# USGS LiDAR Guidelines and Base Specification V.13
# Wetlands Mapping Consortium 4/18/2012

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**Substituting for Karl Heidemann of USGS, primary author of V.13**

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# Objectives, to understand …

- Terminology used with LiDAR datasets
- Difference between standards and specifications
- Vertical accuracy terminology
- *USGS LiDAR Guidelines and Base Specifications* V.13
- Different hydro treatments of LiDAR-derived DEMs
- V.13 common data upgrades that might be appropriate for wetlands mapping
- Why the V.13 specifications were necessary, and …
- to segue into briefings by Amar Nayegandhi and Greg Snyder

# ASPRS' "DEM Users Manual"

1. Intro to DEMs, 3-D Surface Modeling, Tides
2. Vertical Datums
3. Accuracy Standards
4. National Elevation Dataset
5. Photogrammetry
6. IFSAR
7. Topographic & Terrestrial Lidar
8. Airborne Lidar Bathymetry
9. Sonar
10. Enabling Technologies
11. DEM User Applications
12. DEM Quality Assessment
13. DEM User Requirements
14. Lidar Processing & Software
15. Sample Elevation Datasets

# Current User Requirements Menu (2nd edition)

**Table 13.1** User Requirements Menu.

**Project Area** Name of Project Area if applicable: ____________
Project Boundary: ☐ Rectangular ☐ Non-Rectangular ☐ Project Extent Shapefile provided
Over-edge buffer width outside Shapefile area: ________

**General Surface Description**
**Elevation Surface** (choose one or more)
☐ Digital surface model (first/top reflective surface)
☐ Digital terrain model (bare earth)
☐ Bathymetric surface
☐ Mixed surface ☐ Point cloud

**Elevation Type** (choose one)
☐ Orthometric height
☐ Ellipsoid height
☐ Other ____________

**Data Model Types** (choose one or more) * Designate either feet or meters
☐ Mass Points ☐ Grid (post spacing = ___ feet/meters) * ☐ Contour Lines
☐ Breaklines ☐ Grid (post spacing = ___ arc-seconds) ☐ Cross Sections
☐ TIN (average point spacing = ___ feet/meters) * ☐ Other, e.g. concurrent imagery

**Source** (choose one)
☐ Cartographic ☐ Photographic ☐ IFSAR ☐ Lidar ☐ Sonar
If multi-return system, choose one or more: ☐ First return ☐ Last return ☐ All returns

**Vertical Accuracy - General** (See Table 13.2, choose one, or more with explanation) ☐ Other
☐ 1' contour equivalent ($Accuracy_z$ = 0.60 ft) ☐ 5' contour equivalent ($Accuracy_z$ = 2.98 ft)
☐ 2' contour equivalent ($Accuracy_z$ = 1.19 ft) ☐ 10' contour equivalent (Accuracyz = 5.96 ft)
☐ 4' contour equivalent ($Accuracy_z$ = 2.38 ft) ☐ 20' contour equivalent ($Accuracy_z$ = 11.92 ft)

**Vertical Accuracy - Specific** (choose one or more; FVA is mandatory, SVA and CVA are optional)
☐ Fundamental Vertical $Accuracy_z$ = __ (ft or cm) at 95% confidence level in open terrain = $RMSE_z$ x 1.9600
☐ Supplemental Vertical $Accuracy_z$ = __ (ft or cm) = 95th percentile in other specified land cover categories
☐ Consolidated Vertical $Accuracy_z$ = __ (ft or cm) = 95th percentile in all land cover categories combined

**Horizontal Accuracy** (See Table 13.3; choose one) $Accuracy_r$ = $RMSE_r$ x 1.7308
☐ $Accuracy_r$ = ___ feet or meters* *Designate either feet or meters

**Accuracy Reporting** (choose one vertical and one horizontal at the 95 percent confidence level)
☐ Tested ___ (meters/ft) vertical accuracy or ☐ Compiled to meet ___ (meters/ft) vertical accuracy
☐ Tested ___ (meters/ft) horizontal accuracy or ☐ Compiled to meet ___ (meters/ft) horizontal accuracy

**Surface Treatment Factors** (optional – explain with separate text) ☐ Vegetation
☐ Hydro-enforcement ☐ Hydro-conditioning ☐ Buildings
☐ No data areas (Voids) ☐ Suspect areas ☐ Artifacts

**Horizontal Datum** (choose one) **Vertical Datum** (choose one) **Geoid Model** (choose one)
☐ NAD 83 (default) ☐ NAVD 88 (default) ☐ MSL ☐ GEOID03 (default)
☐ WGS 84 ☐ MLLW ☐ Other ____ ☐ Other ____

**Coordinate System** (choose one) ☐ UTM zone ______ ☐ State Plane zone ______
☐ Geographic ☐ Local ______ ☐ Other ______

**Units** Note: Choose one vertical (V) and one horizontal (H) units; V and H units may differ
☐ Elevations to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
☐ Northings/Eastings to ___ decimal places ☐ U.S. Survey Feet ☐ Meters
☐ Decimal degrees to ___ decimal places or ☐ DDDMMSS to ___ decimal places

**Data Format** (See Table 13.4 and explanations. Specify desired format(s) for each product type)
Vector data ____________ Format(s) ____________
Mass points and TINs ____________ Format(s) ____________
Gridded DEMs ____________ Format(s) ____________

**File Size/Tile Size** (Maximum file size, if applicable) _____ Mb / Gb / Other ______
Tile Size, if applicable ☐ _____ ft x _____ ft ☐ _____ meters x _____ meters ☐ Other

**Metadata** Compliant with FGDC's "Content Standards for Digital Geospatial Metadata"

**Delivery Schedule** Date(s) when deliverables are to be submitted by the Producer to the Customer

- Too many choices
- Too many opportunities for adjoining datasets from multiple vendors to be inconsistent and have edge-join issues
- Inconsistency increases costs, reduces usability
- 3rd edition will focus on minimum parameters of the *USGS LiDAR Guidelines and Base Specifications*, V.13, with potential upgrades

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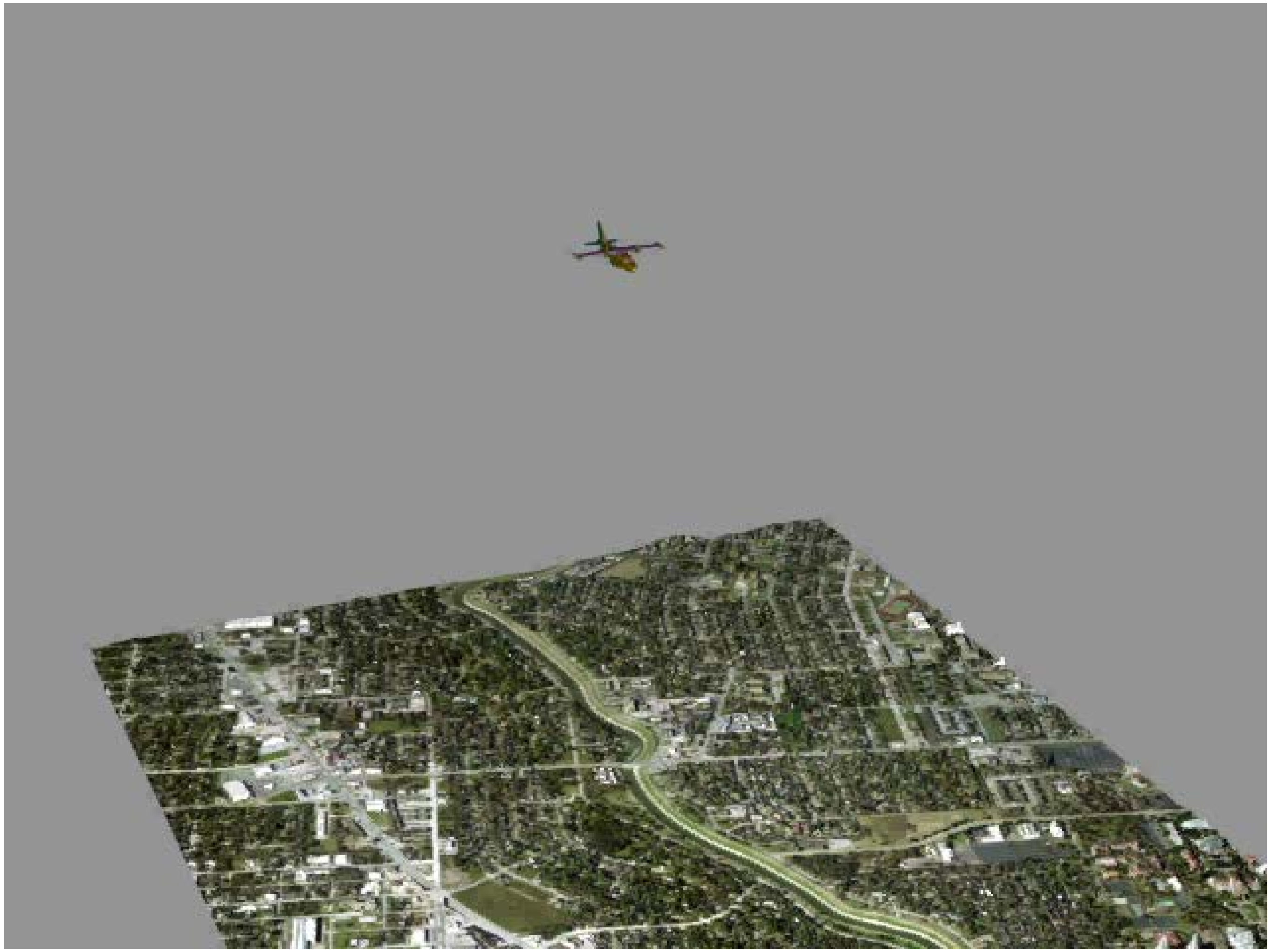
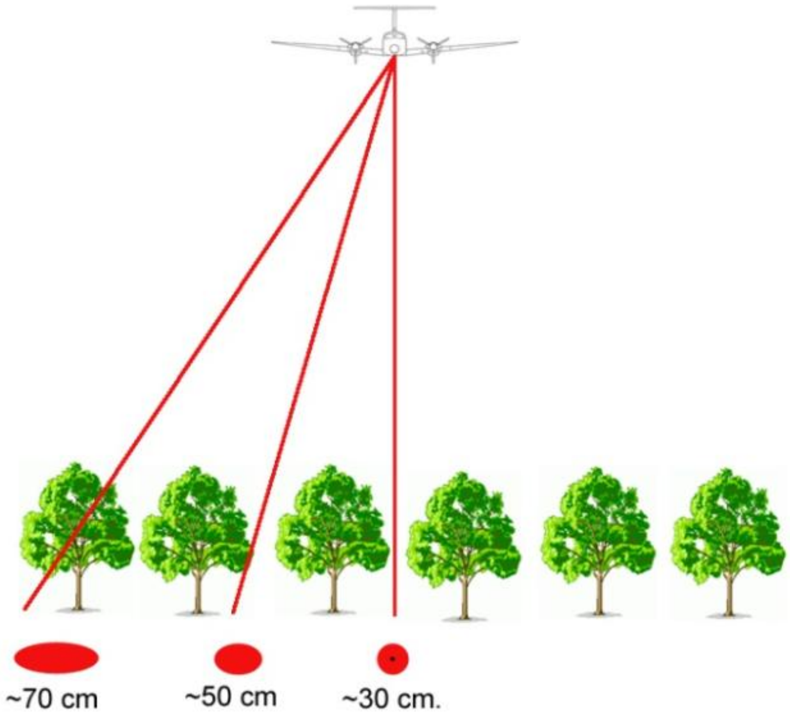
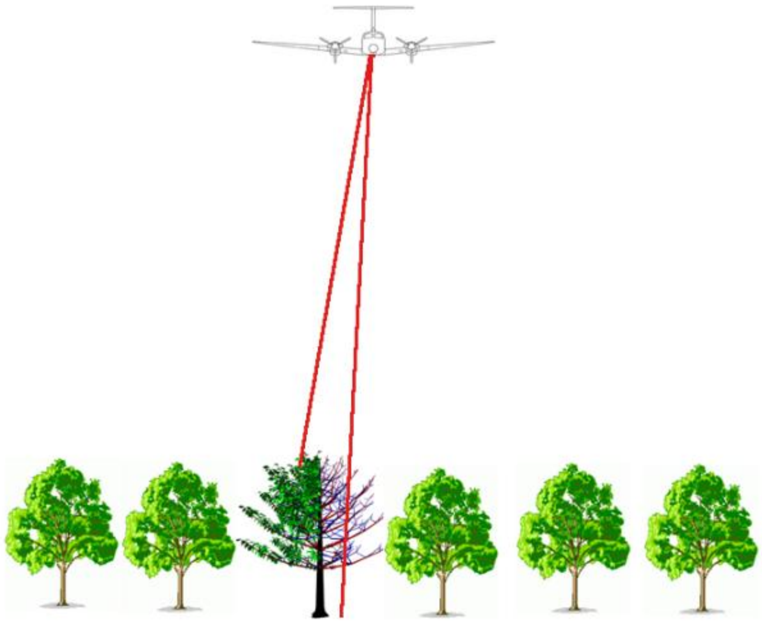
# LiDAR Acquisition Simulation



