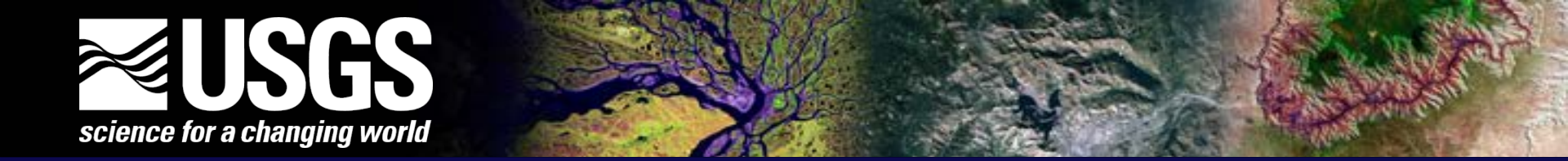

Lidar Topography and Hydrographic Integration: *Fundamentals and Application Issues*

USGS Hydrography Seminar Series,
Seminar #8
Thursday, May 19, 2016

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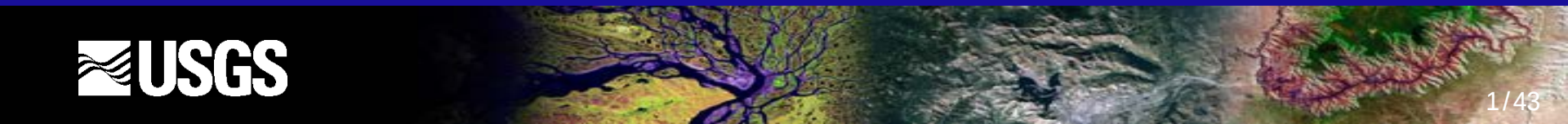
U.S. Department of the Interior
U.S. Geological Survey

Lidar Basics

Troublesome Terminology

Bare-Earth Flavors

Hydrographic Breaklines

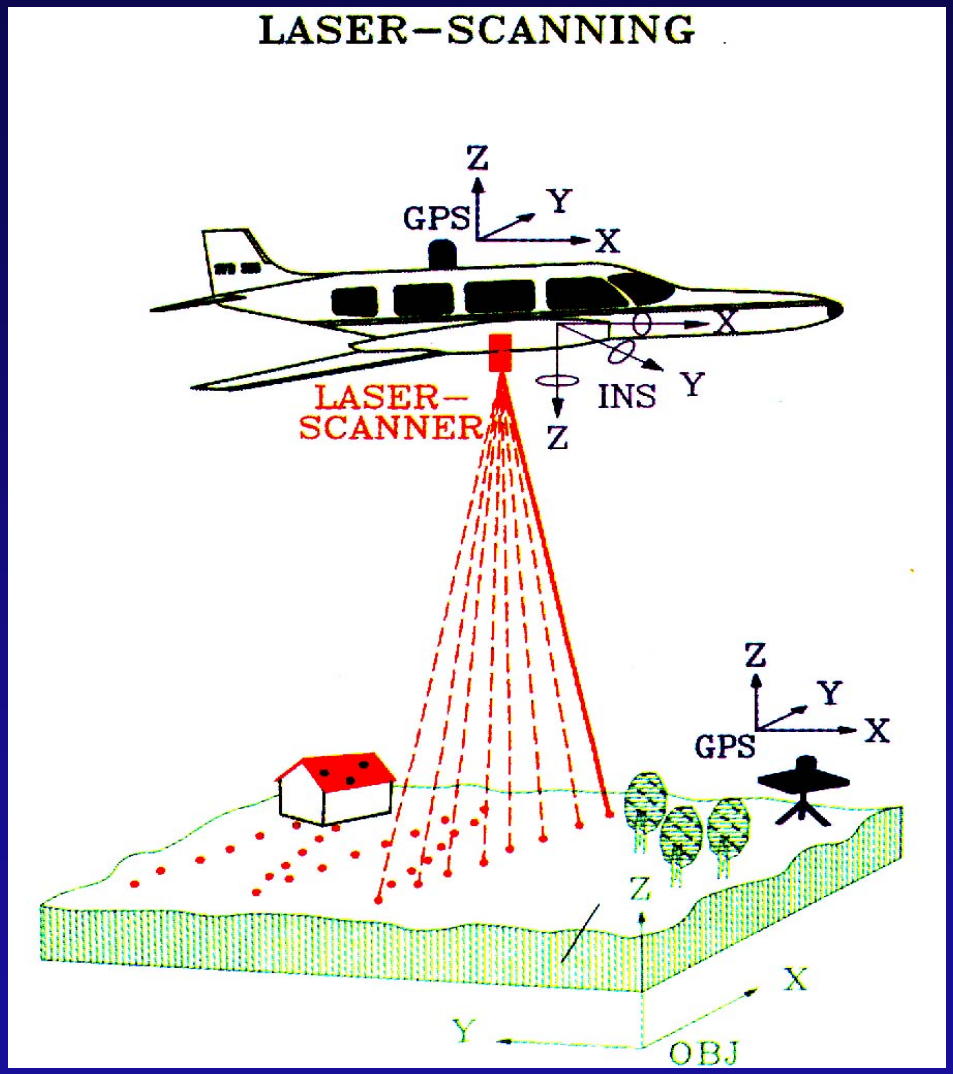


What is Lidar?

- Light Detection And Ranging
  - Active airborne* sensor system
  - Scanning pulsed laser (new technologies on the rise)
  - High-precision clocks provide the time *duration* between emitted pulse and detected reflection
  - High-precision position and attitude sensors onboard provide a *3D origin point* and a *vector direction*
  - *(Speed of Light × Duration ÷ 2) = Vector Length*
  - The complete vector (direction and length) allows the *xyz* location of the 3D reflection point to be computed.

* for our purposes

What is Lidar?



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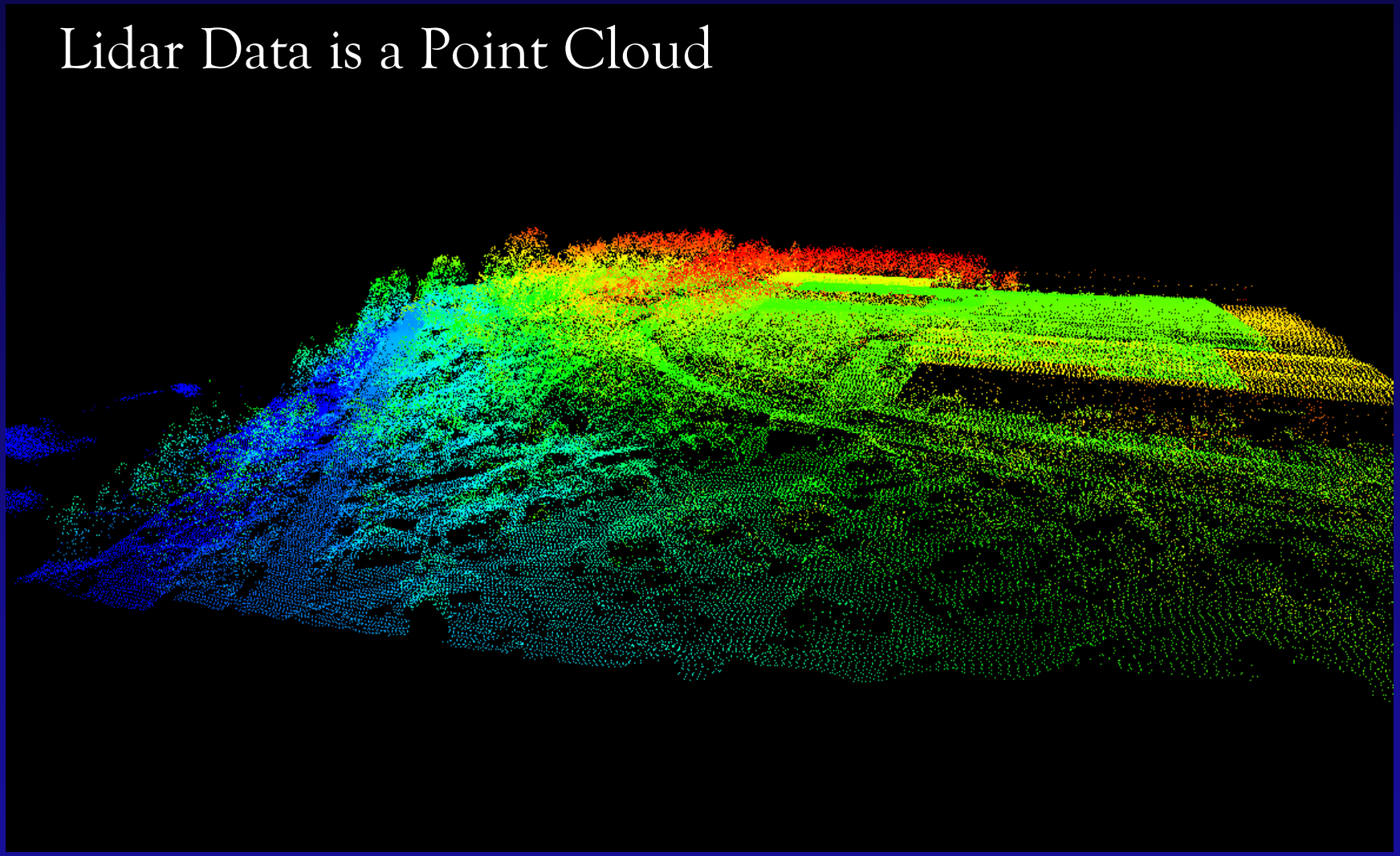
What is Lidar Data?



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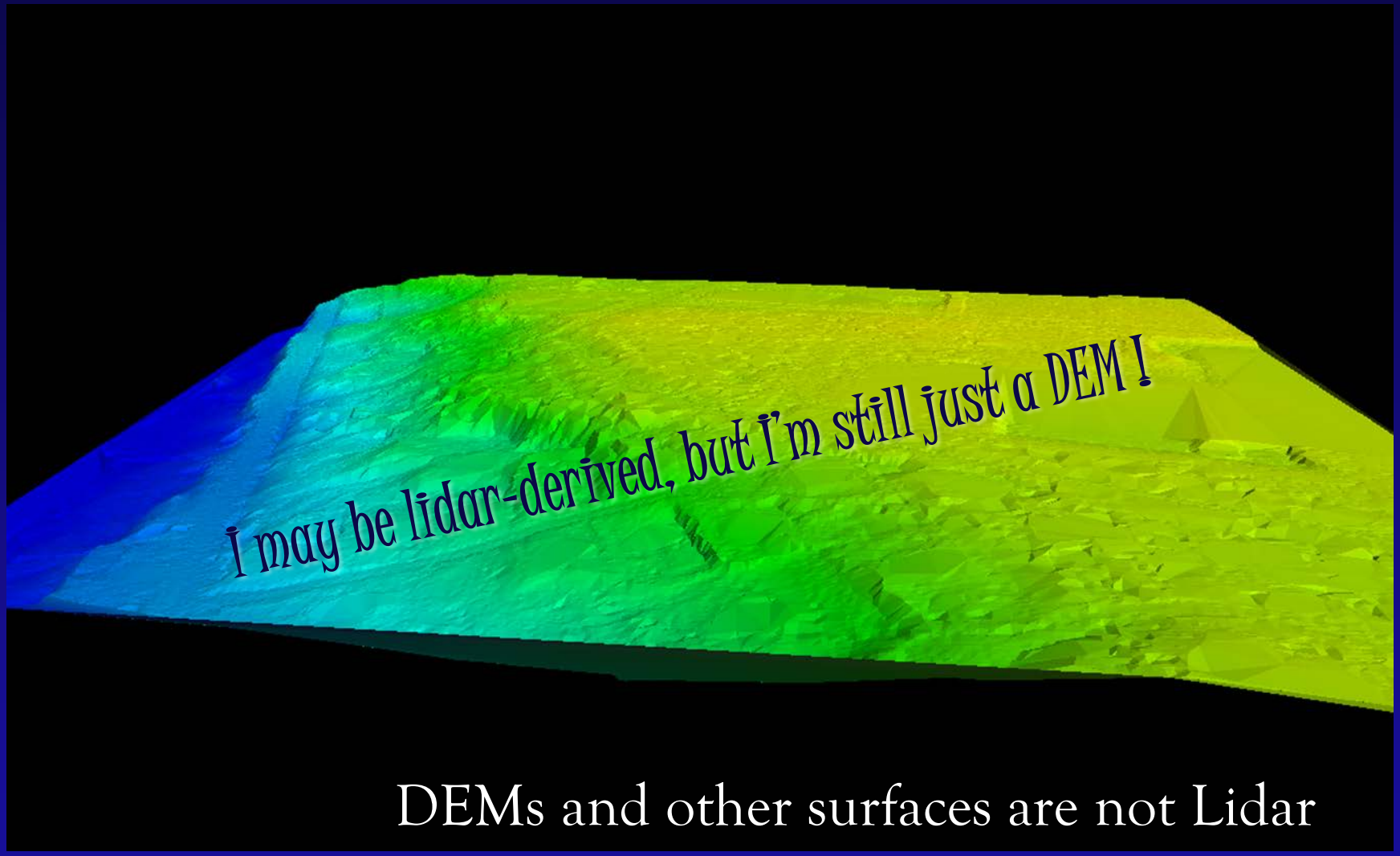
What is Lidar Data?



