Geophysical Site Investigations at the WAC Bennett Dam

Presented By

FRONTIER GEOSCIENCES INC.

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About Frontier:

Established in **1987** to offer comprehensive geophysical consulting and survey services to the geotechnical, engineering, geothermal, groundwater, environmental, and mineral exploration communities.

The company staff have completed more than **1600 projects** worldwide, drawn from the full range geophysical techniques.

Frontier has completed **28 projects** at the WAC Bennett Dam.

The company maintains an active program of **research** and **development**.

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WAC Bennett Dam

Location: 19 km west of Hudson's Hope, B.C., approximately 1200 km north of Vancouver, B.C

Construction was completed 1967. The dam is over 2 km long, and 186 metres high.

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This photo is looking towards the west

1996 Sinkhole

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In 1996 a sinkhole appeared in the dam, triggering a series of geophysical surveys of varying methods to assist in characterizing the sinkhole and confirm the success of remediation.

Geophysical Methods Used

- Streaming Potential Survey (SP)
- Electrical Resistivity Tomography (ERT)
- Vertical Electrical Sounding Survey
- EM34 Conductivity Survey
- EM61 Metal Detection Survey
- Magnetometer Survey
- Ground Penetrating Radar (GPR)
- Downhole Seismic Velocity Testing
- Crosshole Seismic Shear Wave Velocity Testing
- Crosshole Seismic Tomography
- Crosshole Radar Tomography
- Through Dam Tomography
- Temperature Profiling
- Downhole Nuclear Logging
- Boat Based Bathymetry Survey
- ROV High Resolution Bathymetric Inspection
- Towed Body CHIRP Sub-bottom Profiling Survey
- Optical Televiewer (Casing inspection)

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A number of different geophysical methods were tried at the Dam for a variation of objectives

Highlighted Methods

- Crosshole Seismic Shear Wave Velocity Testing
- Remotely Operated Vehicle (ROV) High Resolution Bathymetric Inspections

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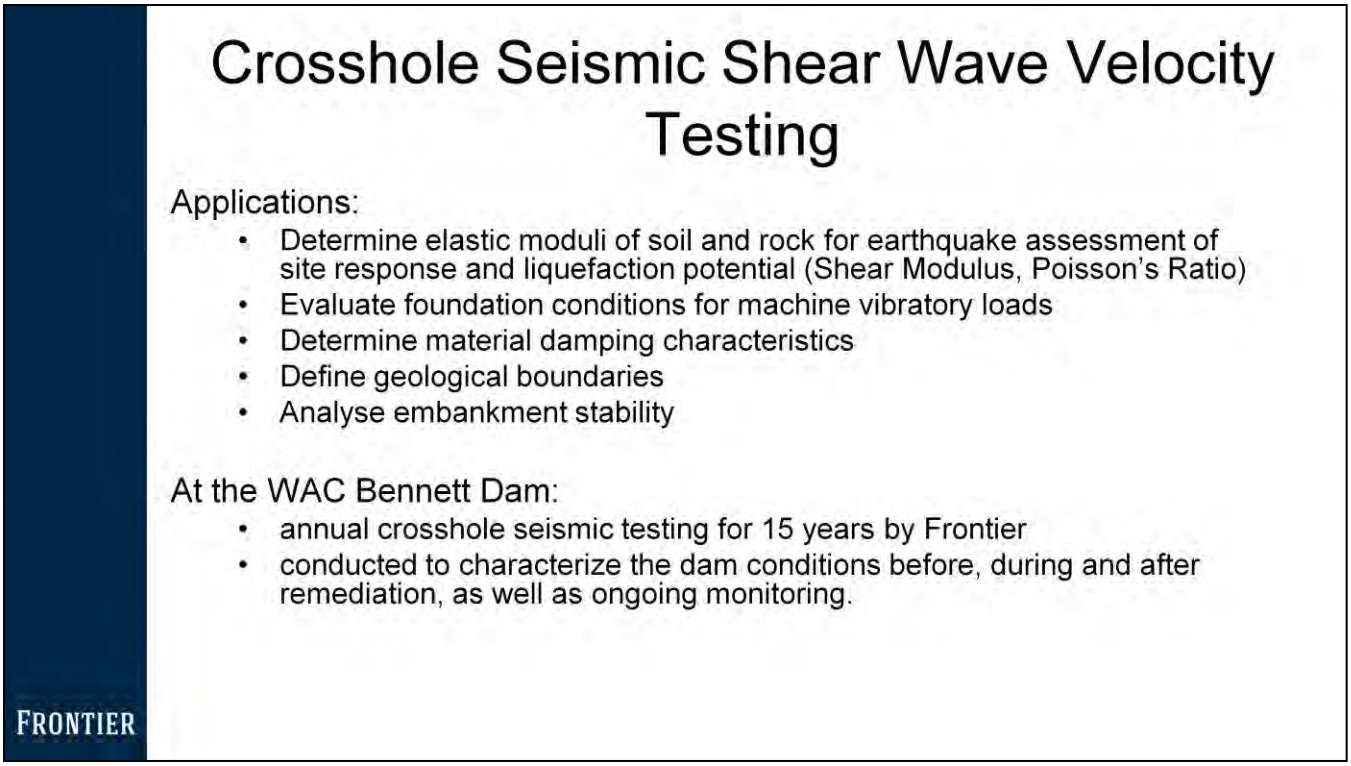
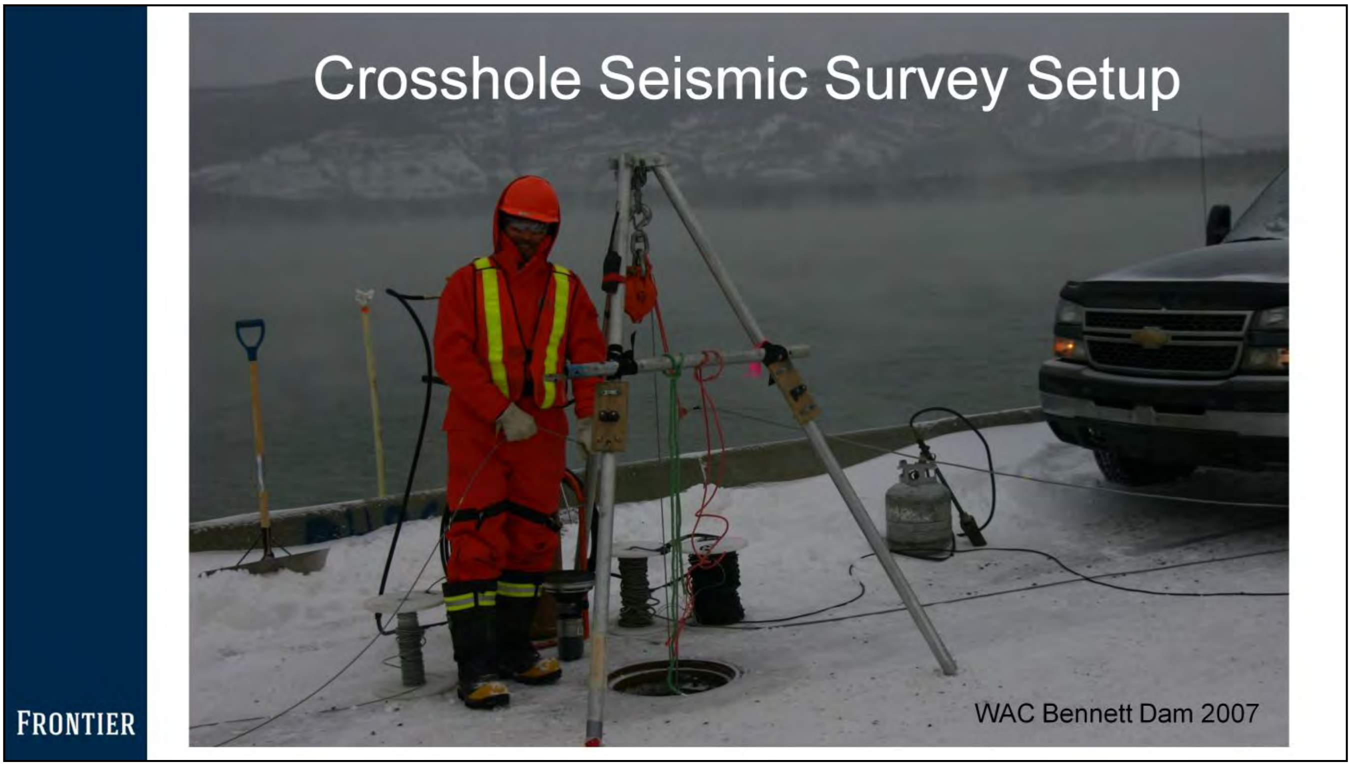


There are quite a few applictaions for crosshole seismic. Crosshole seismic surveying will provide shear wave velocities, which can then be used to deteremine soils properties, site conditions.

