Airborne LiDAR Bathymetry Operations in Challenging Environments as Experienced in Finland

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Key words: Hydrography, Airborne LiDAR Bathymetry, Laser Airborne Depth Sounder

SUMMARY

Airborne LiDAR Bathymetry (ALB) systems are an efficient and cost effective tool to survey shallow water including rivers, lakes, estuaries and the coastal zone and have been used worldwide to support nautical charting and coastal zone planning since early 1990s. Predominantly used in benign environments with predicable weather conditions and water clarity, the operation and success of surveys utilising ALB technology becomes harder in areas above 60 degrees latitude where appropriate survey windows are shorter with more variables affecting the environment.

In November 2015 Fugro operated a LADS HD ALB sensor simultaneously with a high density Riegl VQ-820-G sensor in Finland for the Finnish Transport Authority (FTA). The purpose of the pilot project was for FTA to assess the performance of current ALB technology in these challenging environments in support of their nautical charting program. The requirement was to survey areas of interest spanning both coastal and inland waterway areas to IHO Order 1a specifications.

This paper will review the challenges of optimising ALB operations in Finnish environmental conditions and how an agile operational program managed the challenges of low cloud, turbidity and ice formation. The paper ends with recommendations for the successful operation and application of ALB technology in Finnish waters.

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1. INTRODUCTION

The objective of the Finnish Transport Authority (FTA) survey was to demonstrate the capabilities of the Fugro dual-ALB system solution across both coastal and inland lake areas in Finland, primarily for resultant coverage and seabed object detection performance.

The survey areas included one priority coastal area, 25km to the north-west of Vaasa; "Vallgrund 1". An alternate coastal area , "Vallgrund 2", was located 10km to the west of Vaasa. The two inland lakes priority survey areas were "Kukkosalmi", located 30km east of Savonlinna and "Ahoselka", located 20km north of Lappeenranta. An alternate lake area, "Partakoski", was located 30km to the north-west of Lappeenranta.

Flight lines were planned to achieve complete ALB coverage across each of the survey and alternate areas, and extended a further ~2km in length and ~0.2km in width for additional coverage.

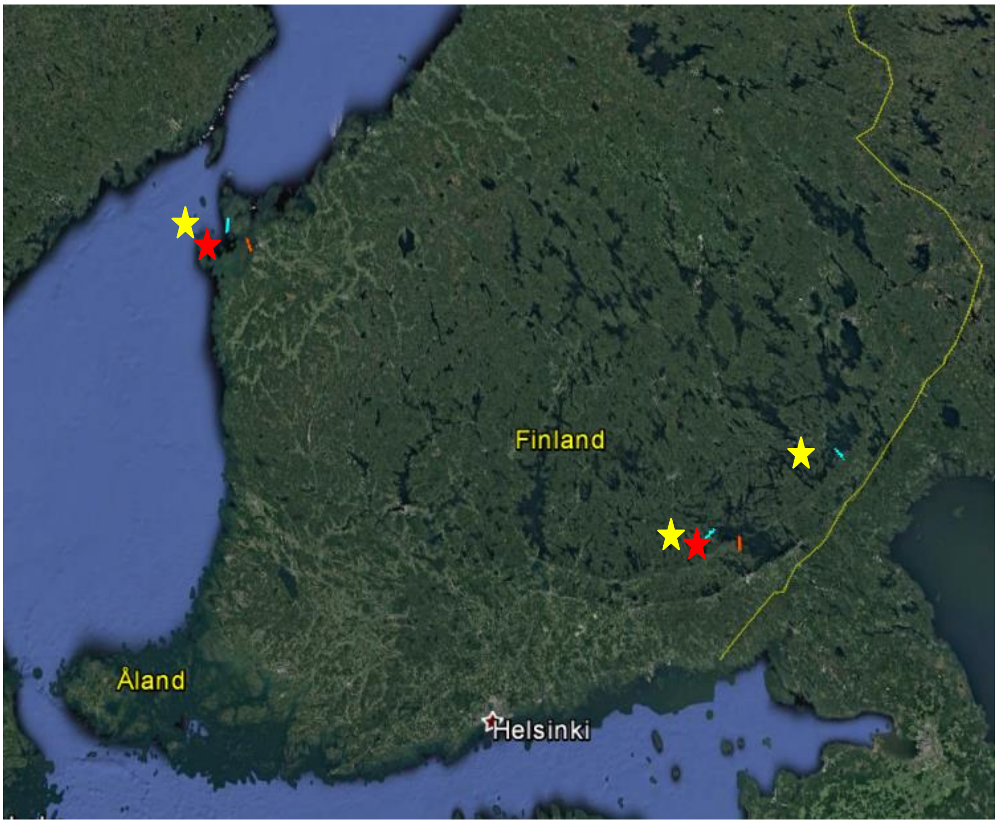

Figure 1 – Overview of the priority (red) and secondary (yellow) coastal and inland lake survey areas.