DEMs and other surfaces are not Lidar

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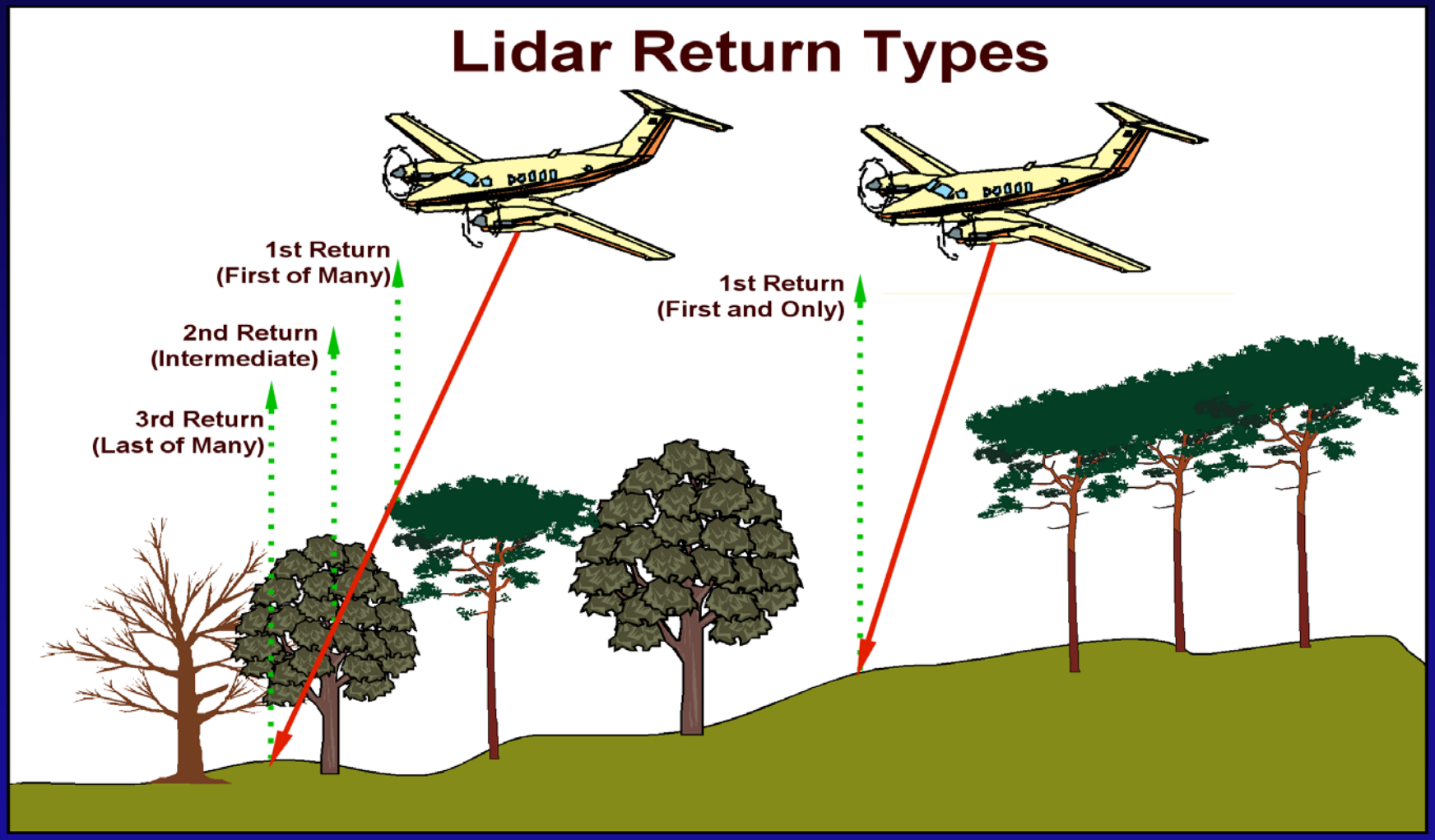
Multiple Return LIDAR



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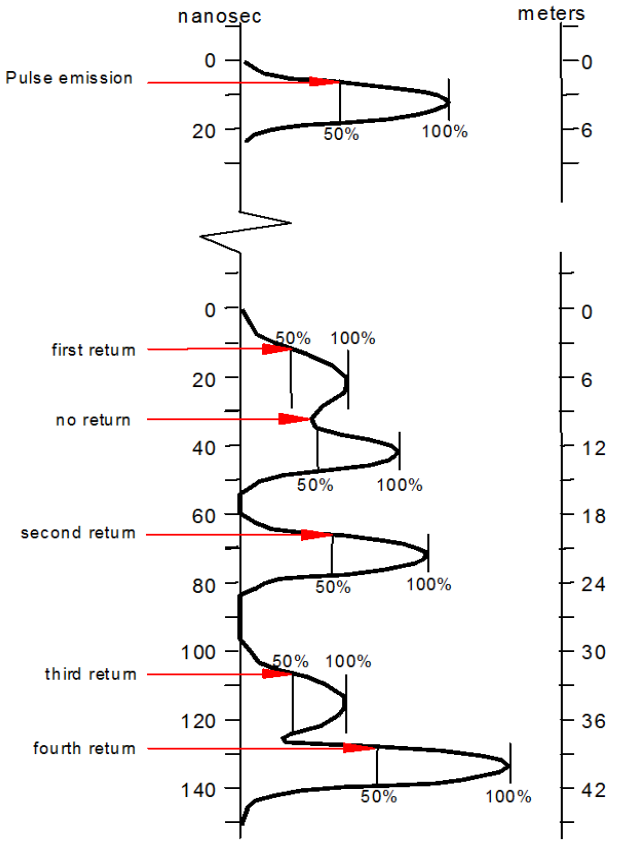
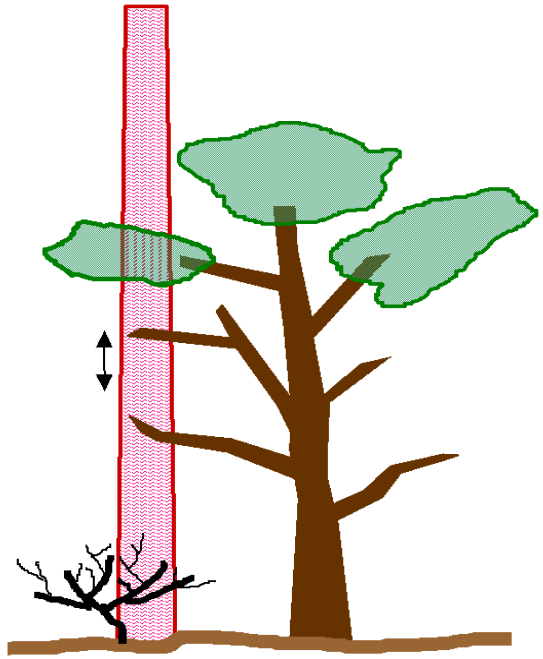
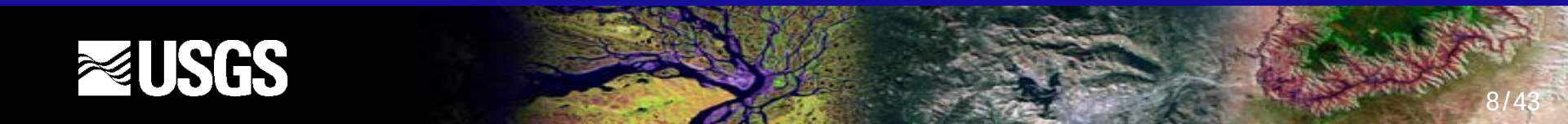
Multiple Return Schematic





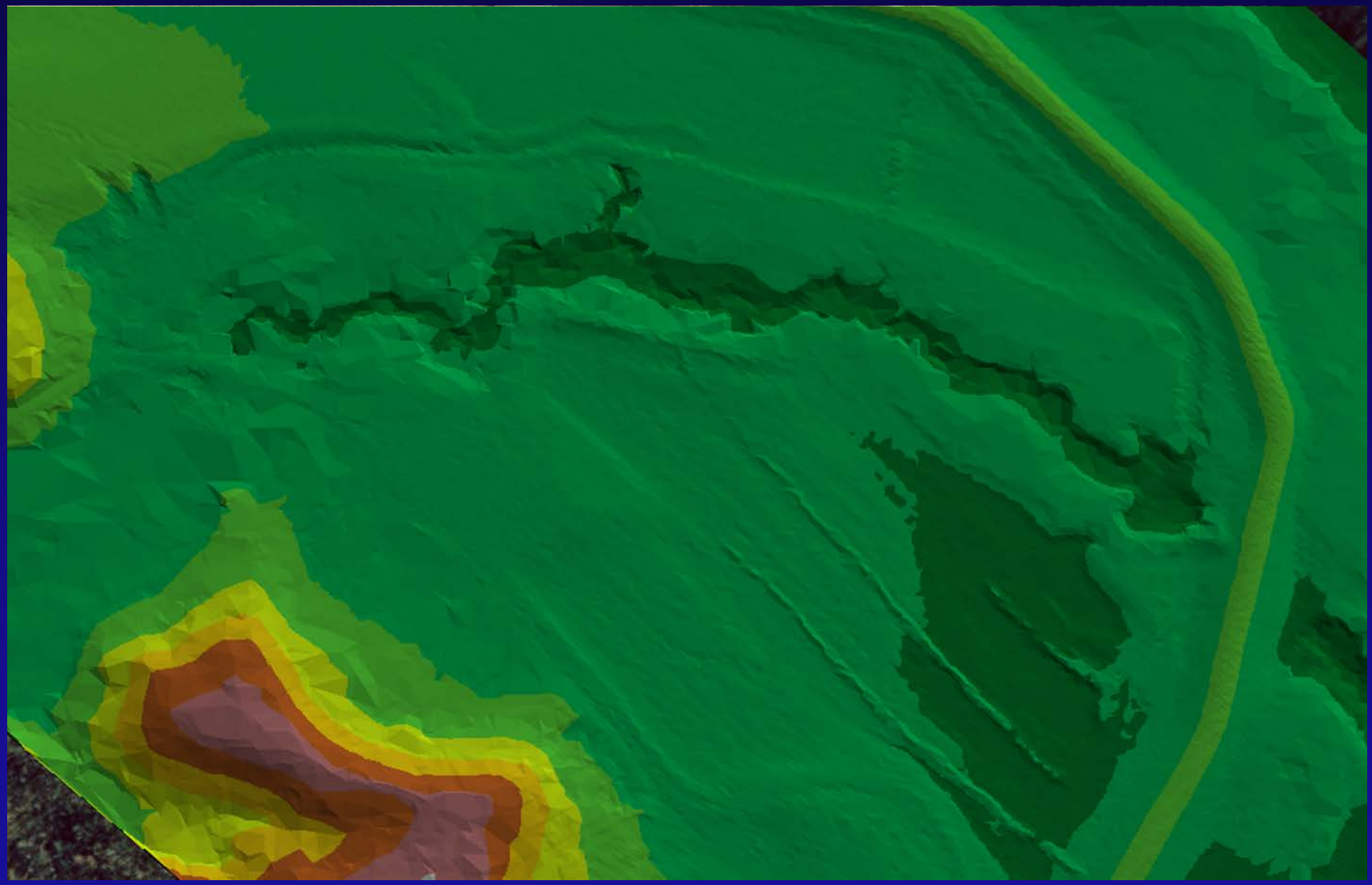
Vegetation Penetration

- Lidar does not, as people often say, “see through trees”.
- Lidar sees *around* trees, through gaps in the canopy.
- If you stand in a forest, look up, and can see the sky, then lidar can likely see and measure you.
  - If you *can’t* see the sky, then lidar can’t see you either.
- Lidar is less effective at measuring the ground in vegetated areas than it is in open areas.
  - Fewer *ground* points, More interpolation.
  - Less accuracy, Less reliability.
- Still, as an active sensor, lidar can see and measure in places that traditional photogrammetry cannot.



Vegetation Penetration

Vegetation Penetration



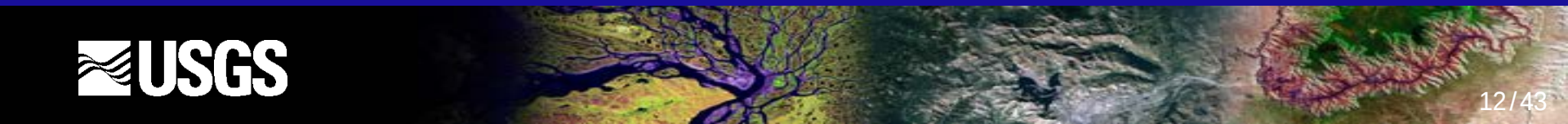
But ...

- Unlike photogrammetry, lidar is a user-independent measurement.
- In photogrammetry, the operator selects a location for a point or vertex in the image, and measures the elevation *at that point*.
- Although lidar does collect in a pattern, the location of points is functionally random.
- So, *LIDAR by itself* cannot trace a stream bank or centerline.
  - ! Hydrographic Breaklines !
  - This must be done after the fact by a human operator
  - Once delineated horizontally, elevations can be conflated to the vertices.
  - Automatic breakline extraction methods have been researched for years; the search continues ...

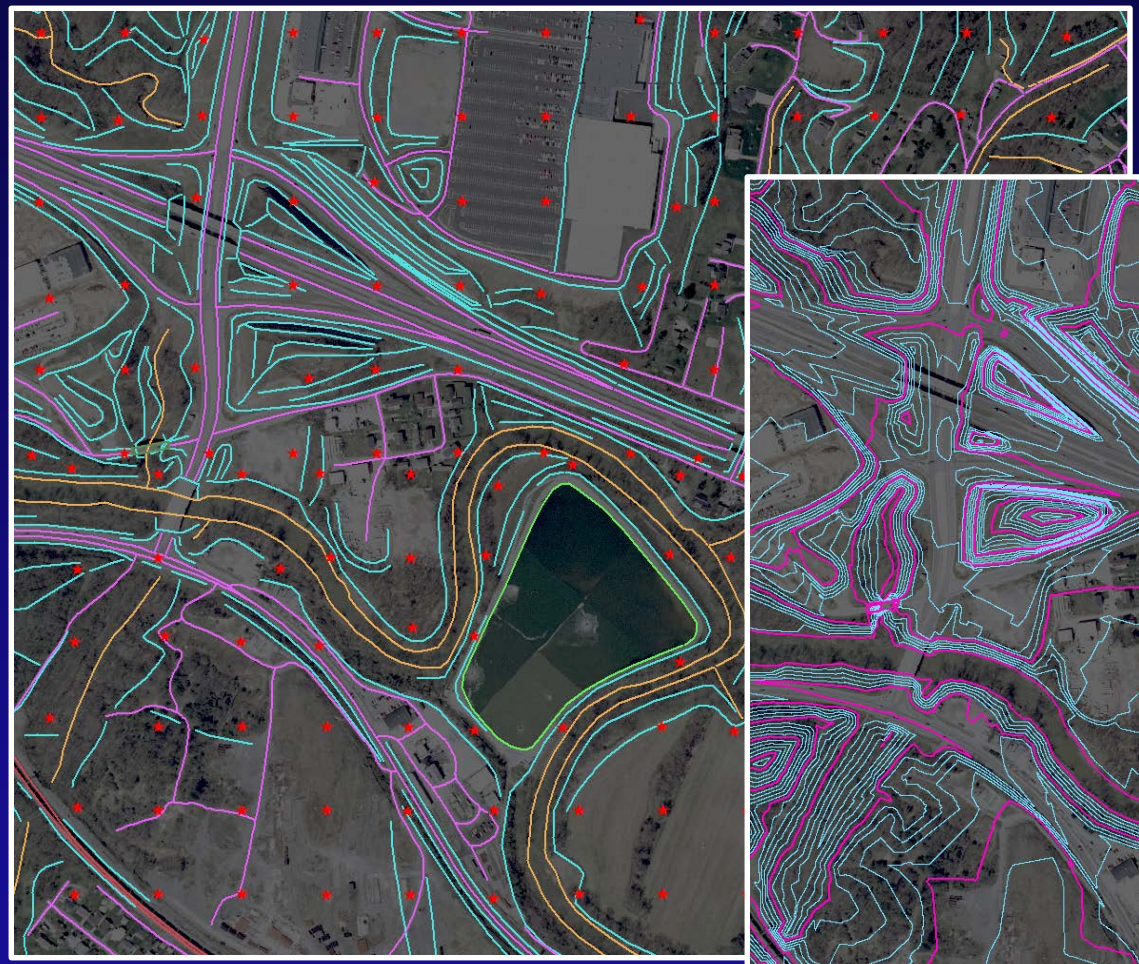
Some Slippery Terms

(depending on who and where you are)

