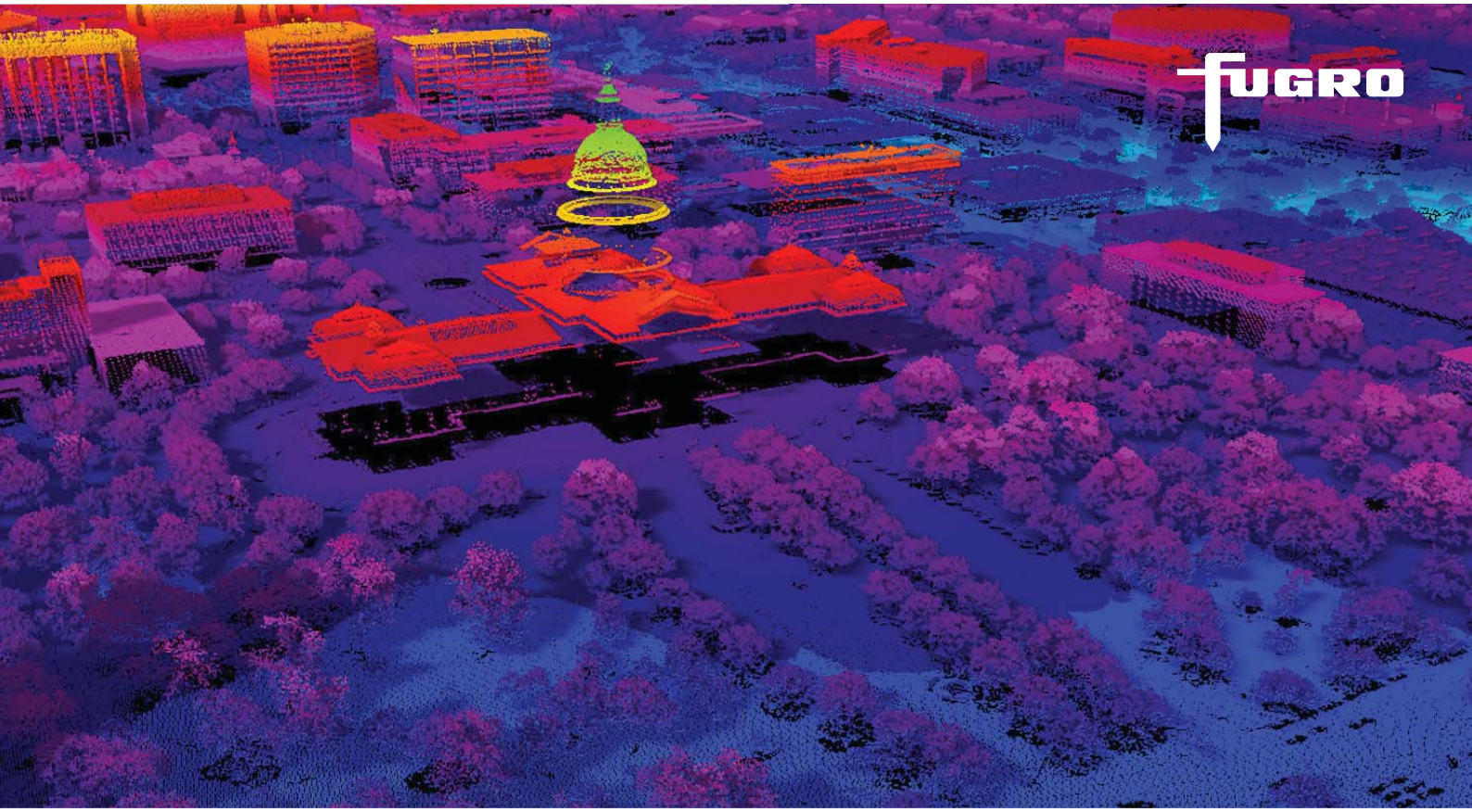


FUGRO
LIDAR DATA SPECIFICATIONS

This document compares lidar specifications to better understand the USGS QL2 lidar specification against the State of Texas requirement for a hybrid QL2+ . Our recent work in Texas provides a good opportunity to compare and identify the importance of adjusted specifications for increased benefits to multiple state agencies and other stakeholders.

PURPOSE

We continue to see variations of state and federal lidar data specifications (QL2, QL2+, QL1, and QL0). Each version provides unique benefits to the region and that region's use of the lidar data.

The data in this document helped facilitate understanding between the State of Texas and USGS with regards to the different specifications, budget, collection parameters and product delivery expectations.

This document's purpose is to share the results of the comparison while considering expanding lidar specifications outside of the standard USGS QL2 data structure.

LIDAR EXPERIENCE

Fugro has acquired and processed over 360,000 linear flight lines miles (150+ projects) in the past 5 years with point densities ranging from 2 to 30 points per square meter (ppsm). Our projects covered over 818 counties and 26 cities. For high density lidar projects (25ppsm+) in the US, we have acquired close to 100,000 flight line miles in the past year.

COMPARISON

Coordinate system
Tiling scheme
Project requirements
Raw point cloud data
Fully classified all-return point cloud
Hydro-flattened breaklines
Intensity images
Bare earth lidar / DEM raster
Metadata
Pilot

BENEFITS

Improve participant buy-in
Increase data use
Reduce duplication of effort
Expands product capabilities

COMPARISON TABLE: STATE AND USGS

Lidar Technical Specifications

Coordinate System	State Specification	USGS Specification
Projection	UTM zones or State Plane Coordinate Systems	UTM zones
Horizontal Datum	NAD83 (2011)	NAD83 (2011)
Horizontal Units	Feet or meters	Meters to 2 decimal places
Vertical Datum	NAVD88, GEOID12B or latest (older GEOID (ex. GEOID99) for change analysis)	NAVD88, GEOID 12B or latest
Vertical Units	Feet or meters (Orthometric, NAVD88)	Meters to 2 decimal places

Notes and Recommendations: When considering delivery for multiple coordinate systems, often times part of the data will require additional data processing steps:

- Re-project the original LAS tile to output projection (an input for DEM generation)
- Re-project and manually correct 3D elevation of original hydro breaklines to maintain downhill flow and monotonicity of water bodies (an input for DEM generation)
- Re-project and manually correct 3D elevations of original bridge breaklines (an input for DEM generation)
- Generate and QC DEM tiles
- Convert DEM tiles to delivery format

