LIDAR Bathymetry in Norwegian Waters

The Norwegian Hydrographic Service (NHS) has and will be utilising airborne LIDAR bathymetry in connection with the ongoing effort to modernise the maritime infrastructure along the Norwegian coast. This article describes the benefits and limitations of the technology, the results of a pilot project conducted in Norwegian waters in 1998 and operational data collection in Norway in 2002.

The long-term plan for the Norwegian Hydrographic Service (NHS) is by 2006 to have the Norwegian coast covered with ENCs and paper charts based on source data from modern surveys. The Enhanced ENC Project was established in 1999 and is responsible for the acquisition of survey data, hiring of consultants to strengthen the internal production line within the NHS and external production of paper charts and ENCs. Two contractors have been hired for consultant services, two have been carrying out chart production since 2000 and a further two have been hired for hydrographic surveying in the period 2001-2006.
Sea surveying using acoustic methods is very time-consuming in shallow waters. A significant percentage of those Norwegian waters that are poorly charted are shallow. The NHS has looked for alternative methods that could help speed up data acquisition. Large, exposed, shallow water areas are difficult to survey by boat without extensive downtime due to weather. Boat operations in these areas can also be hazardous. Following an evaluation of available LIDAR systems, the NHS decided to run a pilot project using LADS Corporation, based on the availability of the system, skilled personnel with experience in nautical charting and system performance.

The 1998 Pilot Project
The NHS conducted a Pilot Project between September and November 1998. A total of 750km2 in two separate areas were illuminated. Consistent depths were recorded down to 25 metres in the northern survey area, with spot depths down to 40 metres. The NHS gained a lot of experience from this project.

Evaluation of the Pilot Project
The evaluation of the Pilot Project revealed LIDAR to be a useful technology for rapid data acquisition in large shallow-water areas. However, the technology also has some limitations.

General Limitations
Maximum achievable depth is dependent upon the clarity of the water column. The experience was that laser depths were approximately twice Secci disc depths. To gain full advantage of LIDAR in Norwegian waters the depth range should be at least 20m. In the southern survey area, near the town of Larvik in Skagerak, the Secci disc depths changed rapidly from 10 metres one day to only 2 metres the following day. In such areas it is vital to monitor water clarity. A result of large daily changes may be seen in Figure 1, where it looks almost as if a survey line is missing.
White water due to breaking waves on shoals, in the surf zone and track of a ship will lead to no depths being measured. The laser light (blue-green) will not penetrate the sea surface to detect the seabed. This leaves â€˜holesâ€™ in the dataset on top of shoals where the least depth has not been recorded and â€˜gapsâ€™ in the surf zone between the soundings on the seabed and heights on land. A definition of â€˜holesâ€™ and â€˜gapsâ€™ in the dataset has to be specified in the contract. Areas that do not comply with the contract have to be resurveyed in a calmer sea state, or the correct depths verified by conventional boat operations.
The data revealed large areas of kelp forests in the northern survey area. The return pulses in those areas contained two bottom return pulses with a reciprocal distance of 1.8-2.0 metres. This is known to be the normal height of the kelp and was also manually observed when flying over the area at low tide.
The â€˜footprintâ€™ on the sea surface was approximately 3 metres in diameter. Small objects (less than 1.5 metres in diameters, G. Gunther) are difficult to detect, even if the â€˜footprintâ€™ hits the object. The same problem arises on pinnacle-shaped shoals. The sounding pattern during the Pilot Project was one depth per 5 metre-grid, and 3 metres in some smaller areas. Even in the areas where the sounding pattern was 3x3, illumination of the seabed was not 100%. The result of this is that shoals in the water depth from 0 metres to 5-7 metres may stay undetected. By comparing MultiBeam Echo Sounder (MBES) data to laser data we verified this.
The size of the illuminated spot on the seabed also makes a detected shoal â€˜widerâ€™ in horizontal direction compared to MBES data. In steep and rough topography, as in Norwegian waters, small position shifts between the run lines and large â€˜footprintsâ€™ from the acquisition system result in a â€˜noisyâ€™ TIN-model. Regarding the sounding pattern, NHS found the 5x5 to be too scattered.

