Karst Sinkhole Detecting and Mapping Using Airborne LiDAR

PIs
Su Zhang
Earth Data Analysis Center;
Department of Civil, Construction, and Environmental Engineering

Shirley Baros
Earth Data Analysis Center

Susan Bogus Halter
Department of Civil, Construction, and Environmental Engineering

Team Members
Ryan Dow (student)
Department of Civil, Construction, and Environmental Engineering

Paul Neville (research staff)
Earth Data Analysis Center

Hays Barrett (research staff)
Earth Data Analysis Center

PRC Members
Claude Morelli
Department of Civil, Construction, and Environmental Engineering

David Hadwiger
New Mexico Department of Transportation

Shawn Penman
Earth Data Analysis Center

Background

- Sinkholes are natural depressions in the Earth's surface; almost always prone to karst area
- Potential sinkholes vs. collapse sinkholes
- Collapse sinkholes could cause substantial damage to transportation infrastructure assets
- Being able to accurately and rapidly detect and map collapse sinkholes is critical to transportation infrastructure asset management and planning
- Transportation management agencies at all levels dedicate a large amount of time and money to detect and map collapse sinkholes as part of their infrastructure asset management programs

Provided by NCKRI

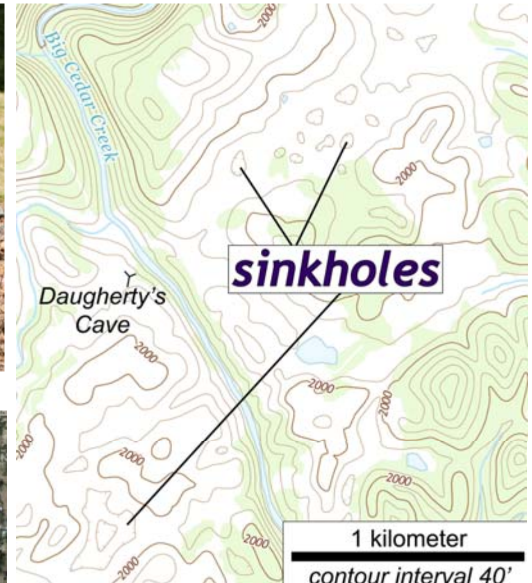
THE UNIVERSITY OF NEW MEXICO

Current Sinkhole Inspection Methods

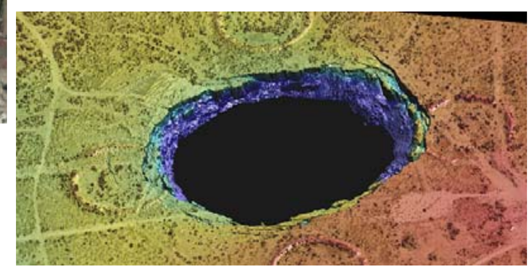
- Primarily through area reconnaissance
  - Visual inspection (collapse sinkholes)
  - Instrumental inspection (potential sinkholes)
- Review of maps
  - Topographic maps
  - Contour maps
  - Geologic maps
- Aerial photography and satellite imagery
- Airborne light detection and ranging (LiDAR)

Provided by Gilmore & Associates, Inc.

Provided by Breakings199



Provided by The Geology of Virginia

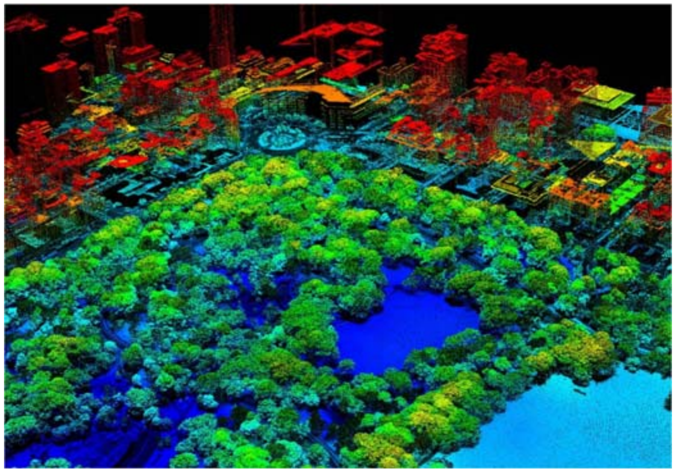


Provided by UT Austin

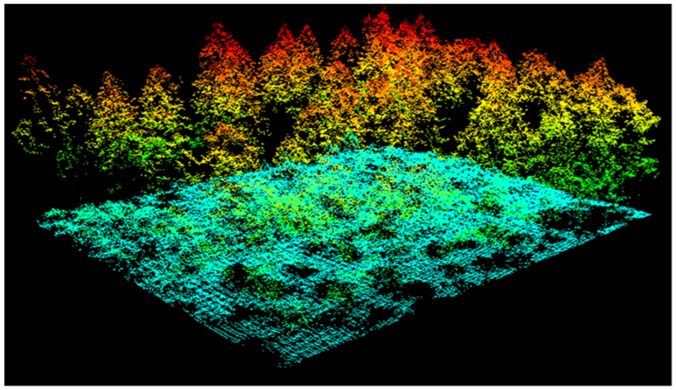
THE UNIVERSITY OF NEW MEXICO

Airborne LiDAR

- LiDAR system attached to a helicopter or aircraft
- LiDAR is a technology that uses light in the form of a pulsed laser to measure distances
- Established method for collecting very accurate elevation data across landscapes
  - Capable of scanning a swath of land covering many miles
  - Day and night data collection
- The resulting data of LiDAR collection are presented in the form of point clouds



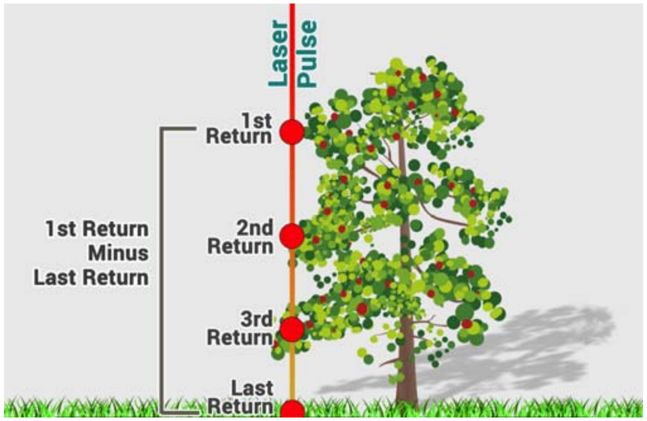
Provided by Applied Imagery

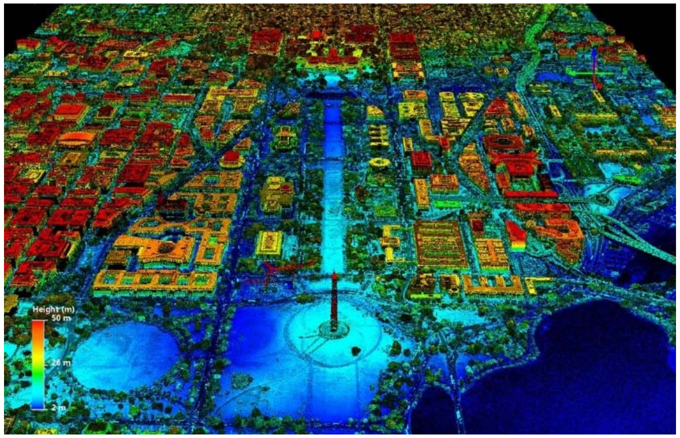


Provided by wur.nl

Airborne LiDAR Advantages

- Provides detailed Earth's surface elevation data
  - Highly accurate measurement in X, Y, Z dimensions
  - Allows the examination of the Earth's surface elevation change accurately and rapidly
- Filters to the ground through the vegetation canopy



