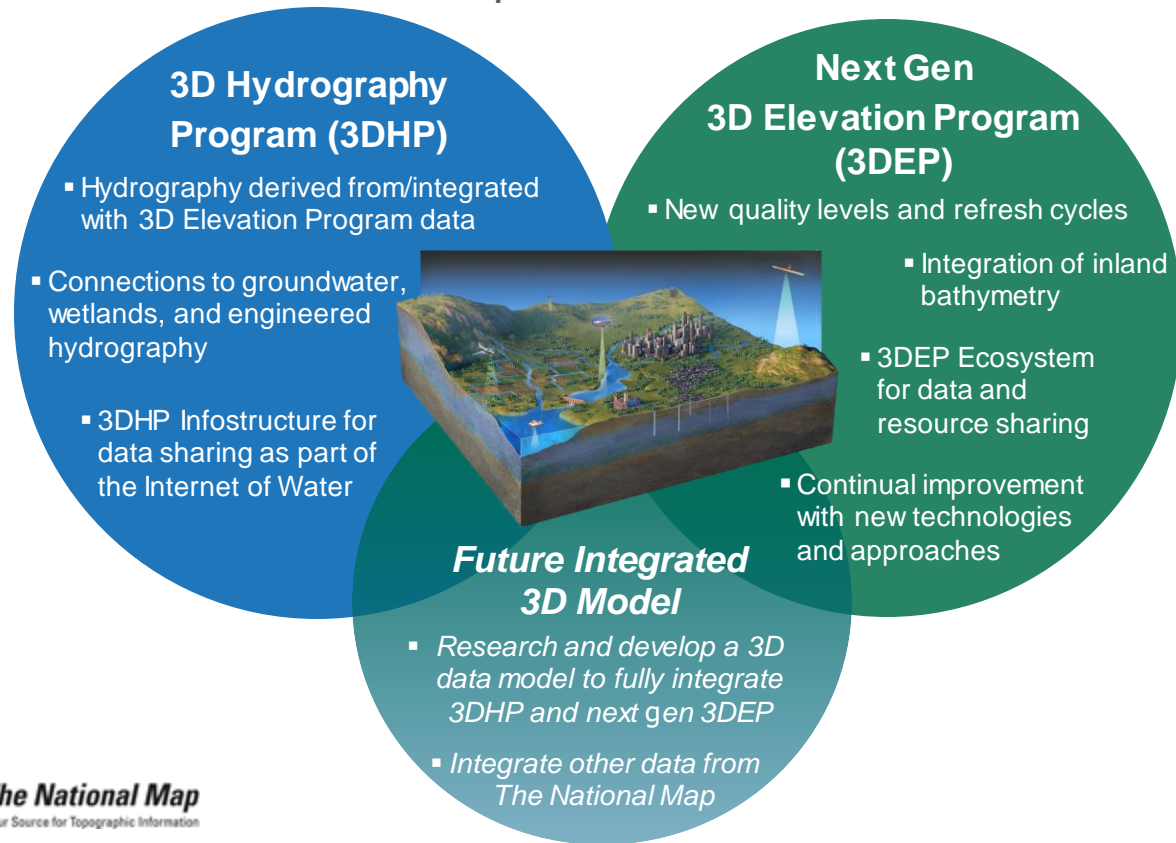
Silvia Terziotti

USGS National Geospatial Program



3D National Topography Model (3DNTM)

The terrestrial component of the 3D Nation vision of a continuous data surface from the depths of the oceans to the peaks of the mountains

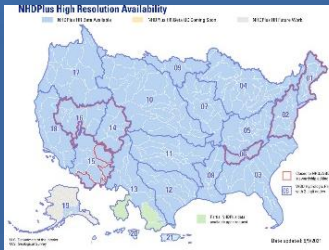


3D National Topography Model (3DNTM)

Integrates elevation and hydrography to model the Nation's topography in 3D

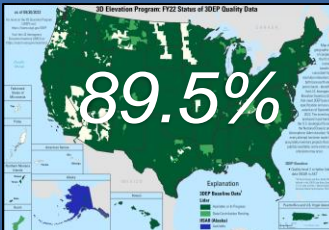
National Baseline Datasets

NHDPlus High Resolution (NHDPlus HR)
hydrography framework



CONUS and southern AK completed, transitioning to 3DHP

3D Elevation Program (3DEP)
first national high-resolution elevation baseline



On track to complete acquisition by FY26

Ongoing

Next Generation Programs



- 3D Hydrography Program
- Next generation 3D Elevation Program - New quality levels and refresh cycles

Under development

Integrated 3D Model

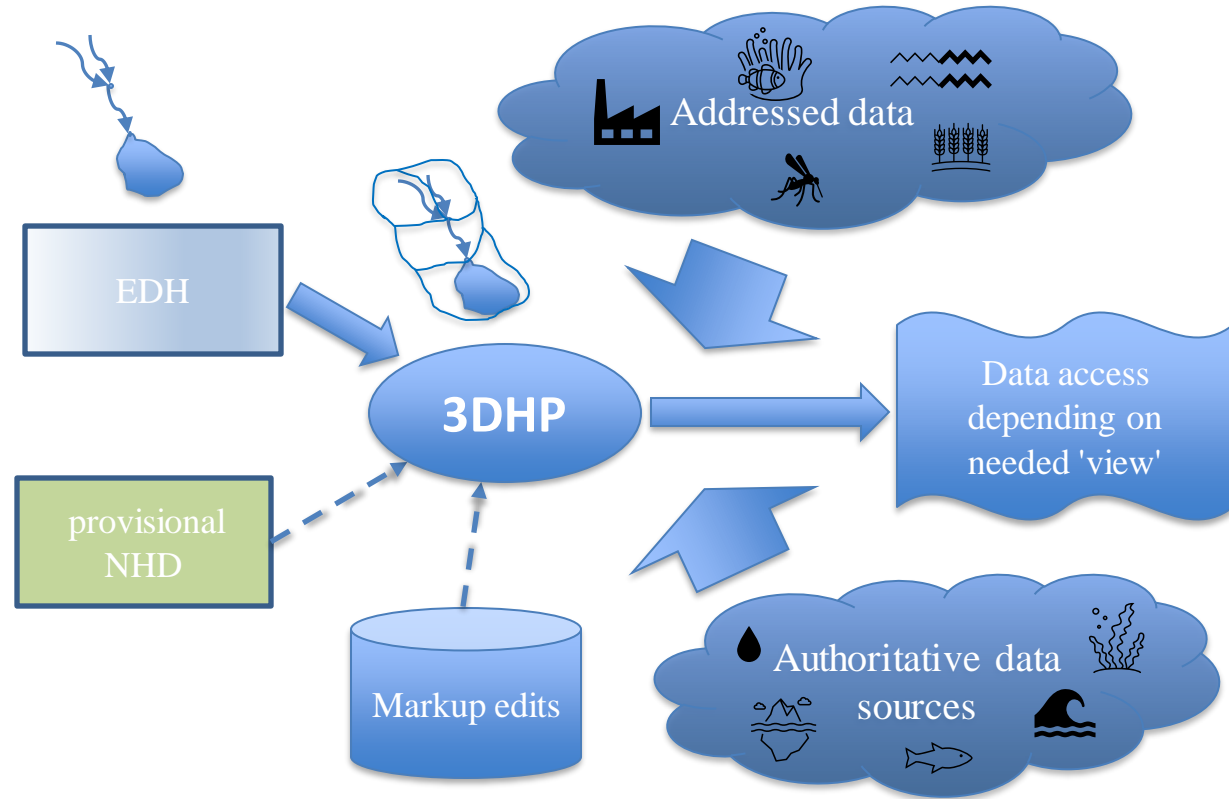


- Research and develop a 3D data model to fully integrate 3DHP and Next Gen 3DEP
- Integrate other data from *The National Map*

Longer-term goal

Data model – Core and Customizable Features


- Elevation-derived hydrography (EDH) will be the primary input for 3DHP.
- Mainstem ids and hydrolocations that will be conflated to EDH. This links the new data to all versions of old data that use mainstem ids
- 3DHP will include many outside attributes addressed to the data
- Authoritative sources will also be integrated.
- Multiple ways to view, download and analyze the data will be possible





**Elevation-Derived Hydrography
Representation, Extraction, Attribution, and Delineation Rules**

Chapter 12 of
Section B, U.S. Geological Survey Standards, of
Book 11, Collection and Delineation of Spatial Data



Specifications
for Hydrography
and Elevation

Hydrography Specifications

Published July 2020

- USGS Techniques and Methods 11–B11: Elevation-Derived Hydrography Acquisition Specifications

Terziotti, S., and Archuleta, C.M., 2020, Elevation-Derived Hydrography Acquisition Specifications: U.S. Geological Survey Techniques and Methods, book 11, chap. B11, 74 p., <https://doi.org/10.3133/tm11B11>.