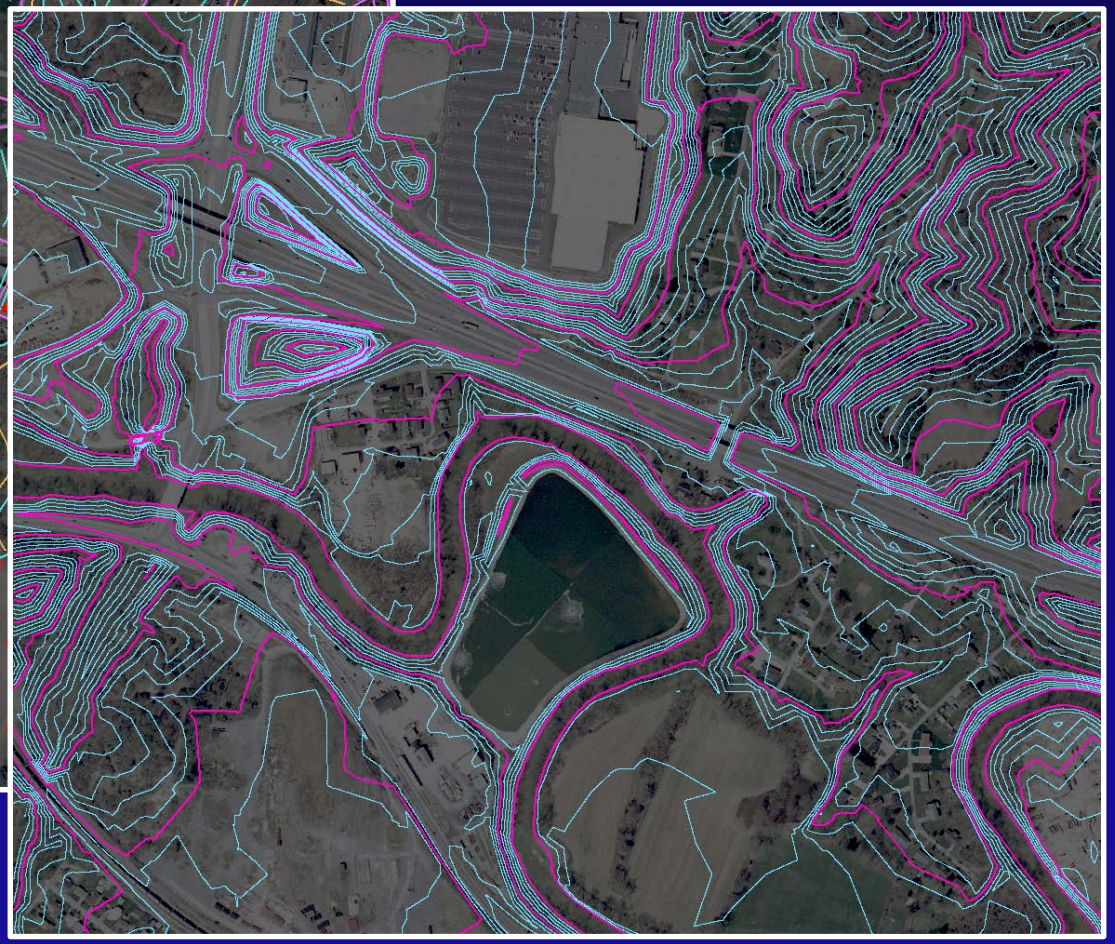
- DTM: Digital Terrain Model
  - Traditionally, DTMs are the output from stereo compilation of vector masspoints and breaklines.
  - DTMs would be used to create DEMs, which in turn would be used to create contours.
- DEM: Digital Elevation Model
  - A continuous raster surface model of the “bare-earth surface”
  - Bare-earth surface can mean many different things
- DSM: Digital Surface Model
  - A continuous raster surface of something other than the bare-earth, e.g., top of canopy.



Classic Stereo DTM

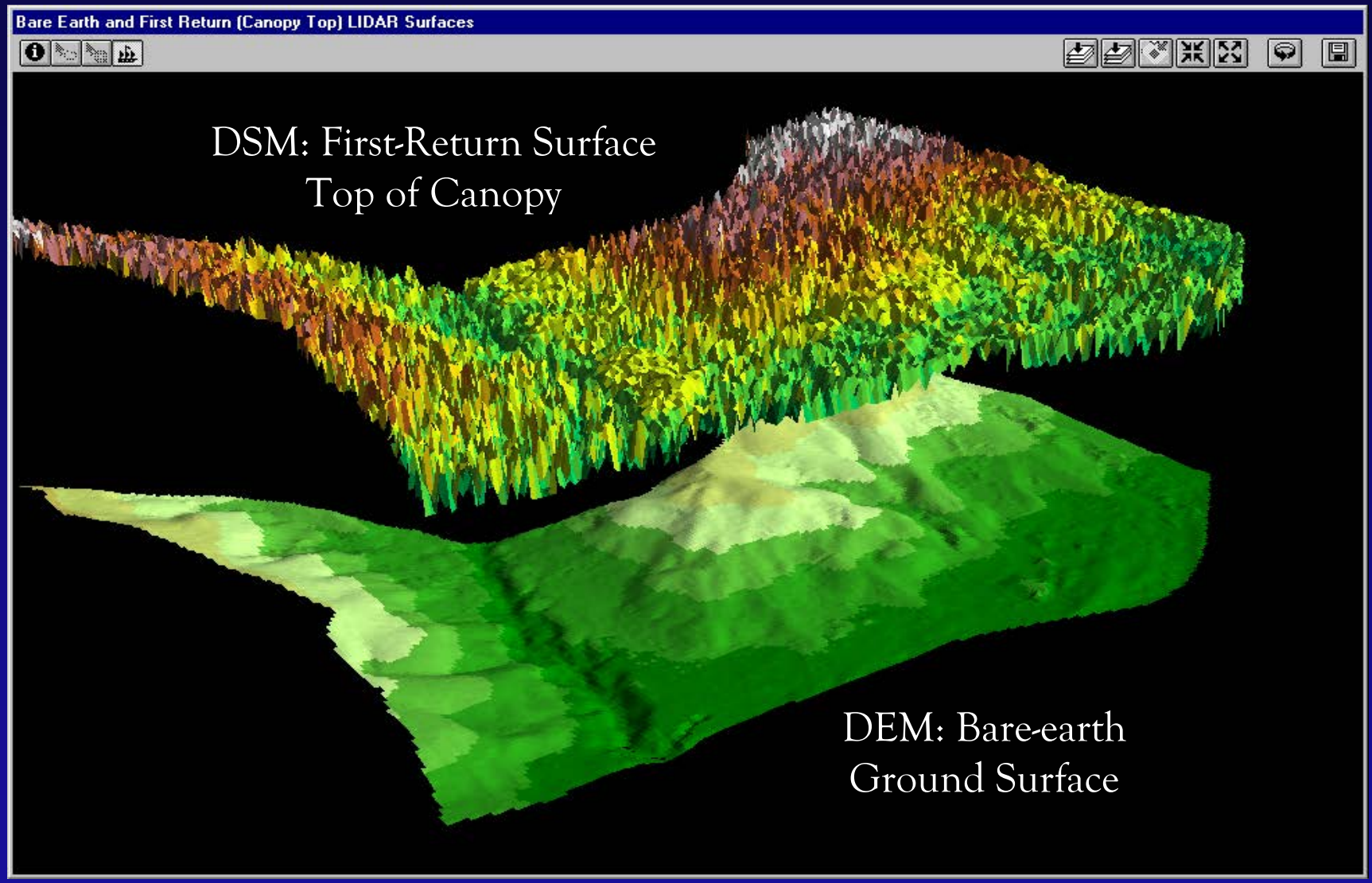


Vector masspoints and breaklines: not a surface.



Contours typically derived from the DTM

DSM and DEM


Bare Earth and First Return (Canopy Top) LIDAR Surfaces
DSM: First-Return Surface
Top of Canopy
DEM: Bare-earth
Ground Surface

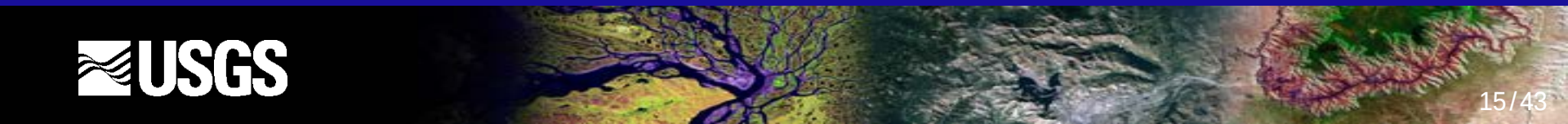
Flavors of DEMs

TOPOGRAPHIC: *Mapping*

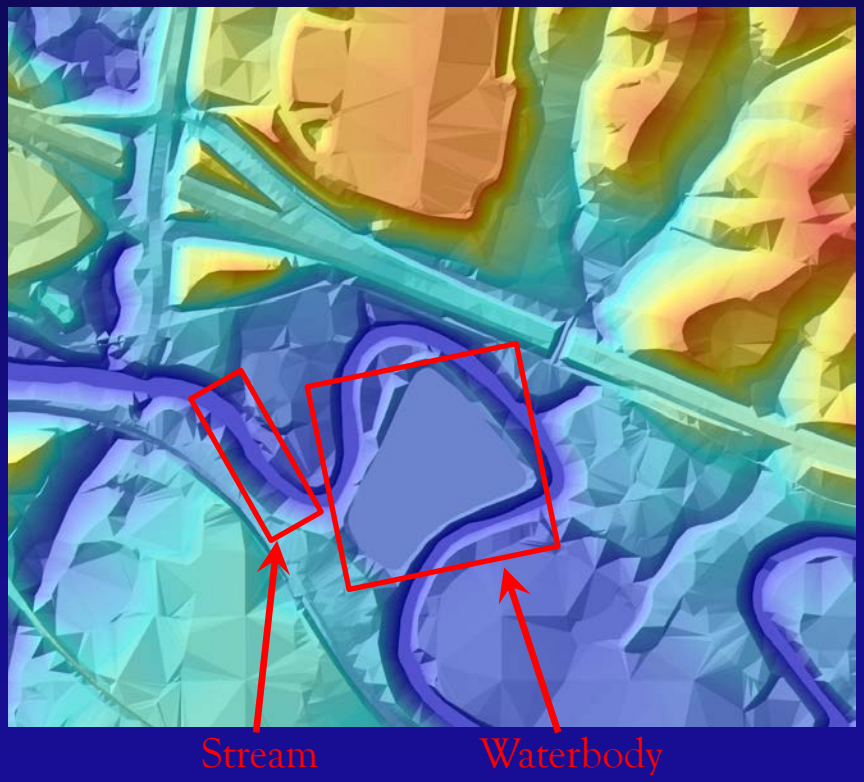
- Stereo-derived: Masspoints and Breaklines
- Pure (raw) Lidar: Lidar points only
- Hydro-Flattened (Simple)
- Hydro-Flattened (Enhanced)

HYDROLOGIC: *Modeling*

- Hydro-Enforced
- Hydro-Conditioned

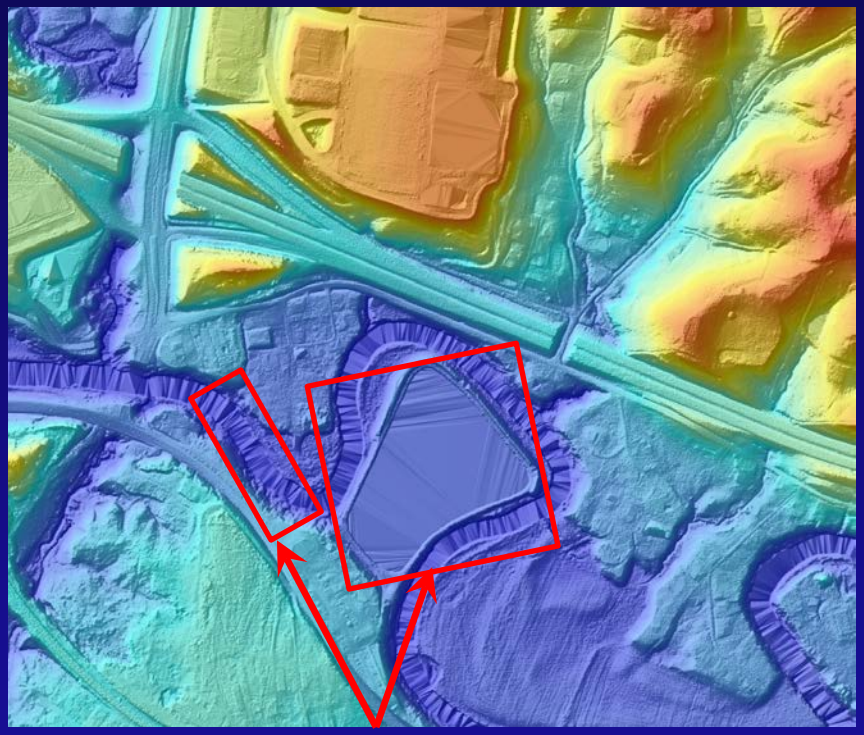


Stereo DTM (Topographic Surface)



