DEVELOPMENTS IN SURVEY TECHNOLOGY AND ITS APPLICATION TO FRESHWATER ENVIRONMENTS

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ABSTRACT

The latest survey sensors capable of capturing high resolution data, combined with survey expertise, processing and visulisation software, are now being used to map freshwater environments. High density point cloud data acquired through simultaneous and seamless data collection techniques is now possible above and below the waterline.

The Rotorua Te Arawa Lakes Programme is working to protect and restore the water quality in twelve Rotorua lakes. Since 2014 the University of Waikato (UoW) and Discovery Marine Ltd (DML) have been using a high resolution Multibeam Echo Sounder (MBES) to accurately survey a number of the lakes. A practical and flexible approach was adopted to enable effective use of commercial resources to produce 3D bathymetric surfaces of the lake beds.

High resolution mapping of Watercare's fresh water reservoirs using MBES and Laser Scanners has enabled the production of 3D fly throughs revealing remarkable detail of the flooded terrain. It has provided Watercare with a baseline data set from which to better understand their assets and the impact of the environment.

This paper provides an overview of the technology, processes and deliverables for these two projects demonstrating the wider applicability of the technology to support regulatory compliance, asset management and environmental planning.

KEYWORDS

Multibeam echo sounder, mobile lasers, freshwater, environment, structures

1 INTRODUCTION

It wasn't that long ago that hydrographic surveying of fresh water bodies was limited to single beam echosounders, sidescan sonars, or in a lot of cases, a chainman equipped with a prism pole doing their best not to get washed away in a river current.

Photograph 1: Traditional river cross section profiles

The aims of this paper are to; present an overview of current technology within the hydrographic surveying and mobile mapping industries; highlight the level of processing required to manage large multipoint data sets; and provide local examples of new types of products which aim to support regulatory compliance, asset management and environmental planning.

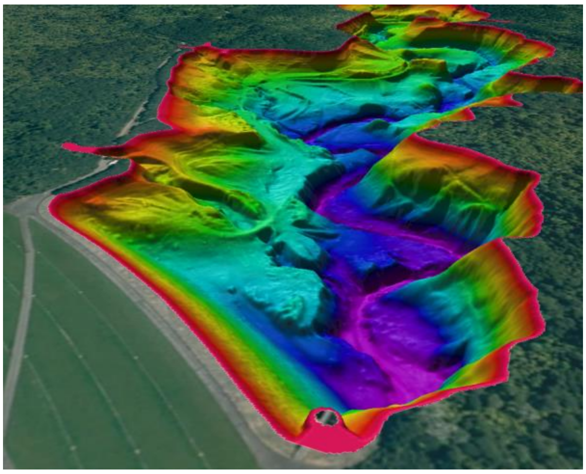
Technological advancements in survey equipment, acquisition software and smaller on water survey platforms has allowed for more data to be gathered to a high degree of accuracy. Hydrographic surveyors are now able to collect high resolution bathymetric data sets in areas that were previously difficult to access with traditionally bulky survey equipment and large vessels.

The improvements in field data acquisition have gone hand in hand with the ability of software applications to process and manage large data sets with a high degree of agility on smaller computing platforms. It is now possible to load and manage very large point cloud data sets, within PC based 3D visualization tools similar to high end gaming technologies and GIS software packages.

This paper describes the marriage of several of these emerging technologies to map, visualise and create accurate easy to use baseline datasets of freshwater bodies, surrounding topography and any associated infrastructure. By creating more detailed and easy to use baseline datasets engineers, scientists and managers are able to make informed decisions on environmental impacts and asset management.

So how do we get from traditional survey techniques providing basic data sets in planimetric form with standard reports to 3D models and fly throughs.

Figure 1: Watercare's Lower Huia dam



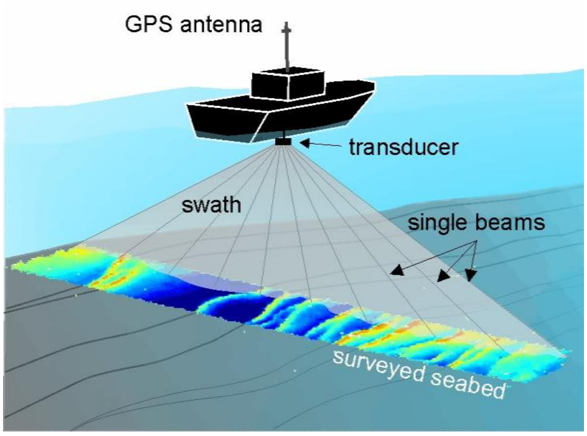
2 TECHNOLOGY OVERVIEW

2.1 MULTIBEAM ECHO SOUNDERS

Multibeam echosounders have been used very successfully for the past twenty years, however, it has only been in the last five years that healthy competition between sonar manufacturers and a growing demand for better data has resulted in a new generation of compact, survey grade, multibeam sonars that are easier to deploy on smaller vessels and are less power hungry than the previous generation of larger sonars.

A quick review of multibeam echosounder technology shows that a sonar emits sound pulses toward the seabed and determines the sea/lake bed depth by timing the return of the sound waves. The difference between a single beam echosounder (like that found in fish finders) and a multibeam echo sounder is the number of beams. Instead of emitting a single sound pulse toward the seabed, it will digitize between 250-800 seabed detections in the across track direction, within a single swath as shown below.

Figure 2: MBES technology



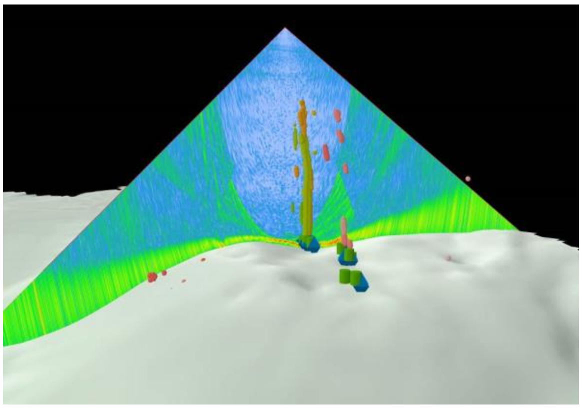
As the echosounders have become more compact it has allowed them to be fitted and operated from smaller vessel platforms as shown below.

Photograph 2: 7m vessel with survey grade MBES fitted

Along with bathymetry, multibeam echosounders produce several other useful data products. Backscatter data, is essentially the acoustic intensity of each returned seabed detection. The geo located intensity can produce valuable backscatter mosaics useful for seabed classification, target identification and detection.

Advances in multibeam acquisition and processing software and hardware are delivering another product that is gaining a high degree of interest - water column data. Water column data refers to any acoustic data that is detected by the sonar above the seabed surface. Water column data is useful for the mapping of fish schools and other mid-water marine organisms, assessing biological abundance, species identification, habitat characterization, underwater gas and oil seeps.

Figure 3: MBES Water column data, sourced QPS website



2.2 GNSS AIDED INERTIAL NAVIGATION SYSTEMS

A modern multibeam echosounder system requires an accurate position and orientation solution providing it with real time data to account for all vessel motion. This brings us to the next important piece of the technology puzzle, Global Navigation Satellite System (GNSS) aided Inertial Navigation Systems (INS).

