Pipeline Inspection by Low Logistics Autonomous Underwater Vehicle with Particular Emphasis on High Resolution Geophysical Data and Access in Very Shallow Water

Bryan M. Keller
Travis Hamilton
Paul Olsgaard
Simon Hird
UTEC Survey

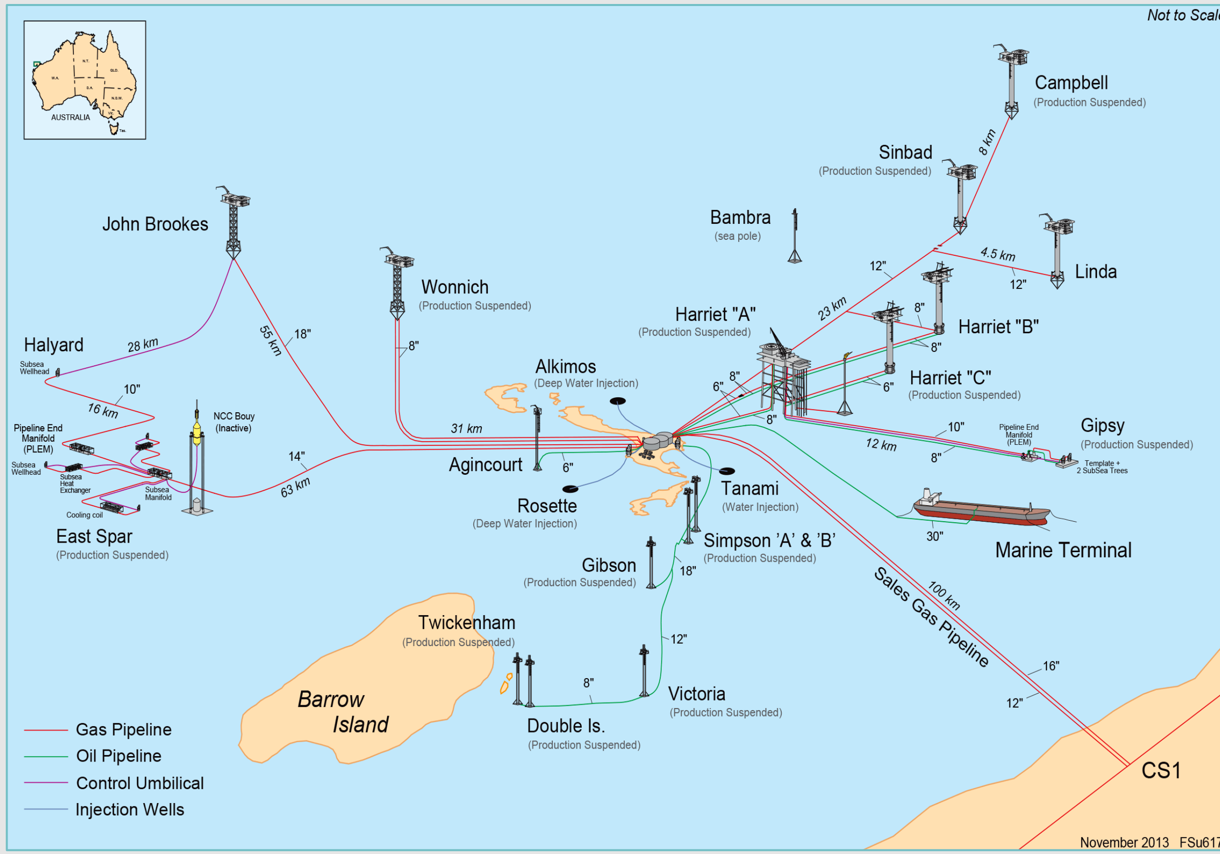
Diranne Lee-Renwick
Quadrant Energy Australia Limited

Introduction

- **UTEC operates the largest fleet of low logistics AUV in the world with over 40 projects completed on six continents.**
- **Today we will focus on a subsea inspection project carried out in Australia in July 2014.**
- **UTEC's client was Quadrant Energy.**
- **43 pipelines of total length 571km.**
- **20 platform site surveys.**
- **Carried out using two Teledyne-Gavia AUVs.**
- **Deployed from support vessel *MV Yardie Creek*.**

Scope of Work

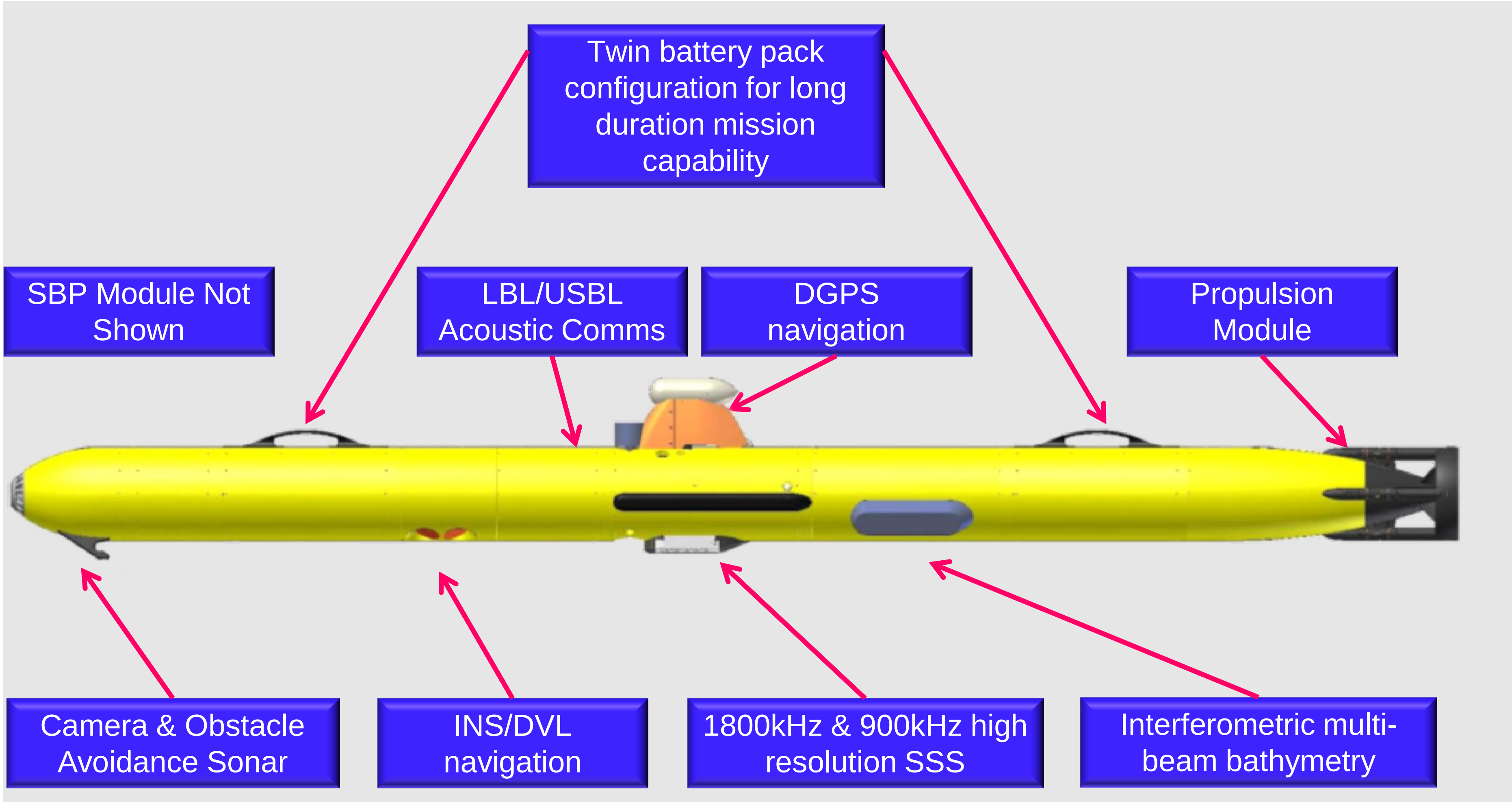
- **All Varanus Island hub subsea facilities and platforms.**
- **Stag and Reindeer fields.**
- **Sales Gas pipeline to the mainland.**
- **43 pipelines, 20 platform and structures.**



