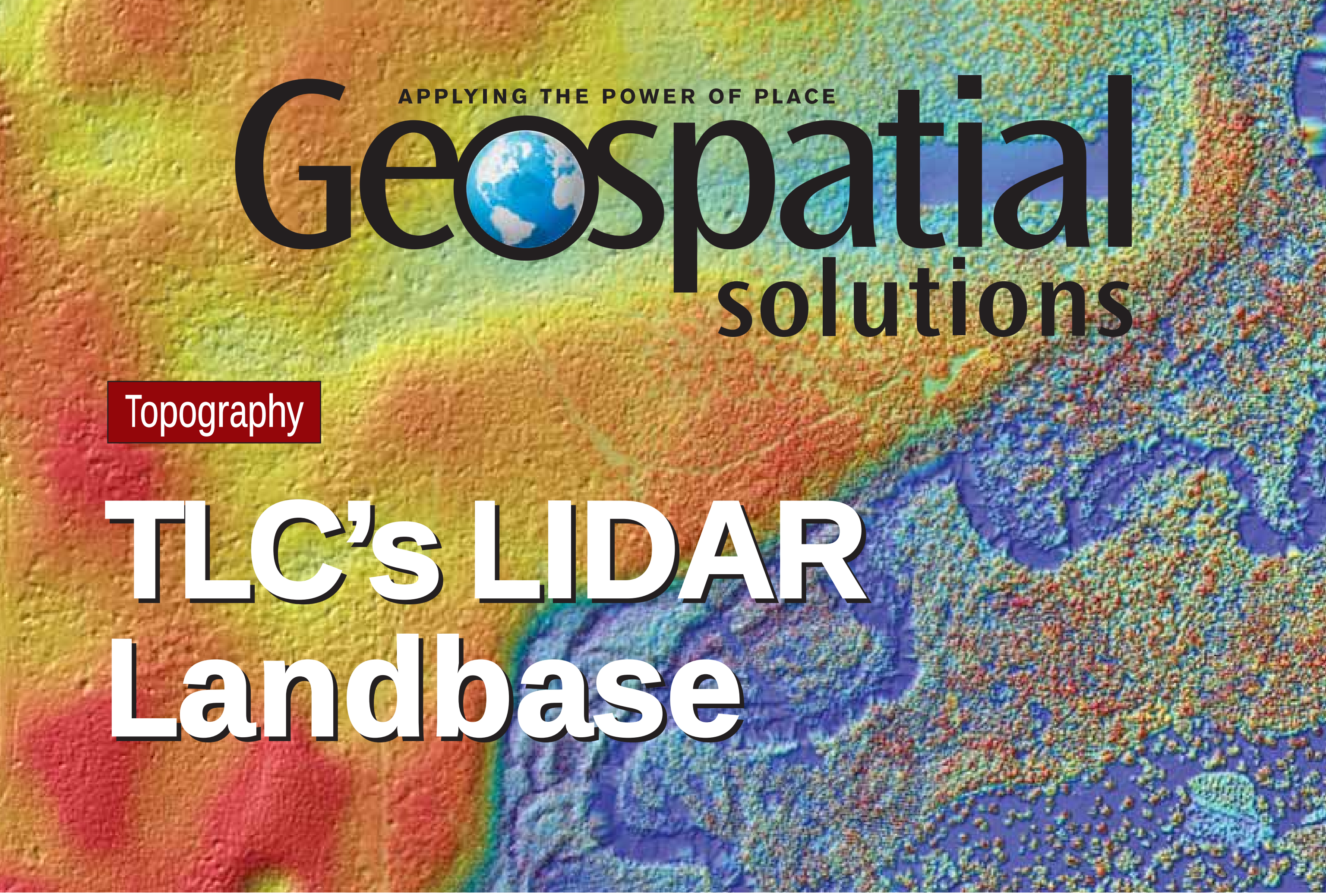

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# TLC's LIDAR Landbase

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**To resolve issues related to landbase inconsistencies, a consortium of stakeholders in the Tallahassee/Leon County GIS turned to LIDAR to update their topographic database, validating results and accuracies via GPS and conventional surveying.**

In January 2001, a consortium comprising the City of Tallahassee, the Leon County Board of Commissioners, and the Leon County Property Appraiser (known as Tallahassee/Leon County, or TLC) contracted a project with an aerial and geospatial services firm to update their legacy planimetric, topographic, and orthophoto databases. The contract included program management, aerial photography, aerotriangulation, softcopy photogrammetric updating of digital terrain models (DTMs), planimetry, contour generation, and aerial image rectification.