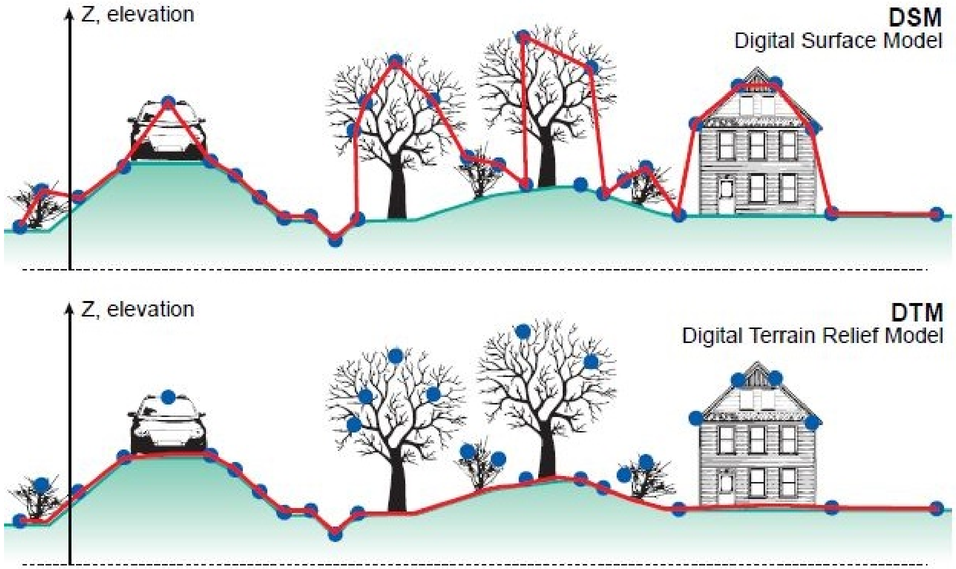


Provided by USGS

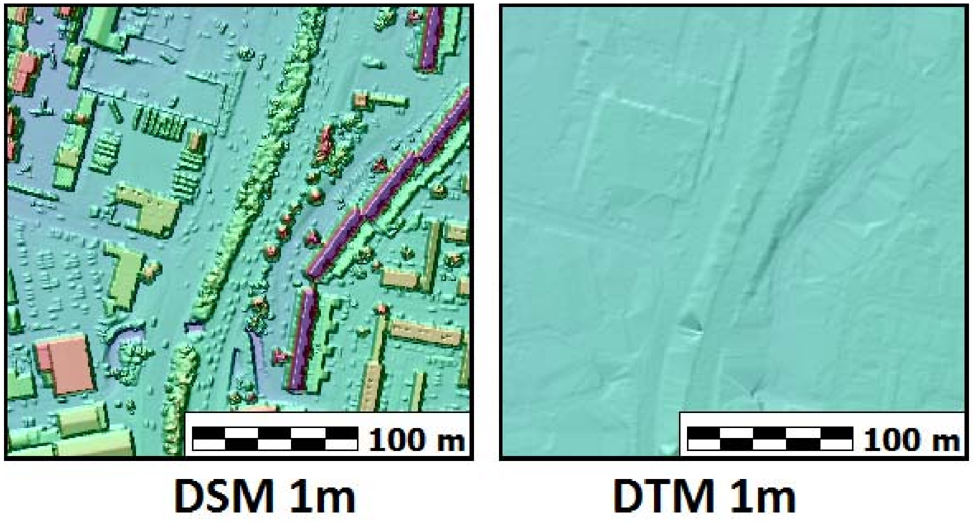
Provided by Caves of South Wales

LiDAR Derived Products

- Digital Surface Model (DSM)
- Digital Elevation Model (DEM) or Digital Terrain Model (DTM)



Provided by 3DMetrica



Provided by USNA

THE UNIVERSITY OF NEW MEXICO

Current Airborne LiDAR-based Sinkhole Detection Methods

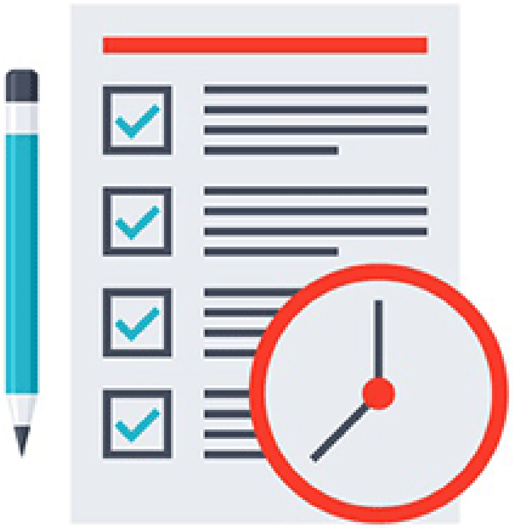
- Only morphology-based feature extraction
  - Focuses on detecting objects that from a distinct shape-transition in reference to their surroundings
  - Geometrically sinkholes are oval-shaped concave depression
- However, sinkholes have varying sizes, shapes, and appearance under various landforms, and they may not even exist in certain contexts
  - A dry stock pond and detention pond may be false positively detected as a sinkhole
- No focus on context-based feature extraction

Provided by Solid Stock Art

THE UNIVERSITY OF NEW MEXICO

Objectives

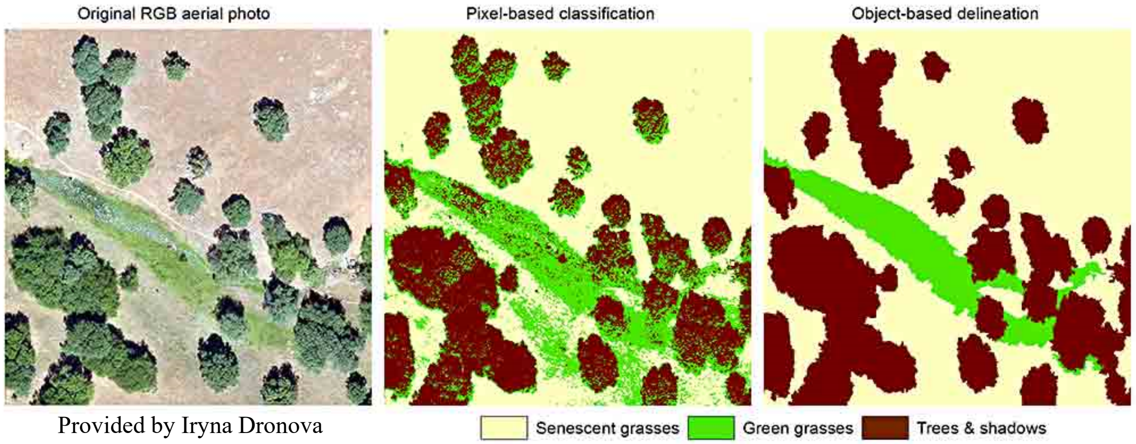
- Develop a complete process and toolset for detecting and mapping collapse sinkholes through the use of airborne LiDAR data
  - Morphology-based
  - Context-based
- Identify best practices for the effective implementation of a statewide sinkholes hazard management system (SHMS)
- Develop a guidebook for airborne LiDAR based collapse sinkhole detection and mapping



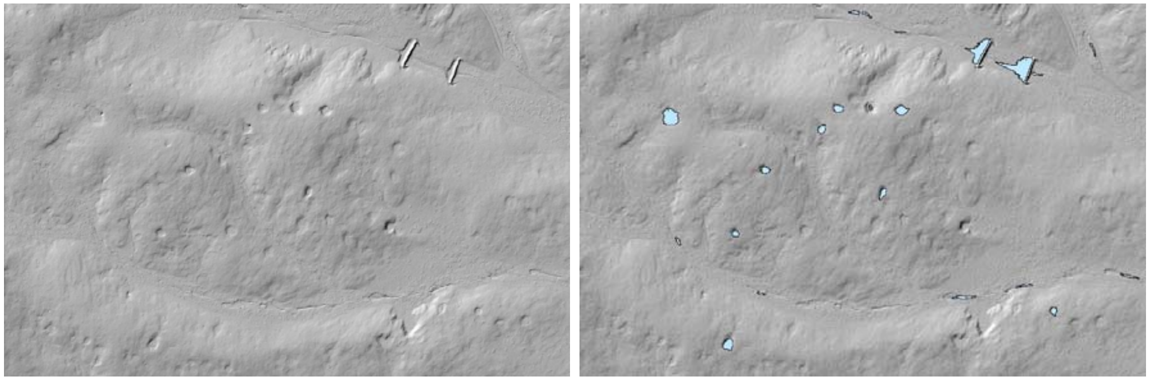
Provided by ProjectEngineer

Context-based Feature Extraction

- Object Based Image Analysis (OBIA)
  - vs. pixel-based image analysis
  - Group image pixels through segmentation (Mean Shift) and then delineate boundary
  - Spectral information (image pixel values)
  - Spatial information (shapes and spatial proximity)