- Traditional stereo-compiled DTM (reference)
- Built from Masspoints and Breaklines
- Coarser resolution than lidar
- Depicts the familiar, expected character of a topographic DEM
  - Flat water surfaces
  - Bridges removed
  - Road edges defined
  - Road fills over culverts retained

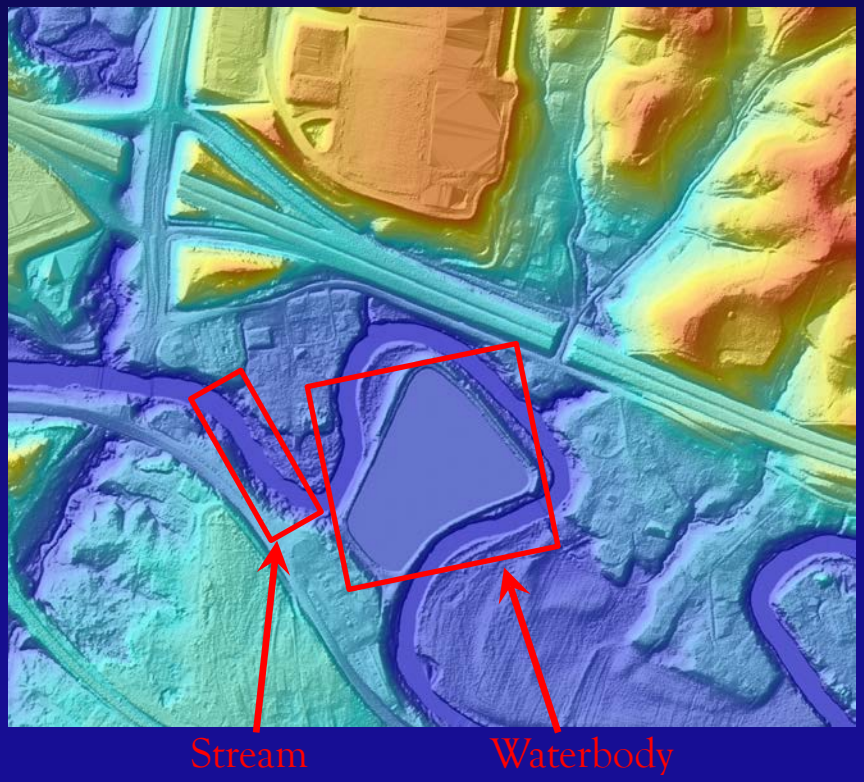
Pure LiDAR (Topographic Surface)



Tinning across Water Surfaces

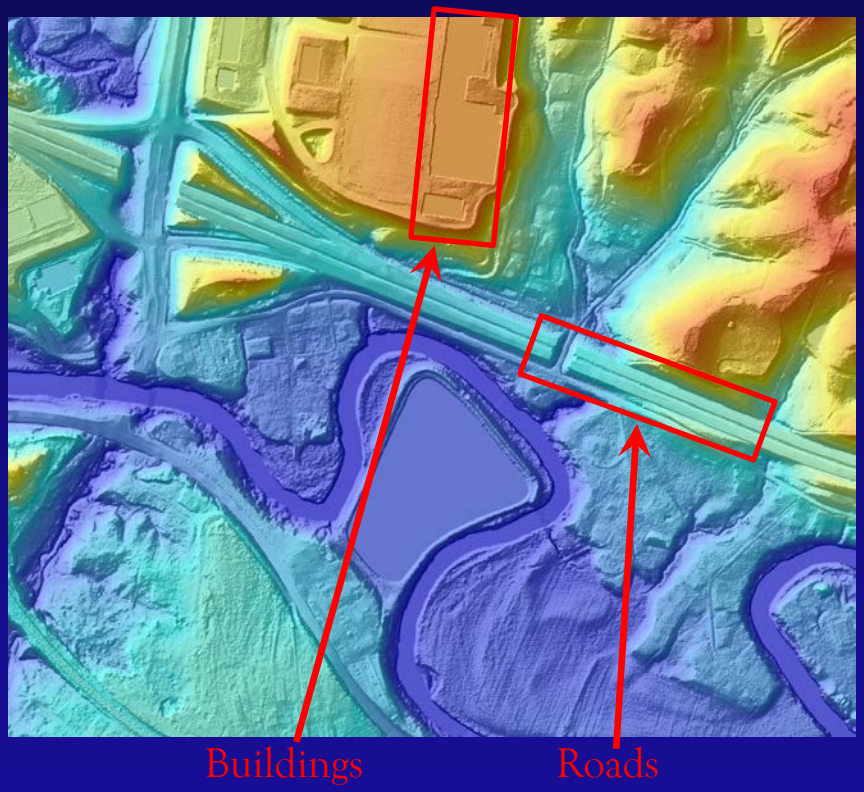
- Created solely from bare-earth lidar points.
- Water surfaces have triangulation artifacts.
  - No lidar returns from water
  - No breaklines to constrain the surface and define the banks.
- Most users regard this as cartographically unacceptable.
- Contours would require extensive editing.

Hydro-Flattened (Simple) (Topographic Surface)



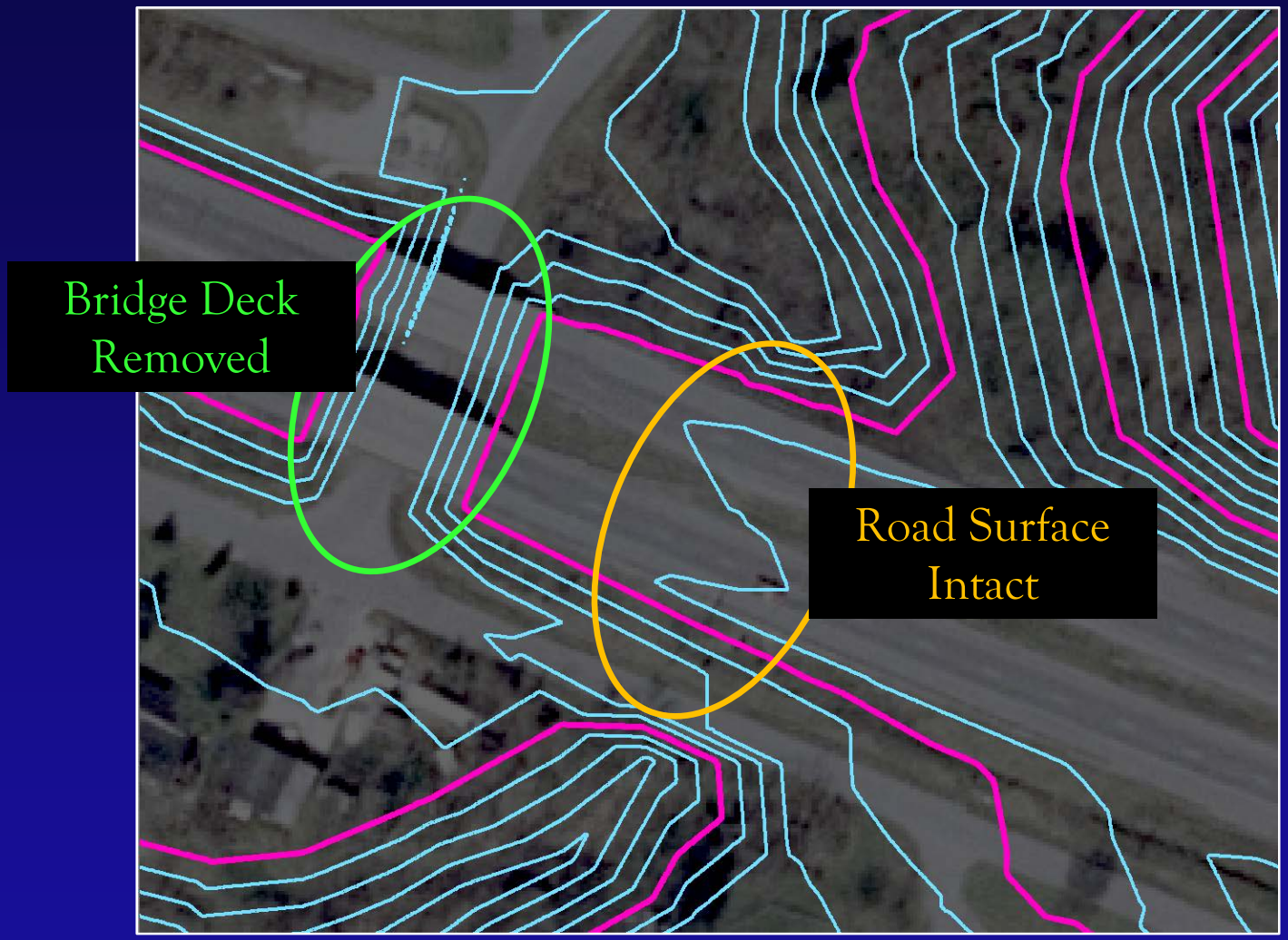
- A Lidar Base Specification goal.
- Supports a consistent surface character across 3DEP, suitable for contouring.
- Removes the most offensive pure lidar artifacts: those in the water.
  - Waterbodies have a single elevation.
  - Streams and rivers are flat bank-to-bank, with monotonic flow.
- Purely a Cartographic enhancement. Water surface elevations are set to meet cartographic needs.

Hydro-Flattened (Enhanced) (Topographic Surface)

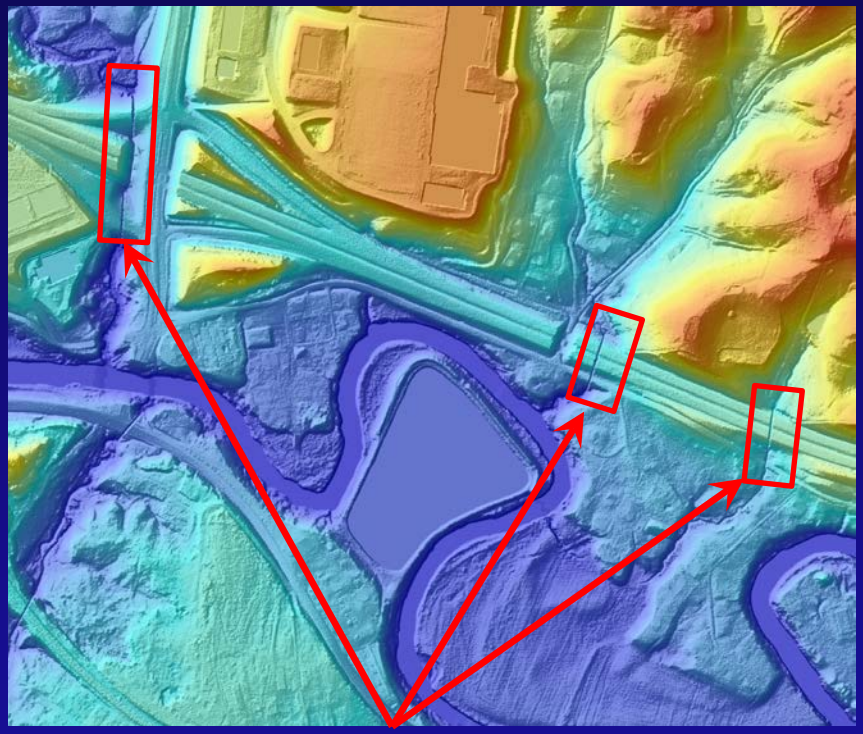


- Further refinement of the Hydro-Flattened surface
- Refines the delineation of roads, single-line drainages, ridges, bridge crossings, buildings, etc.
- Requires a large number of additional detailed breaklines
- A higher quality surface, but substantially more expensive.
- Not cost effective for 3DEP.

Topographic Contours, Detail



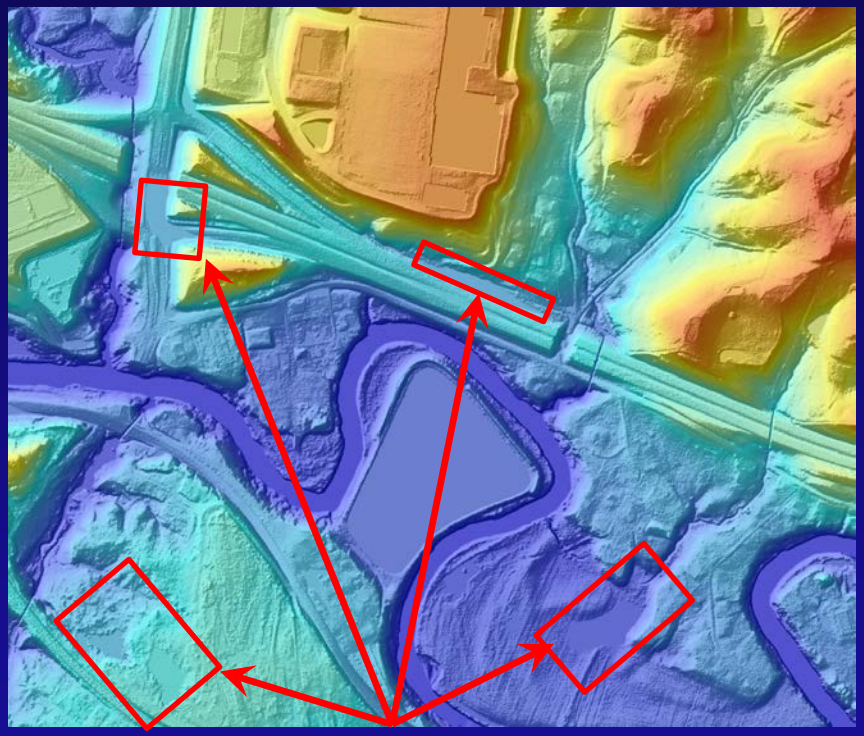
Hydro-Enforced (Hydrologic Surface)