# Flight Planning Considerations




**Maximum scan angle?**



**Leaf-on or leaf-off?**

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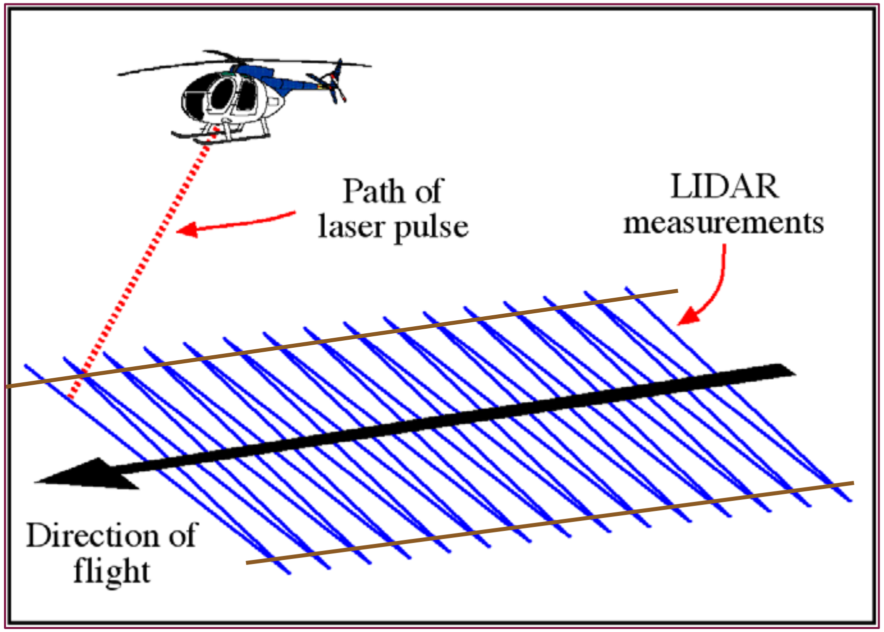
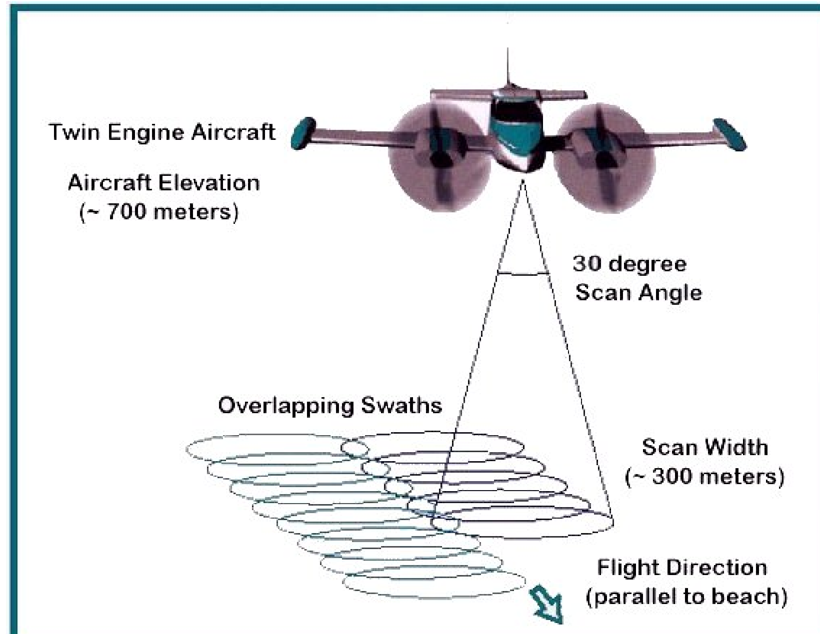
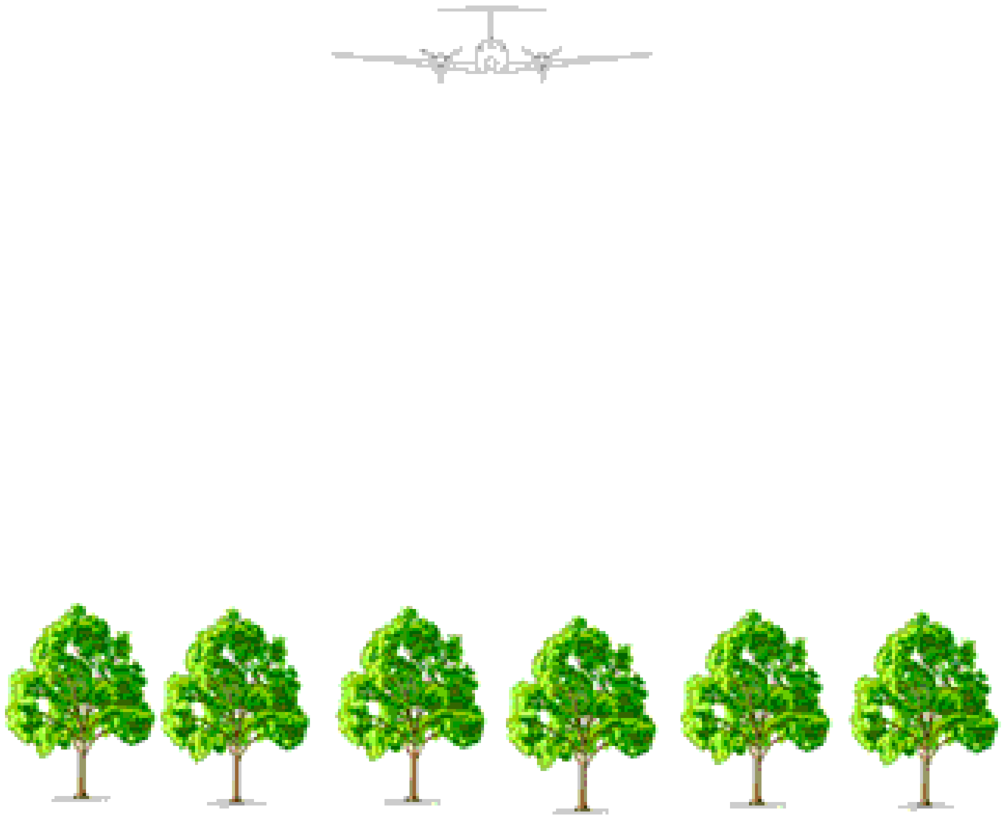
# Multiple Scanning Patterns (two most common)



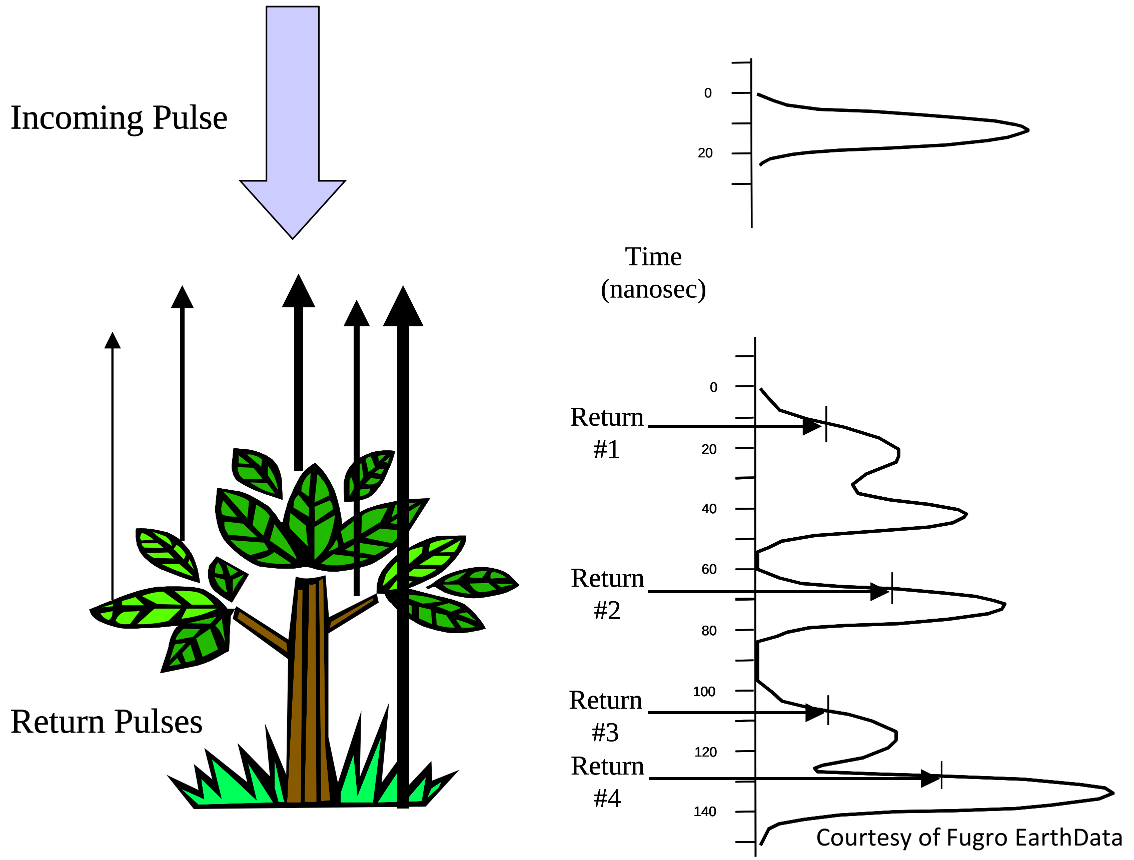




**It is common to withhold the data for a few percent at the tips of the zig-zags where elevations are less accurate**

# Laser Penetration



# Laser Returns




Courtesy of Fugro EarthData

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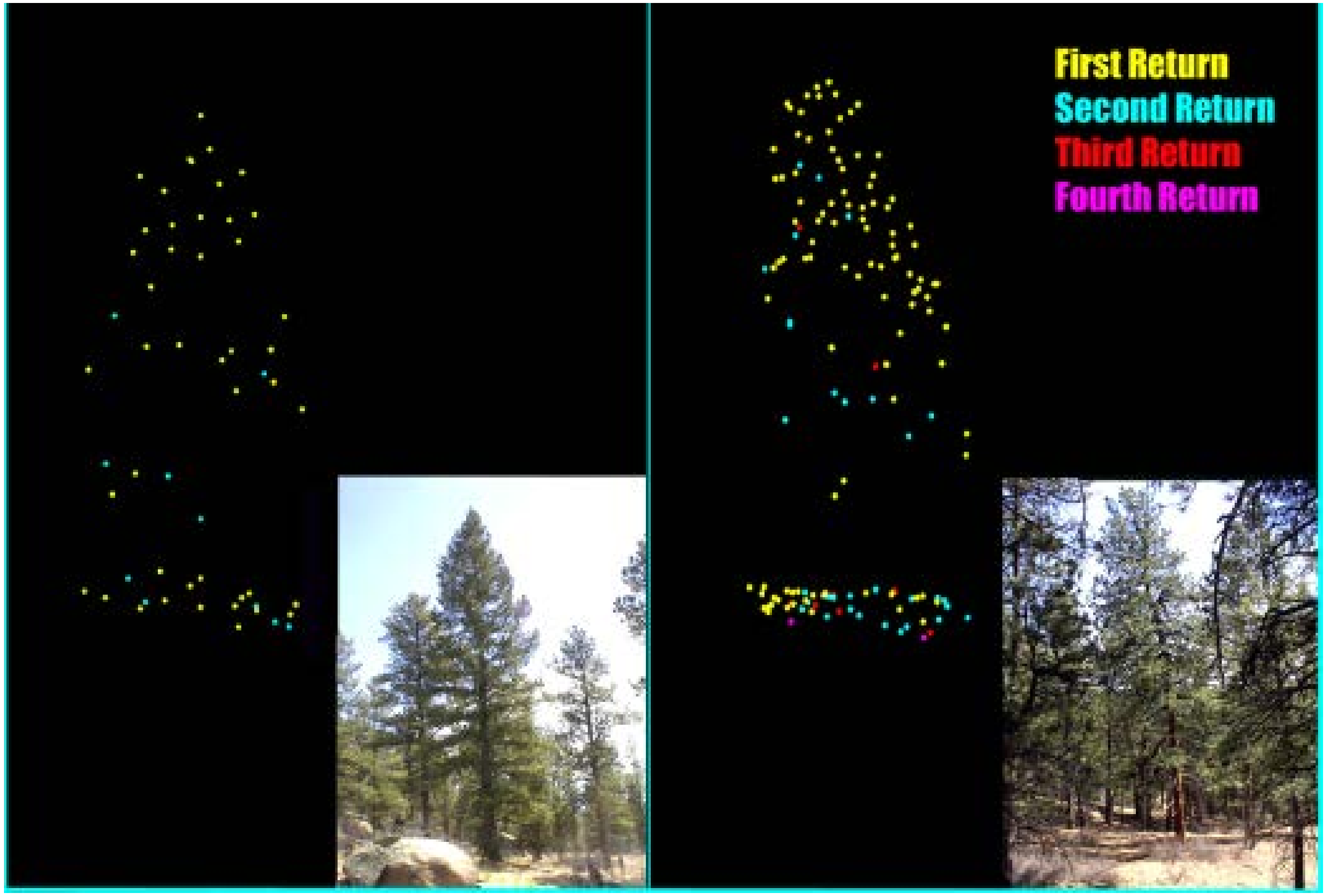
# Example of LiDAR Point Cloud (for just one tree)