The priority and alternate coastal and lake survey areas are presented in Figures 2-4 below:

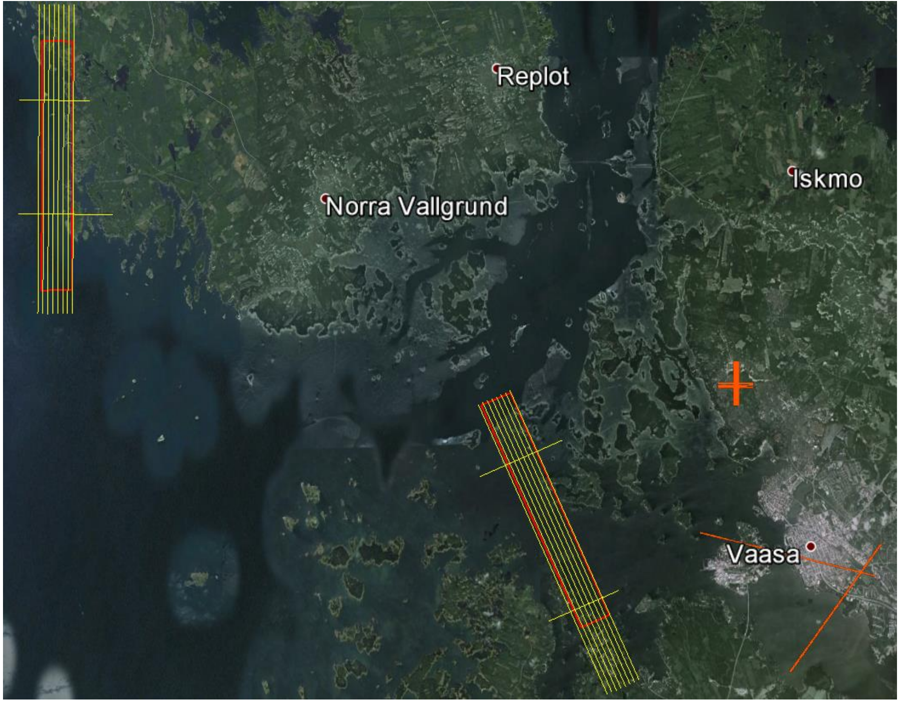

Figure 2 – FTA Costal Areas (red) and FLC Completed Flight Lines (yellow); Vallgrund 1 Priority Survey Area to the NW of Vaasa, Vallgrund 2 Alternate Survey Area to the W of Vaasa and Calibration / Verification Lines Over Vaasa (orange)

Figure 3 – FTA Lake Area (red) and FLC Completed Flight Lines (yellow); Kukkosalmi Priority Survey Area and Verification Line over Kerimaki (orange)

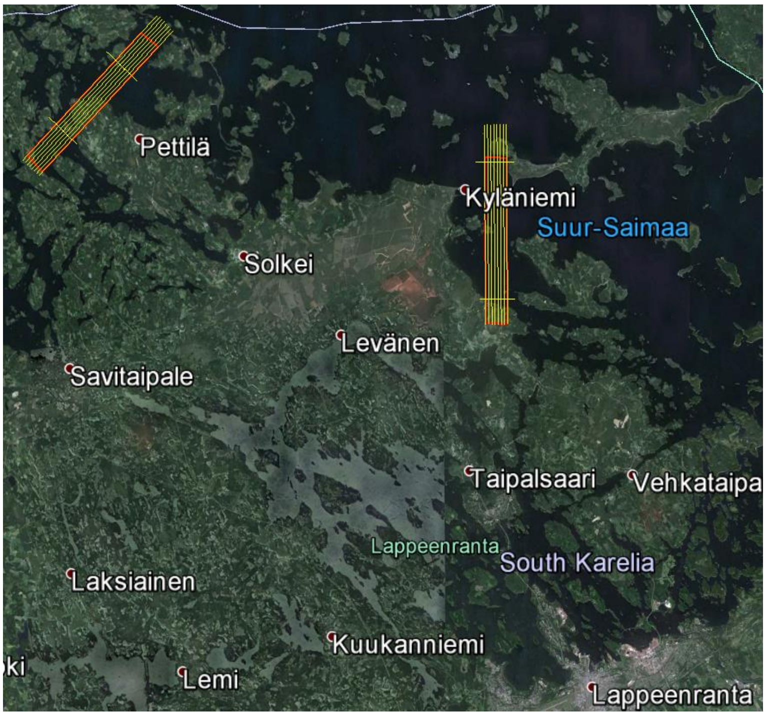

Figure 4 – FTA Lake Areas (red) and FLC Planned Flight Lines (yellow); Ahoselka Priority Survey Area to the N of Lappeenranta and Partakoski Alternate Survey Area to the NW of Lappeenranta

2. SURVEY REQUIREMENTS

The Contract specified that three discrete areas of ~8 x 1km dimensions would be flown at 200% ALB coverage, utilising a 2.5m x 2.5m sounding pattern from the Fugro LADS HD sensor operated simultaneouly with the very high density shallow bathymetric / topographic RIEGL VQ-820-G LiDAR system. The topographic data captured above this limit and was only processed to 5m elevation to allow FTA to extract the 3m elevation contour.