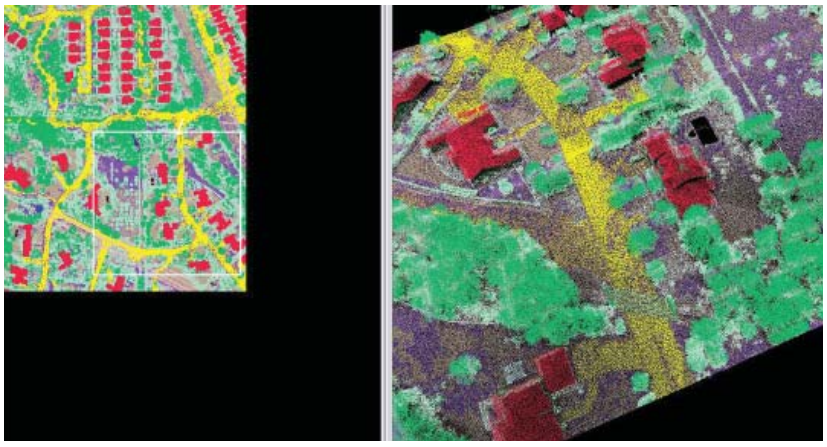
Tiling Scheme and Data Format

Tile Coverage	Full tiles are delivered	Tiles which lie completely within the project area shall be complete to the tile edges. Tiles which lie partially outside the project boundary shall be complete to the project boundary with enough overlap beyond the project boundary to ensure that no parts of the project are omitted.
Tile Size	• 1/64th USGS 7.5-minute quadrangle • Quarter-quarter-quarter quadrangle (DOQQQQ, or DO4Q) • DEM and Intensity tiled deliverables include a 50 meter buffer that extends around all four sides of the tile	• Tiles shall be 1,000 meters x 1,000 meters. • Tiled deliverables shall conform to the tiling scheme, without added overlap. • Tiling scheme will be used for all tiled deliverables. • Tiled deliverables shall edge-match seamlessly in both the horizontal and vertical.
Tile Naming	State Specified - Ex. DO4Q: stratmap17-nps-DO4Qstring	Tile naming shall follow the U.S. National Grid naming convention with prefixes of “las” and “dem” for point cloud and digital elevation models, respectively.

Notes and Recommendations:

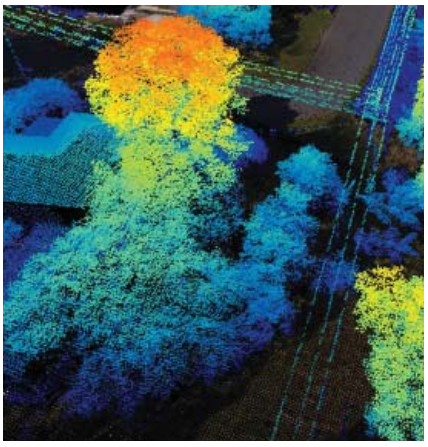
- Tile coverage to the project boundary will have void/empty data areas that are beyond the project boundary extending to the edge of the tile.
- Full tile deliverables will have data to the full extent of each tile.
- The higher the point density, the larger the tile size, the larger the LAS file size. Consider smaller tile sizes for higher point densities.
- Full tile or data cut to the project boundary. When moving to a full tile deliverable, consider recalculating the area size (ex. square miles) as this will alter the data collection and processing area.

Improved Lidar Classifications



High Density Lidar

Colorized by Height



COMPARISON TABLE: STATE AND USGS

Lidar Technical Specifications

Project Requirements	State Specification	USGS Specification
Nominal Post Spacing	≤ 0.500 meter	Aggregate Nominal Pulse Spacing (ANPS) shall be no greater than 0.50 meters (QL2+); assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~95%) of each swath.
Nominal Post Density	≥ 4 ppsm for first-return data	Aggregate Nominal Pulse Density (ANPD) shall be no less than 4 points per square meter.
Uniformity	Spatial distribution of points must be uniform and free from clustering. 90% of cells in a 1-meter grid will contain at least one first-return point. See Data voids for exclusions.	"The spatial distribution of geometrically usable points is expected to be uniform and free from clustering. In order to ensure uniform densities throughout the data set: (1) A regular grid, with cell size equal to the design 2*ANPS will be laid over the data. (2) At least 90% of the cells in the grid shall contain at least 1 lidar point. (3) Clustering will be tested against the 1st return only data of points located in the geometrically usable center part (typically 95%) of each swath. (4) Acceptable data voids identified elsewhere in this task order are excluded."
Buffer	300 meter buffer surrounding the AOI is required for flight planning and acquisition, with no buffer needed in between tiles. Buffer will not be included in final delivery.	The collection area shall be defined as the Defined Project Area, buffered by no less than 100-meters.
Signal Returns	Lidar sensor shall be capable of at least three (3) returns per pulse, including first and last returns. Multiple returns from a given pulse shall be stored in sequential order and point families must remain intact.	The laser system shall be configured to collect multiple echoes per pulse, with a minimum of a first return and a last return and at least one additional intermediate return. All returns captured during acquisition shall be delivered. Return number shall be recorded.
Signal Strength	N/A	The signal strength (intensity) of each return pulse shall be recorded.
Return Attributes	Each return must include: easting, northing, elevation, intensity, order of return (i.e. first-return, second-return), classification, and Adjusted GPS Time. Easting, northing, and elevation must be recorded to the nearest 0.01 m and GPS second reported to the nearest microsecond (or better). May include additional attributes. No duplicate entries.	N/A
Scan Angle	For lidar systems with an oscillating mirror, scan angle should not exceed ±20 degrees from nadir. Total field of view or full scan angle ≤ 40°. Rotating mirror systems are exempt from this requirement, but must provide planning of additional flight lines or other measures over dense urban areas to mitigate shadowing voids resulting from use of a FOV > 40°.	N/A
Scan Overlap	Minimum 30% overlap on adjoining swaths.	Flight line overlap is at the contractor's discretion, but is cautioned to be vigorous to ensure there are no data gaps between the usable portions of the swaths and to ensure the aggregate nominal pulse density (ANPD) can be achieved. Collections in high relief terrain are expected to require greater overlap. Any data with gaps between the geometrically usable portions of the swaths will be rejected.
Swath Length	N/A	Long swaths (those which result in a LAS file larger than 2GB) shall be split into segments, if the contractor has a preference to do so for processing efficiency. In such case, each segment shall thenceforth be regarded as a unique swath. Other swath segmentation criteria may be acceptable, with prior approval. Full Swath data shall be delivered. Edge data from each swath shall not be trimmed from the delivered data.
Data Voids	Data voids are defined as areas > [(4*NPS)2] with no first-return points. Data voids are unacceptable unless caused by water bodies or areas of low near-infrared (NIR) reflectivity (i.e. wet asphalt). No voids between swaths.	"Data Voids: Data Voids [areas => (4*ANPS) 2, measured using 1st-returns only] within a single swath are not acceptable, except: (1) Where caused by water bodies. (2) Where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing. (3) Where appropriately filled-in by another swath."

COMPARISON TABLE: STATE AND USGS

Lidar Technical Specifications

Project Requirements	State Specification	USGS Specification
Data Acquisition Conditions	Leaf-off and no significant snow cover or flood conditions, unless approved by the client. Must be cloud, smoke, dust and fog-free between the aircraft and ground.	Atmospheric: Cloud and fog-free between the aircraft and ground "Ground: (1) Snow free (2) No unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation." "Vegetation: Leaf-off is preferred, however: As numerous factors will affect vegetative condition at the time of any collection, the USGS National Geospatial Program (NGP) only requires that penetration to the ground must be adequate to produce an accurate and reliable bare-earth surface suitable for incorporation into the 3D Elevation Program (3DEP) 1-meter product holdings. Collections for specific scientific research projects may be exempted from this requirement, with prior approval." Time of Day: Time of day is not of concern.
Place of Performance	Unrestricted	Domestic

Notes and Recommendations: Place of performance considerations need to align with State or Federal procurement regulations. Unrestricted data processing typically provides a competitive price with improved schedules. Domestic data processing keeps data within the US but may be more expensive.

