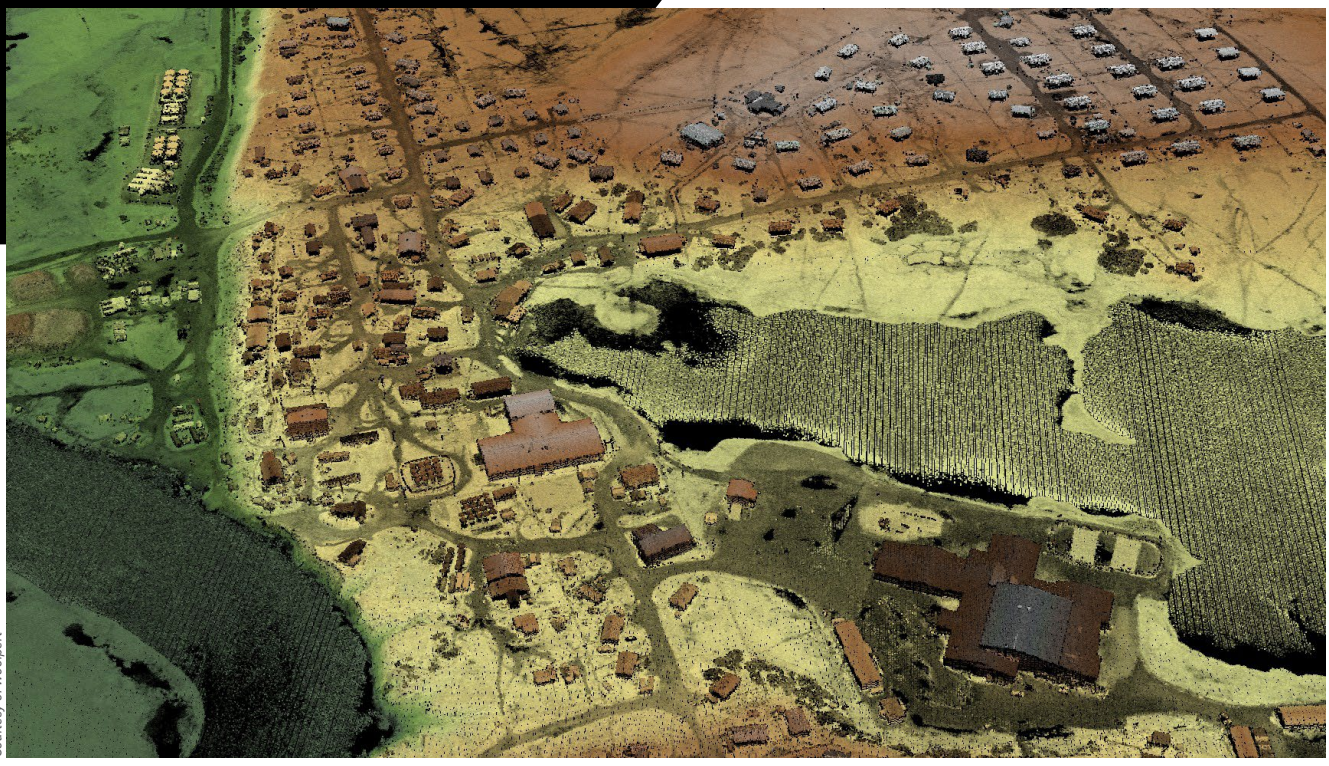


Courtesy of Woolpert

This oblique image of Chevak, Alaska, portrays how water dots the town, providing a constant reminder of past flooding and the potential for future storm surges. A tidally influenced network of streams, influenced by dissipating sea ice and intensified storm activity, crisscrosses the delta.

