Looking Northward in Kings Bay Pilot Area.

Topo-Bathymetric Lidar on the Springs Coast of Florida

Introduction

In peninsular Florida, where the soluble limestones of the Upper Floridan aquifer occur close to the land surface and are not covered by confining sands, terrains of the Southwest Florida Water Management District (SWFWMD, District) have developed into karst landscapes, characterized by sinkholes, sinking streams, underground caverns, and springs. This "Springs Coast" of Florida extends from Anclote Key off Pasco/Pinellas County, Florida northward through the "Big Bend" Region of the Gulf of Mexico where numerous 1st and 2nd order springs emerge both on land and under the Gulf waters.

The King's Bay Springs group (aka Crystal River Springs), in Citrus County, Florida is the second largest springs system in the state (Vanasse Hangen Brustlin Inc., 2009). Over 70 springs, including several, large, named springs, such as Black Springs, Tarpon Hole and Hunter's Spring, are distributed over a 600-acre inland bay forming

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the headwaters of the Crystal River. The springs' cumulative discharge of approximately 567 million gallons per day of mostly fresh, warm water attracts both tourists and the West Indian Manatee population. During the cold winter months when visitors flock to the area to "Swim with the Manatees", it is not uncommon to see more than 300 manatees congregating in the warm waters of the Hunter's Spring.

With the combination of clear, spring-fed water, the manatees, and other natural resources in the area, such as, the Crystal River National Wildlife Refuge, a constant influx of tourists augment and support the nearly 4000 permanent residents of Crystal River. The popularity of the area brought residences, commerce, and excessive nutrients to the bay. As the nutrient-rich water accumulated in the sinkholes, *Lyngbya ssp.*, an invasive algae, flourished. *Lyngbya* forms dense clusters on the rocky, limestone bottom, extends onto the sandy bottom, floats in the water column, and forms large algal mats on the surface inhibiting many recreational activities. The nutrients, algae, and debris interact to fill karst depressions with organic-rich materials which require removal to insure the bay's aquatic health. Hence, the District engaged in a survey to determine the volume of material, algae, muck, debris, etc. to be removed from King's Bay.

In the Spring of 2015, through a cooperative pilot project with the Joint Airborne Lidar Bathymetric Technical Center of Expertise (JALBTCX) and Dewberry Consultants, LLC, a Teledyne-Optech Coastal Zone Mapping and Imaging LiDAR (CZMIL) sensor was used to collect topobathymetric lidar data for a portion of the Kings Bay/Three Sisters springs system in Citrus County, Florida. During that same period, the District also engaged a local hydrographic survey firm to employ "traditional" survey instruments, a single-beam fathometer (Odom MK III-200 kHz) and a low-frequency Sub-bottom Profiler (Ross 8510 – 3.5kHZ), to survey the King's Bay bathymetry. Thus, the project gave the District an opportunity to compare the CZMIL lidar-derived measurements of top and bottom (=derived volume) of unconsolidated materials with comparable conventional survey-derived volumes.