Teledyne-Gavia AUV

- UTEC owns and operates a fleet of seven Gavia AUVs.
- Operating depth range from <2m to 1,000m.
- Small footprint - < 3m long; < 120kg with compact spread layout
- Low logistics – Modular and easy to ship via air freight , mission configurable, small on-deck footprint, lightweight for launch and recovery.

Project AUV Configuration



Support Vessel – MV Yardie Creek

- 34m LOA Multi-Purpose Vessel.
- 2.2m draft.
- Large back deck.
- 6 tonne A-frame.
- Hiab deck crane.
- 21 berths.
- Large survey room.
- 5.8m rigid-hulled inflatable boat.

Launch and Recovery

- Stern launched using winch and A-frame in deeper water.
- Manually deployed from the RHIB in shallow water.
- Used RHIB as standard recovery method – manual lift into custom chocks in the RHIB, then AUV lifted by vessel crane to deck.
- In marginal weather RHIB would tow AUV to stern and place it in purpose-built lifting cradle for A-frame recovery – four occasions.

Field Operations

- Our AUV capability is global with Centres of Excellence in Houston and Aberdeen – completed 40 projects on six continents.
- We have encountered challenges and learned from these.
- Our first AUV job in Australia – drew on that expertise and applied the global learning.
- The people were the catalyst for the success of the project.
- Nine man team drawn from global UTEC AUV pool:

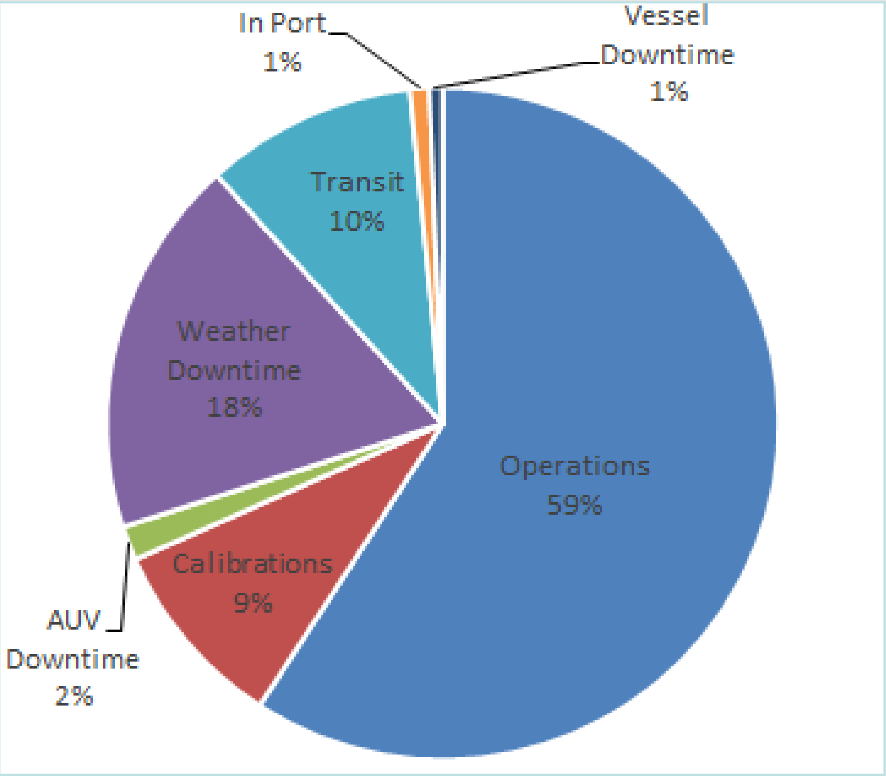
1 x Party Chief	1 x Data Processor
3 x AUV Operators	1 x Geophysicist
1 x AUV Engineer	2 x Online Surveyors

Health, Safety and Environment

- **Total Operational Man Hours = 3,408.**
- **No injuries to any marine, AUV or survey personnel.**
- **No Environmental Incidents.**
- **No Asset Damage.**
- **No Near Misses during operations.**
- **Risk Assessments / Job Safety Analyses completed and reviewed daily.**
- **Safety Briefings / Drills = 53.**
- **Tool Box Talks = 45.**

Productivity

- 27 day project averaging 45km of AUV line survey per day.
- Average includes non-productive time - weather, transits, calibrations and equipment downtime.
- Set a new UTEC record on July 11th with 80.5 line km of survey.
- Surveyed a total of 1,142 line km on pipelines plus 20 platform and structure site surveys.