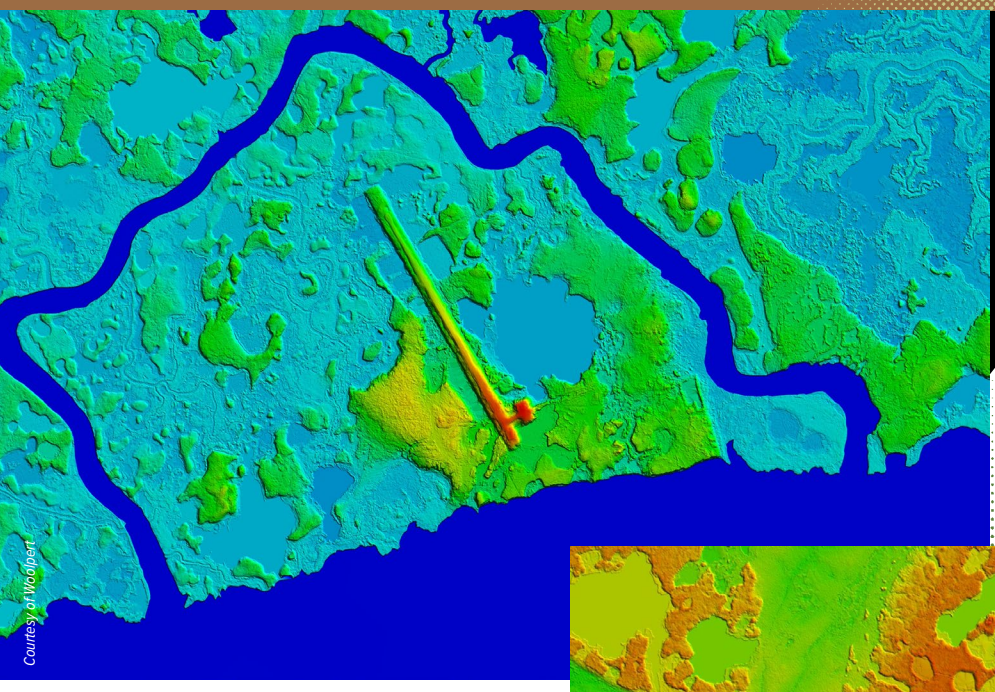
KEEPING THE THREAT AT BAY

Mapping the Alaska Coastline

The expanse and mystery of Alaska are part of its allure, from its rugged terrain to extreme weather to incredible wildlife. But these untamed elements often come at a steep price, especially for those who live, work and raise families in some of the most remote areas of the nation's Last Frontier.

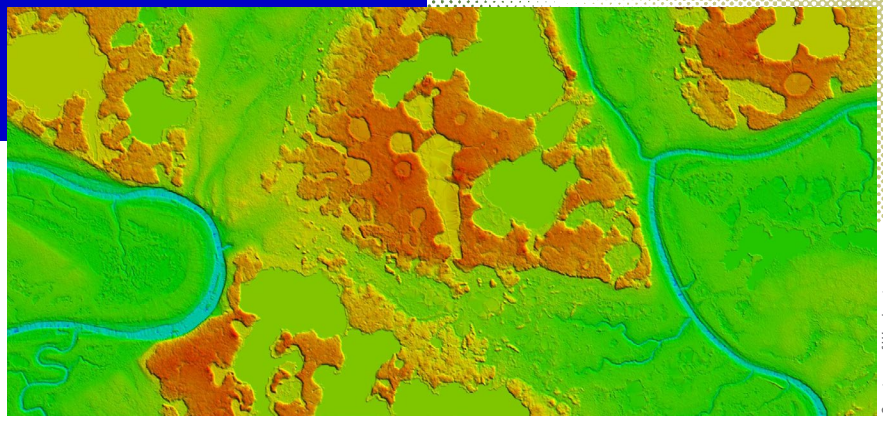
This is the case for the inhabitants of Alaska's Yukon-Kuskokwim River Delta. The approximately 25,000 residents, primarily from native Alaskan tribes, embrace a traditional subsistence of hunting, fishing and gathering in this subarctic region. However, the lifestyle regional families have cultivated for centuries has systematically deteriorated over the last few decades. The shifting topography, dissipating sea ice and intensified storm activity have caused consistent flooding and habitat loss, and restricted access to, from and within the region. The Bering Sea has battered the coastline, forcing residents to

BY MIKE MEISER



Courtesy of Woolpert

This digital elevation model of the village of Newtok, Alaska, shows the proliferation of inland water. The linear feature to the right is a runway, which eventually will be overtaken by the sea. Subsidence, erosion and melting permafrost have forced Newtok residents to begin relocation efforts.



Courtesy of Woolpert

This digital elevation model of a portion of the Yukon-Kuskokwim River Delta was created in part using a threshold-based, object-oriented extraction technique developed by Woolpert and based on lidar intensity imagery, 4-band imagery and digital elevation models.

abandon their homelands to avoid being submerged in the icy waters.