GNSS aided INS is the integration of a survey grade GNSS positioning system coupled with a high accuracy inertial motion compensation unit to provide highly accurate position, heading, attitude and heave in almost all weather and water surface conditions. The time stamped attitude data delivered to the MBES system at high frequency allows for depth data to be motion compensated for all axis, in real time.

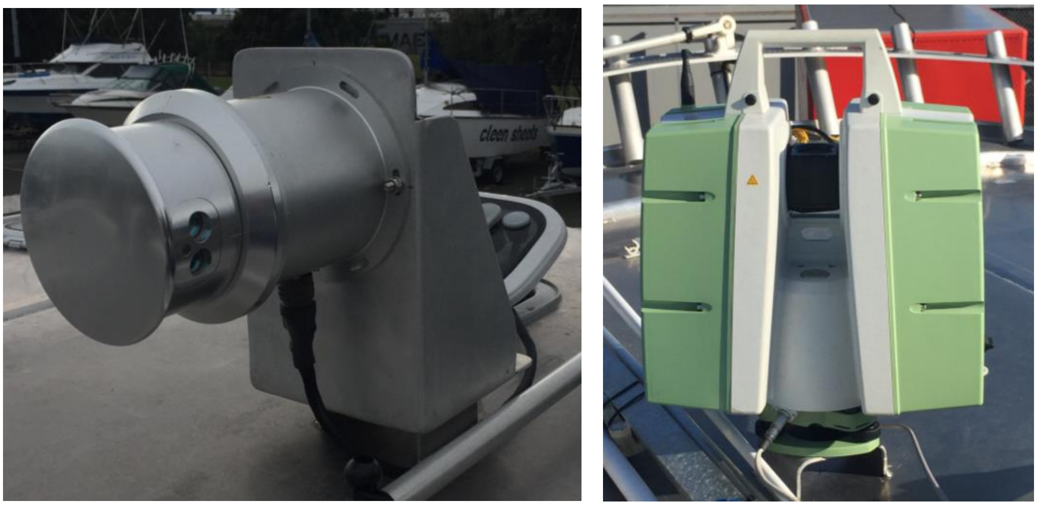
A common installation onboard a multibeam survey vessel integrates the GNSS INS with the multibeam sonar and combines all the incoming data within a navigation software application. The reduction in size, reduced power demand, increased accuracy and ongoing reliability of the GNSS INS sensors has made it possible to simultaneously deploy additional sensors on the same vessel e.g. a mobile laser scanner.

2.3 MOBILE LASER SCANNERS

By coupling the GNSS INS with a mobile laser scanner it is now possible to acquire 3D point cloud data of features above the water surface whilst simultaneously collecting bathymetric data with the multibeam below the waterline. The bathymetric and laser data is simultaneously acquired and logged within the multibeam acquisition software. The result is a single, seamless high resolution dataset above and below the waterline.

A major benefit of this method of acquisition is the survey is not limited by the water level. For example when using multibeam sonar it is common to gather data to within 1-2m of the water surface, subject to the draught of the vessel. By integrating the laser scanner with the multibeam sonar, surface data can be collected up the river banks, stop banks and outfalls even during low lake levels and water flows.

Photograph 3: Mobile laser scanners mounted to a 7m vessel



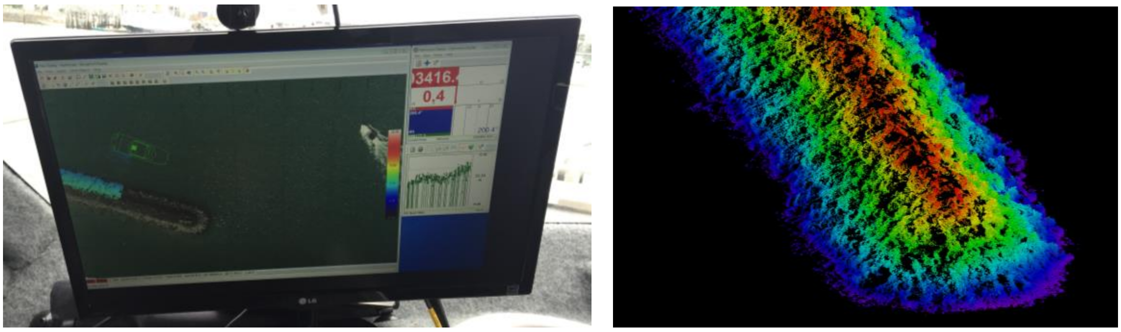
It's possible to reduce vessel operating time and therefore cost of data collection, by acquiring both data sets simultaneously.

2.4 SURVEY SOFTWARE

There are several software suites that are designed specifically to deal with large multibeam datasets including QPS, Hypack, Caris, and EIVA. Terrestrial laser scanning point cloud data is usually collected and processed in purpose built software packages including Bentley Descartes, Trimble Realworks and Leica Cyclone etc.

A number of multibeam software manufacturers have added software drivers enabling their survey acquisition packages to accept profiling laser scanner data, in the same way it treats multibeam data. The laser data is combined with the position and orientation solution providing a mobile laser scanning ability. The QPS software suite which is comprised of QINSy for online navigation/acquisition and QIMERA/Fledermaus for data processing and visualization has the ability to accept both multibeam and laser scanner data.

Photograph 4: Logging of laser data in QPS QINSy



Once captured, multibeam and laser scanning data are very similar in format and can be readily processed before being exported to other software packages such as GIS, typically in ASCII xyz format.

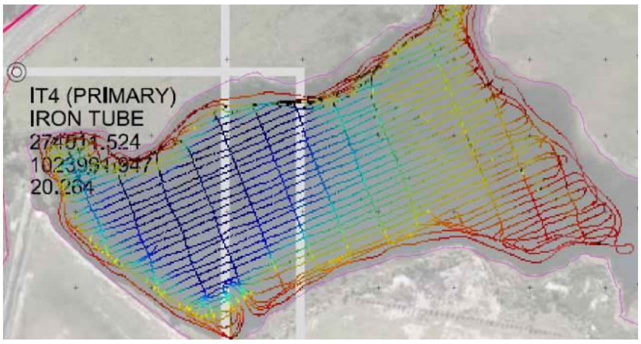
3 EMERGING SURVEY TECHNOLOGY

Unmanned Surface Vessels (USV) equipped with MBES and other emerging technologies are increasingly being employed by surveyors to acquire data safely, when traditional methods are unfeasible or uneconomic.

A USV will typically be around 1m in length, big enough to house an onboard positioning system, an echosounder, batteries and a data telemetry system, whilst still maintaining a vessel draft of less than 0.1m.

During operation the USV is piloted by a shore based operator who can steer by line of sight or onboard camera. The USV has an onboard data telemetry system which sends the vessels real time position and depth to a laptop with navigation software onshore. This allows the operator to follow run lines to ensure complete coverage of the area of interest.

Figure 4: Colour banded SBES data captured by USV



The key advantages of a USV are;

- Very shallow draft (0.1m) allows for it to be operated in shallow water bodies < 0.5m where a manned/powered vessel cannot operate,
- A USV can be deployed into contaminated or hazardous water bodies where it would be unsafe for survey personnel to go,
- When coupled with a robotic total station for positioning a USV can be operated under tree canopies, in steep sided river canyons or under bridges and other structures.