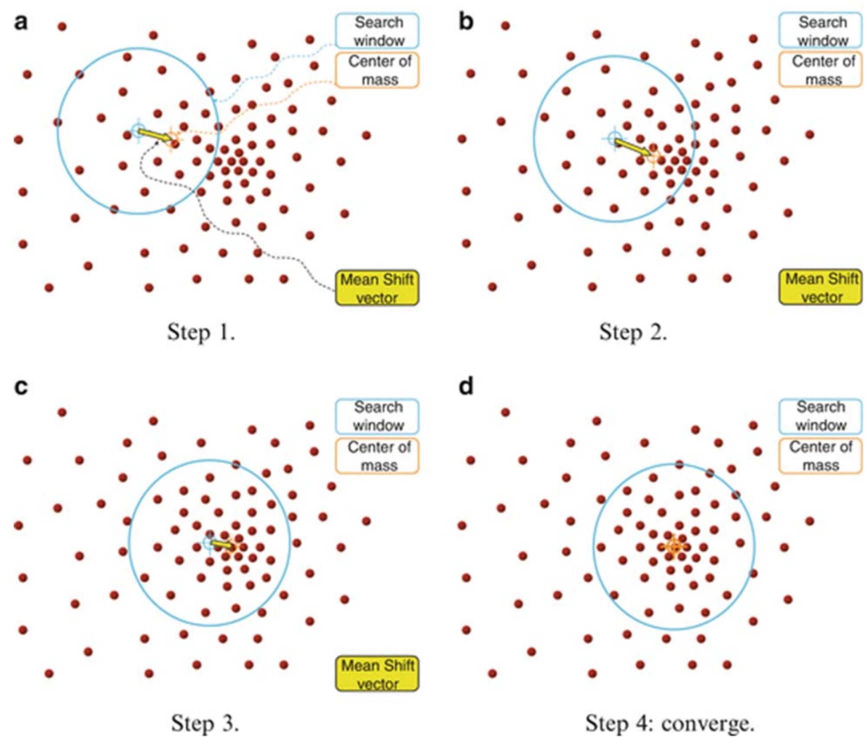
Provided by Iryna Dronova



THE UNIVERSITY OF NEW MEXICO

Segmentation

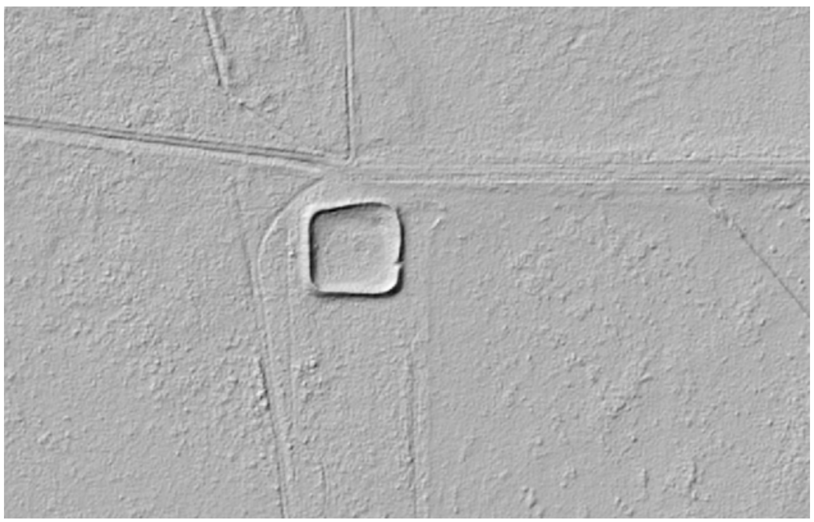
- Region Growing
  - Focuses on finding similar pixels from a seed and neighboring pixels
- Watershed Detection
  - Mostly used for gray-scale images and it treats images like a topographic surface to detect homogeneous pixels to ground them as a watershed
- Mean Shift
  - It is a local homogenization technique that concentrates on damping shading and tonality difference in localized objects to find the clustering of objects
  - It is selected because it is compatible with ArcGIS



Provided by Huang et al.

Context-based Feature Extraction

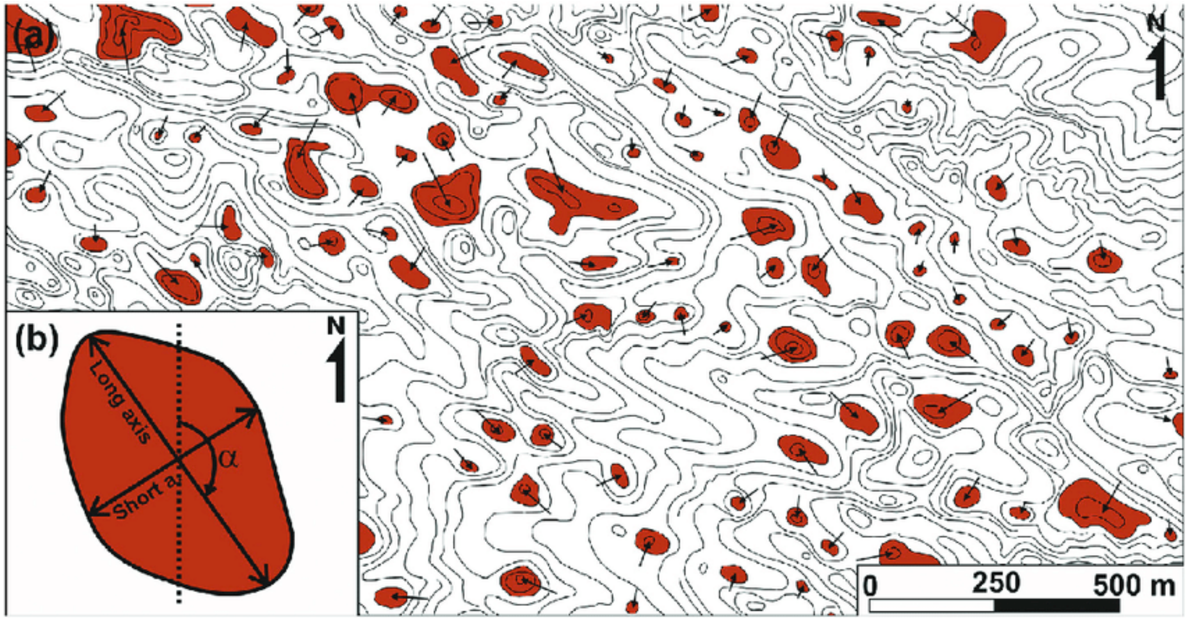
- User provided contextual information
  - Further filter false positively detected sinkholes
  - Can have as many layers as possible



Context Data	Example Sources	Genera Applications
Shape and Spatial Proximity	LiDAR Derived DEM	Delineate sinkhole boundary
Soil Types	USGS Geological maps	Sinkholes will not occur in certain types of soil such as gypsum-rich soils
Infrastructure Boundary	Infrastructure footprint boundary maps	Remove objects that false positively detected as sinkholes such as stadiums
Vegetation	USDA National Agricultural Imagery Program (NAIP)	Vegetation located on top of sinkholes appears circular shape
LULC	USGS National Land Cover Database (NLCD) maps	Remove objects that false positively detected as sinkholes such as dry stock ponds
Hydrology	USGS National Hydrology Database (NHD)	