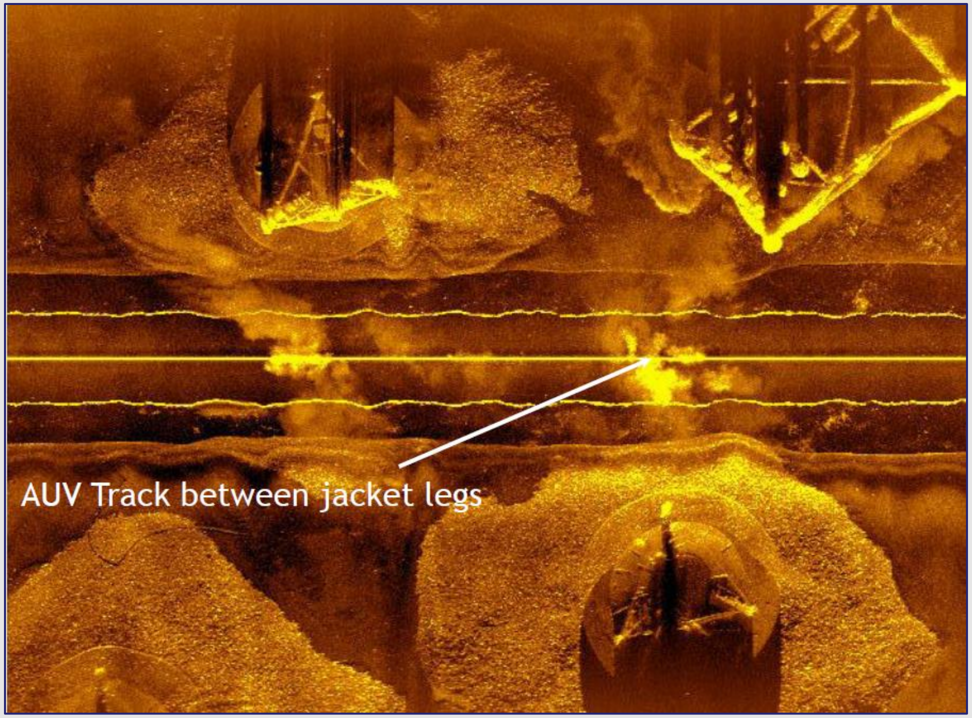
Key to Productivity

- UTEC used two AUVs 'back-to-back' for the first time.
- While one AUV was deployed the other was readied for its mission.
- Each mission duration was between 5 and 6 hours.
- Reduced the on-deck turnaround time from >2 hours for single vehicle ops to <1 hour, which included data download, battery change-out, INS re-alignment.
- The increase in productivity more than offset additional costs.
- Productivity approached that of larger, more expensive AUVs which offer longer mission time due to battery capacity.

Challenges Faced (1)

Platform Site Surveys:

- Greatest risk in AUV missions – surfacing under a platform, colliding with platform legs or subsea structures.
- Ran reconnaissance missions at higher altitudes and offsets prior to primary mission to identify hazards.
- Gained understanding of speed and direction of currents.
- Turned down sensitivity of object avoidance sonar to reduce number of aborted missions due to extensive marine life (fish) under platforms.



Challenges Faced (2)

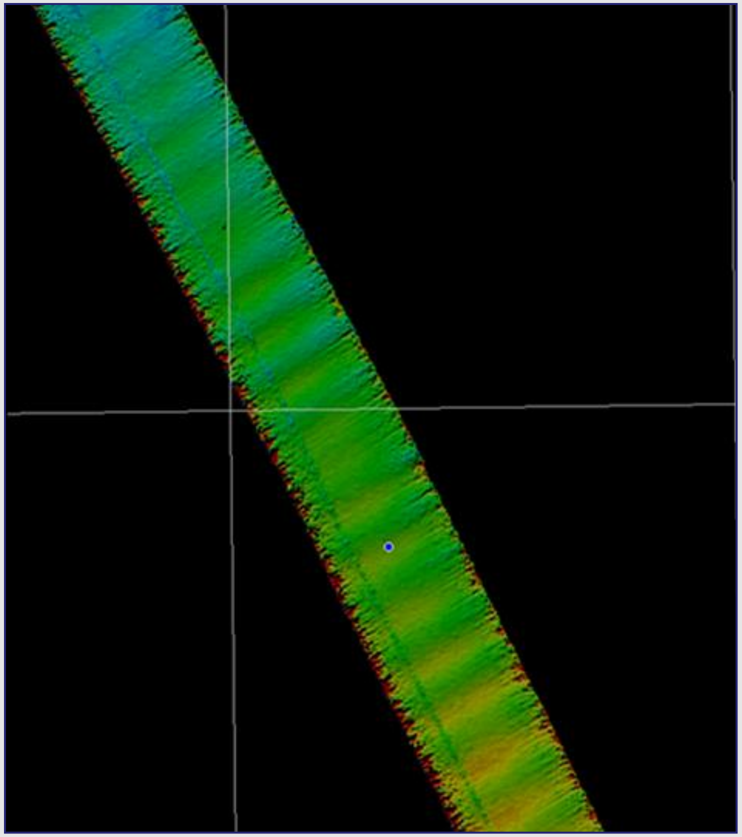
Shallow Water – Near Shore:

- Several pipelines terminated at Varanus Island or mainland.
- Scope called for surveying as near to shore as possible.
- RHIB enabled us to get very close to shore while vessel stayed in deeper water.
- Missions planned to coincide with peaks of high tide.
- Ran AUV on surface at ½ speed.
- Successfully collected high quality data in water depths of 2m and in a couple of cases in less than 1m.

Challenges Faced (3)

Shallow Water – vertical accuracy:

- AUV is a submerged survey platform - acoustic depths must be combined with AUV depth to resolve final sounding depth.
- Waves and swells introduce pressure fluctuations = modulate pressure sensor output without any vertical movement of AUV = vertical offsets in seabed profile; looks like the AUV is 'porpoising'.
- In shallow water even small waves cause significant artifacts in seabed profiles.
- The Z (vertical) coordinate from the INS is recorded in the raw sonar file and we use that to correct these artifacts.