Figure 5: Robotic total station coupled with a USV

The key disadvantages of a USV are;

- Not designed to operate in swift water. Operating speeds of approx. 5ms-1 (9-10 knots) are common for off the shelf products,

- Operating windows are restricted to battery life and telemetry link,

- High cost, $100k-$200k depending on accuracy and MBES system fitted,

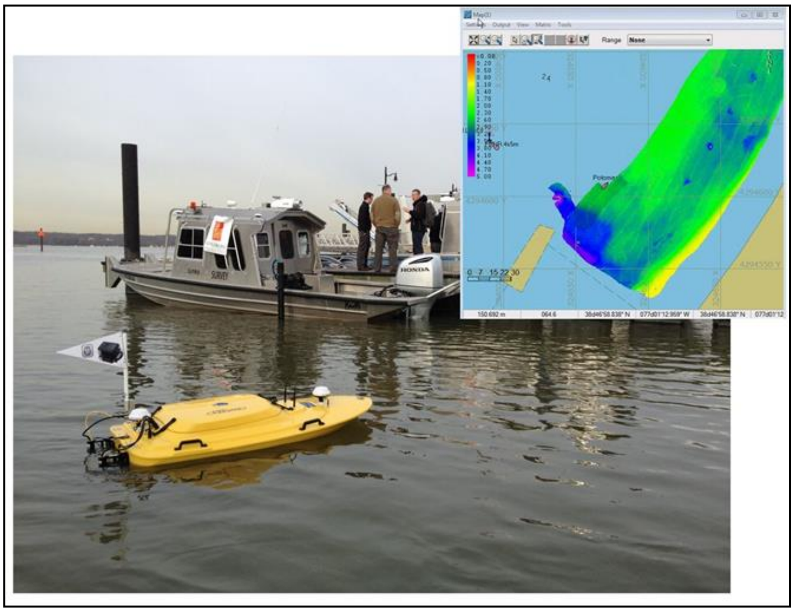
- High dollar value of unmanned equipment on the water,

- A manned safety or recovery vessel is recommended in case the USV becomes stranded, loses power or moves out of range.

At the leading edge of USV technology is the mounting of small form multibeam echosounders to USV's.

One such system was demonstrated at the USA Hydro conference 2015 by Teledyne Oceanscience. Their Z-Boat 1800 with an Odom MB1 multibeam echosounder onboard demonstrated that multibeam data can be collected in shallow, hazardous or restricted access water bodies when operated by properly trained personal. Refer to the demonstration at the following link *www.youtube.com/watch?v=vmEI24aW3OQ*.

Figure 6: Z Boat 1800 fitted with a MBES



Another emerging technology is Unmanned Aerial Vehicle (UAV) mounted Lidar. A Lidar system is a survey technology that measures angular ranges by illuminating them with laser light. Previously these systems could only be carried by helicopter or fixed wing planes, but as manufacturers strive to build ever lighter and more compact Lidar systems it has become a possibility to mount these on a UAV. The UAV can then be preprogrammed to run a pre designed flight path over an area of interest and collect georeferenced height data over land, vegetation and water bodies. Bathymetric Lidar systems can penetrate water bodies providing accurate bathymetry data to depths of approx. 0m-30m. The achievable depth is heavily dependent on the power output and laser colour of the Lidar system. Bathymetric Lidar systems are also restricted by water clarity and turbulence with very clear water bodies realising the best results.

The uses for this technology are still being investigated but include;

- Shallow coastal bathymetry where vessels cannot access,
- Surveying of inaccessible or hazardous waterbodies,
- Erosion/siltation mapping of dynamic waterways,
- Forestry and vegetation growth monitoring.

The key disadvantages of UAV Lidar are;

- High cost, $100k-$250k depending on accuracy and range of system required,
- High dollar value of unmanned equipment in the air,
- In areas of heavy vegetation e.g. (along river banks) the surface of the water may be obscured by vegetation resulting in data gaps.

Figure 7: UAV fitted with Lidar

4 NEW ZEALAND CASE STUDIES

4.1 OVERVIEW

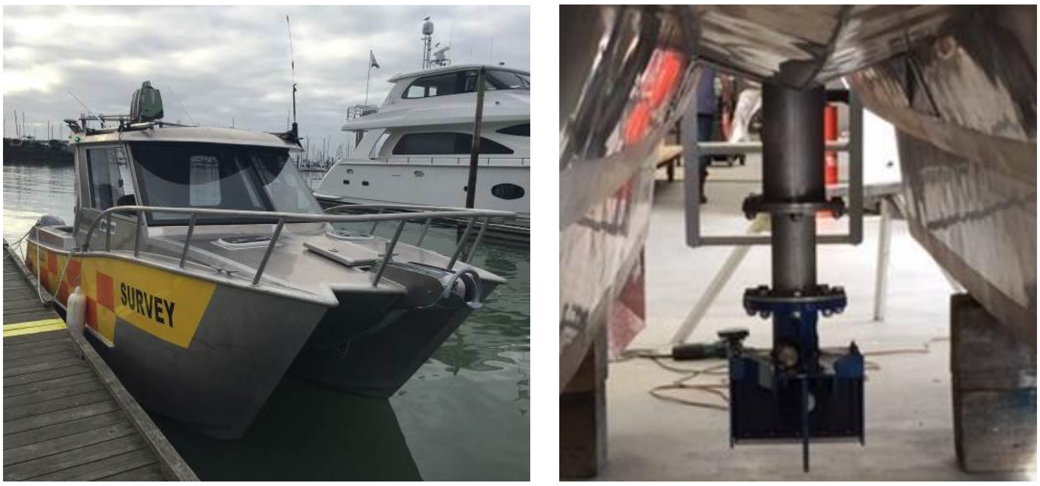
Two projects conducted within New Zealand over the past 24 months highlight the types of technology and visualization techniques now being undertaken in fresh water environments.

4.2 VESSEL

Both surveys in the following case studies were conducted from purpose built survey vessels, one a mono hull with an over the stern multibeam mount, the other a catamaran hull with a moon pool mount.

The catamaran hull is very stable, maneuverable and has a shallow draft. The vessel's moon pool is located in the centre of rotation of the vessel and between the two hulls. The multibeam sonar head can be retrieved through the moon pool, and raised well clear of the water for transits.

Photograph 5: Survey catamaran



4.3 EQUIPMENT

The following list of equipment was utilized for both surveys but on different vessels. All equipment was surveyed into the vessel offset reference frame by terrestrial survey techniques.

Table 1: Survey vessel equipment specs

Equipment	Model / Make
Primary Positioning System	POSMV Wavemaster and UHF radio with reception of CMR+ corrections (RTK solution) transmitted from NPL's Trimble base station
Secondary Positioning System	POSMV Wavemaster GNSS receiver with MarineStar G2 WADGNSS Correction service enabled
Motion Sensor	Applanix POS MV 320 Wavemaster V5
Multibeam Echo Sounder	R2 Sonic 2022 for Watercare project, Reson Seabat 7125 for Rotorua
Singlebeam Echo Sounder	Reson Navisound 210
Sonar Head Sound Velocity Profiler	Valeport Mini SVS
Sound Velocity Profiler	Applied Microsystems Limited "Minos" SVP, Valeport mini SVP
Acquisition Software	R2Sonic Controller & QPS QINSy v8.1
Vessel Computer	Small Form Factor, Intel i7-4770 (4C/8T), 3.4GHz, 64 Bit, WIN7 Pro, 8Gb RAM, 250Gb SSD, 1Tb HDD

4.4 DATA PROCESSING SOFTWARE

Bathymetric and topographic data was cleaned and validated using the QPS suite of programs, including QINSy and QIMERA. Data validation includes quality checks and correct depth reduction. Additional data post processing in the office included the removal of spikes, mid-water contacts, weed and other structures not of value to the survey.

