LIDAR MAGAZINE

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SPECIAL ISSUE

AIRBORNE TECH SHOWCASE


TRUEVIEW

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◀ ON THE COVER
Elevation data provides insights around the J Percy Priest Reservoir and J Percy Priest Dam near Interstate Highway 40 (I-40) in East Nashville, Tennessee. Image shows a blend of digital elevation model (top) and digital surface model (bottom).
Images shared courtesy of USGS.

FROM THE EDITOR

DR. A. STEWART WALKER

Harvest Time

I enjoyed a busy and productive fall. The 58th Photogrammetric Week in Stuttgart in September[1] featured unsurpassed syntheses of the latest technologies amidst the event's venerable traditions. The audience was relieved to be back face-to-face. During the opening minutes of the event, we gravely shared conference chair Uwe Soergel's sorrow at the passing of Fritz Ackermann. The system suppliers did a fine job presenting their wares during the redesigned, sharper demo sessions.

The following month, we were back in Germany. We had the privilege to be the guest of Rapidlasso GmbH on a trip to unravel details of the late Martin Isenburg and his company, providing even more than the tribute by Howard Butler published after Martin's death[2]. We were accompanied by Jorge Delgado Garcia, professor of engineering cartography, geodesy and photogrammetry, Universidad de Jaén, Spain, and Nelson Mattie, CEO of LiDAR Latinoamérica, Santiago de Chile, Chile, and PhD candidate, University of Alberta, Edmonton, Canada, Jorge and Nelson are enthusiastic practitioners who make extensive use of drones as well as LAStools software, especially in Latin America.

What a pleasure to be in the beautiful countryside east of Frankfurt! We were lodged in the town of Neu-Isenburg (not eponymous!) and drove to the idyllic, historic settlement of Sommerhausen, where Martin lived in the house of his mother, who died in 2007. We explored the tiny abode, noting Martin's preference to work, eat and sleep in just the kitchen and living area, heated by an old, wood-burning stove, and the stack of conference badges from events Martin attended in the year or two before his death. His frugality and his wish to leave as little impact on the planet as possible were clear.

Sommerhausen lies on the river Main, just east of the border between Hesse and Bavaria. There Martin taught himself his paddle-board skills, later tweaked in more exotic climes. The town is in the Franken wine region—we relished the views of vines on sunlit hillsides as we walked from Martin's home to his resting place in the town cemetery. After cremation in Sámara, Costa Rica, Martin's remains were flown home and he is buried beside his mother. The simple stone bears their names, crafted in steel by Martin's father, Dieter. His omnipresent coffee mug is embedded in the plants surrounding the stone.

The quiet, uncomplicated scene, as we stood, first in silence, then in discussion of Martin's life, finally brought home to us that he has gone. His contributions live on, of course, in his writings and the Rapidlasso products, but his genius is with us no longer.

1 lidarmag.com/2022/09/27/phowo-flies-once-again/
2 lidarmag.com/2021/10/30/in-memoriam-martin-isenburg-1972-2021/

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The company and the patents have been inherited by Dieter. With the help of Silke Kämmerer, Martin's power-of-attorney for more than ten years, who stepped into the role of CEO after his passing, we are preparing an article that will tell Martin's story in straightforward terms, putting to rest any rumors or exaggerations that may have been fueled over the years. This will also describe the Rapidlasso product line—LAStools, LASzip and BLAST—and the company's ambitious plans for the future. So far, a new website has been constructed[3], a customer database created afresh and various product improvements made, especially a new GUI and a Linux version of the code. We left Sommerhausen and prepared to travel to Essen for the massive Intergeo event, where the Rapidlasso booth played an important role in the ongoing efforts to make customer contact, provide reassurance and communicate that life won't be the same without Martin, but the products are blossoming.

INTERGEO

The annual INTERGEO trade show and conference took place in Essen, Germany, from 18 to 20 October 2022. Spanning three halls in the massive Essen Messe, the event attracted over 14,000 attendees from 102 countries and 457 exhibitors from 31 countries. The conference component of the event attracted 1000 registrants. The event was hybrid and there were 1800 remote attendees.

We enjoyed Essen, but especially appreciated the interaction[4], face-to-face, with international friends and clients. Long may it continue. The 2022 attendance was below pre-covid levels, but we expect both the increased confidence in face-to-face meetings and the multiple attractions of Germany's capital to rectify this in 2023. A few takeaways from this year's event: MMS is mainstream; digital twins are center-stage; climate change angst is pervasive; stereoscopic viewing, shutters and image motion are being revisited; deep learning is in widespread use in practical ways, for example segmentation and object recognition in imagery or point clouds; the GNSS/IMU-camera-lidar-software value chain is being addressed by more and more companies—choose your solutions with care, but take the time to review a few options first.

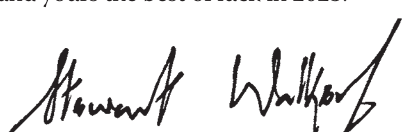
Trimble Dimensions+ 2022

We weren't home but a couple weeks before driving to Trimble Dimensions+ 2022 in Las Vegas. 1463 days: we were told at the start how long it was since we had last met. As in Stuttgart and Essen, attendees were delighted to be back, face-to-face once again. Trimble marketers and PR contractors took tremendous care of us gentlepersons of the press, so we learned a lot[5].

The attendance was 5750, of whom around 1000 were from Trimble (all the ones I encountered were helpful, friendly and very competent in answering my questions), from 62 countries—the largest Dimensions ever. The 400+ sessions featured 574 speakers, 296 of them customers. The anticipation as we filed into the hall on the first morning felt like the Esri or Hexagon shows—praise indeed!

CEO Rob Painter kicked off the opening plenary. He's a clean-cut, boyish looking, energetic management type with an MBA from Harvard. He became CEO in 2020—only the third in 44 years—and seems to be performing expertly. Trimble is prospering and continues to stress the importance of communicating its innovations to the community. While autonomous bulldozers and excavators are certainly Trimble's forte, we in the *LIDAR Magazine* community should be delighted that the company, while recognizing that the geospatial world is tiny compared to construction and some of the other verticals in which Trimble prospers, emphasizes that geospatial people and technology are central to these markets' success. As a result, it continues to develop a fine range of sensors, especially TLS and MMS laser scanners, underpinned by increasingly broad software offerings, which are now changing direction towards sharing and collaboration in the Cloud. Trimble proceeds with its series of well-judged acquisitions, resulting in skills and technologies that not only plug gaps but enhance and broaden the product portfolio. Long may it continue.

As we close out the year, our attention turns to Geo Week, slated for February 13-15 in Denver. Preparations are well underway for the latest iteration of our joint Lidar Leaders awards program which always proves exciting as the industry turns the page. Wishing you and yours the best of luck in 2023.



A. Stewart Walker // Managing Editor

3 rapidlasso.de/
4 lidarmag.com/2022/11/03/intergeo-pulsates-in-essen/
5 lidarmag.com/2022/11/30/trimble-dimensions-2022/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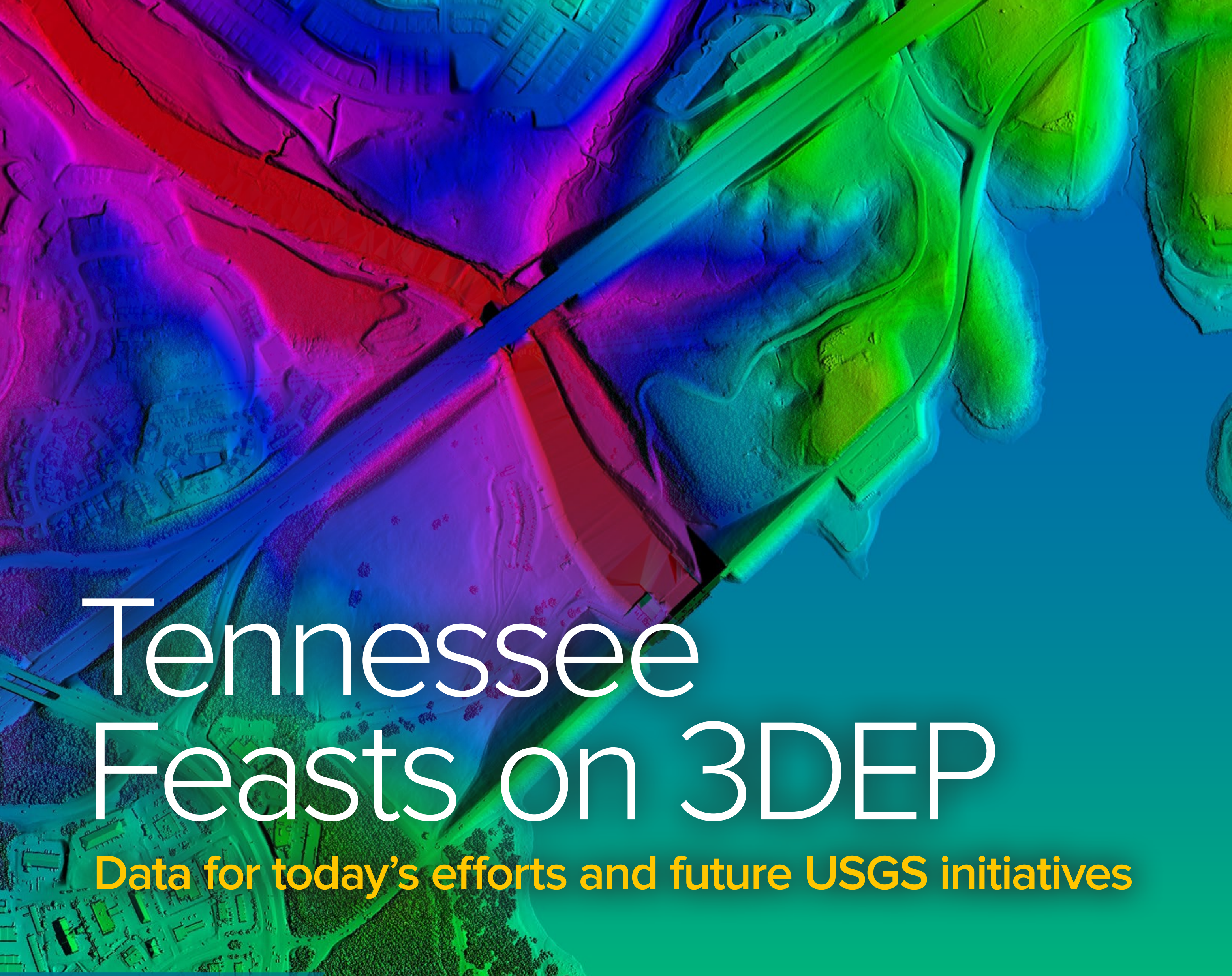


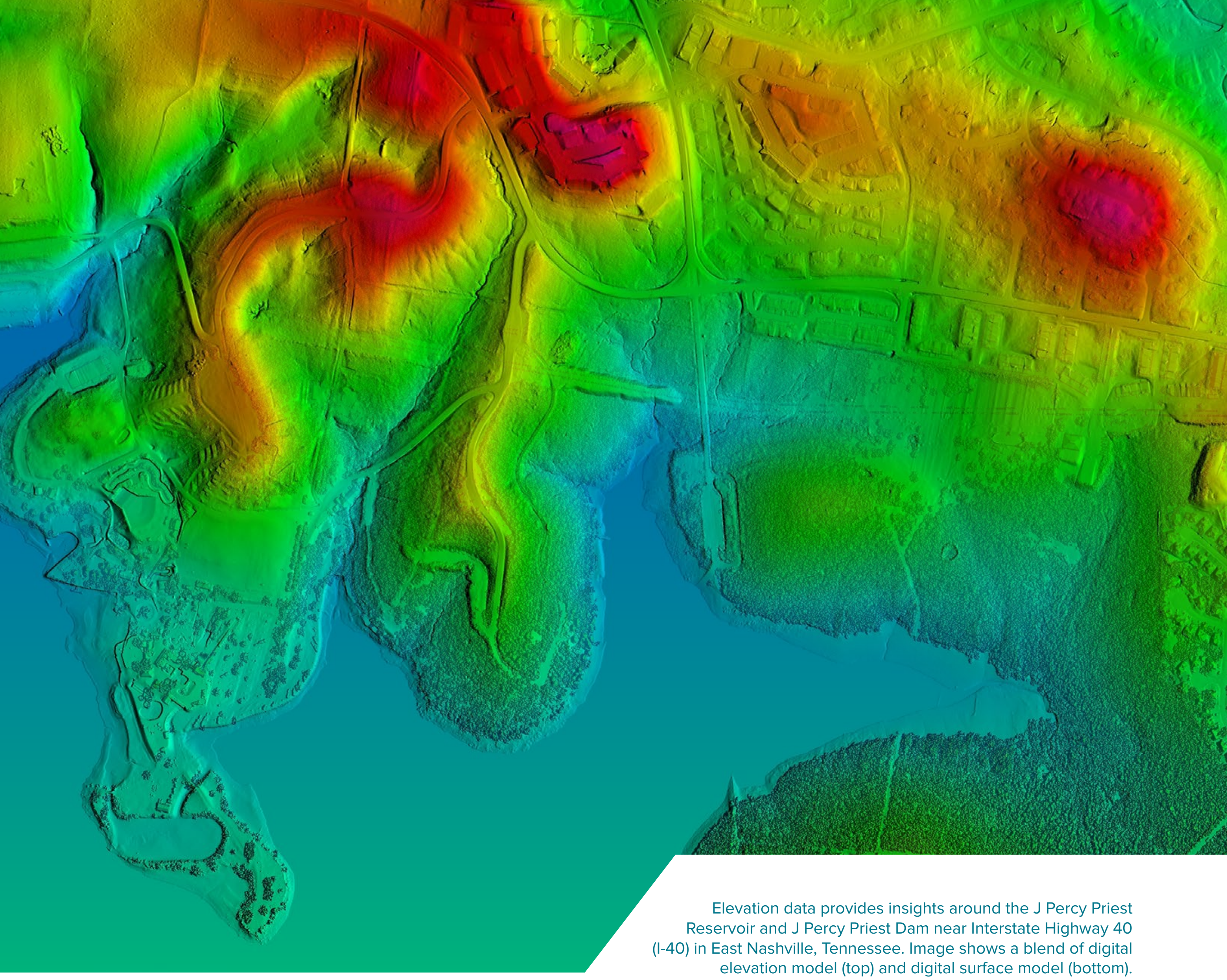
Tennessee Feasts on 3DEP

Data for today's efforts and future USGS initiatives

The 3D Elevation Program (3DEP) of the United States Geological Survey (USGS) entered its first year of production in 2016. With the help of funding partners, private sector mapping companies and the lidar industry, this nationwide mapping program has resulted in more up-to-date elevation data. At the end of 2021, 84% of the U.S. either had access to elevation data or was gathering elevation data that met 3DEP requirements for high accuracy and resolution.

As a result, many states are now using this elevation data to inform critical decisions and support evolving USGS initiatives, including its 3D Hydrography Program (3DHP), which aims to update the National Hydrography Dataset (NHD) to enhance the ability to discover and share water-related analytics. One state that has recently started using 3DEP data and preparing for 3DHP is Tennessee.

BY SAM **MOFFAT**



Elevation data provides insights around the J Percy Priest Reservoir and J Percy Priest Dam near Interstate Highway 40 (I-40) in East Nashville, Tennessee. Image shows a blend of digital elevation model (top) and digital surface model (bottom).

Images shared courtesy of USGS.

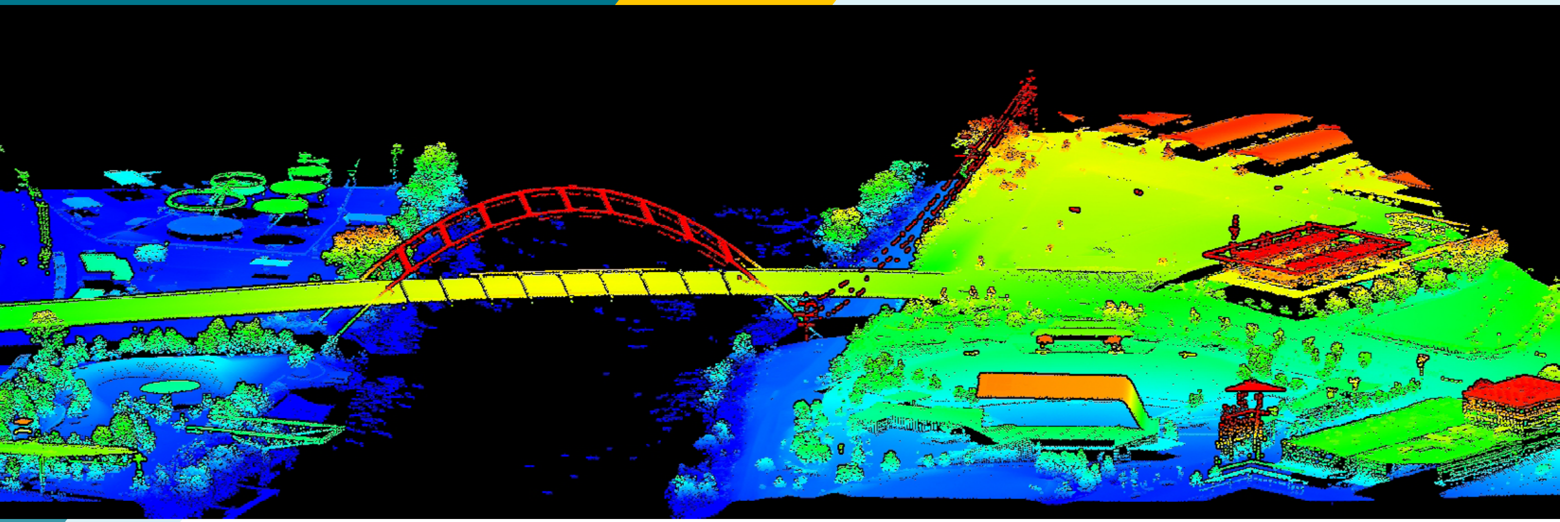
Collaborative data collection, application

Gathering the elevation data for 3DEP in Tennessee was a collaborative effort. In 2015, USGS assigned Woolpert the responsibility of working with state officials to collect Quality Level 2 (QL2) or better lidar data. According to the National Enhanced Elevation Assessment (NEEA)[1], Tennessee could gain $6.3 million in new benefits annually from 3DEP. These would accrue from utilizing elevation data for multiple business uses, including:

- Agriculture and precision farming
- Flood risk management
- Natural resources conservation
- Construction and infrastructure management
- Forest resources management
- Aviation safety and navigation
- Geologic resources hazard mitigation and assessment
- Renewable energy resources
- Stream and river resource management
- Disaster response, law enforcement and homeland security

Dennis Pedersen, the GIS services director for Tennessee's Department of Finance and Administration, observed that Tennessee Department

1 pubs.usgs.gov/fs/2014/3008/pdf/fs2014-3008.pdf



The Korean War Veterans Memorial Bridge in Downtown Nashville, Tennessee.
This is an oblique profile view of a digital surface model from QL1 lidar data at 8 points per square meter.
Image shared courtesy of USGS.

of Transportation (TDOT), Tennessee Department of Environment and Conservation (TDEC), and Natural Resources Conservation Service (NRCS) are among the many organizations utilizing 3DEP data to enhance the success of their projects.