Morphology-based Feature Extraction

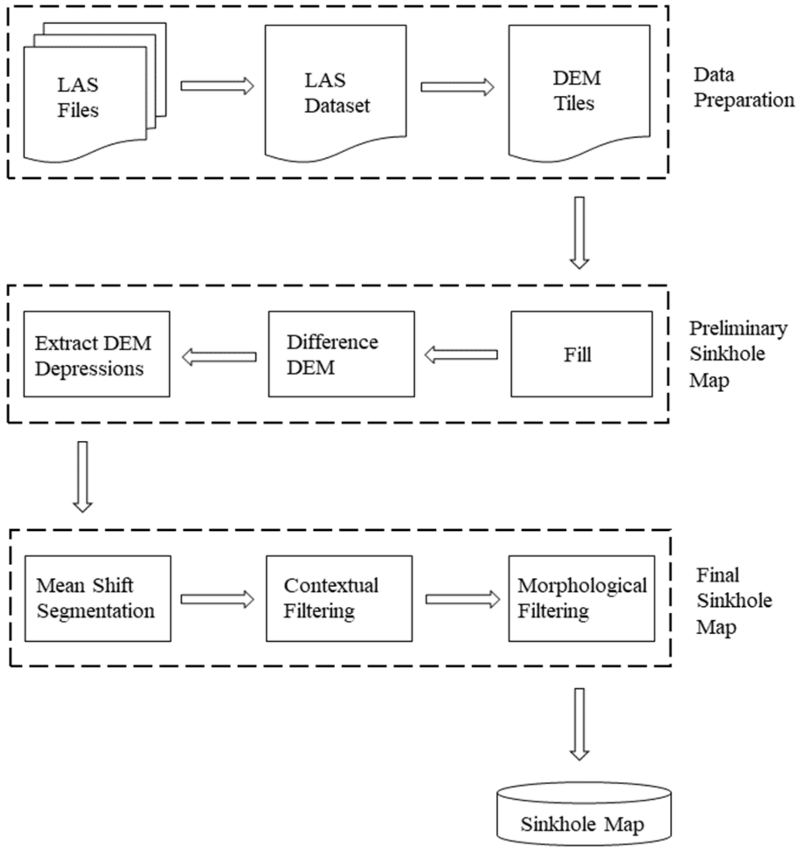
- Morphometric characteristics
  - Area ✓
  - Width
  - Length
  - Perimeter
  - Depth
  - Volume
  - Elongatedness



Provided by Karstic Research Lab

THE UNIVERSITY OF NEW MEXICO

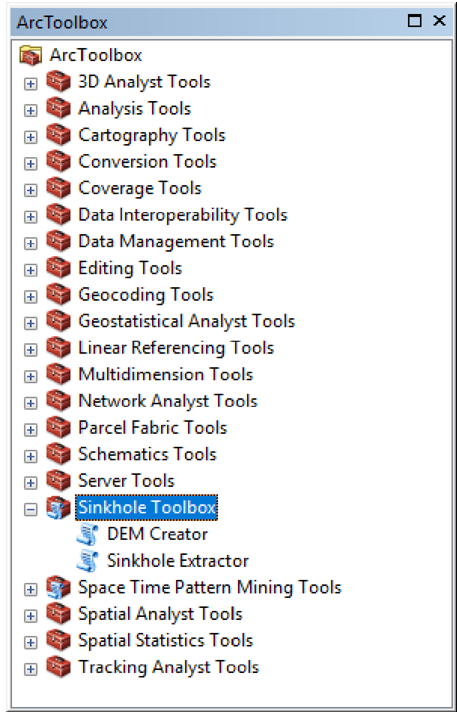
Workflow

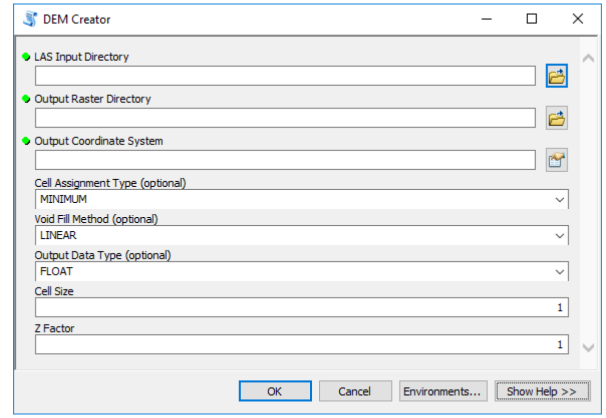


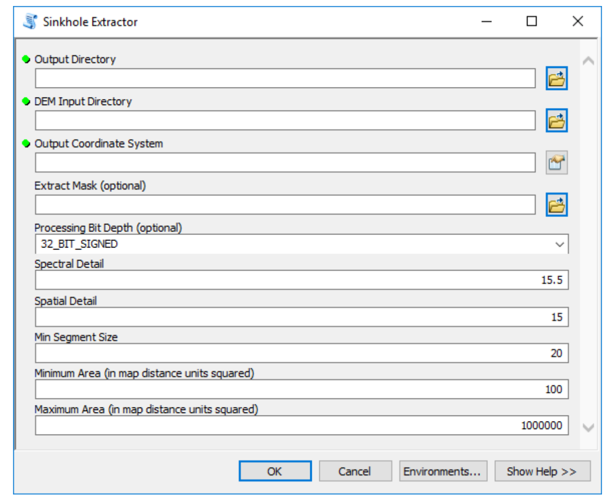
THE UNIVERSITY OF NEW MEXICO

Project Deliverables

- An ArcGIS compatible toolset has been developed based on Object Based Image Analysis (OBIA) techniques
- Best practices for implementing a statewide SHMS have been identified
- A guidebook on the developed toolset has been developed for workforce development and professional training