- USGS Techniques and Methods 11–B12: Elevation-Derived Hydrography—Representation, Extraction, Attribution, and Delineation Rules

Archuleta, C.M, and Terziotti, S., 2020, Elevation-Derived Hydrography—Representation, Extraction, Attribution, and Delineation Rules: U.S. Geological Survey Techniques and Methods, book 11, chap. B12, 60 p., <https://doi.org/10.3133/tm11B12>.

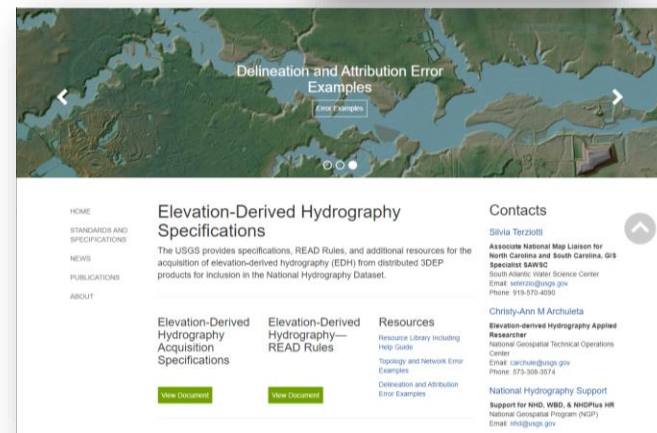
- Specification resources online – UPDATES available

[Elevation-Derived Hydrography Specifications | U.S. Geological Survey \(usgs.gov\)](#)

Elevation-Derived Hydrography Acquisition Specifications 2022 rev. A ([pdf](#))

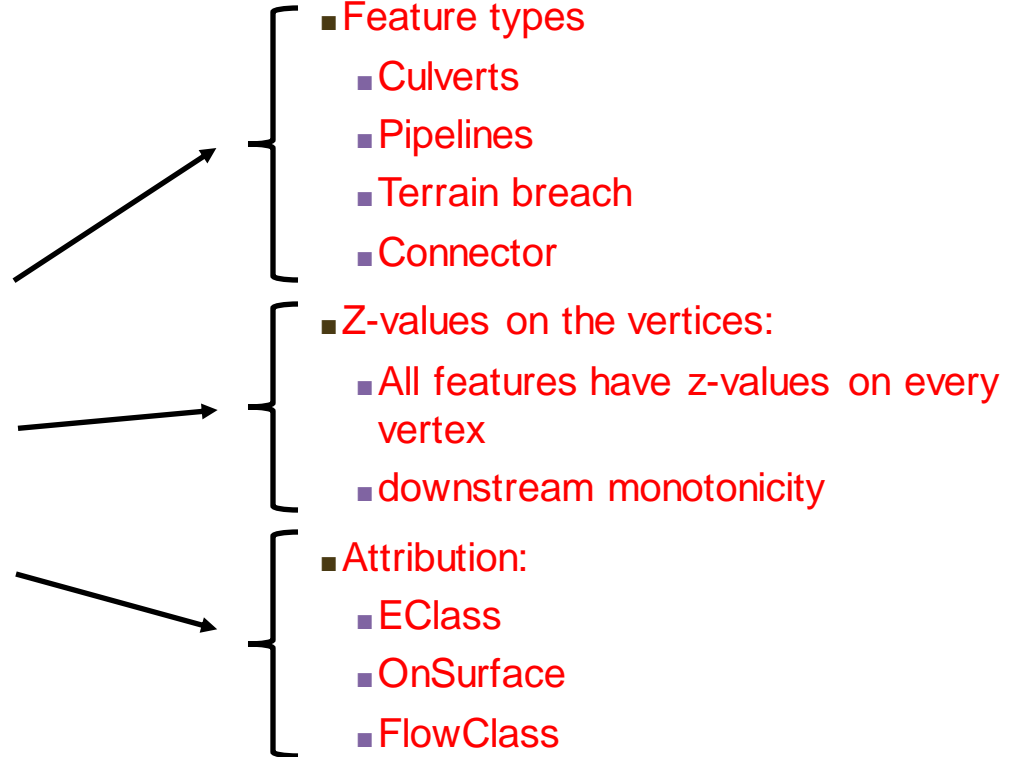
Elevation-Derived Hydrography Acquisition Specifications 2021 rev. A ([pdf](#))

Elevation-Derived Hydrography Acquisition Specifications 2020 rev. A ([pdf](#))



Elevation-derived hydrography specification

- The specification was written to accommodate the hydrography treatment of elevation surfaces.
- The hydrography has:
 1. features that allow breaching the elevation surface,
 2. z-values that allow elevation integration and correction, and
 3. attributes that define features suitable for hydro-enforcement.



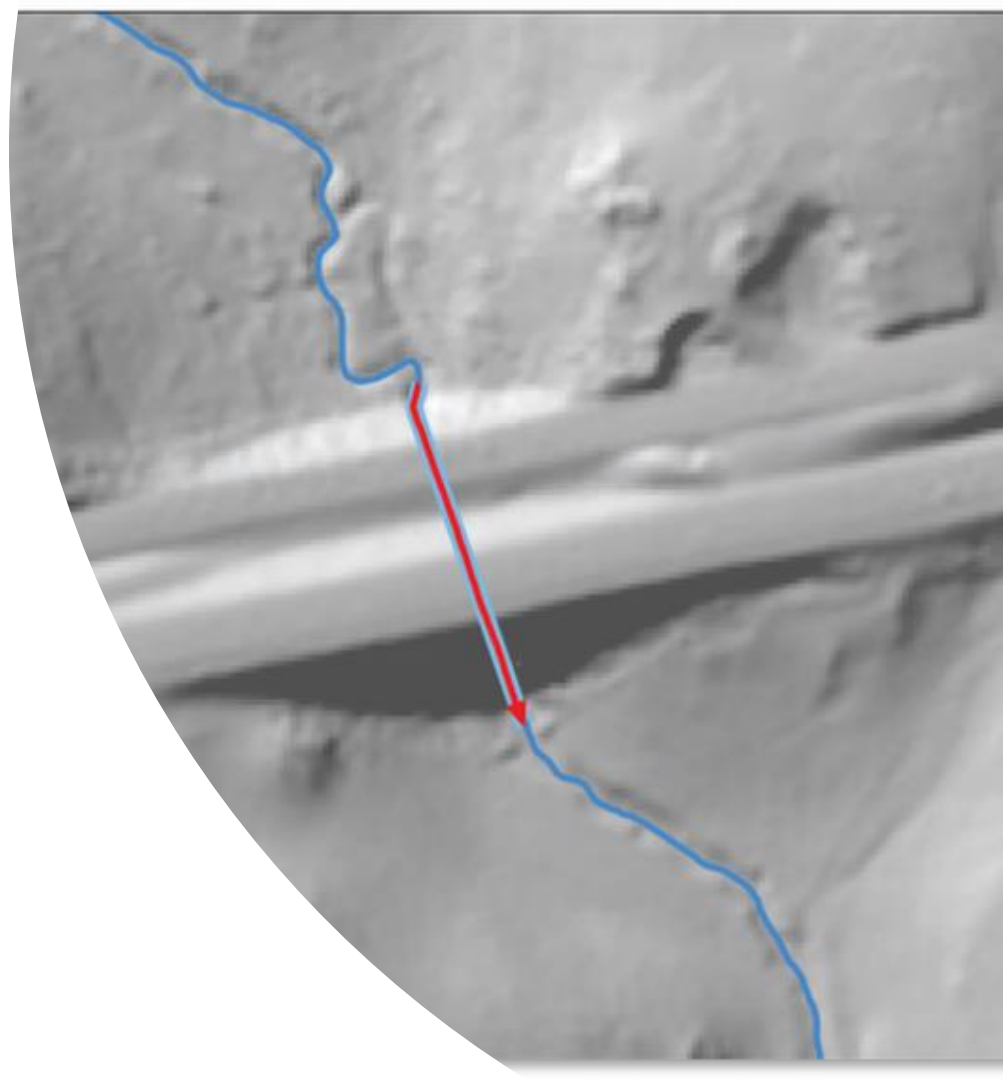
Feature type

Feature types have been defined that can be greater than 1 meter below the surface (underground conduits)

Features can indicate a place where the terrain must be breached (culverts, terrain breaches, connectors)

Depressions in the landscape can also cause issues with maintaining downstream monotonicity.