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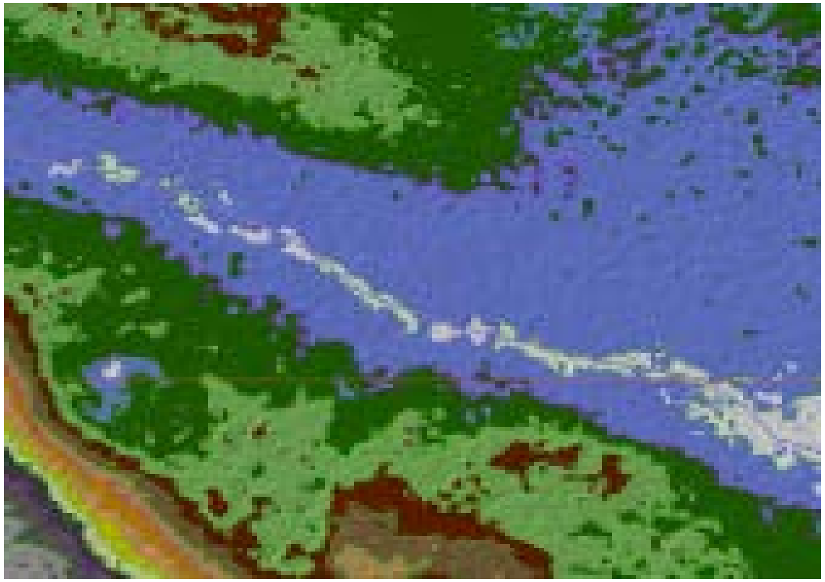
# LiDAR Intensity Image (erratic returns on water)

# Major Advantage of LiDAR (foliage penetration)



**Forest appears impenetrable for topographic mapping; but what are those colored lines?**

**White = depressions from dry stream; "hydro-conditioning" would fill depressions "hydro-enforcement" would drain them; we only hydro-enforce hydrologic features, not topographic features.**

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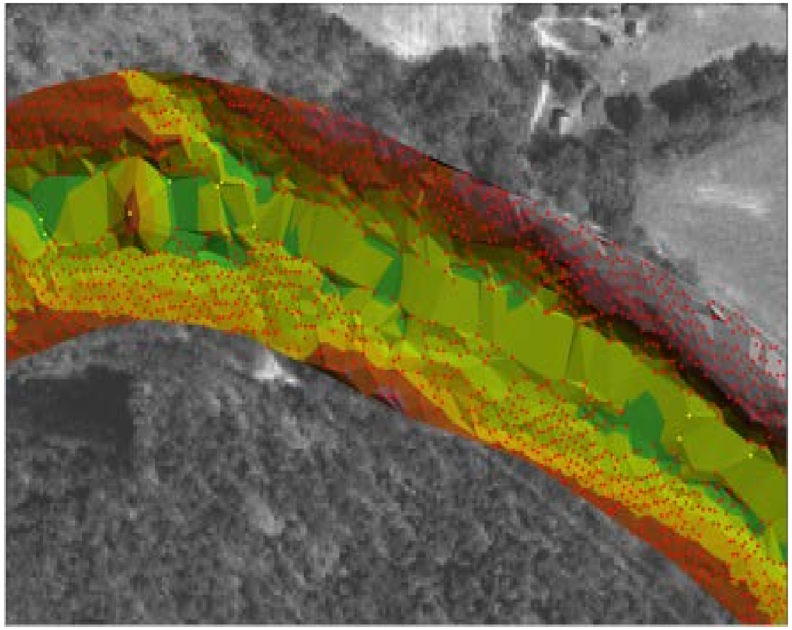
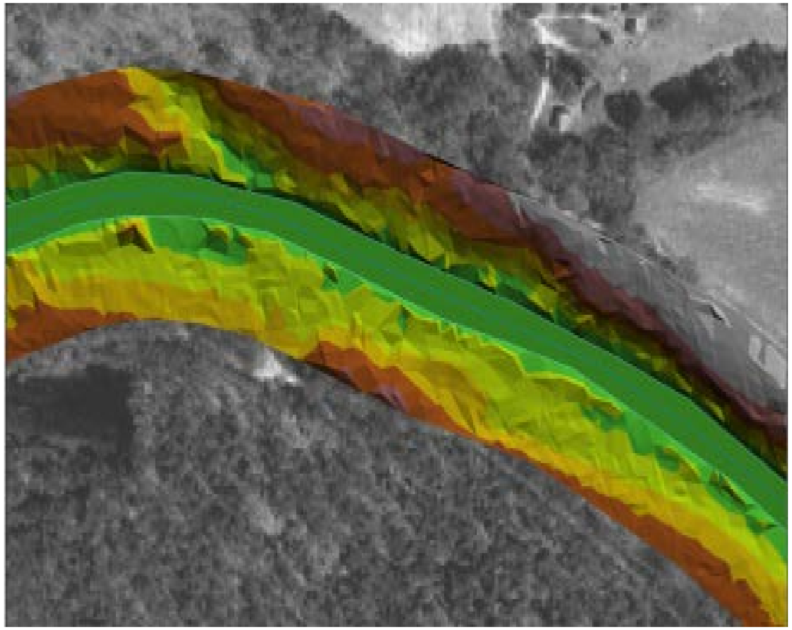
# Before/After Hydro-Enforcement of Stream

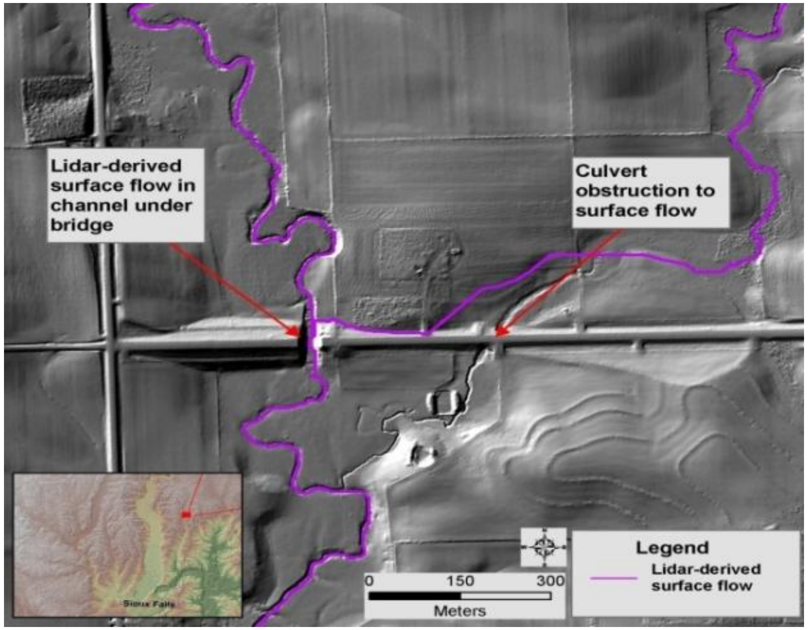


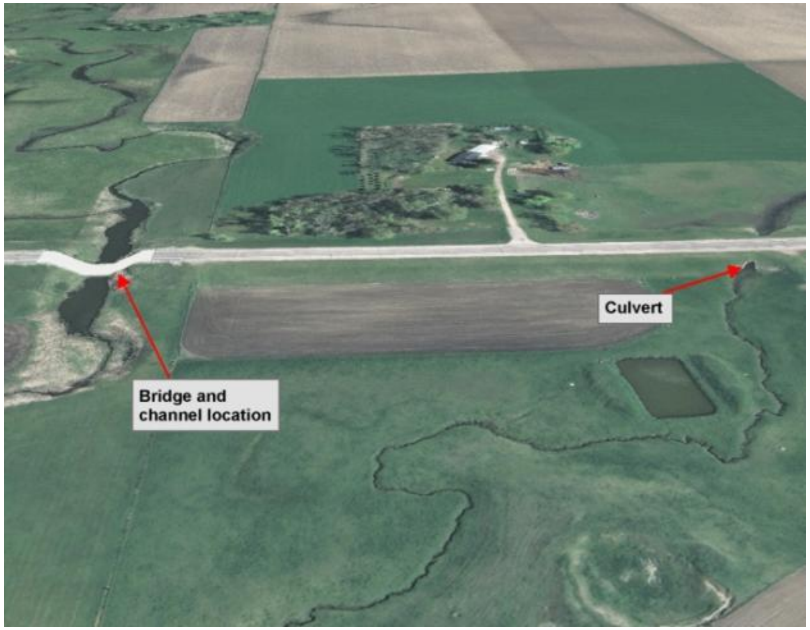
**Before: LiDAR points on shorelines naturally undulate up and down, making it appear as though water cannot pass through**



**After: Hydro-enforce centerline of stream and/or shorelines so that water in hydrologic models flows downstream**

# National Elevation Dataset (NED)




**DEM has bridge removed; culverts are not “cut” beneath road surface, so water appears to pass on north side of road until reaching the stream.**

**When image is draped on DEM for orthophoto, bridge is warped**

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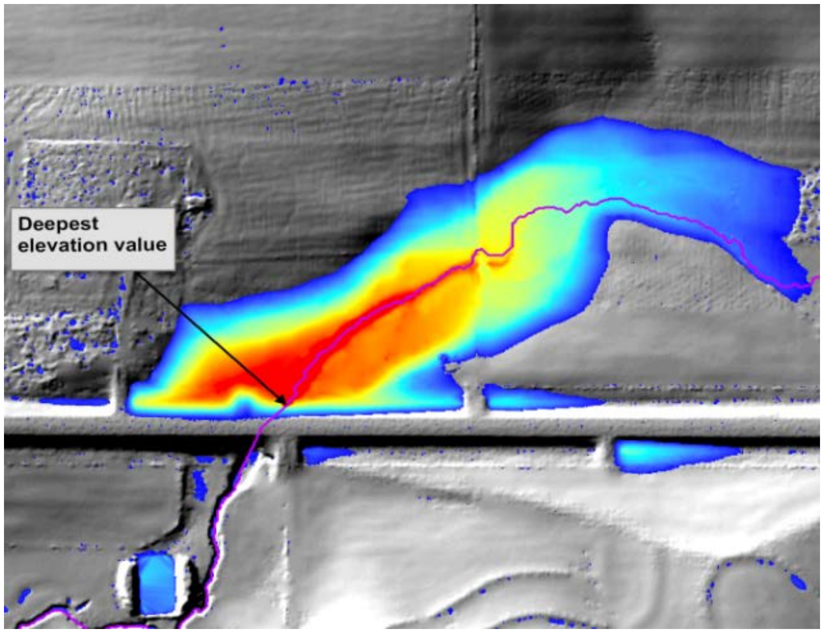
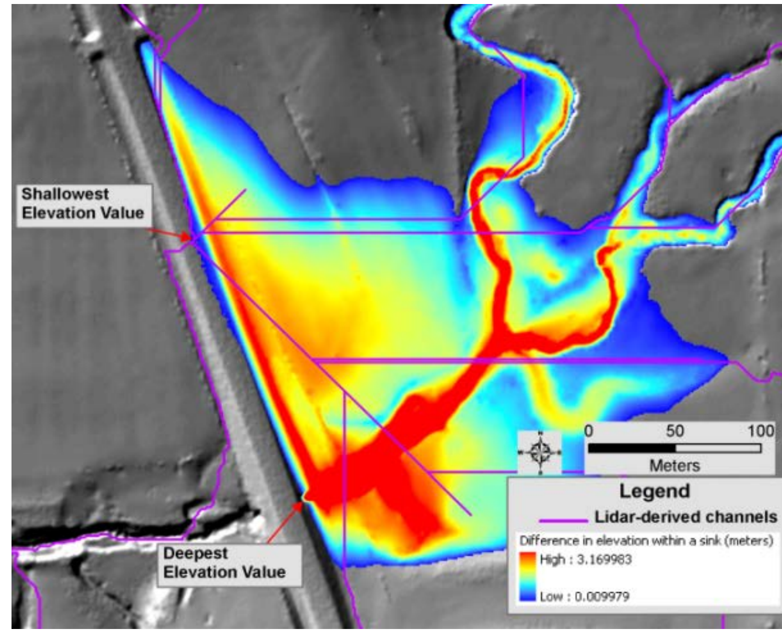
# Alternative treatments of culverts




**Here, the same culvert is manually "cut" through the road surface, so water is channeled beneath the road; but this is not done with the NED.**

**Here, a different culvert is not "cut" so the water would appear to travel north-northwest along the road until crossing at its lowest elevation.**