"The high-resolution lidar data has been very helpful on emergency landslide projects on state transportation routes," said Douglas Ford, civil engineering manager at TDOT. "We also use these data for detailed drainage studies and flood-plain mapping."

As state departments benefit from elevation data, other organizations stand alongside them in utilizing it for critical projects. For example, the U.S. Army Corps of Engineers (USACE) Nashville District is using Tennessee's 3DEP data for various purposes.

"We use the elevation data constantly in our engineering and construction division to accomplish many diverse projects and workflows," said Matthew Davis, geographer in the engineering and construction division of USACE. "It is utilized in geology, hydrology, survey, mapping, civil site and more. It is an invaluable resource for us."

> "According to the National Enhanced Elevation Assessment, Tennessee could gain $6.3 million in new benefits annually from 3DEP."

Private companies in Tennessee are using the state's lidar data and derivatives as well. When state officials surveyed businesses to ask for specific use cases and advantages of the elevation data, they discovered the following insights:

- The state's 3DEP data is a significant cost saver for the developer who is doing a feasibility study to see if a project can happen before performing a topographic survey and engineering design.
- The availability of the data provides the opportunity to give clients a more detailed and accurate product.
- Lidar-derived digital elevation models (DEMs) help perform hydrologic and hydraulic analyses with conceptual and preliminary grading for development projects.
- The data is an asset for planning surface drilling programs. Slope calculation on the DEM shows logging roads that would not have been visible through other methods due to tree cover.

Accessibility has also helped decision-makers benefit from the state's lidar data. Tennessee makes the data approachable, organized and easy to navigate, enabling quick and effective application for officials and residents alike.

"With the high-resolution lidar data, local governments can make effective decisions on flooding and flood risk management, which directly protects their communities," Pedersen said. "These data also give residents access to better online mapping tools and potential tax savings."

KNOWLEDGE IS POWER

See clearly and accurately where vegetation is encroaching.

Image courtesy of Merrick & Company and Aerial Surveys International

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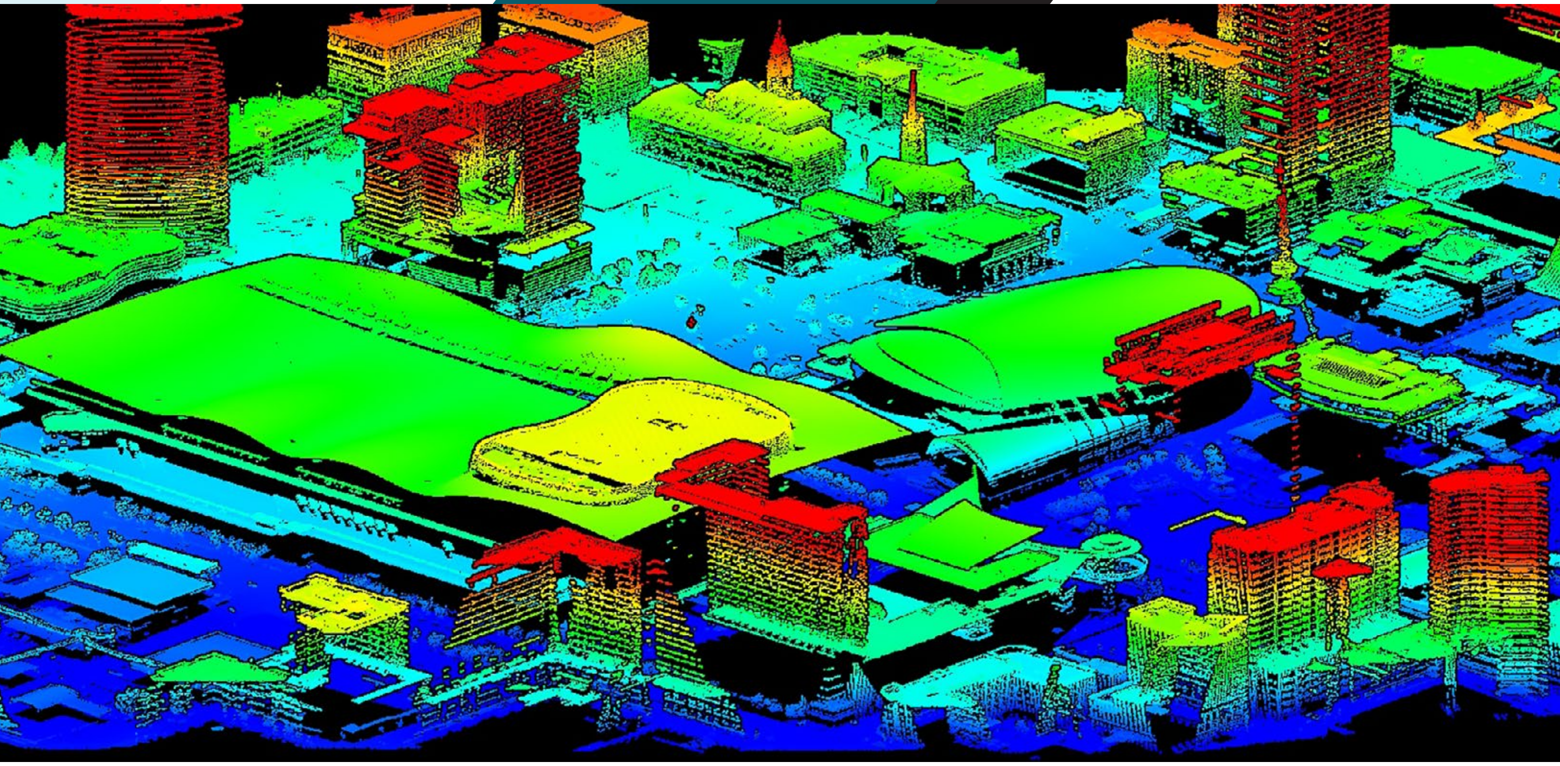


DEM of the Bridgestone Arena and the surrounding area in Nashville, Tennessee, derived from USGS QL1 lidar data at 8 points per square meter.
Image shared courtesy of USGS.

Using 3DEP as the foundation for 3DHP

While the current applications for Tennessee's elevation data are vast, decision-makers in the state are ready to use it for a broader purpose: 3DHP. This program is critical because it will significantly improve the level of inclusion, currency and detail of hydrography data to reflect how the landscape and seascape have changed over time.

"Knowing how to map water is the ultimate end-game of all this mapping," said Volkan Akbay, geospatial project manager at Woolpert. "It's about understanding how water will move and interact. Launching 3DHP is the first step in building a vertically integrated dataset of anything that can affect hydrology, whether it's soils, culverts or levies."

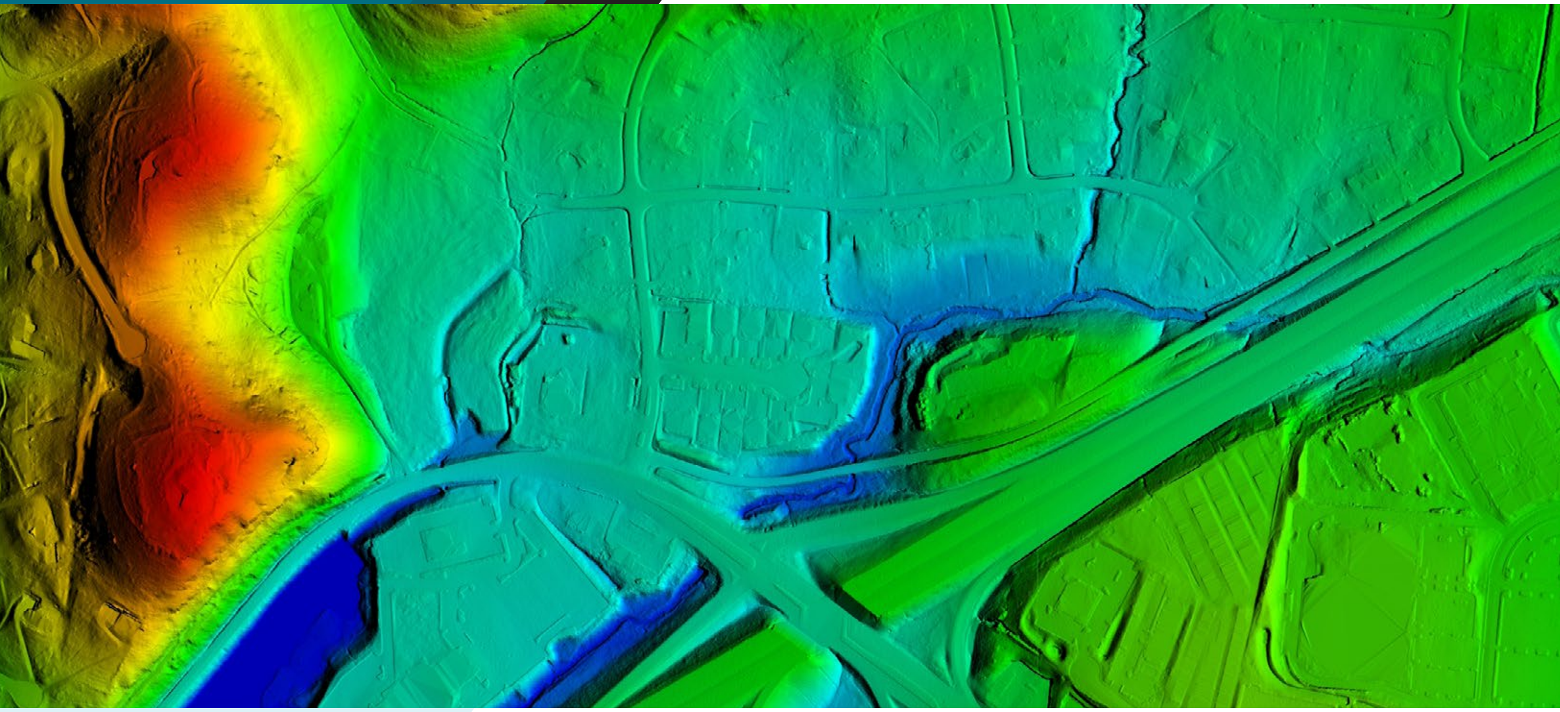
Achieving this ambitious goal requires multiple components, the primary one being accurate, high-resolution elevation data, which 3DEP provides. Engineers can produce a 3D stream network and hydrologic units as well as support hydrologic and hydraulic modeling.

Additionally, states can use 3DHP data to protect and enhance their communities. When asked what specific advantages this new initiative could provide to state officials, Akbay said, "The currency and inclusion of these data and deriving a 3D stream network from lidar data goes a long way in helping with so many different things. From environmental planning to transportation to flood detection, 3DHP can help with everything."

Officials in Tennessee have realized the benefits 3DHP can deliver. The Department of Finance and Administration, STS-GIS Services recently carried out a survey and identified two departments that would significantly benefit from 3DHP: TDOT and TDEC.

How 3DHP will enhance TDOT

The survey of TDOT staff members revealed three divisions that could improve through 3DHP. The first is the Hydraulic Design Section within the Structures Division, which would benefit from increased accuracy of flood flow calculations. This would be due



This DEM shows Highway Interchange I-40 at Highway 70 South and the surrounding area in Bellevue, Tennessee.
Image shared courtesy of USGS.

to better information on the stream network and enhanced elevation data, including connections to groundwater and engineered hydrologic systems. With increased accuracy, the Hydraulic Design Section could properly size critical infrastructure.

"More accuracy in flow calculations would lead to more accurate sizing of bridges and drainage structures on Tennessee roadways and would assist in our calculations for bridge scour," said Wesley Peck, civil engineering manager at TDOT.

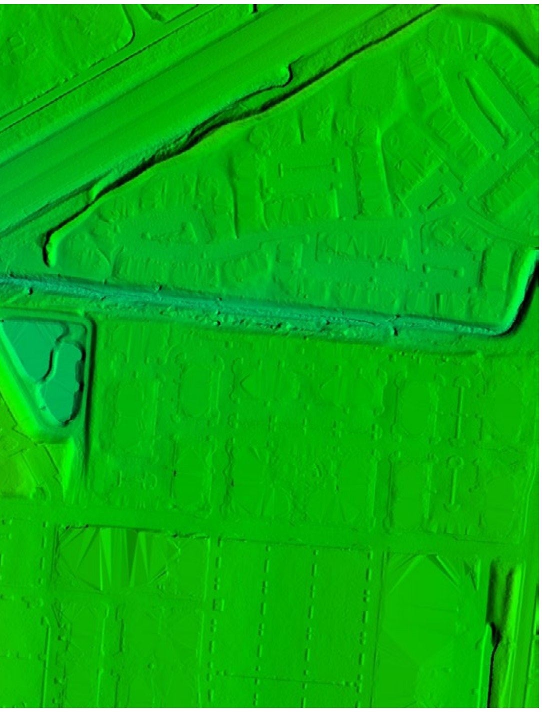
The Long-Range Planning Division is the second office expected to see benefits from 3DHP. The division's planning supervisor, Chris McPhilamy, said 3DHP would offer a healthier and more complete dataset to perform GIS analytics. He explained that these data points would significantly enhance the geohazards project the division is seeking to develop, and the 3DHP data would support more robust water-modeling functionality. That information could help determine where floods may occur and where underground springs or watersheds could potentially erode the roads.

"Further analysis could most likely be done to look at the relationship between land-use, environmental justice and site suitability," McPhilamy said. "We could possibly even look at how the more detailed watershed plays into automobile crashes and how we can create proper drainage for our infrastructure."

Additionally, 3D hydrography data and related insights could help staff research features that receive stormwater discharges from state-owned outfall locations throughout Tennessee.

"If there is a traffic incident that exceeds established thresholds for reporting requirements, the section examines any receiving waters near the location to determine its identity and if the water resource is considered impaired," said Klint Rommel, facility compliance section manager in TDOT's Environmental Compliance Division. "These data would be of great benefit to expedite that process compared to the method the section currently utilizes."

Rommel said he believes 3DHP data could have additional benefits for the division, particularly when planning a project. During the planning phase, staff members prepare documents to showcase improvements to an existing roadway or the proposed alignment of a new roadway. They also conduct research to determine if water features



exist within the proposed footprint of the project. 3DHP data could enhance this process by helping the Environmental Compliance Office decrease potential impacts on features and adjust the alignment if necessary.

How 3DHP will benefit TDEC

Similarly, three divisions in TDEC are positioned to experience significant benefits from 3DHP. Chief among them is the Division of Water Resources, which could use high-resolution hydrographic data to enhance various programs and systems, including the following:

- Safe Dams Program: 3DHP could add value by helping staff analyze dam hazard values to better determine the downstream impacts if a dam fails.
- Municipal Separate Storm Sewer Systems: With hydrographic data, workers could have higher-resolution analytics to determine riparian corridors and assess environmental factors that could impact water quality along state waters.
- Public Water Supply Source Water Protection: 3DHP data could help support decision-making after spill events to ensure workers know whether public water supply sources are at risk for contamination.
- Natural Resources Unit and Aquatic Resource Alterations: Data from 3DHP could help support more robust assessment of regulatory waters in the state. It could also be used in GIS applications to support permitting decisions for Aquatic Resource Alterations.
- Compliance and Enforcement: Staff in this unit could use 3DHP data to assess the impacts of water quality when receiving information regarding reported discharges of contaminants.

The Division of Natural Resources has various use cases for 3DHP data as well. Based on survey responses, the office plans to use the high-resolution data for some of the following reasons:

- Better understand the current and potential distribution of specific natural communities and species
- Improve efficiency in discovering new places to search for natural communities and rare species
- Enhance capabilities to identify potential impacts on natural communities and rare species when examining material in environmental reviews
- Plan for site selection and reduce the impact on natural resources
- Inform restoration or ecological management and implementation
- Support land-protection efforts for high-value aquatic systems affected by surface-to-groundwater connections.