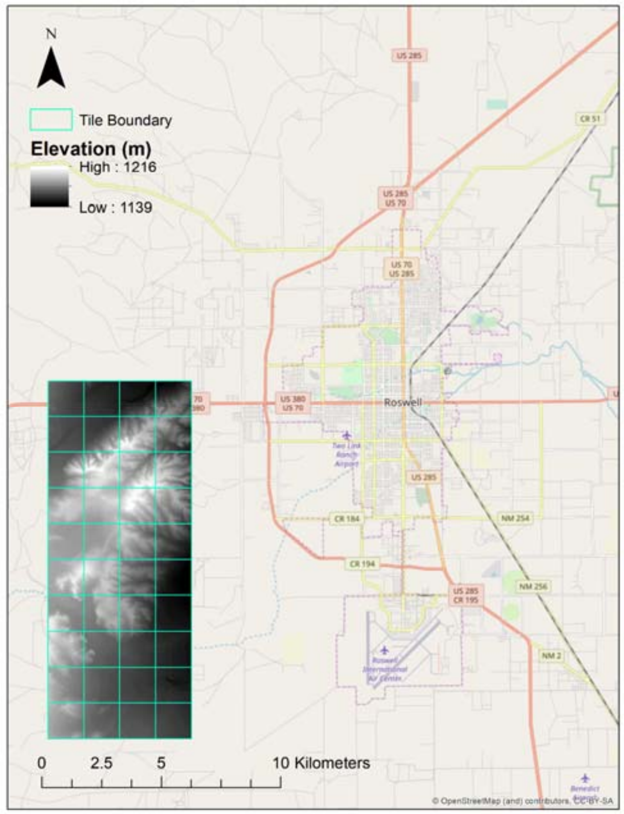


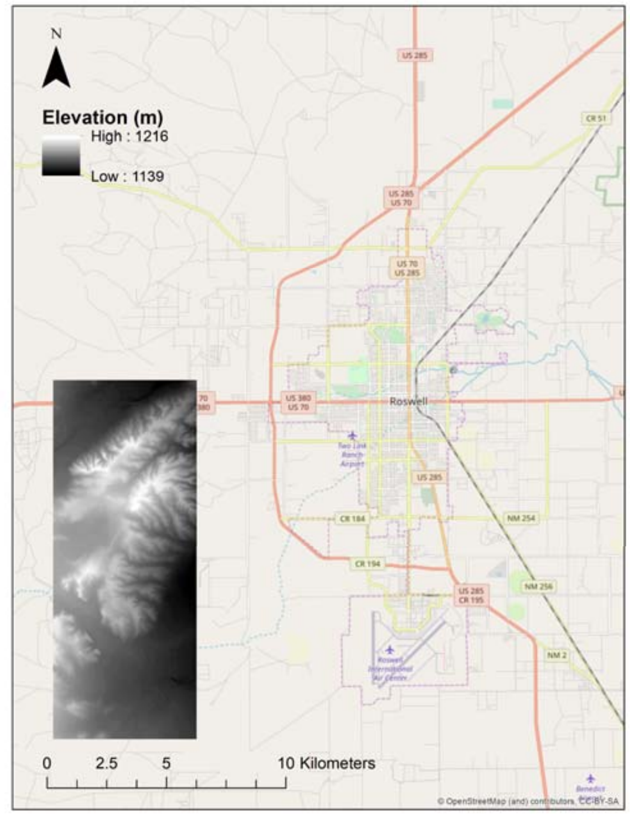




Results and Findings

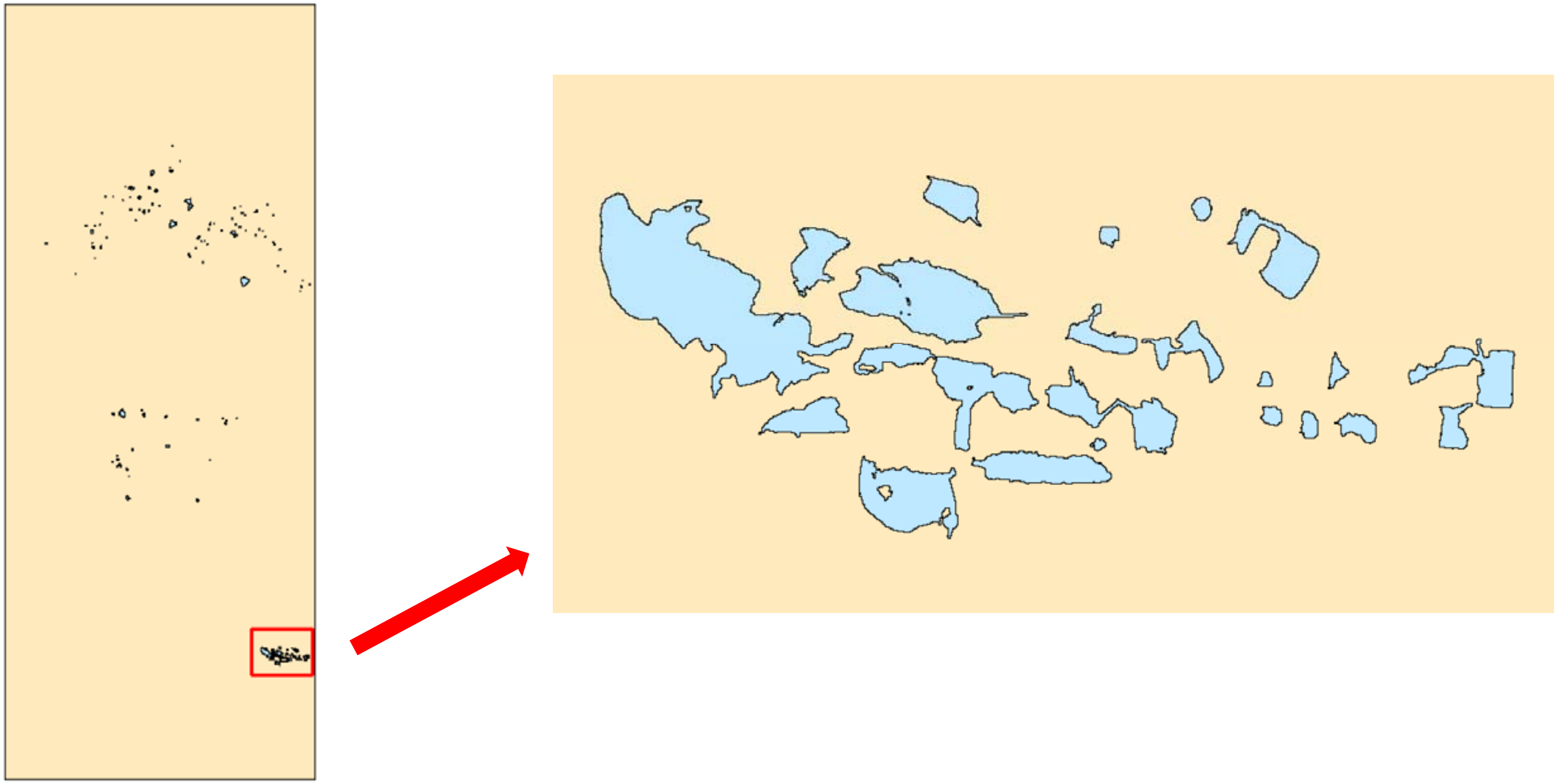
- Study Area
  - Near Roswell
  - 90 km^2





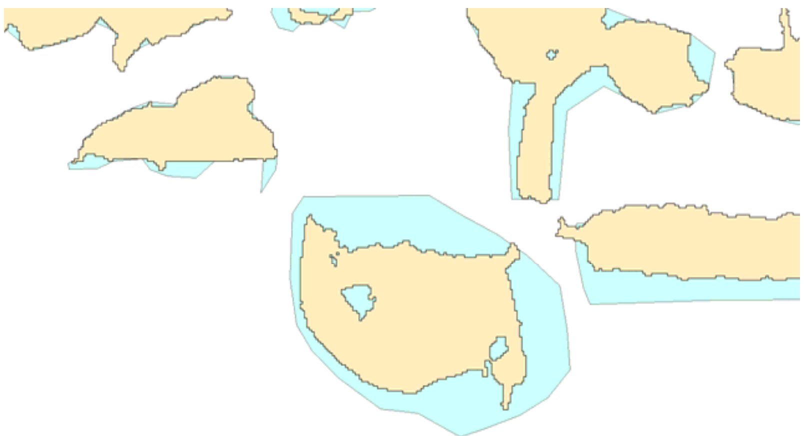
THE UNIVERSITY OF NEW MEXICO

Results and Findings



Results and Findings

- Overall Level Validation
- Cohen’s Kappa coefficient = 0.801



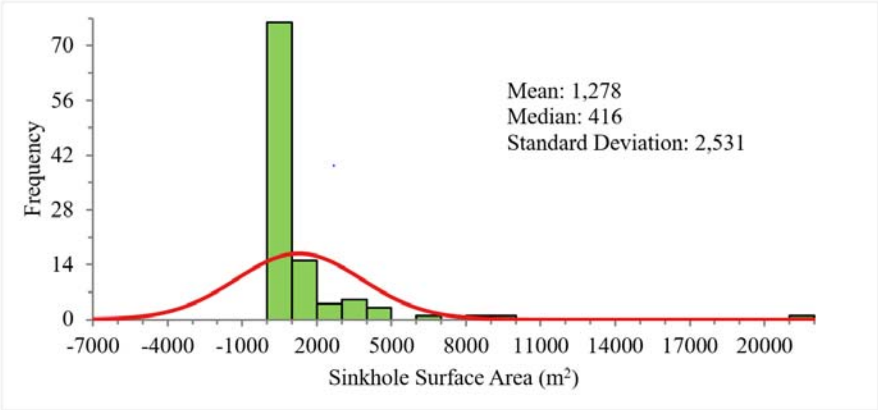
		Ground-Truth Sinkholes		Total
		YES	NO	
LiDAR Detected Sinkholes	YES	107	19	126
	NO	14	235	249
Total		121	254	375

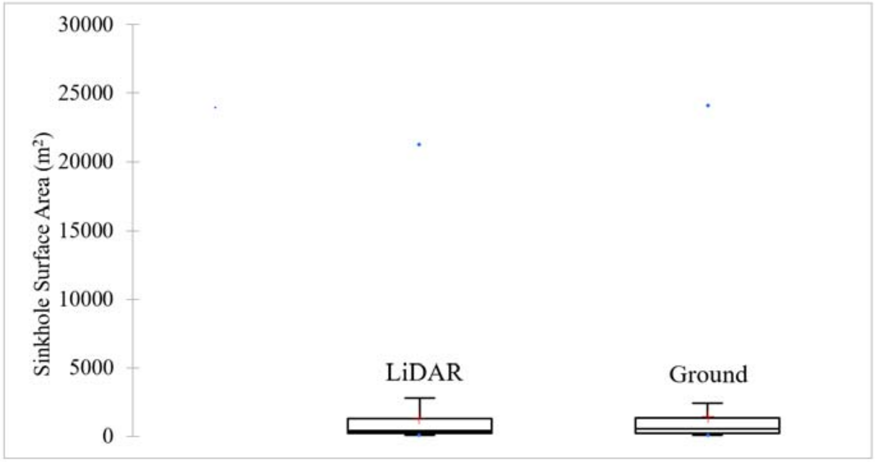
Cohen’s Kappa	Degree of Agreement
< 0.20	Poor
0.2 – 0.4	Fair
0.41 – 0.6	Moderate
0.61 – 0.8	Good
> 0.80	Very Good