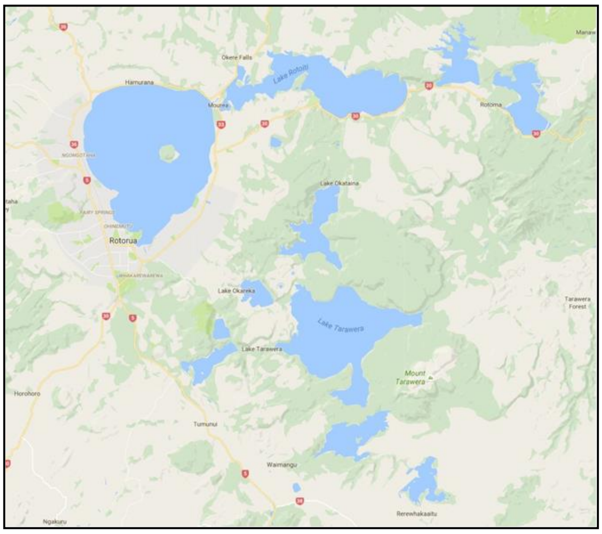
Final datasets were exported to another QPS product, Fledermaus, for data visualization and the rendering of images and video fly throughs.

5 ROTORUA TE ARAWA LAKES PROGRAMME

5.1 SURVEY SCOPE

The Rotorua Te Arawa Lakes Programme is working to protect and restore the water quality in twelve Rotorua lakes. Since 2014 the University of Waikato and Discovery Marine Limited have been using a high resolution MBES to accurately survey a number of the Rotorua lakes.

Figure 8: Te Arawa Lakes Programme



5.2 SURVEY PROCESS

5.2.1 SYSTEM SETUP & CALIBRATION

A survey template is created for each project that includes georeferenced aerial imagery. This is loaded into the navigation software and aids in safety of navigation, survey planning and efficient operations during sounding.

In order to collect accurate multibeam data the system must be calibrated prior to the start of a project. The calibration routine, known as a Patch Test, requires data to be collected on a number of lines covering particular features or lake bed gradient. Data from each survey line is compared to determine the orientation of the MBES head, in the three axis of roll, pitch and yaw relative to the INS. These three angular offsets must be determined to produce accurately corrected and repeatable MBES data.

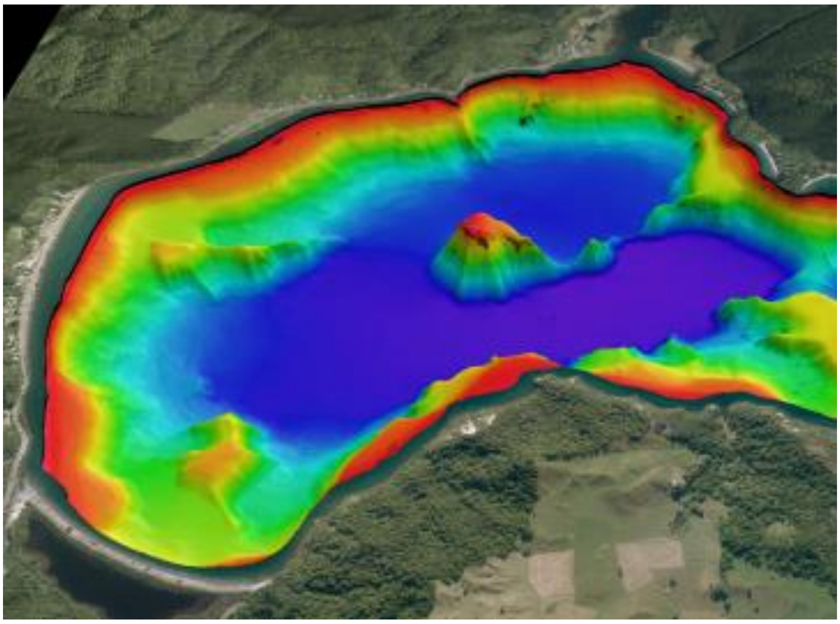
5.2.2 FIELDWORK

For multibeam data acquisition the Reson Seabat 7125 sonar was operated at 300-380 kHz, with 120° opening angle and in equidistant mode. Multibeam backscatter was logged in tandem with the multibeam bathymetry. Attitude correction for all data was provided by the POSMV Wavemaster. Roll, pitch, heading, position and heave data sent from the POSMV was logged and applied to the bathymetry in real-time by QINSy. The POSMV provided excellent results with real-time rotation accuracies of better than 0.02° reported for all three axes during data acquisition.

Vessel sounding speed in open areas of water depth greater than 5m depth was generally 3 - 5 kts. Vessel speed was significantly reduced in near shore shallow water areas; with an average recorded vessel speed often as low as 2 kts. This resulted in the following amounts of effort to survey each lake; Lake Okataina four days sounding; Lake Rotoma three days sounding; Lake Tikitapu (Blue Lake) one day sounding; Lake Rotokakahi (Green Lake) two days sounding; and Lake Okaro one day sounding.

The speed of the vessel and sonar swath angle needed to be carefully managed in the lakes as steep slopes, fallen trees and rocky outcrops were encountered around the lake edges. Caution was necessary in the centre of Lake Rotoma where a volcanic cone rises some 60m from the lake bed to within 1m of the lake surface. Sounding speeds were reduced to ensure complete coverage in the deepest areas of Lake Rotoma (80m deep) and Lake Okataina (84m deep).

Figure 9: Volcanic cone, Lake Rotoma



An inversion layer of very cold ground water and soft lakebed sediment in Lake Rotokakahi provided challenges in acquiring clean multibeam data. Higher than normal power and gain sonar settings had to be used in order to overcome the resulting noise caused by these issues.

5.2.3 PROCESSING

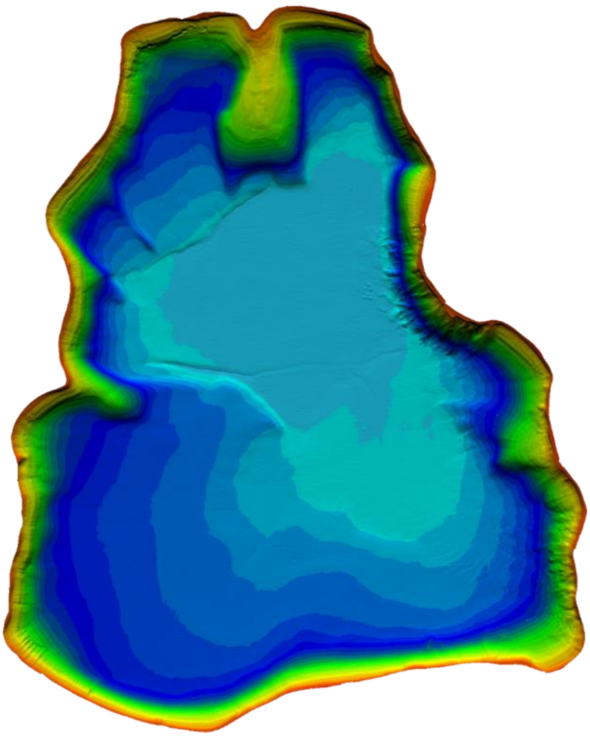
Four days processing and reporting effort was required for this project and consisted of; 1.5 days data validation, cleaning and editing; 1.5 days for the production of data deliverables; and 1 day for finalizing the survey report. Data volumes are generally in the order of 20-25GB per 8 hour sounding day.