Culverts Cut Through Roads

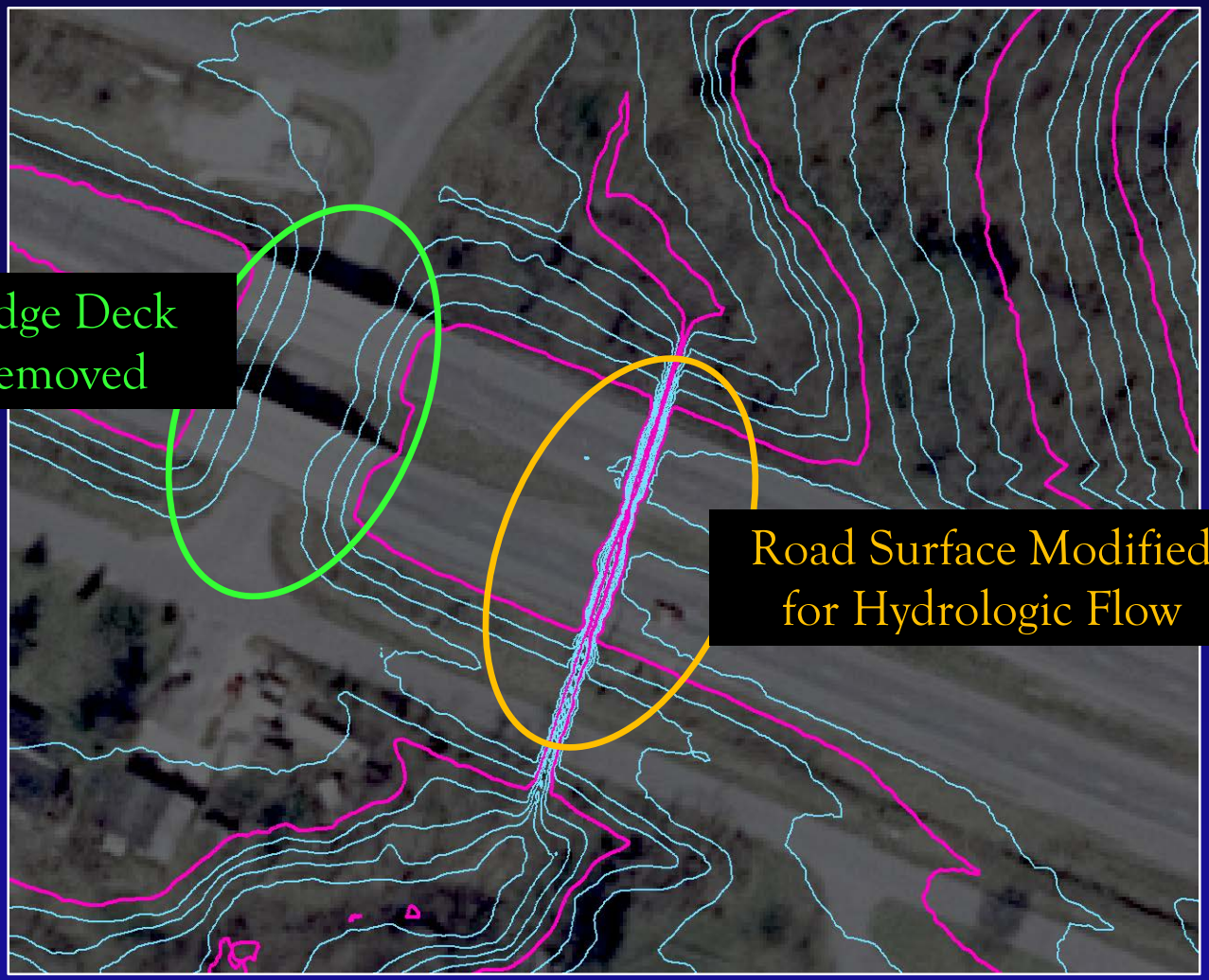
- Engineering surface for Hydraulic and Hydrologic (H&H) modeling.
- Similar to Hydro-Flattened, plus surface modifications to allow continuous surface water flow.
- Water surface elevations may be set at known values.
- Most notably, road fills are cut through at culverts.
- Not useful for traditional mapping or contour development.

Hydro-Conditioned (Hydrologic Surface)



- Another type of surface used by engineers for H&H modeling.
- Similar to the Hydro-Enforced surface, but with sinks filled to their pour point.
- Flow is continuous across the entire surface – no areas of unconnected internal drainage.
- Often developed using tools in ArcGIS Spatial Analyst or ArcHydro.

Hydrologic Contours, Detail



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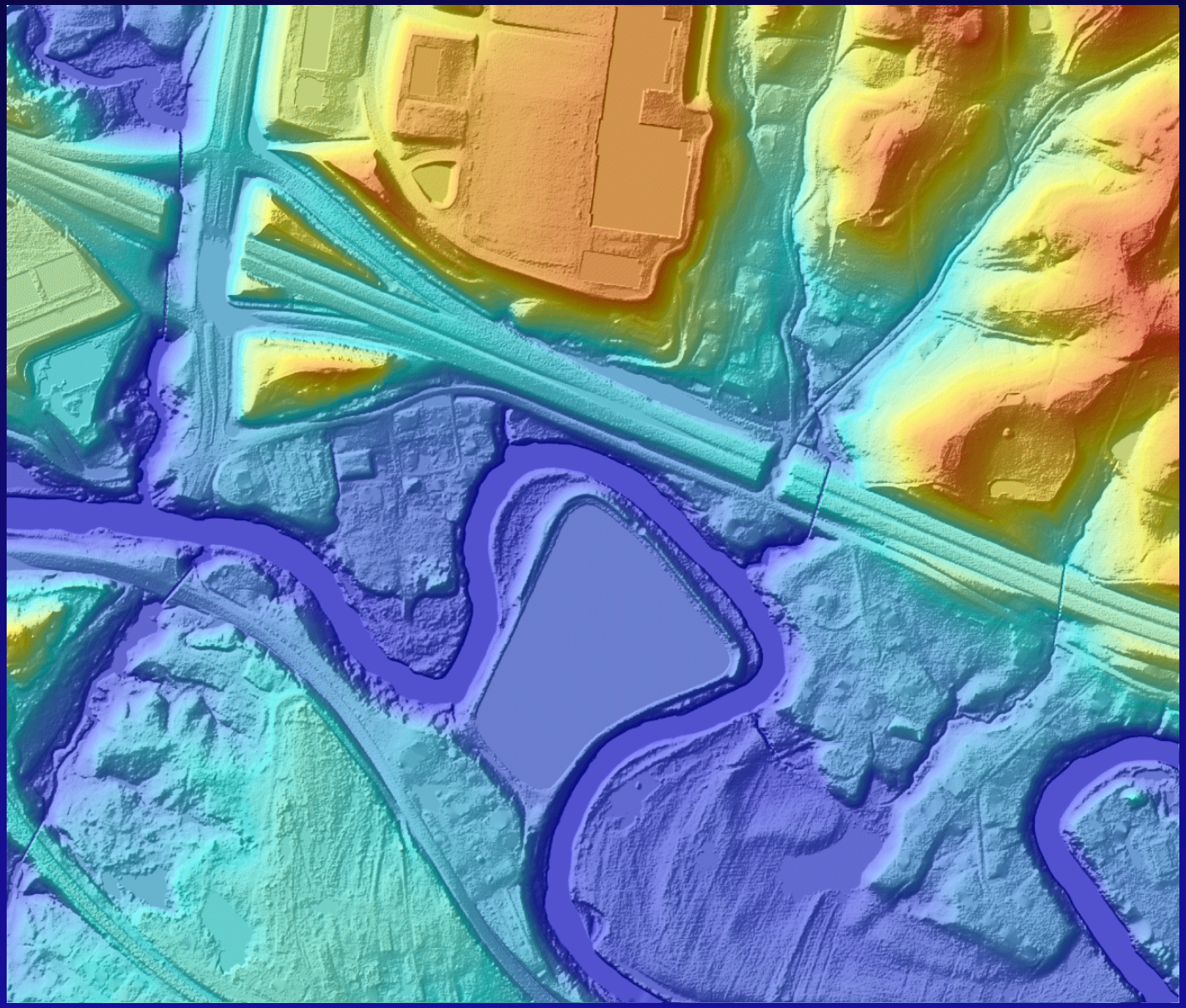

Hydro-Conditioned

Hydro-Enforced

Hydro-Flattened (Enhanced)

Hydro-Flattened (Simple)

Pure (raw) Lidar

Continue

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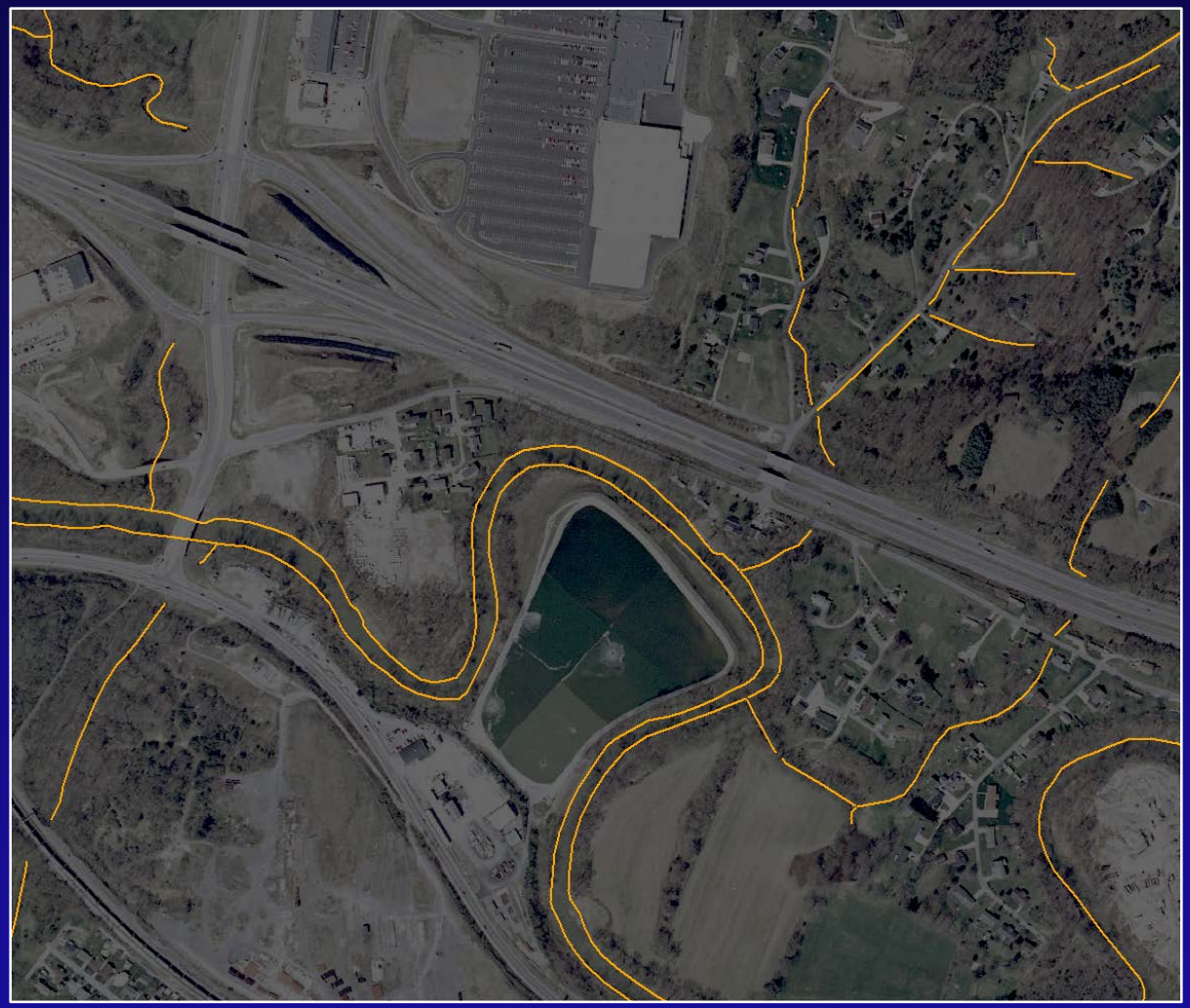
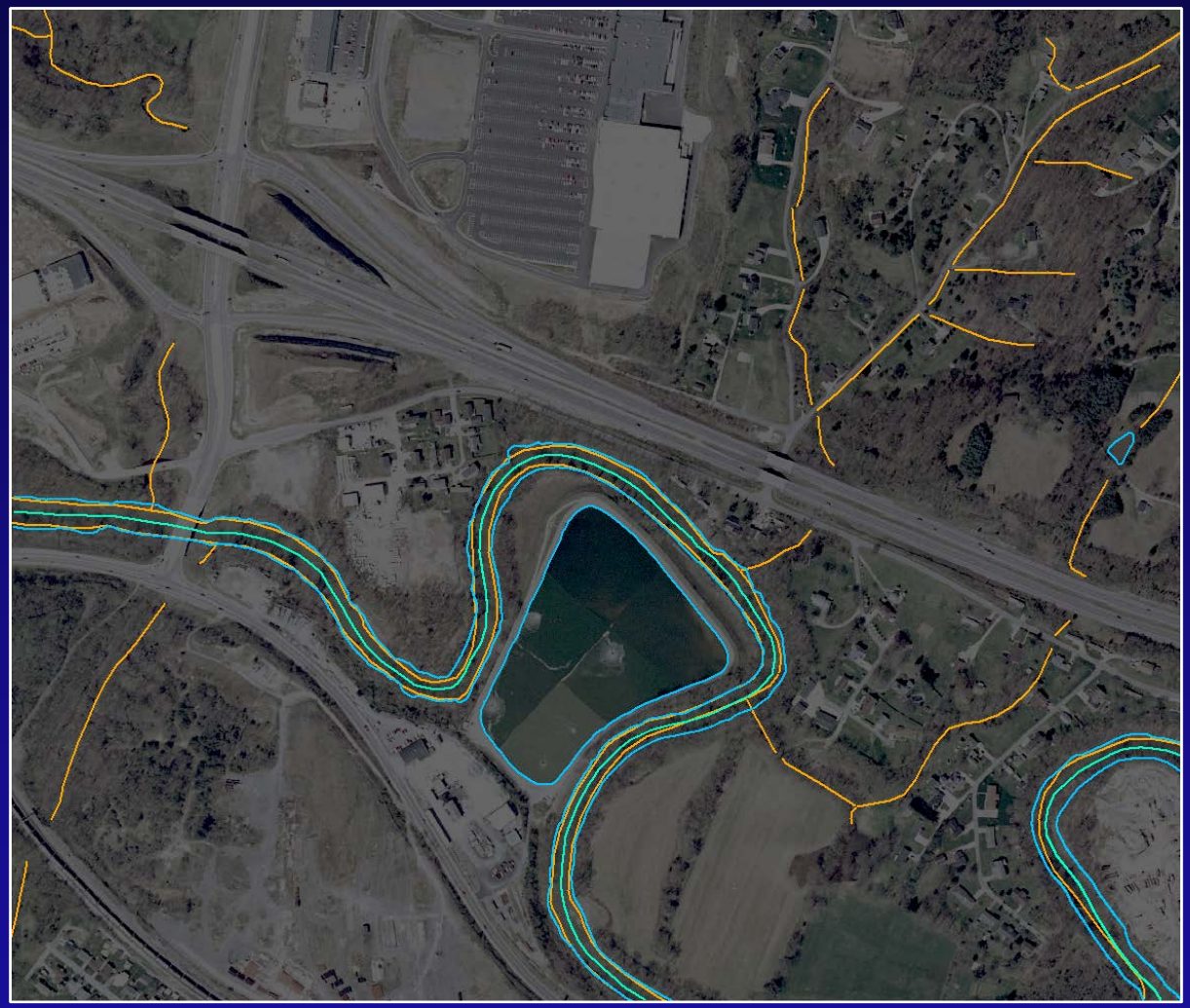
Breaklines and the NHD