Results and Findings

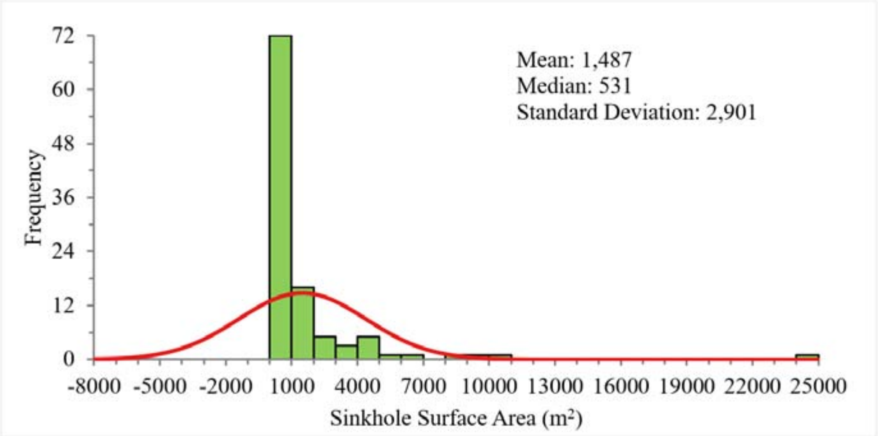
- Individual Level Validation
- Visual Analysis

Airborne LiDAR Detected





Ground Truth LiDAR Detected



THE UNIVERSITY OF NEW MEXICO

Results and Findings

- Individual Level Validation
- Statistical Analysis – Shapiro-Wilk Normality Test

Dataset	Null Hypothesis	P-value
LiDAR Detected Sinkholes	The distribution of the population is normal	< 0.0001
Ground-Truth Sinkholes	The distribution of the population is normal	< 0.0001

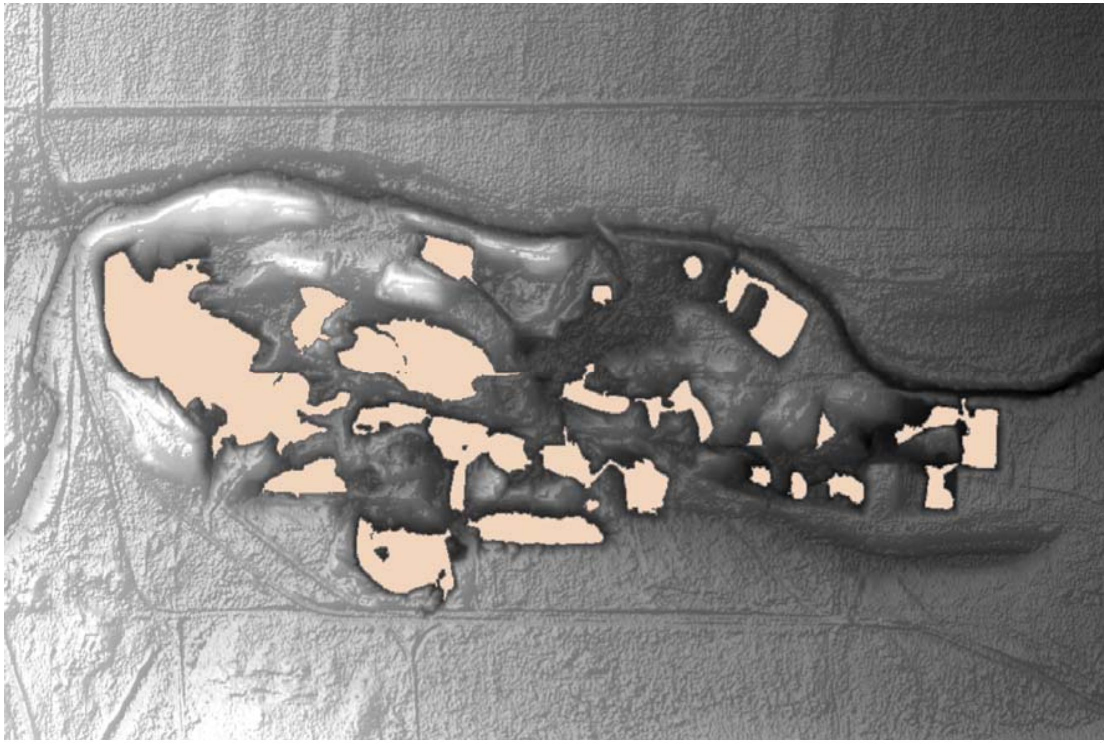
Results and Findings

- Individual Level Validation
- Statistical Analysis – Nonparametric Test

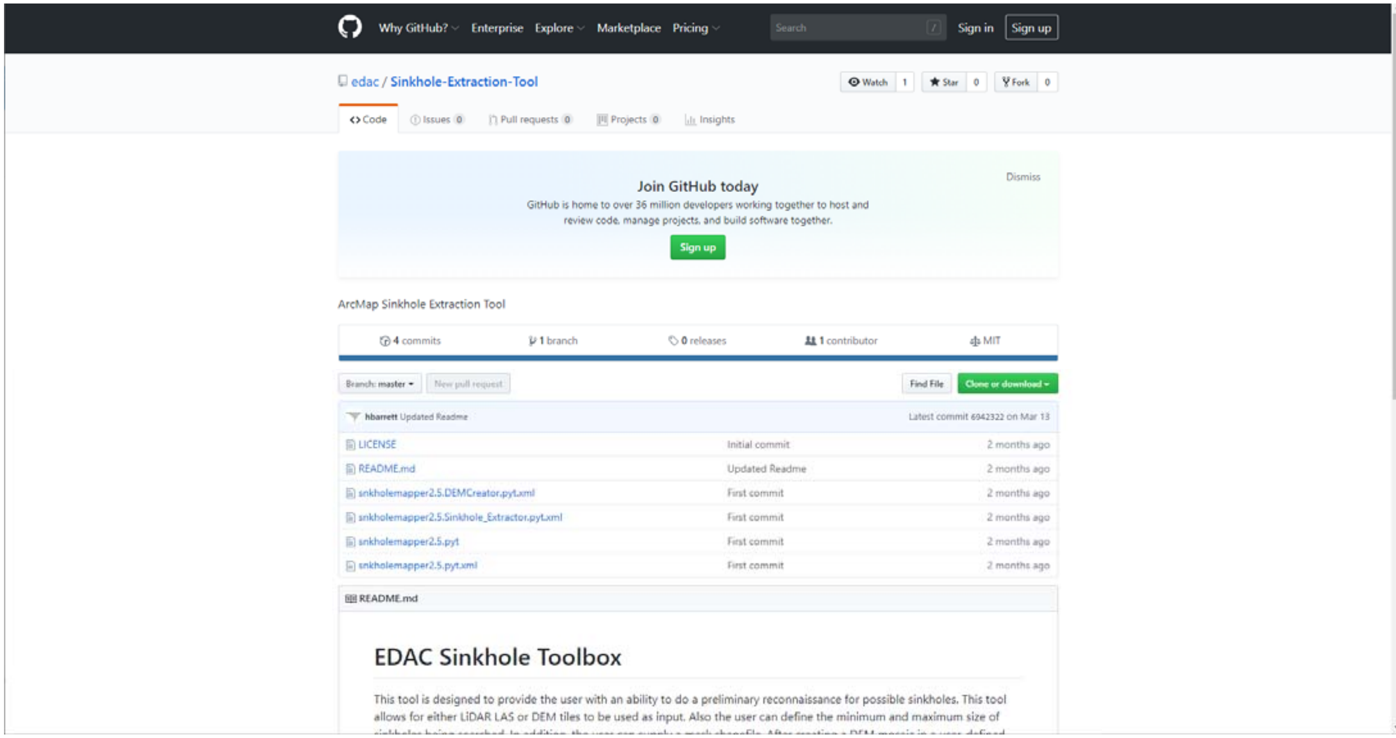
Test	Null Hypothesis	P-value
Paired Group Test – Wilcoxon Signed Rank	The median difference between airborne LiDAR-based measure and ground-based measure is zero	< 0.0001
Unpaired Group Test – Mann-Whitney U	The distribution pattern (shape and spread) of measurement values for airborne LiDAR-based measure vs. ground-based measure is the same	0.282