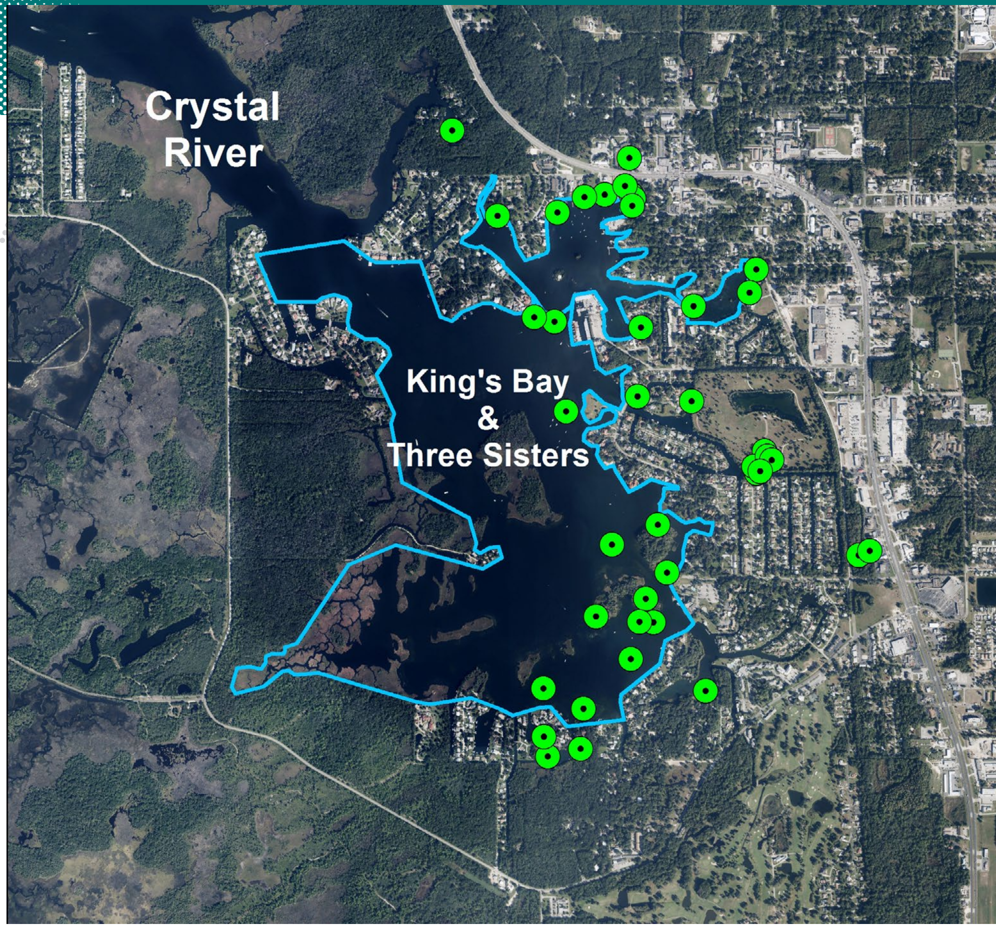

Figure 1: Aerial image of the King's Bay Pilot Project area commonly called "The Phoenix" showing multiple named springs (green markers).

The Pilot Project Area

The area selected for the King's Bay Pilot Project is commonly called "The Phoenix" because of the general shape of the area, resembling the flying Phoenix (**Figure 1**). This one square-mile area contains numerous named springs, over 250 residences, tourist businesses, restaurants, and a commercial fishery. A commercial shipping channel leads from the fishery out to King's Bay proper and through the Crystal River, approximately 7 miles to the Gulf of Mexico.

Sensor Selection Criteria

The District and Dewberry discussed the various commercial sensors available to determine the most appropriate sensor to be used for this mission. Airborne Lidar Bathymetry (ALB) is an established operational technique which has been proven to be an accurate, efficient, highly cost-effective, safe, and flexible method for rapidly charting large and small projects in near-shore waters, navigation channels, coral reefs, coastal engineering structures and adjacent beaches. There are seven (7) variants of airborne lidar bathometers in operation today, each with a unique development history and resulting unique design. Different sensors available in the commercial industry have different characteristics, but they all follow the same basic principles. Some sensors exhibit characteristics to map shallow water at high resolution (often referred to as narrow beam systems), while other sensors attempt to map deeper bathymetry at a reduced spatial resolution (broad beam systems). For ALB sensors in general, scattering and absorption properties of the water column are the primary limitation for depth performance. If the water is too turbid, or has a high fraction of suspended sediments, bubbles, or organic material, the volume backscatter will be greater than the bottom return and no depth can be determined.

> "The SWFWMD found the CZMIL sensor provided a cost-effective and time-efficient method to obtain high quality bathymetric data for Kings Bay."

