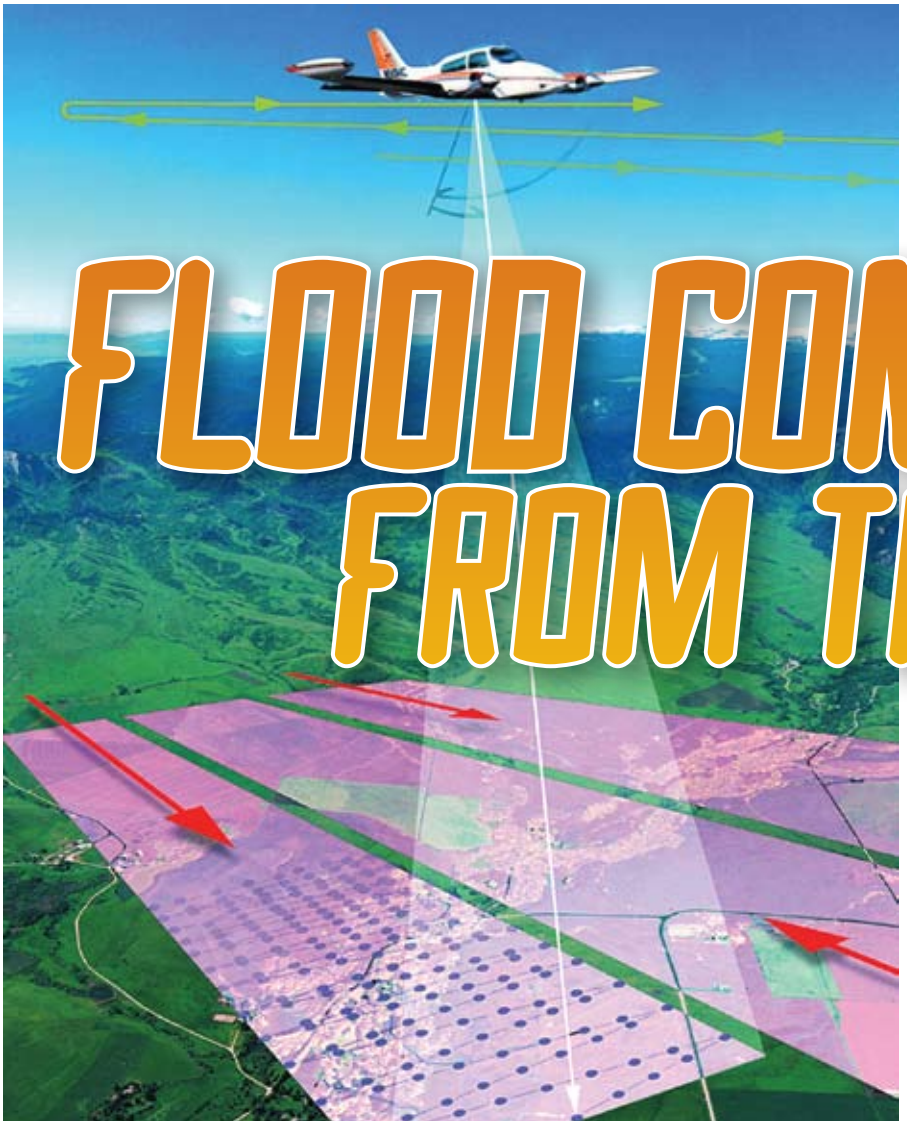


FLOOD CONTROL FROM THE AIR

Advances in LiDAR data collection technology improve flood management in the Red River Basin.

BY DAVID A. WEBB, CP

Above: The collection of highly accurate LiDAR data is expected to improve flood management and response in the Red River Basin. Illustration by Greg Geiger, www.freestylle.net.