Special guidelines have been written for Karst terrain and depressions within non-karst terrain to route flow through areas with depressions.



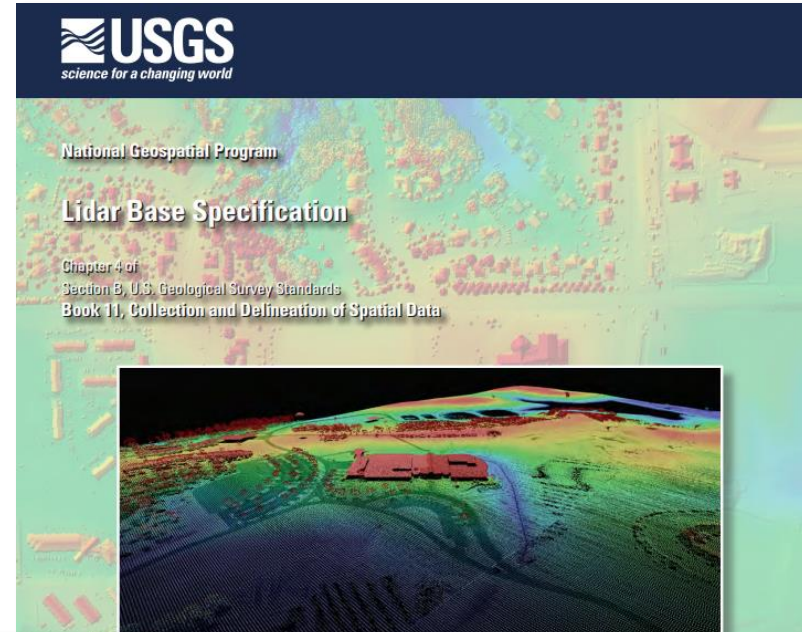
Lidar Base Specifications

First published 2014

Lidar Base Specification By Hans Karl Heidemann
Chapter 4 of Section B, U.S. Geological Survey
Standards Book 11, Collection and Delineation of
Spatial Data

- Suggested citation: Heidemann, Hans Karl, 2018, Lidar base specification (ver. 1.3, February 2018): U.S. Geological Survey Techniques and Methods, book 11, chap. B4, 101 p., <https://doi.org/10.3133/tm11b4>.

Specification resources online – UPDATES available



Download a copy of the Lidar Base Specification 2022 rev. A online content
Revision History

- [2022 rev. A](#)
- [2021 rev. A](#)
- [2020 rev. A](#)
- [Version 2.1](#)
- [Version 2.0](#)
- [Version 1.3](#)
- [Version 1.2](#)
- [Version 1.1](#)

Hydrography and Elevation overlap

LBS contains 2 sections that are important to Hydrography

Lidar Base Specification 2022 rev. A

DEM Surface Treatments

The character of lidar-based DEMs differs from traditional DEMs derived through stereo photogrammetry, necessitating additional treatment of the lidar-based topographic surface. Flattening water surfaces is the primary target of current treatments.

- Bridges
 - *Removal of Bridges – “A structure carrying a road, path, railroad, canal, aircraft taxiway, or any other transit between two locations of higher elevation over an area of lower elevation. A bridge may traverse a river, ravine, road, railroad, or other obstacle. “Bridge” also includes but is not limited to aqueduct, drawbridge, flyover, footbridge, overpass, span, trestle, and viaduct. In mapping, the term “bridge” is distinguished from a roadway over a culvert in that a bridge is an elevated deck that is not underlain with earth or soil. See culvert, saddle.”*
- Hydroflattening
 - *Breaklines for polygons are collected: “Hydro-flattening pertains only to the creation of derived DEMs from lidar points and breaklines. Hydro-flattening makes no changes to the geometry of the originally computed lidar points. Breaklines developed for use in hydro-flattening may also be used to support classification of the point data”*

Hydrography and Elevation overlap

The Bridge and Hydroflattened areas are delivered as Breaklines.

- Delivery of all breaklines collected on or used in support of the project is required for USGS–NGP lidar projects. This **includes breaklines used for bridge and saddle treatments** and any additional breaklines required by project cooperators.
- **Breaklines representing all hydro-flattened features** in a project, regardless of the method used for hydro-flattening, are required for USGS–NGP lidar projects. Specific research projects may be exempt from these requirements with prior approval of the USGS–NGP.
- Breaklines delivered in shapefile or file geodatabase formats, as PolylineZ and PolygonZ feature classes, as appropriate to the type of feature represented and the methodology used by the data producer.

Lidar Base Specification Point Classification

Classes are also important and a possible area for enhancement

Table 5: Minimum light detection and ranging data classification scheme.

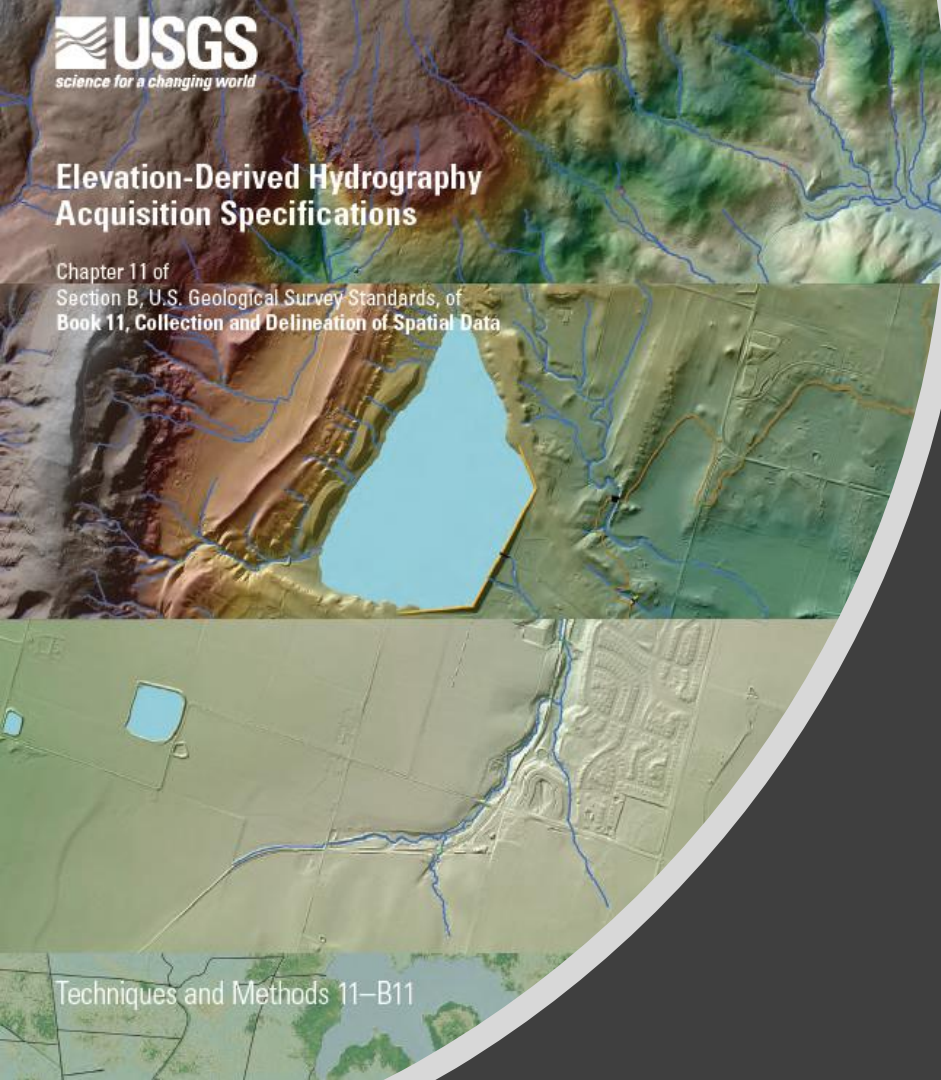
Code	Description
1	Processed, but unclassified
2	Bare earth
7	Low noise
9	Water
17	Bridge deck
18	High noise
20	Ignored ground (<i>typically breakline proximity</i>)
21	Snow (<i>if present and identifiable</i>)
22	Temporal exclusion (<i>typically nonfavored data in intertidal zones</i>)

?