What started out to be a routine photogrammetric maintenance project, however, quickly changed following the first delivery of data. At that time, several inherent problems in the existing topographic data prompted some participants in the consortium to ask "Why were we updating the contour layer that nobody liked?"

Apparently, since TLC's establishment via an interlocal agreement in 1990 to jointly develop and implement GIS with a common landbase, problems arose as a result of consortium members relying on different technologies, procedures, accuracies, and datums. These differences plagued the reliability of legacy datasets, and although these topographic databases met, for the most part, the agreed-upon specifications, the interlocal user community had differing opinions about them. Consequently, when the contractor began delivering updated data to TLC, all the consortium participants' concerns came to the fore. Several discussions ensued, and ultimately the consultant was tasked to evaluate the issues that consortium members had raised with regard to the existing topographic databases.

## Finding a Solution

In order to propose a solution for TLC's landbase,

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the consultant began by independently reviewing and evaluating each consortium member's topographic databases. It then held several meetings to discuss the findings and asked all participants to consider themselves as both partners and stakeholders in this consulting effort. This led to the creation of the Topographic Data Partnership (TDP) and was an extremely important concept for enabling everyone to formulate joint solutions that met the needs of all the involved parties.

During these workshops, the consultant outlined the variety of technologies available to create topographic data so that partners could make intelligent decisions about which direction to pursue. It was important to review older technologies and procedures during these meetings because several of the existing topographic databases relied on such methods. Thus, the techniques discussed with the TDP members were contour-string digitizing, photogrammetric digital terrain model generation, LIDAR (light detection and ranging), and LIDAR enhanced with photogrammetry.

After careful review of all the information about the existing topographic databases, TDP stakeholders arrived at several realizations about their data and decided to investigate LIDAR technology as a means of producing more accurate and complete topographic databases. They contracted the consultant to perform a demonstration project using LIDAR data for a sample area. If that demonstration was successful, TLC would produce a LIDAR database for the entire county.

## Collecting LIDAR

The consultant executed the data collection using its aircraft-mounted LIDAR system in January 2002. The LIDAR technology rapidly transmits pulses of light that reflect off the terrain and other objects (for example, trees, buildings, and power poles). The return pulses are converted from photons to electrical impulses and are collected by a high-speed data recorder that is located in the aircraft. Because the formula for the speed of light is well-known, time intervals from transmission to collection are easily derived. These time intervals are converted to distance based on positional information obtained from GPS receivers and an on-board inertial measurement unit (IMU) that constantly records the attitude (pitch, roll, and heading) of the aircraft.

Although there is control over the density and spacing of the collected elevation points using LIDAR, there is absolutely no way to determine the ground location of these points. For this reason, LIDAR is often called a "blind" data-collection process. However, by compiling photogrammetric breaklines, it is possible to define such features in the LIDAR data as bridges, road edges, and walls more accurately. In addition, the LIDAR system deployed by the consultant was capable of 50-KHz pulse rates and operated with a 30-degree field-of-view (FOV). The small FOV (15 degrees each side off nadir) provided a 30-degree side overlap for each flight line, and the large size of the laser's footprint, coupled with its high pulse rate, resulted in the collection of more ground points (laser returns that penetrated the heavy vegetative cover in the county).

Isolating and determining which laser returns were from ground points was also accomplished during postprocessing using filter algorithms and techniques. This additional processing was neces-

The consultant's aircraft for acquiring LIDAR data.