FTA required final ALB data to be delivered relative to ETRF89, UTM Zone 34 N (coast) / UTM Zone 35 N (lakes) horizontal and N2000 vertical datum. Accuracy of the final dataset was to conform to International Hyrdographic Organization (IHO) Order 1a specifications, intended for surveys where the sea is sufficiently shallow to allow natural or man-made features on the seabed to be a concern to under keel clearance for shipping expected to transit the area (IHO, 2008).

3. SURVEY OPERATIONS

3.1 Survey Equipment

3.1.1 <u>LADS HD</u>

The Fugro LADS HD ALB system used during the FTA contract had 2.5 kHz laser speed (now 3 kHz with the current system) and 7mJ energy per pulse, enabling efficient data collection and greater sounding density, along with excellent water penetration, high signal to noise returns and high quality data. The Fugro LADS HD ALB system routinely outperforms other systems in challenging environmental conditions due to the high laser power and receiver technology.

Features of the Fugro LADS HD sensor include:

- Depth measurement range of 3 x Secchi depth allowing confidence of deep water returns and quantity/quality of returns in turbid waters.
- From review against MBES datasets, the depth accuracy of LADS HD depth measurements achieved IHO Order 1 accuracies.
- Variable sounding density (independent of operating altitude) from 2.0 x 2.0m to 4.8 x 4.8m resolutions (Note: the FTA survey was captured at 2.5m x 2.5m sounding density).

3.1.2 RIEGL VQ-820-G

The Riegl VQ-820-G is a shallow water system with a fully integrated airborne laser scanning system for combined high density hydrographic and topographic surveying. The sensor includes a rotating multi-facet mirror that utilises a green (532 nm) laser to measure up to 510,000 measurements per second (510 kHz). The green laser is designed for measurement of high density (>4 points per m) topographic and shallow water areas.

Features of the Riegl VQ-820-G system include:

- Combined land and shallow water hydrographic airborne survey.
- High spatial resolution (The FTA survey achieved a topographic point density of 8 pts per sq m).
- Typical measurement range of 1 x Secchi depths.

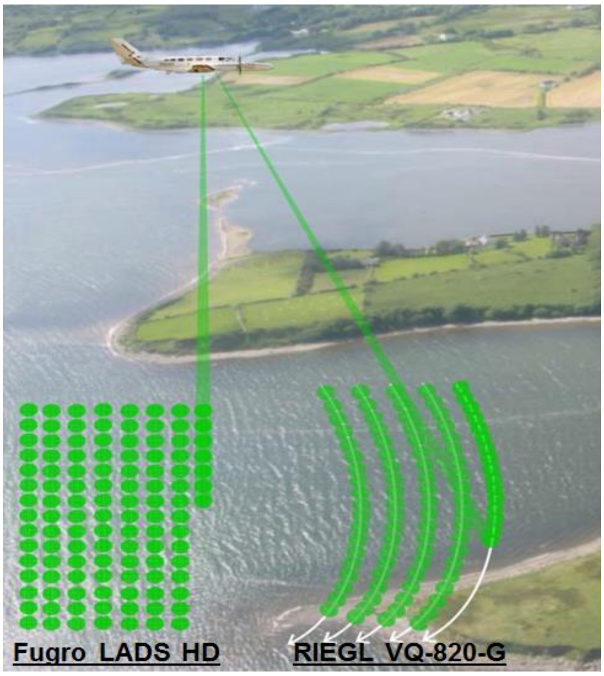

Figure 5 – LADS HD and Riegl VQ-820-G acquisition configuration

3.2 Mobilisation

The Fugro ALB systems, LADS HD and RIEGL VQ-820-G, were successfully installed and ground tested in the a Cessna Grand Caravan C208B between 11 and 14 November 2015 in Lapalisse, France. The aircraft was ferried from France on 16 November 2015, arriving in Vaasa in the late afternoon.

The local, in-country company VRT Finland Oy (VRT) provided in-country liaising, local logistics support and ground control surveying.

3.3 Set To Work and Acquisition Overview

A total of 7 survey and system calibration / verification flights were flown between 18 November and 8 December 2015 from the Vaasa and Joensuu Airports as described below:

Flight #	Date Flown	Take-off Airport	Landing Airport	Objectives Flown / General Comments
1	18 Nov 2015	Vaasa	Vaasa	No objectives completed due to low cloud. Flight aborted due to weather.
2	23 Nov 2015	Vaasa	Vaasa	Survey: Vallgrund 1 area completed at 200% coverage.
3	23 Nov 2015	Vaasa	Vaasa	Calibration / Verification: RIEGL VQ-820-G boresight lines, TIP and GCP points (covered in snow).
4	24 Nov 2015	Vaasa	Joensuu	Survey: Kukkosalmi area flown at <100% coverage. Low clouds. Flight aborted due to weather.
5	6 Dec 2015	Joensuu	Vaasa	No objectives completed due to low cloud. Flight aborted due to weather.
6	7 Dec 2015	Vaasa	Vaasa	Survey: Vallgrund 2 area completed at 200% coverage. Verification: TIP and GCP points, TIP areas.
7	8 Dec 2015	Vaasa	Joensuu	Survey: Ahoselka area flown at <100% coverage. Kukkosalmi area completed at >100% coverage. Calibration / Verification: LADS HD rooftops (Jyvaskyla), CGP points (Kerimaki).