Elevation-Derived Hydrography Acquisition Specifications

Chapter 11 of
Section B, U.S. Geological Survey Standards, of
Book 11, Collection and Delineation of Spatial Data

Techniques and Methods 11-B11

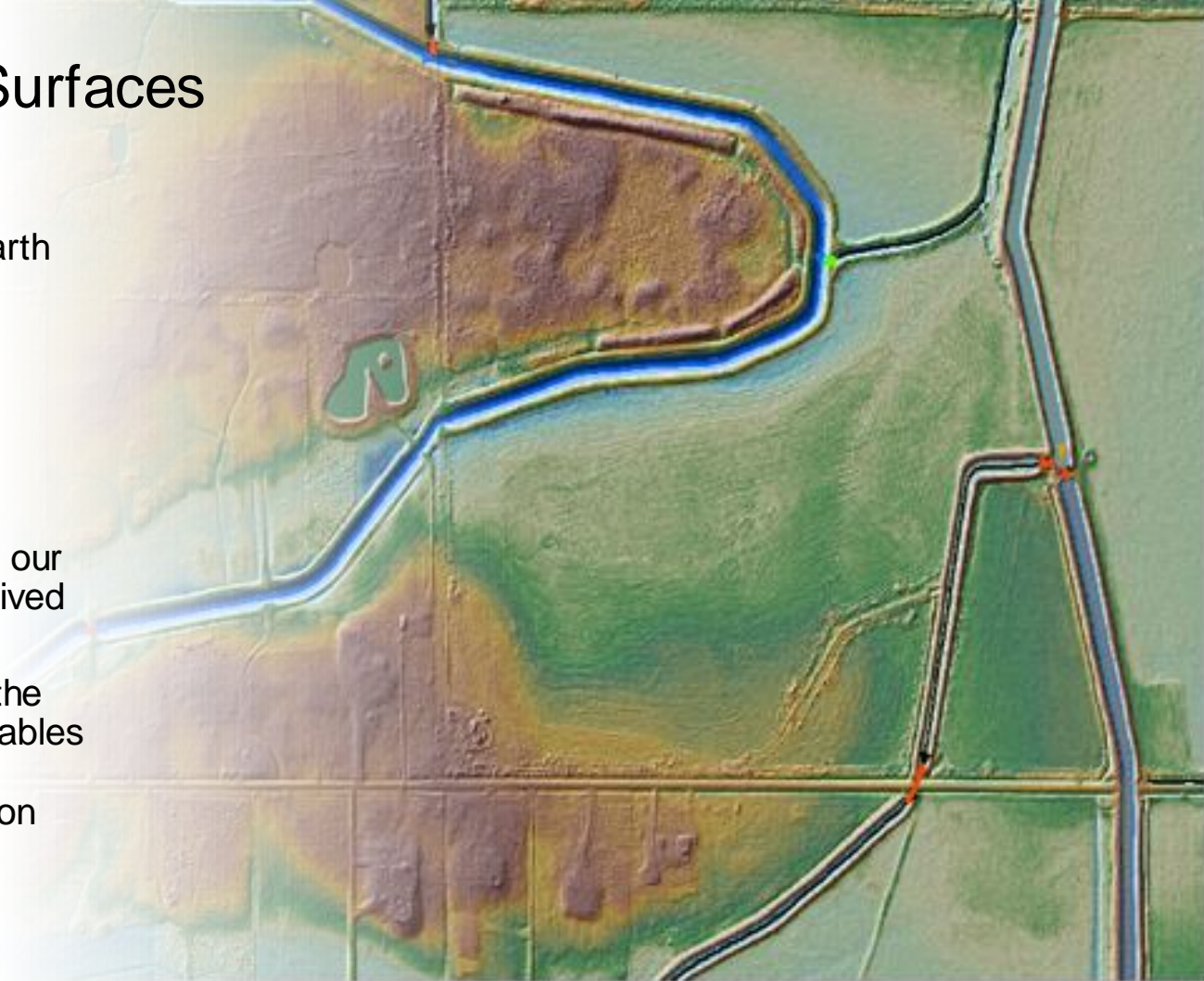


Hydro-
enhancement
of elevation
surfaces

Hydro-enhanced Surfaces

For our purposes, a hydro-enhanced surface is a bare earth DEM that has been modified to represent aspects of a hydrography network.

- We are requesting **hydro-enforced and hydro-conditioned** derivatives in our acquisition of elevation-derived hydrography
- We also require coding in the vector hydrography deliverables that facilitates hydro-enhancement of an elevation surface.



Hydro-enhanced surfaces

For our purposes, a hydro-enhanced surface is a bare earth DEM that has been modified to represent aspects of a hydrography network.

There are variations of hydro-enhancement that are commonly done:

- Culvert-enforcement – lowering the elevation values within the DEM surface to reflect the elevation of the stream that passes through a culvert
- Hydro-enforcement of the entire stream network – slopes of the entire stream network is maintained. The elevation surface is not ‘filled’.
- Hydro-conditioning of the entire DEM surface – ensures that all cells on a DEM surface flow towards a stream network and to an outlet point.

Hydro-enforced elevation surface

What is a hydro-enforced elevation surface ?

Definition in Glossary of LBS and EDH Specifications:

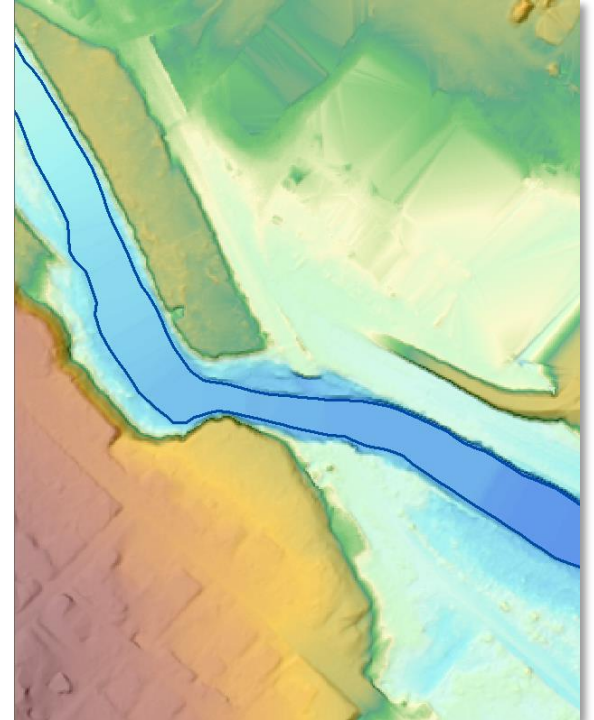
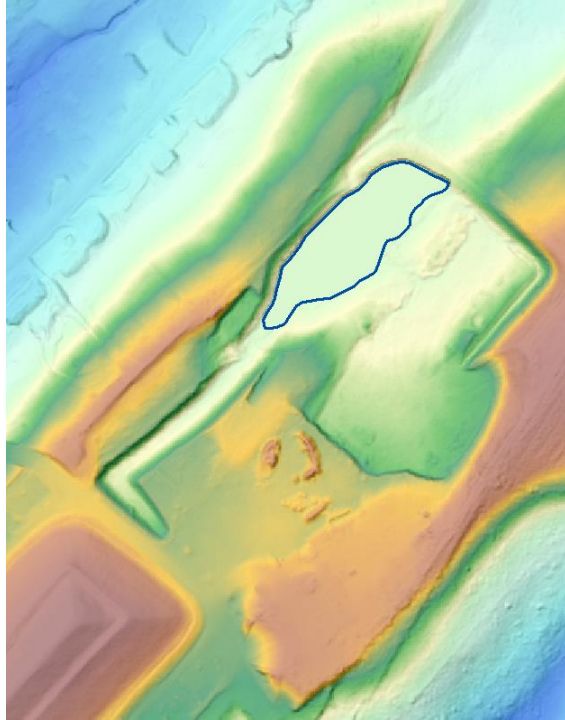
Processing of mapped waterbodies so that **lakes and reservoirs are level** and so that **streams and rivers flow downhill**; for example, a DEM, TIN, or topographic contour dataset with **elevations removed from the tops of selected drainage structures (bridges and culverts) so as to depict the terrain under those structures**. Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels. Hydro-enforced TINs also use breaklines along shorelines and stream centerlines (for example, where these breaklines form the edges of TIN triangles along the alignment of drainage features). Shore breaklines for streams and rivers would be 3D breaklines with elevations that decrease as the stream flows downstream; however, shore breaklines for lakes or reservoirs would have the same elevation for the entire shoreline if the water surface is known or assumed to be level throughout.