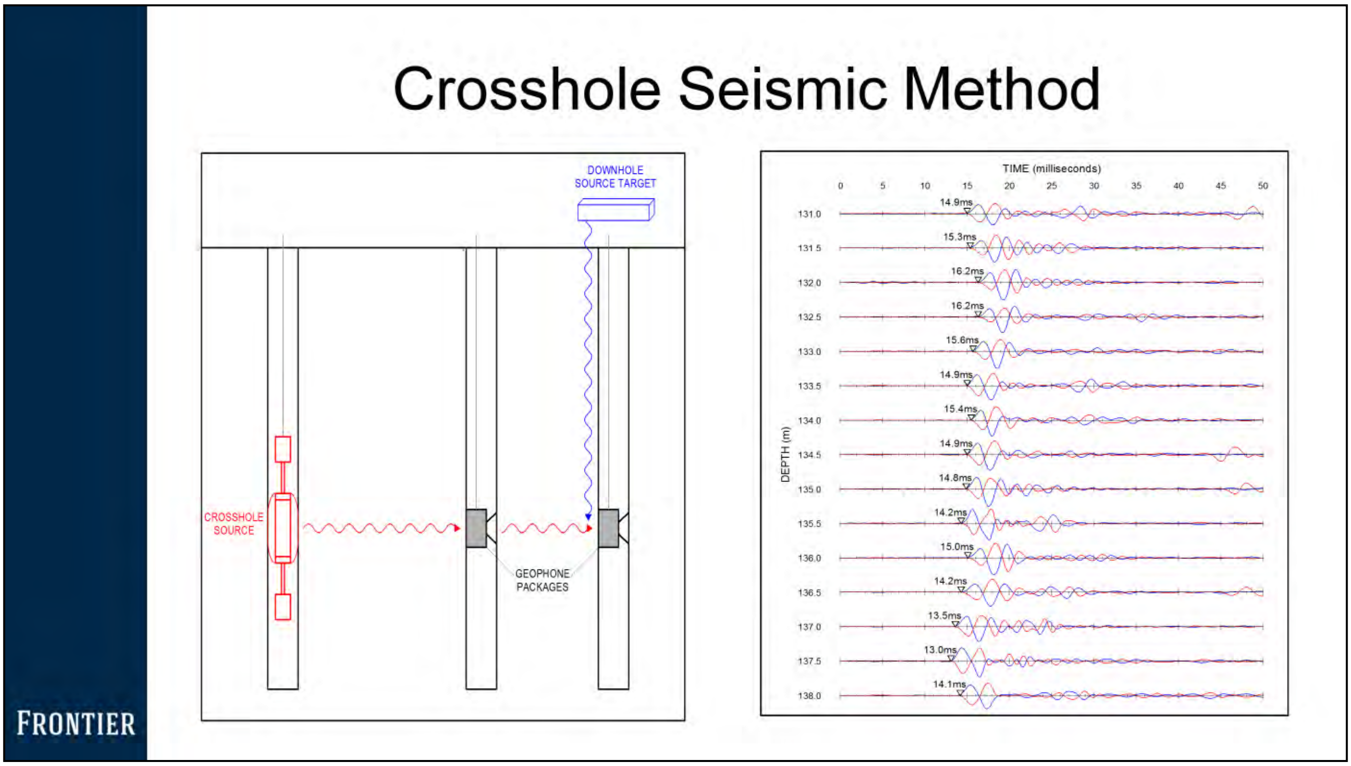
Frontier carried out annual crosshole seismic testing for 15 years

This comprhensive annual crosshole seismic program was conducted to characterize the conditions within the dam before, during and after remediation. This was a part of ongoing monitoring to confirm the continued integrity of the sinkhole repairs.

Crosshole was the most successful of 14 techinique carried out at the dam at that time.



This is what a typical survey setup would look like on the dam.

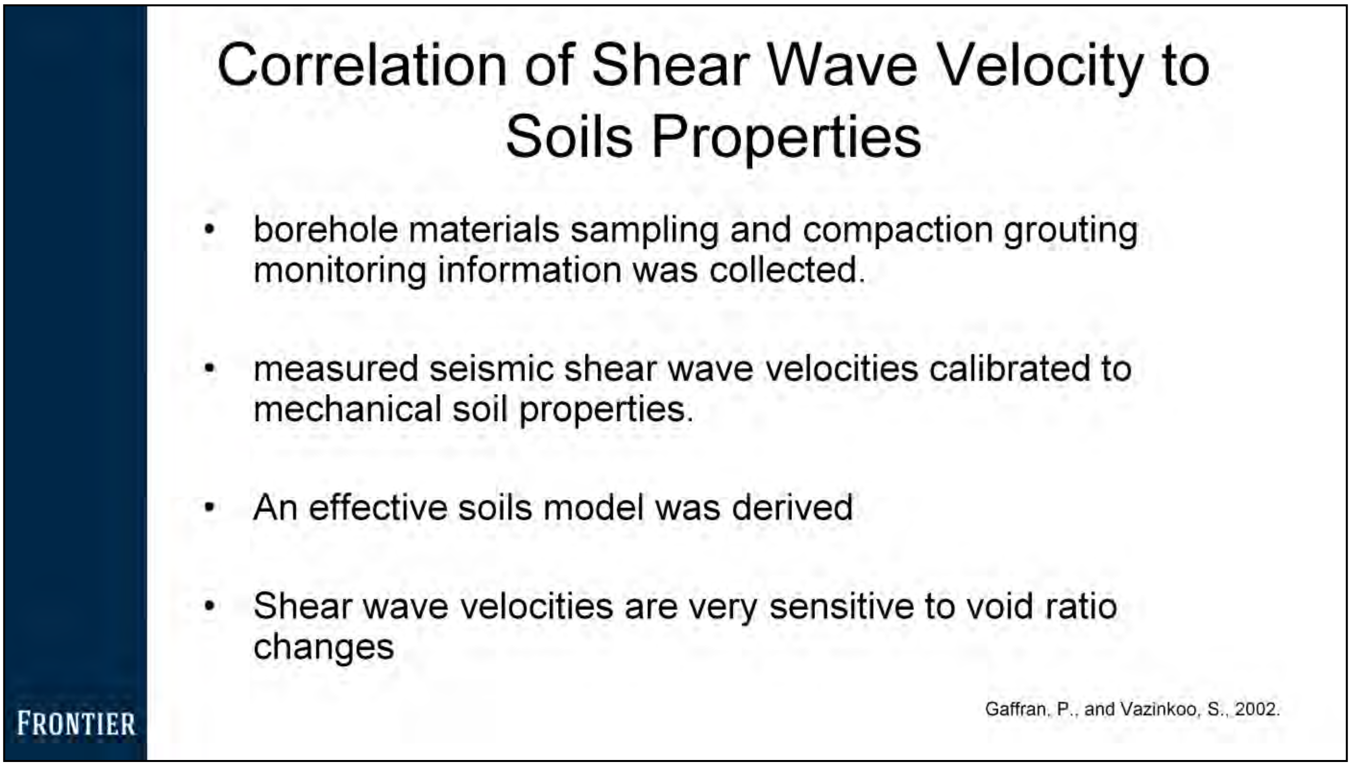


Source or crosshoel hammer is located at particualr elevation in 1 hole, receiver (triaxial dh geophone package) in another hole at the same elevation

The hammer creates a downward and an upward hit,

Data results show the up and down polarized blows with arrival times pocked at the reversal of these polarized waves.