GPS Procedures and Accuracy

Positional Accuracy Validation	The absolute and relative accuracy of the data, both horizontal and vertical, and relative to known control, shall be verified prior to classification and subsequent product development. Report accuracies in metadata as compiled to meet the specified vertical accuracy at the 95% confidence level in open terrain according to the National Standard for Spatial Data Accuracy (NSSDA).	The absolute and relative accuracy of the data, both horizontal and vertical, relative to known control, shall be verified prior to classification and subsequent product development. A detailed report of this validation is a required deliverable.
Relative Accuracy	Relative (swath to swath); RMSDz/Max Diff: < 8.0/16.0 cm	Relative accuracy shall be ≤ 6cm within individual swaths (smooth surface repeatability) and ≤ 8 cm RMSD within swath overlap (between adjacent swaths) with a maximum difference of ±16 cm.
Vertical Accuracy	Non-Vegetated: RMSEz < 10 cm Non-Vegetated: Accuracyz 95% < 19.6 cm Vegetated: Accuracyz 95% < 29.4 cm Horizontal: RMSEr < 25.0 cm	RMSEz ≤ 10 cm (non-vegetated, Swath, DEM)) NVA ≤ 19.6 cm 95% Confidence Level (Swath, DEM) VVA: ≤ 29.4 cm 95th Percentile (DEM)
Acquisition GPS Procedures	At least two (2) GPS reference stations in operation during all missions, sampling positions at 1 Hz or higher frequently. Differential GPS baseline lengths shall not exceed 40 km, unless otherwise approved. Differential GPS unit in aircraft shall sample position at 2 Hz or more frequently. Lidar data shall only be acquired when GPS PDOP is ≤ 4 and at least 6 satellites are in view.	N/A
Geodetic Control	Fugro will provide required ground control for acquisition and processing; checkpoints are collected by the 3rd party QA/QC vendor and the NVA and VVA assessments are done by the 3rd party QA/QC vendor	"Supplemental Ground Control: Differentially corrected GPS Ground Control used to supplement the Airborne GPS positional accuracy. Quality Checkpoints: The Contractor shall collect additional Ground Control Checkpoints in each project area which shall be delivered in ESRI Arc Shape format and will be used by the Government for validation. Positional Accuracy Standards for Digital Geospatial Data (American Society for Photogrammetry and Remote Sensing, 2014) http://www.asprs.org/a/society/committees/standards/ASPRS_Positional_Accuracy_Standards_Edition1_Version100_November2014.pdf should be consulted to determine the minimum number of checkpoints required. The quantity of checkpoints is linked to the size of the project's AOI. Adherence to the ASPRS recommendations is required, but in no case shall an NVA be based on less than 20 check points."

Notes and Recommendations: Check point surveys are either completed by the lidar data vendor or by a 3rd party QAQC vendor. Consider standardizing the check point survey quantity so that price comparisons are equal. Be sure to identify who is performing the check point survey and performing the independent data accuracy validation and reporting when comparing technical and cost proposals.

Raw Point Cloud

Format	N/A	Fully compliant LAS v1.4, Point Record Format 6.
Withheld & Overlap	N/A	Proper use of the LAS withheld and overlap bits is required. Use of the overlap bit is required for marking overlap points.

COMPARISON TABLE: STATE AND USGS

Lidar Technical Specifications

Raw Point Cloud	State Specification	USGS Specification
Spatial Reference	N/A	Georeference information included in LAS header (OGC WKT). In accordance with LAS specification Version 1.4 - R13 published 15 July 2015, the Coordinate Reference System (CRS) shall be represented in each LAS file using OGC (2001) dialect of Well Known Text (WKT) (www.opengeospatial.org/standards/ct, document # 01-009). ESRI WKT or OGC (2015) dialects are not accepted.
GPS Times	N/A	GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each return. In compliance with LAS specification requirements, the encoding tag in the LAS header must be properly set.
Intensity Values	N/A	Intensity values, 16 Bit, Linear Rescaling.
Swaths	N/A	Full swaths, all collected points to be delivered. Swaths may be segmented, as described in the NGP Lidar Base Specification, at the contractor's discretion if needed. Otherwise, 1file per swath, 1 swath per file.
Reports	N/A	A report of the assessed relative vertical accuracy of the point cloud (smooth surface repeatability and overlap consistency) shall be provided and dated. Raw swath point cloud data shall meet the required accuracy levels before point cloud classification and derivative product generation. A report of the assessed absolute vertical accuracy (NVA only) of the unclassified lidar point data in accordance with the guidelines set forth in the Positional Accuracy Standards for Digital Geospatial Data (American Society for Photogrammetry and Remote Sensing, 2014) shall be provided and dated. Raw swath point cloud data shall meet the required accuracy levels before point cloud classification and derivative product generation.
Notes and Recommendations: Raw lidar point clouds typically cause larger file storage requirements with no return on investment. This requirement is usually waived.		
Fully Classified All-Return Point Cloud		
Format	All-return point cloud in fully-compliant LAS version 1.4. All points must be classified according to the ASPRS classification standard for LAS.	Fully compliant LAS v1.4, Point Record Format 6.
Spatial Reference	Projected and defined in the project Spatial Reference Framework	Georeference information included in LAS header (OGC WKT). In accordance with LAS specification Version 1.4 - R13 published 15 July 2015, the Coordinate Reference System (CRS) shall be represented in each LAS file using OGC (2001) dialect of Well Known Text (WKT) (www.opengeospatial.org/standards/ct, document # 01-009). ESRI WKT or OGC (2015) dialects are not accepted.
Tile Buffer	None; tiled delivery, without overlap	None; tiled delivery, without overlap
ASPRS Classifications	1 - Unclassified 2 - Bare-earth Ground 3 - Low Vegetation (0.01m to 1.00m above ground) 4 - Medium Vegetation 1.01m to 3.00m above ground) 5 - High Vegetation (greater than 3.01m above ground) 6 - Building 7 - Low Point (Noise) 9 - Water 10 - Ignored Ground 13 - Bridges 14 - Culverts	1 - Processed, but unclassified 2 - Bare-earth Ground 7 - Low Noise (low, manually identified, if necessary) 9 - Water 10 - Ignored Ground (breakline proximity) 17 - Bridge Decks 18 - High Noise (high, manually identified, if necessary)
Withheld Points	Outliers, noise, blunders, geometrically unreliable points near the extreme edge of the swath, and other points deemed unusable are to be identified using the "Withheld" flag. This applies primarily to points which are identified during pre-processing or through automated post-processing routines. Subsequently identified noise points may be assigned to the standard Noise Class (Class 7), regardless of whether the noise is lower or higher relative to the ground.	Proper use of the LAS withheld and overlap bits is required.
Overlap Class	The ASPRS Overlap Class (Class 12) shall NOT be used. All points must be classified unless identified as "Withheld".	Use of the overlap bit is required for marking overlap points.