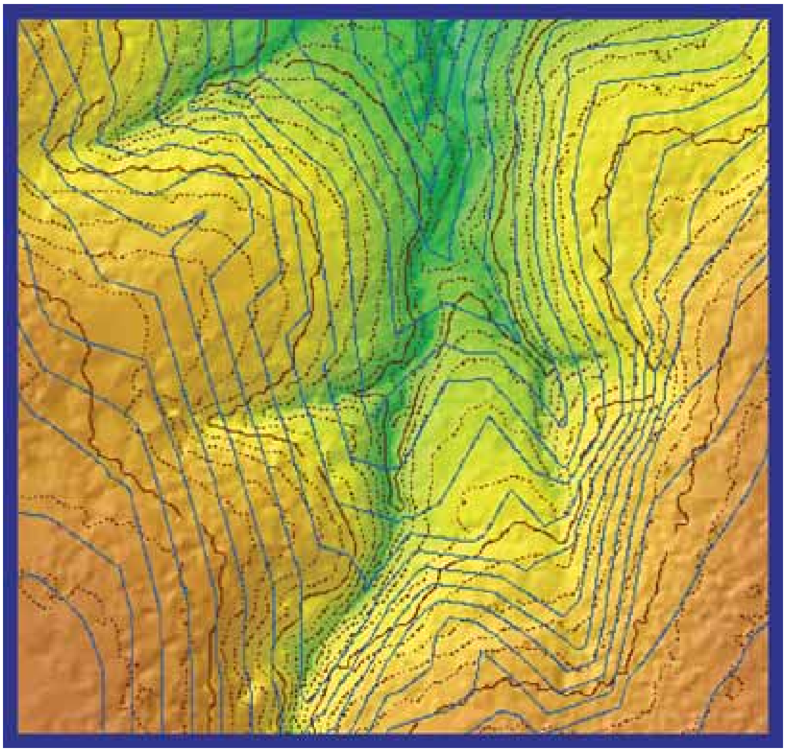


**Figure 1.** TLC's existing topographic data disagreed dramatically with the actual terrain. The blue contour lines in this figure were derived from the old DTM, and the brown contour lines were derived from the new LIDAR data.

sary because each laser pulse results in multiple returns of varying intensity. For example, a first return from a single laser pulse may indicate tree canopy, a second weaker return might denote low-lying vegetation under that canopy, and an even weaker third return could result from the laser bouncing off the bare earth. By using filtering algorithms and postprocessing routines, the consultant was able to remove the first return (canopy data) to derive a remaining set of points representing the bare earth under that vegetation canopy. The consultant postprocessed the data using supplemental breaklines, imagery-validation routines, and quality-control procedures as well.

After completing the LIDAR postprocessing, the consultant held another workshop with the TDP stakeholders. The workshop included a discussion of the techniques used as well as a hands-on demonstration of the resulting LIDAR databases for the study area. Results of the prototype LIDAR data are illustrated in Figure 1 and Figures 2a–2c. Figure 1 shows how TLC's existing topographic data disagreed dramatically with the actual LIDAR-collected terrain. The blue contour lines were derived from an old DTM and the brown contour lines were derived from the new LIDAR data. Figures 2a–2c evince how entire drainages were excluded in the old DTM-derived contours, showing how laser technology was able to produce results where traditional photogrammetry could not. In these examples, an ancient river-drainage system was uncovered under the tree canopy.