Key points from the definition

1. “lakes and reservoirs are level”
hydro-flattened
2. “streams and rivers flow downhill”
z-values on vertices must be downstream monotonic
3. “elevations removed from the tops of selected drainage structures (bridges and culverts) so as to depict the terrain under those structures.”
Z-values on culverts and other underground connections replace z-values of elevation

Hydro-flattened waterbodies

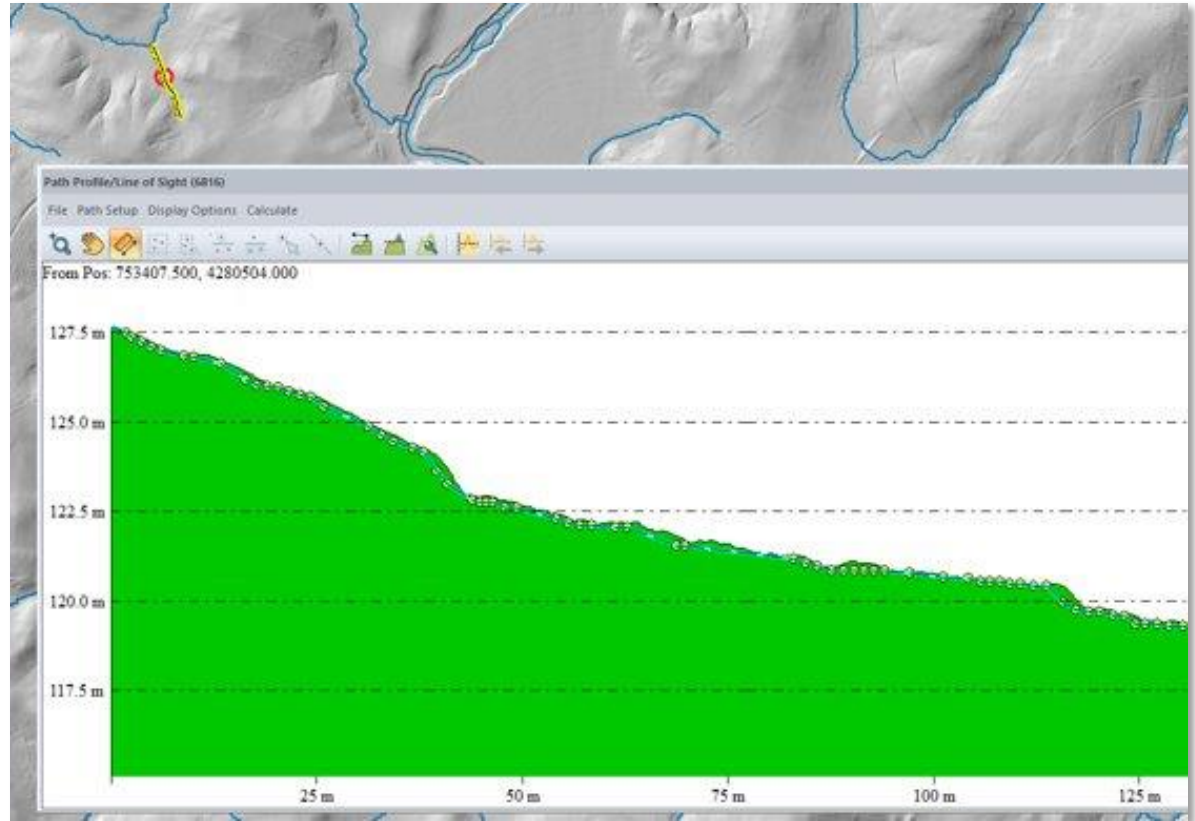
- All polygon features are hydro-flattened.
- Lakes are flattened with 1 value for the entire feature.
- Streams or long lakes are flattened but maintain a downstream direction in the z-values assigned to vertices.



Downstream monotonicity

Hydro line features should have z-values and flow, based on the z-values assigned to their vertices, in a downstream direction.

This graph shows the elevation surface in green, and the vertex z-values as circles. The circles do not vary except in the downstream direction. Each vertex is at or below the one upstream.

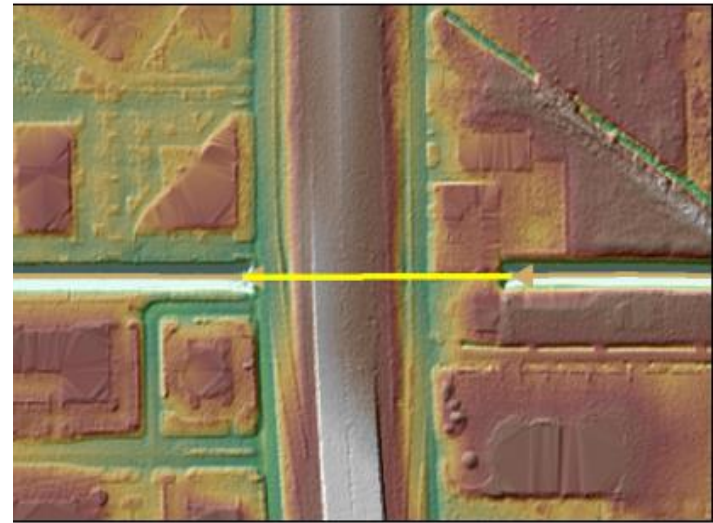


Removing elevation rises that block flow

An elevation rise can occur at roads or other manmade structures.

Other features can also block flow: a fallen tree, large rock, fence line or berm.

The cells in the DEM that rise at the road (in this example), must be altered to flow downhill.

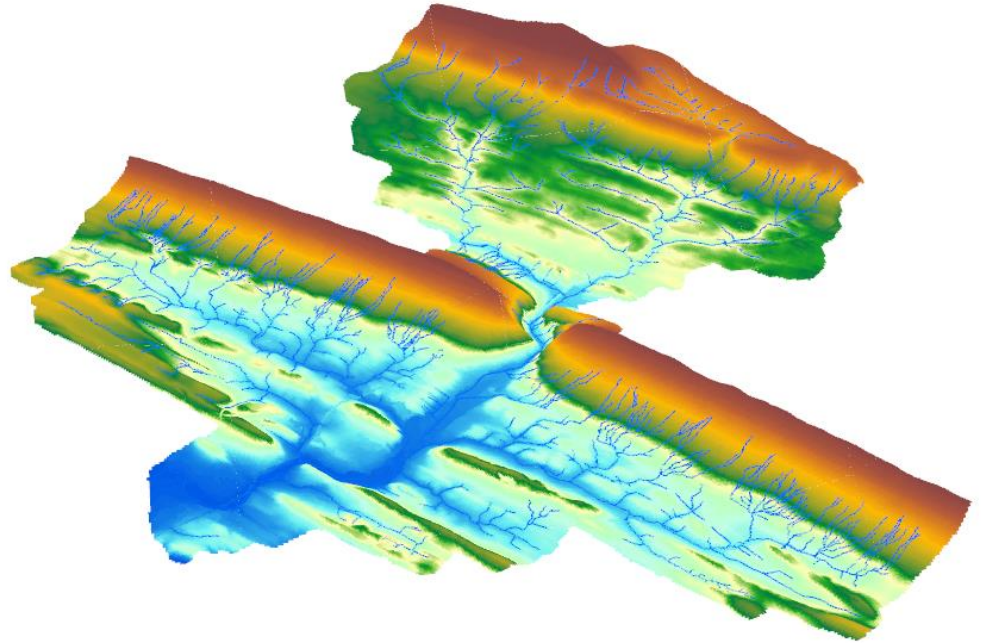


Components needed to hydro-enhance a DEM

Bare-earth DEM

Hydrography

- with z-values at vertices
- attribution that indicates features should be used for hydro-enhancement