Stereo-compiled
hydrographic breaklines

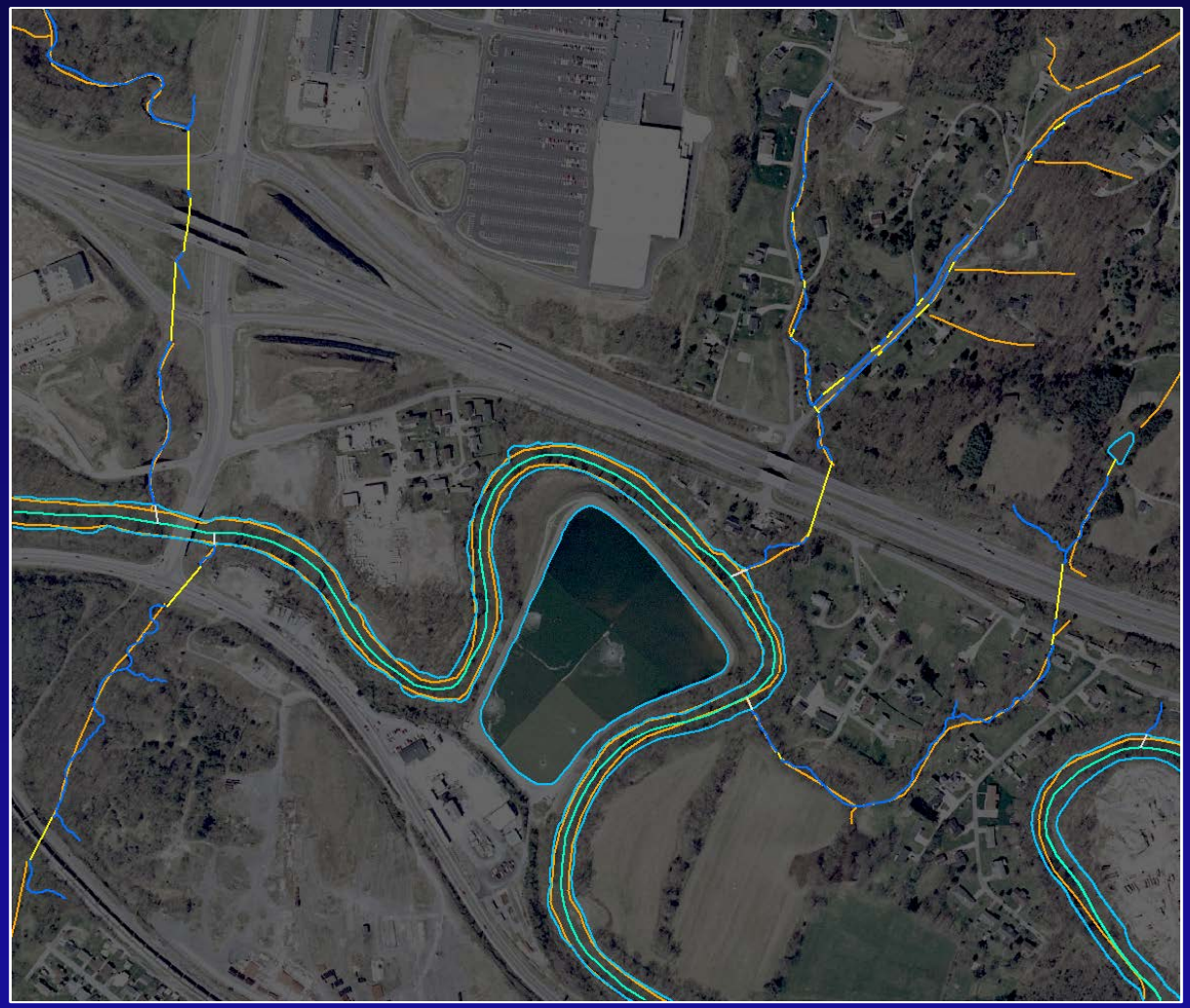
Breaklines and the NHD



Stereo-compiled hydrographic breaklines

Lidar-derived hydrographic breaklines (hydro-flattening only)

Breaklines and the NHD

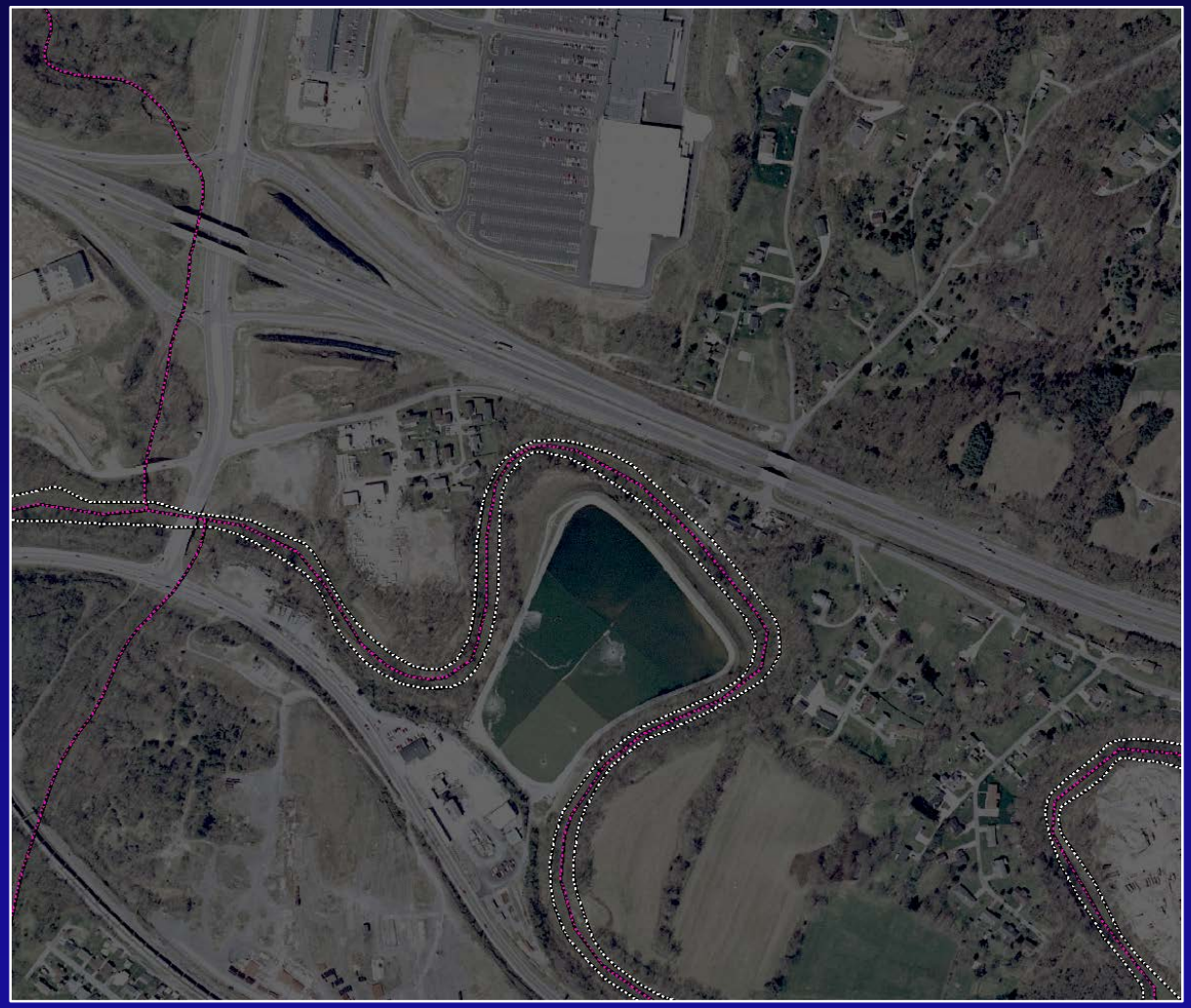


Stereo-compiled hydrographic breaklines

Lidar-derived hydrographic breaklines (hydro-flattening only)

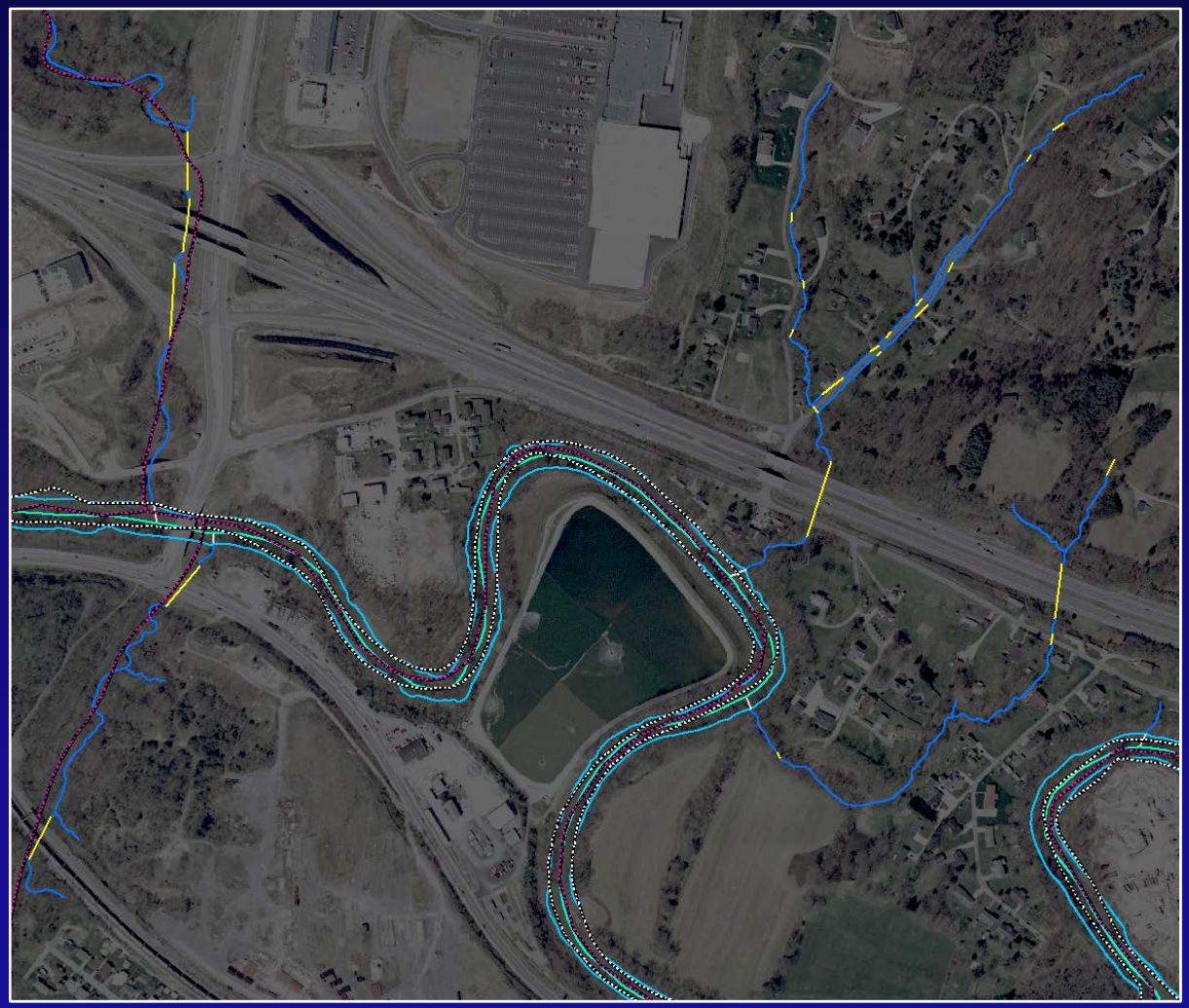
Lidar-derived hydrographic breaklines (expanded collection)

Breaklines and the NHD



NHD Flowlines and
Area polygons

Breaklines and the NHD

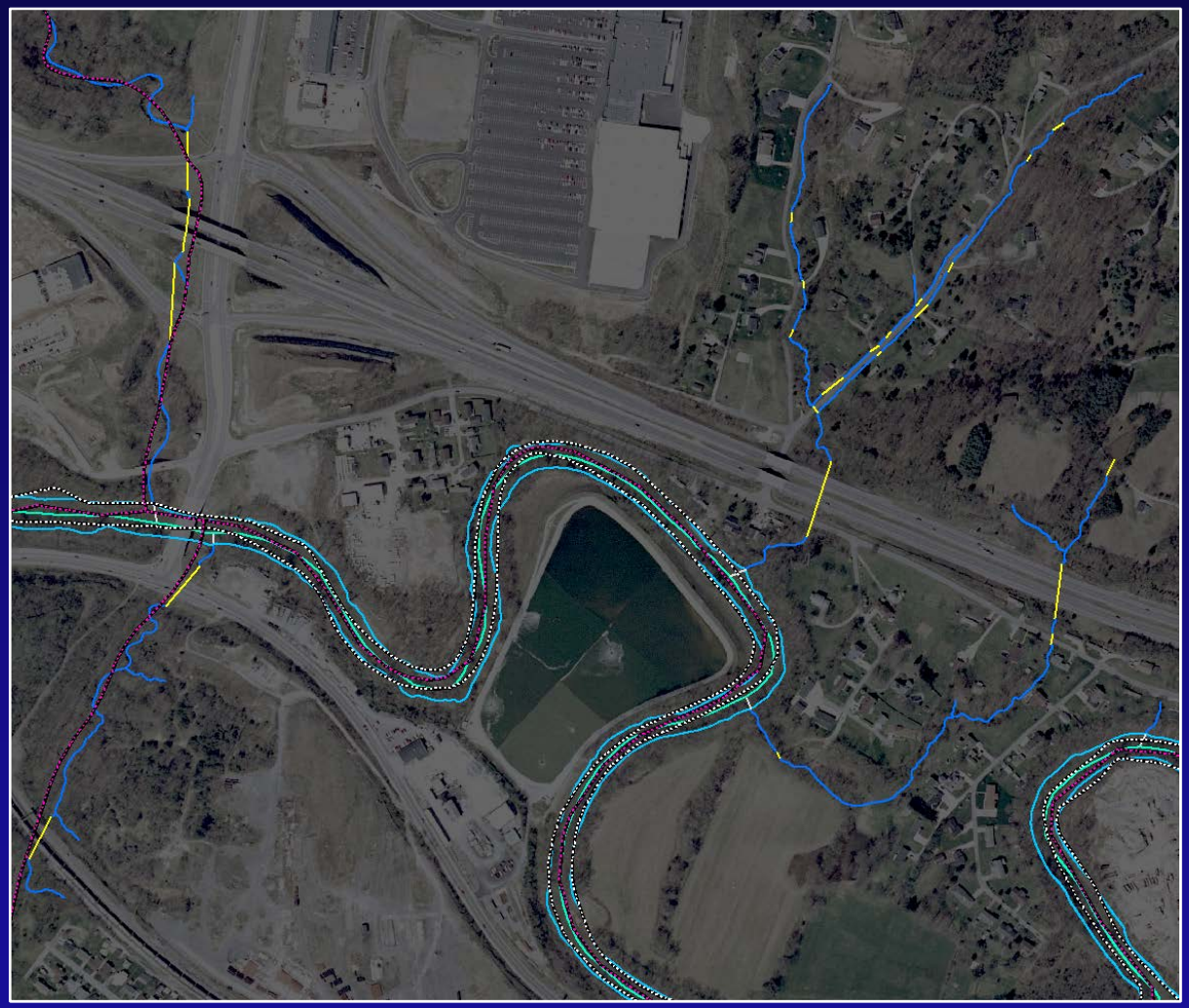


NHD Flowlines and Area polygons

Lidar-derived hydrographic breaklines (expanded collection)

Obvious similarity between these datasets.