COMPARISON TABLE: STATE AND USGS

Lidar Technical Specifications

Fully Classified All-Return Point Cloud	State Specification	USGS Specification
Classification Accuracy	Within any sample 1 km x 1 km area, no more than 1% of non-withheld points in the classes listed above will possess a demonstrably erroneous classification value. This includes Unclassified points (Class 1) that should be correctly included in a different class as required by this specification. This requirement may be relaxed to accommodate collections in areas where the client agrees classification to be particularly difficult.	N/A
Classification Consistency	Point classification shall be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions will be cause for rejection of the entire deliverable.	N/A
GPS Times	Each return must include: easting, northing, elevation, intensity, order of return (i.e. first-return, second-return), classification, and Adjusted GPS Time. Easting, northing, and elevation must be recorded to the nearest 0.01m and GPS second reported to the nearest microsecond (or better). May include additional attributes. No duplicate entries.	GPS times are to be recorded as adjusted GPS time, at a precision sufficient to allow unique timestamps for each return. In compliance with LAS specification requirements, the encoding tag in the LAS header must be properly set.
Intensity Values		Intensity values, 16 Bit, Linear Rescaling

Notes and Recommendations: Lidar classification additions provide opportunity to build lidar-derived data products from the base data. For example:

- Building classification = building footprints, 3D building models and building change analysis
- Vegetation classification = vegetation height and density raster products and vegetation health and statistics
- Improved classifications = provides a detailed process for precisely selecting and classifying lidar points for data analytics
- Culverts = improves the generation of the hydro-enforced DEM by removing artificial water pooling where culverts exist

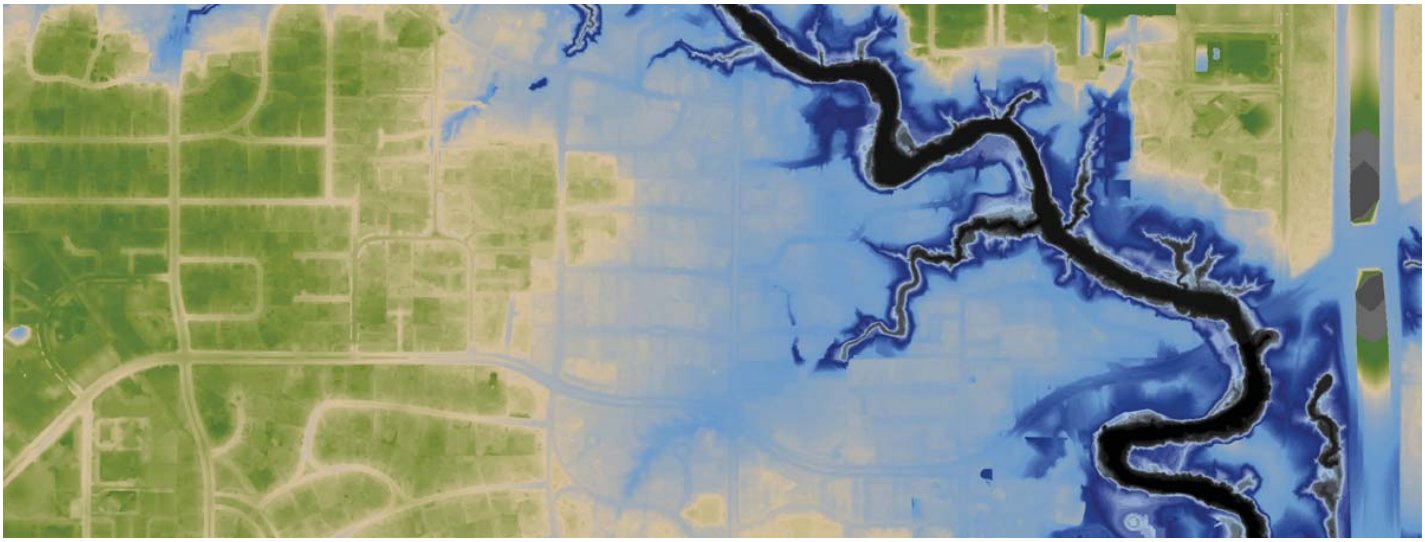
Hydro-flattened Breaklines		
Format	Non-tiled Esri feature class in ArcGIS version 10.3 geodatabase format Waterbodies (ponds, lakes, and reservoirs), wide streams and rivers ("double-line"), and other non-tidal waterbodies are to be hydro-flattened within the DEM, resulting in a flat and level bank-to-bank gradient. Bare-earth lidar points that are near the breaklines (proximity not to exceed NPS) shall be classified as Ignored Ground (class value equal to 10).	Non-tiled Esri feature class in ArcGIS version 10.3 geodatabase format Breaklines for all hydro-flattened areas will be delivered, regardless of technique used for hydro-flattening the DEM. No geometric changes shall be made to the originally computed lidar points. Bare-earth lidar points that are near the breaklines shall be classified as Ignored Ground (class value equal to 10) and excluded from the DEM generation process. This process prevents unnatural surface artifacts from being created between mass points and breakline vertices. The proximity threshold for reclassification as Ignored Ground is at the discretion of the data producer, but in general shall not exceed the aggregate nominal pulse spacing (ANPS).
Spatial Reference	Projected and defined in the project Spatial Reference Framework	Breaklines in the same coordinate reference system and units (horizontal and vertical) as the lidar point delivery.
Stream Resolution	Hydro-flattening shall be applied to all streams that are nominally wider than 15.25 meters (~50 feet), and to all non-tidal boundary waters bordering the project area regardless of size. Stream features should be made continuous even when a segment narrows below this threshold for a distance of at least 1600 meters to maintain cartographic integrity. Flattened rivers and streams shall present a gradient downhill water surface, in accordance with the immediately surrounding terrain. In cases of drought, flood or rapidly moving water demonstrating conditions where the water surface is notably not level bank to bank, the water surface will be represented as it exists during acquisition while maintaining an aesthetic cartographic appearance.	100' nominal width: This should not unnecessarily break a stream or river into multiple segments. At times it may squeeze slightly below 100' for short segments. Data producers should use their best professional judgment. Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain. The first two paragraphs of the Digital Elevation Model Hydro-Flattening section of USGS Lidar Base Specification v1.2 apply to non-hydrographic terrain generation below bridges. The bare earth surface below the bridge shall be a continuous logical interpolation of the apparent terrain lateral to the bridge deck. Where abutments are clearly visible, the bare earth interpolation shall begin at the junction of the bridge deck and approach structure. Where this junction is not clear the contractor shall use their best judgment to delineate the separation of below-bridge terrain from elevated bridge surface. Streams, rivers, and water bodies meeting the criteria for hydro-flattening in the USGS Lidar Base Specification v1.2 shall be monotonically continuous where bridge decks have been removed. All breaklines used to enforce a logical terrain surface below a bridge shall be considered a required deliverable.