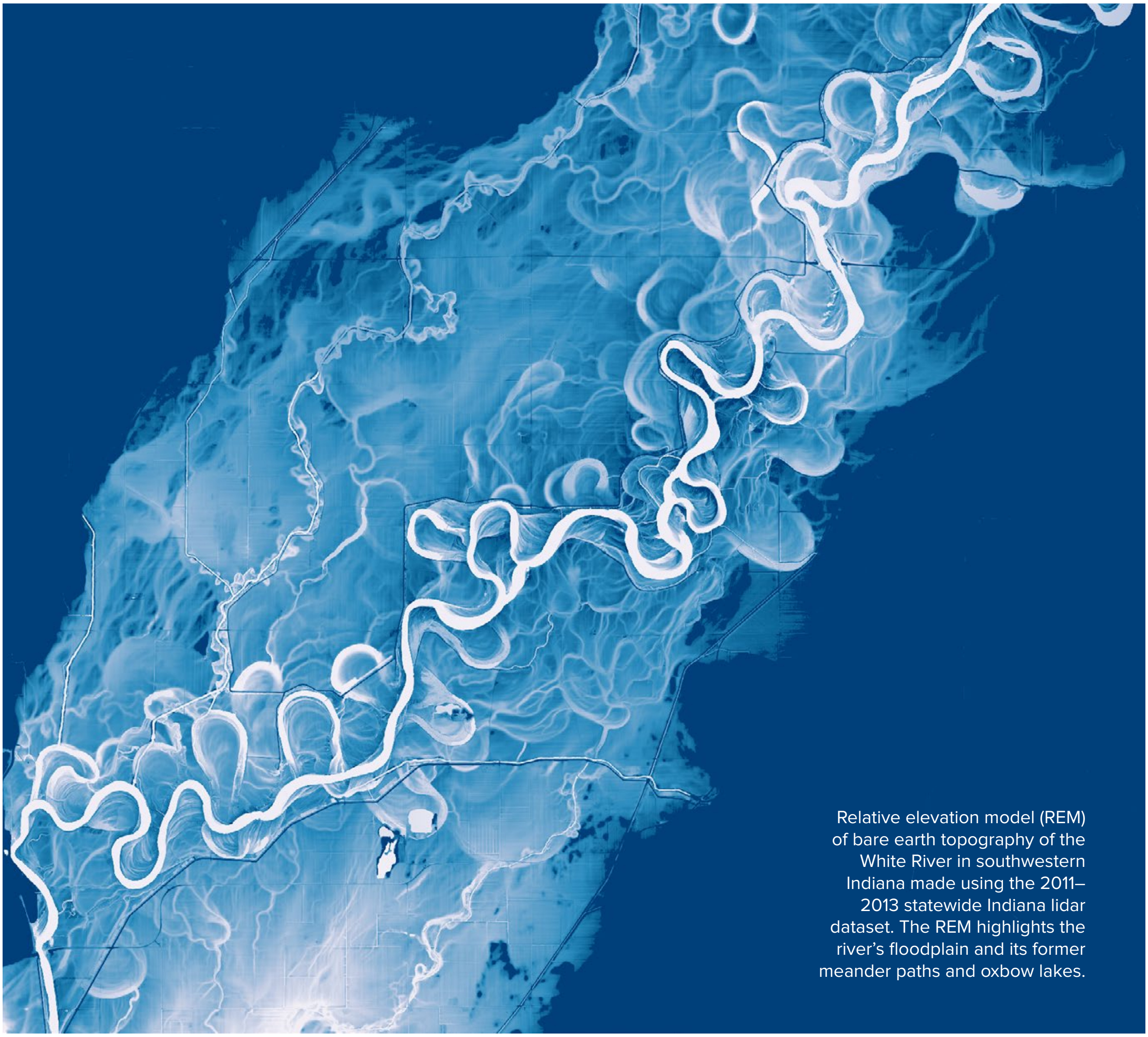
The third TDEC office expected to reap benefits from 3DHP is the Division of Geology. Survey results show that the data could help improve the mapping of hazard features, particularly sinkholes and other subsidence features. With karst terrain, including sinkholes, caves and sinking streams, abundantly present in Tennessee, the updated hydrography dataset would be ideal for mapping features at higher resolutions. Additionally, the division could use the data to update hydrologic features on recently generated geologic base mapping products.

As USGS rolls out 3DHP, Tennessee is ready to collect and employ high-resolution hydrographic data similar to how it has been successfully employing 3DEP data. USGS has already started tackling implementation milestones, for example assembling governance and communication structures and launching pilot programs in Alaska and the continental United States. In fiscal year 2023, USGS plans to begin contracting out 3DHP data acquisition and processing.

Woolpert Geospatial Program Director **Sam Moffat** is a Certified GIS Professional and a Tennessee native, who specializes in large-scale federal, state and local government mapping programs.

The Impact of Open Access Lidar Topography

BY EMILY ZAWACKI



Relative elevation model (REM) of bare earth topography of the White River in southwestern Indiana made using the 2011–2013 statewide Indiana lidar dataset. The REM highlights the river's floodplain and its former meander paths and oxbow lakes.

OpenTopography's partnership with Indiana provides open and web-based access to statewide lidar topography and the framework for the first map of statewide topographic change

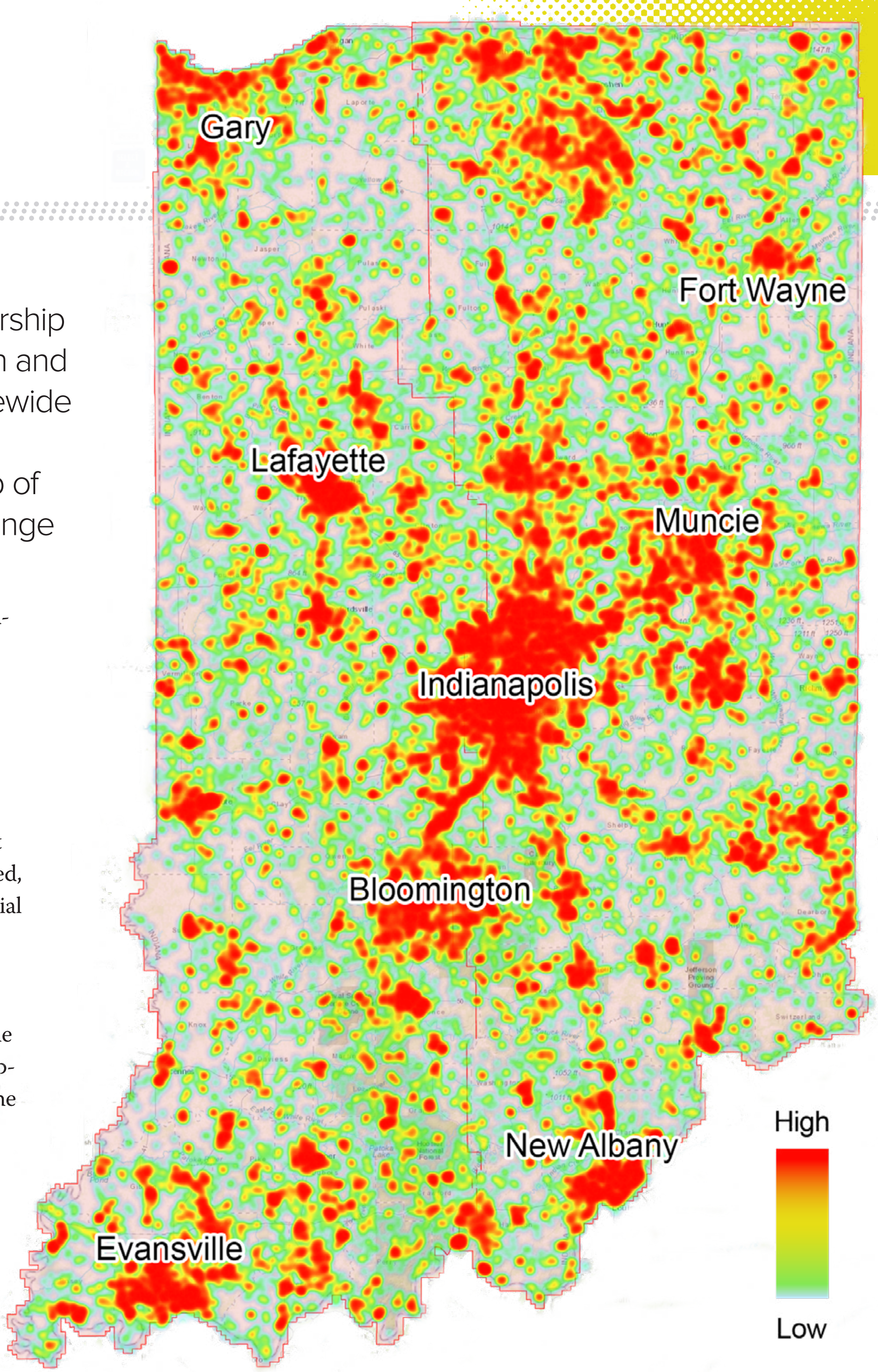


Figure 1: Usage heat map of the 2011–2013 Indiana statewide lidar point cloud on OpenTopography. Red areas indicate regions with the highest data usage.

The rapid increase in high-resolution lidar topography coverage around the globe demonstrates its massive utility for tasks like flood mitigation, infrastructure development, national security, conservation management, scientific research, and education. Given the considerable cost of collecting lidar data, open, web-based, and seamless access pathways are crucial to increasing the utility of the data and maximizing the return on investment. Over the past dozen years, the OpenTopography facility, funded by the National Science Foundation, has established itself as a recognized leader in the distribution of large volumes of lidar point-cloud and raster topographic data to a global community. Since it began, OpenTopography has emphasized the co-location of data alongside processing tools to give users of varying levels of expertise and computing resources on-demand access to the data and derivatives for numerous applications.

OpenTopography facilitates user-friendly access to large volumes of topography data from lidar, photogrammetry, and radar technologies. It hosts and distributes data ranging from smaller-area, user-contributed UAS (drone) photogrammetry datasets to global coverage data products like the popular NASA Shuttle Radar Topography Mission datasets. Central to the OpenTopography vision is free and open access to data co-located with user-initiated processing tools, along with educational resources to support a global community of users. The OpenTopography facility is based at the San Diego Supercomputer Center at the University of California, San Diego and is operated in collaboration with Arizona State University and UNAVCO, a non-profit, university-governed consortium.

OpenTopography has formed partnerships with academic, commercial, and

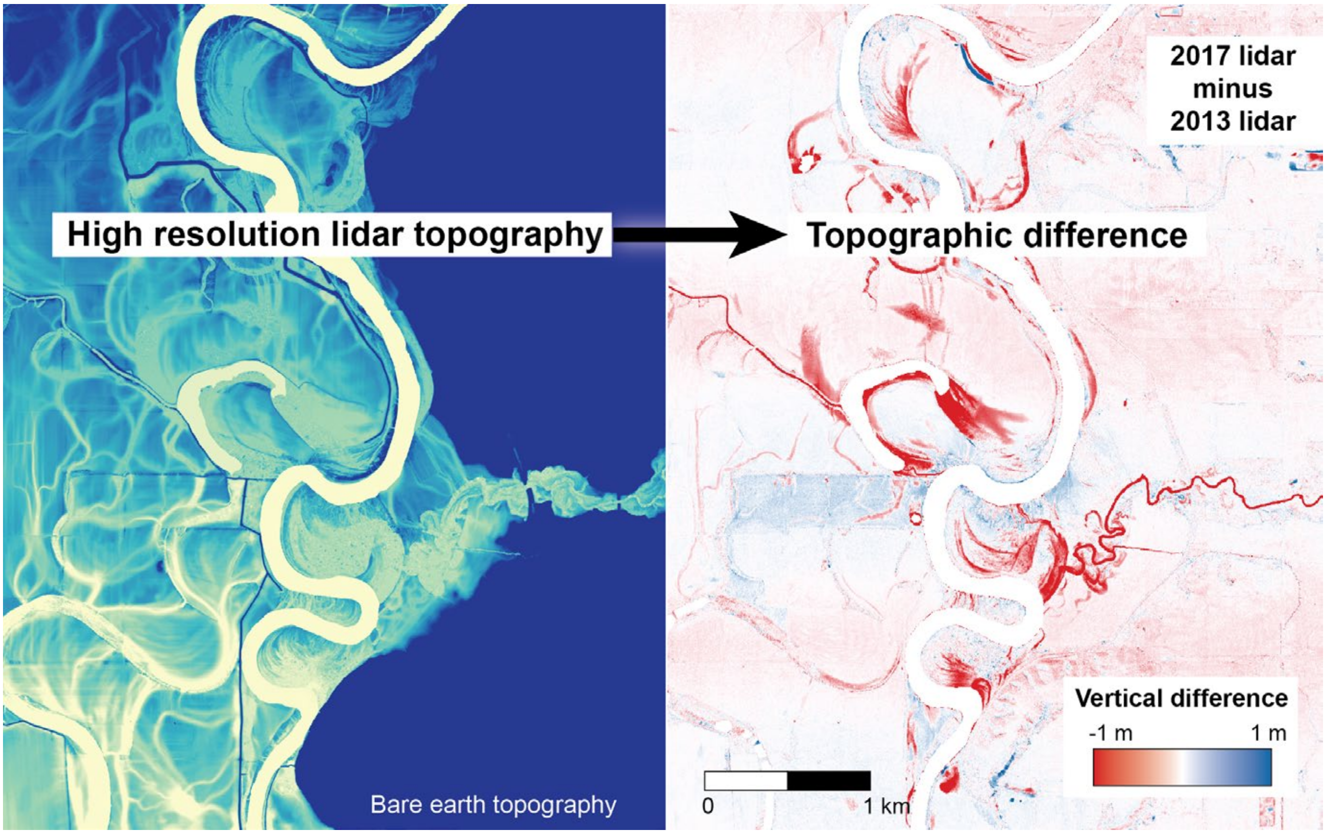


Figure 2: Topographic differencing uses high-resolution lidar topography collected from different years to determine the natural and anthropogenic vertical change at Earth's surface.

governmental agencies—including Toitū Te Whenua Land Information New Zealand (LINZ) and the National Center for Airborne Laser Mapping (NCALM)—to host and provide open, web-based access to lidar data. OpenTopography currently provides access to over 41 trillion lidar points via data hosted locally or federated from public data repositories. In 2012, OpenTopography entered into a partnership with Indiana to host the state's newly collected statewide high-resolution lidar dataset. For over a decade, OpenTopography has enabled users in Indiana, and across the globe, to quickly and easily access this data. Open and efficient access to lidar has broad impacts across sectors ranging from agriculture and infrastructure development to scientific research and education.

Almost 165,000 unique users have accessed high-resolution topographic data and derived products via the OpenTopography web portal, and close to 300,000 users have accessed topography products via its application programming interfaces. Beyond hosting data, OpenTopography provides on-demand processing tools to generate digital elevation models, topographic hillshades, slope maps, and contour lines, as well as advanced tools for hydrologic routing and for calculating topographic change from overlapping datasets. With the growing availability of state and national scale lidar datasets—in some cases with repeat coverage—OpenTopography has begun to exploit this "Big Data" for computation of high-resolution landscape change. OpenTopography's initial exploration in this space included producing the first map of statewide topographic change, motivated in part by OpenTopography's partnership with the state of Indiana.

Data hosting and Indiana partnership

OpenTopography has worked with the Indiana Geographic Information Council (IGIC) since 2012 to host and provide access to the 2011–2013 Indiana statewide lidar acquisition collected by

IndianaMap. This continues to be the most popular and heavily used point-cloud dataset on OpenTopography. Over the lifetime of this dataset, more than 492 billion points have been processed on-demand by users via the OpenTopography portal. In addition to private and commercial sector applications, the 2011–2013 Indiana statewide lidar collection has facilitated research related to canopy height and forest structure, extracting infrastructure elements like building roofs and bridges, agricultural productivity, cellular communication systems, archaeology, and lowland meandering rivers.

"Hosting Indiana's 2011–2013 statewide lidar collection on OpenTopography was one of the best decisions we ever made," said Megan Compton, the Geographic Information Officer for Indiana.

OpenTopography also provides a detailed set of usage analytics to data providers. These provide not only a metric of success in terms of investments in data collection, but also insights into the data itself, including novel use cases and information helpful in planning for repeat surveys. For the Indiana lidar point-cloud data, heavy usage is particularly focused around urban areas, although data is accessed from across the entire state (**Figure 1**).

"Hosting our statewide lidar on OT has also resulted in several unanticipated benefits. It's impressive to see the number of academics, students, and users worldwide who take advantage of Indiana's seamless lidar data set for their studies, research, and projects," said Shaun Scholer, the GIS Program Director for the State of Indiana. "An additional economic development benefit is the large number of Indiana small business users taking advantage of this service. These users are not members of what we know as Indiana's GIS community. Still, they represent the engineers, surveyors, hydrologists, farm/agriculture service providers, planners, and construction professionals who benefit from free and easy access to this authoritative and homogenous statewide lidar dataset."

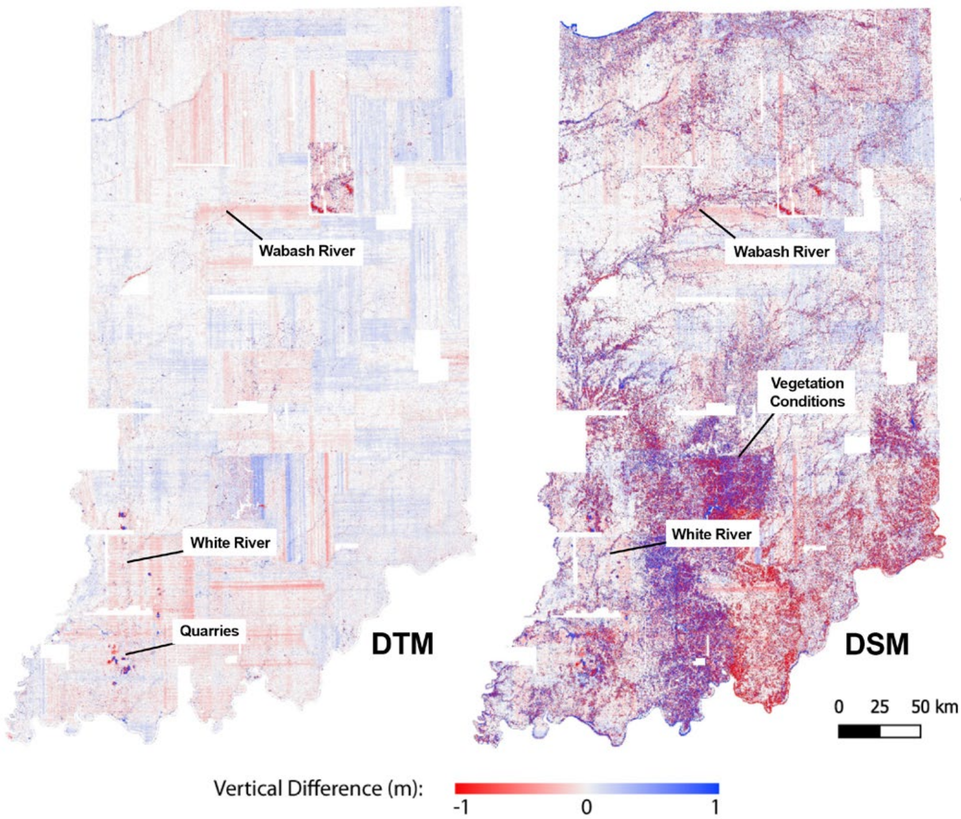


Figure 3: The differenced digital terrain model (DTM) and the differenced digital surface model (DSM) for the state of Indiana calculated from high-resolution lidar topography collected in 2011–2013 and 2016–2020. (The distinct north-south and east-west oriented lines primarily seen in the DTM do not represent change and are an artifact of positioning errors in the lidar data.)