LADS System Limitations
During the Pilot Project, LADS inhibited the laser when passing over ships and inhabited islands. Although the laser is eye safe, LADS preferred to operate the system in a very conservative manner. The laser system had problems in retaining the correct elevation of the platform when the infrared (IR) laser beam passed over land and all data in the swath had to be invalidated. These problems resulted in â€˜holesâ€™ in the dataset around islands, as shown in Figure 2. Additional lines were flown across the initial line pattern to try to cover what was lost due to IR and inhibiting.
Validation of the data was done line-by-line, which led to discrepancies between depths in the overlap. This was not detected before the NHS inspected the delivery of digital data.

Operational Use of LIDAR in 2002
One of the critical paths in the Enhanced ENC Project is the data acquisition. To make this less vulnerable NHS allocated the largest

shallow water areas to the contractor using LIDAR. because such systems are very efficient as regards time and cost-effectiveness. In a lesson learned from the Pilot Project, the NHS wanted the operational use of LIDAR to be an integrated part of a complete operation to optimise survey spread and minimise LIDAR limitation. The NHS decision on which technology was to be utilised in different survey areas was based on a comprehensive operational evaluation, including quality assessment and considerations concerning the operational use of the area.

LIDAR operations were initially planned for the autumn 2001 but due to the 11th September incident, the aircraft failed to get flight permission for the transit from Australia to Norway. The operation was therefore postponed to the spring of 2002. This resulted in a hectic flight/boat operation. When conducting boat operations close to the flights/validation of LIDAR data, the operating procedure must be well defined to make sure that all anomalies in the LIDAR dataset are know and can be planned for in the boat operation.

The NHS also plans to use LIDAR for the 2005 season. It has, in co-operation with the Norwegian Coast Guard, measured and registered the Secci disc depth along the Norwegian coast for several years to reveal the best seasonal windows for laser surveys.

Prior to the 2002 season, Tenix LADS Corporation (TLC) improved the system to also detect heights. This improvement also resolved the elevation problem. Another improvement is the introduction of manual operator attenuation of the system in place of inhibiting the laser when passing over ships and inhabited areas.

The bottom detection algorithm has been improved in the TLC LIDAR system since the Pilot Project and will now be able to distinguish between the surface and bottom detection from a measured water depth of approximately 0.7 metres and downwards. This has also improved the systems ability to detect smaller objects, according to test results conducted by TLC. The NHS cannot verify these tests because the Pilot Project did not include a specific and organised object-detection test containing known objects.

The white water problem cannot be solved technically. The drying area is something that should have been detected by the LIDAR system, but flying sorties on days when the sea-state was too rough resulted in too much white water on shoals (even down to 2-3 metres). It is crucial that all undetected shoals and poorly established drying areas are inspected by boat-operations if the results from the LIDAR data do not meet contract specifications. The prime contractor had some difficulties in merging LIDAR data with EM1002 and EM3000 data, especially on slopes. This was related to the earlier mentioned â€˜footprintâ€™-size of the LIDAR system, which is much bigger than EM1002/EM3000 and lead to a lot of manual work in merging LIDAR and MBES data.

The data delivered from the LIDAR system contained too much noise. This was partly related to detection of kelp on one survey line and not on the neighbouring line, which were flown on different sorties. The reason kelp was only detected on one of the survey lines has not been tested but it may be related to different tidal stage, current direction, angle of illumination or sea-state. The other reason for noise in the dataset was slopes, as described above. The survey lines were still validated line-by-line, although the operator had the option of looking at neighbouring lines and its soundings. By exporting the complete dataset this will contain anomalies that will be beyond specification. Both LIDAR and MBES data must be validated and approved by area-based processing/validation in order to get a dataset with as much redundancy as possible whilst remaining within specifications.

Land topography will be a restriction for the LIDAR system operating from a fixed-wing aircraft. The LIDAR companies are moving from helicopters to fixed-wing aircraft, perhaps because of the high operating costs for helicopters.

Different surveying patterns were considered and NHS chose 200 5x5. In ports and fairways with critical under-keel clearance MBES will be used due to the rough and stony seabed. In spite of the mentioned limitations, LIDAR bathymetry proved to be an efficient supplement to traditional boat-based surveying methods.

As a quality control, the NHS planned the external hydrographic work to have a large overlap with our own, modern MBES data (EM3000) for some of the areas. This was done to verify the contractorsâ€™ calibration. Comparing the LIDAR data with our own, the depth on selected critical shallow areas was in accordance with specifications.

Summary

In spite of the described limitations, LIDAR systems are an efficient supplement to MBES systems in shallow waters. The use of LIDAR technology is a necessity for NHS to reach its goal of covering the Norwegian coast with official ENCs by the end of 2007.