To find a solution to this growing, time-sensitive challenge, in 2016 the U.S. Geological Survey (USGS) contracted with Woolpert and partner Kodiak Mapping Incorporated (KMI) to collect Quality Level 2 (QL2) lidar data over areas of the Yukon-Kuskokwim River Delta region to provide precise, constructive information upon which to develop a plan of action to address the needs of the region.

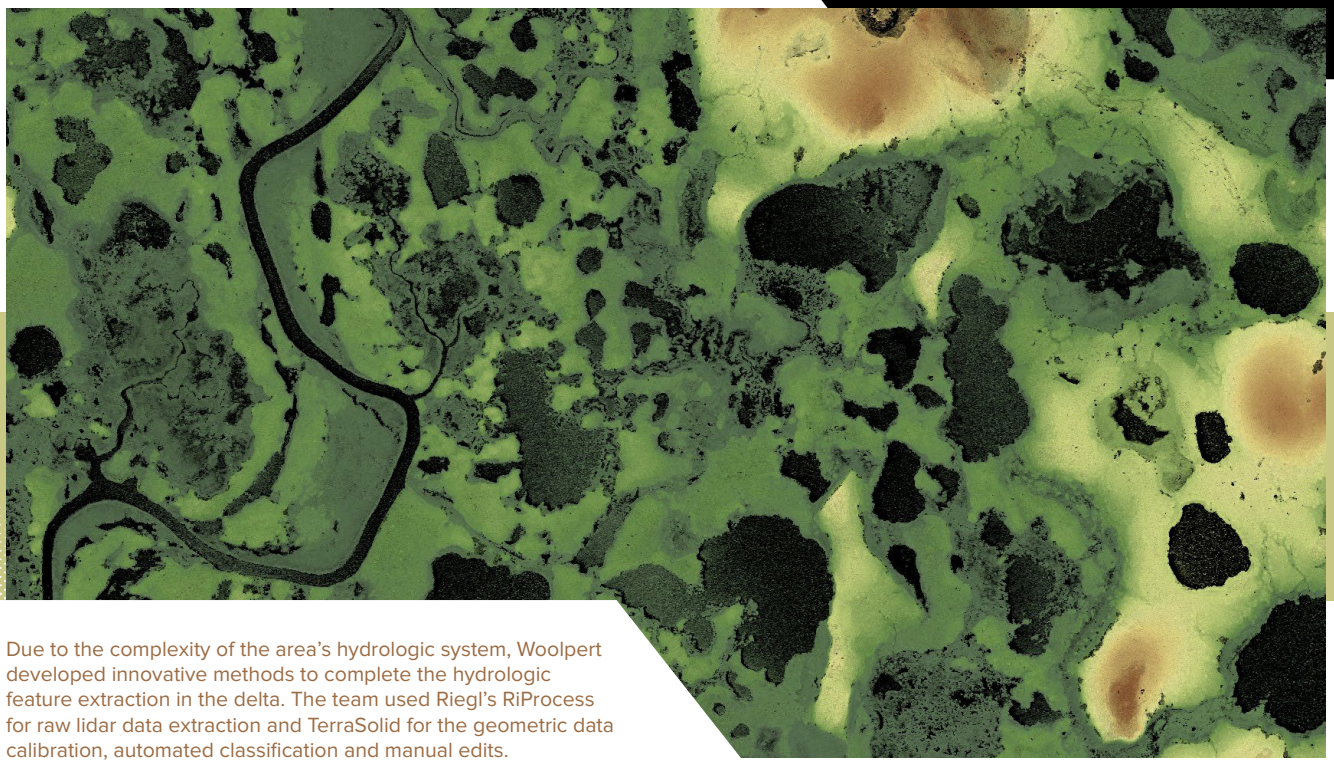
Defining the Relentless Environment

Living in the Yukon-Kuskokwim River Delta has never been easy, but there was a balance and a consistency upon which the locals relied. However, deteriorating delta conditions have eroded that stability and adversely affected nearly every aspect of life in the region.

The town of Newtok, for example, illustrates the plight of many towns on the Yukon-Kuskokwim River Delta. The community of more than 300 is located almost 100 miles west of Bethel, Alaska, which is the closest sizeable city. That mileage is measured as the crow flies.