The Indiana Geographic Information Office (IGIC) is in the process of moving all of its public-access GIS to the cloud to support Indiana's next generation of the IndianaMap. Besides cloud-based storage that will support the discovery, viewing, analysis, and creation of custom maps and applications using the IndianaMap data from a standard web browser, it will also enable open, cloud-optimized streaming and geoprocessing of the newest statewide Big Data geospatial data assets. These include 6-inch pixel orthoimagery and Quality-Level-2 (QL2) lidar data stored in cloud-native formats. In addition, IGIC is planning for OpenTopography to be an essential tool for existing and new users of Indiana's latest lidar data.

Big Data topographic differencing of Indiana

In addition to the 2011–2013 Indiana statewide lidar coverage hosted on OpenTopography, Indiana has repeat statewide lidar coverage collected between 2016 and 2020 as part of the U.S. Geological Survey's 3D Elevation Program (3DEP) initiative. These two datasets and Indiana's partnership with OpenTopography presented an ideal case study to compute the first ever lidar-based map of statewide topographic change at the decadal timescale.

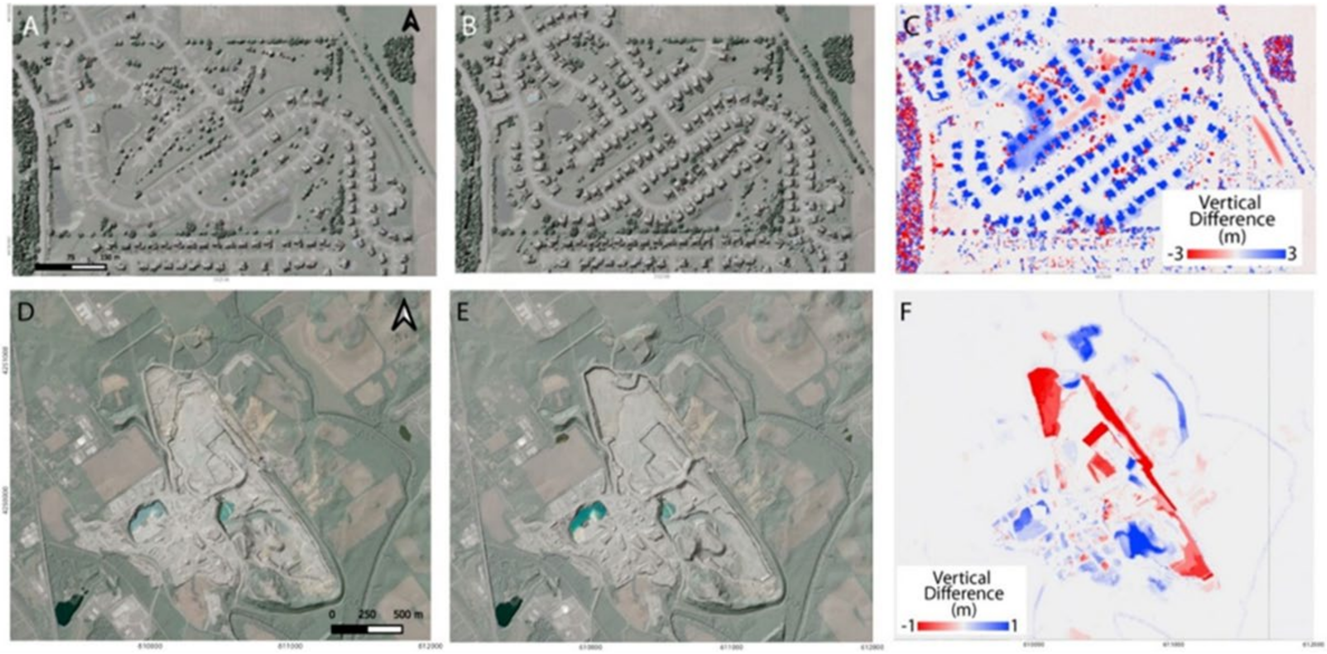


Figure 4: (A–C) A new housing development highlighted on the differenced digital surface model and (D–F) Sellersburg Stone Quarry excavation and piles near Louisville, Indiana, highlighted on the differenced digital terrain model.

"Topographic differencing" uses topography datasets of the same area acquired at different times to quantify and visualize both natural and anthropogenic changes at Earth's surface and changes in land cover over time (**Figure 2**). Previous studies of topographic differencing have only been conducted at the site or local scale, and this work by OpenTopography was the first to compute topographic change at the significantly larger full-state scale.

Starting from the original point-cloud datasets, OpenTopography produced one-meter-scale digital terrain and digital surface models (DTM and DSM), topographic change maps, and canopy height models over the 36,300 mi^2 area of Indiana. The methods and full results of this differencing work are described in an open-access publication[1]. The resulting data products are also available in an easy-to-browse web map on OpenTopography[2]. The Indiana statewide map of vertical topographic difference reveals a variety of processes related to the agricultural, forest, river, urban, and coastal environments of Indiana that are dynamically modifying the landscape.

For example, the differenced DTM and DSM reflect pronounced physical changes due to mining and quarrying near the western and southern state borders. The Wabash and White rivers create prominent change patterns stretching across the central and southern portions of the state due to fluvial, riparian, and anthropogenic activity. Color variations in the DSM change map—particularly within the south-central portion of the state—reflect the different seasons of lidar acquisitions and leaf-on versus -off conditions (**Figure 3**). Other notable examples of change included significant erosion along the Lake Michigan shoreline near Indiana Dunes National Park, rivers forming new meander paths and oxbow lakes, newly constructed housing developments and highway overpasses, and land-use changes related to agricultural activities. These results highlight the dynamic natural and anthropogenic changes in surface environments seen statewide over the span of a decade (**Figure 4**).

1 Scott, C.P., M. Beckley, M. Phan, E. Zawacki, C. Crosby, V. Nandigam and R. Arrowsmith, 2022. Statewide USGS 3DEP lidar topographic differencing applied to Indiana, USA, *Remote Sensing*, 14(4): 847. doi.org/10.3390/rs14040847.

2 portal.opentopography.org/indiana

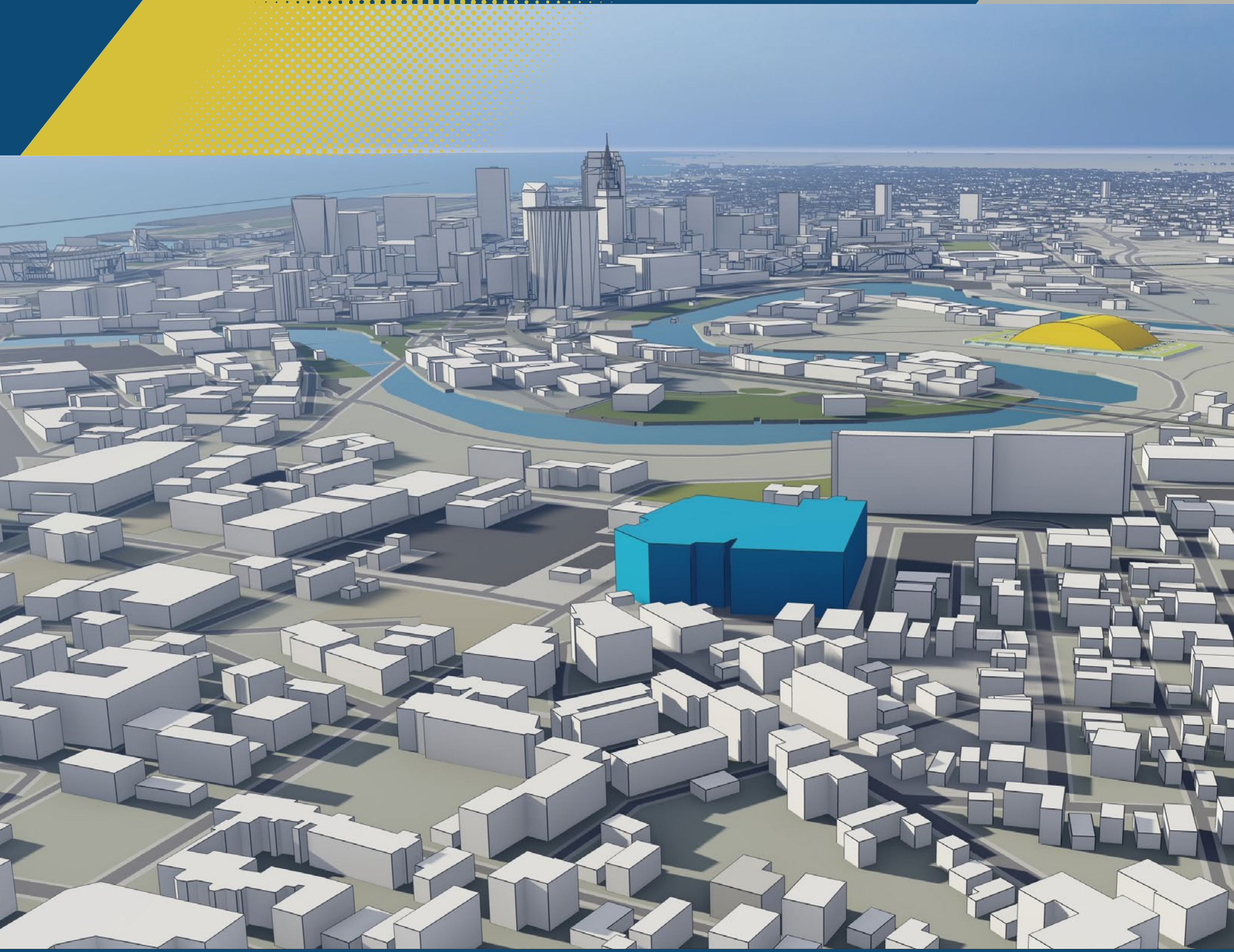
Outlook

The large and sustained use of the 2011–2013 statewide Indiana lidar dataset on OpenTopography illustrates the power of these datasets, and their wide reach when open, easy-to-use, online access is offered. This Indiana test case suggests that organizations funding public lidar collections should invest in, or partner with, data distribution systems designed to make data easier to access and use to achieve maximum return on investment in the data.

The statewide topographic differencing of Indiana highlights the dynamic natural and anthropogenic changes seen at the statewide scale. These Big Data approaches to topographic analyses can be crucial in monitoring natural hazards such as shoreline erosion, river flooding, and sinkhole formation, in addition to evaluating changes to infrastructure, new construction, and agricultural trends, OpenTopography has now begun applying machine learning to classify these maps of change to better discern the dominant processes and their spatial footprint. OpenTopography estimates that approximately a third of the lower 48 United States is covered by overlapping public domain lidar datasets, indicating that the OpenTopography Indiana statewide map of topographic change is feasible across much larger swaths of the US.

With large-scale processing innovations and data hosting, OpenTopography enables new discoveries and applications related to observing the Earth's surface using high-resolution topography. OpenTopography is interested in developing new partnerships with commercial and governmental agencies to expand the reach and impact of lidar data.

Dr. Emily Zawacki is a Research Scholar at Arizona State University and works on communications, education, and outreach activities for OpenTopography.



Digital Twin Comes Of Age

Key to 21st-century city planning and operations; centerpiece of smart city evolution

BY QASSIM ABDULLAH

The concept of the digital twin originated in manufacturing industry around 2002 and has been gaining momentum in the geospatial industry since around 2016. Digital twins and 3D models are often confused because they are both virtual representations of the physical environment. The digital twin, however, distinguishes itself from the static 3D model by its ability to incorporate data and information from other systems and to evolve over time to support all facets of an asset or ecosystem, from planning through operations.

This dynamic capability has enabled digital twin applications to reproduce quickly over the last few years, with industries from manufacturing to supply chain to healthcare capitalizing on the value of this geospatial tool. One of the most promising applications is as multifaceted as the concept itself: city planning and management.

According to a recent report by Guidehouse Insights[1], a global technology consultancy, due to relatively low costs and high utility, the incorporation and benefits from municipal digital twins are expected to grow immensely over the next decade. The group estimates that revenue generated from digital twins will rise from more than $331 million in 2022 to $2.5 billion by 2031, representing an annual growth rate of more than 25%. The primary limiting factor to this growth is expected to be lack of knowledge about the technology and its applications.

That's where we come in.

Digital twins, 3D modeling and smart cities

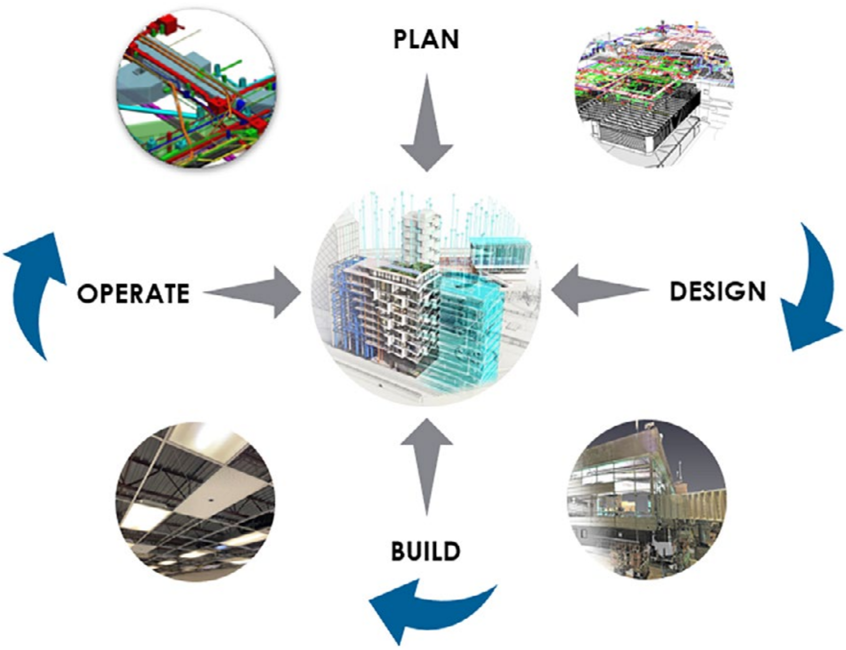
Digital twins and 3D models have contrasting applications in a city setting. Consider the difference between a highway overpass model and a digital and dynamic replication of a highway. A 3D model is the best platform for presenting a realistic environment for the interpretation of integrated data. That model then provides a base that can be fed architecture and engineering designs, real-time environmental measurements, and daily operations data, to make it a living, breathing digital twin.

Immense amounts of data are collected daily by local, state and federal agencies to support the planning and operation of cities. This data supports infrastructure, water and sewer services; energy and utilities; transportation; property management; healthcare; social services; education; parks and recreation; police and rescue; etc.—pretty much everything that contributes to city facilities and functions.

In most cities, each of these databases is siloed. If they are integrated into a digital twin, city officials gain access across city departments to make individual and collaborative decisions. This not only helps achieve synergies to advance each department and service, but also provides the framework to identify opportunities to improve the city's overall operations, research, planning, resilience and emergency response.

Although a digital twin can be created without it, building information modeling (BIM) plays an integral role in creating an accurate digital twin for industrial facilities and the urban environment. BIM is a collaborative work method for structuring and managing assets by utilizing data accumulated throughout each asset's life cycle. BIM employs augmented and virtual reality to envision a project so changes can be discussed and next steps determined. The integration of data from multiple BIM sources, alongside other data and information accrued, creates a digital twin that

1 guidehouseinsights.com/news-and-views/annual-municipal-digital-twin-revenue-is-expected-to-grow-at-a-compound-annual-growth-rate-of-25-by



increases access to that information, forging connections for improved and defensible decision-making.

For a municipal digital twin, moreover, BIM is essential. Every city structure represented in the BIM should include a complete development history, from planning to construction to operations, before it is added to the digital twin, to accurately reflect those assets within the virtual environment.

The implementation of a digital twin is highlighted in the goal of a smart city, which is to use digitally managed infrastructure to achieve a more sustainable and livable municipality. This is accomplished by improving the quality of life for citizens by ensuring that available resources are functioning correctly and are utilized efficiently. The real-time, integrated data of the digital twin enables the city to optimally manage and operate its assets. The combination of these concepts can effectively serve current city development projects, informing data-rich multidisciplinary models to manage valuable resources through visualization and analytical modeling.

City applications—the ROI

Taking advantage of readily available municipal data and the adoption of evolving technologies around the world, city GIS and IT managers have been taking the lead on the integration and management of this data. Many cities are building 3D models with increased dimension and detail, including the integration of building interiors. These models are supported by the current capabilities of the geospatial industry, including high-accuracy and high-resolution lidar data and imagery acquired from platforms such as satellites, aircraft, drones and road vehicles. These city models represent a cornerstone for the municipal digital twin, enhancing shared information among all levels of government to address traditional and emerging municipal issues.

According to experts in the field, roughly 70% of the return on the digital twin investment comes from facility operation and management after construction is completed, because the digital twin supports the life cycle of the project. This digital access to the physical structure is then extended and shared with city and departmental managers. While an economic development officer will want to know how many people live in a building, a fire marshal will want to know immediately where his crew can find access to those people, the utility company will want to know how those people are utilizing various energy resources to support grid reliability, etc. A digital twin combined with artificial intelligence can provide a city's engineering and maintenance team with an early warning about a routine maintenance schedule and can warn the team of a defect in any segment of the utilities network.

Correct implementation of a digital twin requires a massive investment in digital twin infrastructure, data governance, and stakeholders' coordination and collaboration, through agreed frameworks and processes. It also changes workflows and requires the workforce to gain new skills. The continuing drop in the cost of IT infrastructure coupled with affordable cloud data storage and processing will contribute to the affordability of the digital twin, as will the fact that costs associated with the technology can be shared across departments. Additional savings can be accomplished by reducing physical security and maintenance personnel.

A mature digital twin platform can be extended to connect the wider

> "The learning curve is the biggest impediment to municipal digital twin technology and applications. It is our job to fix that."

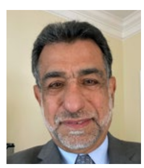
community of citizens with their government using smart city concepts. Citizens can login to the platform to learn about health and environmental issues and regulations, review their energy use and how it compares to their neighbors', check in on city development plans and how they affect their neighborhoods, etc. Much of this citizen interaction happens through a smart hub, representing elements of a smart city that are encompassed within the digital twin ecosystem.