5.2.4 REPORTING & DELIVERABLES

Traditionally lake maps have consisted of individual depth values or bathymetric contours at set intervals dependent upon on the detail of the survey.

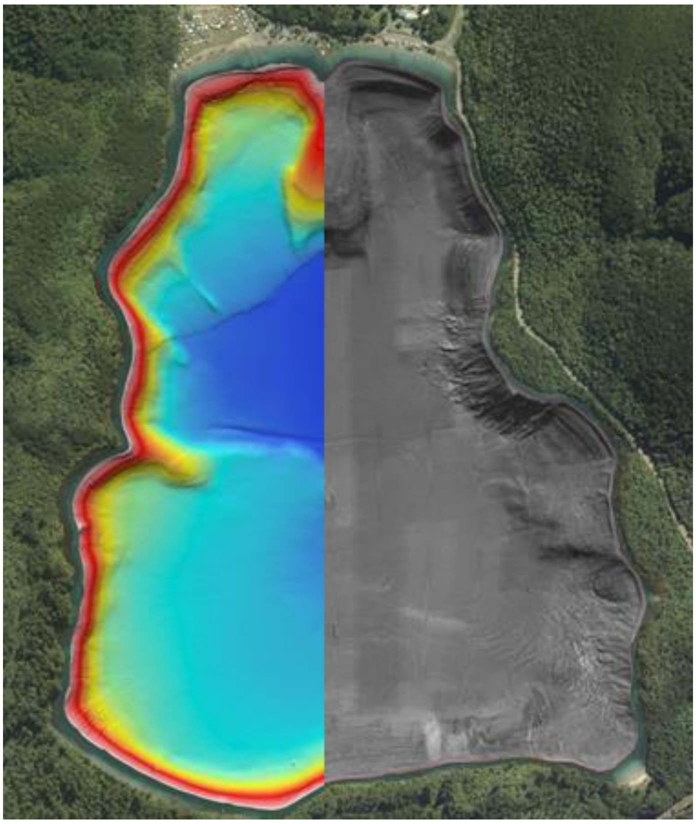
More recently, with higher accuracy surveys 2D colour banded images are being created from ASCII xyz gridded datasets, such as that of Lake Tikitapu (Blue Lake) shown below. In this instance the data below is colour banded at 2m intervals and reveals more of the lake bed detail.

Figure 10: 2m bathymetry, Lake Tikitapu (Blue Lake)



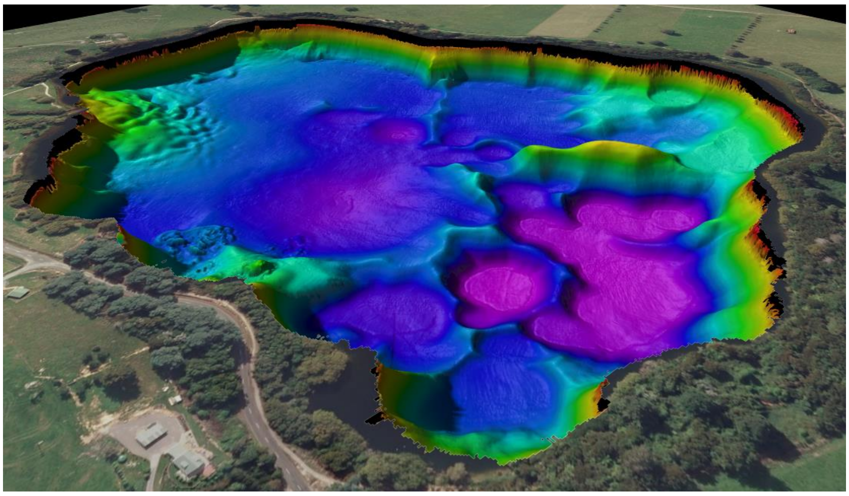
However, when georeferenced aerial imagery is combined with the multibeam backscatter data and is draped over the bathymetry dataset we begin to get a real insight into the lake bed geography.

Figure 11: Multibeam back scatter, bathymetry and imagery, Lake Tikitapu (Blue Lake)



These datasets are providing high quality baseline information for scientists and managers in understanding geological activity, biological habitats and the propagation of flora and fauna throughout the entire lake.

Figure 12: Crater systems, Lake Okaro



Submerged landslides appear to be common features throughout the lakes in the Te Arawa project. The images below highlight the detail revealed when backscatter imagery is draped over the lake bed surface.

Figure 13: Submerged land slide, Lake Okataina

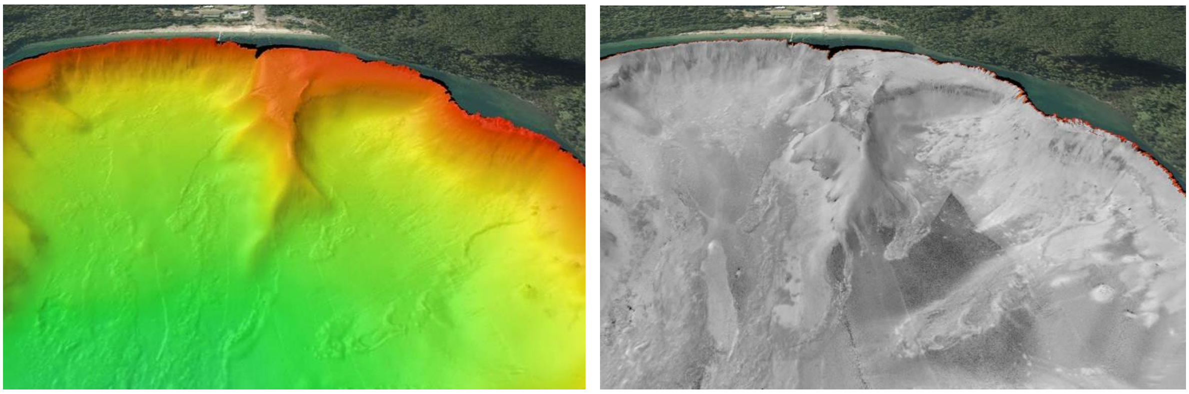
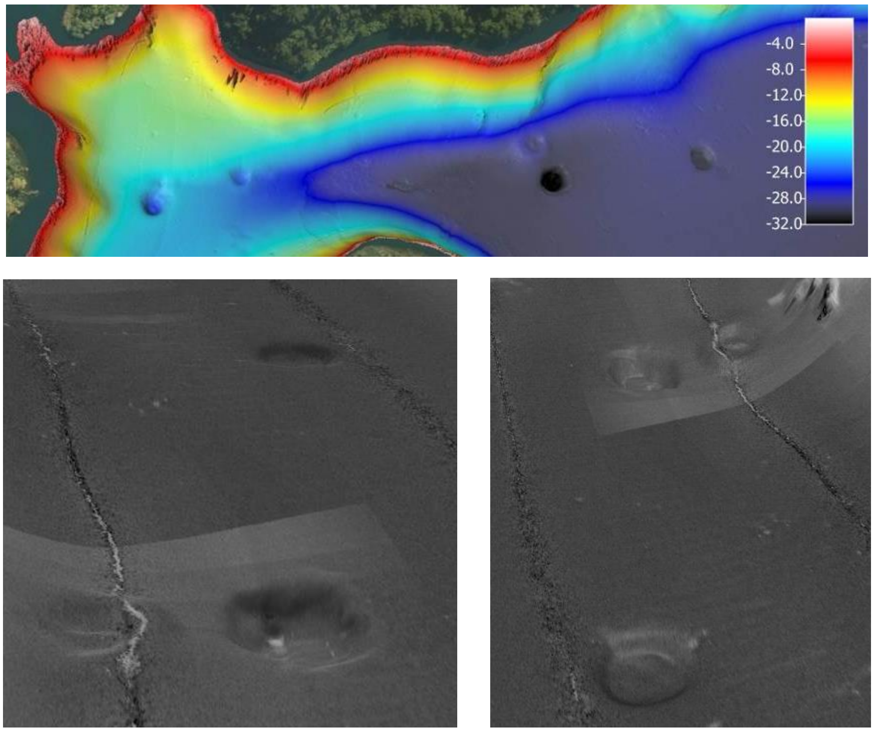