Breaklines and the NHD



Since some of these breaklines are going to be collected anyway:

1. Can those be used to update and improve the NHD?

2. Is it worth expanding breakline collection to include single-line features?
   - Improved and added data for the NHD
   - Would support production of hydrologic DEMs

Ele-Hydro Integration

- Elevation
  - Steeped in a tradition of Topographic mapping.
  - Increasing requests for Hydrologic surfaces.
  - Already collecting limited breaklines for hydro-flattening.
  - Additional breaklines would improve topographic surfaces, and allow production of requested hydrologic surfaces.
- NHD
  - Always looking to update and improve their data.
  - Already has a clear and well-defined GIS data dictionary.
  - Interested in incorporating elevation information in the NHD.

An ideal setting for cooperation and integration!

Ele-Hydro Integration

- Initial Steps
  - ☑ Examine the existing NHD Data Dictionary for compatibility and conflicts with Elevation requirements.
  - ☑ Resolve differences between Elevation and NHD needs to produce a single Data Dictionary that supports both programs.
    - ☑ Topology and attribution
  - ☑ Test the new Data Dictionary in-house for functional viability.

Ele-Hydro Data Dictionary (excerpts, draft)

POINTS							
Feature Topology	Elevation Description	EClass	EType	SFType	NHD Description	FGroup	FCode
Always Point	Spot Elevation (verified as high accuracy)	2	1001	1	*n/a*	0	00000
n/a	*n/a*	0	0000	0	Sink/Rise (Emergence or disappearance of a drainge in karst landscape)	1	45000
Point or Line	Gate (connecting two single-line flows; marks a potential change in flow direction)	3	1003	*tbd*	Gate	1	36900
Point, Line, or Polygon	Dam/Weir (connecting two single-line flows; marks a change in WSEL)	3	1004	*tbd*	Dam/Weir	1	34300
Point, Line, or Polygon	Other Topographic Element	2	1303	*tbd*	*n/a*	0	00000

Ele-Hydro Data Dictionary (excerpts, draft)

LINES							
Feature Topology	Elevation Description	EClass	EType	SFType	NHD Description	FGroup	FCode
Point or Line	Gate (crossing polygonal water features; marks a potential change in flow direction)	3	1003	*tbd*	Gate	2	36900
Point, Line, or Polygon	Dam/Weir (crossing polygonal water features; marks a change in WSEL)	3	1004	*tbd*	Dam/Weir	2	34300
Line or Polygon	Stream (narrow; 1D, depicted as singleline; in a braided area, the apparent "Main Channel")	1	1101	*tbd*	Stream/River (1D)	3	46000
Line or Polygon	Canal/Ditch (narrow; depicted as singleline)	1	1102	*tbd*	Canal/Ditch (1D)	3	33600
Line or Polygon	Culvert (singleline, or centerline of polygonal culvert)	1	1103	*tbd*	--> Stream/River	3	46000
				tbd	--> IF Canal/Ditch	3	33600
				tbd	--> IF Artificial Path	3	55800
Line or Polygon	Spillway (singleline, or centerline of polygonal spillway)	1	1104	*tbd*	--> Stream/River	3	46000
				tbd	--> IF Canal/Ditch	3	33600
				tbd	--> IF Artificial Path	3	55800
Always Line	Stream Braid (narrow single-line streams; NOT the apparent "Main Channel")	1	1105	*tbd*	Stream/River (1D)	3	46000
Always Line	Centerline (any waterbody)	1	1201	*tbd*	Artificial Path	3	55800
Always Line	Link (singleline to centerline)	1	1202	*tbd*	Artificial Path	3	55800
Always Line	Elevation Terminus Line (i.e., artificial "centerline" of a boundary waterbody)	1	1203	*tbd*	*n/a*	0	00000
Always Line	Flattener	1	1204	*tbd*	*n/a*	0	00000
Point, Line, or Polygon	Other Topographic Element	2	1303	*tbd*	*n/a*	0	00000
n/a	*n/a*	0	0000	0	Bridge (WATER conveyance; very rare)	2	31800
n/a	*n/a*	0	0000	0	Connector	3	33400
n/a	*n/a*	0	0000	0	Sink/Rise (Emergence or disappearance of a drainge in karst landscape)	2	45000

Ele-Hydro Data Dictionary (excerpts, draft)

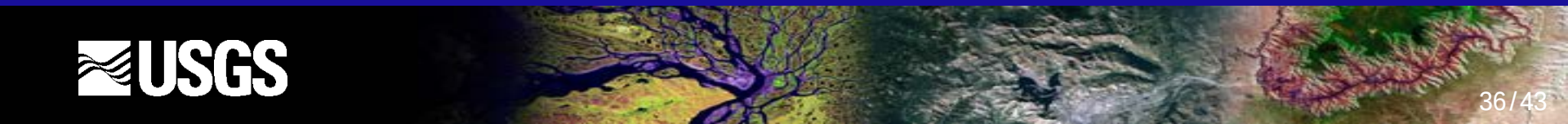
POLYGONS							
Feature Topology	**Elevation Description**	**EClass**	**EType**	**SFType**	**NHD Description**	**FGroup**	**FCode**
Point, Line, or Polygon	Dam/Weir (LARGE; also use Centerline as centerline)	3	1004	*tbd*	Dam/Weir (LARGE; also use Artificial Path as centerline)	4	34300
Line or Polygon	Canal/Ditch (Wide, depicted as doubleline with centerline)	1	1102	*tbd*	Canal/Ditch (Wide, depicted as doubleline with Artificial Path as centerline)	4	33600
Line or Polygon	Spillway (LARGE; also use Spillway Line as centerline)	1	1104	*tbd*	Spillway (LARGE; also use Artificial Path as centerline)	4	45500
Always Polygon	Lake/Pond(use Centerline as centerline)	1	1106	*tbd*	Lake/Pond (use Artificial Path as centerline)	5	39000
Always Polygon	River (Wide, 2D, depicted as doubleline with centerline)	1	1107	*tbd*	Stream/River (Wide, depicted as doubleline with Artificial Path as centerline)	4	46000
	--> If wide, and braided or with numerous islands, the centerline should follow the apparent "Main Channel"			*tbd*	Area of Complex Channel (very complex wide 2D "river"; main channel identified with Artificial Path centerline)	4	53700
Always Polygon	Reservoir (use Centerline as centerline)	1	1108	*tbd*	Reservoir (use Artificial Path as centerline)	5	43600
Always Polygon	Boundary Waterbody	1	1111	*tbd*	--> IF Sea/Ocean	4	44500
				tbd	--> IF Stream/River	4	46000
				tbd	--> IF Lake/Pond	5	39000
Always Polygon	Bridge Deck (ANY TYPE)	3	1301	*tbd*	*--> IF Bridge (WATER Conveyance; very rare)*	*4*	*31800*
				tbd	--> (else,)	0	00000
Always Polygon	Swamp/Marsh Area (Reference area for Elevation)	9	1401	*tbd*	Swamp/Marsh	5	46600
Always Polygon	Braided Stream Area (Reference area for Elevation) (This is NOT the same as the NHD Code 53700)	9	1402	*tbd*	*n/a*	0	00000
Always Polygon	Unusually Inundated Area (Reference area for Elevation)	9	1403	*tbd*	*n/a*	0	00000
Always Polygon	Island/Sandbar-Intermittently/Partially Submerged	2	1404	*tbd*	*n/a*	0	00000
Always Polygon	Low Confidence Area (pre-determined) (Reference area for Elevation)	9	1501	*tbd*	*n/a*	0	00000
Always Polygon	Low Confidence Area (sparse bare-earth) (Reference area for Elevation)	9	1502	*tbd*	*n/a*	0	00000
Line or Polygon	Culvert (LARGE; also use Culvert Line as centerline) (uncommon)	1	1103	*tbd*	*n/a*	0	00000
Point, Line, or Polygon	Other Topographic Element	2	1303	*tbd*	*n/a*	0	00000

Notable Differences

Elevation and NHD databases are very similar, but …

- NHD includes many features that are not relevant to elevation surfaces
  - e.g., well, pipeline, flume
- Elevation requires a few features that are irrelevant to the NHD
  - e.g., “flatteners”
- Some features in the NHD need to be topologically subdivided for effective use in elevation applications
  - e.g., water bodies features passing under bridges
  - culverts; typically not segmented in the NHD

Although NHD and Elevation data requirements are remarkably similar, the decision was made to use independent attributes and codes to avoid confusion in identifying features of interest between the two primary stakeholders.



While important to NHD for modeling water flow, pipelines would not be included in a DEM.

"Flatteners" are lines used in elevation to ensure that the surfaces complex water bodies are set to a consistent elevation. They do not represent flow or hydrographic features.

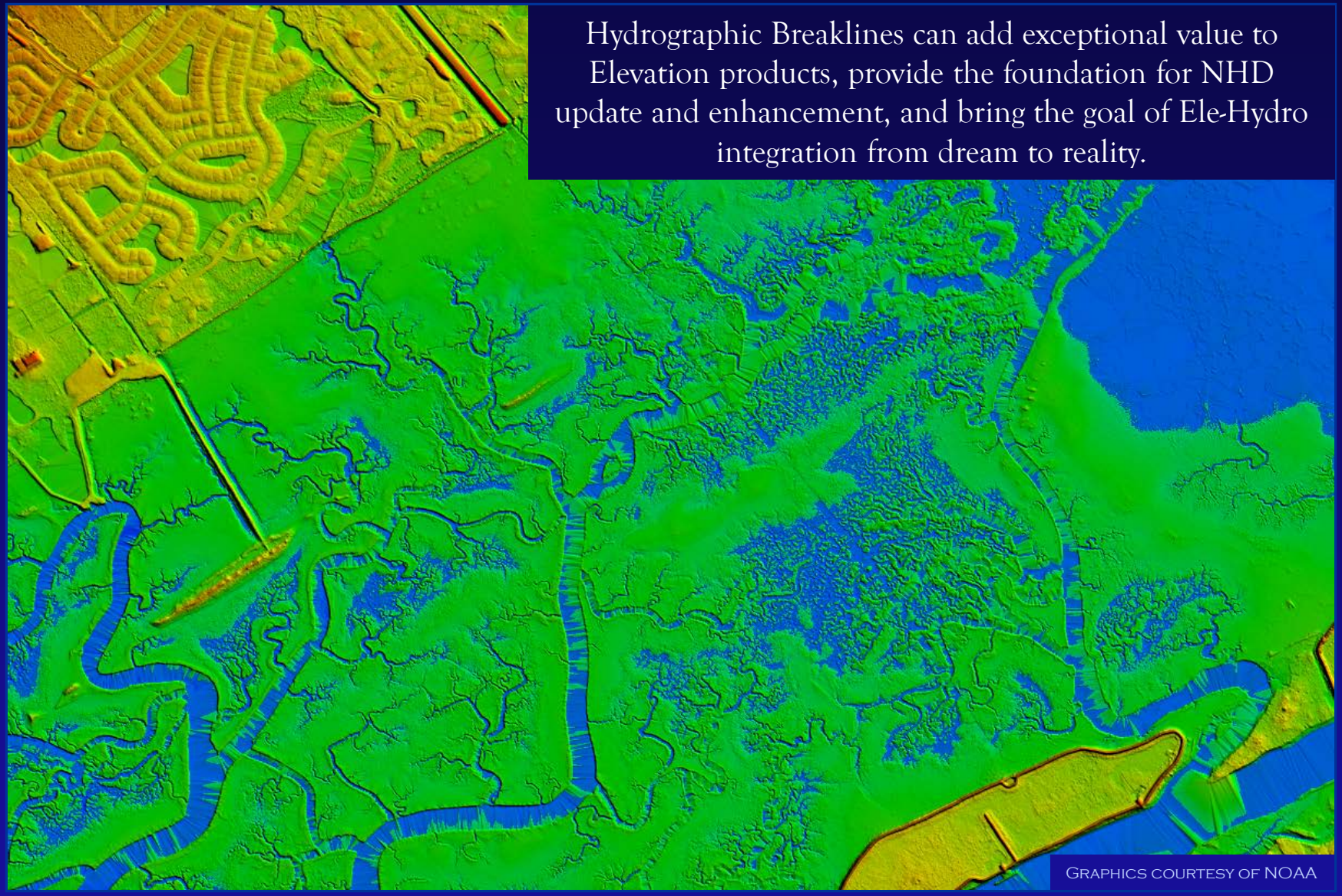
Elevation needs to remove waterbody segments under bridges; the NHD does not.