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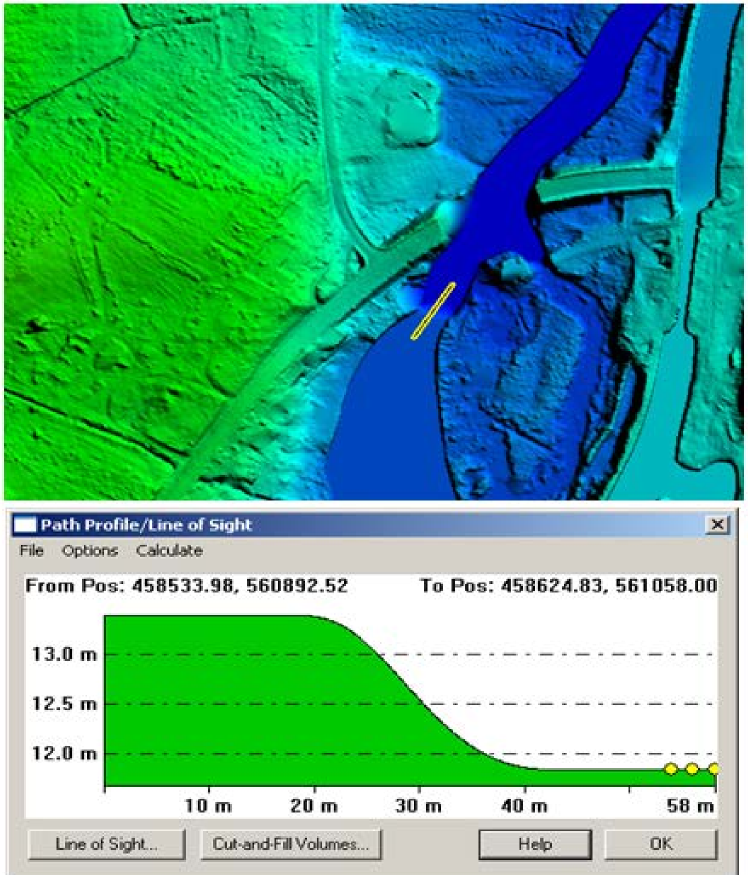
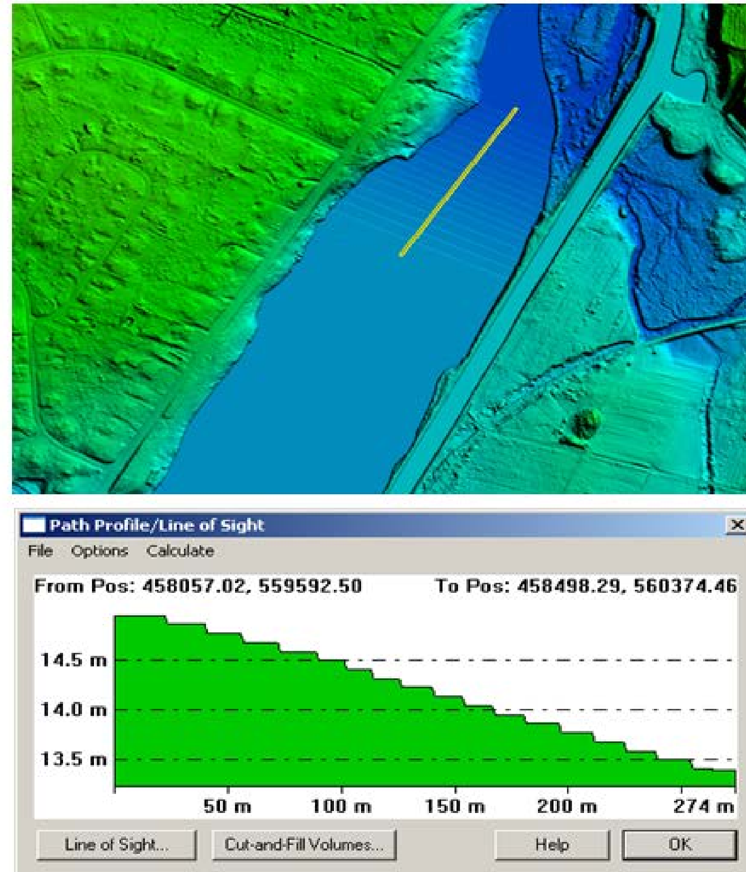
# Hydro-Enforcement and Hydro-Flattening




**Smooth gradient**




**Stair-stepped gradient**

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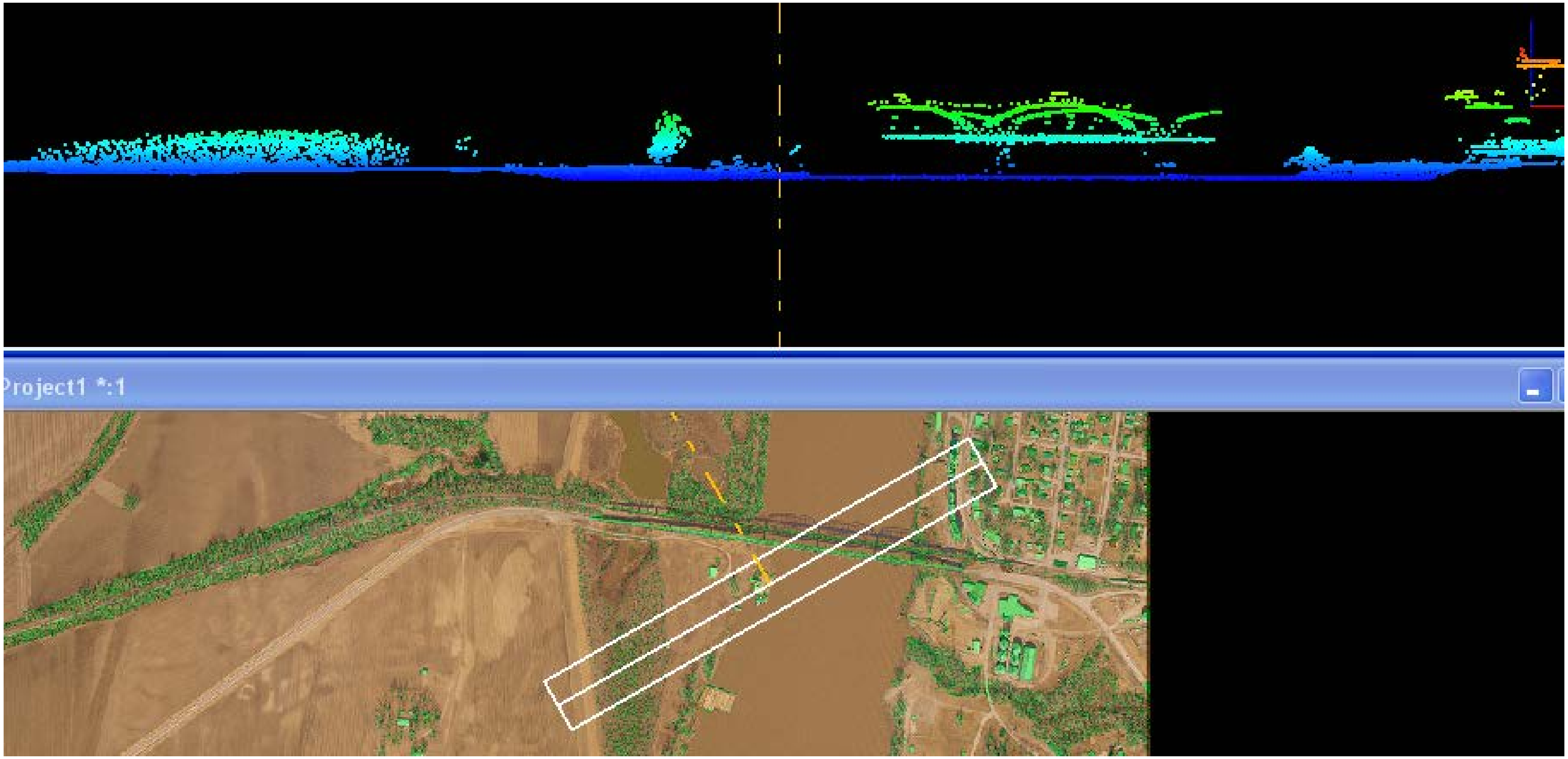
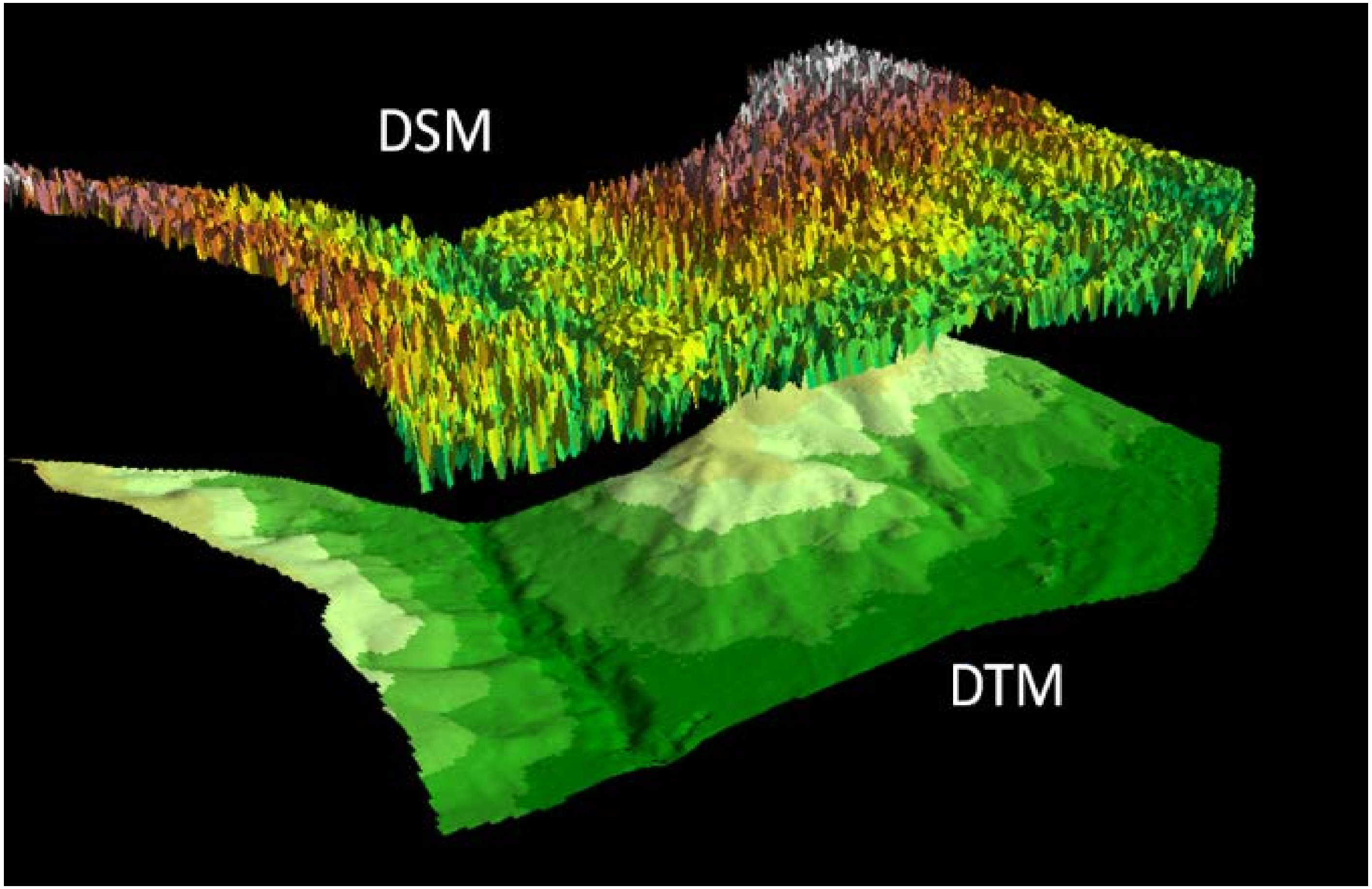
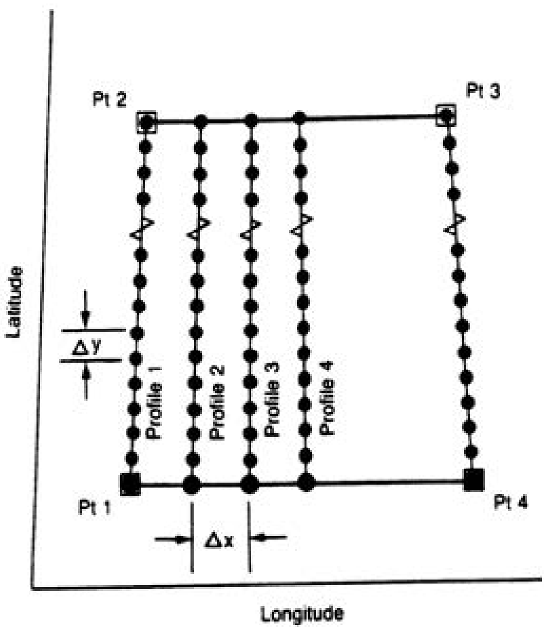
# LiDAR profiles (cross-sections) also popular