From these picked arrival times and the raypath distance a shear wave velocity is calculated for each measurement location

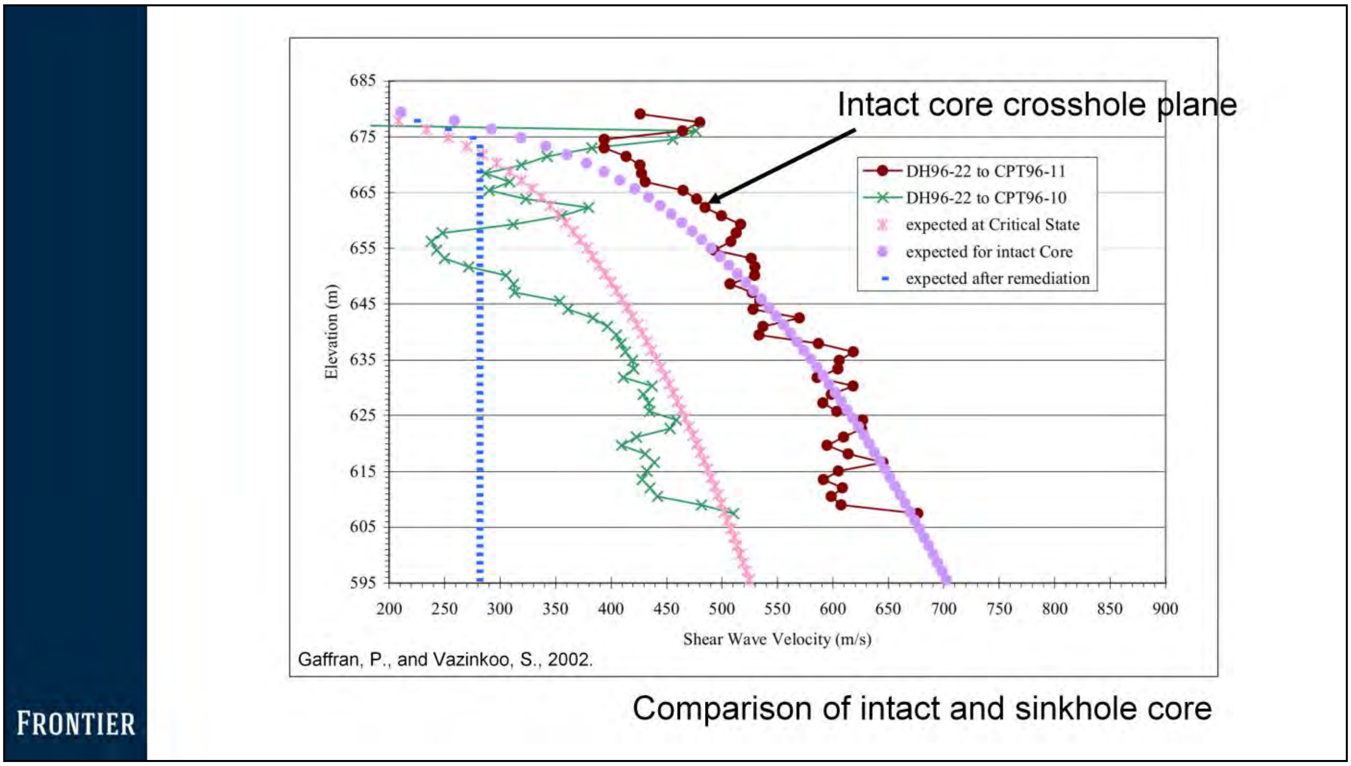


During the sinkhole remediation, an extensive amount of seismic data was collected, along with geotechnical data. A large amount of comprehensive borehole materials sampling and compaction grouting monitoring information was collects.

This information provided an opportunity to calibrate the measured seismic shear wave velocities to mechanical soil properties.

A effective soils model was derived that can be used to predict shear wave velocities for a range of mechanical soil properties.

It was observed that shear wave velocities are very sensitive to void ratio changes, significantly at low void ratios.

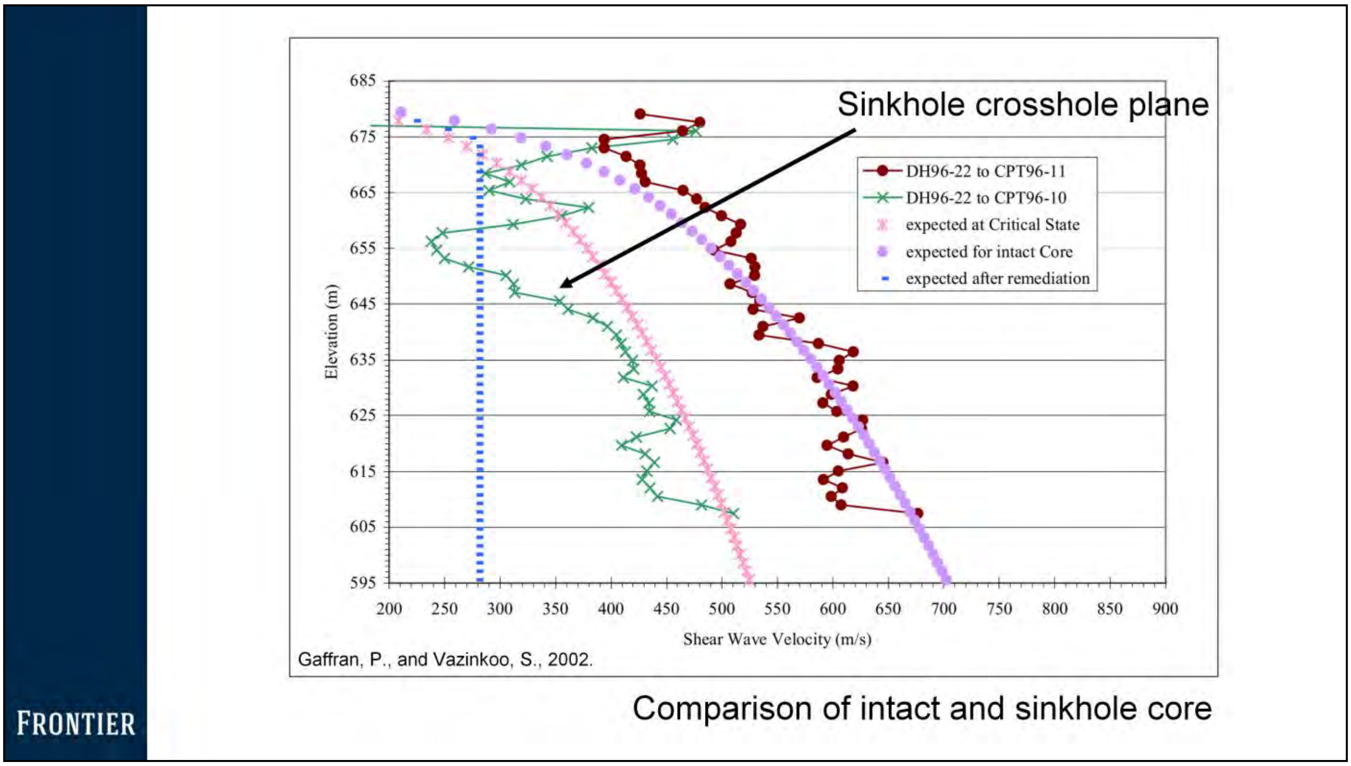


This figure compares to crossplanes surveyed at the Bennett dam.

Expected values for intact and critical state dam core is presented here in pink and purple.

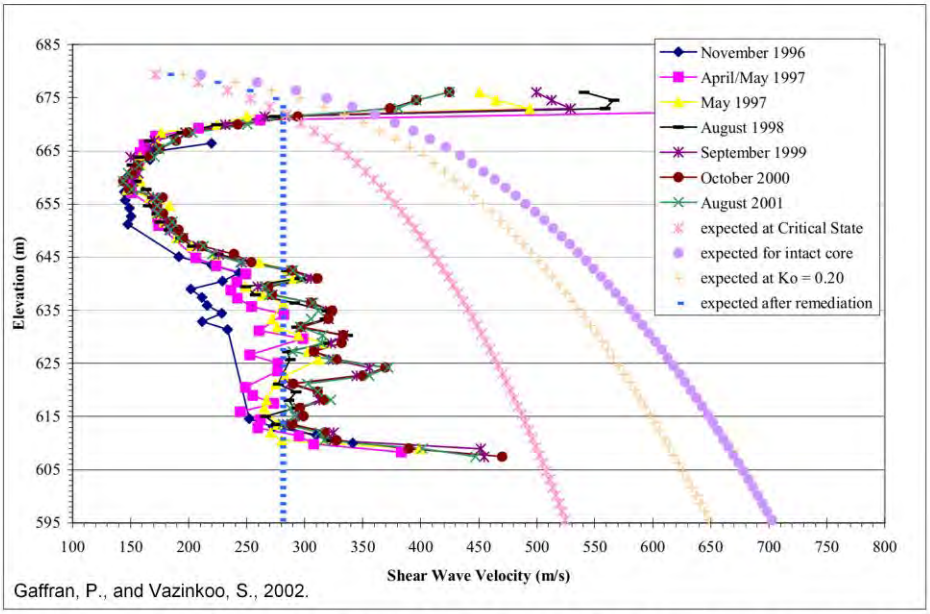
The intidacted red curve shows collected shear data for a plane between hole 22-11. This plane is located mostly outside the limits of the sinkhole between which the dam core is intact.