Table 1 – FTA Demonstration Survey and Calibration / Verification Flights.

3.4 Data Processing Strategy

Across all FTA demonstration survey areas, the LADS HD data was used from a minimum depth of 2.0 – 2.5m deep to its extinction depth which varied across the areas. All LADS HD topographic and very shallow water data was rejected in favour of the RIEGL VQ-820-G high density data, until its extinction depth of typically 2.5 – 3.5m.

This resulted in a seamless ALB dataset from 5m elevation to the LADS HD extinction depth, in some cases beyond 12m depending on the area, once both LADS HD and RIEGL VQ-820-G datasets were merged.

3.5 Results

3.5.1 Coastal Areas: Vallgrund 1 and Vallgrund 2

Maximum depths of ~10m were achieved across isolated areas of Vallgrund 1 while solid ALB coverage was typically attained between 5 and 7m depth. The 100% + 200% data coverage and vertical accuracy across Vallgrund 1 was highly variable due to the generally poor water clarity conditions.

Significant gaps are located where water clarity was poor: offshore and on the seaward side of shallow / drying areas. At these locations the vertical accuracy of the ALB data also deteriorated significantly and achievement of IHO Order 1a cannot be confidently claimed.

Typically water clarity improved across areas more protected from swell; the landward side of the shallow / drying areas and along much of the coastline. Across these areas the LADS HD waveform quality improved significantly indicating IHO Order 1a data accuracy and target detection could be confidently claimed.

Gaps in ALB coverage also exist along the coastline where sea ice is present. These ice gaps typically occur across very shallow water in the upper reaches of bays. The vertical accuracy of all heights on drying rocks, islands and coastline for the Vallgrund 1 dataset was impacted by the presence of ~30cm accumulated snow.

Maximum depths of ~6m were achieved across isolated areas of Vallgrund 2 with solid ALB coverage attained between 4 and 5m depth. The 100% + 200% data coverage and vertical accuracy across Vallgrund 2 was highly variable, due to the extremely poor water clarity conditions.

Generally the significant gaps are located where water clarity was poor offshore. At these locations the vertical accuracy of the ALB data also deteriorated significantly and achievement of IHO Order 1a cannot be confidently claimed.

Vallgrund 2 was flown following and during a period of very strong winds and moderate sea state. If this area had been flown on the day that Vallgrund 1 was conducted it is quite likely that marginal to good coverage would have been achieved, as most of this alternate costal area is protected from the predominant swell.