Newtok tops the list of communities facing the probable, if not imminent, need for relocation due to recurring flooding and loss of usable land. Subsidence, erosion and melting permafrost have forced residents, who had a median age of 22.8 according to the most recent U.S. Census data, to begin relocation efforts. However, picking up an entire community and moving it to a new site is no simple task, no matter how good the plan, how developed the infrastructure or how young the residents. Newtok is gradually re-establishing itself in Mertarvik, without an established public infrastructure, airfield or emergency response plan.

Ironically, the environment upon which the Yukon-Kuskokwim River Delta residents has relied is helping to facilitate these life-altering issues. The 50,000-square-mile delta is located on the coast of western Alaska. The terrain is extremely flat, measuring only 3 to 4 meters above sea level in most places, and is especially vulnerable to storm surges from the Bering Sea,



Due to the complexity of the area's hydrologic system, Woolpert developed innovative methods to complete the hydrologic feature extraction in the delta. The team used Riegl's RiProcess for raw lidar data extraction and TerraSolid for the geometric data calibration, automated classification and manual edits.

Courtesy of Woolpert

where inundations have exceeded 30 kilometers inland.

Thousands of lakes and small ponds, and a tidally influenced network of streams crisscrosses the land. Thawing permafrost oversaturates the tundra, causing runoff and floodwaters to breach the high ground between ponds and rivers. New wetlands emerge, pockets of subsidence dot the land and the shoreline suffers from frequent erosion. Season to season and year to year, the terrain is changing.

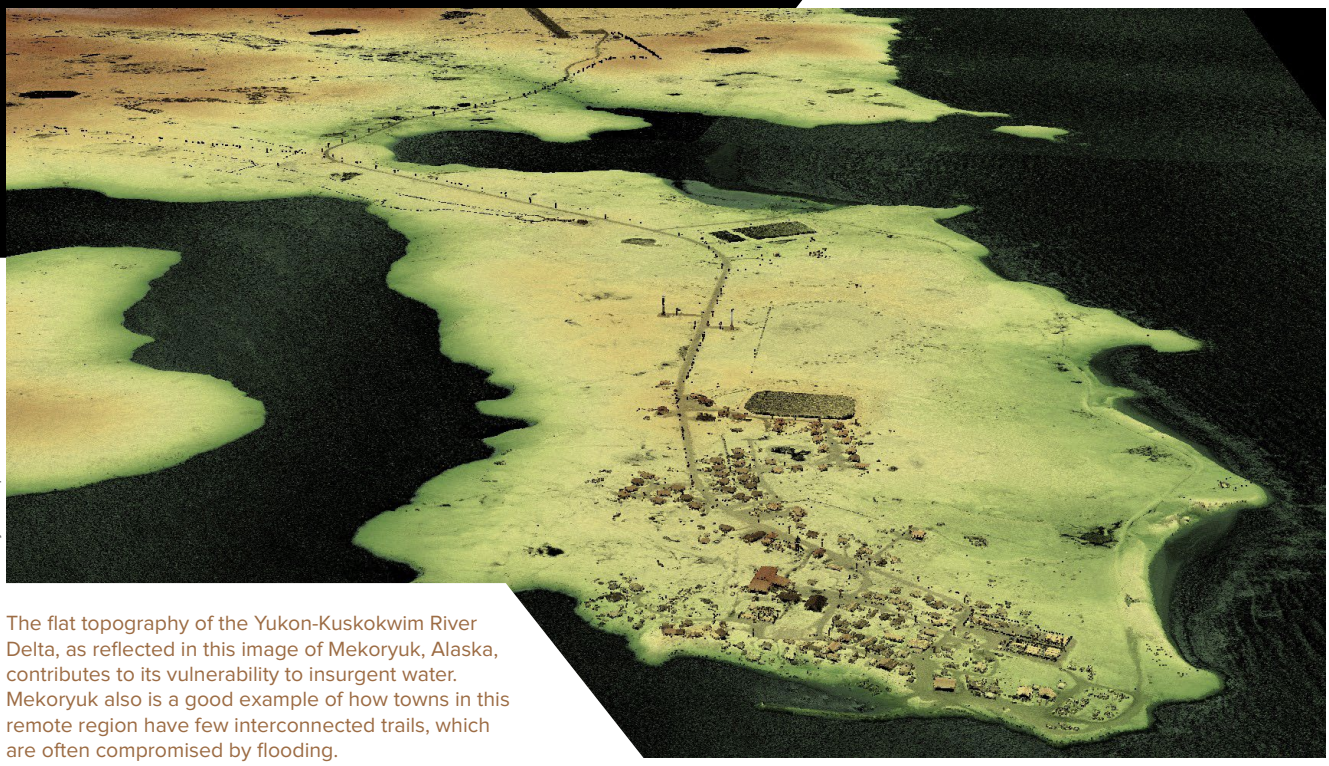
Regional warming also has caused significant melting of the area's sea ice, which acts as a natural flood and weather barrier between the Bering Sea and the delta. The combination of diminished protection from the sea ice barrier, rising average sea levels and the flat topography leaves the region extremely susceptible to flooding. The warming trend responsible for the melting sea ice is expected to continue and, with it, increasing the likelihood of future flooding.