Data Processing Workflow

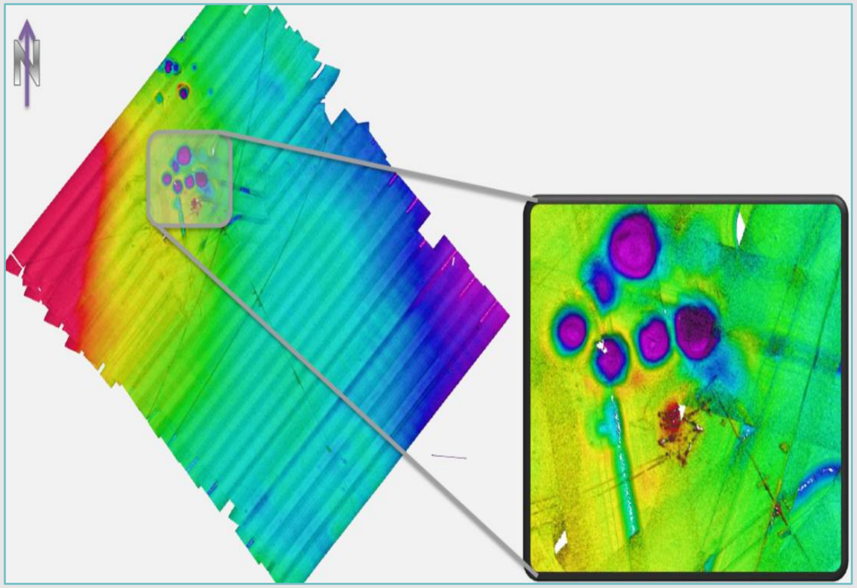
- **Data processors, geophysicists and charting specialists create comprehensive data sets for reporting and charting.**
- **Four stage iterative process:**

Process Bathymetry Data → **Navigation processing to remove INS drift and surface swell artifacts** → **Re-process Bathymetry Data. Process Side-scan Sonar data** → **Perform Geophysical Interpretation**

Data Processing - Bathymetry

Ocean Imaging Consultants 'CleanSweep' software:

- **Corrections for any positional drift from Inertial Navigation System.**
- **Filters for Navigation and Attitude .**
- **Filters for cleaning any 'outlier' soundings.**
- **Algorithms for applying tides, including interpolated tides between multiple stations.**
- **Angle Varying Gain corrections for the backscatter.**



Example of AUV GeoSwath bathymetry data depicting Spud Can Depressions

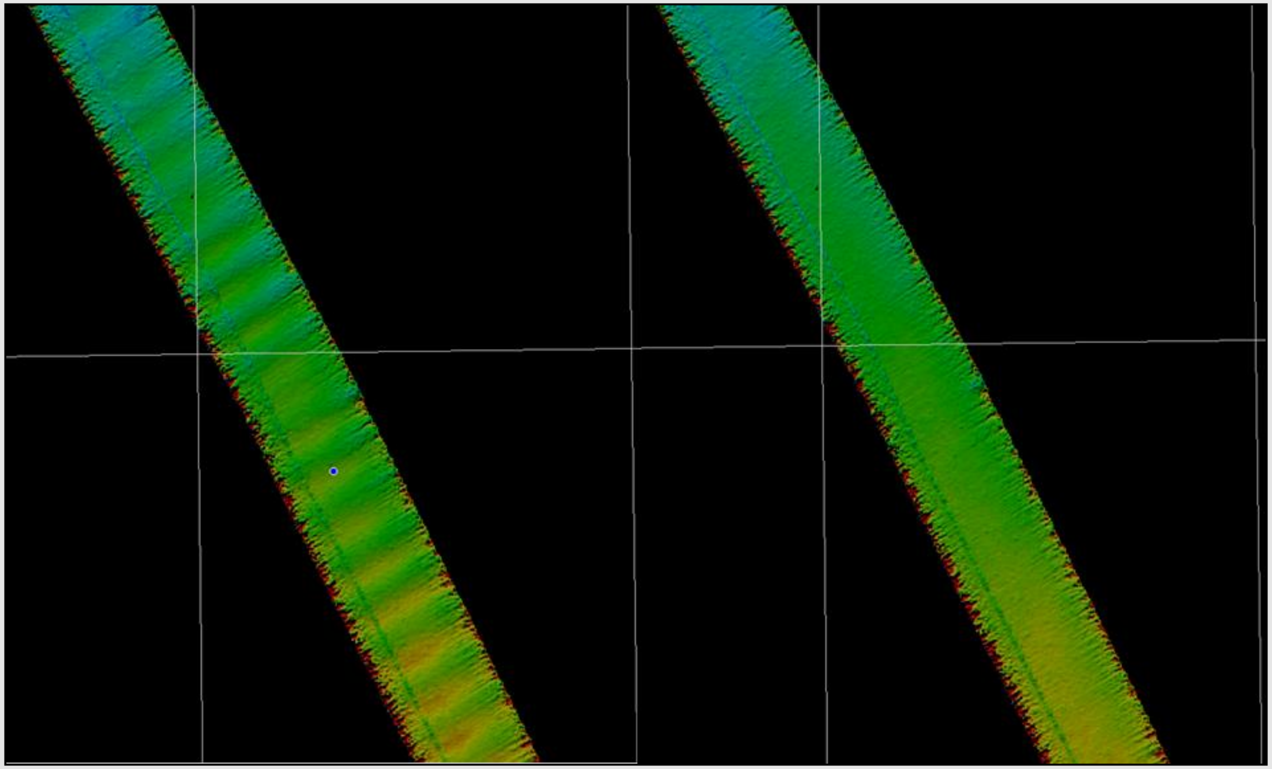
Removing INS Drift

- A small linear drift over time or distance traveled is expected from the Inertial Navigation System.
- We use InterNav (part of CleanSweep) to correct.
- This matches adjacent swathes and applies a weighting to positions near the start of a mission in preference to those near the end.
- By overlapping start and end of consecutive missions we constrain the uncertainty.
- Horizontal uncertainty was constrained to less than 2m over the project.

Removing Swell / Wave Artifacts

- Caused by pressure fluctuations from surface swells and waves.
- Makes it look as if the AUV is 'porpoising' when it is in fact stable.
- A secondary record of the INS 'Z' (vertical) co-ordinate is captured in the raw GeoSwath files.
- Apply a smoothing filter to the pressure sensor depth gives a long period trend of AUV depth.
- Applying a high-pass filter to the INS 'Z' coordinate leaves a zero mean high frequency record of vertical movement.
- Combining the two processed records provides an accurate AUV depth record free of swell and wave artifacts.