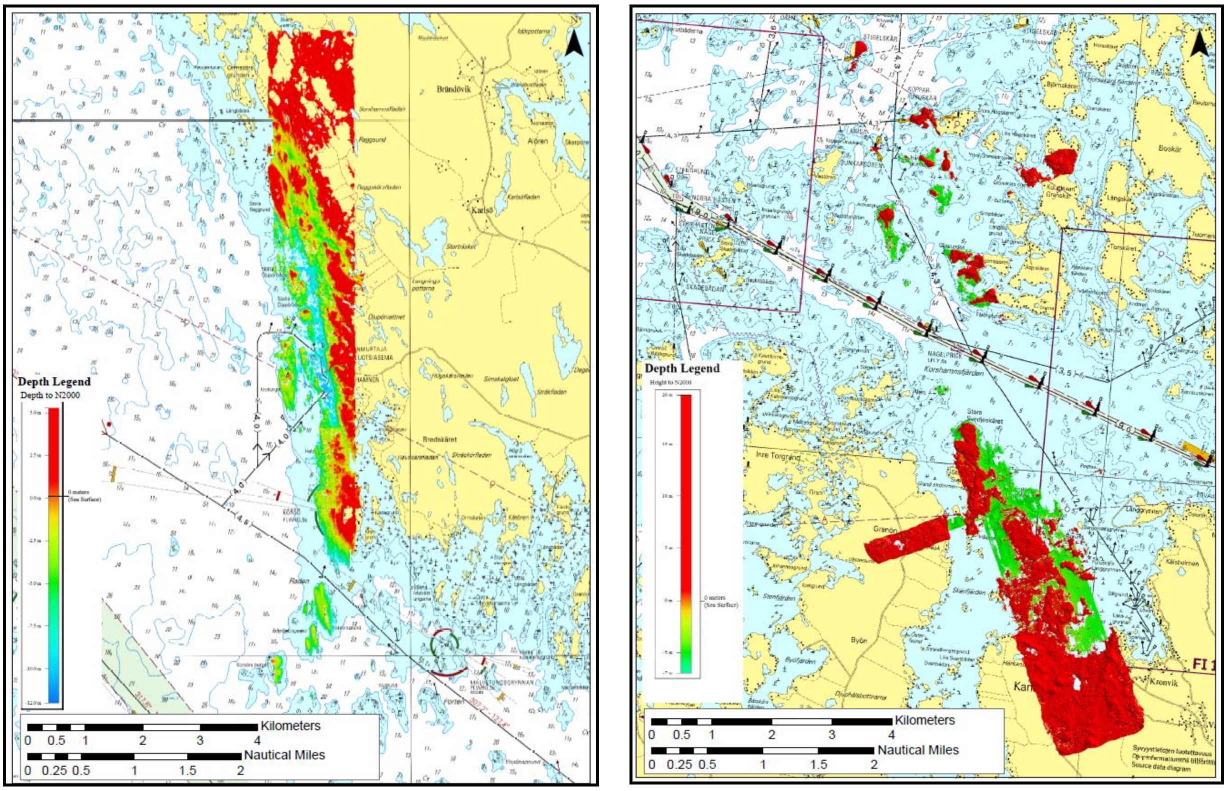

Figure 6 – Vallgrund 1 100% + 200% ALB Coverage (left); Vallgrund 2 100% + 200% ALB Coverage (right)

3.5.2 Lake Areas: Kukkosalmi and Ahoselka

Survey conditions were almost ideal at Kukkosalmi, with strong winds at survey altitude the only challenge. Maximum depths beyond 12m were typical across the north of area, resulting in almost complete ALB coverage. No snow or ice was observed. Areas of aquatic vegetation above the lake surface were noted during data acquisition and evident during data processing. Where the vegetation was dense and the deliniation of the seabed was in question, the ALB data was appropriately reclassified into a 'non-seabed' class.

The generally good water clarity across the Kukkosalmi area and resultant LADS HD waveform quality indicated IHO Order 1a can be claimed for both vertical accuracy and target detection.

The water clarity was extremely poor across the Ahoselka survey area with the ALB systems unable to acquire depths beyond 2m. After conduct of four main lines, it was deemed that a satisfactory reconnaissance had been performed. Conduct of the alternate lake area at Partakoski was considered, but as it was assumed that this area would exhibit similar water clarity to Ahoselka, it was decided that the remaining flight time should be allocated to the Kukkosalmi priority lake area.

Due to the extremely bad water clarity conditions across the Ahoselka area, achievement of IHO Order 1a cannot be confidently claimed in this area.

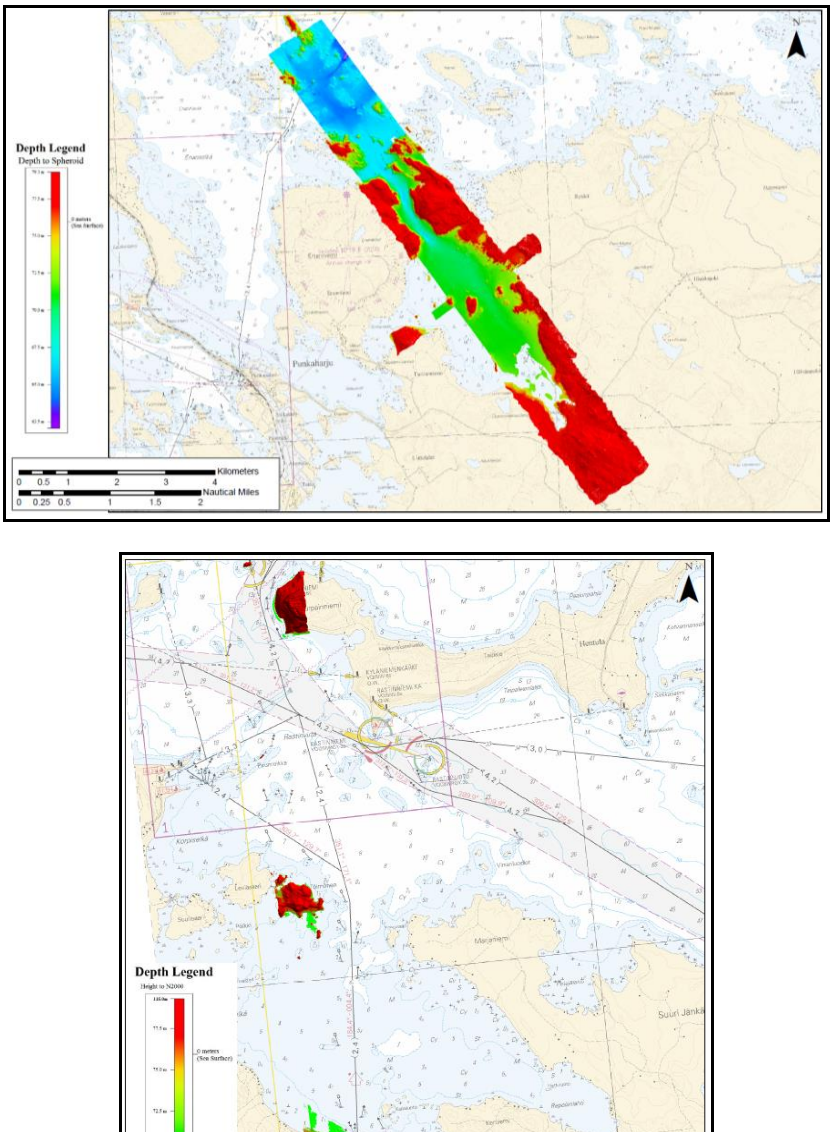

Figure 7 – Kukkosalmi 100% + 50% ALB Coverage (top); Ahoselka 100% ALB Coverage (4 lines) (bottom)