The Red River flows northward at a minimal slope as it traverses the relatively flat terrain between North Dakota and Minnesota. As the snow melts and the rains begin each spring, the rising water challenges the river's capacity. At least once a year, the Red River overflows its banks. Most of these floods are minor; however, in 1997, an extreme set of conditions conspired to create the region's most disastrous flood since 1826. Heavy winter snowfall, fluctuating spring temperatures, early spring rains and an April blizzard caused unprecedented runoff into the Red River Basin. Rising river levels caused extensive backflow into tributaries, and the river banks and supporting systems simply could not contain the increased water volume. Floodwaters crested at a record 54 feet in Grand Forks, N.D., and reached three miles inland there and in the twin city of East Grand Forks, Minn. Approximately 60,000 residents were forced to evacuate their homes; some never returned. Damage from the flood totaled $3.5 billion.

This event highlighted the need for improved elevation data throughout the Red River Basin to help scientists and decision makers better understand, predict and respond to future flood events. "The 1997 flood was an unprecedented and historic event that stressed–and in some cases exceeded–the mathematical limits of flood-modeling software as well as our understanding of floods in this region," explains Charles Fritz, director of the International Water Institute (IWI). The devastation caused by the flood sparked the creation of the Red River Basin Mapping Initiative, a $5 million program that was officially launched in May 2008 to collect high-accuracy elevation data over the entire U.S. portion of the Red River Basin using airborne LiDAR mapping technology.

"Much of the uncertainty in current forecasting models is related to the unknown influence of overland flooding from ungaged hydrological basin inputs," Fritz says. "A seamless, highly accurate digital elevation model [DEM] for the entire Red River Basin will enable flood managers to more accurately estimate and model the ungaged hydrological flows entering the Red River system."

Securing Interagency Funding

The long path to funding the initiative started in 2000 with the formation of the International Water Institute within North Dakota State University at Fargo. Organized by recommendation of the International

Flood Mitigation Initiative, which is funded by the Federal Emergency Management Agency (FEMA), the institute is tasked with coordinating watershed education, information and research in the Red River Basin.

In its first year, the institute hosted a digital elevation meeting to explore terrain-mapping technologies and potential funding opportunities. Meetings continued annually, and letters of support for a large-scale mapping program were generated, yet obtaining funding for the estimated $5 million project remained an obstacle. Following a meeting in 2005, Fritz requested a resolution of support from the Minnesota Red River Watershed Management Board along with a financial commitment. The board agreed, authorizing up to $500,000 if matching contributions could be secured from its counterpart in North Dakota and from the federal government.

Over the next two-and-a-half years, Fritz organized an aggressive funding strategy that would eventually include 13 local, state and federal partners. "Obtaining the financial commitment from local and regional entities was relatively easy because they were close to the problems, had vivid memories of the 1997 flood and the need for better elevation data, and they understood how they could use these data to improve response to flood events and make defendable resource management decisions," Fritz says. But as he moved up the government ladder, the challenges increased substantially due to limited budgets with different funding priorities. "There were even some strongly opposed to the project because they believed it was technologically impossible," he says.

This project map shows the Red River as it extends beyond the United States into Canada.

Working with state legislators and the congressional delegation, Fritz did eventually secure full funding in 2007. He credits U.S. Sen. Byron Dorgan from North Dakota, Minnesota state Sen. Keith Langseth and North Dakota state Sen. Tom Fischer for overcoming the final budget challenge. A formal request for proposals was issued nationally by the institute in November of that year. In December, Fugro Horizons of Rapid City, S.D., was selected as the most qualified firm to perform the Red River Basin Mapping Initiative.

The Right Technology at the Right Time

The funding opposition Fritz faced from state government officials who believed the project was not technologically feasible wasn't completely unfounded. The project required a 15-centimeter (6-inch) vertical accuracy root mean square error (RMSE) to support FEMA standards for flood-plain mapping. Given the large project size–41,700 square miles–and the goal to complete the project within a two-and-a-half year time frame, the project seemed daunting, especially when using standard airborne LiDAR mapping technology.

In 2007, however, Leica Geosystems released its Leica ALS50-II airborne laser scanner system, which included numerous improvements over existing technology. With a maximum pulse rate frequency of 150,000 pulses per second and the ability to maintain clean pulse patterns at higher acquisition altitudes, the Leica ALS50-II allows for more efficient and cost-effective LiDAR data collection, gains that are realized with the addition of Leica's new Multiple Pulse in the Air (MPiA) upgrade. When equipped with MPiA, the ALS50-II can fire a second outgoing pulse prior to receiving all returns from the first outgoing pulse. The result significantly increases point densities for a given set of collection parameters compared to conventional LiDAR technologies.