Figure 14: Landslide debris, Lake Rotokakahi

While underwater landslides appear to be common, less common are the circular depressions found in the lakebed located towards the western end of Lake Rotokakahi. Five such depressions are evident in the dataset and appear to line up in an east-west orientation. The diameters range from 25-35m and have depths of 1-3.5m below the surrounding lake bed.

Figure 15: Circular depressions, Lake Rotokakahi (Green Lake)

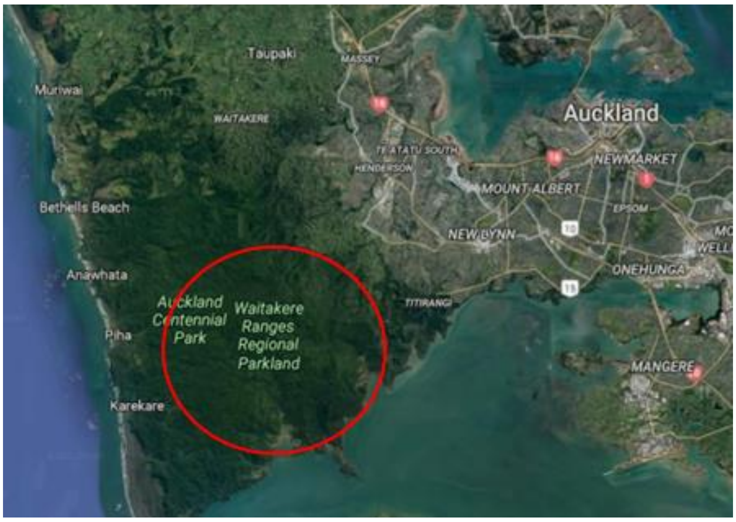


6 WATERCARE SERVICES LTD, AUCKLAND DAMS

6.1 SURVEY SCOPE

As Auckland's population steadily grows, so too does the security of its freshwater supply. As part of Watercare's ongoing monitoring work several freshwater reservoirs across Auckland have been mapped by multibeam sonar. Topographic laser scanner data was also trialed to capture point cloud data on dam infrastructure. Aspects of two recent surveys of the Lower Nihotupu and Lower Huia Dams are reviewed below.

Figure 16: Dam locations in Auckland's Waitakere Ranges



6.2 SURVEY PROCESS

6.2.1 SYSTEM SETUP & CALIBRATION

A similar methodology was employed for system setup and calibration for both the Lower Nihotupu and Lower Huia. A survey template was created for each project that included georeferenced aerial imagery and any dam infrastructure information. All information was loaded into the navigation software and assisted with safe navigation of the vessel, survey planning and ensuring efficient operations during sounding. The vehicle, vessel, trailer and equipment were all subject to careful cleaning in accordance with Didymo prevention guidelines prior to deployment.

Prior to commencing sounding in each reservoir, all calibration values and sensor offsets were checked and confirmed. A Patch Test was completed for each reservoir, which required MBES data to be collected in a pattern of reciprocal survey lines, over a lake bed feature or steep gradient. The MBES data from each survey line is compared to determine the angular bias of the MBES head, in the three axis of roll, pitch and yaw (heading). The three resultant angular corrections are entered into the acquisition software and applied in real-time data providing accurate, corrected and repeatable MBES data.

6.2.2 FIELDWORK

Vessel access to the two reservoirs provided some challenges, with only small access ramps available to launch and recover the vessel from. The use of a smaller, lighter vessel fitted with a small MBES system was an important factor in safely deploying the equipment and personal onto the reservoir.

Photograph 6: Vessel launching in tricky conditions

The MBES system used was the R2 Sonic 2022 MBES, operated at 400 kHz, between 120° and 130° opening angle. Multibeam backscatter from the sonar was logged in tandem with the multibeam bathymetry. Attitude correction for all data was provided by the POSMV Wavemaster. Roll, pitch, heading and 3D position data sent from the POSMV was logged and applied to the bathymetry in real-time by QINSy. The POSMV provided excellent results with real-time rotation accuracies of better than 0.02° reported for all three axes during data acquisition.