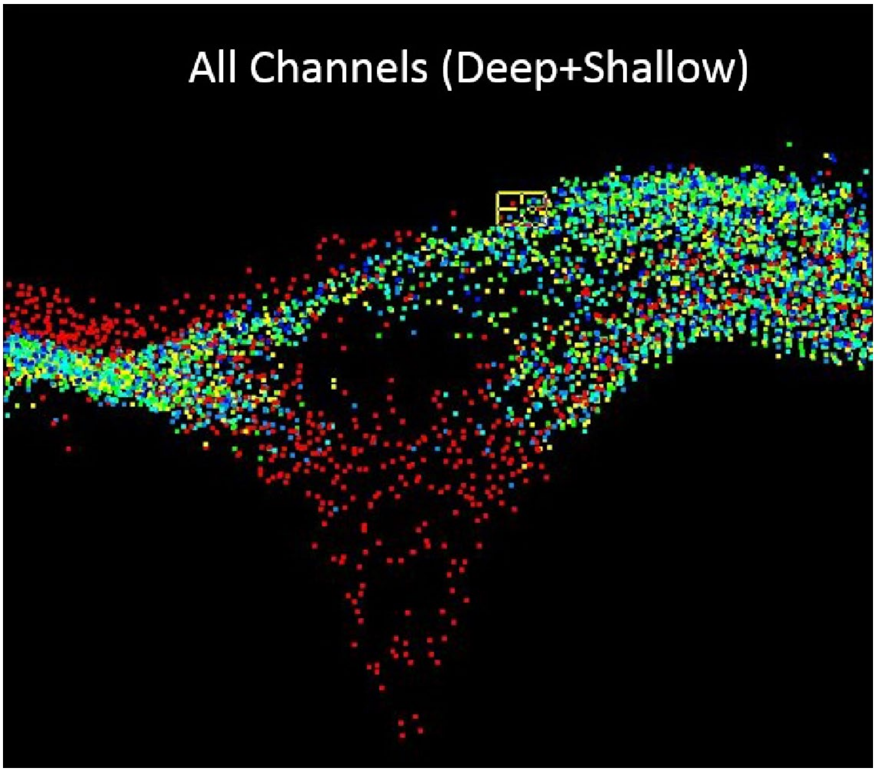

Figure 2: A profile across a spring from the CZMIL sensor in King's Bay. Red points are returns from the deep 40-mrad channel that profiles the depth in the spring vent, whereas the other colors represent returns from the 7 shallow 2-mrad channels that illustrates the returns from the shallow sea-floor.

Deriving reliable bathymetric measurements for this project required a sensor that was capable of mapping shallow bathymetry at high resolution as well as the deeper bathymetry in the spring vent. The system also had to be capable of mapping the depth of the unconsolidated layer to determine the volume of material, algae, muck, debris, etc. to be removed from King's Bay. This requires a relatively short-width pulse that has the ability to reflect off multiple targets over a short distance between the unconsolidated layer and the bottom of the sea floor. The CZMIL sensor was selected for this mission because it has characteristics of high resolution narrow-beam systems as well as broad-beam systems for deeper bathymetry.

The CZMIL laser emits pulses at a rate of 10,000 per second, each with 2-ns pulse width. The pulses are scanned using a spinning Fresnel prism. The resulting scan pattern is a circle on the water surface, with 2.8-m diameter laser footprints spaced 2-m apart. Operational altitude is 400 m and speed is typically 140 knots. CZMIL has three (3) receivers, one infrared Avalanche Photo Diode for surface detection, one deep field-of-view (40 milliradians) Photo Multiplier Tube (PMT) for deep water, and a shallow water receiver (6 milliradians) comprised of seven (7) PMT segments (2 milliradians each) for shallow water and topographic measurements. For shallow water and topography, measurement spacing is 70 cm. Lidar waveforms are digitized for each receiver and receiver segment, a total of 9 waveforms per laser pulse. This segmented detector approach enables high resolution and more accurate data for shallow water bathymetry, whereas the deeper channel enables lower resolution bathymetry in the deeper and more turbid waters. **Figure 2** elucidates the benefits of using the CZMIL sensor for this project – it depicts a profile cross-section across a sample spring in King's Bay. The shallow water bathymetry is determined using the 7 PMT segments (various colors except red) whereas the deeper bathymetry is obtained using the deep field-of-view PMT (red dots).

