Appendix B – LPQ TLS and ALS Metadata

Terrestrial and Airborne Lidar Analyses

Terrestrial Lidar/Laser Scanning (TLS)

- Field work
    - Equipment
        - Leica MS60 Multistation
            - Total station and laser scanner in one
            - 1.5 meter (m) minimum and 1000 m maximum range
            - 1” angular accuracy horizontal and vertical
            - 1000 hertz (hz) to 1 hz sample rate
            - 1 millimeter (mm) noise/error at 50 m in 1000 hz mode
            - Reflective intensity and imaging capabilities
        - Trimble RTK GNSS
            - High precision, corrected, surveying of ground control points
    - Survey and Scanning Methods
        - Set up
            - Survey tripod setup
                - Choose best location for line of sight angle to terrain
                - Proper height and horizontal position for best survey angles
                - Level tripod by eye
            - MS60 setup
                - Total station
                    - Mount Tribrach on tripod
                    - Level tribrach
                    - Mount MS60 on tribrach
                    - Turn on MS60
                    - Center the MS60 using either the laser plummet or the plumb bob
                    - Level MS60 according to onboard graphical interface bubble using tribrach adjusters
                    - Measure height from ground straight below MS60 to the MS60 using the Leica survey measuring tape
        - Tie into survey coordinate system
            - Survey measurement of ground control points
                - NAD83 UTM 12N
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            - Resection total station into 2 known survey points
                - Resection is a method for determining an unknown position (position finding) measuring angles with respect to known positions

        - Setup tripods and traverse prisms over known survey ground control points
        - Enter know coordinates of survey points into the MS60
        - Shoot laser measurements from MS60 to prisms
            - Measures both distance and angle
        - Calculates position of the MS60 total station from the 2 known points
        - All measurements from this time forward are done in the project coordinate system
    - Laser scanning
        - Laser scanning was conducted around the MS60
        - The maximum distance measured was approximately 35 meters
        - Scanning rate was 1000 hz
        - Scan density was set to 1.5 centimeter (cm) at approximately 10 m from the MS60
        - Scans took approximately 1 hour each
        - Scans collected approximately 1 million points each
        - Each scan displayed onboard the MS60 and was preregistered due to the resection and traverse methods used
            - All scans were:
                - In real project coordinates real-time in the field
                - Stitched together
                - Oriented correctly
                - Scaled correctly
                - Able to be analyzed for errors in the field
    - Traversing
        - After resecting into the project coordinate system and conducting the first scan, a survey traverse was conducted to move the scanner while staying tied into the coordinate system
        - The traverse tripods and prisms were moved to an area in the desired next scanning location
        - This prism was foresighted in from the MS60, measuring the new prisms exact location
        - Then the MS60 was moved to take the place of the new prism and the prism was placed back on the old MS60 location
        - The MS60 then backsighted the prism which sat in its old location
        - This procedure confirmed the accuracy of the new MS60 location within 1 millimeter of the previous location
        - Scanning was then conducted
        - Following scanning, the traverse routine continued to add new scan stations around the sinkhole
- Schedule
    - 5 Scans were completed over 2 separate days
        - Day 1 completed 2 scans

        - Day 2 completed 3 more
    - Scanning field days were approximately 1 month apart, from mid-November to mid-December
    - No rainfall or significant weather occurred between scanning days
    - Each field day lasted approximately 5-6 hours onsite
- Data processing and analysis
    - 5 raw Leica scan files were downloaded from the MS60 via USB flash drive
        - .sdb file format
        - 30.9 MB, 28.6 MB, 37.3 MB, 19.5 MB, 25 MB
    - Leica Infinity survey and scanning software
        - 5 raw scans were merged into one .las (LAS) file
        - Saved otherwise unchanged
        - 7.05 million points
        - LAS File size
            - 193 MB
    - 3DReshaper point cloud processing and analysis
        - Re-registration
            - Initial field survey used an incompatible elevation geoid
            - Used corrected final coordinates for the ground control points
            - Manually re-registered/transformed the entire lidar point cloud to the proper coordinate system
        - Classification and filtering
            - Noise reduction first
                - Thinned point cloud by local area density statistical analysis then removing points based on percentage location in the data distribution
                - Removed 1.4% of noisy points = 95,419
                    - Resulting cloud = 6.9 million points
            - Spatial decimation
                - Decimated the cloud to 2 areal densities
                    - 10 cm for 3D PDF generation and other light-weight applications
                        - Resulting cloud = 640 thousand points
                    - 1 cm for detailed analysis
                        - Resulting cloud = 5.4 million points
            - Ground classification
                - Geometric classification of ground only points
                - Spatial resolution of 5 cm
                - Setting to ignore noisy points used
                - Resulting cloud ~= 3 million points
            - Manual editing
                - Further removal of vegetation
                - Partially iterative process with the first stages of surface meshing (see *Meshing* below)

        - Resulting cloud ~= 2 million points
    - Meshing
        - Started with iterative process for further manual removal of noisy vegetation points (see *Classification and filtering>Manual editing* above)
        - High resolution version
            - 2 step meshing
                - First step – Noise reduction
                    - This step used to fill holes and remove any errors from overlapping points
                    - Acts as averaging triangles between multiple points
                    - Very low detail mesh created, but it covered the entire area of points and filled holes
                - Second step – Refinement
                    - Interpolation and details added
                    - Selected deviation error from interpolated points, maximum number of triangles to generate and the minimum triangle size to use
                    - Deviation error = 0.001 m
                    - Number of triangles = 1,000,000
                    - Minimum triangle size = 0.01 m
            - Resulting mesh

Airborne Lidar/Laser Scanning (ALS)

- Downloaded Pima Area Government (PAG) lidar data from the University of Arizona library system
    - Lidar from 2005, 2008 and 2015
    - These are the only ones that covered the sinkhole site
- Files
    - LAS formats
    - Datums
        - 2005 and 2008
            - NAD83 HARN datum
            - NAVD88 Geoid?
        - 2015
            - NAD83 (2011) for 2015
            - NAVD88 Geoid 12A
    - Sizes
        - 2005
            -
        - 2008
            -
        - 2015
            - .

- Reprojection/transformations
    - LASTools
        - Las2las version 2015
            - From
                - AZ State Plane
                - Central
                - Feet
                - Navd88
            - To
                - NAD83 UTM 12N
                - Meters
        - Lacking detailed options or functionality
            - 2018 version
                - More projection options,
                - But feet elevations were not converted to meters
                - Appears to be a bug
                - Lacking details of UTM
            - 2015 version
                - Converted correctly
                - But lacking
                    - Vertical datum geoids
                    - Complete EPSG codes
                    - Details of UTM projection datums
    - Reprojection results
        - 2008 and 2015 reprojected to NAD83 UTM 12N metric
        - Offset by about a meter
        - 2008 data transformed to match the 2015 data as the correct datum
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