COMPARISON TABLE: STATE AND USGS

Lidar Technical Specifications

Hydro-flattened Breaklines	State Specification	USGS Specification
Waterbody Resolution	All water impoundments, natural or man-made, nominally larger than 2 acres Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, to be treated as rivers The entire water surface edge must be at or below the immediately surrounding terrain.	~2-acre or greater surface area (~350' diameter for a round pond) Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, will be treated as rivers. Flat and level water bodies (single elevation for every bank vertex defining a given water body). The entire water surface edge will be at or just below the immediately surrounding terrain.
Non-Tidal Boundary Waters	Represented only as an edge or edges within the project area; collection does not include the opposing shore. The entire water surface edge must be at or below the immediately surrounding terrain. Water surface is to be flat and level, as appropriate for the type of water body (level for lakes; gradient for rivers).	Represented only as an edge or edges within the project area; collection does not include the opposing shore. The entire water surface edge will be at or below the immediately surrounding terrain. The elevation along the edge or edges will behave consistently throughout the project. May be a single elevation (i.e., lake) or gradient (i.e., river), as appropriate.
Tidal Waters	Tidal water bodies are defined as water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, large lakes, and the like. This includes any water body that is affected by tidal variations. Tidal variations over the course of a collection or between different collections will result in lateral and vertical discontinuities along shorelines. This is considered normal and these anomalies should be retained. The final DEM is required to represent as much ground as the collected data permits. Water surface is to be flat and level, to the degree allowed by the irregularities noted above. Reasonable planning efforts should be made to minimize tidal deviations if possible. Scientific research projects in coastal areas often have specific requirements with regard to how tidal land-water boundaries are to be handled. For such projects, the requirements of the research will take precedence.	Water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any significant water body that is affected by tidal variations. Tidal variations over the course of a collection, and 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 requires either the removal of ground points or the introduction of unmeasured ground into the DEM. The USGS NGP priority is on the ground surface, and accepts the unavoidable irregularities in water surface. Scientific research projects in coastal areas often have very specific requirements with regard to how tidal land-water boundaries are to be handled. For such projects, the requirements of the research will take precedence.
Islands	Permanent islands 4,000 m2 (1 acre) or larger shall be delineated within all water bodies.	Permanent islands 4,000 m2 (1 acre) or larger shall be delineated within all water bodies.
Bridges and Culverts	Stream channels should break at road crossings (culvert locations). These road fills in Class 14 Culverts should not be removed from the DEM. However, streams and rivers should not break at elevated bridges. Bridges should be removed from the DEM (see 'Artifacts' under Bare Earth Lidar/DEM Raster). When the identification of a feature such as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.	Streams should break at road crossings (culvert locations). These road fills should not be removed from DEM. However, streams and rivers should not break at bridges. Bridges (as defined in the USGS Lidar Base Specification v1.2) shall be removed from the DEM. When the identification of a feature as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.

Notes: Improved or tighter hydro specifications support further development of 1- or 2-foot contours and hydro-enforced DEMs.



Hydro-flattened Bare Earth Raster DEM

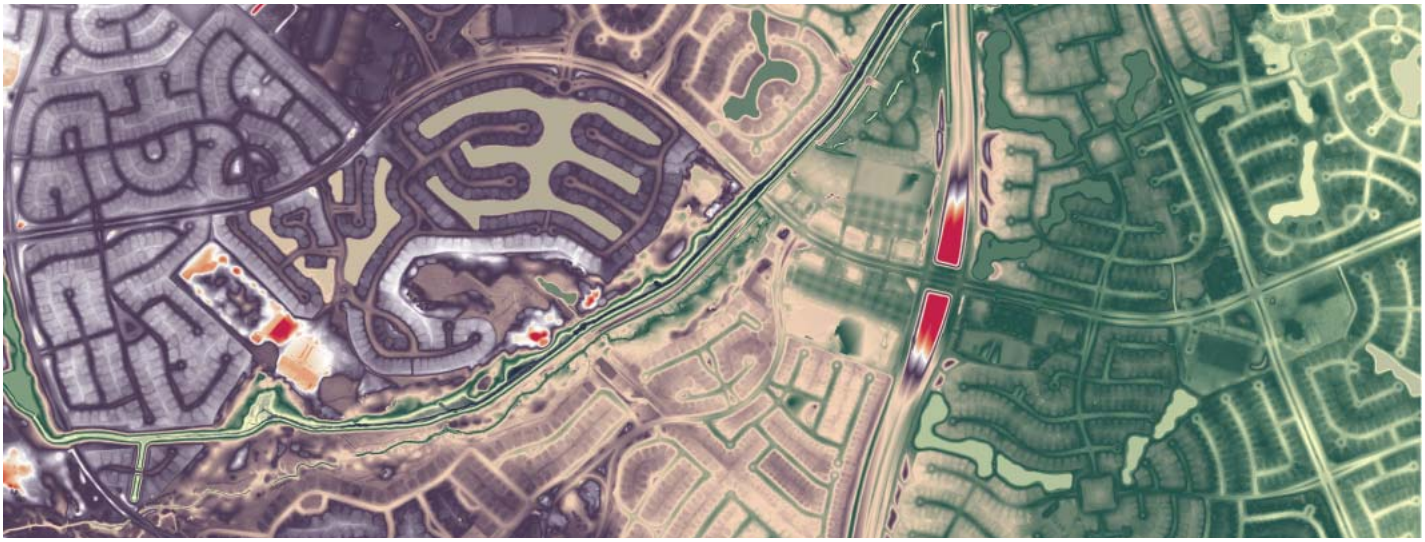
COMPARISON TABLE: STATE AND USGS

Lidar Technical Specifications

Intensity Images

Format	Raster image of first-return intensity values in GeoTIFF format	256 color gray scale and GeoTIFF format
Spatial Reference	Projected and defined in the project Spatial Reference Framework	N/A
Spatial Resolution	0.5-meter DO4Q tiles	0.5 meter
Tile Buffer	All final image tiles should have a buffer that extends 50 meters around all four sides of the image tile. All final image tiles should have 90 degree corners, not rounded. The extents shall be computed by projecting the geographic corners and side midpoints to the required projection, then adding the buffer on each side of the resulting minimum bounding rectangle.	Tiled to match the Classified LAS and DEM files
Radiometric Resolution	Unsigned 8-bit, 16-bit or 32-bit (highest available; 16-bit for planned sensor) Intensity images should typically contain original digital number (DN) values ranging from 0 - 100 or greater for ≥ 80% of areas with diverse land cover conditions.	8-bit
Histogram	Histogram should be very close to normally distributed with minimal or no clipping.	N/A
Consistency	Images should be consistent in contrast and tone across project AOI. There should be no striping, tiling, or banding across project AOI.	N/A