Photograph 7: Bathymetry survey

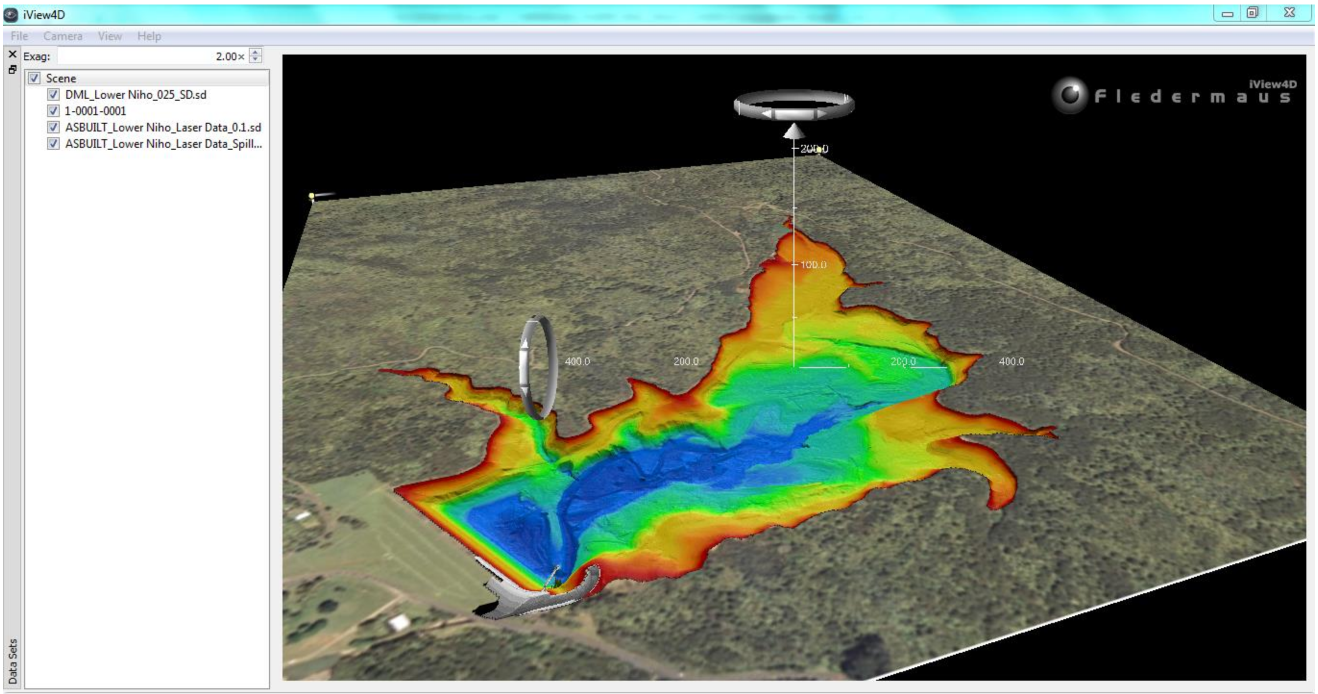
Vessel sounding speed in open areas of water depth greater than 5m depth was generally 5kts, with significantly reduced vessel speeds in near shore shallow water areas, bell towers, spillways and other dam infrastructure. Each reservoir required approximately 10hrs to complete MBES sounding.

6.2.3 PROCESSING AND REPORTING

Each reservoir required 2 weeks to process, which included data cleaning, reporting and generating specific deliverables required for each project. Each data set was cleaned using the QPS suite of programs which allows the data to be visualized and validated with the removal of all data outliers or errors.

The deliverables for these projects typically consisted of a 1m Digital Terrain Model (DTM) grid of the reservoir bed, a point cloud of any laser scanner data, 0.5m DXF contour file, Google Earth KML file, colour banded 2D and 3D surface imagery, water volume calculated at 1mm intervals and a comprehensive report of survey. All the data deliverables are packaged together in a 3D software viewer which allows the client to visualize data layers by controlling a 3D fly through window.

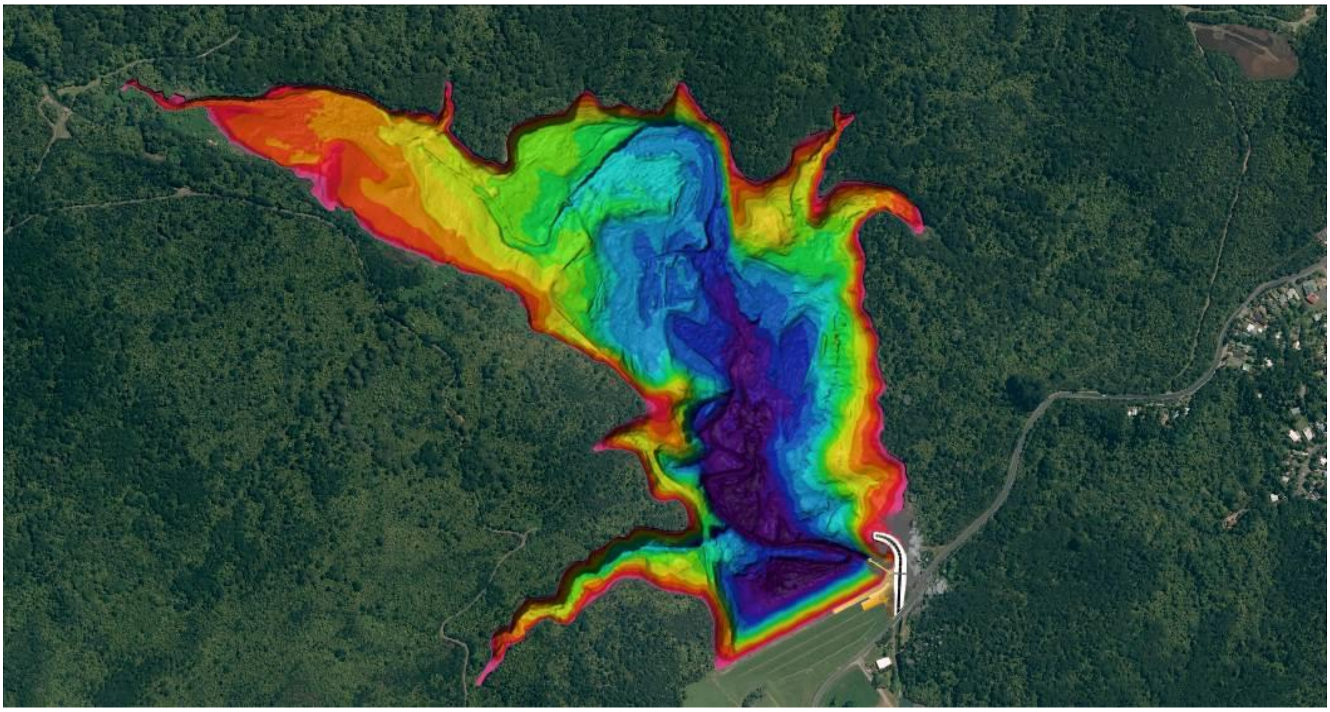
Figure 17: Free viewer 3D Visualisation software for QPS data - iView4d



6.3 RESULTS

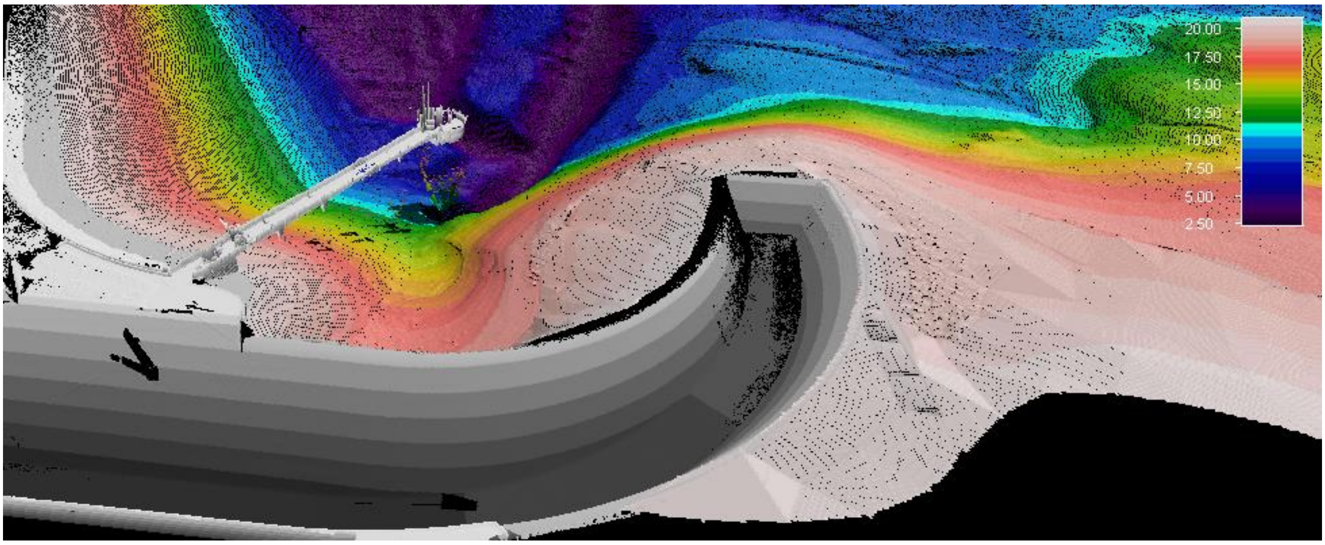
Selections of views from the two final data sets are shown below.