As we can see it correlates well with the expected curve well with expected curve



Compared with a sinkhole plane there are some signifcant differences.

This plane extends arcss a protion of the sinkhole between holes 22-10. This plane is characterized by lower velocities observed in the data.



History of crosshole plane CPT96-10 to 11, 1996 to 2001

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A typical sinkhole plane over 6 years of surveying. This plane spans across the sinkhole between holes 96-10 amd 96-11.

First surveyed in 1996 after the initial sinkhole. With annual crosshoel surveys plotted. The original survey in blue denotes lower velocities across the sinkhole

The effect of the remediation is seen as a general velcoity increase of approcimately 90m/s. Velocities are still lower than intact core.

This illustrates the need for an ongoing crosshole surveying ot monitor dam core conditions and integrity of the sinkhole repairs.

ROV High Resolution Bathymetric Inspection

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To acquire detailed mapping of the underwater dam surface

High Resolution Bathymetry Survey

Inspection was carried out in 2013 by:

- Ocean Floor Geophysics (OFG)
- PK Geophysics
- Cellula Robotics
- Frontier Geosciences

Purpose:

- Underwater inspection of the dam using robotics and remote sensing technology.
- Establish a baseline Digital Elevation Model for an on-going program of monitoring dam structures

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The survey was carried out by a partnership of four companies

OFG, PK, Cellula, and Frontier

Purpose was underwater inspection of the dam using robotics and remote sensing technology

Also to establish a baseline Digital Elevation Model for an ongoing program of monitoring the dam structures and surrounding areas

Inspection Specifications

Coverage Area
- 0.84 km^2

Multibeam Sonar
- 2 cm depth resolution

Total Horizontal Position Uncertainty
- 1 m

Total Vertical Position Uncertainty
- 10 cm

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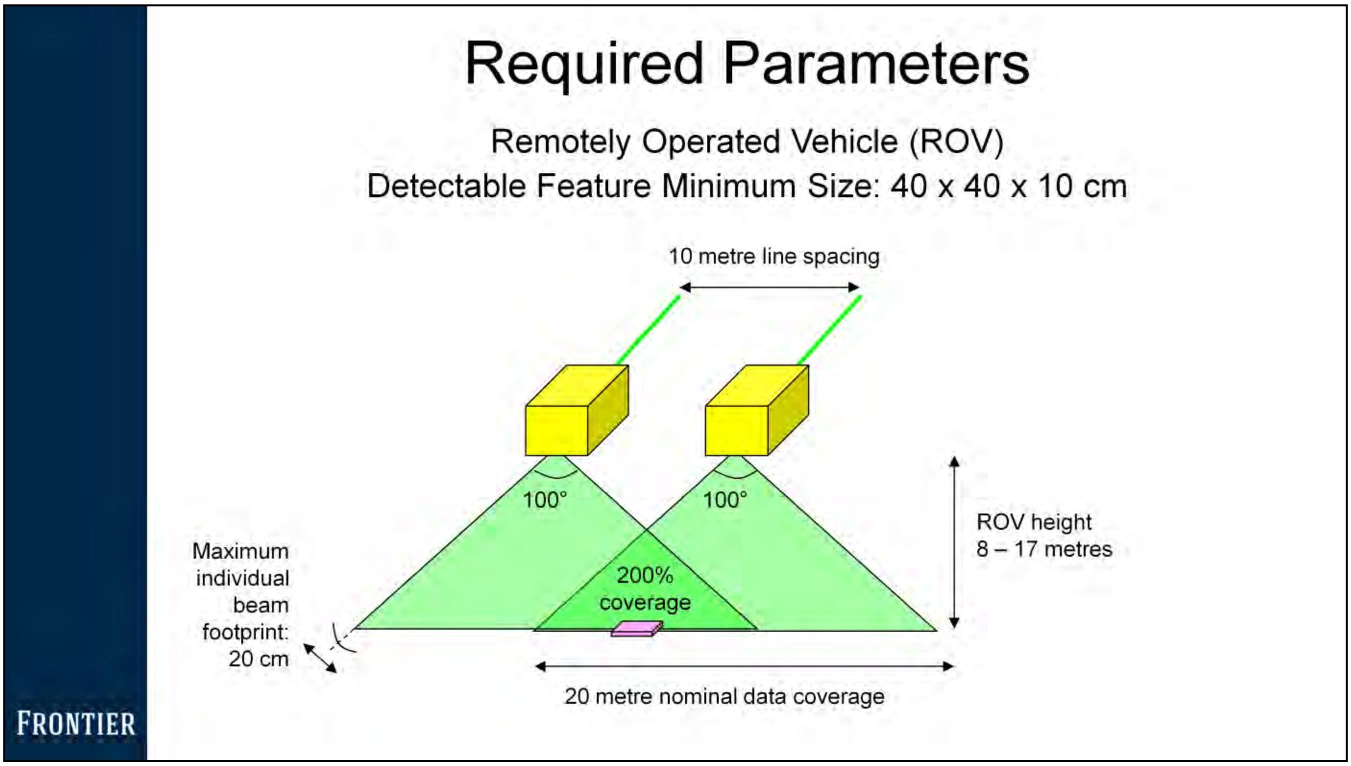
Survey area was split into 100m x 100m grids tiles

Positioning uncertainty was maintained at 1m for horizontal and 10 cm for vertical.



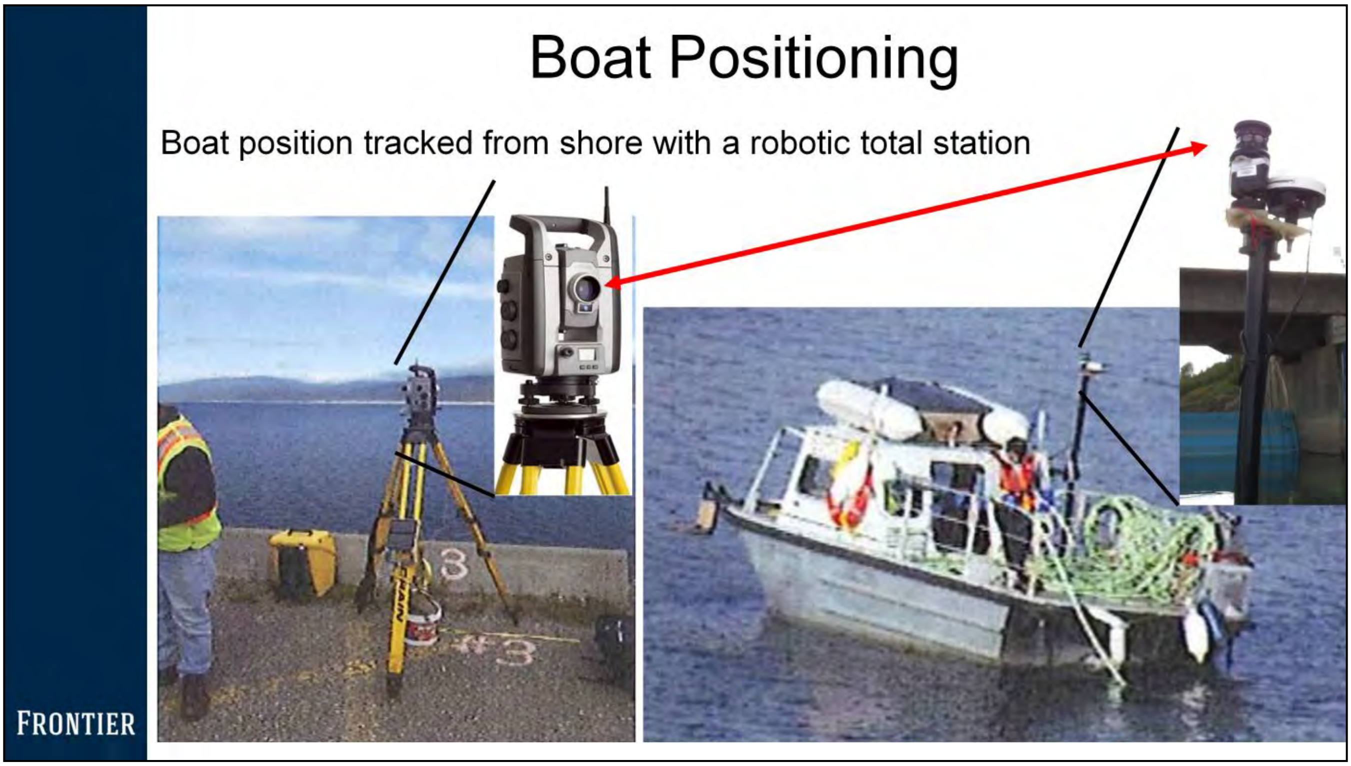
Additional survey paramaters were for ROV with a minimum detectable feature size of 40x40x10 cm