Classification of CZMIL LiDAR

The District contracted with Dewberry Consultants, LLC. to assist in refining the CZMIL LiDAR data, and to construct a hydrographic breakline to represent the land-water interface at the time of the overflight. Dewberry Consultants LLC. used a combination of Teledyne-Optech Hydrofusion, Pure File Magic Area Based Editor (PFM/ABE), and Microstation/Terrasolid software and other proprietary software to analyze the data. The ASPRS LAS 1.4 Bathymetric classification system was modified to include Class 46 defined as the "Top of Unconsolidated Material" as in **Table 1**.

With the CZMIL LiDAR data processed and a hydrographic breakline compiled, two – 5ft cell-size Digital

Table 1. ASPRS (LAS v1.4) Lidar Classes used in this study

CLASS	DESCRIPTION
2	Ground
40	Bathymetric Ground
41	Water Surface
42	Synthetic Water Surface
45	No bottom found
46	Top of Unconsolidated Material

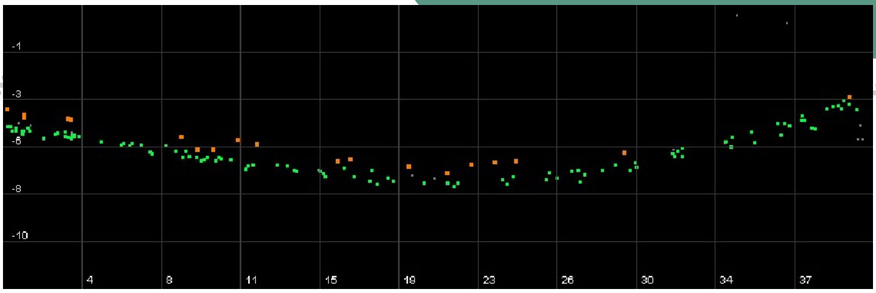

Figure 3: Typical CZMIL profile through a karst depression. Green points are Class 40 (Bathymetric Bottom) and Orange points are Class 46 (Top of the Unconsolidated).

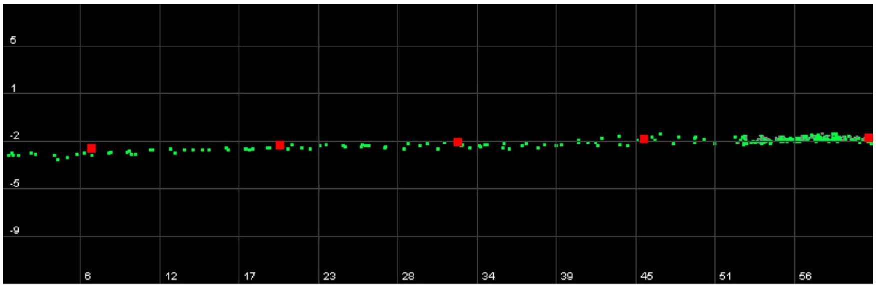

Figure 4: Typical profile through an area with no unconsolidated material. The Green points are Class 40 CZMIL and the Red squares are Ross 8510 soundings. There are no Orange (Class 46) points in this profile.

Elevation Models (DEMs) were constructed. One DEM was constructed to represent the bathymetric bottom of the Pilot Area. To construct this DEM, the Class 2 (Ground) and Class 40 (Bathymetric Ground) points were interpolated into a Triangular Irregular Network (TIN) using GeoCue – LP360 and extracted to a DEM. The second DEM was constructed to represent the top of the unconsolidated material, as a Digital Surface Model (DSM). This DEM/DSM was constructed by the same methodology as the first DEM, only using the Class 2 (Ground) and Class 46 (Top of Unconsolidated Material) classified LiDAR. Hence, the volume of unconsolidated material could be computed as the difference between DEM2 (top of unconsolidated) and DEM1 (bathymetric ground).