As their benefits are more widely understood, the application of digital twins will continue to expand and improve the management of assets in multiple environments. The geospatial industry expects increasing demand for these technologies and the corresponding opportunities they present. It must pay close attention to forthcoming opportunities in the digital twin market for multiple reasons:

- Geospatial data and information are critical enablers for smart cities and therefore digital twins.
- Geospatial data and information form the framework for the digital infrastructure needed for digital twin implementation.
- Digital twins do not exist in isolation; they exist in an ecosystem of interconnected and interwoven systems, many of them based on geospatial data components.

In addition to AI and deep learning, data analytics and modeling fields will prosper from the tremendous amount of data generated from operating an asset within a digital twin that needs to be converted to knowledge.

We need to continue to expand these technologies and advance their applications, while educating those who can most benefit. As the Guidehouse Insights study noted, the learning curve is the biggest impediment to municipal digital twin technology and applications. It is our job to fix that.



Qassim Abdullah, Ph.D., PLS, CP is vice president and chief scientist at Woolpert. He has more than 40 years of combined industrial, R&D and academic experience in analytical photogrammetry, digital remote sensing, and civil and surveying engineering. When he's not presenting at geospatial conferences around the world, Qassim teaches photogrammetry and remote sensing courses at the University of Maryland and Penn State, authors a monthly column for the ASPRS journal *PE&RS*, and mentors R&D activities within Woolpert.

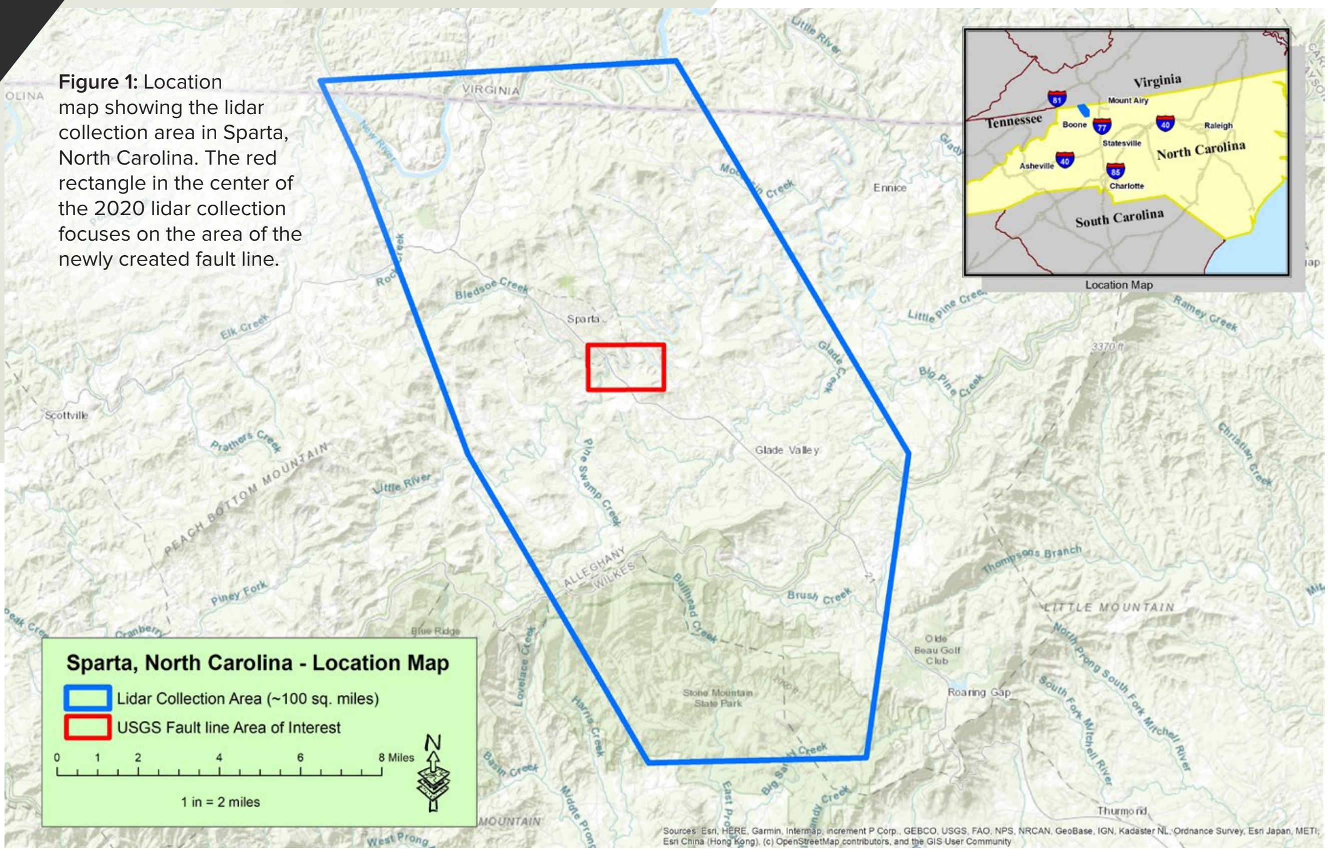


Figure 1: Location map showing the lidar collection area in Sparta, North Carolina. The red rectangle in the center of the 2020 lidar collection focuses on the area of the newly created fault line.

High-Density Lidar Finds the Fault

Probe based on collections before and after seismic event in North Carolina

BY AL **KARLIN**, ANDREW **PETERS** AND MICHAEL **BARANOWSKI**

The United States Geological Survey (USGS) has been actively engaged in collecting and publishing high-quality, lidar-derived elevation data through the 3D Elevation Program (3DEP) since 2016. The USGS Base Lidar Specification[1] identifies Quality Level 2 [QL2: 2 pulses/m^2 (ppsm); fundamental vertical accuracy = 10 cm $RMSE_Z$] as the minimum for lidar elevation in the contiguous US (CONUS). With continuously improving lidar technology, however, achievable pulse densities and vertical accuracies are increasing well beyond QL2 and the cost to increase lidar quality is

1 usgs.gov/ngp-standards-and-specifications/lidar-base-specification-online

Figure 2: A fissure (left) in a parking area, and residential damage (right; *Charlotte Observer*) following the Sparta, North Carolina earthquake.

decreasing. With newer technologies offering greater terrain resolution, applications previously unavailable or cost-prohibitive to lidar survey are emerging. High-resolution lidar data provides the gateway to evaluate subtle changes in terrain morphology, such as karst features, subsidence, uplifts, and fault lines. A recent seismic event near Sparta, North Carolina illustrates an emerging application of high-resolution lidar.

The Sparta, North Carolina earthquake

A relatively small seismic event, measuring 5.1 M_W (moment magnitude scale, approximately equal to the Richter scale for magnitudes less than 8), occurred near the small town of Sparta, North Carolina (**Figure 1**) in the early morning of 9 August 2020. The earthquake was a shallow (2.3 miles deep) event not associated with an active fault line, though the effects were felt as far away as Washington, D.C. and Atlanta, Georgia. Local and national news media services photographed the aftermath of the event, documenting multiple road fissures and personal property damage (**Figure 2**). The event was the strongest earthquake in North Carolina since 1926, with an additional 20 aftershocks recorded after 20 days.

On 4 February 2021 at approximately 23:03 and again at approximately 23:30, two smaller earthquakes (2.6 M_W) occurred at a depth of 1.25 miles in the Sparta, North Carolina area. Light to very weak shaking was reported for these events.

Lidar data acquisition

The Sparta, North Carolina area was mapped in late 2016 by the State of North Carolina in cooperation with USGS 3DEP using a Geiger-mode sensor at the QL1 specification, but of course this was prior to the seismic event. Dewberry, a privately held consulting firm and a USGS Geospatial Products and Services (GPSC) prime contractor, was tasked in late 2020 in support of 3DEP to collect very high density, QL1+ (> 8 ppsm) topographic lidar for approximately 100 square miles (551 750 m x 750 m tiles) in the vicinity of Sparta, North Carolina (**Figure 1**) to document the effects of the earthquake. The USGS task order specified an increased lidar pulse density and

Specification (lidar)	USGS specification	Achieved
Aggregate nominal pulse spacing (m)	≤0.20	0.18
Aggregate nominal pulse density (ppsm)	≥24	>30
Nonvegetated vertical accuracy (m, 95% confidence level)	≤0.196	0.055
Vegetated vertical accuracy (m, 95th percentile)	≤0.300	0.152

Table 1: Lidar acquisition specifications for the Sparta, North Carolina data collection.

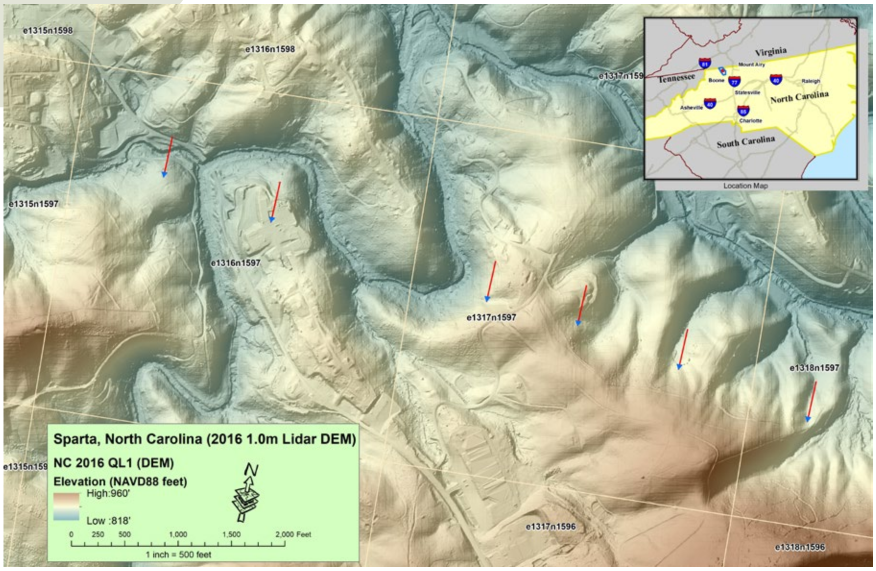


Figure 3: DEM of the USGS area of interest (red rectangle in **Figure 1**) derived from Geiger-mode lidar in phase 4. The arrows indicate the area of the fault created by the 2020 earthquake; the grid (yellow line) is the USGS lidar tiling grid.

substantial ground control to assure high accuracy.

Historically, Dewberry has been "sensor agnostic", not owning or operating any lidar sensors. For this acquisition the Dewberry team was able to select and deploy the most up-to-date sensors. For the Sparta, North Carolina mission, Dewberry recommended a Teledyne Optech[2] Galaxy T2000 lidar sensor and sufficient survey control to meet USGS Base Lidar Specification for QL0—a nonvegetated vertical accuracy (NVA) of 5 cm $RMSE_Z$. The details of the acquisition and delivered specifications are provided in **Tables 1 and 2**, respectively.

Available and updated lidar

The State of North Carolina conducted a statewide lidar collection program between 2014 and 2018. The program was conducted in five phases, with phases 1 through 3 collected using traditional, linear lidar sensors, at a pulse density of 2 ppsm with 9.25 cm $RMSE_Z$ for nonvegetated vertical accuracy. Phase 4, which included the Sparta, North Carolina area, was collected in 2016 using a Geiger-mode lidar sensor at 8 ppsm. The lidar data and derived products are available for download at both the North Carolina Spatial Data Download site[3] and at the U.S. National Map[4] and serve as a pre-earthquake baseline terrain.

Following the earthquake and analysis of the data collected in 2021, USGS geologists identified locations of newly created fault lines. In order not to obscure visualization of the actual fault, the arrows in **Figures 3 through 5** point to those fault lines. Prior to the earthquake (**Figure 3**), the Geiger-mode lidar shows smooth elevation transition in the vicinity of the future fault line. The terrain shows no sharp breaks or evidence of morphogenic change.

The newly collected, linear-mode QL1+/QL0 lidar data was used to construct a DEM with cell size 0.5 m (**Figure 4**). While the 2016 and 2020 DEMs appear similar at first glance, upon close examination a shadow (fault line) is discernible in the 2020 DEM, most clearly between the arrows in USGS tile e1317n1597 (to the east of the center of the DEM).

To facilitate visualization of the fault line, Dewberry used Esri Arc Hydro in ArcGIS Pro to construct a 0.5 m cell-size, curvature and topographic wetness index slope model of the area containing the presumptive fault line. The slope model (**Figures 5A and 5B**) clearly illustrates the rift resulting from

2 Now Teledyne Geospatial.

3 sdd.nc.gov/NCIDLogin.aspx. Login account required.

4 apps.nationalmap.gov/downloader/#/

Specification (acquisition)	
Sensor	Teledyne Optech Galaxy T2000
Scan frequency (Hz)	110
Scanner pulse rate (kHz)	1000
Altitude (m AGL)	1067
Flight speed (knots)	145
Nominal swath width on the ground (m)	776
Swath overlap (%)	60

Table 2: Lidar density and accuracy specifications for the Sparta, North Carolina data collection.

the original earthquake. In **Figure 5A**, the fault line is clearly seen at the ends of the arrows. **Figure 5B** shows the USGS interpretation of the fault line superimposed on to the DEM.

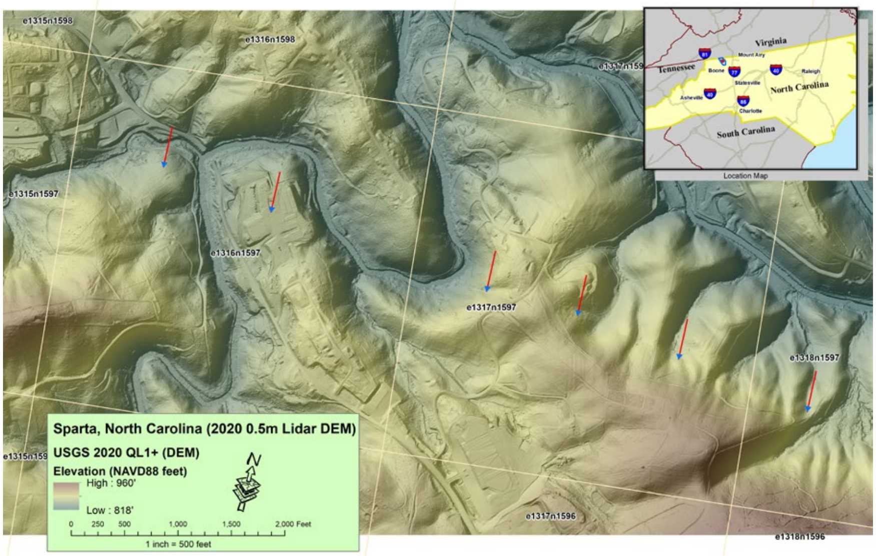


Figure 4: USGS 2021 high-density (0. 5m) lidar-derived DEM of the USGS area of interest (red rectangle in **Figure 1**). The arrows indicate the area of the fault created by the 2020 earthquake; the grid (yellow line) is the USGS lidar tiling grid. The fault line is vaguely visible in the area between the arrows in USGS cell e1317n1597.

Lessons learned

- Temporal challenge. As earthquake events are not predictable and the need to survey immediately post-event is paramount, the contracting, planning, and mobilizing of personnel and sensors is challenging. The Sparta, North Carolina event was no exception. As earthquakes are extremely rare in the area, and with the initial quakes occurring at 08:07 EDT on a Sunday, it was difficult to mobilize local authorities to begin to determine what was happening. Once it was realized that a quake had occurred in a remote portion of North Carolina, USGS needed to decide how to proceed, what data to acquire and how to acquire it in as efficient a manner as possible. It was critical to mobilize personnel and equipment to a remote area and conduct both ground and aerial surveys in a time-sensitive manner. Dewberry assisted USGS by quickly identifying the available data sources, evaluating the quality of the data and reviewing available lidar technologies to resurvey the area.
- Terrain challenge for check point survey. Once USGS, through discussions with Dewberry, determined that a lidar survey with very high resolution and precision (QL1+/QL0) was needed to characterize the earthquake, Dewberry assessed the terrain, planned the mission, and deployed personnel for both ground and aerial survey. Using the most recent and best available aerial imagery, Dewberry determined that the Teledyne Optech sensor was the best choice to map the rugged, densely vegetated terrain. To achieve the high penetration to the ground required for the survey, Dewberry determined that a 60% lidar swath overlap was necessary along with 30 high-quality survey ground points to assure vertical accuracy. Ground survey using Global Navigation Satellite System (GNSS) in mountainous terrain pushed the limits of the technology. To mitigate these challenges Dewberry used GoogleEarth™ and available ortho-imagery for the control plan, 3D views, street view, and line of sight to strategically place all control points so they would achieve optimal spacing and field of view to provide the rovers with the ability to "see" the largest number of satellites no matter the time of day at which each control point was collected.
- Remote accessibility and vegetation. The area around Sparta, North Carolina is both remote and mountainous. Outside the immediate populated area of Sparta, there are few roads through the heavily vegetated terrain. This led to several challenges during

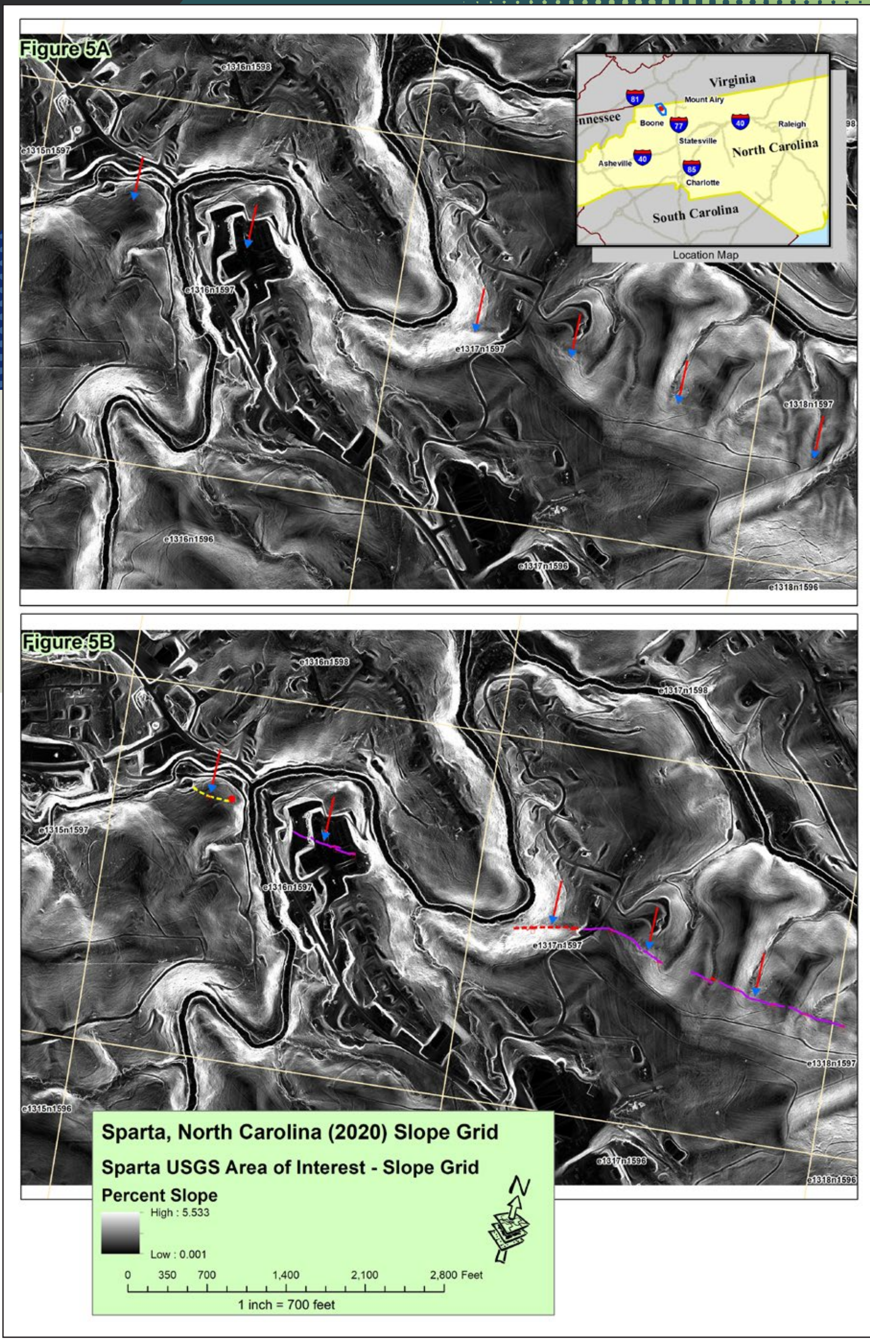


Figure 5: Slope models after the earthquake. In **Figure 5A** (top), the fault line is at the ends of the arrows. **Figure 5B** (bottom) shows the USGS interpretation of the fault line on the DEM.

the lidar collection and personnel deployment. Few difficulties were encountered for the control collection. Dewberry picked good locations for the control and North Carolina has an impressive Virtual Reference Station (VRS) real-time kinematic (RTK) network: of all the points collected, only three required static GNSS surveys.