Figure 18: Final MBES data Set – Lower Nihotupu Dam



The image below shows the MBES data surface and laser scanner point cloud data combined to show a near seamless data set. Bell tower, walkway and spill way are clearly defined by the laser scanner data and merge into the MBES bathymetry.

Figure 19: Integrated laser scanning and MBES data, Lower Nihotupu Dam



Much like a topographic point cloud, each individual point captured by the MBES system can be visualized and interrogated. The image below shows the dense underwater point cloud extracted around the Bell Tower and walkway piles from the final data set.

Figure 20: MBES point cloud image of Lower Nihotupu Dam

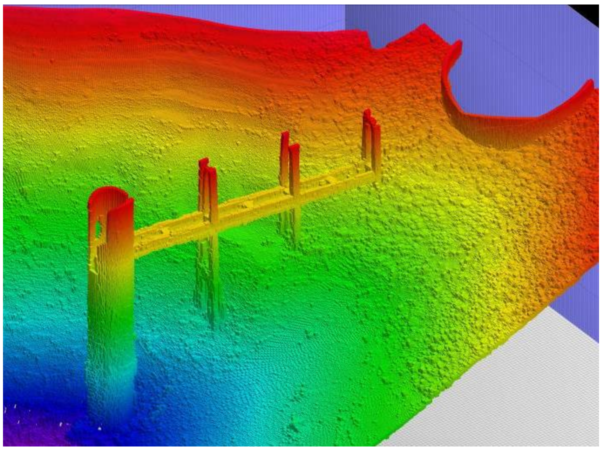
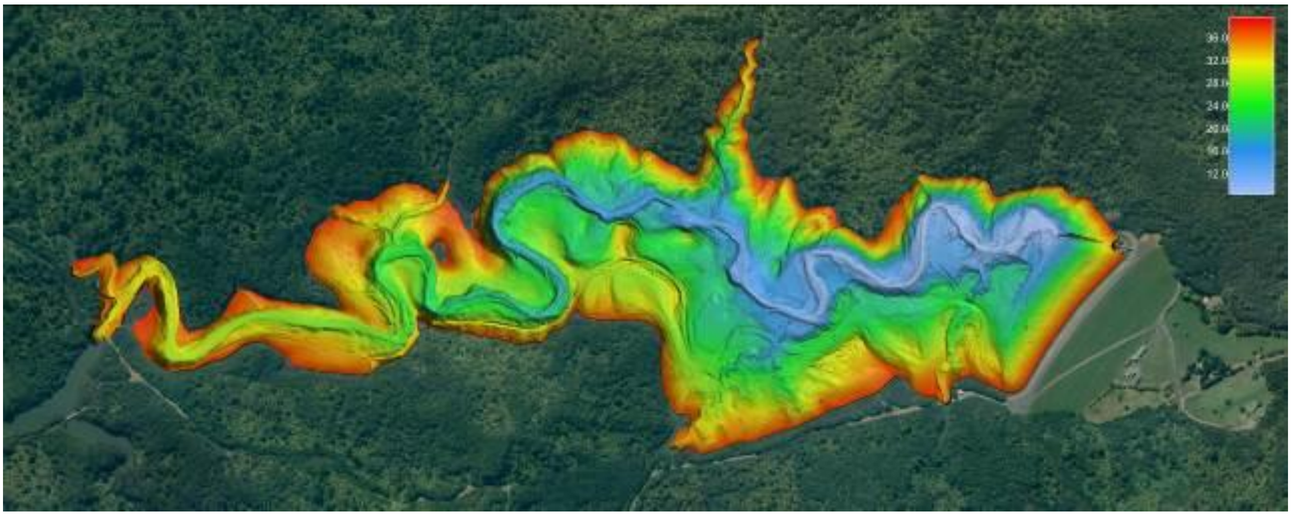


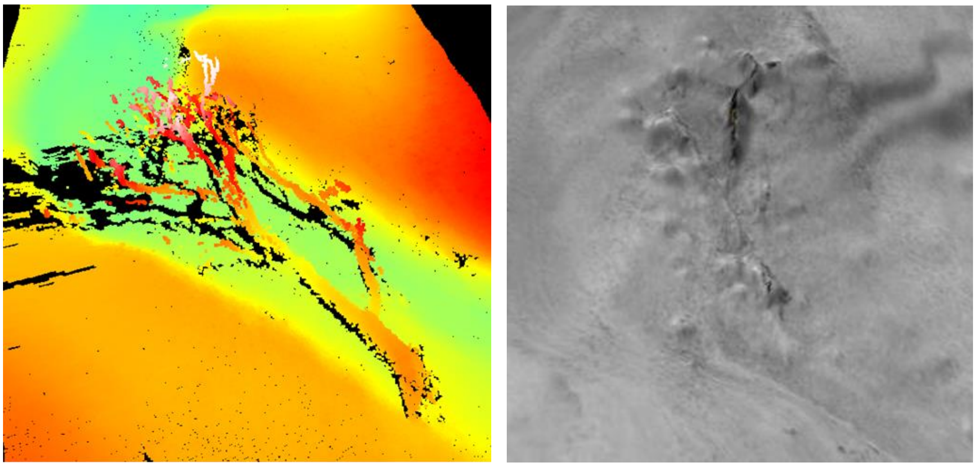
Figure 21: Final MBES data set, Lower Huia Dam



The acoustic backscatter recorded by the MBES system can be used to identify changes in lake bed geomorphology or manmade features. In the case of flooded valleys, historic features such as river sediments or land-slides can be identified along with vehicle tracks, light gauge rail or tree stumps.

Figure 22: Backscatter imagery draped over bathymetry, Lower Huia Dam

Figure 23: Large log in both bathymetry and backscatter, Lower Huia Dam



7 CONCLUSIONS

Advancements in global hydrographic survey and mapping technology are being utilised in freshwater environments around New Zealand. MBES systems mobilised on small platforms are capable of capturing dense data sets of lake beds and rivers in order to establish volumes, sedimentation or erosion rates and identify geomorphologic features. Point cloud data from laser scanners can be combined with MBES data to provide seamless data sets above and below the water line. More cost effective sensor platforms, smaller sensors, and increased computing power will develop over time resulting in improved access to challenging areas, more data and better risk management.

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