Figure 3 is a typical profile (10' wide) showing the Class 40 (Bathymetric Ground/Green) and the Class 46 (Top of Unconsolidated/Orange) CZMIL LiDAR. The unconsolidated layer is easily defined from the lowest bathymetric ground in this depression.

CZMIL LiDAR Accuracy Assessment

The conventional hydrographic survey conducted nearly concurrently with the CZMIL overflight provided an opportunity to assess the vertical accuracy of the LiDAR. The hydrographic survey was conducted at an interval of approximately 100-foot cross-sections with depth soundings recorded at approximately 20-foot intervals. This methodology resulted in measuring 2788 soundings with the Ross 8510 Sub-bottom Profiler for "hard bottom" and 1956 soundings with the Odom MKIII for the "top of the unconsolidated". For comparison, the CZMIL recorded 1,259,953 bathymetric reflections.

Figure 4 shows a typical hard-bottom profile. In these areas, neither the CZMIL nor the sonar identified any unconsolidated materials and the elevation data were nearly identical. The

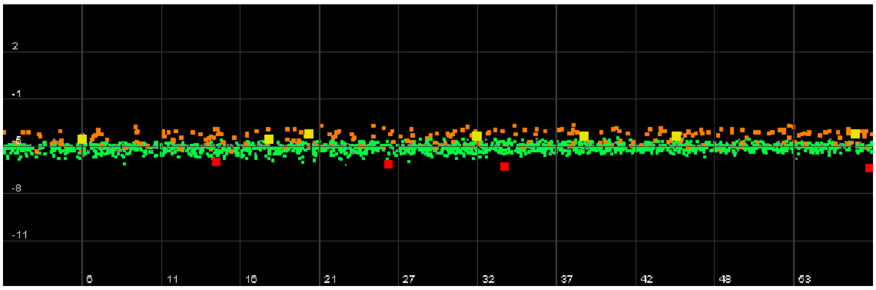

Figure 5: Typical profile through an area with unconsolidated material. The Green points are Class 40 CZMIL, the Orange points are Class 46 CZMIL and the Red squares are Ross 8510 soundings and the Yellow squares are the Odom MK III soundings.

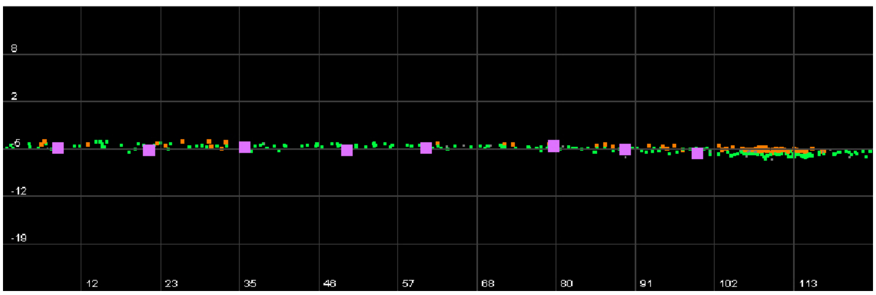

Figure 6: Typical profile through the USACE shipping channel at King's Bay. The Green points are Class 40 CZMIL, the Orange points are Class 46 CZMIL and the Purple squares are the USACE sonar data.

mean difference between 2573 sonar hard-bottom soundings from areas of only hardbottom and the closest CZMIL range the mean difference was –0.17 feet. When all 2788 hardbottom sonar points were compared to the CZMIL LiDAR, the mean difference increased to -0.43 feet. The error distribution was normal with a standard deviation of +/- 1.7' for all observations.