Business
needs

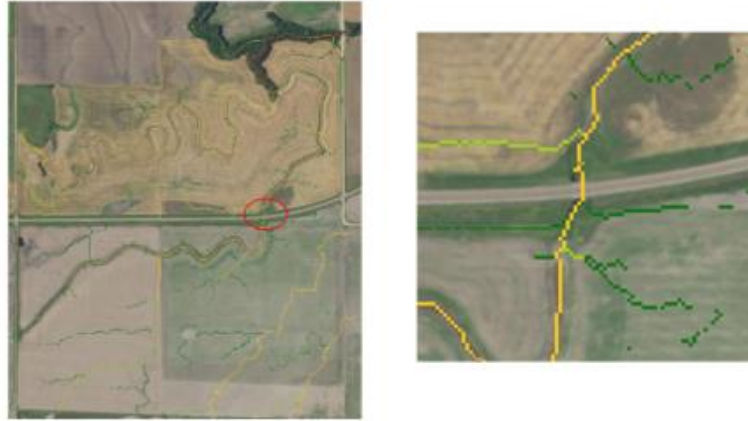
Use cases - NRCS

Tools and Model needs:

- Many applications that need watersheds or catchments
- Runoff is very important
- Soil loss equations are used in many applications
- Conservation effects (CEAP)
- Dam breach analysis – inundation effects
- Movement of nutrients need to have connectivity
- Right now hydro-enhancement is produced as ‘one off’ products

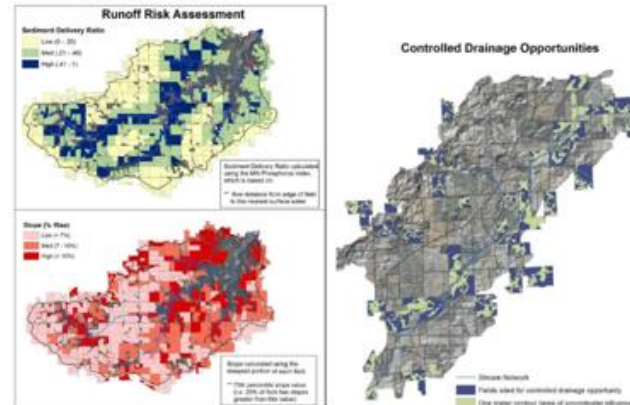
Could save time and money if data was delivered hydro-enforced as a National standard and source

Hydro Enforcement



Agricultural Conservation Planning Framework

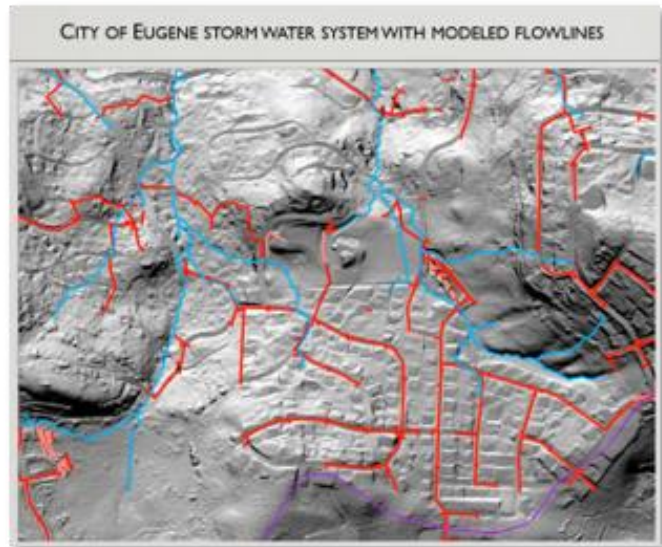
Figure 2: Examples of output maps



Use cases - BLM

Actively developing hydrography for Western Oregon for 5 or 6 years

- Need for managing timber sales
- Locating inception points and finding flow downstream of those points
- Finding many culverts that are needed to enforce the correct flow
- Initially thought that hydro-enforcement was just at road crossings, but have found many more areas where it would be helpful
 - Wide streams, ag areas, urban areas
 - Quite an expense
- Fill volumes behind culverts and depths behind roads very important to know.
 - Knowing culvert locations would be very helpful

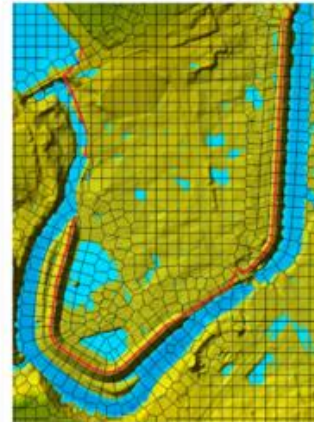


Use cases - FEMA

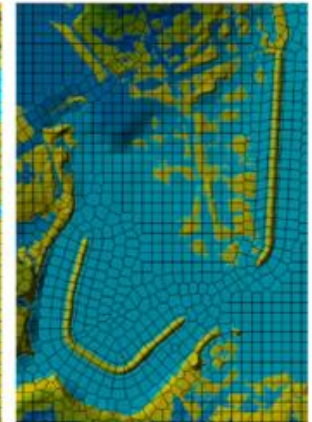
Hydrologic and hydraulic applications

- 1D and 2D modeling flood risk, inundation, HAZUS and flood loss
- Enhanced analysis requires topographic data and land/channel roughness, bathymetric data, bridge/culvert locations
 - Usually, a combination of lidar and locally acquired or surveyed data
 - Modeling done with and without engineered features such as levees
- Hazard quantification is becoming more and more refined – leveraging lidar and outside sources
 - Bridge location, building footprints, levees, culverts, bathymetry all important

FEMA's Flood Strategy is Changing



With Levee



Natural Valley

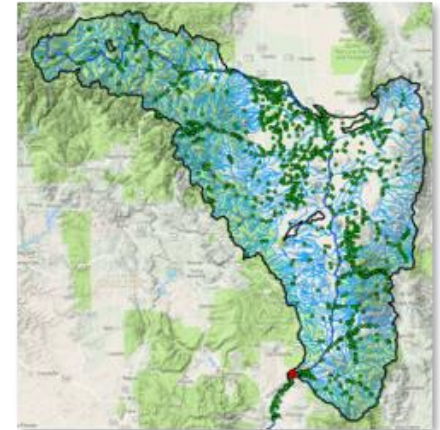
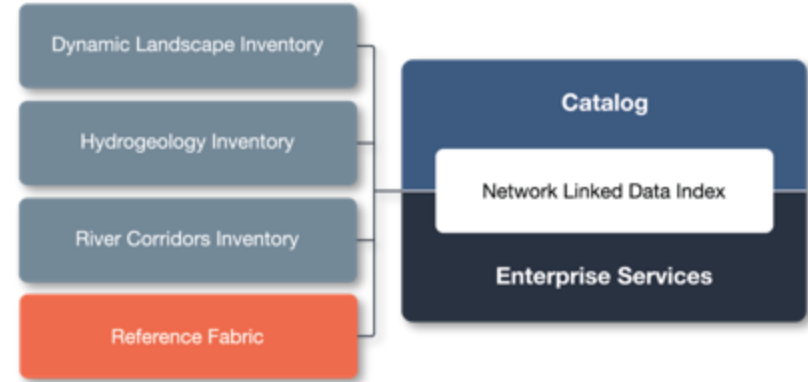
Use cases – USGS Water Mission Area

USGS is responsible for monitoring surface and ground water quality and quantity.

- The National Hydrologic Geospatial Fabric is being developed out of the WMA to provide monitoring data in the most appropriate geospatial context
- The NHGF will be a way to access hydro data, be web-accessible, and provide geospatial content in a reproducible workflow

Example applications include: basin delineation, flow conditioned continuous parameter grids, cross-sections and overbanks, inundation and flood plain mapping surface water storage, surface and ground water interactions.