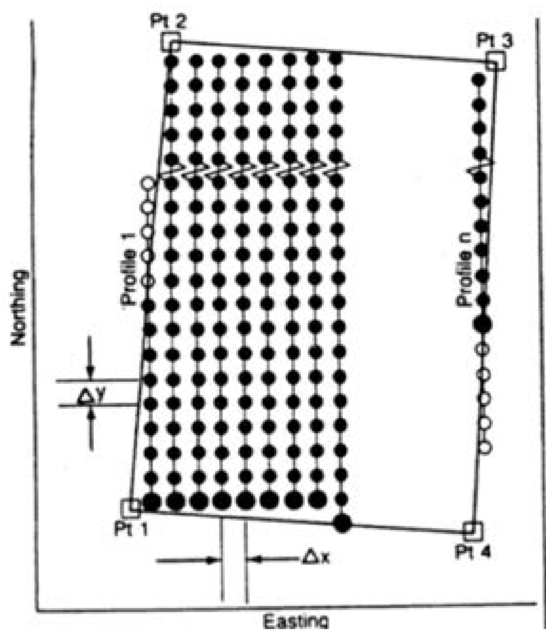
# 1st return for DSM; last return used for DTM filtering



# Gridded Digital Elevation Models (DEM), Contours




**DEM Δx and Δy in arc-seconds of longitude and latitude (NED)**

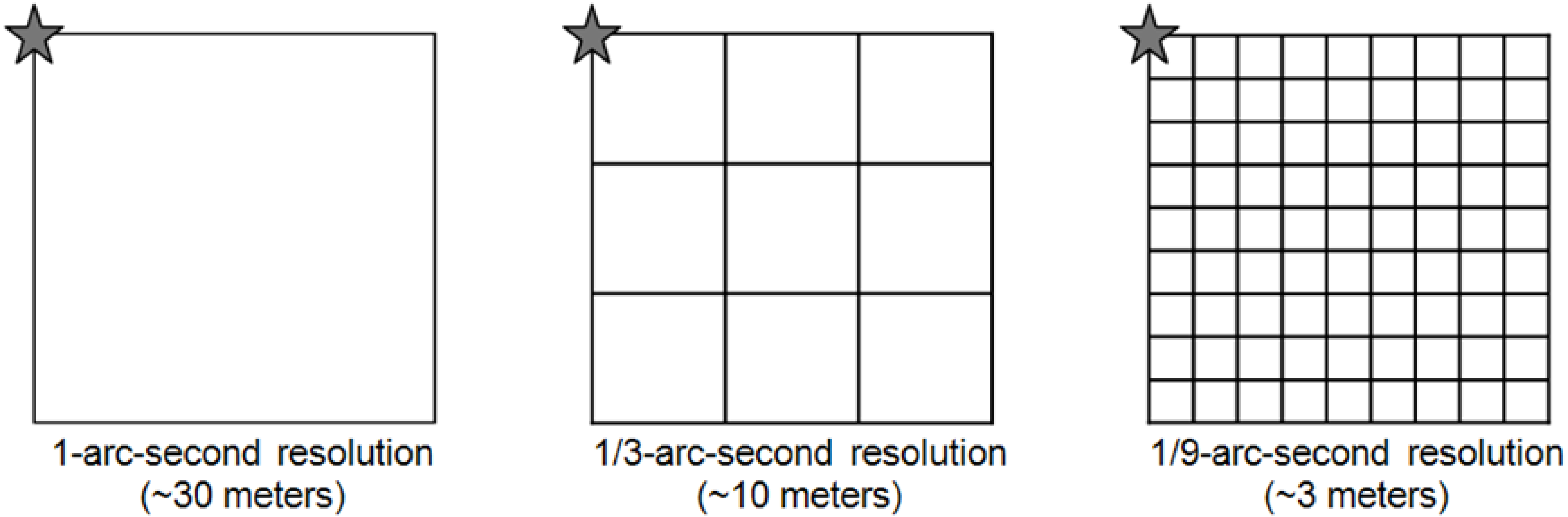



**DEM Δx and Δy in feet or meters, UTM or State Plane Coordinates**


**Contours are produced from LiDAR mass points and breaklines**

**DEM Δx and Δy is also called the DEM “Post Spacing” or “resolution”**

# "Nested" NED Cells with Different Resolutions




**Though not currently available, future NED is expected to include 1/27-arc-second resolution (~1 meter) gridded DEMs.**

**Today, where available, LiDAR point cloud data are accessible from the USGS Center for Lidar Information, Coordination, and Knowledge (CLICK).**

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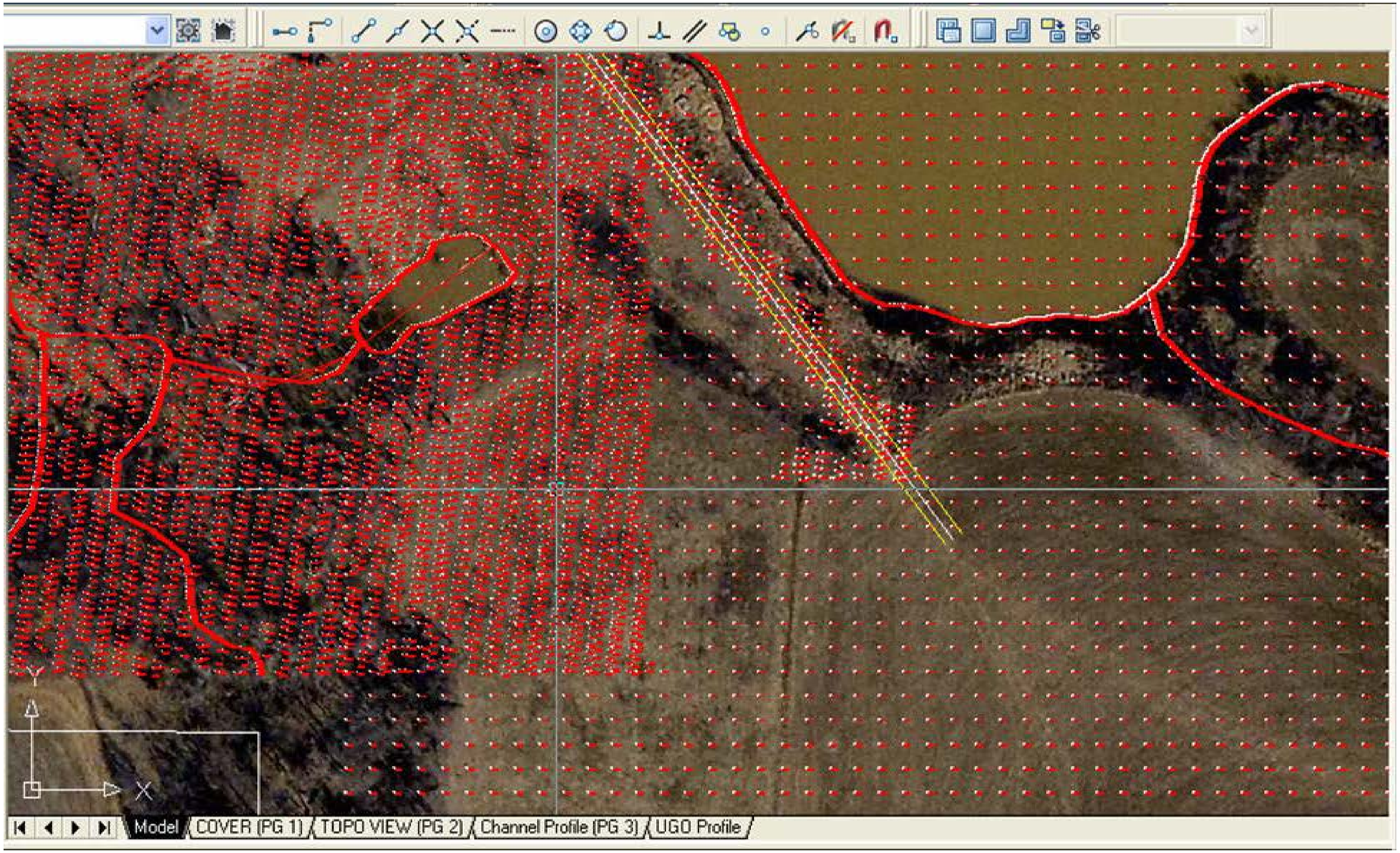
# Irregular Nominal Pulse Spacing (NPS) is always denser than uniformly-gridded DEM Post Spacing

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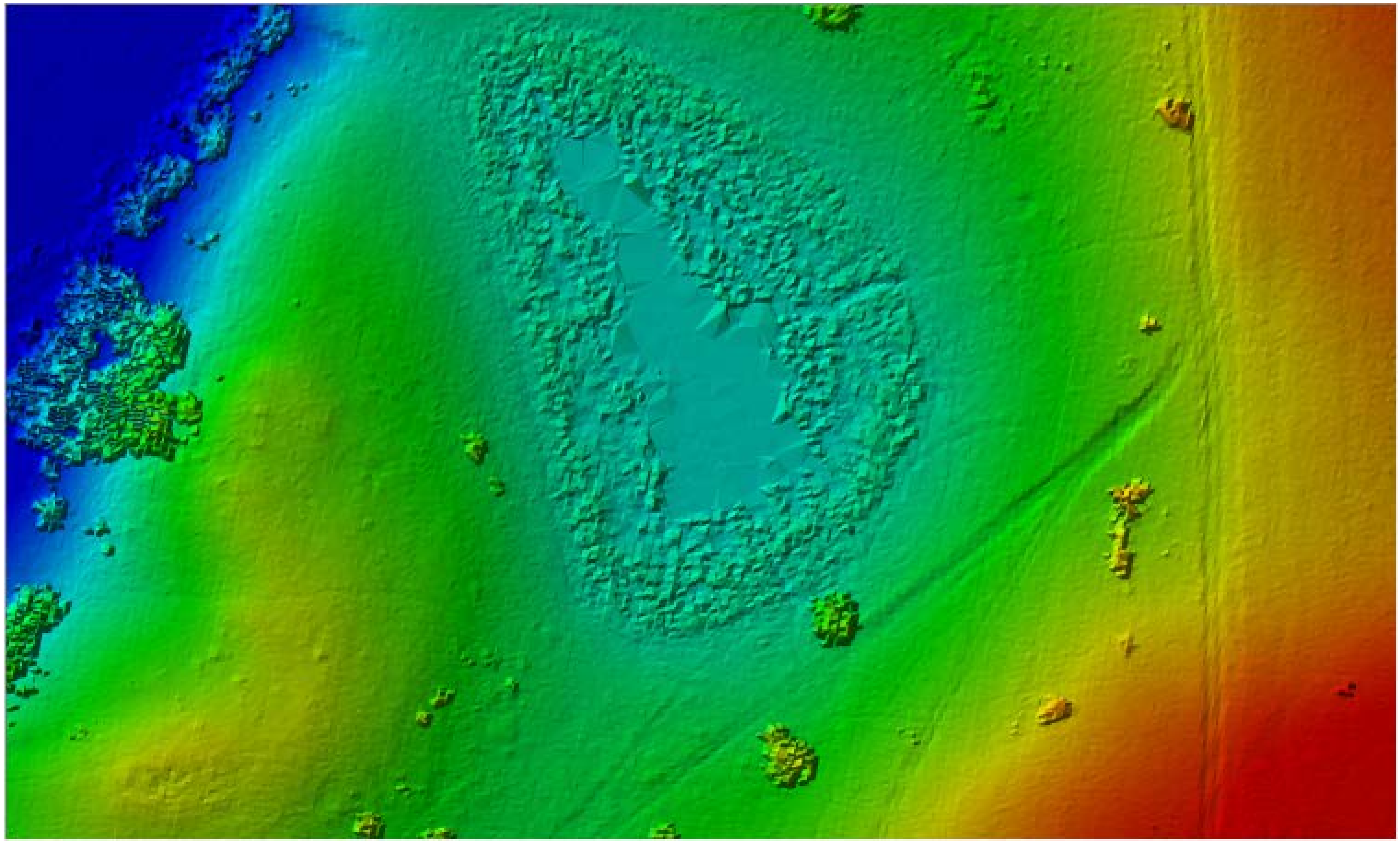
# LiDAR in a Wetland Environment

- High resolution DEMs derived from LiDAR can support the identification of likely wetland locations
- Detailed Classification of the LiDAR Point Cloud allows much more detailed and accurate delineation of the wetland area than otherwise possible, even from photogrammetry
- LiDAR Point Cloud data can further provide much richer information about the vegetation within the wetland.
  - Point Heights
  - Possibly Intensity values