In areas where unconsolidated materials were found, the agreement among the three instruments (CZMIL, Ross 8510, and Odom MK III) was also good (**Figure 5**). Although these areas tended to be more "noisy" resulting from the higher density of CZMIL LiDAR reflections, the agreement was still obvious. The mean difference between the CZMIL LiDAR ranges for the Top of the Unconsolidated (Class 46) and the 1956 soundings from the Odom MK III fathometer was 0.2 feet with a standard deviation of +/- 0.9 feet. The distribution of these errors was also normal with a standard deviation of +/- 0.8'.

As a final accuracy assessment, the US-Army Corps of Engineers maintains a shipping channel from the Commercial Fishery, through the Pilot Area and into Kings Bay. The USACE last surveyed the shipping channel in March 2014, approximately 13 months prior to the CZMIL overflight. **Figure 6** shows the close agreement between the CZMIL LiDAR and the USACE soundings in the shipping channel. The mean difference for 147 USACE soundings in the Pilot Area was -0.1 foot with a standard deviation of +/- 0.4 feet.

Volumetric Calculations

To estimate the volume of unconsolidated material in the Pilot Area, the DEM constructed from the bathymetric ground CZMIL reflections was subtracted from the DEM/DSM constructed from the "Top of the Unconsolidated" material reflections. The results are shown in **Figure 6** where the majority of the unconsolidated material is shown to be between 0.5' – 1.5' in depth. The distribution of the unconsolidated material deposition demonstrates that more deposition occurs along the back-bay areas, back-water areas than in the central portion of the Pilot Area. Areas of active springs are seen as tan areas contained in the "Phoenix" (in **Figure 7**) illustrating "blow-out" areas resulting from the spring flow.

Using the "difference DEM" to compute the total volume of the unconsolidated material from these LiDAR-derived surfaces resulted in a volume of approximately 4 million cubic feet with a surface area of a little over 5 million square feet.

General Conclusions—Advantages and Disadvantages:

The close agreement between the CZMIL LiDAR ranges and the conventional sonar survey provided the District with a high level of confidence in the accuracy of the LiDAR-derived surfaces used for volumetric calculations. The District instructed its consultants to proceed to use the CZMIL LiDAR data, in lieu of the sonar survey data for all unconsolidated sediment thickness analyses, design drawings and conceptual options of probable cost for sediment removal. It was the District's finding that surface interpolations using the sonar data may introduce

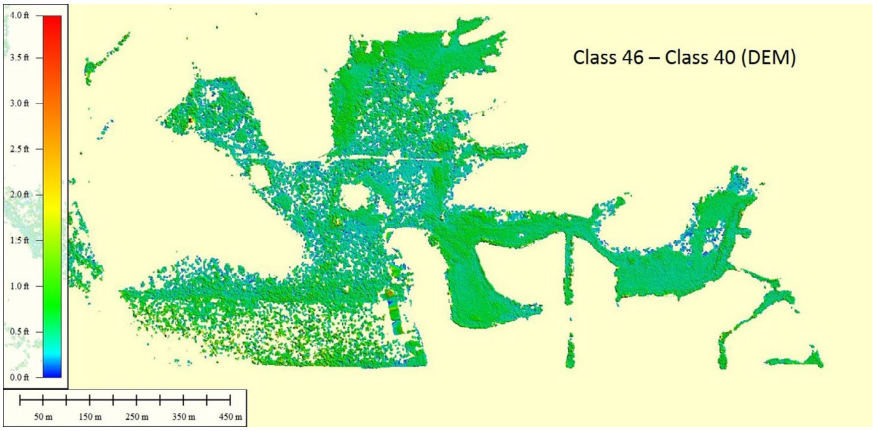

Figure 7: Difference DEM showing areas of unconsolidated material deposition in the King's Bay Pilot Area. Areas in green show more material than areas in blue. Tan areas are areas of no unconsolidated deposition.

greater error than the LiDAR data, likely resulting from the karst geology and large survey transect interval (100 feet). In fact, the sonar survey completely missed a large spring vent (**Figure 8**) simply as a function of the transect interval.