4. ANALYSIS OF CHALLENGES ENCOUNTERED

4.1 Weather and Water Clarity

The weather was the most significant limiting factor for efficient conduct of ALB data acquisition encountered during the FTA demonstration survey. This was to be expected during the months of November and December, due to the late timing of the contract. The majority of days during the deployment were unsuitable for ALB operations due to the height of cloud. Cloud heights were predominantly between 700 and 1000 feet, with 1200 feet being the lowest survey altitude for the LADS HD and RIEGL VQ-820-G systems.

Operations in November 2015 saw the commencement of snowfall that resulted in accumulation on the ground. Air temperatures dropped below 0 degrees Celcius frequently, resulting in the formation of lake and sea ice. Fortunately the snow and ice melted in late November during a warmer period, allowing all but one demonstration area to be surveyed under snow-free and ice-free conditions.

Operations within the costal areas revealed that the main driving factor for poor water clarity along the Finnish coast is sea state, caused by moderate to strong winds. Tides are not significant in the Baltic Sea and water levels are predominantly driven by the direction and strength of wind. Thus, tidal currents should not impact upon water clarity significantly. Coastal water clarity could also be adversely affected following the snow melting period with increased river discharge into the coastal environment and in spring and early summer due to phytoplankton blooms.

Poor water clarity wihtin the lake areas are believed to be mainly driven by by moderate to very strong winds and snow melt resulting in increased river discharge in spring.

4.2 Seabed Reflectivity

Coastal and lake areas completed during the FTA demonstration survey exhibited low seabed reflectivity. When the seabed is composed of dark coloured sediment and geology much of the laser energy is absorbed, resulting in limited reflection to the ALB recieving optics. This is apparent by observing the amplitude of the reflected surfaces in the waveforms. Low signal amplitude results in limited depth penetration, whether that be from suspended sediment in the water column or the low reflectance of the seabed itself.

The LADS HD automated gain control is designed to maximise the amplitude of the seabed signal. It uses a dynamic gain range in order to achieve good amplitude signals for unreflective surfaces, while minimising saturated signals from highly reflective ones, such as white sand. Most historical Fugro ALB surveys have been across contrasting reflectivity seabeds, but the Finland survey areas appeared to all be very non-reflective. Tuning the shallow water gain to the Finnish environmental conditions required a number of flights and may account for some of the gaps observed in the LADS HD coverage across Vallgrund 1 and Vallgrund 2.

The resultant coverage and depth penetration across the Kukkosalmi area is indicative of relatively low seabed reflectivity, suitable water clarity and correct functionality of the shallow water gain during the final flight.

5. RECOMMENDATIONS

5.1 Managing Weather and Water Clarity

Analysing snow cover and ice presence statistics is one way of developing a suitable weather window for ALB operations in Finland. When there is snow on the ground, topographic elevations determined by ALB are in error by the magnitude of the snow height. ALB is unable to penetrate lake or sea ice. The average end date of permanent snow cover for southern Finland is mid-April, with the average date of first snow cover in mid-October. Lake ice generally melts by May of each year. Poor water clarity could be expected within the lakes during and following the most significant melting periods, due to peak river discharge.

The optimum method for managing low cloud is maximising the rate of data acquisition when cloud is at high elevation or there are clear skies. During the summer periods, when there is significantly more than 12 hours of daylight each day, two or even three flights could be conducted each day in good weather conditions, assuming suitable manning of pilots and operators was in place. Although optimal daylight hours is an advantage during this period, the occurence of phytoplankton blooms during spring and early summer may be a limiting factor as discussed later in this section.

During the FTA demonstration survey, a 2-week poor weather period was experienced while in southeast Finland. There were a number of days when conditions were suitable at Vaasa over this period, however a transit to the coastal areas was not possible due to the low cloud and icing conditions between Joensuu and Vaasa. Icing conditions would not prevent transits between coastal and lake areas during summer months, if the weather forecasts indicated that one area would be suitable while the other was not. Therefore, the most efficient ALB operations are most likely to be conducted in southern Finland between mid-May and early-October of each year. The latter part of this period is most probably more suitable, avoiding phytoplankton blooms during spring and early summer.