Results and Findings

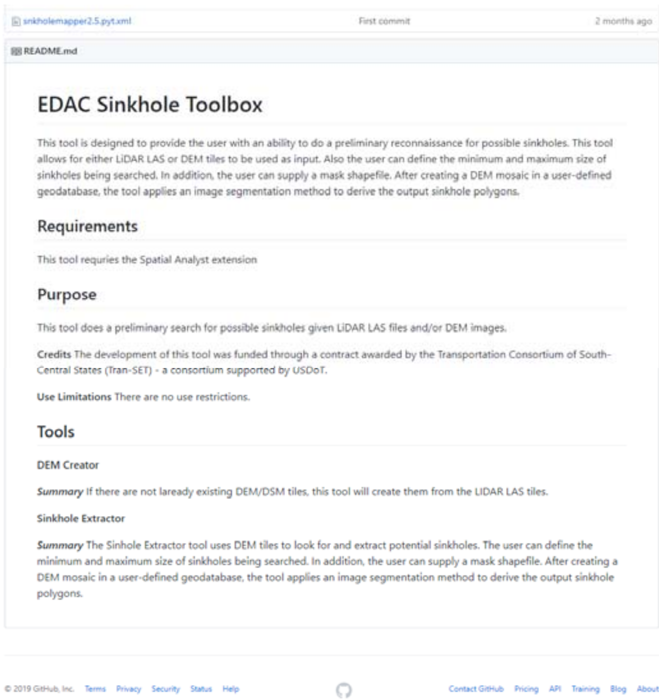
- The airborne LiDAR detected sinkholes can be potentially applied to evaluate overall sinkhole risks for rapid, high-level information checks
- At the individual level, airborne LiDAR detected sinkholes and ground-truth sinkholes do not have statistically similar morphometric measurements
- Higher vertical accuracy airborne LiDAR data will provide more accurate detection results



Tools Availability (https://github.com/edac/Sinkhole-Extraction-Tool)



Tools Availability (https://github.com/edac/Sinkhole-Extraction-Tool)


snkholemapper2.5.pyt.xml First commit 2 months ago

README.md

EDAC Sinkhole Toolbox

This tool is designed to provide the user with an ability to do a preliminary reconnaissance for possible sinkholes. This tool allows for either LiDAR LAS or DEM tiles to be used as input. Also the user can define the minimum and maximum size of sinkholes being searched. In addition, the user can supply a mask shapefile. After creating a DEM mosaic in a user-defined geodatabase, the tool applies an image segmentation method to derive the output sinkhole polygons.

Requirements

This tool requries the Spatial Analyst extension

Purpose

This tool does a preliminary search for possible sinkholes given LiDAR LAS files and/or DEM images.

Credits The development of this tool was funded through a contract awarded by the Transportation Consortium of South-Central States (Tran-SET) - a consortium supported by USDoT.

Use Limitations There are no use restrictions.

Tools

DEM Creator

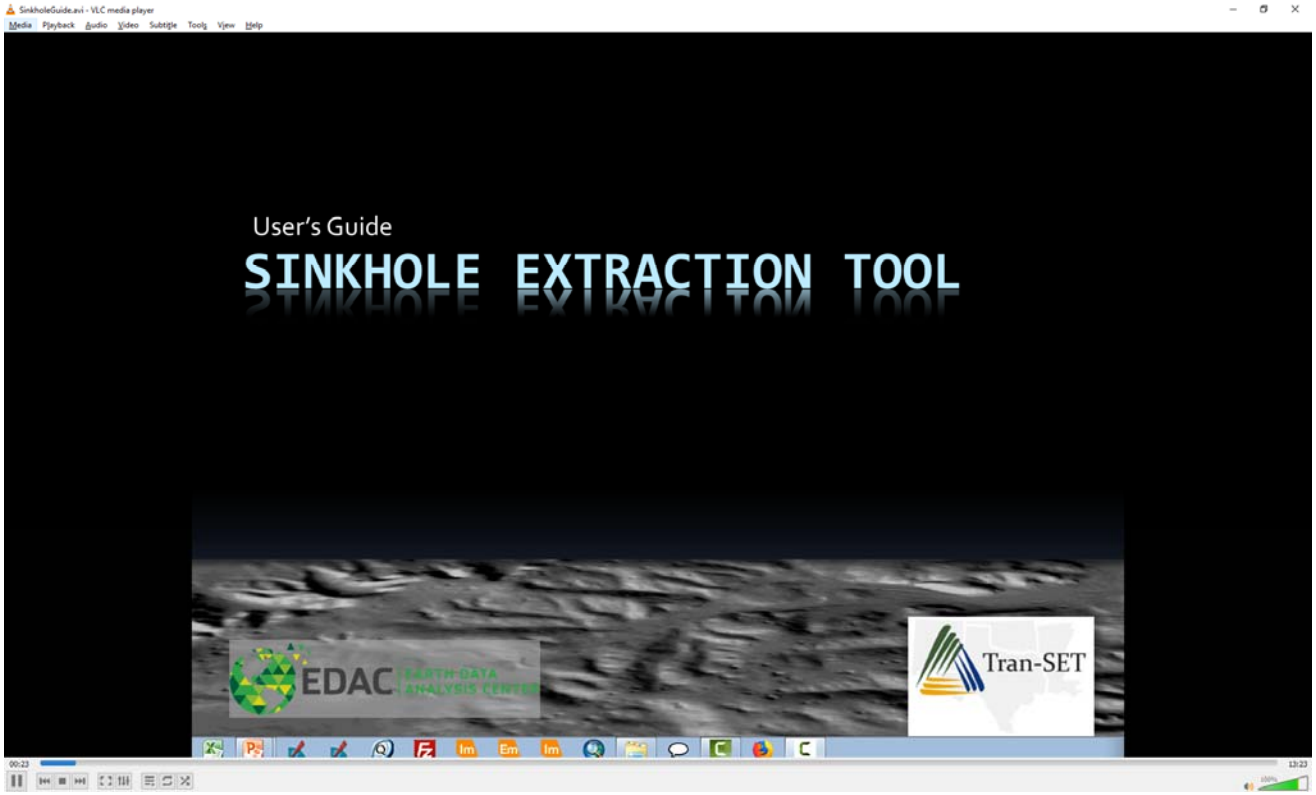
Summary If there are not laready existing DEM/DSM tiles, this tool will create them from the LIDAR LAS tiles.

Sinkhole Extractor

Summary The Sinhole Extractor tool uses DEM tiles to look for and extract potential sinkholes. The user can define the minimum and maximum size of sinkholes being searched. In addition, the user can supply a mask shapefile. After creating a DEM mosaic in a user-defined geodatabase, the tool applies an image segmentation method to derive the output sinkhole polygons.