> "The combination of diminished protection from the sea ice barrier, rising average sea levels and flat topography leaves the region extremely susceptible to flooding."

Further contributing to the swelling tides are notable increases in Bering Sea storm activity—both in frequency and fury. With each storm comes the threat of storm surges, copious precipitation, wind damage and irreversible erosion. The storms battering the coast are gradually whittling away at the remaining landmass.

Mapping a Solution

The Alaskan government has collected aerial imagery and mapping data across the state for many years. Most recently, the state employed interferometric synthetic aperture radar (IfSAR) technology to capture 5-meter elevation data across Alaska's interior. Small pockets of high-resolution lidar also were flown in the Yukon-Kuskokwim River Delta region, proving high-quality lidar to be a very effective tool for analysis.



Courtesy of Woolpert

The flat topography of the Yukon-Kuskokwim River Delta, as reflected in this image of Mekoryuk, Alaska, contributes to its vulnerability to insurgent water. Mekoryuk also is a good example of how towns in this remote region have few interconnected trails, which are often compromised by flooding.

However, much of the existing elevation data was insufficient for detailed analysis of the delta due to the complex nature of the coastline, where a 6-inch elevation change is significant. Continued flooding intensified the demand for high-resolution lidar to assist with infrastructure and relocation planning, as well as wildlife habitat monitoring.

Seeing this need, and using the input of several state and federal agencies, in 2016 the USGS tasked Woolpert with acquiring QL2 lidar data over the most populated and imperiled territory in the delta. KMI, an Alaskan-owned and operated company, teamed with Woolpert to provide the lidar data acquisition and ground control services for the fast-track project. The project's 1,667-square-mile area of interest was located between the Yukon and Kuskokwim Rivers and included the threatened communities of Hooper Bay, Newtok, Chevak, Scammon Bay, Emmonak and Mekoryuk.

Since native Alaskan communities are known for their careful land stewardship, the team acknowledged that public buy-in would be critical to the collection's success. Prior to the lidar data acquisition, Woolpert assisted with a public outreach campaign to provide delta-area residents with information about the project's goals, technology and benefits, while also explaining the necessity and function of the survey crews. The project team's communications also paved the way to safe and convenient locations for base stations and survey checkpoints.

The flight crews established an operational base camp at Bethel, which is the primary hub community of the Kuskokwim region. Secondary base stations were established in communities throughout the area of interest. Alaska weather conditions dictated an abbreviated flying window, and the Woolpert/KMI team set out to acquire as much data as possible during the extremely short season—acquiring the data over just 48 days.