Bare Earth Lidar / DEM Raster	**State Specifications**	**USGS Specification**
Format	Hydro-flattened 32-bit floating point raster DEM in .img format	32-bit ERDAS .IMG floating point raster format
Spatial Reference	Projected and defined in the project Spatial Reference Framework	Georeference information shall be included in raster files
Spatial Resolution	1-meter DO4Q tiles	No greater than 0.5 meter, and no less than the design Nominal Pulse Spacing (NPS)
Tile Buffer	All final image tiles should have a buffer that extends 50 meters around all four sides of the image tile. All final image tiles should have 90 degree corners, not rounded. The extents shall be computed by projecting the geographic corners and side midpoints to the required projection, then adding the buffer on each side of the resulting minimum bounding rectangle.	Tiled delivery, without overlap or gaps
Quality	Visible seams, stepping, gaps, or quilting that are not naturally occurring is cause for rejection No “plateau effect” from rounded or integer elevation values (must be floating point)	N/A
Artifacts	Vegetation, bridges, buildings, and other artifacts to be completely removed from Class 2 Bare-earth Ground Artificial dams in waterways caused by bridges or other adjacent structures are not permitted with the exception of culverts	N/A



Hydro-flattened Bare Earth Raster DEM

COMPARISON TABLE: STATE AND USGS

Lidar Technical Specifications

Bare Earth Lidar / DEM Raster	State Specifications	USGS Specification
Filtering	No over-aggressive filtering of the Ground class resulting in gaps or a degradation of DEM quality No under-aggressive filtering of the Ground class resulting in a degradation of DEM quality	DEM tiles will show no edge artifacts or mismatch. A quilted appearance in the overall project DEM surface, whether caused by differences in processing quality or character between tiles, swaths, lifts, or other non-natural divisions, will be cause for rejection of the entire DEM deliverable.
Sinks	Depression sinks, natural or man-made will not be filled	Depressions (sinks), natural or man-made, are not to be filled (as in hydro-conditioning or hydro-enforcement).
Breaklines	Hydro breaklines shall be used to define water channels and water bodies	Water Bodies (ponds and lakes), wide streams and rivers ("double-line"), and other non-tidal water bodies as defined in Section III are to be hydro-flattened within the DEM. Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are larger than ~2 acre in area (equivalent to a round pond ~350' in diameter), to all streams that are nominally wider than 100', and to all non-tidal boundary waters bordering the project area regardless of size. The methodology used for hydro-flattening is at the discretion of the data producer.
No Data	Data voids outside the project boundary and acceptable internal voids will be coded as a unique NODATA value; -9999	Void areas (i.e., areas outside the project boundary but within the tiling scheme) shall be coded using a unique "NODATA" value. This value shall be identified in the appropriate location within the file header.
Bridges		Bridges (as defined in the USGS Lidar Base Specification V1.2) shall be removed from the DEM. Roads or other travel ways over culverts shall remain intact in the surface. The bare earth surface below a bridge shall be a continuous logical interpolation of the apparent non-hydrographic terrain lateral to the bridge deck. Where abutments are clearly visible, the bare earth interpolation shall begin at the junction of the bridge deck and approach structure. Where this junction is not clear, the contractor shall use their best judgment to delineate the separation of below-bridge terrain from elevated bridge surface. (See USGS Lidar Base Specification v1.2, section on Digital Elevation Model Hydro-Flattening.) No geometric change shall be made to the originally computed lidar points. Bare-earth lidar points that are near breaklines shall be classified as Ignored Ground (class value equal to 10) and shall be excluded from the DEM generation process. This process prevents unnatural surface artifacts from being created between mass points and breakline vertices. The proximity threshold for reclassification as Ignored Ground is at the discretion of the data producer, but in general shall not exceed the aggregate nominal pulse spacing (ANPS). Streams, rivers, and water bodies meeting the criteria for hydro-flattening in the USGS Lidar Base Specification v1.2 shall be monotonically continuous where bridge decks have been removed. Any breaklines used to enforce a logical terrain surface below a bridge shall be considered a required deliverable.
VVA Assessment	3rd Party QA/QC Vendor; not a requirement for the data provider	A report on the assessed absolute vertical accuracy (NVA and VVA) of the bare-earth surface in accordance with the guidelines set forth in the "Positional Accuracy Standards for Digital Geospatial Data" (American Society for Photogrammetry and Remote Sensing, 2014). Absolute vertical accuracy requirements using the ASPRS methodology for the bare-earth DEM are listed in "Absolute vertical accuracy for digital elevation models, Quality Level 0–Quality Level 3" (table 5).