10 m line spacing was done with an ROV height between 8 and 17 m, resulting in 200% coverage of the lake bottom

An example of ROV operations were conducted from a survey vessel and land

ROV Pilot and Pilot Station

Rov pilot driving the ROV while near surface and a look at the pilot station used while at depth.

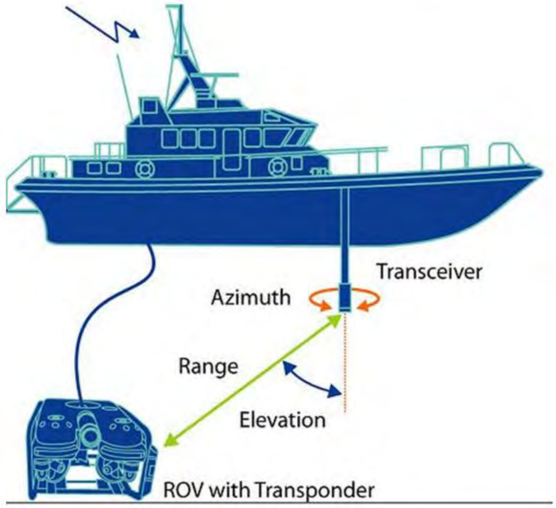


One of the most important things for an underwater ROV survey is accurate positioning information for your vehicle.

For this survey the survey vessel position was tracked form on shore with a robotic total station. Which would be tied into a benchmark or monument on the dam

ROV Positioning

ROV position tracked from boat with a underwater acoustic positioning system (USBL)



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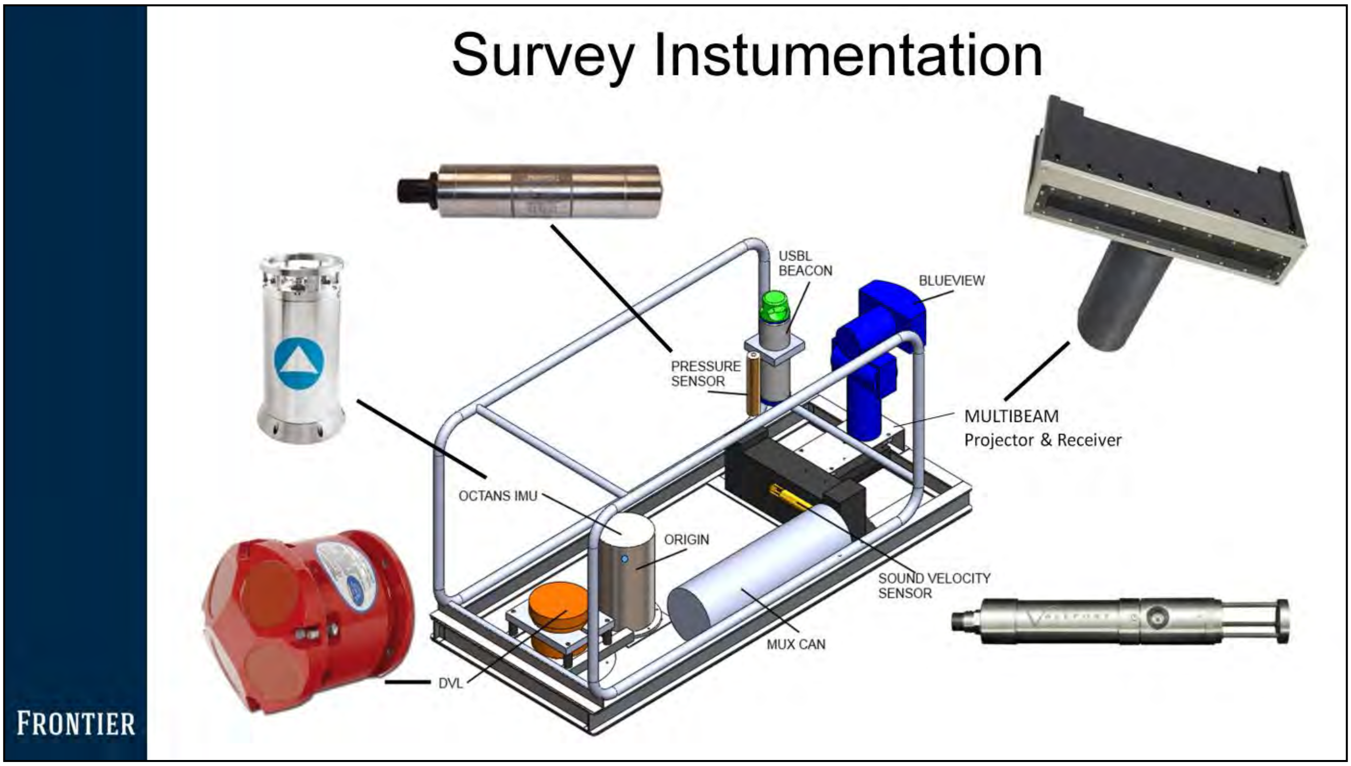
ROV positioning in relation to the survey vessel is tracked form the boat with an underwater acoustic positioning system (USBL).

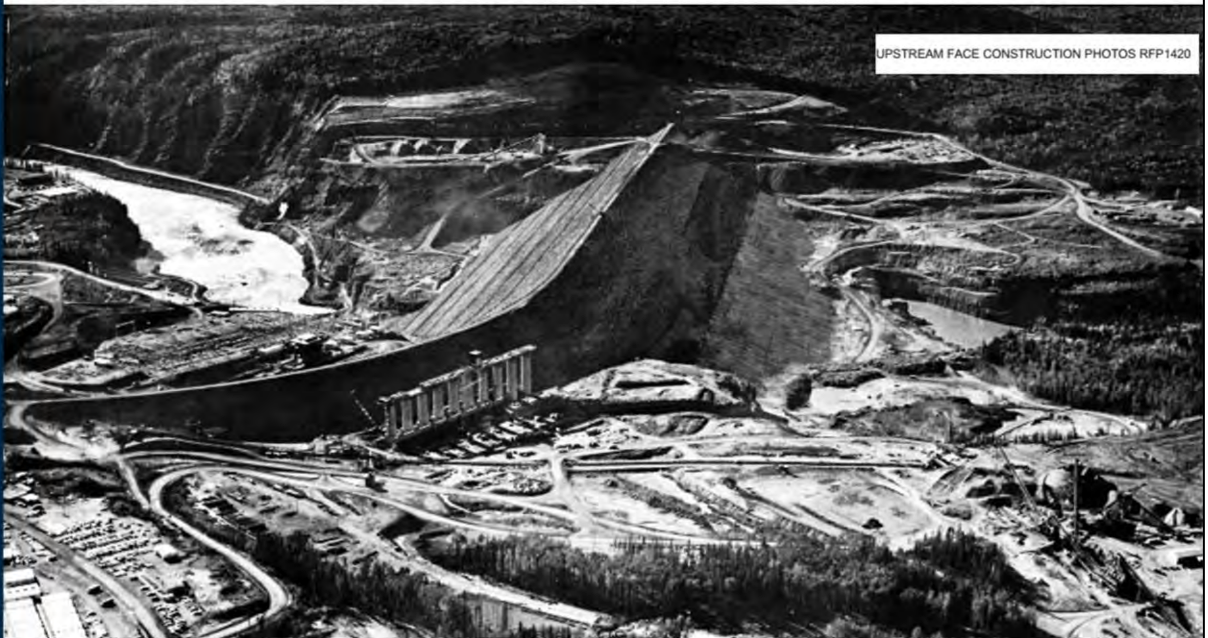
This photo shows the transceiver mounted to the side of the vessel. While the transponder is located on the ROV.