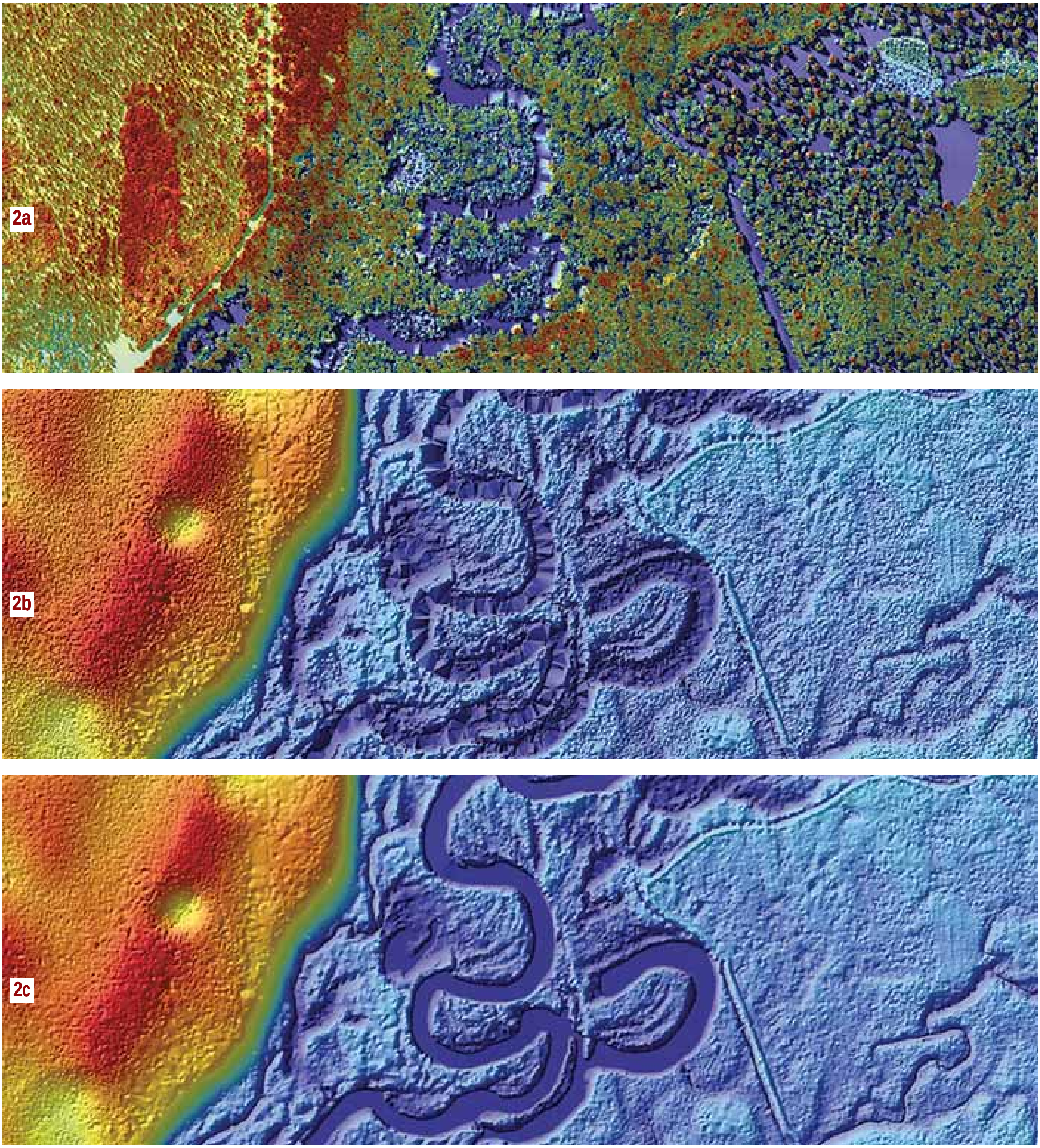
The results illustrated in Figures 2a–2c were a particularly dramatic illustration of the power of LIDAR for TLC because the area is susceptible to flooding during hurricanes. As Greg Mauldin, GIS analyst for Leon County, explained, "Because of these data, we will now be able to plan and design more accurate drainage scenarios. This will be critical during evacuation planning during hurricane season."

Other advantages of LIDAR-derived data became apparent to TLC members during the workshops as well, and as a result, the consortium contracted the consultant to collect LIDAR data and deliver a topographic database for TLC's entire 750-square-mile service area.

## The Ground-Truth Survey

The consultant executed the LIDAR filtering, processing, and photogrammetric breakline enhancements for the entire county in November 2002 and delivered the topographic database to TLC in December 2003. The TLC stakeholders knew that LIDAR would produce more accurate elevation data when compared with their traditional photogrammetric DTMs. However, they needed a method to validate the increased accuracy obtained by using the LIDAR digital surface model (DSM). Consequently, the next step in the project involved conducting a ground-truth survey, and TLC worked very closely with the consultant to create a survey plan.