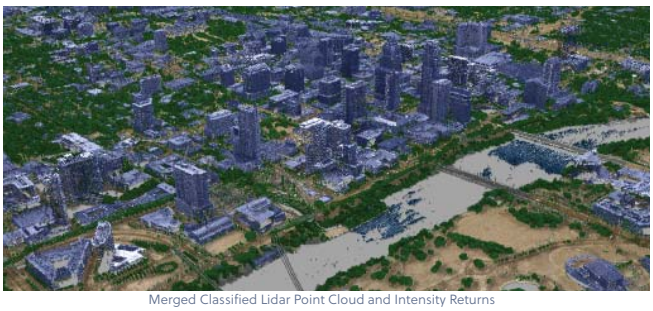
Granger Dam Bare Earth Raster DEM

Granger Dam Spillway Bare Earth Raster DEM

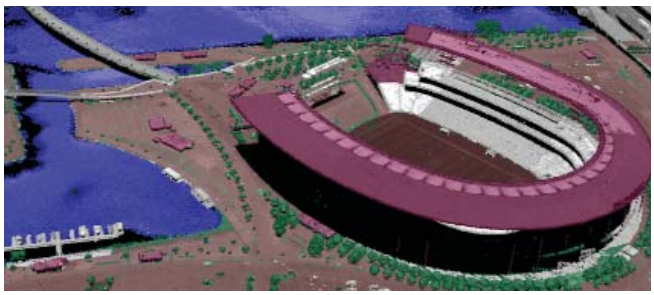
COMPARISON TABLE: STATE AND USGS

Lidar Technical Specifications

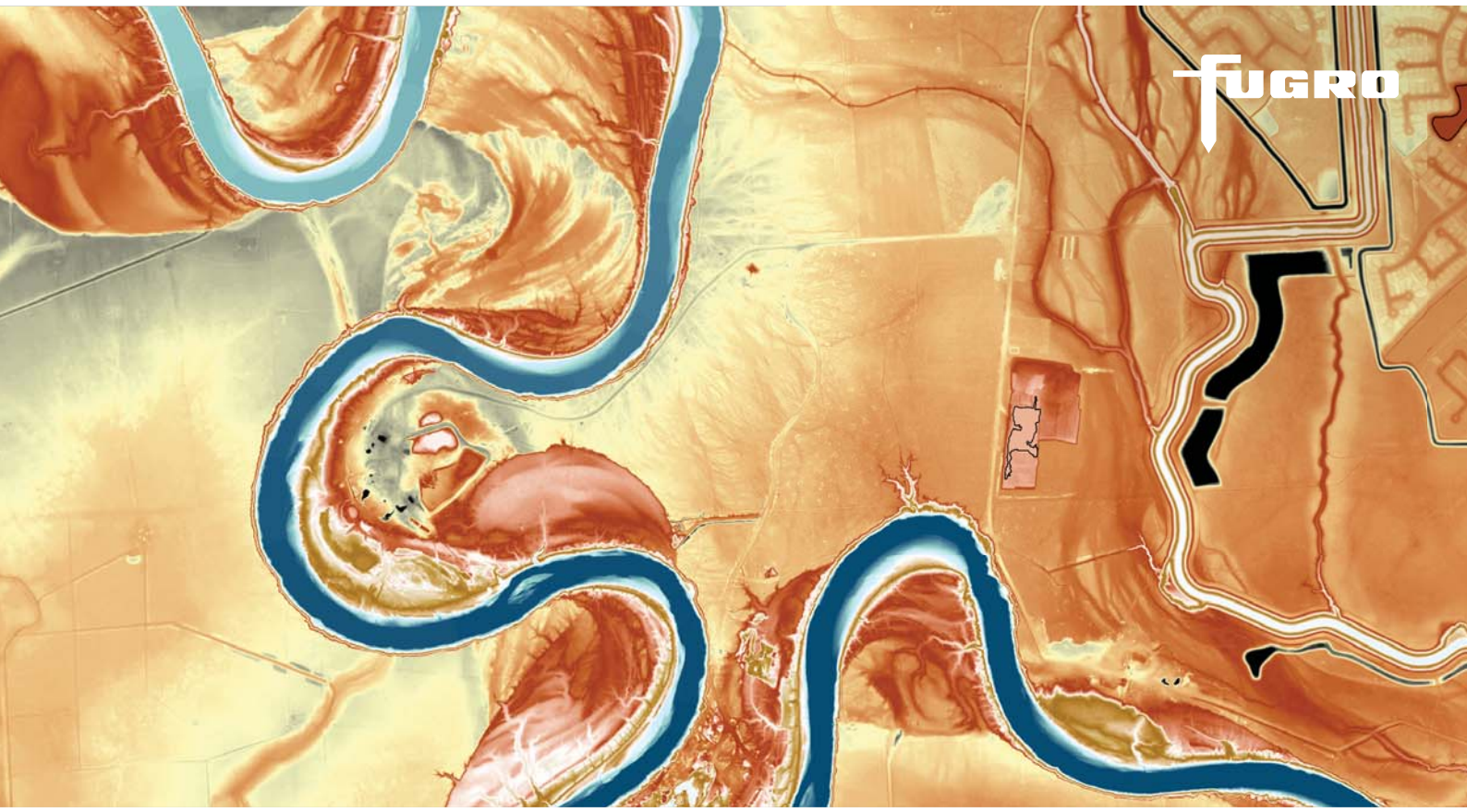
Metadata	State Specifications	USGS Specifications
Reports	"Survey Report detailing the collection of control used for calibration. Data provider is not responsible for checkpoints."	Collection Report detailing mission planning and flight logs. Additionally, a flight index shall be delivered in file geodatabase format. Flight index shall contain flight line ID, acquisition date, start time and end time for each flight line. Survey Report detailing the collection of control and check points used for calibration and QA/QC. Processing Report detailing calibration, classification, and product generation procedures including methodology used for breakline collection and hydro-flattening. "QA/QC Reports (detailing the analysis, accuracy assessment and validation of: (01) The point data (absolute, within swath, and between swath) (02) The bare-earth surface (absolute) (03) Other optional deliverables as appropriate" Project Report: The contractor shall deliver a production report which details: A record of field work procedures; Data derivation and adjustments; Quality control procedures and results; Any problems encountered and solutions used in resolving such problems; Statistical report summarizing the results of the airborne GPS adjustment and the overall accuracy of the adjusted IMU data.
Control and Checkpoints	"All control used to calibrate, control, process, and validate the lidar point data or any derivative products are to be delivered. Data provider is not responsible for checkpoints."	All control and check points used to calibrate, control, process, and validate the lidar point data or any derivative products are to be delivered. All check points shall be delivered with each delivery block.
Data Extents		Geo-referenced, digital spatial representation (shapefile) of the precise extents of each delivered dataset. This should reflect the extents of the actual lidar source or derived product data, exclusive of Triangular Irregular Network (TIN) artifacts or raster NODATA areas. A union of tile boundaries or minimum bounding rectangle is not acceptable. ESRI Polygon shapefile is preferred.
Product Metadata	FGDC compliant, XML format metadata Project-level metadata for non-tiled data in XML format (project, hydro breaklines) Tile-level metadata consisting of separate XML files paired with each data tile (LAS, DEM, Intensity)	FGDC compliant, XML format metadata One file for Project One file per lift One file per tiled deliverable product group (classified point data, bare-earth DEMs, etc.) Product group metadata should contain contents unique and specific to that product group, a renamed copy of the project level metadata is not sufficient. Metadata files for individual tiles are not required.
Pilot		
Pilot Data	The lidar vendor (in consultation with project partners) will select a minimum of four (4) contiguous tiles within the project AOI which shall serve as a Pilot area. The Pilot will be delivered to the client and the QA/QC review consultant and shall include all-return point cloud, DEM and intensity image products delivered in final product form to meet or exceed the specifications established in this document. It is recommended that processing of other data in the AOI be suspended until the Pilot data have been approved by the client.	Contractor shall deliver a Project Pilot consisting of no less than 4 tiles of the CLASSIFIED LAS, hydro-flattened Bare-Earth DEM tiles, breaklines and associated UNCLASSIFIED point cloud data. Pilot delivery shall report the NVA of the UNCLASSIFIED point cloud and Bare-Earth DEM.



Merged Classified Lidar Point Cloud and Intensity Returns



Baylor University Classified Lidar Point Cloud



FUGRO
ABOUT US

We are the world's leading geo-data specialist, collecting and analyzing comprehensive information about the Earth and the structures built upon it. Through integrated data acquisition, analysis and advice, we unlock insights from geo-data to help our clients design, build and operate their assets in a safe, sustainable and efficient manner.

The world is changing faster than ever before. Over the coming decades, population growth and urbanization will lead to an increasing demand for energy, water, food, minerals, metals, buildings, industrial plants and infrastructure. The energy mix, infrastructure and built environments must evolve if these challenges are to be tackled successfully, while meeting global climate change objectives.

Sustainability for Fugro is continuously rethinking what we do and how we do it. We execute our projects with the highest regard for the safety and well-being of everyone who works for and with us, and minimize our impact on the environment, while remaining compliant with relevant rules and regulations. We are committed to conducting our business ethically and responsibly.

Fugro's services are essential for the sustainable development and operation of our clients' infrastructure, plants, buildings and natural resources. We contribute significantly to the development of sustainable energy, such as offshore wind farms, and to projects that mitigate the impact of climate change such as flood and coastal protection.