All instrumentation was state of the art.
USBL Beacon used to track ROV from boat
Track ROV depth with Pressure Sensor
Track ROV progress along bottom with Acoustic Doppler Velocity Logging System
Track bottom with Multibeam Sonar R2Sonics
OCtans IMU used pitcvh roll heading

All these used together to produce a high resolution map of the lake bottom bathymetry

Construction Photo - Lake Bottom Topography



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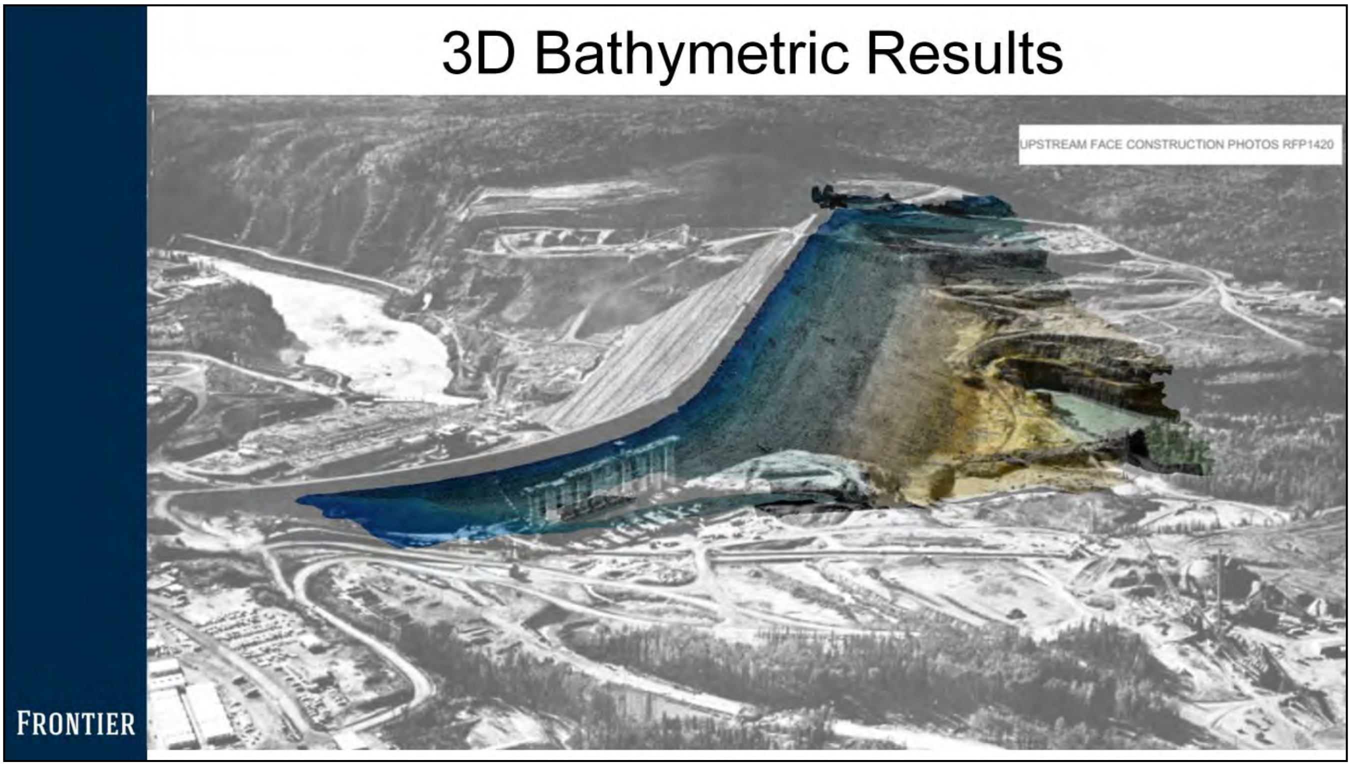
Here is a photo of the dam during construction, looking southwest



Wirth the 3D results of the bathymetry overlaid on the construction photo at 60%

3D Bathymetric Results

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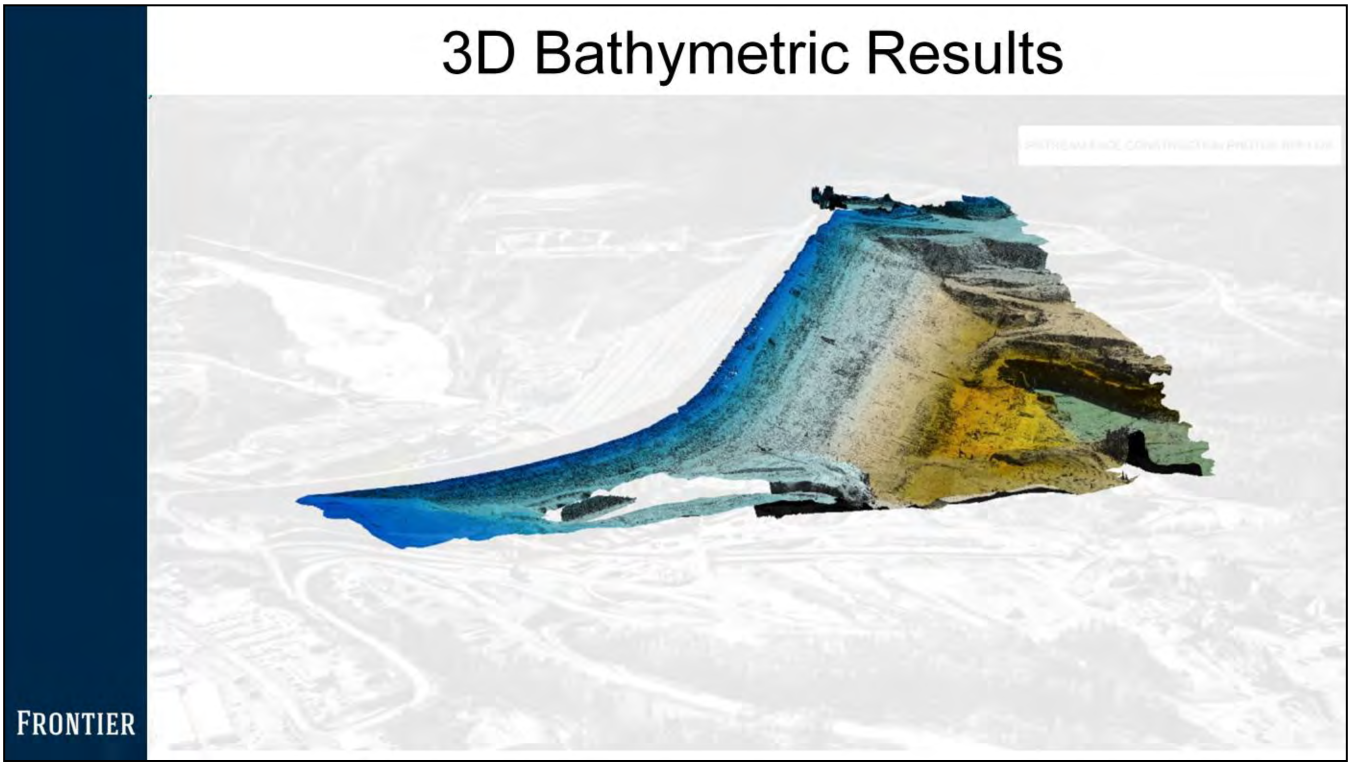
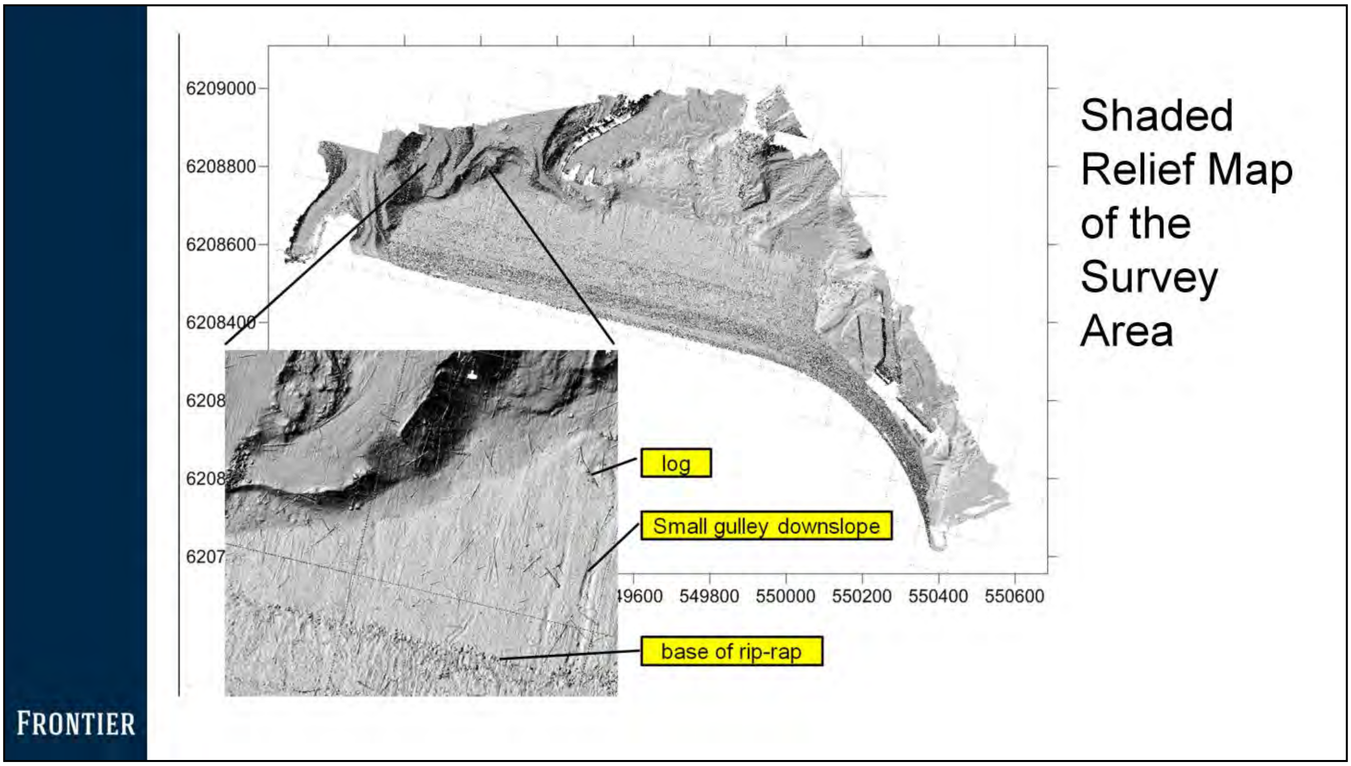
30%