Fugro Horizons Inc. and its airborne partners on the project, Fugro EarthData Inc. and North West Geomatics Ltd. (also known as North West Group), had each invested in an ALS50-II MPiA system that year. "For us, this new technology really made the Red River project possible," says Guy Meiron, vice president of engineering for Fugro Horizons. "The ability to field match three Leica ALS50-II MPiA systems for the same mass collect meant we could ensure a high standard of data consistency across the project."

In addition to the LiDAR data collection, the project also calls for concurrent leaf-off imagery over the central corridor of the Red River. As a quality-control measure, the imagery will be used to define LiDAR point classifications throughout the toughest vegetation along the Red River. The imagery will also provide a basis for future photogrammetric collection of water-body and terrain breaklines to further supplement the LiDAR-based DEM.

Making the Most of Modern Tools

Even with the advantages of the latest-generation airborne LiDAR technology, meeting the project delivery schedule of two-and-a-half years is a huge undertaking, especially given the relatively small window for data collection between long periods of snow cover. To meet this challenge, the data acquisition mission is designed to take place in five phases during three spring and two fall flying seasons.

Airborne Acquisition

Each phase was originally planned to cover about 8,000 square miles of acquisition and processing with the first acquisition beginning in spring 2008. With three aircraft dedicated to LiDAR collection and one aircraft for the photography acquisition, the Fugro Horizons team was onsite from mid-April to the end of May. Looking to capitalize on what turned out to be optimal flying conditions, the team increased their anticipated collection of 12,000 square miles of flight-line data.

The National Guard transported U.S. Geological Survey personnel from East Grand Forks, Minn., to Grand Forks, N.D., by way of the flooded Sorlie Bridge. Photo courtesy of the U.S. Geological Survey.

LiDAR data were acquired at 8,000 feet above mean terrain (AMT) from three twin-engine aircraft. The ALS50-II systems were set to collect data at a 45-degree field of view with an average post spacing of 1.37 meters and reflection intensity values of 3+4 return pulse mode–i.e., recording up to four LiDAR returned pulse signals at a time. Color aerial photography was acquired at 17,500 feet AMT using a 6-inch focal length, film-based Zeiss RMK TOP 15 camera, which was equipped with a high-resolution, distortion-free lens and forward-motion compensation. Both data collection types employed airborne GPS, and the LiDAR collection further employed inertial measurement unit (IMU) technology for position and orientation information thereby reducing the number of GPS ground survey points needed to control the mapping output.

Over the course of four-and-a-half weeks, the flight crews averaged nine data-acquisition flights per week with a maximum of 15 mobilizations when conditions were ideal. In the end, the team flew a total of 415 flight lines to cover nearly 20,000 flight-line miles, far exceeding expectations for a single aerial data acquisition phase. The total land area mapped during this first mission covered almost 18,000 square miles, nearly 10,000 square miles more than called for in the original contract.

According to Marshall Swenson, vice president of flight operations for Fugro Horizons, several factors led to the success of this initial acquisition phase. "First, we based the LiDAR collect on proven configurations that we have used for other large-area missions in support of flood-plain mapping programs," he says. "Second, communications among the Fugro Horizons, Fugro EarthData and North West Group have been honed through years of teaming together on large projects, which streamlines our flight-coordination efforts."

Swenson also notes that the team had a certain measure of good luck with the spring weather, which was ideal for flying. As a result, IWI allowed Fugro Horizons to focus exclusively on data acquisition in the first phase, which enabled the team to log more flight miles and gather more data than originally planned.