Swell / Wave Artifacts Removed



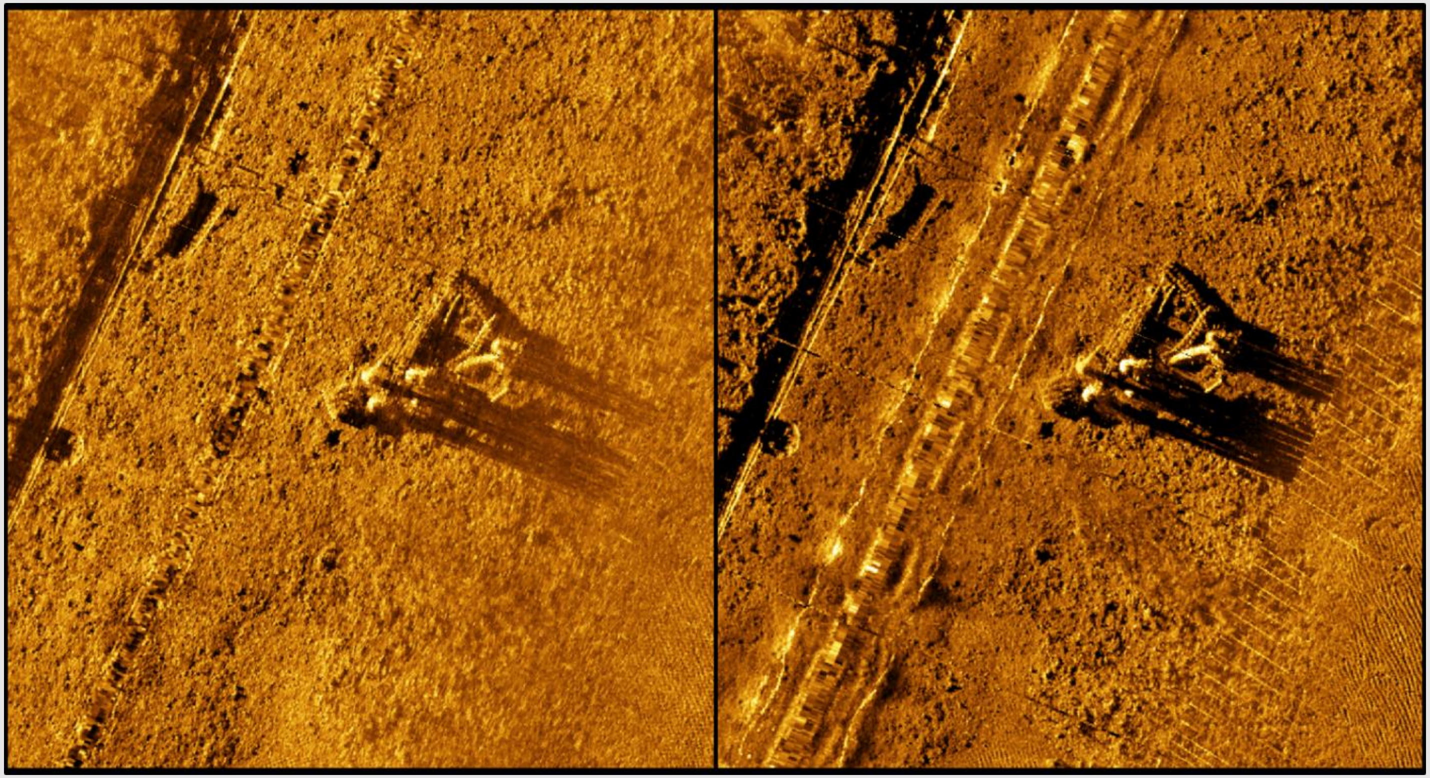
Digital Elevation Model with pressure sensor depth only, revealing the artifacts of 40cm wave heights and 30m wave lengths.

Combined depths with artifacts filtered and removed

Processing Side-Scan Sonar Data

- MST SSS operates at 900kHz - an appreciable increase in resolution over GeoSwath SSS.
- GeoSwath navigation is more accurate.
- By using CleanSweep's import/export tools we applied the GeoSwath navigation and altitude data to improve the MST data.
- High resolution MST SSS mosaics were used for areas requiring a high level of detail.

Processing Side-scan Sonar Data



GeoSwath SSS (Left) vs MST SSS (Right)