For the validation, TLC required GPS and conventional vertical points to be surveyed in order to quantify the results of the LIDAR acquisition strategy and digital vegetation removal (filtering) in obscured regions of the county. Indeed, it is common to perform ground-truth surveying during or following a LIDAR mission. The primary purpose of this type of validation is to assist in determining how accurate the contour and elevation data are in obscured areas. This step is very important, given that LIDAR datasets are typically held to a higher standard than traditional photogrammetrically com-




**Figures 2a–2c.** The LIDAR data revealed that TLC's old DTM-derived contours excluded entire drainages. In these examples, an ancient river-drainage system was discovered under the tree canopy. Figure **2a** is the raw LIDAR data, **2b** is auto-filtered, and **2c** is enhanced with photogrammetric-breakline collection.

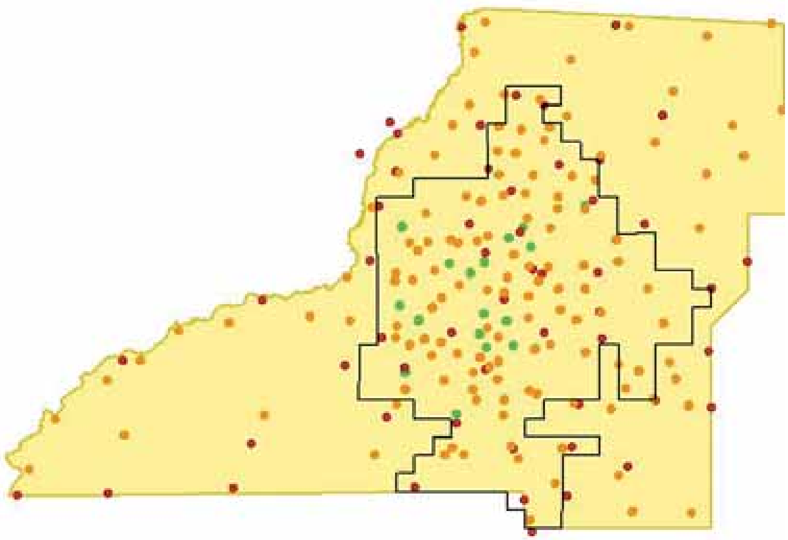


**Figure 3.** This map of Leon County shows the location of the vegetation and pavement ground-truth points. Although the majority of the points are located within the Tallahassee metropolitan area, they are well-distributed throughout the county overall.

piled DTMs. That is, a photogrammetric DTM in an obscured area (a heavily vegetated region in which elevations cannot be compiled) is typically held to an accuracy standard based on the height of the vegetation in that particular area. Therefore, in the dense forests of Leon County, where the average tree height is 80 feet, the contour accuracy for a photogrammetric DTM would need to meet a ±40-foot accuracy standard. Conversely, a LIDAR-derived DSM would be expected to be accurate to ±1.5 feet or less.

To determine the accuracy of the LIDAR DSM for Tallahassee and Leon County, a ground-truth survey was conducted during April 2003 in such unique urban land-use/land-cover subregions as bare earth and low grass, high grass, fully covered coniferous trees, fully covered deciduous trees, ravine areas, and sandy areas. The survey plan consisted of analyzing several land-use and vegetation classification categories in these areas. The final vegetation types used in the ground-truth survey included tall grass, hardwood forest, live oak hammock, open pine forest, pine forest, mixed pine and hardwood, sandy soil with pine, sand and grass, and shrubs. The actual locations of the survey areas were thoughtfully selected based on knowledgeable resources at TLC. As Doug Jacoby, the consultant's GIS project manager, noted, "The ground-truth locations adequately represented the biodiversity of the county."

The ground-truth accuracy assessment included surveying individual points and cross sections in marshes, under trees, on low-ground cover, and in urban areas across Leon County. Two Tallahassee companies, Diversified Design & Drafting Services and Allen Nobles & Associates, completed the actual field-surveying tasks. When surveying in heavily vegetated areas, which was most of the time, they used digital levels to collect the ground-truth elevations. Where feasible, they employed survey-grade GPS receivers.