Even during the most suitable months, access to alternate survey areas allows for optimum management of possible poor weather and water clarity. Alternate areas should be located far enough apart that they have the potential to exhibit different weather conditions. An example of this under the FTA demonstration survey was the provision of the Vallgrund 2 alternate coastal area. When low cloud prevented conduct of any flights across the lake areas in southeast Finland during late November and early December, the Vallgrund 2 coastal area was flown under almost ideal weather conditions.

When water clarity is the prime consideration, the priority and alternate areas do not necessarily have to be significantly distant from one another, just that one would expect them to exhibit different levels of turbidity over time. At the commencement of every ALB survey there is a learning process to understand an area and the environmental conditions that drive water clarity. While secchi disc depth measurements are one way to assess the conditions before a survey, during a survey the best way is to conduct ALB reconnaissance, generally by flying a number of cross lines across each of the areas at project start.

Fugro flight plans always include a targeted area and alternatives if they are available. During data collection, the ALB operator can assess in real time the current conditions based on the maximum depth achieved and waveform quality, to determine if the seabed is being detected and the impact of turbidity. If it is determined that it is not worth persevering in the targeted area, the operations can be diverted to the alternate area(s). In order to minimise transit times between primary and alternate areas when water clarity conditions are deemed unsuitable, the survey areas should typically be within 30 minutes flight time of each other. The provision of the two priority lake areas at Kukkosalmi and Ahoselka, under the FTA demonstration survey is a good example of this approach.

Aquatic vegetation also limits the coverage achieved by ALB, albeit poor weather and water clarity have the greatest influence on effective ALB operations. During the late spring and summer months it is expected that aquatic vegetation growth would be at peak levels. Water clarity may also be degraded by phytoplankton blooms which typically occur in spring and early summer. Therefore late summer and autumn may be the optimum period for ALB survey in Finland.

In terms of data collection rate, it is anticipated that about 30 SqKm of seabed data can be collected per flight when using 2.5m x 2.5m laser patterns. This would result in a maximum weekly data production of up to 300SqKm coverage per week assuming a flight tempo of up to 10 effective flights a week is achieved.

5.2 ALB Surveys of Coastal Areas

Coastal areas such as those flown during the FTA demonstration pose the greatest risks to safe and efficient conduct by traditional acoustic survey methods. The coverage and number of drying, awash and shallow rocks detected by ALB at Vallgrund 1 shows the benefits of conducting ALB operations across such complex geomorphology areas that are dangerous to navigate within. However, acquiring and processing complete, high quality ALB data across coastal areas such as Vallgrund 1 is very challenging, due to the poor water clarity associated with exposure to moderate sea state.

Each coastal area that is prioritised for nautical charting should be considered for ALB acquisition on a case-by-case basis. Sechhi disc observations provide a useful reconnaissance tool, but ultimately the assignment of different types of alternate areas results in the optimal ALB coverage during a survey. When offshore, inshore, exposed and protected areas are all available to fly during ALB surveys and it is accepted that not all areas will be flown, but the best water clarity areas will be completed, a successful ALB survey should be the result.

5.3 ALB Surveys of Lake Areas

The positive results from the Kukkosalmi survey indicate that large scale ALB surveys could be successfully completed across Lake Puruvesi, and other surrounding lakes that exhibit similar, suitable water clarity. With repeatable ALB depths to between 12 and 14m achievable across Puruvesi and other similar lakes, significant expanses of these lakebeds could be surveyed to IHO Order 1a standards. With charted depths of more than 25m at Puruvesi, ALB would not result in complete coverage across the entire lake. It would however cover the navigable depths of the lakes. If a complete bathymetric dataset is required, gaps in ALB datasets due to it being too deep and beyond the sensors laser extinction depth could be efficiently and safely infilled using acoustic techniques.

5.4 100% Versus 200% Coverage

For the FTA demonstration survey the planned main lines were flown twice during the same flight to achieve the required 200% coverage. This is not typical of 200% coverage ALB surveys and was performed due to the restrictive weather conditions. Generally, with a swath width of 186m, 200% lines would be designed at 80m line spacing. Every second line would be flown during the course of one sortie and the lines in between would be completed during a flight on a different day, under different environmental conditions. This approach of conducting 100% coverage one day and 200% coverage on another was successfully implemented during eight years of ALB surveys for NOAA, the nautical charting authority for the United States of America. The majority of those surveys were conducted in Alaska, where conditions were similar to those experienced in Finland.

Most of the NOAA survey areas exhibited extremely complex seabeds, with thousands of shallow, awash and drying rocks. The Alaskan seabeds were generally of dark colour, resulting in high absorption of the laser energy and limited reflection to the sensor. Water clarity was highly variable. Aquatic vegetation could be extremely dense and was mainly comprised of kelp, which had a very high growth rate in summer. All of these environmental limitations were managed by flying areas at 200% coverage, with the first pass at high tide and the second pass at low tide. The kelp typically lay across the sea surface like a blanket during low tide, but the rocks within the intertidal zone were drying and easily surveyed. At high tide the kelp tended to stand straight up, allowing increased ALB penetration through to the seabed.