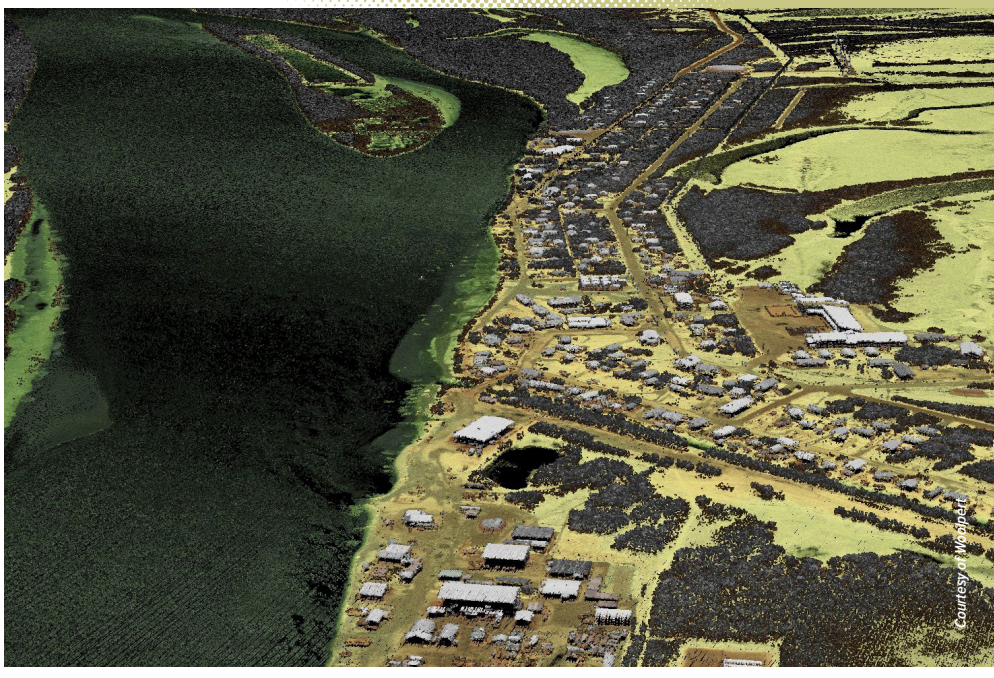
For the acquisition, the team used a Riegl LMS-Q780 lidar sensor mounted on a C-182 Katmai aircraft. Optimized for a 60-degree field of view, the sensor's rotating polygon mirror produced evenly spaced points and an equally dense laser footprint pattern on the ground. Flying at a height of 2,100 meters above ground level and at a speed of 110 knots, the lidar employed a pulse repetition frequency of 400 kHz. The team also

used an 80-megapixel RCD30 digital camera to acquire 4-band red, green, blue and near-infrared imagery data simultaneously with the lidar.

Ideal data collection conditions are hard to come by in Alaska, and this acquisition effort was no stranger to challenges. The remoteness of the project area required very careful planning for fueling, base station placement and surveying. Tidal changes affected the timing of flights, and the short autumn season prior to a snowy winter left an abbreviated window for acquisition. Heavy cloud cover and rain halted the lidar data acquisition for over a month but did not cut short the overall acquisition effort.

The team hit its available window, completing the lidar mapping acquisition within a month and a half, and then embarked on a ground survey to support the aerial data acquisition. The survey crews established reasonable and evenly distributed checkpoints at communities throughout the area of interest, eliminating the need for helicopter access and special-use permits.

During the lidar data acquisition, quality assurance/quality control (QA/QC) was conducted on all incoming data to ensure thorough coverage and adherence to all USGS specifications on point density and distribution. The Woolpert team used Riegl's RiProcess for raw lidar data extraction and TerraSolid for the geometric data calibration, automated classification and manual edits. Due to the complexity of the area's hydrologic system, the firm developed innovative methods to complete the hydrologic feature extraction. The resulting method, which was based on the lidar intensity values and 4-band imagery, used a threshold-based object-oriented extraction technique:



This oblique image of In Emmonak, Alaska, illustrates the proximity of residents and infrastructure to the Bering Sea. In this small fishing village, like in towns throughout the delta, the combination of diminished protection from the sea ice barrier, rising average sea levels and the flat topography leaves the delta region highly susceptible to flooding.

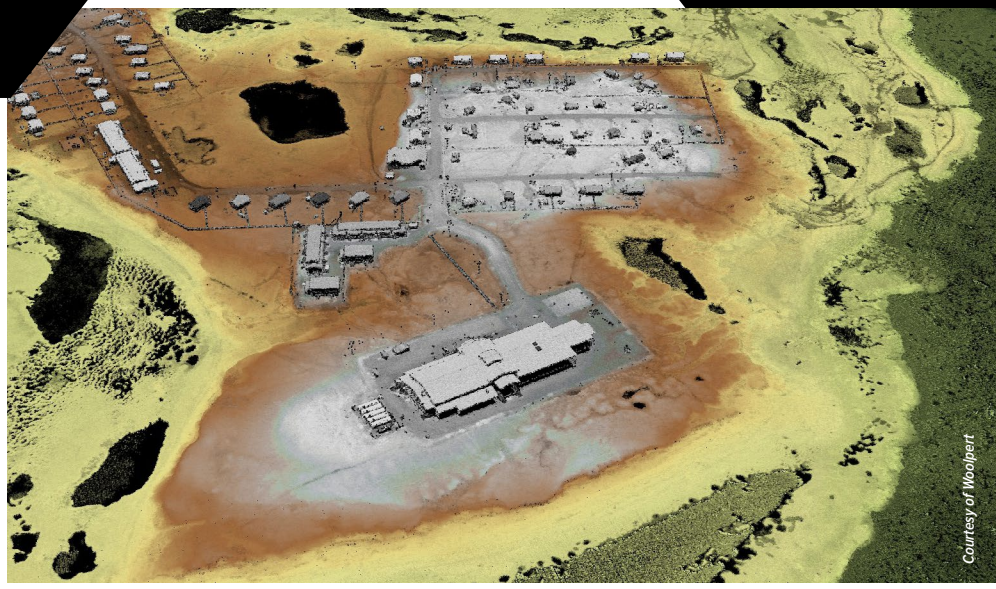
> "The highly accurate elevation data was made publicly available and is supporting agencies at the local, state and federal levels."