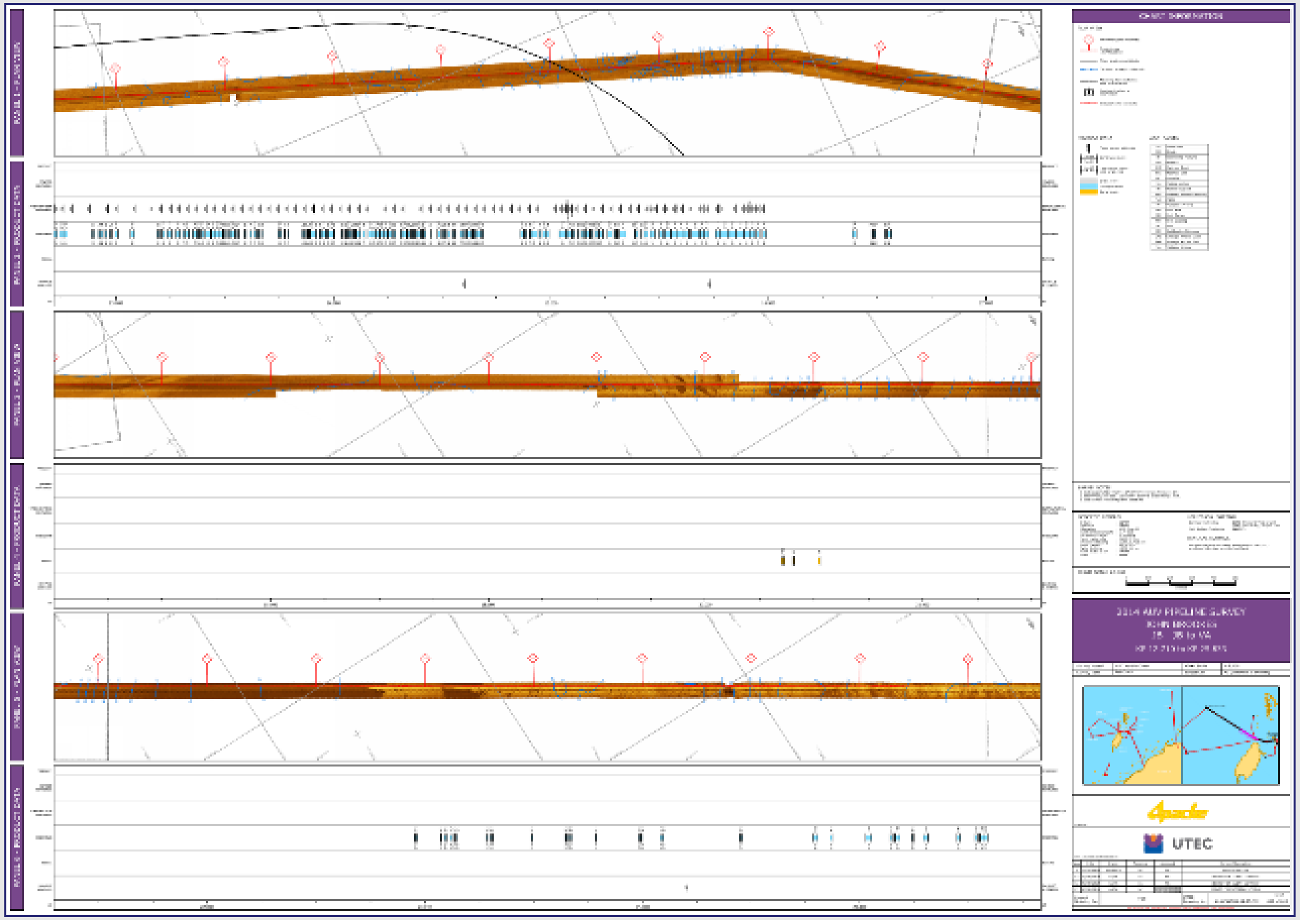
Geophysical Interpretation

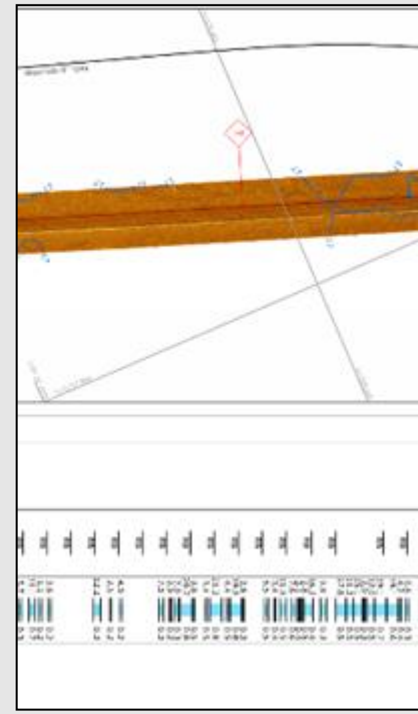
- **Fully processed GeoSwath and MST SSS data exported in XTF format to Chesapeake Technology 'SonarWiz' software.**
- **SonarWiz used to identify freespans, pipeline burial and other contacts.**
- **SonarWiz includes tools for identifying, measuring and cataloguing events into a database for export to spreadsheets. This includes a freespan tool specially built for UTEC for this project.**
- **The freespan tool combines point contact attributes with a linear feature allowing the feature to be catalogued with height of freespan.**
- **Databases then exported to Excel and used for event listing and Pipeline Alignment Charts.**

Data Presentation

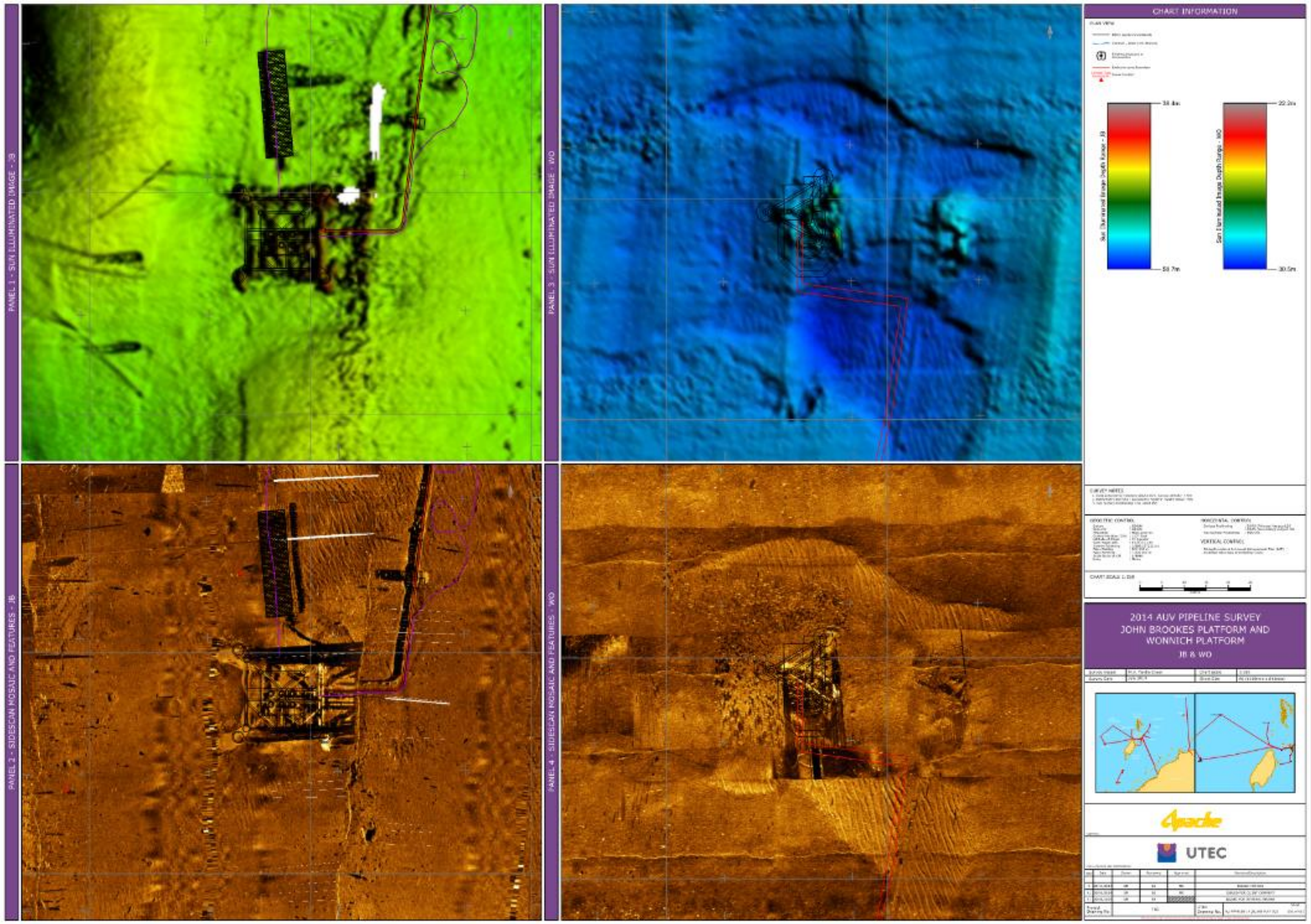
- Field reports identified areas of concern while still in the field.
- Interim reports identified critical freespans and cross-checked these against prior year surveys.
- Fully processed data exported to Geographical Information System (GIS) for final QC checks.
- Having all items in a single GIS allows consistency checks prior to charting.
- Each event target is checked against the digital elevation model and the mosaics to ensure correct identification and position.
- Final report provided Pipeline Alignment Charts (plan view and pipeline events) and full Pipeline Events Listings (freespans, debris, sections of burial etc.)