Advantages of LiDAR

The District identifies several advantages to using LiDAR for this project. Those advantages include:

1. The LiDAR were very accurate in determining the bathymetry for hard, reflective sands and limestones. The LiDAR also were good at mapping the distribution of the unconsolidated materials.
2. The high data density LiDAR data insure a faithful representation of the bathymetry. The cost of collecting sonar data at the same density as the LiDAR is cost-prohibitive,
3. The LiDAR survey was collected in 5 flightlines taking under 2-hours and was processed within 2 weeks. The sonar survey for the same area took over a month, and required another 60 days for processing.
4. The LiDAR survey was non-intrusive on the local population. The air craft was flown at ~1200' AGL and did not interfere with recreational and/or commercial activities occurring in the bay, and
5. The LiDAR were more cost-effective for the District.

While the District feels that the advantages to using the LiDAR are great, there are also some disadvantages. The disadvantages include:

1. The LiDAR data are most reliable at determining the depths and distributions of the hardbottom, reflective sands and limestones. Where the unconsolidated material was also reflective, the LiDAR returns determined their surface. However, in karst holes or places with lower reflective unconsolidated material, the LiDAR may or may not accurately measure the thickness of the unconsolidated layer.
2. The LiDAR data require considerably more digital storage than the processed sonar data. The sonar for the Pilot Area were delivered as Esri-GeoDatabase consuming less than 15 MB; the LiDAR (and associated imagery) are over 2 GB.

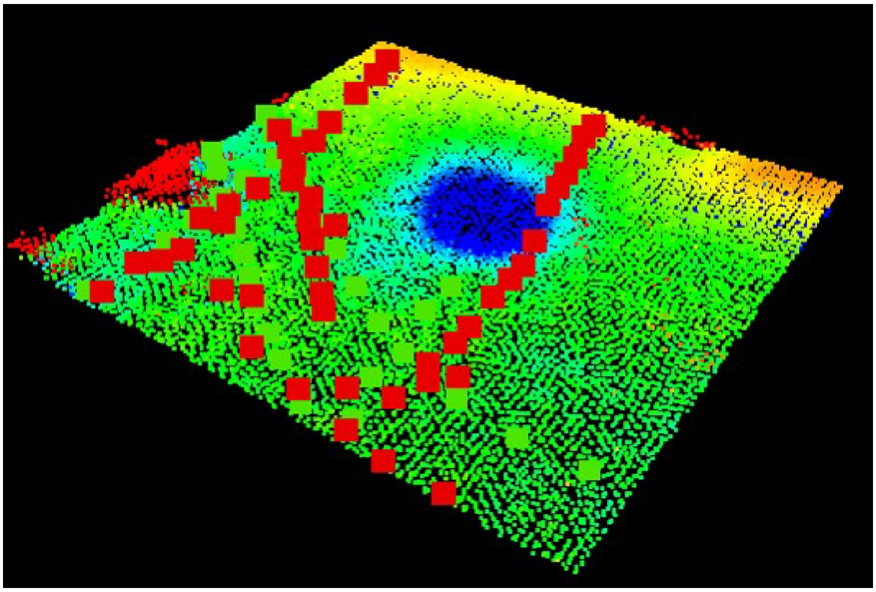

Figure 8: CZMIL Lidar surface with sonar (squares) transects showing sonar missing the spring vent in King's Bay.

3. The LiDAR data require relatively clear water and reflective bottom conditions to achieve the desired results. Environmental conditions at King's Bay vary with season and rainfall, limiting the available window for LiDAR missions,
4. The LiDAR data are most reliable where the bottom is hard and reflective. As the *Lyngbya* increases in density, the hard-bottom is obscured and the unconsolidated materials become less reflective.

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Citations:

Vanasse Hangen Brustlin, Inc. 2009. *An Inventory of Spring Vents in Kings Bay, Crystal River, Florida.*

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