Data Processing

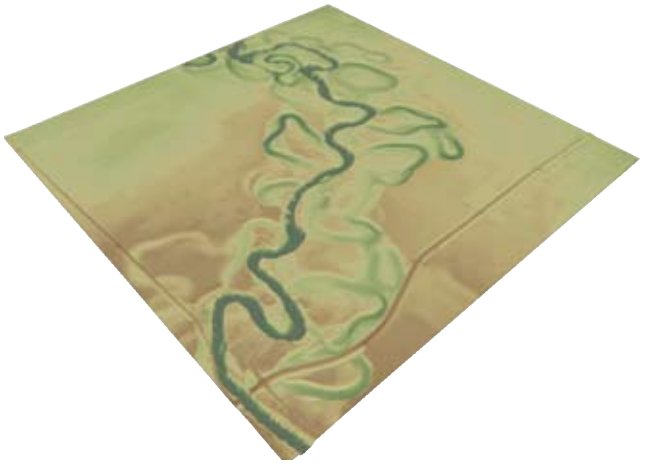
Using its own proprietary bore-site calibration software, Fugro Horizons preprocessed the raw LiDAR, GPS and IMU data to the required 15-centimeter vertical and 1-meter horizontal RMSE accuracy requirement. The data set for each flight line was also checked to ensure project area coverage, detect data gaps between overlapping flight lines and evaluate tension/compression areas (sections where data points were more or less dense than the average project-specified post spacing). Production staff then processed the LiDAR data into the project coordinates removing overlaps and clipping the data sets to extend a buffer area surrounding the project boundaries.

Surfacing of the total data set, also achieved with proprietary software, eliminated noise and other obvious erroneous elevation points. Computer algorithms were used to perform automated removal of some structures and vegetation to derive the bare-earth elevation model. Staff then edited the surfaced bare-earth LiDAR data and stereo imagery using softcopy photogrammetric workstations with 3D viewing and compilation capabilities.

Quality Control

Houston Engineering Inc., based out of Fargo, N.D., is working under a separate contract with the institute to provide independent quality control of the LiDAR data. The firm's multistep efforts include a systematic check to ensure files are complete; a comparison between check points and LiDAR deliverables to calculate the RMSE; and a visual assessment to evaluate any data voids, misclassifications and anomalies. To date, the quality-control reports prove the data to be solid. After 59 check points were performed on the first block of delivered data, the RMSEs were 9.4 centimeters for low grass/open ground, 11.6 centimeters for high grass, 12.7 centimeters for brush, 6.4 centimeters for forested areas, and 6.9 centimeter for urban areas, with an average RMSE of 9.6 centimeters for the entire first block of data.

"Under real-life project application and stringent quality control and assessment, the high accuracies we are achieving over the Red River Basin are a direct result of the most advanced LiDAR instrumentation and good project execution," says Paul Harwig, president of Fugro Horizons. "Enabling a higher-quality DEM than previously possible, these acquisition and processing advancements are also working to eliminate some of the recognized difficulties with determining orthometric heights from LiDAR data."



This 3D perspective view of the LiDAR data shows how the river has meandered over the years. The dark green is the current river channel.

Final Deliveries and Usage

Airborne acquisition for the second scheduled mission began in late October. Weather permitting, this mission will complete data collection over the western half of the project putting the entire Red River Basin Mapping Initiative on track for completion up to six months early.

"Expanding the data collection areas for each planned mission has definitely helped us get in front of the project schedule," says Gene Ensor, project manager at Fugro Horizons. "Progressively delivering 3,500 square miles of data every 60 days allows us to ensure that our approach is sound and required RMSE accuracies are being met or exceeded before moving on to the next project phase. Keeping the processing and quality control three to six months ahead of the next LiDAR and film collect has allowed for resource leveling in all areas."

When complete, the project will vastly improve upon the current patchwork of mixed data sets that now comprise the base-level elevation data for the region. And though improved flood management and response was the primary motivation for this project, the institute and its funding partners have numerous plans for the LiDAR data, which will be made publicly available through CLICK, the USGS Center for LiDAR Information Coordination and Knowledge Web site.

"From the very beginning, the Red River Basin Mapping Initiative has been about making better and more defendable resource-management decisions," Fritz says. "Applications of LiDAR data are boundless and limited only by our ability to comprehend how these data will eventually be integrated with existing and new technologies to make decisions that enhance the lives of residents in the Red River Basin."

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Web Exclusive: *View this article at www.pobonline.com for details on the ground survey portion of this project.*