2 acres for lakes and ponds, and 30 meters nominal width for streams and rivers. This massive undertaking required a substantial amount of manual quality control.

Finding Success

The result of the acquisition was extremely accurate lidar data of the Yukon-Kuskokwim River Delta. In a typical lidar project, the distance between lidar points is 0.7 meters with 2 points per square meter collected on bare-earth/open-terrain surfaces. The accuracy of Yukon-Kuskokwim project's data was required to be 10 centimeters root mean square error (RMSEz), and Woolpert's data came in "well below the required specification."

This highly accurate elevation data was made publicly available by the state of Alaska (maps.dggs. alaska.gov/elevationdata/) and is supporting agencies at the local, state and federal levels, allowing them to better evaluate the locations of communities at the greatest risk of



With more than 1,100 residents, Hooper Bay one of the most populated areas of the Yukon-Kuskokwim River Delta. This digital elevation intensity model shows Hooper Bay's buildings and roads surrounded by lakes and small ponds.

flooding and inundation. In villages such as Emmonak and Scammon Bay, the Federal Emergency Management Agency (FEMA) is developing enhanced evacuation and emergency response plans based on the data.

The Alaska Department of Natural Resources Division of Geological and Geophysical Surveys (DGGS), the Western Alaska Landscape Conservation Cooperative, and a variety of other agencies are reviewing the lidar data to better support coastal flooding and storm surge mapping. These applications will help communities to quantify their risk of inundation and identify safer locations for community building.

The Yukon-Kuskokwim River Delta region also is home to the Yukon Delta National Wildlife Refuge, the second-largest refuge of its kind in the United States. The refuge also has one of the largest concentrations of waterfowl in the world, the refuge's habitat health is of global importance. The United States Fish and Wildlife Service (USFWS) is using the lidar elevation data from this project to track habitat changes, better understand waterfowl habitats and predict future movements. USFWS officials also are using the lidar data to pinpoint changes in topography that can impact water chemistry, affect sensitive salmon populations and alter migratory wildlife patterns.

Since every storm surge, flood or other topography-altering event damages and sometimes destroys public infrastructure, there are efforts underway to design and implement more sustainable trails, stronger infrastructure and more resilient public works systems throughout the delta. Three-dimensional designs based on this elevation lidar data are helping engineers to envision and create more stable and longer-lasting infrastructure components.

Conclusion

The lidar data of the Yukon-Kuskokwim River Delta has proved and will continue to prove to be a highly effective tool for assessing the topography of the region. In the case of Newtok, community leaders, government officials and private contractors are using the lidar data to select locations best-suited for future infrastructure placement and the long-term viability of the community. This data provides rich, highly accurate topographic information to help residents throughout the delta community better understand its changing environment.

This project illustrates the overarching purpose of the geospatial community, which is to protect and preserve land and life through the application of knowledge and technology. Through efforts such as these by the USGS—which plans to add this lidar data on its National Map Viewer at viewer.nationalmap.gov/launch/—as well as other government agencies and geospatial firms, we can improve the quality of life for people all over the Earth.

Mike Meiser, CMS, PMP is a geospatial project manager and associate at Woolpert, where he has worked for 12 years. Meiser is a Certified Mapping Scientist with a specialization in lidar and a Project Management Professional, as well as a member of the American Society for Photogrammetry and Remote Sensing.