- All components of the 3D NTM vision
- Hydro-enhanced surfaces needed for most of these applications



Use cases – UT Austin

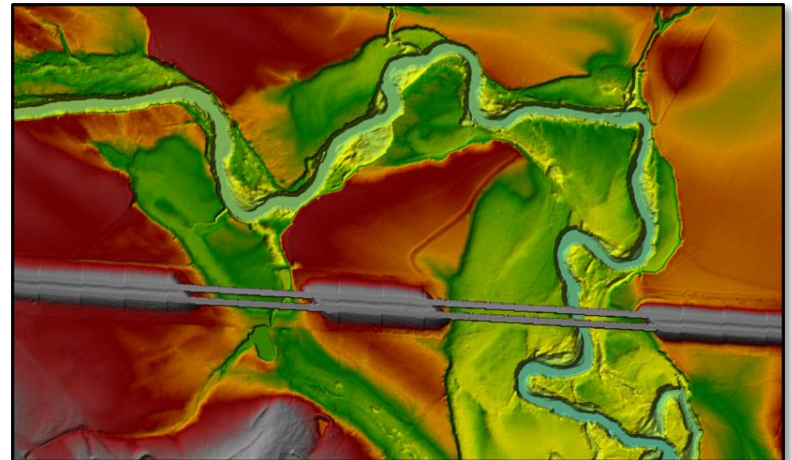
Flooding applications and forecasting:

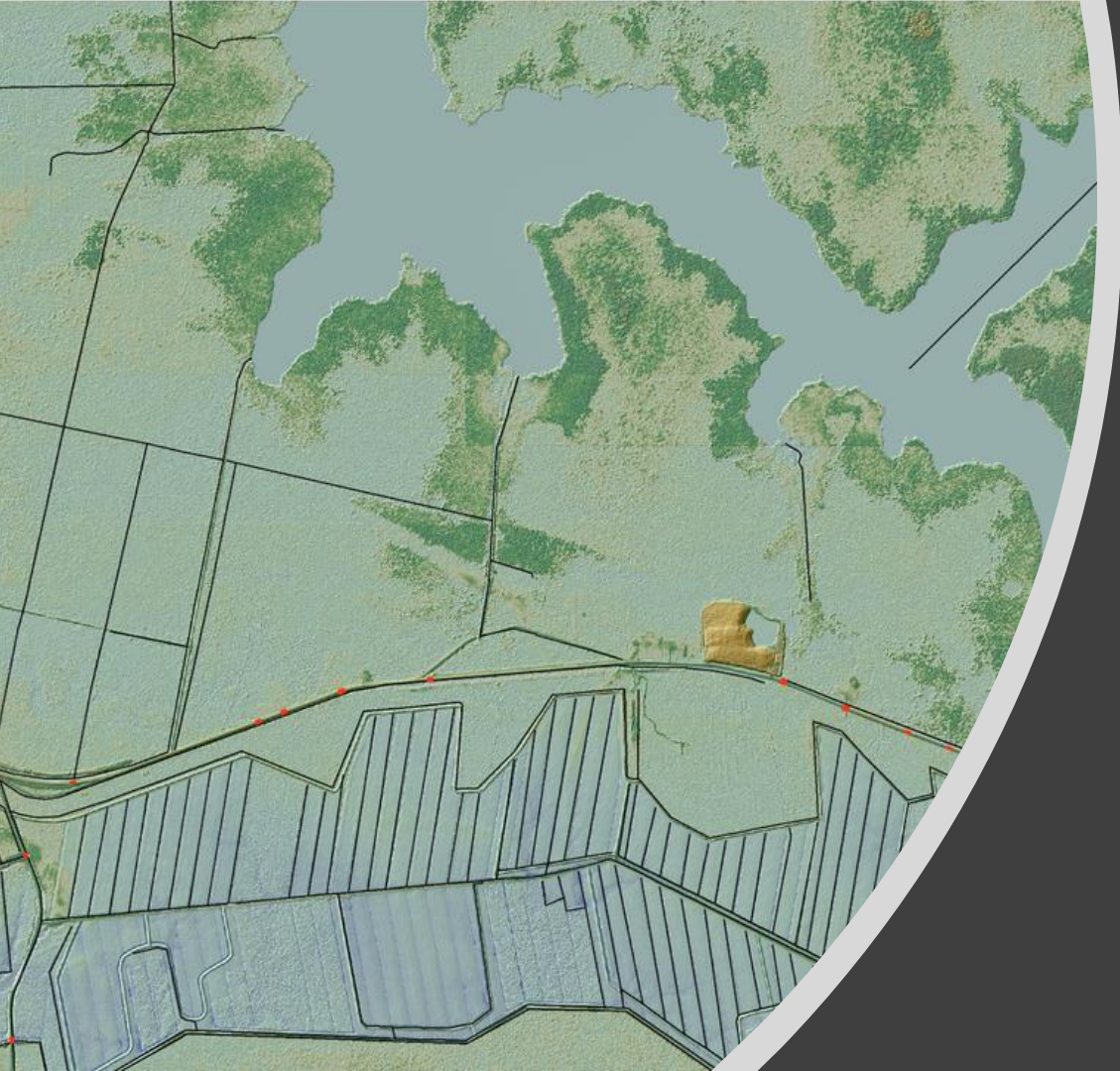
Downloading wide areas of lidar data to simulate flood extent

- Accessed USGS WCS 3DEP REST to automate download of lidar data
- Other data sources were combined into a HEC-RAS model and depth grids were created at hourly steps using a super-computer.
- Recreated the flooding at time steps. Can be compared to data collected in the field and model results.
- **Able to do this because of the easy access to the elevation data**

Bulk bridge harvesting

- Fill in the bridge deck information that is removed from bare earth DEMs.
- Create a “healed” DEM that is bare earth plus the bridge
- Create automated bridge envelopes





Next Steps

Definitions of Hydro-enforcement and Hydro-conditioning

Draft guideline documents have been written describing hydro-enforced and hydro-conditioned elevation surfaces.

We are determining if they meet all the criteria that are needed for 3DHP's creation of other surface derivatives such as flow-direction rasters and catchments.



Characteristics of a hydro-enforced DEM:

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

1. The hydro-enforced elevation surface shall match the source digital elevation model (DEM) used to derive the elevation-derived hydrography data in z-values **except** where z-values have been replaced by the z-values assigned to the elevation-derived hydrography features for downstream monotonicity.
 - a. Z-values for every vertex in every linear feature from the elevation-derived hydrography data shall replace the z-values of the corresponding cell in the source elevation DEM.
 - b. Exceptions are:
 - i. Any feature that is not used for elevation derivatives (EClass = 0),
 1. Any feature that has uninitialized (undefined or indeterminate) flow associated with it,
 2. Area of complex channels, dam/weir, ice mass, playa
 - ii. Any feature that crosses above other hydrographic features (pipelines)
2. Any raster cell that is overlain by an elevation-derived linear feature, but does not have a vertex associated with it, must have a z-value that is at or below the upstream vertex value and at or above the downstream vertex value.
 - a. Linear interpolation between vertices is required for cells that represent the linear features to avoid stairstep appearance
3. Downstream monotonicity shall be maintained for cells that correspond to the elevation-derived hydrography features.

Expected Outcomes

1. Obstructions are removed from the elevation surface where manmade or natural anomalies impede the flow paths of water on the DEM surface.
2. Elevation values reflect the z-values of the vertices of the elevation-derived hydrography linear features used for hydro-enforcement.
3. Downstream monotonicity is enforced within cells that correspond to the stream network.
4. Cells along the network will flow towards an outlet point or true sink in the elevation surface.

Guidelines for Creating Surfaces

Tools are being developed to hydro-enforce and hydro-condition surfaces.

Features used to hydro-enhance are selected from the EDH.

Any features that are above ground or have no flow direction are not selected.

All cells are replaced that are coincident with the stream network.