Additional details on the earthquake

Figueiredo, P.M., J.S. Hill, A.J. Merschat, C.M. Scheip, K.G. Stewart, L.A. Owen, R.M. Wooten, M.W. Carter, E. Szymanhski, S.P. Horton, K.W. Wegmann, D.R. Bohnenstiehl, G.W. Thompson, A. Witt, B. Cattanach and T. Douglas, 2022. The Mw 5.1, 9 August 2020, Sparta earthquake, North Carolina: the first documented seismic surface rupture in the eastern United States, *GSA Today*, 32: 4-11. https://www.geosociety.org/GSA/Publications/GSA_Today/GSA/GSAToday/science/G517A/article.aspx and USGS Poster Publications 10742 and 10753.

Acknowledgements

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Drones and Imagery Bring Precision Agriculture Concepts to Forestry

With drones, experts help grow forests of timber with precision

BY SCOTT NOULIS

The revolution of precision agriculture—with its drone-guided application of fertilizer and pesticides and continuous mapping and monitoring of crop needs—has arrived in the forest.

Just as farmers use mapping to optimize growing conditions, foresters can apply sophisticated tools to better plan and manage the forest.

F&W Forestry Services, for one, applies a geographic information system (GIS) approach to assess the health of clients' forests and maximize lumber yield. F&W's forest consultants are increasingly using drones to capture details to guide forest management plans, and simply to provide a top-down view of the forest.

"Landowners can see the quality of the work from the air," said Bryan Croft, regional manager at F&W. "And they learn a little bit more about their property too."




Drone imagery of forestry provides a foundation to give landowners detailed location intelligence on their harvests without performing costly and hazardous physical inventories.

Farming rich forest land

F&W manages hundreds of thousands of acres of privately-owned yellow-pine plantations in southeast Georgia and northern Florida. Like modern farming, this is not a plant-and-watch operation: much can be done to improve the health and yield of each tree. The company undertakes considerable mechanical work, guided by maps, including: dragging a drum chopper behind a tractor to knock down brush; preparing seedling beds by mounding topsoil in rows; and spot raking to increase bed quality.

Each of these tactics has been shown to improve yield, sometimes dramatically. One study from the 1970s[1] showed a 76 percent increase in pine growth with a program of fertilizer and bedding. That impressive yield led to the quick spread of the practice. Yellow-pine forests have been farmed for the past 200 years in the region known as America's wood basket, and it didn't take long for tree-farming practices to spread. Many owners apply all these practices in their highly managed forests.

"We have some of the most productive soils in the southeast," Croft said. "We can really grow trees fast."

Pine plantation forests are planted with precision with special tractors that evenly space seedlings. Some are even hand-planted for further control and consistency. "All the bedding work is done with GPS, and the beds are very straight, very consistent," Croft said.

The precision work is guided by maps that F&W creates. The maps contain

1 fs.usda.gov/treesearch/pubs/42891

An F&W forester stands next to a pine tree with just one-and-a-haf years of growth.

details about soil type, vegetation health, and topography.

F&W also uses GIS to record all the services it applies to each forest tract. Drones provide owners with an added assurance that the work that was contracted has been done. "When you're communicating with a forest owner 1,000 miles away, and you're telling them, 'Hey, it rained six inches yesterday, there's water flowing down the road, and it's too wet to work,' it's nice that you can fly up above and take a picture to show them," Croft said.

Flexibility of flights

Drones provide other important capabilities that F&W consultants are just beginning to exploit.

"Using the drone to quickly take a couple of shots for our inspection reports has been an eye-opener for a lot of landowners," Croft said. "In today's real-time world, the quicker you can get information out that's accurate, the better off you are."

The flexibility and low cost of launching a drone, and the data drones can gather, is why they've become essential to field operations at F&W and elsewhere.

"We're flying drones in the southeastern United States out to Arkansas, Texas, the northeast around New York and Vermont, and we're flying a lot in the United Kingdom," said Collier Kidd, a GIS and mapping specialist at F&W who also manages the drone program.

In June 2021 F&W had its busiest flying month with 119 flights, because it's easiest to see forest health during the heaviest growing months of summer. Kidd estimates that they've flown more than 50,000 acres since the drone program began in earnest a few years ago. The drones provide imagery for site preparation work, maintenance, and readiness for planting season. They

> "Drones provide imagery for site preparation work, maintenance, and readiness for planting season. They also help plan for harvest."

also help plan for harvest, which occurs year-round, depending on the market and the interest of the owner.

"Most landowners are growing timber to around age 20 to 25 years, before clear cutting and starting a new plantation," Croft said. "We're thinning timbers as early as age 8, and often do a second thinning after 16 to 18 years."

F&W planted roughly 24,000 acres last year for clients in Croft's region, which equates to roughly 38 square miles of new forest to meet the demand for lumber to build housing and other structures.

Making the most of drone mapping

Croft credits F&W's growth to adding mapping and drone imaging capacity to its consulting services.

In its real-estate business, imagery and point clouds of a forest tract are often enough to convince a person to buy. "If you've got somebody interested in a property we have for sale in Virginia, but they live in Texas, you can save them a trip to look at the property. The imagery is that good," Kidd said. He sees a future in using the drones for marketing materials and connecting with potential buyers.

Croft has hopes for more 3D viewing of the land and the trees and the ability to analyze how trees respond to treatments.

"I think there's potential to jump into changes in leaf-area index after fertilization applications, and maybe even seeing changes in foliage color to forecast growth and yields," Croft said. "The holy grail would be the ability to conduct an inventory without sending a forester."

For Croft, the convenience of a drone to cover more ground and gather more input is probably the most important factor.

"On those days when you want to look at something off in the distance, and it's either 100 degrees or it's knee-deep in water, it's a nice tool to have," he said. "You can never really predict when those days will come, so it's good to have it in the truck with you at all times."

Learn more about how GIS helps maximize the value of timber assets[2]. This article originally appeared on Esri Blog[3].

2 esri.com/en-us/industries/natural-resources/segments/forestry
3 esri.com/about/newsroom/blog/

A DRONE TOOL FOR FLEET OPERATORS

Collier Kidd, a GIS and mapping specialist at F&W Forestry Services, has been integrating Site Scan for ArcGIS[4] to streamline data capture and flight planning for F&W's growing fleet of drones.

The drone management solution used previously was inefficient; requiring too much of his time to manage the process and act as a middleman between all the pilots. He also had to process imagery and then upload and share it himself.

Now, the pilots have access to quickly upload and process what their drones captured. This comes in handy to ensure they captured what they came to collect.

It also means F&W can provide to owners quick feedback and answers that otherwise would have taken days or even a week.

Kidd also finds the tools he has as an administrator very useful. He can review the work of the pilots, and keep track of their licenses and Federal Aviation Administration (FAA) registration. He can see and manage battery use and remind pilots if their certification is set to expire soon.

With the drones, the operators cover more ground, and can do that safely as they don't have to walk through hazardous terrain to inventory the forest.

"Ultimately, the goal is to get everybody in our company flying drones and realizing all the advantages of it," Kidd said.

4 esri.com/en-us/arcgis/products/site-scan-for-arcgis/overview

Scott Noulis is a solution engineer on the Natural Resources team at Esri. He works with organizations in the petroleum, forestry, and renewables industries to incorporate location intelligence and GIS into solutions that address business challenges. His prior experience includes various roles as a GIS professional in the energy industry.

Florida Lidar Workshops Go Hybrid

A synopsis of the 12th event in the successful series

After two years of remote/online lidar workshops in compliance with recommendations against large, in-person gatherings, the Florida Region of ASPRS and the Geomatics Section at the University of Florida returned to the UF/IFAS Mid-Florida Research and Education Center for the 12th UF/ASPRS Lidar Workshop on 19 May 2022. The workshop was offered as a "hybrid" event where a participant could choose to attend either in-person or on Zoom. There were 59 in-person attendees and 109 on Zoom.

The workshop followed what has become a standard agenda: ASPRS Florida Region business meeting; federal and state agency updates; keynote address; industry and sponsor updates; and academic/application presentations. The program also included a roundtable discussion presented by three industry leaders. Below is a synopsis. All presentations are available on the my.asprs.org website.

ASPRS Florida Region business meeting

As this was the first in-person meeting at the UF/IFAS Mid-Florida Research and Education Center since the covid-19 outbreak in 2020, the Region thanked the University for re-hosting the meeting.

The newly elected Regional Officers and Board of Directors were introduced and the newly elected vice-president of the region, Dr. Youssef Kaddoura, summarized the activities of the ASPRS Region Officers Council.

COMPILED BY AL KARLIN

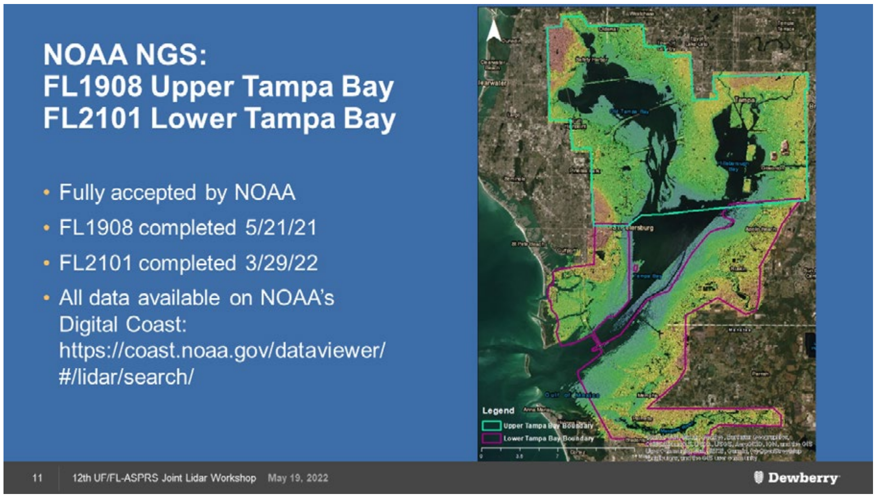


Figure 1: NOAA/NGS Tampa Bay Shoreline Mapping completed in in March 2022.

Federal and state agency updates

As the USGS/State of Florida Peninsular lidar project has wound down and was scheduled for completion in late June 2022, several of the state agencies were finalizing their QA of the delivered data and did not provide updates for this workshop.

- **St. Johns River Water Management District.** Sandra Fox presented several of her findings regarding the use of the new lidar data in wetlands and demonstrated some approaches to adjusting the digital elevation models based on vegetation for use in developing topobathymetric DEMs around lakes for the District's Minimum Flows and Levels program.
- **Southwest Florida Water Management District (SWFWMD).** Nicole Hewitt presented updates on both lidar and imagery projects being conducted by SWFWMD, which was making good progress on enhancing the USGS Florida Peninsular lidar and was in the process of selecting consultants for the District-wide 2023 ortho-imagery collection.
- **Florida Department of Environmental Protection (FDEP).** Parker Hinson gave updates of FDEP imagery services, emphasizing internal services, such as current and historical aerial orthophotos available through a custom GIS Desktop "DataMiner" tool, in addition to public data available via REST services, the FDEP Open Data Portal, and the Map Direct application.

Figure 2: NOAA/NGS Indian River Lagoon topobathymetric lidar mapping update.

Furthermore, he provided information about the Florida Geographic Information Office's online hub (floridagio.gov), which now includes a GeoResources page and updated Terrestrial LiDAR Dashboard.

- **National Aeronautics and Space Administration/NISAR Program.** Dr. Batu Osmanoglu, NASA-GSFC NISAR Deputy Program Applications Lead, said that the anticipated launch date is now 29 January 2024. He discussed several applications of interest to the Florida-based audience and encouraged them to join the NISAR Community either as "Early Adopters" or in the "Community of Practice".
- **US Geological Survey/National Oceanic and Atmospheric Administration.** Xan Fredericks (USGS), along with Emily Klipp and Elise MacPherson (both Dewberry), reported on current projects. Xan focused on the new USGS topoBuilder application available to the public (http://topobuilder.nationalmap.gov/): the user can create an on-demand topographic map. Emily and Elise presented updates on the completion of the USGS/Florida Peninsular lidar project and the Hurricane Michael lidar data for the Panhandle of Florida. Emily also described two NOAA/National Geodetic Survey topobathymetric lidar projects of significance to the state. The NOAA/Tampa Bay shoreline mapping project has been completed and accepted by NOAA (**Figure 1**). The data is available on the NOAA Digital Coast. The second project was the topobathymetric lidar mapping of 616 square miles of the Indian River Lagoon (**Figure 2**). The lidar acquisition of this project was nearing completion.

Keynote Address: Guy "Harley" Means, PG, Director and State Geologist—Florida Geological Survey (FGS).

FGS is a branch of FDEP. Co-authored by Alan Baker, PG, also of FGS, the keynote was entitled "Lidar applications in an elevation-challenged state". While the focus was on the FGS uses of lidar, the talk began with a humorous anecdote… that Florida has the lowest highest elevation point of *any* state in the US, and hence, is elevation-challenged!

He discussed how FGS uses lidar for multiple applications including, delineating historic river flow (**Figures 3 and 4**), identifying karst features such as

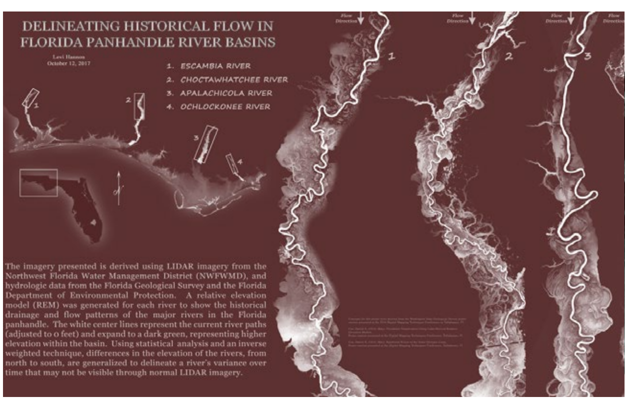


Figure 3: Delineating historic flow in four rivers in the panhandle of Florida.

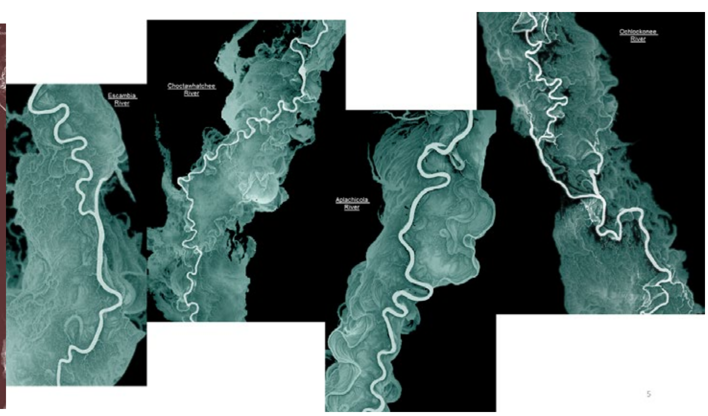


Figure 4: Lidar relative elevation map (REM) for the four rivers in the panhandle of Florida.

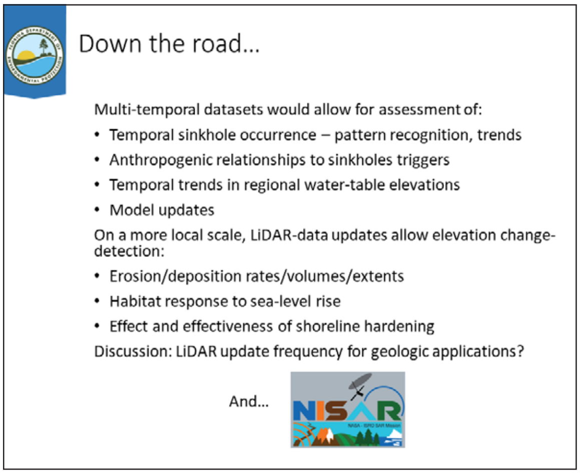


Figure 5: Future uses of multi-temporal lidar data by the Florida Geological Survey.