Thus, 200% ALB surveys do not typically achieve 200% coverage everywhere, as water clarity and aquatic vegetation conditions can vary over time. Conducting 200% coverage across Finnish coastal areas is considered essential for maximising seabed coverage and achieving detection of seabed objects greater than 2x2x2m in size.

In reviewing the Kukkosalmi dataset it is evident that IHO Order 1a horizontal and vertical accuracy has been achieved with 100% confidence. IHO Order 1a target detection capability could also be claimed across the 200% coverage areas. But the question is, does the 100% coverage across Kukkosalmi achieve IHO Order 1a target detection? This can be appraised by comparing the detection of small rocks on the independent 100% and 200% coverage lines. For the most part, the features have been detected on both lines; only one of the chart comparison items for Kukkosalmi was detected by the LADS HD system on one flight line, but not the second. All other features that were overflown at 200% coverage existed on both the 100% and 200% lines. Thus, one could argue that 200% coverage lines may not be necessary to achieve IHO Order 1a target detection across suitable water clarity areas, such as those experienced at Kukkosalmi – 100% coverage may be sufficient. However, the other argument is that 200% overflight always results in additional coverage (fewer and smaller gaps) and fewer refly lines when water clarity is suitable.

In addition to maximising coverage, the other significant benefit of conducting 200% coverage is the redundancy of data over real seabed features and disproval of noise. ALB waveform interpretation can be quite straightforward across flat and undulating seabeds, but is extremely difficult in complex, turbid areas. The addition of 200% coverage enables data processors to confirm the existence of a detected rock by comparing waveforms between the two overlapping lines, acquired under different environmental conditions. Conversely, the additional data can be used to disprove a possible rock as noise, by ensuring there is no detection on the second pass. Data processing times are increased with twice the data across the same area. However, the process of deciding whether a detected feature is real or false is shortened when 200% data is available for comparison.

5.5 ALB System Power and Point Density

From the limited penetration of the RIEGL VQ-820-G system across all of the FTA survey areas (2.5 – 3.5m depth) it is apparent that a low power ALB system could not expect to achieve depths much greater than 4m within Finnish waters. A high power system will be required in addition to achieve significant coverage across such lake and coastal areas.

Conversely, high power systems with a longer pulse width, struggle to accurately detect the seabed in the very shallow water zone. Low power systems excel in such environments, providing high density coverage where the high power systems can struggle.

The accurate and complete detection of shallow, awash and drying rocks is paramount for determining safe navigation. Thus, successful ALB surveys are significantly enhanced when a high power, deep water system is complemented by an independent, simultaneously operated, high density, low power system.

In order to claim IHO Order 1a target detection, an ALB system must fully illuminate the seabed with high power laser energy, or saturate the area with very high density points at low power. The LADS HD system achieves full illumination of the seabed at the 2.5m sounding pattern as the footprint is ~2.3m in diameter at the sea surface, and diverges slowly with depth. Use of a wider, lower density sounding pattern could result in small seabed objects going undetected between adjacent soundings.

The RIEGL VQ-820-G system provides >8 points per square metre when operated at 1400ft or below. This ensures complete detection of shallow, awash and drying features, even when they are as small as 1x1x1m in dimension. Even with the greater feature detection capability within the shallow water region using the RIEGL VQ-820-G system, IHO Special Order is not generally achievable.

5.6 Summary of Recommendations

- Utilise a high-power system in order to achieve sufficient depth penetration and resultant coverage, even across marginal water clarity areas with unreflective seabeds.

- Complement the high-power system with a very high density low-power system in order to fully survey the very shallow, awash and barely drying features.

- Survey all coastal areas at 200% coverage, with the 100% lines flown on one day and the 200% lines flown on another, during different tidal states.

- Due to the low seabed reflectivity, water clarity management and nature of the area, it is reccomended to survey all lake areas at 200% coverage if target detection confidence is required. 100% coverage across lake areas could be employed, but target detection confidence could fall, gaps will be larger and a higher refly budget would be required.

- Provide for alternate coastal and lake areas to effectively manage poor weather and water clarity.

- Prioritise suitable lake areas to be surveyed concurrently with complex coastal areas with poor water clarity, as the data processing effort, time and cost will be significantly less across lake areas (significantly more ALB coverage per dollar spent).

- Identify potential alternative areas that could be targeted should priority areas be proven to do not be suitable for ALB survey.

- Exploit the good water clarity areas. Utilise alternates instead of persisting in areas consistently unsuitable for ALB.

- Conduct ALB surveys during the optimal weather and water clarity periods; June to October may have the best weather, but note that late summer / early autumn may have the clearest water avoiding phytoplankton blooms in spring and early summer; as a result August, September and October may be the optimum period for ALB operations.

- Have sufficient resources in place to maximise good weather windows, with multiple long-endurance flights during the long days of daylight.

- If MBES infill surveys are planned to fill gaps in ALB coverage or conduct ALB investigations, schedule the boat work for the following year, so that the ALB data may be fully processed and reported prior to MBES operational planning and execution to ensure vessel safe navigation.

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