© 2019 GitHub, Inc. Terms Privacy Security Status Help Contact GitHub Pricing API Training Blog About

Tools Users Guide Availability

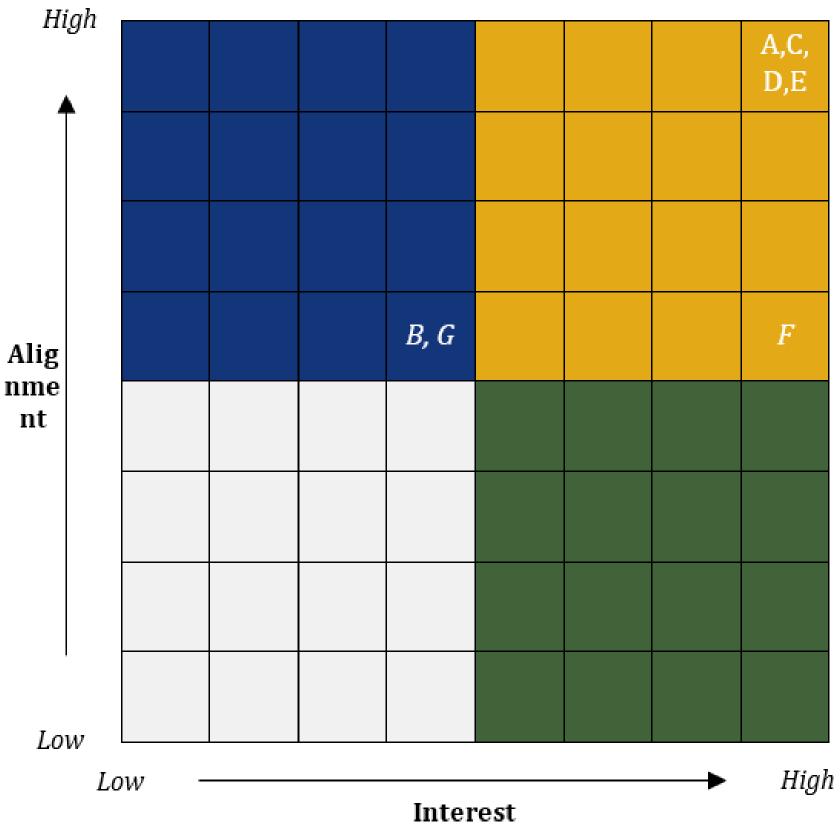


THE UNIVERSITY OF NEW MEXICO

Project Specific T2 Plan

ID	Stakeholder Name	Stakeholder Type	Category(ies)
a	NMDOT District 2	State DOTs	Ally; Early potential adopters; Sponsors of research and T2; Deployment team
b	NCKRI	Research Institute	Ally; Late potential adopters
c	UNM EDAC	Research Institute	Problem owners; Researchers and developers; Deployment team
d	UNM CCEE	Research Institute	Problem owners; Researchers and developers; Deployment team
e	NMDOT Research Bureau	State DOTs	Ally; Sponsors of research and T2
f	Region 6 State DOTs	State DOTs	Late potential adopters
g	Other state DOTs	State DOTs	Late potential adopters

Project Specific T2 Plan



	Low Interest	High Interest
High Alignment	Inform and raise interest	Engage closely and ally
Low Alignment	Minor (minimal effort)	Negotiate, lobby, or neutralize

THE UNIVERSITY OF NEW MEXICO

Project Specific T2 Plan

ID	Engagement Activity [Approx. Date]	Stakeholder(s) Involved	Info Communicated to Stakeholder	Info Gathered from Stakeholder	Resources Required
1	Stakeholder Webinar #1 [December 2018]	All, but specifically A, C, D, E, F, and H	Introduce project (objectives, tasks, timeline, significant results, and key outcomes)	Obtain input for: [1] other potential adopters [2] candidate case studies to conduct	Webinar platform; point of contacts in each stakeholder; dedicated time for webinar coordination
2	Stakeholder Webinar #2 [February 2019]	All, but specifically A, C, D, E, F, and H	Introduce the developed GIS tools for creating preliminary sinkhole maps	Obtain input for: [1] other potential adopters [2] general feedback	Webinar platform; point of contacts in each stakeholder; dedicated time for webinar coordination
3	Research Report [March 2019]	All	Research summary	Obtain input for: [1] general feedback [2] method improvement	Time for manuscript
4	Stakeholder Webinar #3 [April 2019]	All, but specifically A, C, D, E, F, and H	Introduce the developed GIS tools for creating final sinkhole maps	Obtain input for: [1] other potential adopters [2] general feedback	Webinar platform; point of contacts in each stakeholder; dedicated time for webinar coordination
5	Stakeholder Webinar #4 [June 2019]	All, but specifically A, C, D, E, F, and H	Introduce the validation results of final sinkhole maps and the case studies results	Obtain input for: [1] other potential adopters [2] general feedback	Webinar platform; point of contacts in each stakeholder; dedicated time for webinar coordination
6	Stakeholder Webinar #5 [August 2019]	All, but specifically A, C, D, E, F, and H	Introduce the case studies results	Obtain input for: [1] other potential adopters [2] general feedback	Webinar platform; point of contacts in each stakeholder; dedicated time for webinar coordination
7	Journal Publication [August 2019]	All, but specifically A, C, D, E, F, and H	Project summary	Obtain input for: [1] general feedback [2] method improvement	Time for manuscript development
8	TRB 2020 Meeting Publications/Presentations [January 2020]	A, C, D, E, F, G, H	Updating research communities on project	Obtain input for: [1] general feedback [2] other potential adopters	Travel funds; time for manuscript development

Project Specific T2 Plan

ID	Stakeholder Name	Barriers to Technology Adoption	Potential (or Actual) Actions to Address the Barriers
a	NCKRI	[1] Late potential adopters need the technology to be "validated" and "proven to work" before taking steps or investments toward adoption [2] May focus on aspects that are different from engineering	[1] Frequently highlight more involved adopters and their benefits of using the developed tools [2] Provide a plan to enable them to share their "success stories" when they adopt the tools
b	Region 6 state DOTs	[1] Late potential adopters need the technology to be "validated" and "proven to work" before taking steps or investments toward adoption [2] May not have a point of contact for technology adoption	[1] Frequently highlight more involved adopters and their benefits of using the developed tools [2] Leverage the TranSET network to identify key point of contact
c	Other state DOTs	[1] Late potential adopters need the technology to be "validated" and "proven to work" before taking steps or investments toward adoption [2] May not have imperative sinkhole issues and may not have a point of contact for technology adoption	[1] Frequently highlight more involved adopters and their benefits of using the developed tools [2] Leverage the TranSET network to identify key point of contact

THE UNIVERSITY OF NEW MEXICO

PI Questionnaire and Self-TRL Score

- The tools developed from this research project will be provided to the state DOTs or transportation agencies for free access and usage. Commercialization and licensing of research outputs will be not pursued
- ArcGIS software package (10.3 and newer) needs to be readily available
- End users need to have intermediate GIS skills

Categories	TRL Score	Description	To achieve the given TRL score, you must answer "Yes" to EVERY question at that level.
Basic Research	1	Basic principles & research	• Do basic scientific principles support the concept of the project outcome? • Has the outcome development methodology or approach been developed?
	2	Application formulated	• Are potential framework applications identified? • Are outcome components and the user at least partly described? • Do preliminary analyses or experiments confirm that the application might meet the user need?
	3	Proof of concept	• Are outcome performance metrics established? • Is outcome feasibility fully established? • Do experiments or modeling and simulation validate performance predictions of outcome capability? • Does the outcome address a need or introduce an innovation in the field of transportation?
Applied Research	4	Components validated in laboratory environment	• Are end user requirements documented? • Were individual components (if any) successfully tested in a ***laboratory environment*** (a fully controlled test environment)?
	5	Integrated components demonstrated in a laboratory environment	• Are target and minimum operational/functional requirements developed? • Is component integration demonstrated in a laboratory environment (i.e. fully controlled setting)?
Development	6	Field or full-scale test demonstrated in relevant environment	• Is the operational/functional environment fully known (i.e. user community, physical environment, and input data characteristics as appropriate)? • Was the field or the full-scale experiment tested in a realistic environment outside the laboratory (i.e. ***relevant environment***)? • Does the field or full-scale experiment satisfy all operational/functional requirements when confronted with realistic problems?
	7	Fully integrated outcome demonstrated in operational environment	• Are available components ready to be fully integrated in the final outcome? • Is the fully integrated outcome demonstrated in an ***operational environment*** (i.e. real-world conditions, including the user community)? • If applicable, are all outcome components tested individually under expected conditions?
	8	Outcome proven in operational environment	• Is the outcome proven in an operational environment (i.e. meet target performance measures)? • Was a rigorous test and evaluation process completed successfully? • Does the outcome meet its stated purpose and functionality as developed?
Implementation	9	Outcome refined & adopted	• Is the outcome deployed in its intended operational environment? • Is information about the outcome disseminated to the user community? • Is the outcome adopted by the user community?

THE UNIVERSITY OF NEW MEXICO

Tran-SET

Transportation Consortium of South-Central States

Solving Emerging Transportation Resiliency, Sustainability, and Economic Challenges through the Use of Innovative Materials and Construction Methods: From Research to Implementation

NMDOT

National Cave and Karst Research Institute

THE UNIVERSITY OF NEW MEXICO