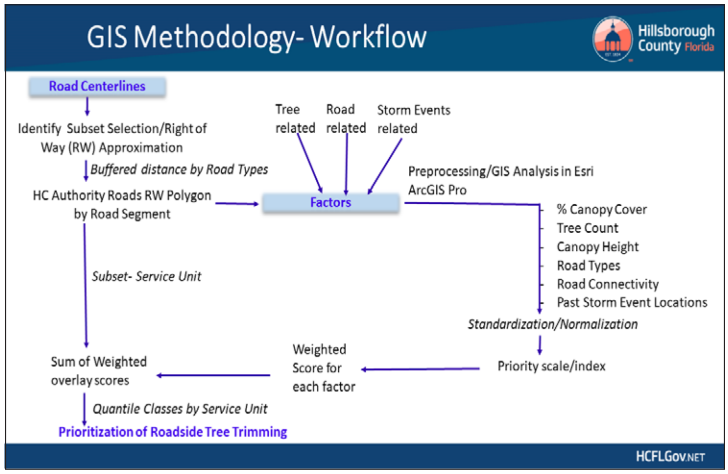


Figure 6: GIS workflow diagram to improve prioritization for urban tree trimming and maintenance.

sinkholes and other closed depressions, assessing aquifer vulnerability, and mitigating geologic hazards..

The talk ended with a glimpse into the future and FGS's plans to have a temporal sequence of lidar data for the state (**Figure 5**).

Roundtable discussion

Following the lunch break, Dr. Steve Medeiros of Embry-Riddle Aeronautical University and the Florida Region Board of Directors led a roundtable discussion, "What considerations were significant for lidar missions 10 years ago that are no longer important?" The panelists were three lidar industry leaders, Amar Nayegandhi (Dewberry), Michael Zoltek (GPI Spatial) and Dr. Nikolas Smilovsky (Bad Elf). As expected, the discussion quickly turned to the available technologies and all three noted the enormous advances in both positioning and laser systems.

Industry and sponsor updates

FL-ASPRS welcomed a new industry sponsor, ETM Survey, which described several services including advances in UAV orthophotography and terrestrial lidar. Returning industry sponsors included Pickett and Associates, which featured a new Teledyne Geospatial G2 Sensor System and news of its recent merger with ESP Associates; Pointerra, with new projects in emergency response, and 360 imagery and vectors; NV5 Geospatial, with topobathymetric lidar and multibeam echosounder data integration; and Riegl Laser Measurement Systems, which discussed the impact of beam parameters on the performance of a topobathymetric lidar sensor. Other sponsors included Kucera International, Woolpert and TileDB.

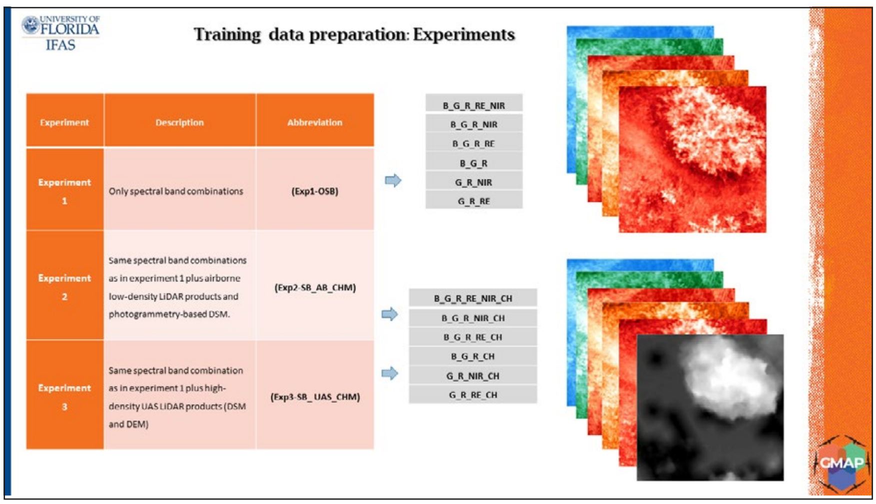


Figure 7: Training data regimes tested for the machine learning vegetation classification.

Academic/application session

The Workshop concluded with three academic/application presentations.

Figure 8: Ali Gonzales-Perez (left; University of Florida) is presented with an autographed copy of *The DEM Users Manual* by one of the authors/editors, Amar Nayegandhi (right; Dewberry).

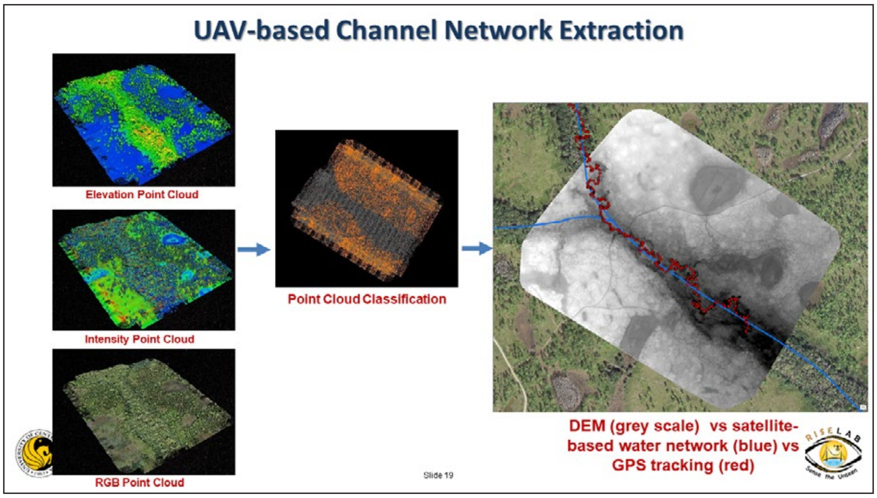


Figure 9: Water channel network extraction using high-resolution UAV lidar and multispectral imagery.

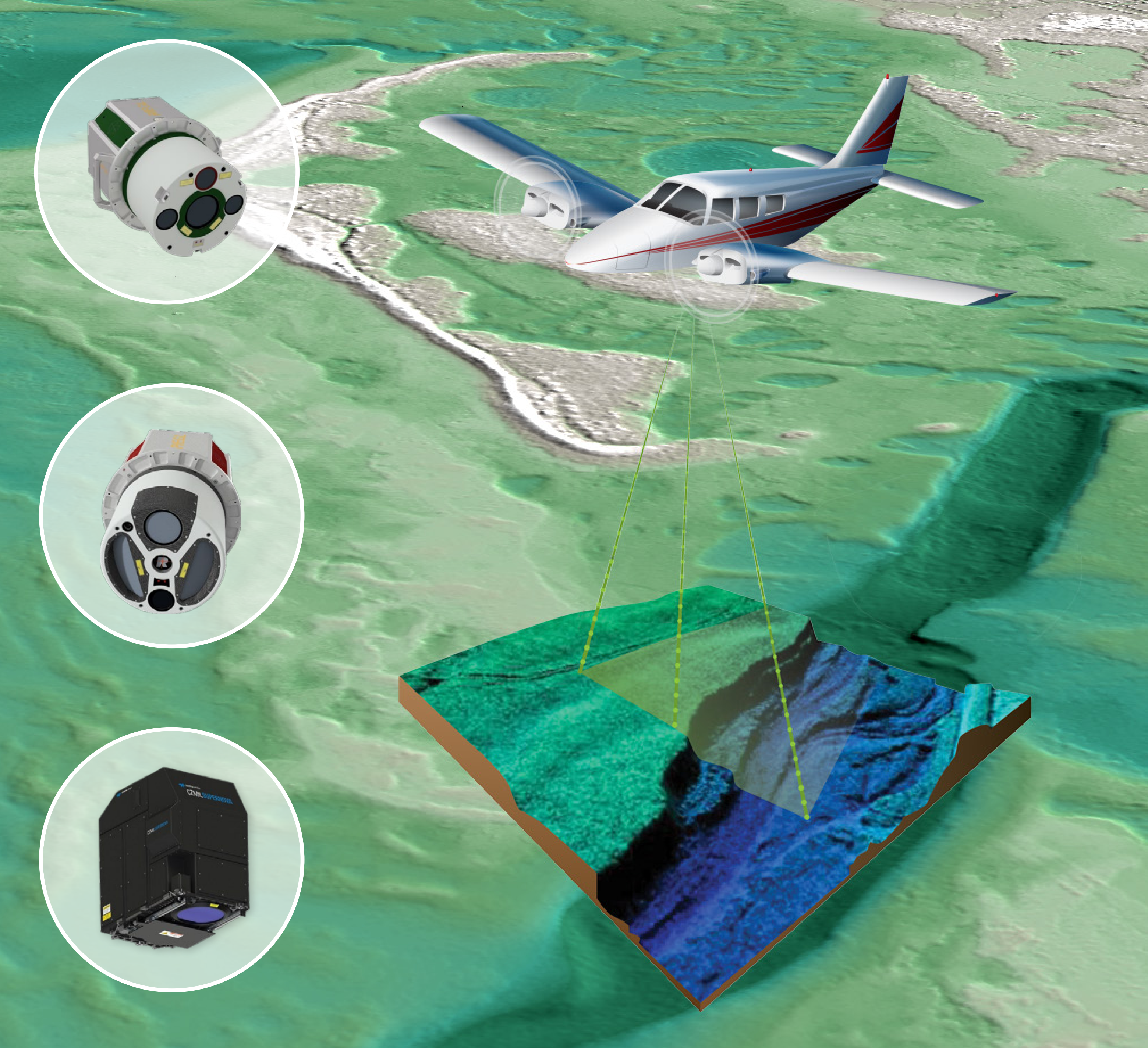
- **Sarita Karki, Senior GIS Analyst, and Fredrick Hartless, Operations Manager, Hillsborough County Public Works**, presented their application on "Using lidar and road types to prioritize roadside tree trimming in Hillsborough County," highlighting the benefits of using lidar to estimate tree canopy and tree height to increase efficiency of roadway maintenance and to help identify priority roads for tree trimming activities (**Figure 6**).
- **Ali Gonzales-Perez, University of Florida**. Ali, a PhD student, and co-authors at the University of Florida, Dr Amr Abd-Elrahman and Dr Benjamin Wilkinson, presented their research on "Deep and machine learning image classification of coastal wetlands using unpiloted aircraft multispectral images and lidar datasets." The research used multiple remote-sensed datasets, including imagery and lidar, as inputs to a deep learning model to classify coastal wetland vegetation species. Several different training techniques were tested and compared (**Figure 7**). The deep learning model proved superior to two alternative machine learning models in resolving wetland species.

For the past five years, it has been Dewberry's privilege and custom to promote student participation at the UF/FL-ASPRS workshops by providing each student presenter with an autographed copy, signed by both Dr. David Maune and Mr. Amar Nayegandhi, of the ASPRS *DEM Users Manual*[1] (**Figure 8**).

- **Patrick Sun, University of Central Florida.** Dr. Sun and co-authors, Syed Sina Shid-Moosavi, Craig Jariz, Arnittar Kanya and Dr. Dingbao Wang, from the University of Central Florida, gave the final presentation of the workshop, "Toward robust UAV-based water network sensing in Florida forests." This underlined the flatness of Florida (reminiscent of the keynote) and used very high-resolution UAV remote sensing (**Figure 9**) to delineate perennial and intermittent water courses. This presentation is published on pages 40–44 in this issue.

1 Maune, D.F. and A. Nayegandhi (eds.), 2018. *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, 3rd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, 652 pp.

Alvan "Al" Karlin, Ph.D., CMS-L, GISP is a senior geospatial scientist at Dewberry, formerly from SWFWMD, where he managed all the remote sensing and lidar projects in Mapping and GIS. With Dewberry, he serves as a consultant on Florida-related lidar and imagery projects, as well as general GIS-related projects. He has a PhD in computational theoretical genetics from Miami University in Ohio. He is a past president of the Florida Region of ASPRS, an ASPRS Certified Mapping Scientist – Lidar, and a GIS Certification Institute Professional. He currently serves as a Director of the Florida Region of ASPRS



APPLYING THE LATEST TURNKEY SOLUTIONS AND REMOTE SENSING TECHNOLOGY **FROM DATA ACQUISITION TO CLIENT DELIVERY**

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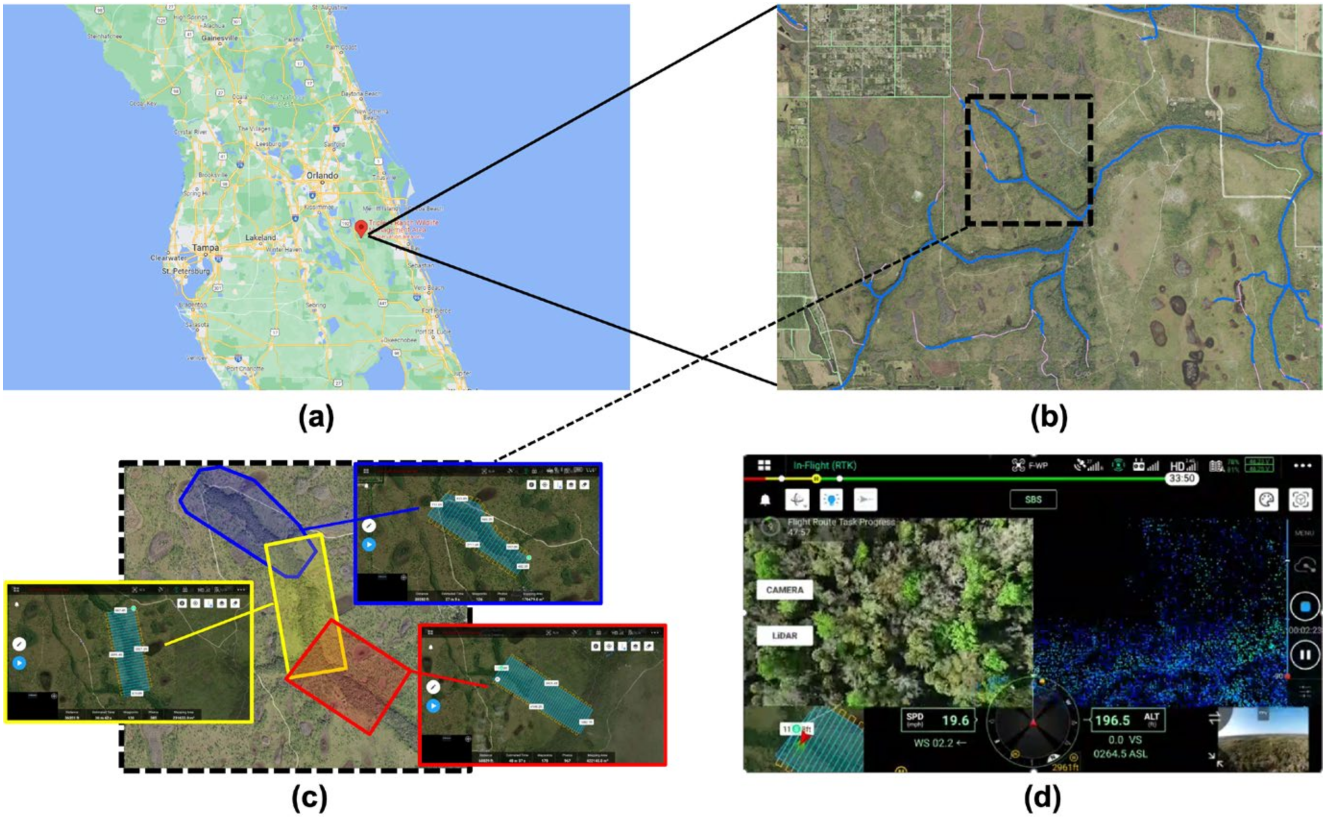

Figure 1: (a) Google map of the central Florida area and the location of the study area (Triple N Ranch Wildlife Management Area, St. Cloud, Florida); (b) enlarged map of case study area (black rectangle) marked with blue lines of perennial stream from USGS; (c) map of Little North Prong and plans of three UAV flight routes; (d) example of lidar data collection from UAV.

