MAPPING SHALLOW RIVERS UNDER LOW-FLOW CONDITIONS

Airborne Lidar Bathymetry

Although operational for more than twenty years, Airborne Lidar Bathymetry (ALB) has rarely been used in riverine areas. The US Bureau of Reclamation adopted it to study how flow change in the Yakima Rivera affected fish habitat. The authors show that ALB offers accuracy and precision at least as good, if not better than that achieved in typical survey by boat with sonar and GPS.

The United States Bureau of Reclamation needed to create an accurate hydraulic model of the Yakima River in Washington State to study how changes in river flow would effect downstream fish habitat. For many years the United States Bureau of Reclamation (from now on called 'the Bureau') has been surveying rivers using vessel-based acoustic methods and/or land survey. Whilst both methods are reliable and accurate, they show significant limitations. They are:

- time-consuming and labour intensive
- dangerous, especially during periods of high flow
- susceptible to significant problems of access
- offering no full bottom coverage.

Coverage is irregular because in most cases the river is surveyed along a series of cross-sections and profiles, so requiring data interpolation.

Low Flow Conditions
Airborne Lidar Bathymetry (ALB) may address all these limitations. It is an efficient airborne remote-sensing technology with production rates of up to 70km2 per hour over large linear areas. It can provide complete bottom coverage at point densities up to 2m x 2m, whilst surveyors do not need to get in or on the river. The technology seems thus the perfect tool for mapping riverine areas. However, while ALB technology has for many years been used with great success in 'clear water' coastal environments, it has always been thought to have limitations in shallow-water river areas. Major limitations here include lack of water clarity caused by transport of sediments, and difficulty in determining depths when these are less than 50cm. The algorithms developed to allow depth extraction in as little as 20cm of water were generally effective only in coastal environments. Because (parts of) rivers are often very shallow, such a limitation would result in large areas where depths could not be extracted. After consulting with Optech, the Bureau conducted an ALB survey on the meandering Yakima River in Washington State, US, during 'low flow' conditions. The SHOALS-1000T was used to collect bathymetric data with point density of 2m x 2m on the Easton and the Kittitas Reaches, where maximum water depth is 4.5m. From 26th August to 2nd September the flow was controlled at three dams, Cle Elum, Kachess and Keechelus, and flow control resulted in sediment concentration of 275 parts per million at Easton Reach and 3,100 at Kittitas Reach. One day would be required for sediments to settle, allowing the team approximately five days during which the survey would need to be executed.

Airborne Survey
The 2m x 2m point density required resulted in the selection of the following mission parameters: flying height 300m above the river, survey speed 24 knots and a swath width of 60m, to give several parallel lines covering the extents of the river. First the Kittitas Reach was surveyed: fifty flight lines and 153 flight-line kilometres covering 5.8km2 were flown, taking about four hours. Next the Easton Reach was flown, with 41 flight lines and 394 flight-line kilometres covering 17.8km2 in about five hours. Kinematic GPS was used to position the aircraft. One control point was established at each site, with two, dual-frequency GPS receivers. Kinematic GPS data were logged once per second and this data combined with airborne GPS data to compute Post-Processed Kinematic (PPK) solutions of aircraft trajectories. After completing the airborne survey, all data was auto-processed in the field to verify coverage.

Quality Control
To check the results the Bureau collected ground-truth using RTK GPS on each reach, a total of fourteen cross-sections and four longitudinal profiles. This was totally independent of the air survey. The data was not provided to Fugro Pelagos or Woolpert until the survey data was fully processed and delivered to the Bureau. Fugro also collected ground-truth in both reaches as part of its own quality control and to verify the integrity of the ALB data. This data was collected after the airborne survey and using PPK GPS methods.

New Algorithms
The results of the initial Lidar data processing were very poor. Although the waveforms looked good and showed the very subtle bottom return, the shallow algorithms of the system were unable to determine depths and 'pick' the bottom. Experts from Optech spent several weeks developing new algorithms. Critical to their success was clear water and a highly reflective river bottom. In this case the water was very clear, thanks to the controlled flows, and the bottom consisted of light-coloured cobble, which is optically reflective. Using the new

algorithms produced much better results; depths were successfully derived over most of the river. Next, the accuracy of the depths was tested by comparison of the ALB data with the PPK GPS ground-truth. In all cases the ALB data matched the ground-truth to within the quoted system accuracies of 25cm. This was better than expected. Optech had thought some degradation in accuracy might result from the new algorithms.

Independent Test

The Bureau then conducted an independent test by comparing the ALB data with their own ground-truth data using two methods. The first was a qualitative comparison of Bureau ground-truth combined with terrestrial Lidar point data flown in November 2000 and the corresponding ALB data, also combined with the November 2000 Lidar data. The data was compared by displaying TINs (Triangulated Irregular Network) created from the two datasets, using a utility available for ArcMap. The second method involved computing mean, median and standard deviation of height differences between the two datasets. The statistics were determined in ArcMap by searching a radius of 90cm from each ground-survey point. The ground survey of 328 data points had 232 Lidar data points within the 90cm radius. Since increasing the distance from a survey point makes the elevation of the channel bed more likely to vary from that of the survey point, the final data was classified to evaluate Lidar points 30cm, 60cm and 90m from a survey point. Differences in quality of the ground survey between the Easton and Kittitas reaches led to the data being further classified to include all survey points, Easton Reach points only and Kittitas Reach points only.

Results

The Easton Reach, which is the shallower of the two, shows standard deviation within the tolerance of 25cm. However, the ALB data shows a bias (the mean in Table 1) of approximately 15cm. Kittitas Reach results do not look impressive, with a standard deviation of 39cm and a bias of approximately 23cm. The bias is due to the survey-rod not being perpendicular to the ground, and to the presence of boulders. The ALB survey will generally pick the most shoal-rich feature within the ALB footprint. The sample sizes for comparison are relatively small for both reaches, with 141 points available on the Easton Reach and only 91 points available on the Kittitas Reach. A much larger sample size would be required to draw reasonable and accurate conclusions. Nevertheless, accuracy and precision of ALB data appears to be at least as good, if not better than a typical sonar and GPS survey, and is within acceptable bounds for hydraulic modelling.

Future Research

Further investigations are required, and much more ground survey will be collected during the next aerial survey. After initial ALB data collection in August 2004, five more reaches of the Yakima River were flown for ALB data in April 2005. A more dense set of ground-truth data was also collected in all five reaches at the time of the ALB data collection. The Bureau is currently awaiting delivery of this data.

Concluding Remarks

The high point density is a vast improvement on sonar or RTK GPS survey, and when lower accuracy does present this is likely to be compensated for by better representation of the riverbed. What is more, the costs of ALB survey are similar to those of sonar when the reach is greater than 24-32km. The larger the project, the more feasible ALB becomes, although shorter reaches can also benefit from ALB savings through reduced mobilisation when the method is combined with other surveys in the same region.