10% data collected on a 10cm by 10 cm cell size



The high resolution bathymetry survey provides detailed images of the lake bottom. Shaded relief map of survey area, mosiaked image of survey tiles (100m x 100m)

Survey Results: Shaded Relief Map Detail

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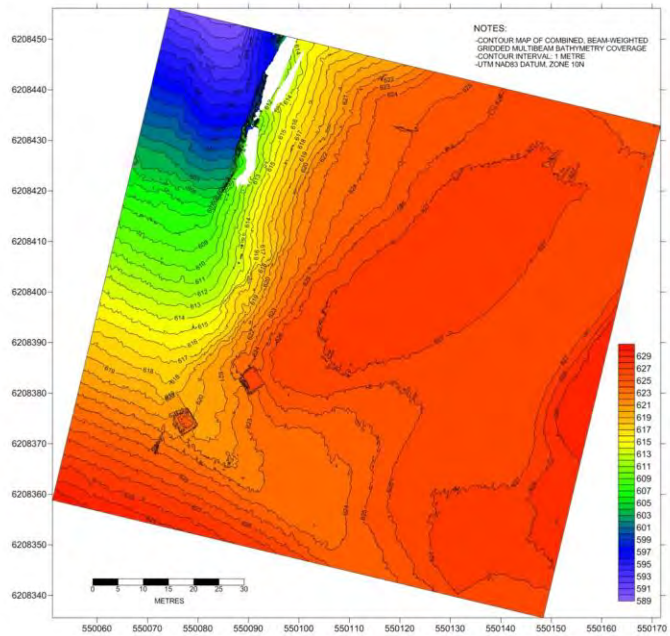
An exanple of map detail in the

Data Combined and Contoured



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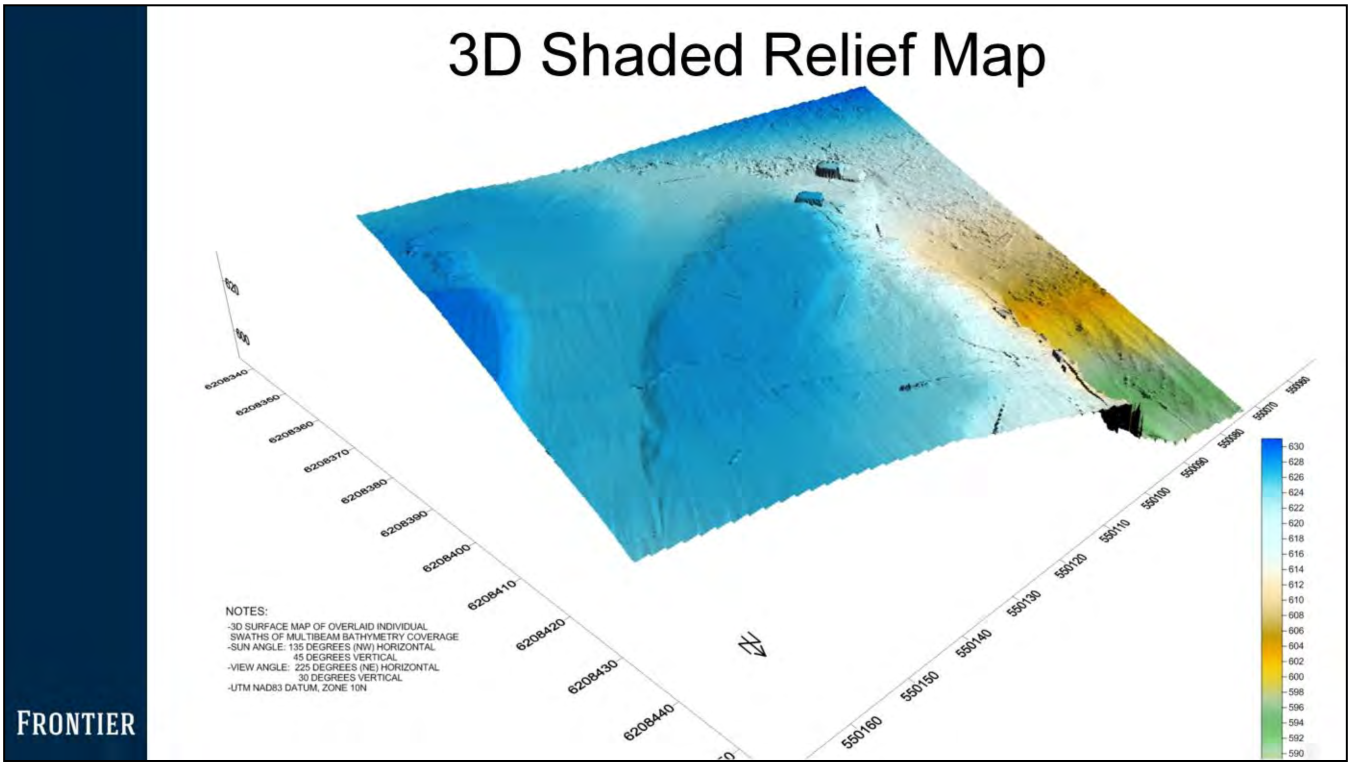
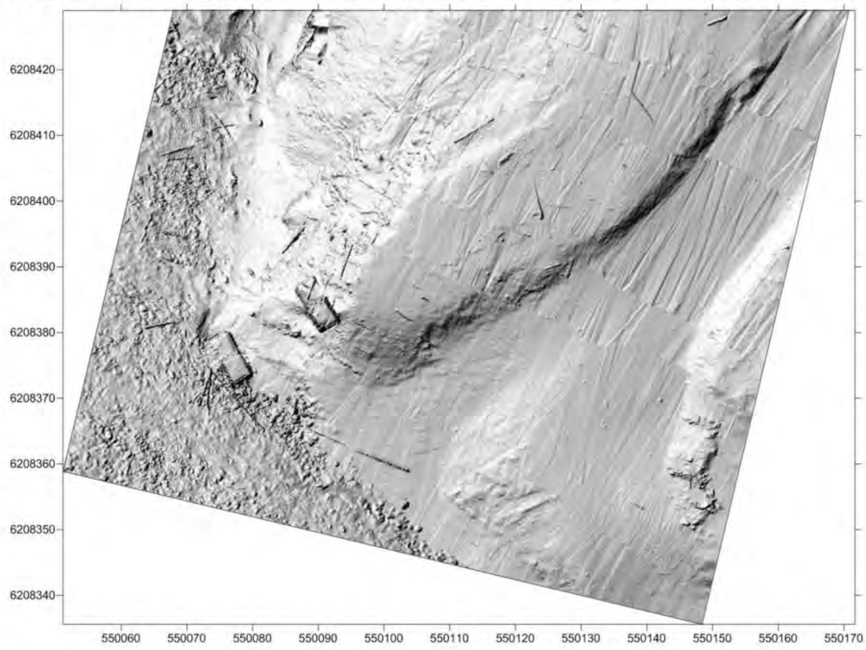
Contours drawn from interpolated depth grid for all traverses.