In total, the surveyors collected approximately 850 independent points in heavy vegetation as part of the ground-truth survey. Figure 3 is a map of Leon County illustrating the location of the vegetation and pavement ground-truth points. The points are well-distributed throughout the county. Additionally, the majority of the points are located within the Tallahassee metropolitan boundary.

**Quantifying the Accuracy.** Based on the ground-truth survey data, TLC and the photogrammetric consulting firm deployed LIDAR data-processing software to quantify the vertical accuracy of the bare-earth DSM. Table 1 shows the results of a ground-truth survey by primary vegetation classification. These results clearly indicate that the LIDAR collection and

**Table 1.** Results of the TLC ground-truth survey in heavy vegetation

| | Tall Grass | Hardwood | Live Oak Hammock | Mixed Pine/ Hardwood | Open Pine | Pine | Sand/ Pine | Sand/ Grass | Shrub |
|---|---|---|---|---|---|---|---|---|---|
| RMS | 0.69' | 0.63' | 0.41' | 0.81' | 0.58' | 0.58' | 0.68' | 0.92' | 0.69' |
| Ground Truth Points | 262 | 31 | 25 | 171 | 64 | 89 | 25 | 31 | 119 |

**Table 2.** Results of the unobscured urban ground-truth points

| | #Pts | Standard Deviation | Mean Error | Minimum Error | Maximum Error | SSE | RMSE |
|---|---|---|---|---|---|---|---|
| Photo Control | 58 | 0.35 | -0.02 | -1.30 | 0.94 | 7.098 | 0.349 |
| Pavement | 218 | 0.52 | -0.05 | -2.39 | 2.09 | 59.081 | 0.520 |

postprocessing procedures yielded excellent results in each vegetation class that was evaluated in the ground-truth study. Moreover, the extra cost for the ground-truth surveys proved to be justifiable because users now have quantifiable accuracy statistics and know exactly what to expect in all areas of the project when working with the data.

Ground truthing was also undertaken in unobscured urban environments, with an additional 276 independent survey points collected in open, hard-surface areas (pavement on roads and parking lots). Table 2 summarizes the accuracy of the LIDAR DSM based on the ground-truthing results in these areas. The findings of that analysis were as expected.

It should be noted that although the results and accuracies may be unique to this project, the consultant and TLC believe that LIDAR will produce similar results with a comparable conservative flight plan. This plan included a low-altitude flight, high laser-pulse rate, large beam footprint, adequate flight-line side overlap, and application of advanced filtering methodologies.

In the future, the consulting photogrammetric firm plans to create a database of ground-truth results for all its LIDAR projects, with the goal of modeling the behavior of LIDAR and filtering techniques for specific vegetation and land-use types. These types of advanced databases, in conjunction with research being performed by universities and manufactures, will ultimately provide the user community with valuable information concerning the performance of LIDAR in heavy vegetation.

## Keeping Current

With the LIDAR database now integrated into TLC's business processes and everyday use, maintaining the currency and accuracy is a priority. TLC had traditionally updated the landbase for the entire county at the same time every five years. Interest in normalizing annual budgets and an ever-increasing need to keep the landbase more current, however, has prompted TLC to adopt a new incremental update methodology. The incremental updating will be based on the division of the county into three mostly urban sections and six mostly rural sections. One urban section and one rural section will be mapped and updated each year. This strategy allows the urban area to be updated every three years, and the entire county every six years. In addition to these predefined areas, TLC may elect to add additional isolated "hot spot" areas (typically those undergoing development) to the update cycle. Figure 4 identifies some possible areas for updating.