Culverts must be differentiable from streams in order to create both topographic and hydrologic DEMs.

Ele-Hydro Integration

- Current Activities
  - Incorporate the Data Dictionary into the Lidar Base Specification, version 1.3
    - Data STRUCTURE only;
    - NO capture requirements at this point.
  - Conduct Pilot Projects with GPSC contractors to:
  - Gauge costs and quality of additional breakline collection.
  - Determine the most effective and appropriate extent of collection for integrated breaklines.
    - Scale and Feature Types

Hydrographic Breaklines can add exceptional value to Elevation products, provide the foundation for NHD update and enhancement, and bring the goal of Ele-Hydro integration from dream to reality.



Graphics courtesy of NOAA

USGS

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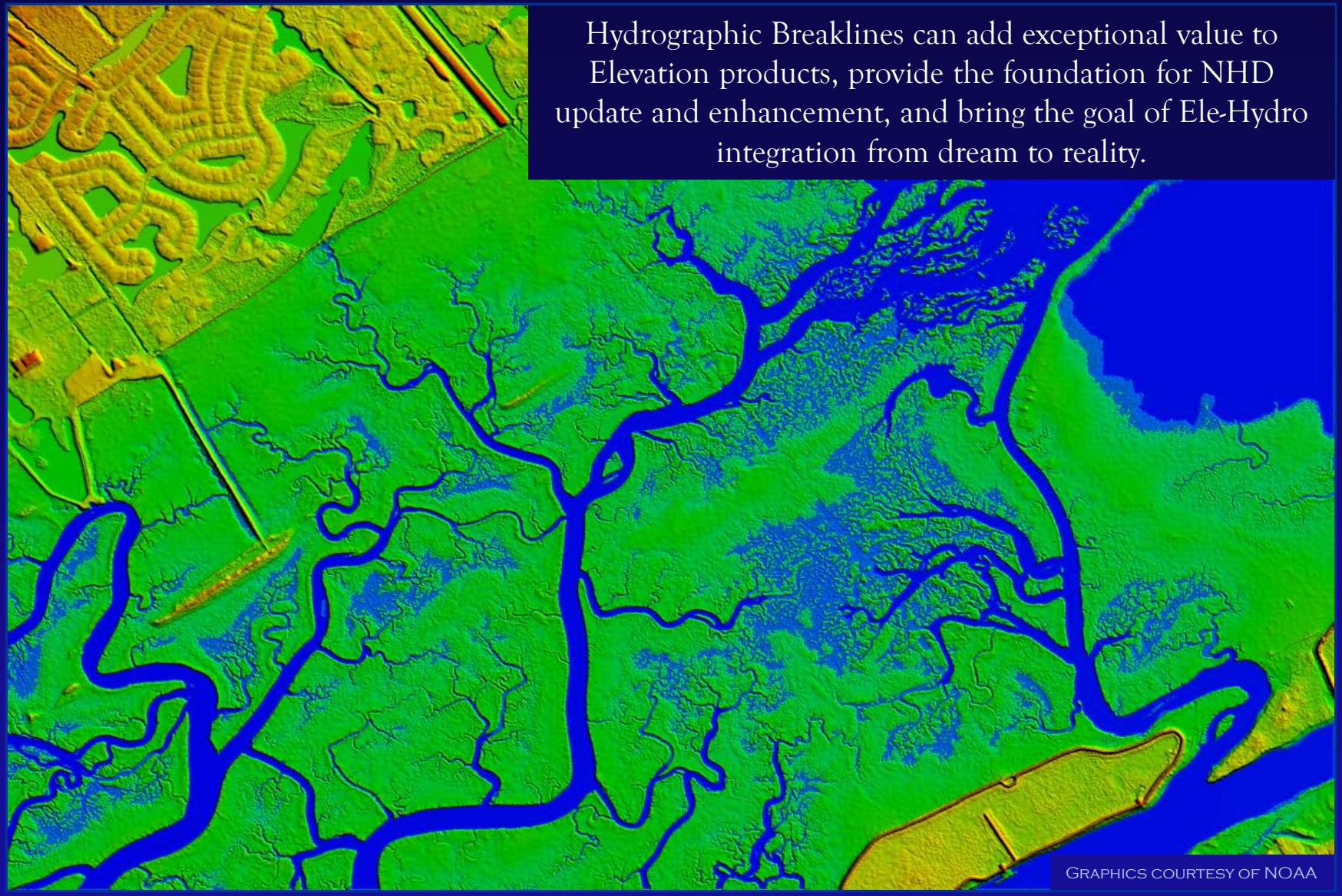
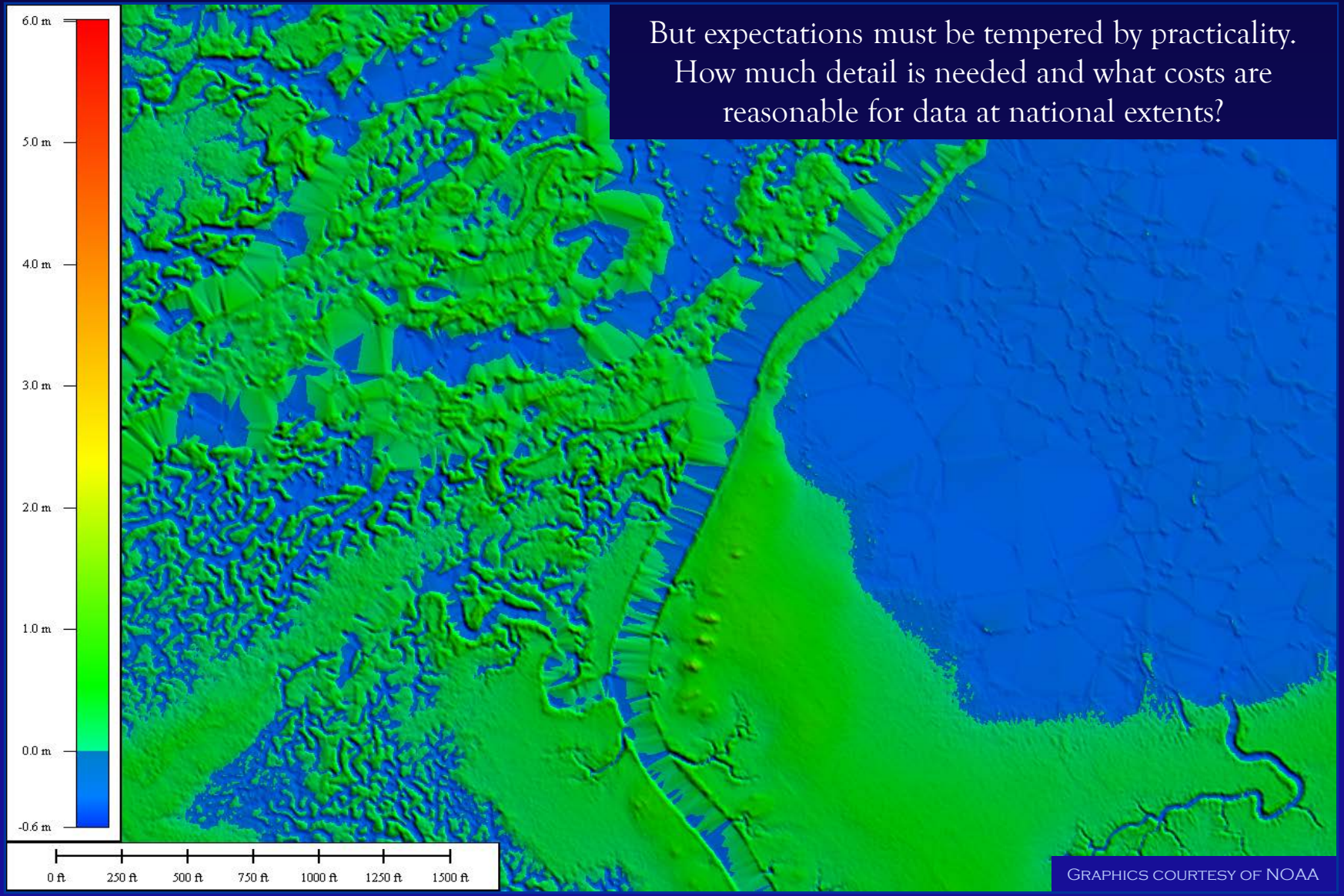


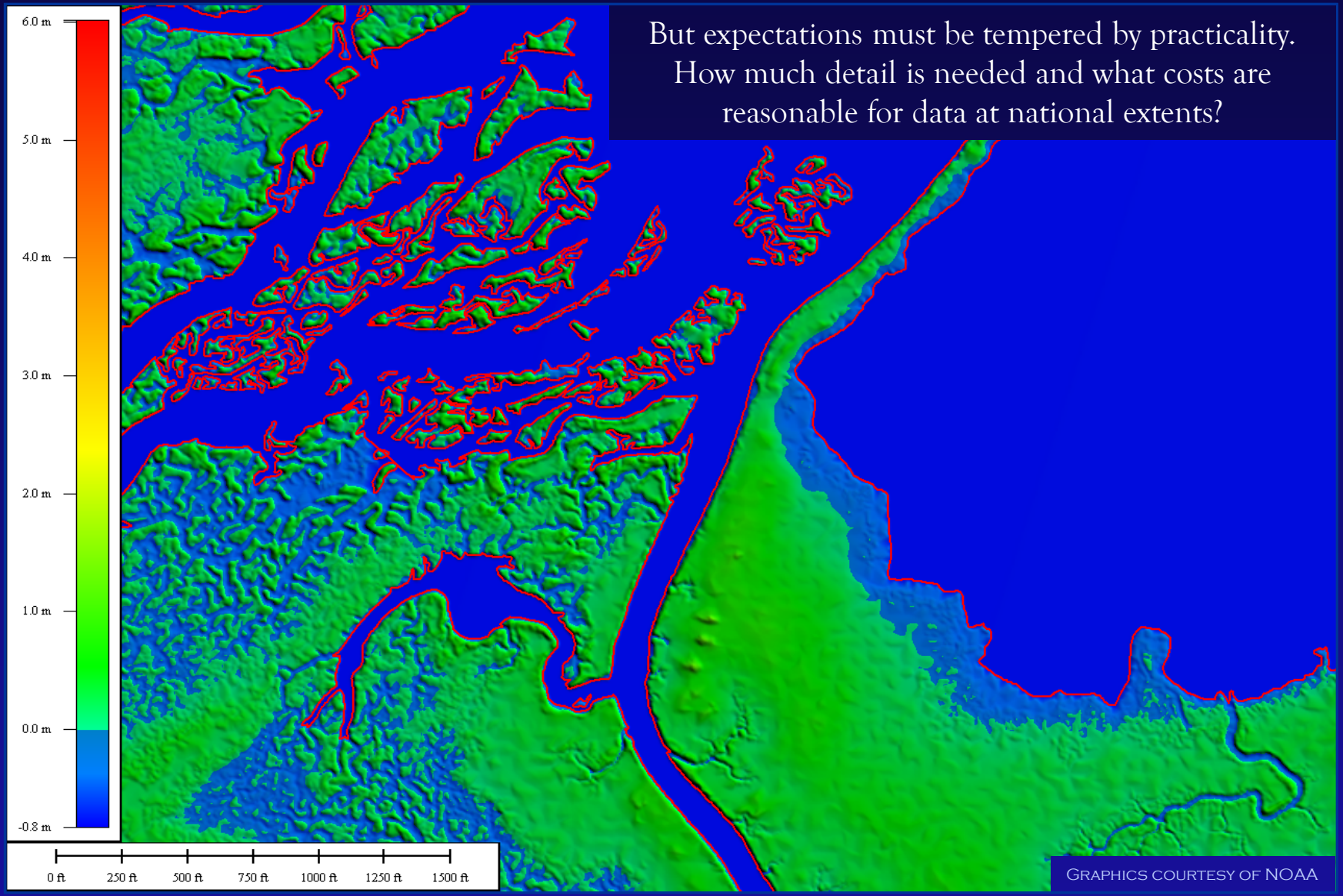
Graphics courtesy of NOAA

USGS



But expectations must be tempered by practicality. How much detail is needed and what costs are reasonable for data at national extents?

Graphics courtesy of NOAA



But expectations must be tempered by practicality. How much detail is needed and what costs are reasonable for data at national extents?

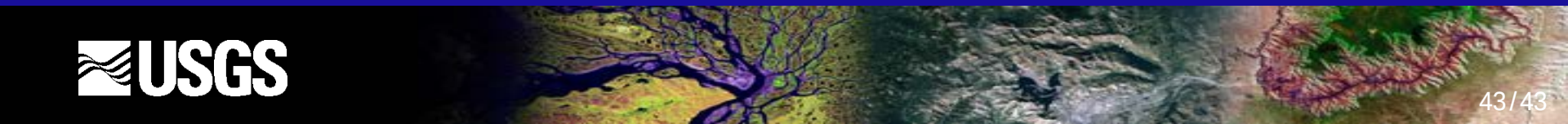
Graphics courtesy of NOAA

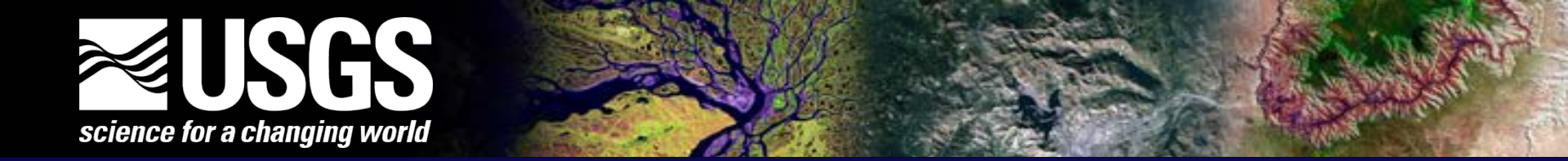
Ele-Hydro Integration

- Future Tasks
  - Develop internal processes to utilize the additional data.
  - Introduce capture requirements into the Lidar Base Specification and GPSC Task Orders.
  - Produce and distribute new and improved Elevation and Hydrographic products.

<u>Conclusion:</u>
Integrated Elevation and Hydrography.
Stronger Together.

Ele-Hydro!





Lidar Topography and Hydrographic Integration: *Fundamentals and Application Issues*

USGS Hydrography Seminar Series,
Seminar #8
Thursday, May 19, 2016

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U.S. Geological Survey