# LiDAR in a Wetland Environment (DSM)



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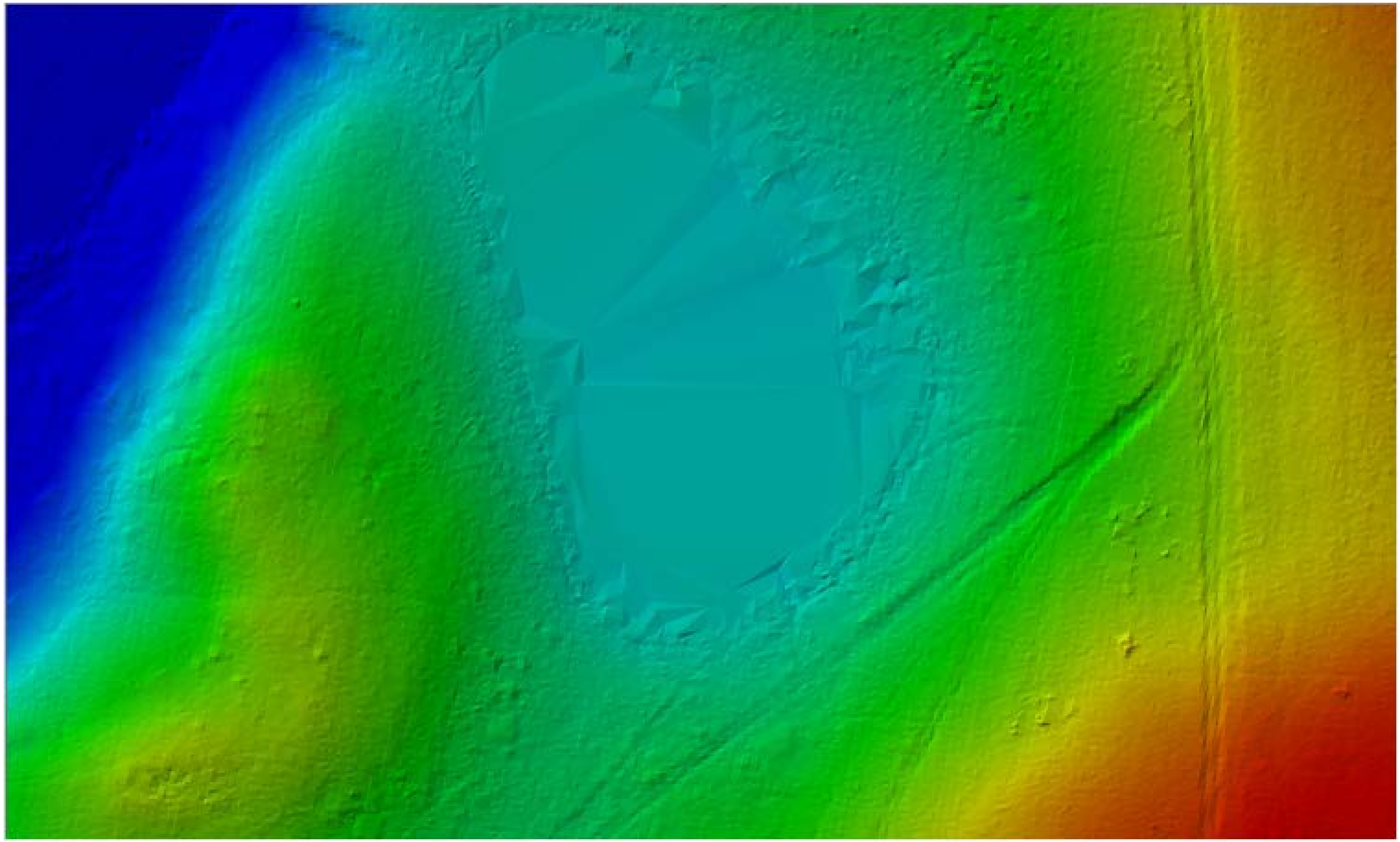
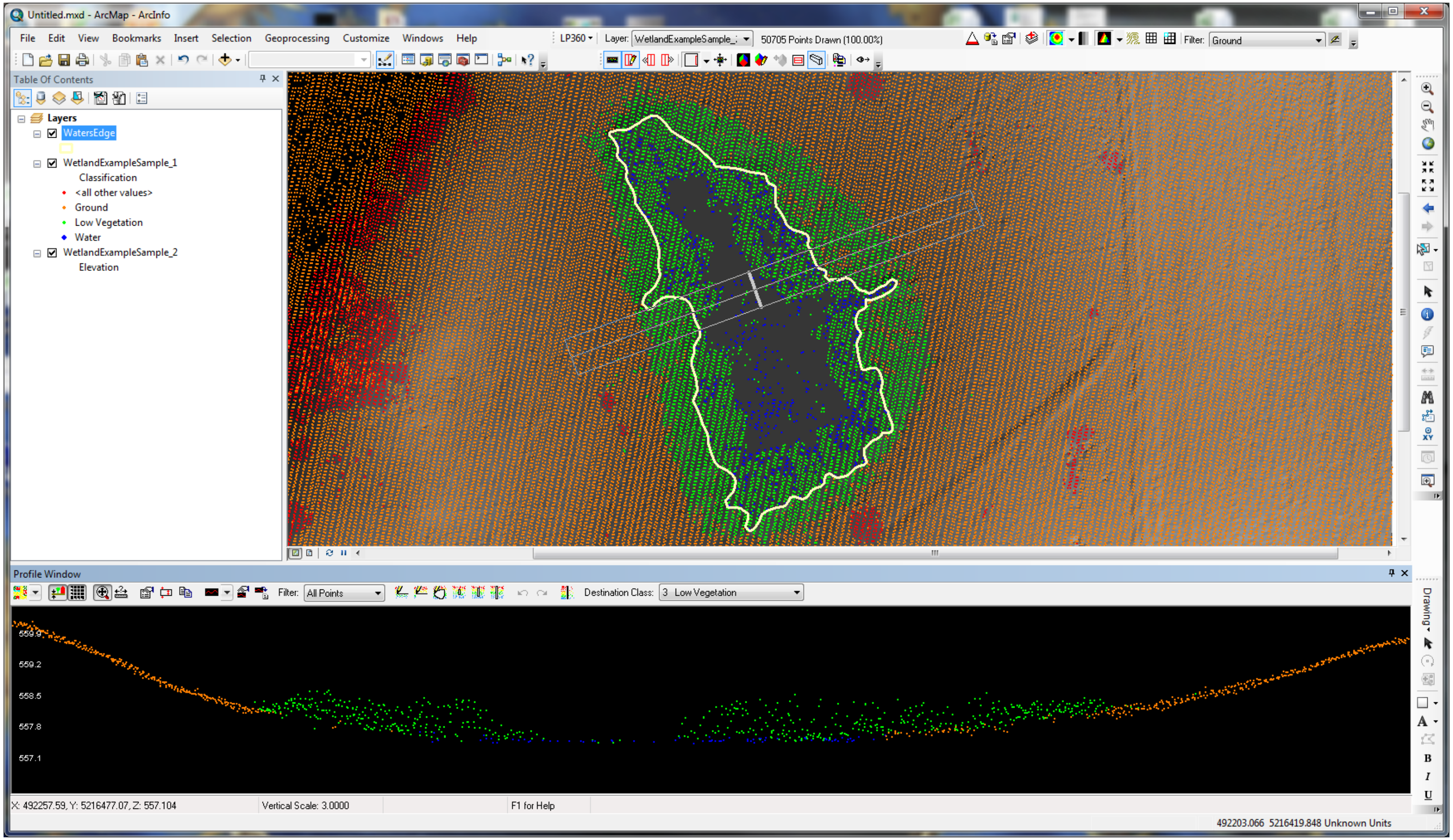
# LiDAR in a Wetland Environment (DTM)



# LiDAR in a Wetland Environment

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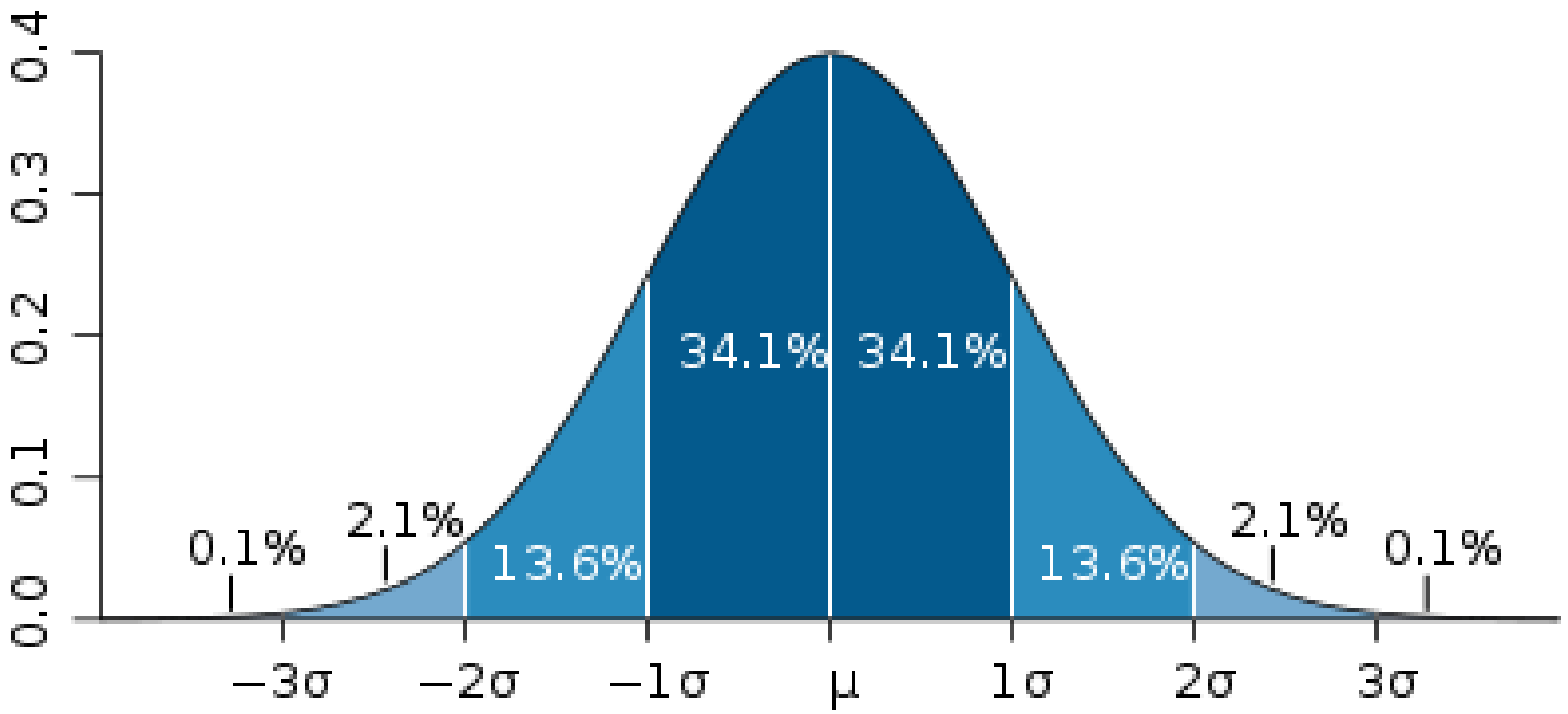
# Standards vs. Specifications

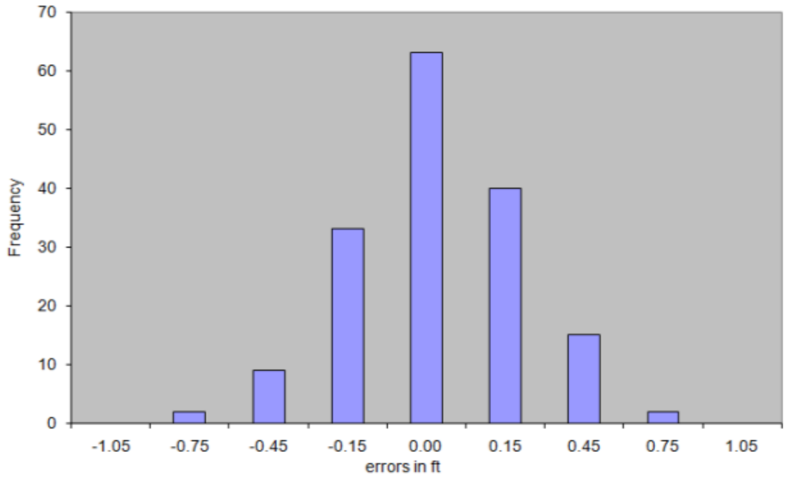
Standards generally involve national/international consensus, and are rigorous. For example:

- The National Map Accuracy Standard (NMAS) of 1947, designed for paper maps with contour lines, requires vertical accuracy such that 90% of test points must be accurate within ½ the contour interval as printed on the map.
- The National Standard for Spatial Data Accuracy (NSSDA) of 1998, designed for digital elevation data, has no accuracy thresholds, but requires accuracy to be reported at the 95% confidence level, based on $RMSE_z$ x 1.9600, assuming that data from LiDAR or other sensors have elevation errors that approximate a normal error distribution.