UAV-based Watershed Surveying over Florida Forests

High-density lidar facilitates new avenues of study

BY PENG "PATRICK" SUN[1], SYED SINA SHID-MOOSAVI, CRAIG JARIZ, ARNITTAR KANYA AND DINGBAO WANG

The temporal dynamics of creeks are important for understanding the hydrologic processes, predicting floods, and assessing climate-change impacts. At the watershed scale, the understanding of river form, process and function is largely based on locally intensive mapping of river reaches, or on spatially extensive but low-density data scattered throughout a watershed (e.g., cross-sections). In the 1960s, researchers

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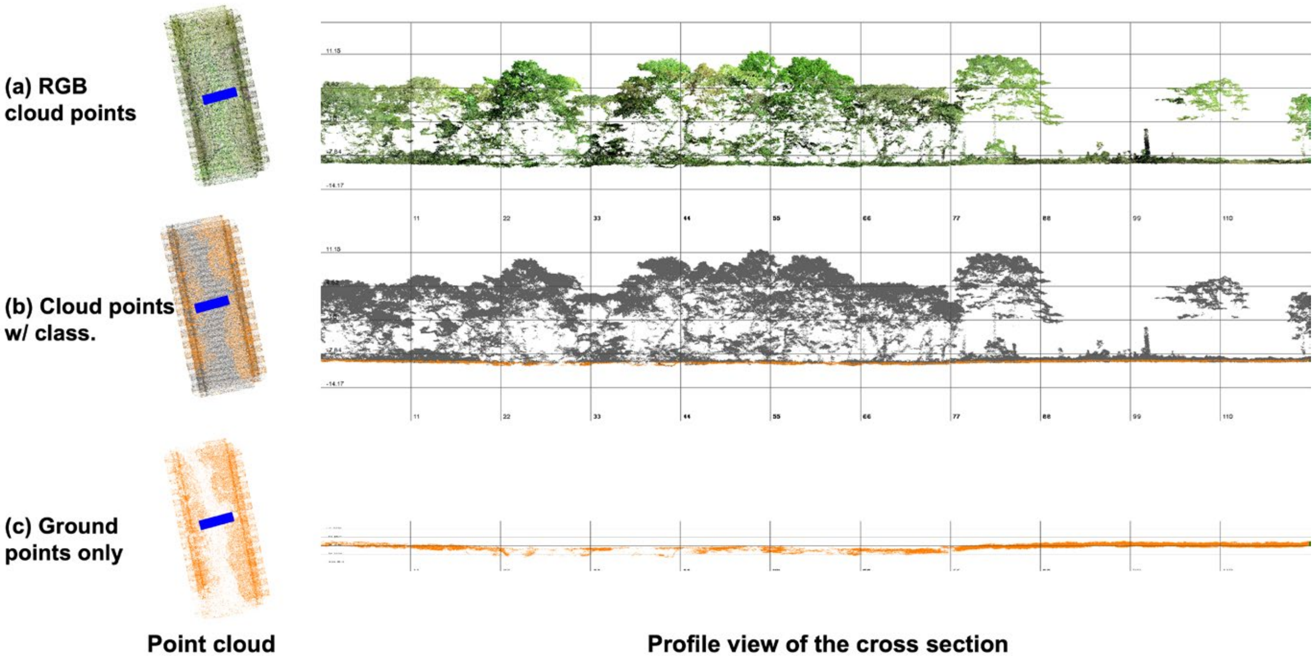

Figure 2: The point-cloud classification process of lidar data of the forest (mid-stream of the North Little Prong in Triple N Ranch) with narrow creeks with profile view of the cross-section (denoted in blue): (a) raw 3D point clouds collected from lidar with true color rendering, (b) ground point classification (ground points in orange and other classes in gray), and (c) processed ground return points.

began to use early forms of remote sensing (e.g., aerial photos) (Leopold and Langbein, 1966) to investigate morphology and the driving processes involved. The Landsat program in 1972 led to a rapid uptake in spaceborne remote sensing for detection of former river channels (Ghose et al., 1979), investigation of water quality and suspended sediment (Aranuvachapun and Walling, 1988), and mapping of flood hazards (Rango and Anderson, 1974). Although satellite images can provide data for large areas (e.g., 10×10 km^2), most of them are of low spatial resolution. Therefore, from a satellite-based survey, water surface area can only be determined for rivers more than 100 m wide. It was considered that data with a resolution of 1 m were high-resolution (Mertes, 2002), which is no longer the case. Development of airborne laser scanning (ALS) facilitated high-resolution collection of topographic data over large areas. Subsurface techniques more traditionally reserved for oceanic studies began to be used on fluvial systems for research in the early 2000s, with the deployment of acoustic doppler current profiling (ADCP) (Muste et al., 2004) and multibeam echo sounding (MBES) (Fonstad et al., 2013). Further improvements in resolution, but with limited spatial extent, came through the use of terrestrial laser scanning (TLS) (Heritage and Milan, 2009) in the late 2000s.

In the last few years, the use of unmanned aerial vehicles (UAVs) has allowed the collection of high-resolution imagery from which dense models of the earth's surface are created (Fonstad et al., 2013). Many of the aforementioned methods have been used for a range of sensing applications in river science, as well as newly emerging bathymetric lidar sensing (Mandlburger et al., 2020).

The remote sensing measurement for watershed mapping consists mainly of two categories based on the light sources: with passive illumination (e.g., optical photogrammetry, multispectral imaging) and with active illumination (e.g., lidar). The advances in optical remote sensing (with passive illumination) of rivers can generate accurate and continuous maps of features at sub-meter resolutions across entire watersheds as long as the aerial view is unobstructed. Obstacles to achieving the task include shadows, water clarity, illumination condition, and occlusion. In addition to the obstacles, the reflective and refractive nature of transparent water makes it hard to obtain the shared imagery features (between overlapping images) which are needed for 3D object reconstruction. Hence, although the photogrammetry-based methods (e.g., orthomosaic map, photogrammetric ranging) are used only for river corridor sensing on open water areas, it is challenging for them to provide 3D reconstruction of the water surface, especially when rivers are narrow with dense canopies above (e.g., in Florida forests).

UAVs can take high-resolution images during both wet and dry seasons within a short survey time and UAV-based sensing methods can provide information on the temporal dynamics of wet channel networks. In this study, we investigate the application of UAV-based lidar to reveal the topography and channel network in a Florida watershed with forest. Dense vegetation (e.g., bushes, trees) along the two banks of a channel can block views for imaging systems mounted on satellites and planes. The study wants to measure the water surface area (especially small creeks) in a more accurate and robust fashion. An affordable and efficient UAV-based sensing solution will generate high-resolution topographical and remote sensing data of the ground surface and stream water surface, offering considerable functionality, particularly for the locations that are relatively inaccessible from low-resolution data acquired from space. The UAV system includes an industrial quadcopter mobile platform equipped with a robust control system, UAV-compatible sensing devices (e.g., lidar), and a real-time kinematic (RTK) positioning unit. Laser pulses emitted from a lidar system reflect from the objects both on and above the ground surface (e.g., tree canopy, vegetation, building, ground), causing different returns. Lidar is used to generate a digital 3D topographical model of the surface due to differences in laser return times.

We have performed a preliminary study of Triple N Ranch Wildlife Management Area at St. Cloud, Florida (**Figure 1a**) using UAV-based lidar sensing. Owing to the large area of the Triple N Ranch, a small portion, the North Little Prong (**Figure 1b**), was selected for the UAV surveying. The UAV mission was divided into three parts as shown in **Figure 1c**: upstream with a coverage 42 acres, midstream, 57 acres, and downstream, 104 acres (in red box). The times for the three routes with dense mapping were 27, 30 and 48 minutes, respectively. With a flying height of ~200 feet above the forest (**Figure 1d**), both the RGB imagery and the lidar 3D point clouds could be collected together.

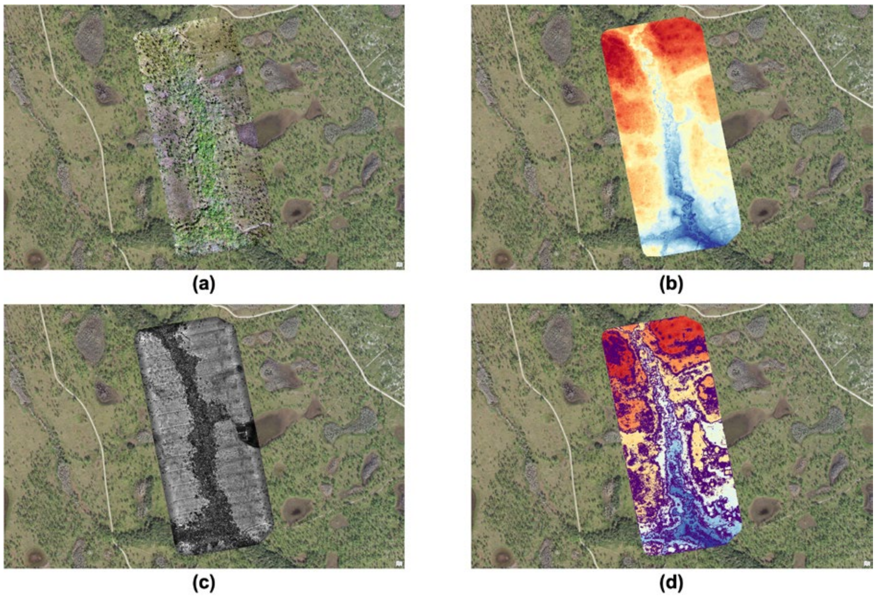

Figure 3: (a) Orthomosaic map of upper-stream of Little North Prong with RGB color, (b) digital elevation model from classified ground points, (c) distribution map of lidar pulse intensity, and (d) digital elevation model (with 1-m topographic contour lines) from ground points on GIS base maps.

Field tests will be performed on a quarterly basis to investigate the seasonal change in water surface evaluation (e.g., wet channel, ponded water). In addition to the UAV-based surveying method, conventional surveying (e.g., manual GNSS, tape measurement, ground reference points) will be used to provide ground control points. In order to derive the DEM (digital elevation model), the following data processing steps are carried out: the raw lidar 3D point cloud is collected (with color rendering) (**Figure 2a**); 3D point clouds are then classified into ground returns (e.g., ground, river banks) and other returns (e.g., trees, bushes) (**Figure 2b**); the points with ground returns are filtered out to show land cover (**Figure 2c**); and elevation contours are overlaid on the DEM to show the topographic features of the ground. Along the channels, repeated runs will be performed in areas with different forest systems and over time to detect seasonal variations' effect on the water elevation dynamics.

In addition, we are studying how to obtain accurate surface topographic information in a watershed by combining different data features (e.g., RGB imaging system, laser pulse intensity features from lidar). This data can be used to extract

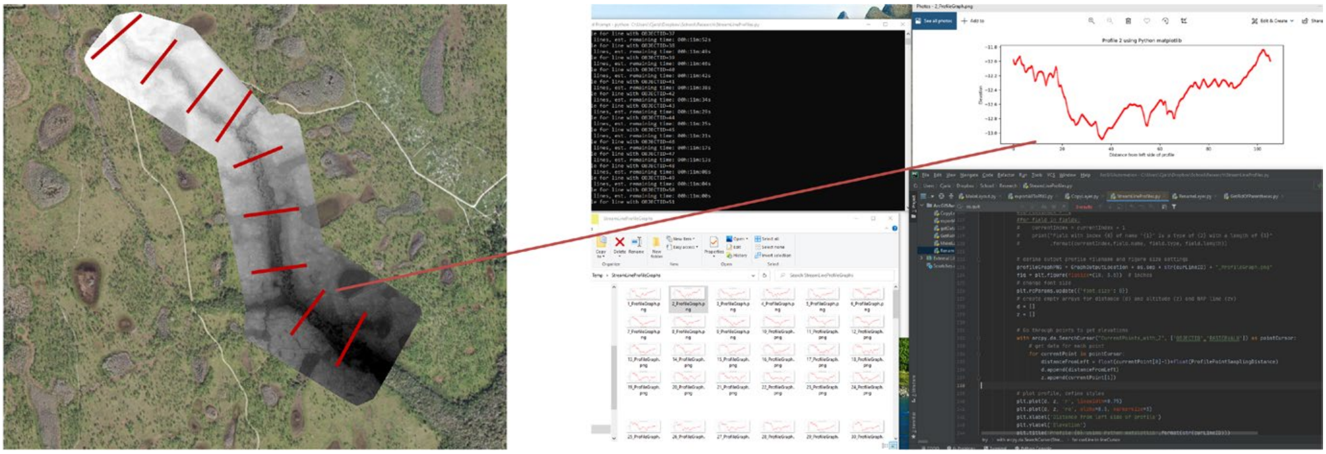

Figure 4: Water network extraction using profiles along a creek.

topographic information for a watershed and we expect to reveal and detect concave shapes on the ground even under heavy vegetation conditions, which is common in Florida. We will use a data fusion algorithm to enhance topographic mapping in forest areas, such as DEM (**Figure 3b**) used for topographic and hydrologic mapping (**Figure 3d**). We can also measure the settlement of the study area and identify potential ponding locations or creek locations at a high spatial resolution (e.g., 10 cm x 10 cm), using a DEM. In addition to the DEM generation, we found that moisture mapping over a natural or built environment could be achieved by using multispectral sensing (Hassan et al., 2022). Based on the different indices computed from multispectral bands, different sensing tasks could be fulfilled (e.g., vegetation sensing, moisture sensing). We will explore the fusion of other imagery data (e.g., thermal infrared, multispectral) into the DEM for watershed mapping in the future. ArcGIS tools may not be able to extract the channel network from the DEM with small elevation changes, such as the flat topography in Florida. Hence, we are trying other algorithms (Hooshyar et al., 2016), for example, firstly extract the profiles from DEM at different locations of creeks (**Figure 4**) and then try to connect them into a creek line. An algorithm to extract channel networks in Florida forests using UAV-based remote sensing data is still under development and will be published in a future article.

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Leica BLK2FLY ready for work in Pompeii.

Integrated Sensors Emerge in Pompeii

Lidar gives new insight into Archaeological Park

Archaeology has always been the way to bridge the past with the future. Without learning from the past, we can't advance architecture, engineering and construction. But we also have to be sure we can preserve the past. Now, with newer technologies that integrate sensors into robotics carriers, exploring and protecting ancient ruins is less dangerous and the results from the expeditions are more accurate. Consider the work currently underway in Pompeii.

Most people are aware that the ancient city of Pompeii was destroyed by the eruption of the Mount Vesuvius volcano in 79 CE. As a UNESCO World Heritage Site, Pompeii has been preserved under the ashes. Each year, more than 2.5 million tourists come to see the ruins of the streets and houses and imagine what life was like in the

BY VALERIO **BRUNELLI**

Leica BLK2FLY in the air, Boston Dynamics “Spot” with CAM+ and Leica BLK ARC in Pompeii with their handler.

once thriving city with its luxurious homes and public buildings. Its current estimated value is EUR 986 billion.

Yet Pompeii is at risk. Through the years, archaeologists and historians have been warning about the negative impact of neglect and mismanagement of the site. In 2008, the Italian government declared Pompeii a state of emergency and UNESCO started to consider adding the entire area to a list of World Heritage Sites that are in peril.

Unfortunately, another force is at play. Given the high value of Pompeii, the ancient city attracts some nefarious characters. Thieves have learned to excavate tunnels under the city at night to steal valuable artifacts, including frescos, statues and ornaments, from ancient homes and buildings. The extensive network of looters smuggles the goods overseas or creates fake documentation to resell the expensive artifacts Recently, police have been cracking down on looters by more carefully monitoring what’s happening underground, in the nearby waters, and in the air around Pompeii.

Protecting and preserving Pompeii

The high levels of looting have made preserving and protecting the city an imperative. One of the most prominent efforts to support this is led by Archaeological Park of Pompeii and is known as Smart@POMPEI.

The Smart@Pompei project is using innovative technology to improve the quality of monitoring of the existing areas, and to further knowledge regarding the progress of recovery or restoration. It also improves the quality of exploration and digital representation of unknown areas.To achieve its goals, researchers are using a combination of hardware and software, including integrated sensors and robotics, to scan and capture areas on the ground, in the tunnels, and from the air, continually and accurately.

Specifically, the Park is collaborating with Leica Geosystems, part of Hexagon, and Sprint Reply, a Gruppo Reply company that specializes in systems integration, robotics and process automation.

The initial phase of experimentation, which is currently underway, uses the Leica BLK2FLY and the Leica BLK ARC. The BLK2FLY is an autonomous, flying laser-scanner that captures exteriors, structures and environments to create 3D point clouds while in the air. The BLK ARC is an autonomous laser-scanning module designed to be integrated with robotic carriers. The result is autonomous mobile laser-scanning with minimal or no human intervention.

At Pompeii, the BLK2FLY autonomously conducts 3D scans from the air, while the BLK ARC is attached to "Spot" by Boston Dynamics. Additionally, the Spot CAM+ sensor adds a pan-tilt-zoom camera. This supports image capture and processing optimized for high-resolution monitoring of artifacts and objects. These integrated sensor solutions are used to explore and scan tunnels and other hard-to-reach areas, automate routine inspections and safely collect data. Sprint Reply's smart platform for data analysis is used to make sense of the data gathered from the robot inspections.

The data collected from the ground and the air allows scientists, researchers and technicians at the Park to create 3D point clouds. By studying the data and creating digital twins of the environment, they can proactively identify any areas that are at risk for damage or collapse. Furthermore, the 3D scans enable them to know if something has been moved. Arguably, just the presence of the technology is helping to deter theft.

Until now, robotics and autonomous reality-capture products were often seen as solely for the industrial and manufacturing world. However, the ability to safely enter and exit hard-to-reach areas, and scan and capture them in detail is proving to be beneficial to the preservation and protection of historical sites as well.

"Spot" at work in one of Pompeii's tunnels.

Valerio Brunelli holds a PhD in environmental and geological sciences. He joined Leica Geosystems, part of Hexagon in 2012 and is responsible for business development in scanning technology and monitoring solutions. His background includes roles as a geologist, CAD (2D/3D) & GIS expert, and land/geomatics surveyor (3D modelling, topographic and bathymetric). Brunelli has also worked as an independent technical consultant, a senior surveyor and a remote sensing/designer/GIS expert for several global environmental engineering companies. He has expertise in natural hazards, risk and vulnerability assessments, and engineering designs.


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CHOOSE THE SENSOR EXACTLY RIGHT
FOR YOUR SPECIFIC SURVEYING MISSION!
DISTRIBUTED, SUPPORTED AND SERVICED BY
RiCOPTER®
... A RIEGL® COMPANY
NEW
1.6 kg
360° FOV
100 / 200 kHz
eff.pulse rate
extremely lightweight
3.5 kg
360° FOV
1.2 / 1.5 MHz
eff. pulse rate
powerful sensor for various applications in wide area UAV surveying
2.0 kg
100° FOV
2 MHz
eff. pulse rate
NFB (Nadir/ Forward/ Backward) Scanning for an optimal coverage of complex and vertical targets
2.6 kg
100° FOV
2 MHz
eff. pulse rate
fully integrated IMU/GNSS system
NFB (Nadir/ Forward/ Backward) Scanning for an optimal coverage of complex and vertical targets
4.1 kg
75° FOV
1.5 MHz
eff. pulse rate
versatile scanner for use on high-speed UAVs, helicopters or small manned aeroplanes
9.8 kg
40° FOV
(elliptic scan pattern)
200 kHz
eff. pulse rate
water penetration
2 Secchi depths
for topo-bathymetric LiDAR applications
efficient high resolution coastline or shallow water surveying
miniVUX-1UAV
miniVUX-3UAV
VUX-1UAV[22]
VUX-1LR[22]
VUX-120[23]
VUX-160[23]
VUX-240
VQ-840-GL
for applications using low-flying small or mid-sized multi-rotor UAVs
e.g. mining, topography, forestry, landslide and avalanche monitoring
for applications using fixed-wing UAVs
e.g. corridor mapping, city modeling
for applications using higher-flying large UAVs or helicopters
e.g. mapping with the need of detailed high-resolution data
Explore the full portfolio of proven RIEGL LiDAR sensors and systems
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Surveyor 32.
One System.
Dual Use.
Yes, You Can Do Both!
Designed to easliy move from a UAV to a ground vehicle. Optimize your ROI.
Spend more time scanning, only 30 seconds to initialize.
We Make 3D Mapping Easy. Learn more on our website. www.LiDARUSA.com
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3D MAPPING SOLUTIONS