Safety is key to all our operations. Fugro is committed to providing a safe and secure workplace for all employees, subcontractors and clients. We firmly believe that incidents can be prevented by pro-actively identifying and managing health and safety risks arising from our activities and embedding appropriate safety standards and practices in operations and workforce behaviours. We are committed to adhering to applicable laws and regulations and the expectations of society at large, and to conducting business in a responsible manner.

GEOSPATIAL SERVICES

Our global acquisition-to-production resources are combined with rigorous quality management procedures to meet customer needs for detailed and accurate spatial information.

Lidar

Fugro operates a suite of lidar systems to provide high quality, fast and accurate terrain mapping. Our lidar services include state-of-the-art topographic and bathymetric data capture from planes, helicopters, boats, vans and all terrain vehicles. Lidar point densities range from 2 ppsm to 100 ppsm.

Orthoimagery

Fugro transforms data from a range of aerial sensors into spatially accurate map products and GIS datasets. We offer orthoimagery products ranging from 1" to 12' pixel resolutions in a variety of formats - multispectral, hyperspectral, and thermal.

Oblique Imagery

Fugro's oblique imagery solution, PanoramiX, combines high-resolution vertical and oblique imaging with powerful 3D mapping and visualization capabilities. Create measurements, generate reports, and inspect conditions of ground features at pixel resolutions ranging from 1" to 6".

3D Model Environment

Orthoimagery draped digital elevation models to fully textured 3D oblique models, we expand the 2D GIS environment to a more usable 3D dataset. Our high-resolution 3D model environment merges powerful GIS layers for a more intelligent and seamless map.

Topographic and Planimetric

Topographic and planimetric data generation has always been a cornerstone for successful mapping. We offer topographic data to 1-foot contour intervals, planimetric data to 1"=20' scale, and highly detailed thematic maps.

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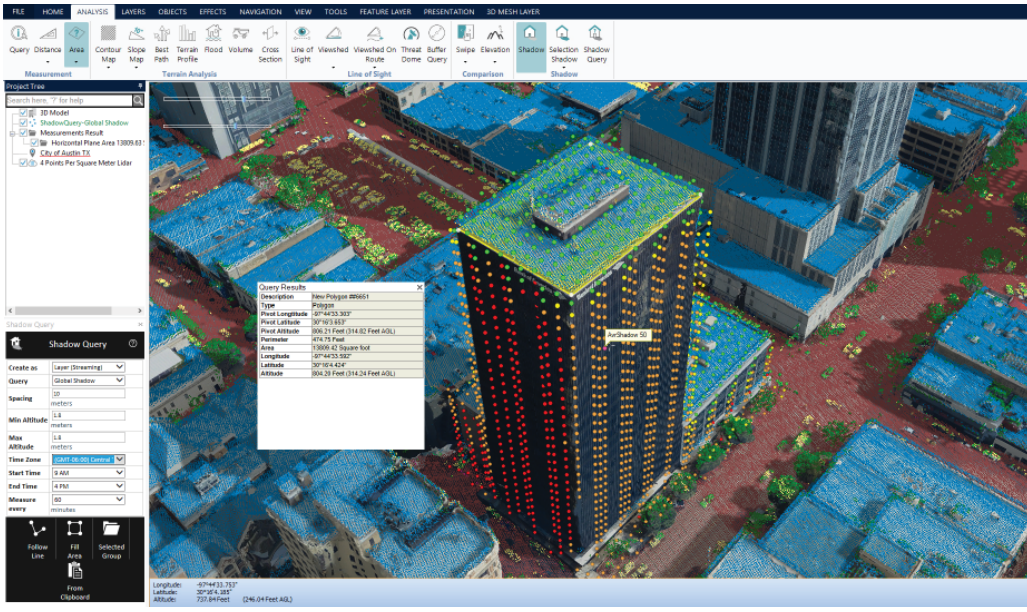


Fugro SIMmetry - a 4D GIS desktop and online platform for analyzing complex GIS data easily

GIS PLATFORMS

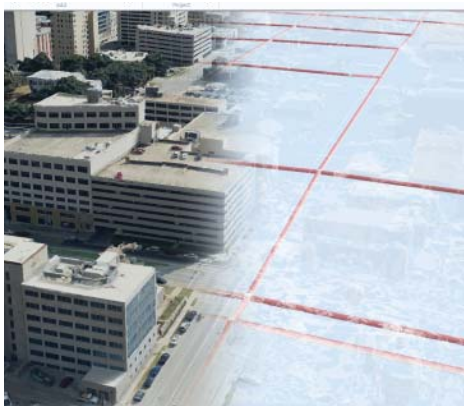
Fugro Access

Designed as a robust web application, Fugro Access provides clients with an overview of project status, a portal for orthoimagery QC, and is a central location for communicating project relevant details.

SIMmetry

A scalable 3D/4D GIS platform for managing and serving a wide range of existing and streamed datasets. With an intuitive interface, the platform provides real-time access to exceptional visualization and critical analytics, via desktop and web based. SIMmetry is designed to provide efficient, low bandwidth streaming of data rich content across multiple platforms. SIMmetry transforms existing and new datasets, including topography, land hydrography, engineering as-built drawings, surface and subsurface utility, facility management and transmitted signal data (security cameras, flood gauges, etc.) into an accurate and shareable 3D GIS.

3D model and topographic lidar data combined



Visualize and interact with features above and below ground in SIMmetry

EQUIPMENT LIST

Fugro Owned Equipment

Topographic Lidar Acquisition Systems

Make/Model	Type	Qty
Leica ALS80	Topographic Lidar - Wide Area	2
Riegl LMS Q680i	Topographic Lidar - Wide Area	3
Riegl LMS Q1560i	Topographic Lidar - Wide Area	2
Fugro FLI-MAP	Topographic Lidar – Corridor	3
Fugro ARAN Mobile Mapper	Mobile Lidar/Pavement/Asset Inventory	1

Topographic / Hydrographic Systems - Riverine & Coastal

Make/Model	Type	Qty
Fugro RAMMS	Topobathymetric Lidar: manned & unmanned	2
Riegl VQ820 G	Topobathymetric Lidar	2
SHOALS 100-T	Topobathymetric Lidar	2
Fugro FAS-900	Hydrographic and geophysical surveying: manned & unmanned	2
Fugro ROCIS	Current measurement & derived bathymetry	1

Imagery Acquisition Systems

Make/Model	Type	Qty
Leica ADS80-SH82	Digital Imagery (Vertical)	2
Leica ADS100	Digital Imagery (Vertical)	2
PanoramiX (MIDAS)	Digital Imagery (Vertical & Oblique)	3
Phase One iXM	Digital Imagery (Vertical)	3

Aircraft

Make/Model	Type	Qty
Cessna 441 Conquest-II	Turbo Prop	3
Cessna 310-R	Piston	1
Piper Navajo PA31-350	Piston	4

Fugro Aviation Hangar

LMS Q1560 Topographic Lidar Sensor

Riegl

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