Pipeline Charts

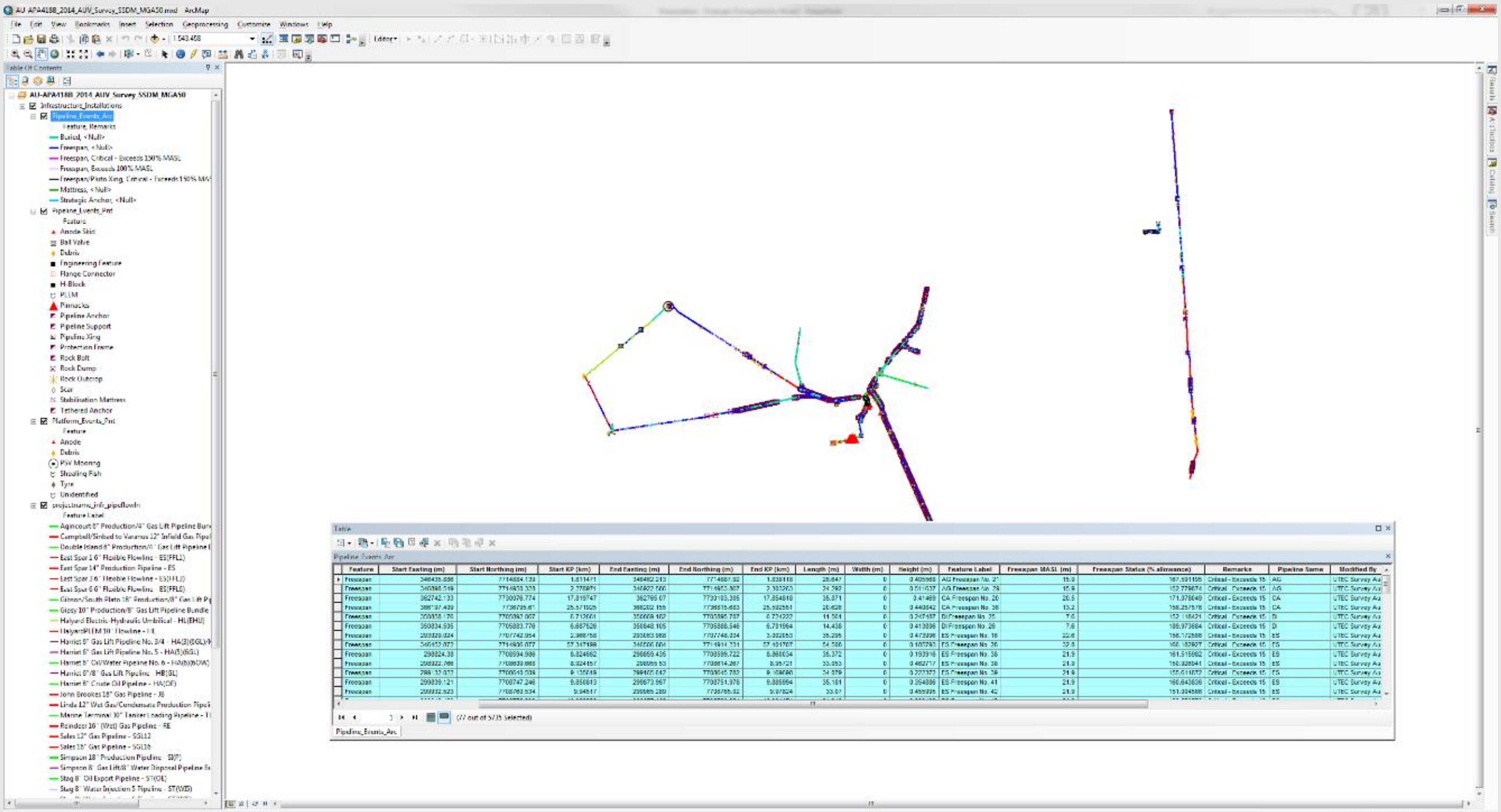




Platform Charts



Geographic Information System - GIS



an ACTEON company

UTEC

Final Report

2 SUMMARY OF RESULTS

The features evented and mapped, for the 2014 survey for each asset are quantified in the summary tables below. Specifically, each pipeline asset was evented for their freespans (with MASL highlighted), specific engineering features, debris which lies in proximity to the pipeline and condition of the seabed that may interfere with pipeline structure. Each platform asset had their surrounding seabed mapped for debris and remedial work engineering features. Further details of each asset are in Section 13.

2.1 Pipeline Assets

The table below show a quantified breakdown of events for each pipeline as per survey objective:

Asset	Asset Code	Pipeline KP	Surveyed Length	Shallowest KP/Depth	Total Events	No. of spans > MASL	No. Debris	Result Section
Agincourt-Oil Production & Gas Lift	AG(P) & AG(GL)	7.076	5.998	KP3.429 0.15m	325	7	1	13.8
Campbell-Gas Raw	CA(GE)	31.156	30.907	KP1.809 3.56m	550	10	11	13.18
Double Island-Oil Production & Gas Lift	DI(P) & DI(GL)	7.197	7.197	KP0.461 1.98m	30	2	1	13.19
East Spar-Gas Raw	ES	62.590	61.605	KP56.570 0.32mm	2513	252	5	13.1
East Spar-Gas Raw	ES(FFL3)	1.862	1.862	KP1.605 94.76m	103	N/A	1	13.21
East Spar-Gas Raw	ES(FFL1)	1.768	1.768	KP0.095 94.63m	121	N/A	1	13.20
East Spar-Gas Raw	ES(FFL6)	2.030	Survey data not usable					
Gibson South Plato-Oil Production & Gas Lift	GSP(P) & GSP (GL)	3.750	3.750	KP0.101 4.67m	82	3	1	13.22
Gipsy-Oil Production & Gas Lift	GP(P) & GP(GL)	12.633	12.633	KP11.340 22.08m	69	0	2	13.23
Halyard-Gas Raw	HL	15.638	15.638	KP15.479 96.11m	58	N/A	0	13.2
Halyard EHU-Electrical Hydraulic	HL(EHU)	27.688	27.688	KP0.114 44.69m	112	N/A	0	13.3
Harriet-Gas Lift	HB(GL)	10.348	10.098	KP0.979 3.89m	63	0	0	13.9
Harriet-Oil Production	HA(OE)	10.325	10.077	KP9.355 3.87m	5	0	0	13.10
Harriet-Gas Lift	HA(3)(6GL)	3.870	2.250	KP0.307 21.48m	2	0	0	13.24
Harriet-Gas Lift	HA(4)(6GL)							
Harriet-Gas Raw	HA(5)(6GL)	2.003	1.352	KP0.045 22.02m	2	0	0	13.25
Harriet-Oil Production	HA(6)(6OW)	1.989	1.236	KP0.903 22.34m	3	0	0	13.26
Harriet-Gas Flare	HF	0.131	Survey data not usable					
John Brookes-Gas Raw	JB	54.440	53.453	KP5.680 1.13m	1380	176	15	13.6
Linda-Gas Raw	LA	4.577	4.577	KP4.576 24.99m	142	3	0	13.11
Marine Terminal-Oil Export	TLL	3.836	3.584	KP0.970 3.84m	11	0	4	13.12

Figure 39 RE Freespan/Pluto Xing No. 665 (KP69.246 to KP69.370)

The table below show Debris Items mapped along and in close proximity to the Reindeer 16" (Wet) Gas Pipeline (RE).

Event No.	Items	Easting (m)	Northing (m)	KP	Dimensions (m) L x W x H
24	Debris	432852.23	7698319.79	41.907	1.6 x 1.4 x 0.4
43	Debris	433865.62	7704109.55	48.874	3.9 x 0.9 x 1.4
44	Debris	433800.64	7704681.26	49.648	0.4 x 0.3 x 0.7
45	Debris	433619.25	7706256.03	49.901	2.3 x 1.1 x 0.3
76	Debris	433083.58	7710947.48	54.891	0.9 x 0.8 x 0.3
5	Debris	432961.72	7712021.69	55.607	0.5 x 0.6 x 0.4
308	Debris	431100.26	7737014.79	67.705	1.8 x 1.4 x 0.9
331	Debris	430626.72	7743964.86	68.099	0.4 x 0.4 x 0.4
332	Debris	430572.52	7744737.45	73.798	0.4 x 0.3 x 0.3
337	Debris	430555.21	7744989.75	77.181	0.2 x 0.2 x 0.1
437	Debris	430202.38	7749967.34	41.907	1.0 x 0.2 x 0.1
440	Debris	430151.61	7750681.11	48.874	0.5 x 0.4 x 0.4
599	Debris	429316.34	7762749.36	49.648	0.4 x 0.3 x 0.7
608	Debris	429287.46	7763142.98	49.901	1.1 x 0.3 x 0.2
739	Debris	428894.27	7768827.70	54.891	0.5 x 0.2 x 0.3
784	Debris	428656.48	7772202.90	55.607	0.6 x 0.3 x 0.5

14.10 John Brookes (JB) Platform

Reference Drawings: AU-APA418B-14-JB_WO-PLAT-001.

The John Brookes (JB) Platform was surveyed by the Gavia AUV on the 1st of July 2014 and 13 items of debris, and 3 moorings, were recorded.

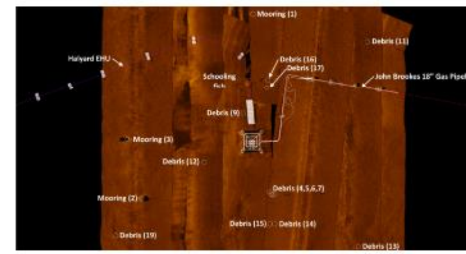


Figure 100 JB Platform Debris Overview

The table below show Debris Items mapped in close proximity to the John Brookes (JB) Platform.

Events No.	Items	Easting (m)	Northing (m)	Dimensions (m) L x W x H
1	PSV Mooring	303894.18	7738017.80	5.0 x 5.0 x 2.1
2	PSV Mooring	303781.31	7737831.13	5.1 x 5.0 x 2.0
3	PSV Mooring	303766.70	7737891.90	5.0 x 4.9 x 2.2
4	Debris	303910.63	7737838.07	1.3 x 0.2 x 0.1
5	Debris	303912.59	7737835.88	2.2 x 0.2 x 0.1
6	Debris	303913.45	7737834.82	2.3 x 0.5 x 0.3
7	Debris	303916.01	7737835.19	2.3 x 0.3 x 0.2
9	Debris	303884.08	7737917.75	0.4 x 0.2 x 1.1
11	Debris	304009.37	7737990.27	4.3 x 2.6 x 0.2
12	Debris	303844.66	7737868.93	0.6 x 0.7 x 0.2
13	Debris	304000.46	7737783.56	1.1 x 0.4 x 0.4
14	Debris	303915.92	7737805.81	1.8 x 1.2 x 0.1
15	Debris	303911.33	7737805.87	1.5 x 0.7 x 0.2
16	Tyre	303909.14	7737952.12	1.3 x 1.3 x 0.1
17	Debris	303907.84	7737944.04	0.5 x 0.4 x 0.1
19	Debris	303755.16	7737794.54	2.5 x 0.3 x 0.1

Table 49 JB Platform Debris List

Meeting Quadrant's Expectations

- Project met Quadrant's expectation as set out in the Scope of Work.
- AUV operations in very shallow water meant that 92% of all pipeline kms were surveyed.
- Total of 571km of pipe surveyed with one-pass each side i.e. 1,142 km of AUV track-line.
- Twenty platforms and subsea structures surveyed, which was 100% of subsea assets specified in Scope of Work.
- Total duration was 27 days in mid-winter including mob, demob and transits.
- Less than 2% operational downtime and only 18% weather downtime impacting launch and recovery.
- On a per kilometre basis AUV surveys are calculated to be less than 50% of the cost of an ROV survey.
- AUV surveys substantially contribute to subsea integrity management strategies.

Questions?

Quadrant Energy

UTEC