Individual grids have a higher resolution and used to create shaded mosaic from previous slide

Multibeam data collected from ROV at depth



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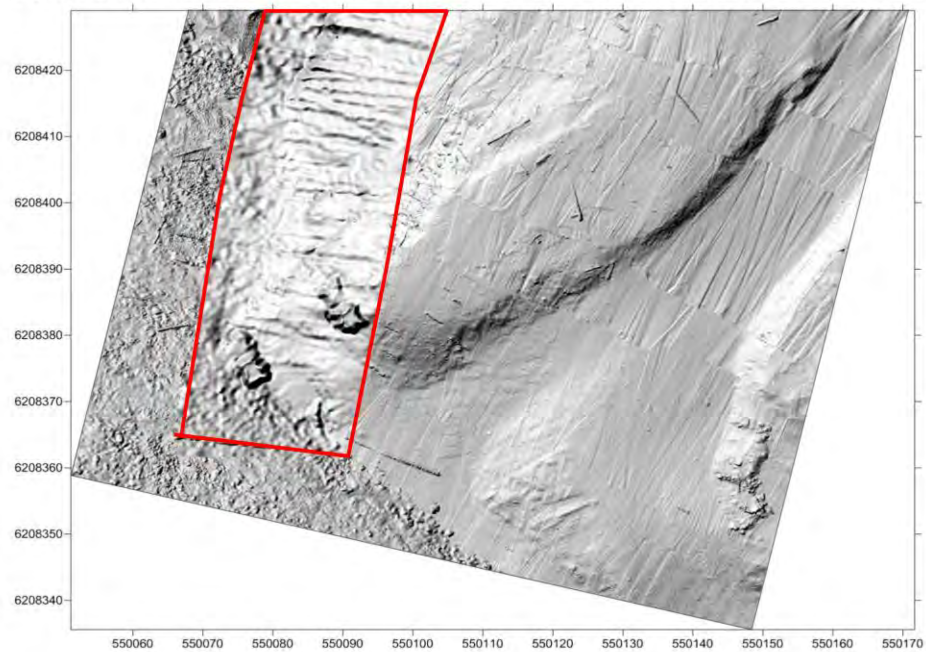
Multibeam data collected from lake surface



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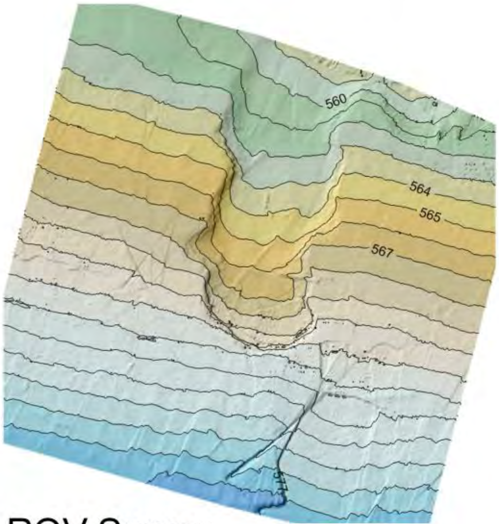
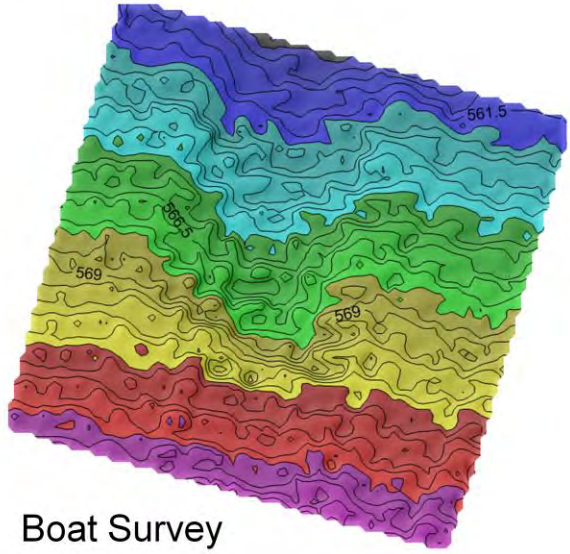
ROV vs Boat Based Survey Results



ROV Survey



Boat Survey

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Re-Inspection of Features of Interest

- Landing Gear Attached to ROV
- High Resolution Scanning Sonar (Blueview)

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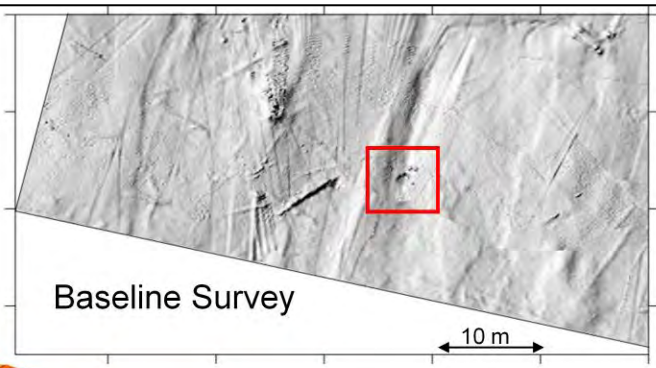
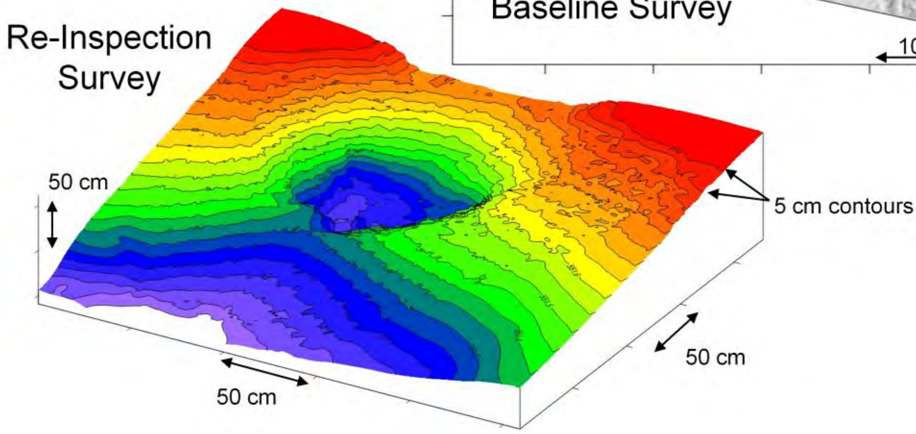
Feature of Interest





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Questions?