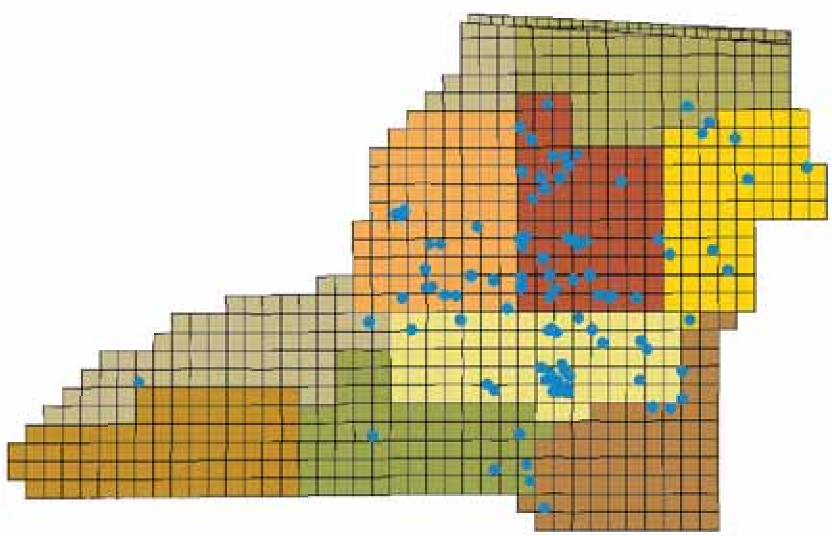


**Figure 4.** In addition to predefined areas, TLC may elect to add additional isolated "hot spot" areas to its data-update cycle. This map identifies some possible areas for updating.

When new data are captured and delivered, TLC will rely on an automated change-detection methodology codeveloped with its consultant. This methodology will assist with locating modifications to the planimetric and topographic landbase and will be executed using one of the consultant's software tools, which TLC has integrated into its business processes, augmented with local data.

## Awarding Benefits

Overall, the LIDAR project proved to be a great success for updating TLC's entire topographic landbase. In fact, because of the very high-accuracy results, applications for the data, and that acceptance of the database by the consortium's geospatial user community, TLC and the consultant received several industry awards. In 2003, the project was awarded a first-place prize in Colorado (the consultant's home state) for the Topographic Data Partnering and LIDAR Project into the American Council of Engineering Companies (ACEC) annual design competition. This achievement made the project eligible for the national ACEC competition, where it was awarded honorable-mention recognition. The project also received the prestigious Urban and Regional Information Systems Association (URISA) Exemplary Systems in Government (ESIG) Award in 2003. This award recognized exceptional achievements in the Single Process Systems category

To determine the accuracy of the LIDAR DSM for Tallahassee and Leon County, a ground-truth survey was conducted using GPS and traditional surveying methods under some of the difficult heavy-vegetation locations within the region.

as an outstanding and working example of applying information-system technology to automate a specific process or operation of an agency.

In addition to the awards, TLC has experienced numerous other benefits. The project enabled the consortium to illustrate how landbase projects save taxpayers time and money, and it reaffirmed the trust and common set of objectives shared among the stakeholders in the 15-year-old consortium. The excellent results obtained by the LIDAR project additionally demonstrated significant social, economic, and sustainable design that will have many future benefits to the citizens of Tallahassee and Leon County. For example, a program called Blueprint 2000 — a wide-ranging set of projects that promises to reshape Tallahassee in the coming decades with a series of public-works activities for transportation, storm water, flood control, and environmental projects — will be taking advantage of the highly accurate LIDAR data. Finally, the LIDAR data have enabled TLC stakeholders to be better-prepared to respond to and mitigate the impact of such natural disasters as hurricanes and floods, to which the area is susceptible.

## Manufacturers

**Merrick & Company** served as the consultant and prime contractor for the TLC project. It completed the LIDAR acquisition using the airborne laser topographic mapping system based on the **LH Systems** (now **Leica Geosystems GIS & Mapping**) ALS40 platform. That system includes an **Applanix** POS/AV IMU/GPS unit (the current version of POS/AV contains a **Trimble** BD950 GPS receiver) and a GPS flight-management system from **Track'Air**. The laser system is mounted in a **Cessna** 402C twin-engine aircraft. **Diversified Design & Drafting Services** and **Allen Nobles & Associates** completed the field GPS ground truthing and surveying using Trimble GPS units. Merrick's MARS® LIDAR processing software was used to quantify and validate the accuracy of the DSM. TLC integrated Merrick's Tracker software into its process for identifying topographic changes as new LIDAR data are collected and delivered. ⊕

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