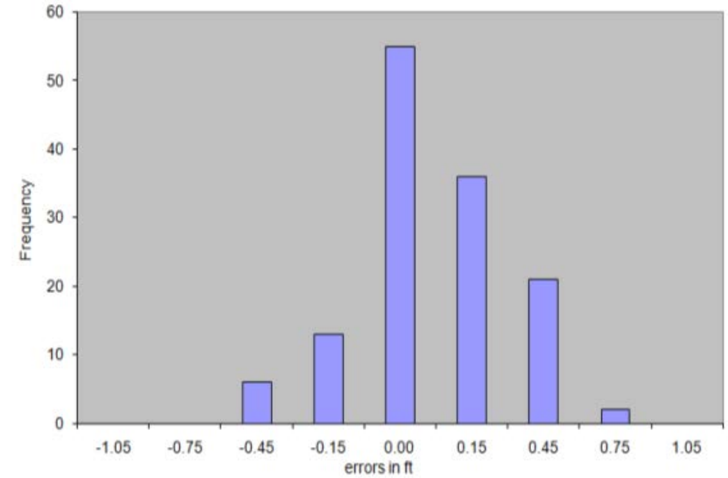
# Normal Error Distribution



# LiDAR errors don't always follow a normal distribution




**Approximates normal distribution in open terrain (grass, sand, dirt, rocks)**




**Differs from normal distribution in vegetated terrain (brush, shown here)**

**The American Society for Photogrammetry and Remote Sensing (ASPRS) uses:**

- **Fundamental Vertical Accuracy (FVA) in open terrain only = RMSEz x 1.9600**
- **Supplemental Vertical Accuracy (SVA) in individual land cover categories, using 95th percentile errors**
- **Consolidated Vertical Accuracy (CVA) in all land cover categories combined, using 95th percentile errors**

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# Most Popular Table from *DEM Users Manual*

| NMAS Equivalent Contour Interval | NMAS LE90, 90% Confidence Level | RMSEz | NSSDA $Accuracy_z$, 95% Confidence Level |
|---|---|---|---|
| 1 ft | 0.5 ft | 0.30 ft or 9.25 cm | 0.60 ft or 18.2 cm |
| 2 ft | 1.0 ft | 0.61 ft or 18.5 cm | 1.19 ft or 36.3 cm |
| 4 ft | 2.0 ft | 1.22 ft or 37.0 cm | 2.38 ft or 72.6 cm |
| 5 ft | 2.5 ft | 1.52 ft or 46.3 cm | 2.98 ft or 90.8 cm |
| 10 ft | 5.0 ft | 3.04 ft or 92.7 cm | 5.96 ft or 181.6 cm |
| 20 ft | 10.0 ft | 6.08 ft or 185.3 cm | 11.92 ft or 363.2 cm |

**Different RMSEz multipliers convert easily between 90% and 95% confidence levels**

**Equivalent Contour Interval = 3.2898 x RMSEz**

**Such “standards” have national relevance to all users of geospatial data**

# Standards vs. Specifications

Specifications provide technical requirements/acceptance criteria that a mapping product must conform to in order to be considered acceptable for its intended use.

The *USGS LiDAR Guidelines and Base Specifications*, v.13, are relevant for a wide array of applications, but they are not perfect for everyone. V.13 defines minimum parameters for the NED.

For production of Flood Insurance Rate Maps (FIRMs), FEMA's Procedure Memorandum No. 61 specifies that V.13 will be used, but with a few exceptions, e.g., hydro-enforcement.

Members of the Wetlands Mapping Consortium should consider V.13 specifications, but might consider "buy-up" data upgrades to better meet unique needs.

The goal is to collect nationwide LiDAR data to v.13 specifications – or better – recognizing that wetlands have special needs.

# V.13 LiDAR Collection Specifications

1. Multiple discrete returns (≥3) or full waveform (Amar to discuss benefits of waveform LiDAR)
2. Intensity values for all returns
3. Nominal Pulse Spacing (NPS) of 1-2 meters, per single swath
4. NPS by swath overlap discouraged; OK with prior approval
5. Data void areas <$(4*NPS)^2$ using 1st returns, single swath, except where caused by water or poor surface reflectivity
6. Spatial distribution (2*NPS grid; 90% of grid cells with at least one LiDAR point) for single swath, 1st return data
7. Scan Angle ≤40° (±20° from nadir)

# V.13 LiDAR Collection Specifications

8. Vertical absolute accuracy per NDEP/ASPRS methodology:
   - FVA ≤24.5 cm $Accuracy_z$ 95% (12.5 cm RMSEz)
   - CVA ≤36.3 cm, $95^{th}$ percentile
   - SVA ≤36.3 cm, $95^{th}$ percentile (target values); SVAs tested for each landcover type representing ≥10% or total project area
9. Relative accuracy ≤7 cm RMSEz within individual swaths; ≤10 cm RMSEz within swath overlap
10. Flightline overlap ≥10%
11. Collection area buffered by minimum of 100 meters
12. Collection conditions: cloud and fog-free; snow free; no flooding/inundation; leaf-off preferred (negotiable)

# V.13 Data Processing Specifications

1. Per ASPRS LAS format v1.2 or v1.3 (1 = processed, but unclassified; 2 = bare-earth ground; 7 = noise; 9 = water; 10 = ignored (breakline proximity); 11 = withheld, per rules)
2. .wdp for full waveform data packets
3. Adjusted GPS times, unique timestamps for each pulse
4. NAD83/HARN; NAVD88 with most recent geoid model
5. UTM meters preferred; SPCS acceptable
6. If feet, specify U.S. Survey foot or International foot
7. Split long swaths (large files) into segments ≤2GB
8. Rules for File Source ID and Point Source ID
9. Multiple returns from a given pulse stored in sequential order

# V.13 Data Processing Specifications

10. All collected swaths delivered as part of "raw data deliverable" to include calibration swaths and cross-ties, but excluding data outside project area, aircraft turns, transit to project site
11. Rules for use of "withheld" flag for edge outliers, noise points, etc.
12. All points not "withheld" are to be classified
13. Absolute and relative accuracy (FVA) shall be verified prior to classification and subsequent product development; validation report is a required deliverable
14. Classification accuracy errors ≤2% within any 1km$^2$ area
15. Rules for classification consistency across entire project area
16. Tiling scheme rules; seamless edge-match

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# V.13 Hydro-Flattening Specifications

- Rules for flattening/leveling of inland ponds and lakes ≥2 acres
- Rules for flattening inland streams and rivers with nominal width ≥100’ (level bank-to-bank and forced to flow downhill -- monotonic); water surface below surrounding terrain.
- Cooperating partners may require collection of single-line streams; if so, use v.13 guidelines for use and limitations, e.g., no cuts into the DEM at road crossings for culverts
- Elevated bridges are removed from DEM, but culverts are not removed.
- Rules for breakline collection, extraction, or integration
- Rules for non-tidal boundary waters
- Rules for tidal waters (next slide)

# Rules for Tidal Waters

- "Tidal variations over the course of a collection or between different collections, will result in discontinuities along shorelines. This is considered normal and these 'anomalies' should be retained. The final DEM should represent as much ground as the collected data permits."
- "Variations in water surface elevation resulting in tidal variations during a collection should NOT be removed or adjusted, as this would require either the removal of valid, measured ground points or the introduction of unmeasured ground into the DEM. The USGS NGP priority is on the ground surface, and accepts there may be occasional, unavoidable irregularities in water surface."
- Scientific research requirements will take precedence.

# V.13 Specifications for Data Deliverables

1. Metadata: Collection Report; Survey Report; Processing Report; QA/QC Reports; Control and Calibration points; precise extents of each delivered dataset; FGDC compliant product metadata, XML format, one file for each project, lift, tiled deliverable product group (classified point data, bare-earth DEMs, breaklines, etc.)
2. Raw Point Cloud: All returns, fully compliant LAS v1.2 or v1.3; point record format 1, 3, 4 or 5; georeferenced information included in all LAS file headers; adjusted GPS times to allow unique time stamps for each pulse; intensity values (native radiometric resolution); 1 file per swath, 1 swath per file, file size ≤2GB

# V.13 Specifications for Data Deliverables

3. Classified Point Cloud: Fully compliant LAS v1.2 or v1.3; .wdp extension for waveform data; georeferenced information included in all LAS file headers; adjusted GPS times to allow unique time stamps for each pulse; intensity values (native radiometric resolution); tiled delivery without overlap (tiling scheme TBD); minimum classification scheme:

| Code | Description |
|---|---|
| 1 | Processed, but unclassified |
| 2 | Bare-earth ground |
| 7 | Noise (low or high, manually identified, if needed) |
| 9 | Water |
| 10 | Ignored ground (breakline proximity) |
| 11 | Withheld |

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# V.13 Specifications for Data Deliverables

4. Bare Earth Surface (Raster DEM):
   - Cell size ≤3 meters or 10 feet; ≥ design Nominal Pulse Spacing
   - 32-bit floating point raster format (ERDAS .IMG preferred)
   - Georeferenced info included in each raster file
   - Tiled delivery, without overlap.
   - Per rules on edge artifacts, mismatch, appearance, void areas, vertical accuracy, hydro-flattening
   - Depressions (sinks), natural or man-made, are NOT to be filled (as in hydro-conditioning)
5. Breaklines (used in hydro-flattening): in PolylineZ or PolygonZ format, per rules specified

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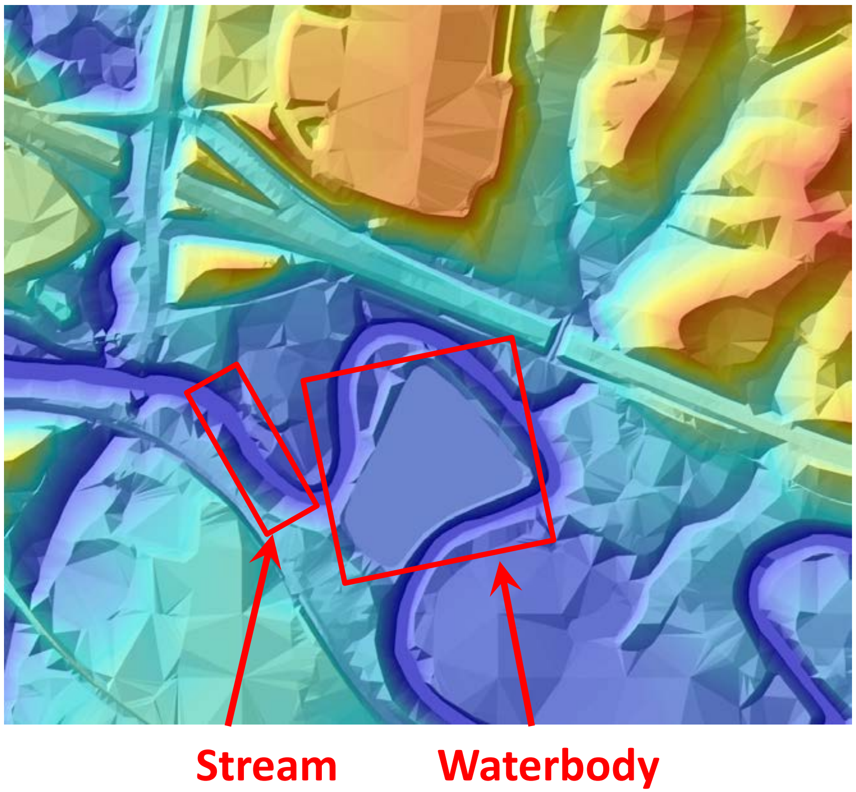
# Different Treatments of LiDAR DTMs and DEMs

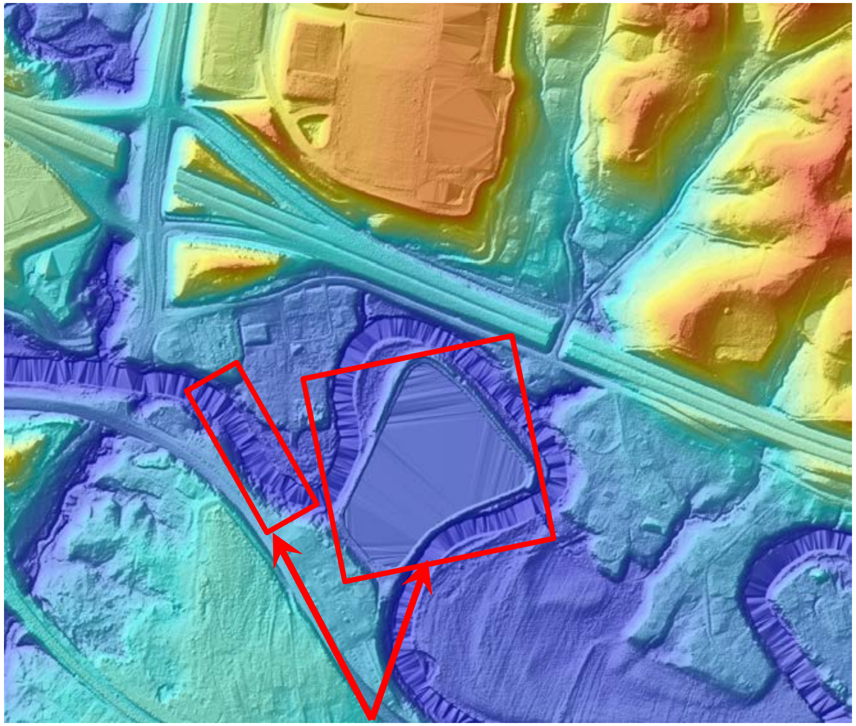
- Traditional Stereo DTM (Topographic Surface)
- Pure LiDAR (Topographic Surface)
- Hydro-Flattened (Topographic Surface)
- Full Breaklines (Topographic Surface)
- Hydro-Enforced (Hydrologic Surface)
- Hydro-Conditioned (Hydrologic Surface)