1. Create a continuous rasterized layer of z-values from stream line segments.
 - a. Get features that have flowdirection associated with them
 - b. Output as shapefile
 - c. Run gdal_rasterize in OSGeo4W Shell

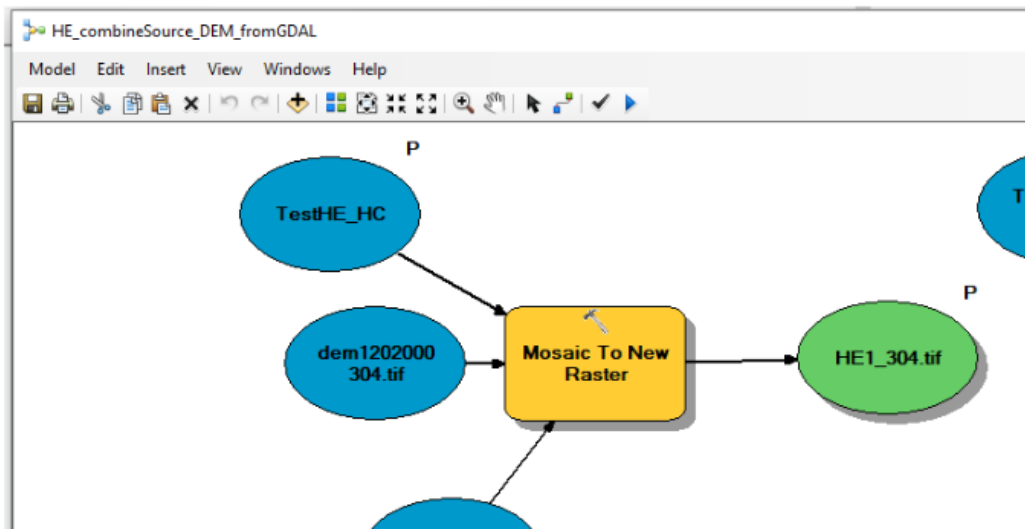
Coordinates are xmin ymin xmax ymax or left, bottom, right, top

Left bottom right top

```
gdal_rasterize -3d -l EDH_Lines_forHE EDH_Lines_forHE.shp -a_nodata -9999 -tr 1 1 -at -ot Float32 -te 330416.000122 3264575.00012 428790.000122 3386258.00012 StreamsHEz.tif
```

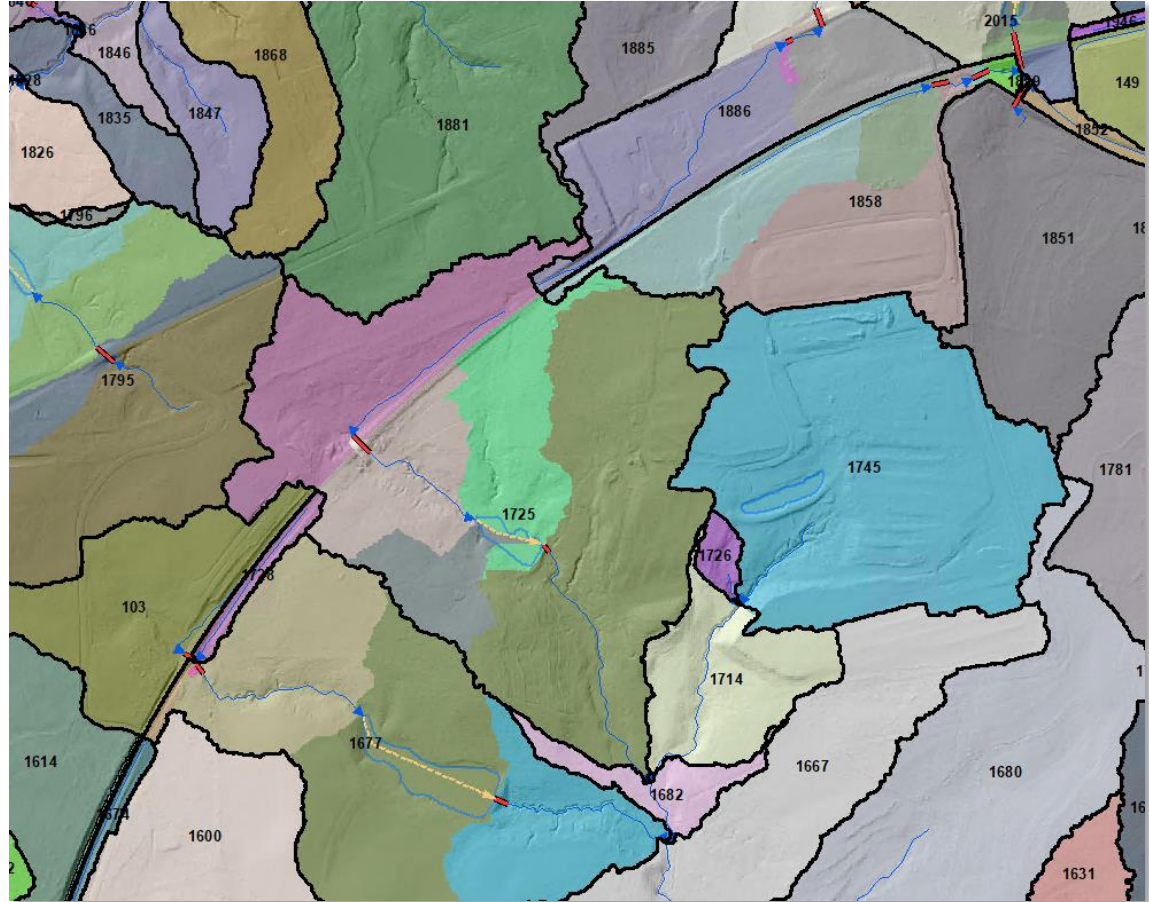
[Hydro Enforce using GDAL.docx \(sharepoint.com\)](#)

2. Take the rasterized lines and mosaic them back into the original surface with merge

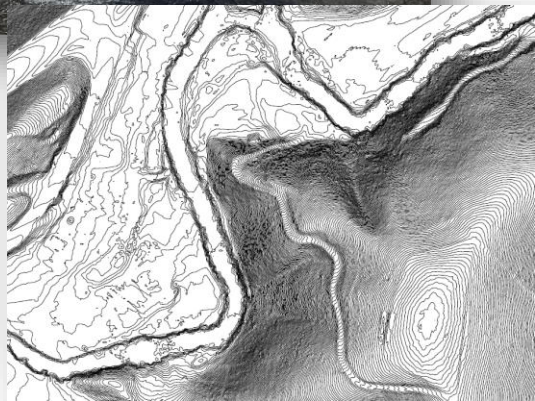
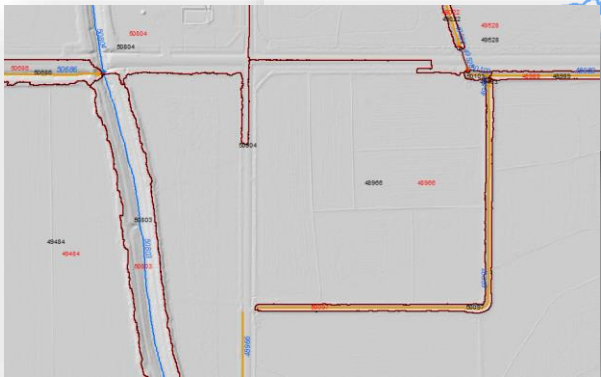
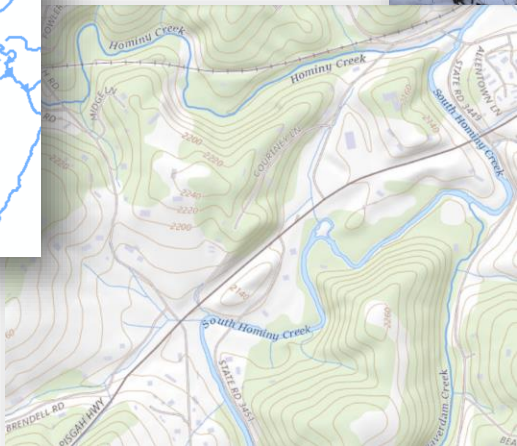
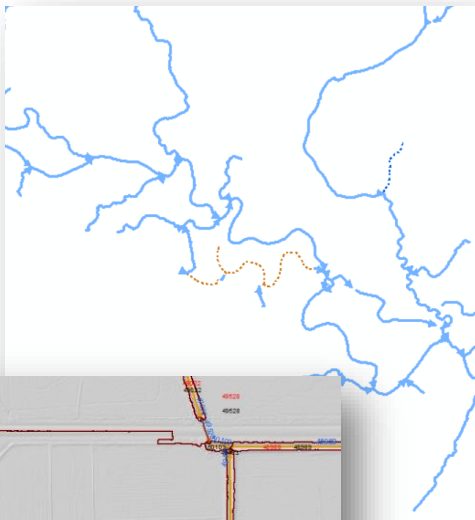


Derivative products are created

- Stream network slope preserved in surface
- Catchments for individual features
- Catchments for aggregated features
- Hydrolocations on network defining catchment outlets
- Attributes such as slope, elevation ranges, drainage area assigned to stream segments



Views of 3DHP data model





THANK YOU!

SE Texas EDH project area
3D Elevation Program (3DEP) data