# Traditional Stereo DTM (Topographic Surface)




- Reference image of the traditional stereo-compiled DTM
- Built from Masspoints and Breaklines
- Much coarser resolution than LiDAR
- Demonstrates the familiar and usually expected character of a topographic DEM
- Most notably, the “flat” water surfaces

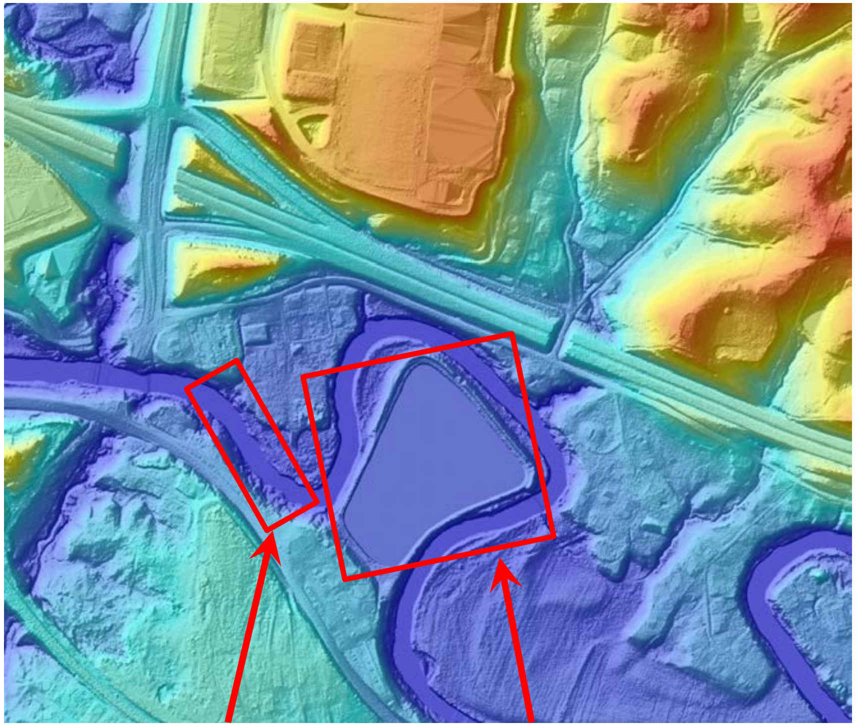
# Pure LiDAR (Topographic Surface)



**TINning in Water Areas**

- DEM created only using bare-earth LiDAR points
- Surface contains extensive triangulation artifacts (“TINning”).
- Cause by the absence of:
  - LiDAR returns from water
  - Breakline constraints that would define buildings, water, and other features (as in the Stereo DTM).
- Aesthetically and cartographically unacceptable to most users

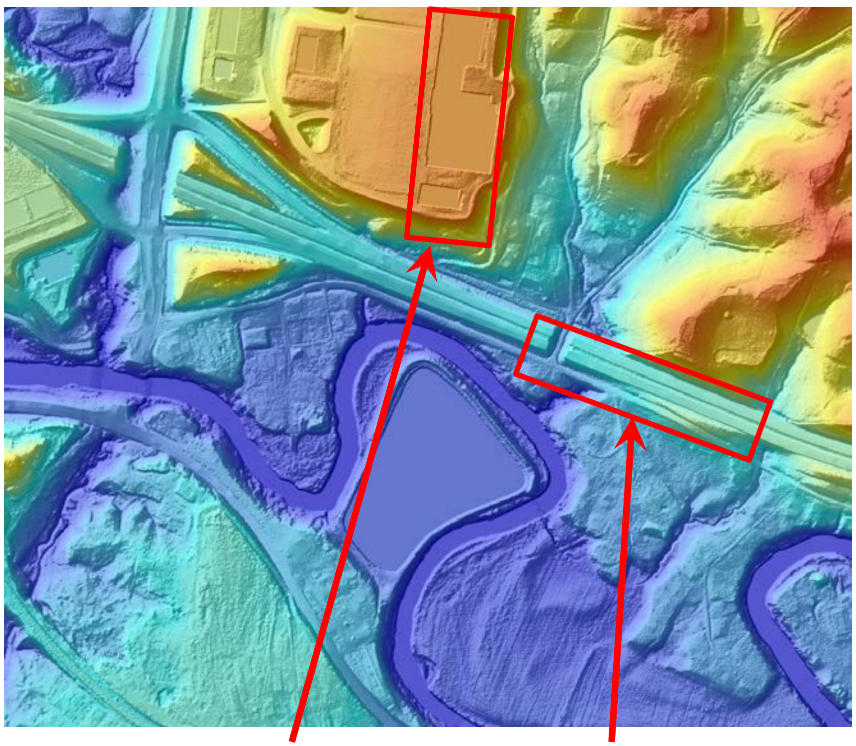
# Hydro-Flattened (Topographic Surface)



**Stream** **Waterbody**

- The goal of the v13 Spec
- Intent is to support the development of a consistent, acceptable character within the NED
- Removes the most offensive pure LiDAR artifacts: those in the water.
  - Constant elevation for waterbodies.
  - Wide streams and rivers are flattened bank-to-bank and forced to flow downhill (monotonic).
- **Carries ZERO implicit or explicit accuracy with regards to the represented water surface elevations – It is ONLY a cartographic/aesthetic enhancement.**
- Building voids are not corrected due to high costs
- Most often achieved via the development and inclusion of hard breaklines.

# Full Breaklines (Topographic Surface)




- A further possible refinement of the hydro-flattened surface
- Removes artifacts from building voids
- Refines the delineation of roads, single-line drainages, ridges, bridge crossings, etc.
- Requires the development of a large number of additional detailed breaklines
- A higher quality topographic surface, but significantly more expensive.
- Not cost effective for the NED.

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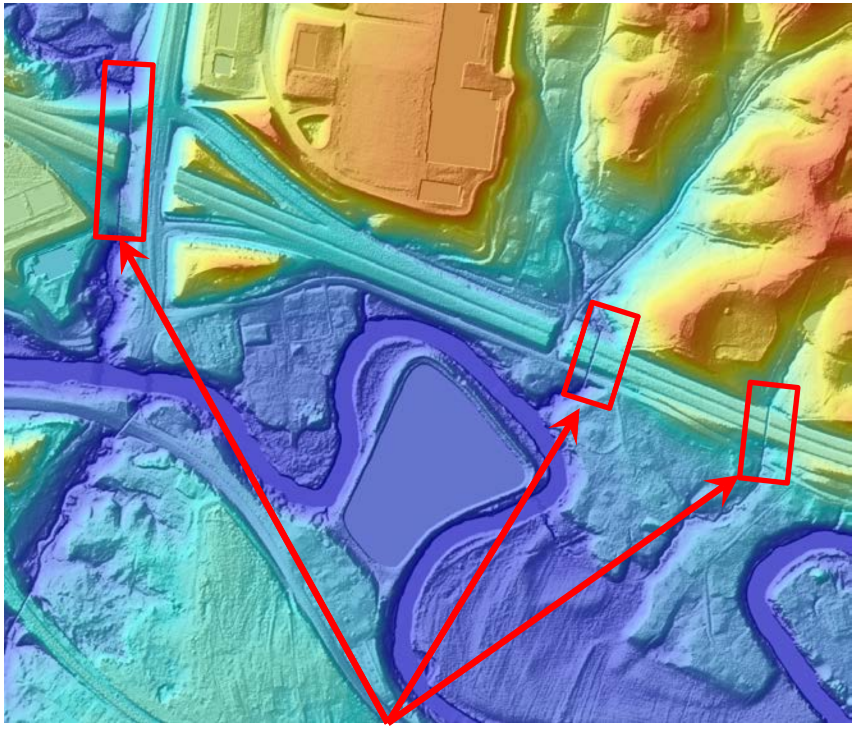
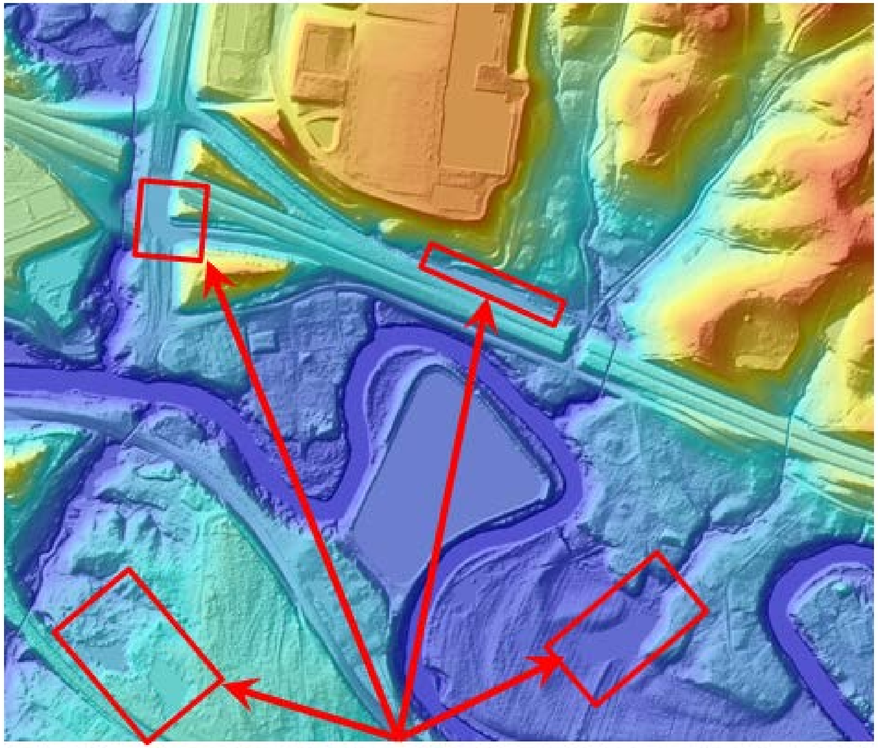
# Hydro-Enforced (Hydrologic Surface)



Culverts Cut Through Roads

- Surface used by engineers in Hydraulic and Hydrologic (H&H) modeling.
- NOT to be used for traditional mapping (contours, etc.)
- Similar to Hydro-Flattened with the addition of **Single Line Breaklines:** Pipelines, Culverts, Underground Streams, etc…
- Terrain is then cut away at bridges and culverts to model drain connectivity
- Water Surface Elevations (WSEL) are often set to known values (surveyed or historical).

# Hydro-Conditioned (Hydrologic Surface)



Filled Sinks

- Another type of surface used by engineers for H&H modeling.
- Similar to the hydro-enforced surface, but with sinks filled
- Flow is continuous across the entire surface – no areas of unconnected internal drainage
- Often achieved via ArcHydro or ArcGIS Spatial Analyist

# V.13 Common Data Upgrades

1. Independent 3rd party QA/QC
2. Higher Nominal Pulse Spacing (NPS)
3. Increased Vertical Accuracy
4. Full waveform or topo/bathy collection with red/green lasers
5. Tide coordination, flood stage, plant growth cycle, shorelines
6. Top-of-canopy (1st return) Digital Surface Model (DSM)
7. More detailed LAS classification for vegetation, buildings
8. Hydro enforced and/or hydro conditioned DEMs
9. Single-line hydro feature breaklines; other breaklines
10. Building footprints with elevations/heights

# Why the V.13 Spec was Developed

- To establish some sort of consistency across LiDAR collections, mostly with regards to the Point Cloud (major challenge)
- To get data that is uniform in structure, formatting, content and handling:
  - 1st so that Quality Assurance steps do not have to change with every Scope of Work
  - 2nd to get consistent Point Cloud deliverables to viably exploit the other benefits of LiDAR data
  - 3rd to simplify the acquisition and delivery of data that is interoperable and usable by a broad array of federal, state and local users at minimal costs
- To improve the National Elevation Dataset and CLICK with nationally consistent data that meet minimum specifications, enhanced where necessary for special requirements such as wetlands mapping

# Following my presentation…

- Amar Nayegandhi will present a case study of using topographic and topobathymetric LiDAR sensors to map wetlands.

- Greg Snyder will summarize the recently-released *National Enhanced Elevation Assessment* for which Dewberry worked closely with USGS during the past year. Major lessons:
  - LiDAR datasets available nationwide are too-frequently of poor quality, with marginal utility to others; many datasets have such poor metadata that we don't know who produced the data; how and when it was produced; or how accurate it should be.
  - Coordinated acquisition of LiDAR data to USGS V.13 specifications or better will ensure that such data will be usable for the maximum number of potential users, and we will save taxpayer dollars by avoiding duplication of efforts for different quality datasets.

# http://lidar.cr.usgs.gov/USGS-NGP

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