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Multibeam Bathymetric Measurements for Shallow Seabed Features Mapping using Unmanned Surface Vehicle

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Abstract: Subsea pipelines are constructions of pipelines laid onto or embedded into the seabed used for the distribution of fluids such as gas or oil. Over time, changes in the morphological seabed around the pipeline area possibly caused by natural processes such as erosion, scouring, or other geological anomalies may potentially lead to pipeline failure due to the presence of pipe anomalies in the form of free-spanning pipes. In general, this phenomenon occurs in pipelines with a dynamic sedimentation environment caused by tidal changes or underwater currents. Pertamina Hulu Mahakam (PHM) performs regular pipeline inspection as part of the pipeline maintenance program. Visual methods via underwater camera and acoustic methodology such as bathymetry were used to obtain the seabed pattern as well as underwater objects. The Mahakam pipeline networks extend from very shallow waters within the river delta area offshore at a depth more than 100m. For very shallow environments where manned vessels have a limited access, bathymetric measurements were done using Multibeam Echosounder (MBES) installed on an Unmanned Surface Vehicle (USV), controlled and monitored via radio communication over a certain distance. In 2021, PHM, in collaboration with Elnusa, conducted a pipeline inspection survey on one of the pipes, with a diameter of 24 inches and a length of 109 meters.. The results of the bathymetric measurements using the USV demonstrated that no indication of the presence of free-spanning pipelines could be found in the underwater vicinity. The depth of the river varied from -1.2 meters to 2.7 meters (Chart Datum). The topographical conditions showed a sloping riverbed with a maximum slope of 12°-13° from the direction fo the floodplain area towards the center of the river/main channel. Seven (7) pockmarks were identified around the pipeline having a diameter of about 29 to 52 cm and a depth of about 6 to 20 cm. In addition, attention should be paid to the possible presence of gas seepage in the pockmarks area, interpreted from the image of reflected acoustic waves in the water column captured by the MBES equipment.
Keywords: Pipelines, bathymetry, seabed, MBES, USV

Abstrak: Jalur Pipa dasar laut merupakan konstruksi pipa yang terletak atau tertanam di dasar laut yang digunakan untuk distribusi fluida seperti gas atau minyak bumi. Seiring waktu, perubahan morfologi dasar laut jalur pipa akibat transformasi alam seperti erosi, pengikisan tanah atau anomali geologi lainnya dapat berpotensi mengakibatkan kegagalan pipa karena adanya anomali pipa berupa pipa melayang (free-span). Fenomena tersebut pada umumnya terjadi pada jalur pipa dengan lingkungan sedimentasi dasar laut yang dinamis akibat pengaruh pasang surut dan arus bawah laut. Sebagai bentuk tanggung jawab program pemeliharaaan penggunaan pipa, Pertamina Hulu Mahakam (PHM) melakukan inspeksi pipa secara reguler. Metode surveinya adalah visual dengan kamera dan alat akustik seperti bathimetri untuk mendapatkan rona dasar laut dan objek permukaan dasar laut. Jaringan pipa Mahakam membentang dari perairan sangat dangkal di area delta sungai hingga laut lepas pada kedalaman lebih dari 100m. Untuk lokasi yang sangat dangkal dimana akses yang terbatas untuk dilewati oleh kapal berawak, pengukuran batimetri dengan multibeam echosounder (MBES) dipasang pada wahana permukaan air tanpa awak (Unmanned Surface Vehicle/USV) yang dimonitor dan dikontrol menggunakan radio komunikasi dengan jarak tertentu. Pada tahun 2021, PHM dengan Elnusa bekerja sama untuk melaksanakan survey inspeksi pada salah satu pipa dengan diameter 24 inch dengan panjang 109 meter disurvei. Hasil survei MBES batimetri menggunakan USV tidak ditemukan adanya indikasi pipa yang melayang di bawah air. Hasil survei batimetri menunjukkan bahwa kedalaman sungai bervariasi dari -1.2 meter sampai 2.7 meter (PHM Chart Datum). Kondisi morfologi menunjukkan dasar perairan yang menurun dengan kemiringan maksimal 12°-13° dari arah banjir/floodplain ke arah tengah sungai/main channel. Tujuh (7) pockmarks teridentifikasi di sekitar jalur pipa dengan diameter sekitar 29 sampai 52 cm dan kedalaman cekungan antara 6 sampai 20 cm. Selain itu, perlu diperhatikan adanya rembesan gas di area pockmarks yang diinterpretasi dari citra pantulan gelombang akustik pada kolom air yang tertangkap oleh alat pengukuran MBES
Kata kunci: Jalur pipa, batimetri, dasar laut, MBES, USV

1 INTRODUCTION

Subsea pipelines are underwater constructions commonly manufactured from steel polyethylene and used to transport oil and gas products. Pipelines are considered to be the most favoured method for transporting fluids from one location to another. However, they are also vulnerable, as damage or defects are always associated with high economic as well as environmental losses. Major reasons for failure in subsea pipelines include corrosion, natural processes, and third-party activities (Bai & Bai, 2014; Senouci, Elabbasy, Elwakil, Abdrabou, & Zayed, 2014). Pipeline corrosion can occur from internal fluid, often containing acids such as H2S. Corrosion can lead to stress cracking or leakage in pipelines (Ho, El-Borgi, Patil, & Song, 2020). On the seabed, the pipelines face other potential dangers. Fishing equipment or ship anchors that accidentally latch on a pipeline can drag and impact the pipeline form (De Groot, 1982; Kawsar et al., 2015). This is a major problem for pipelines in shallow environments where third party activities (i.e. fishery) can damage the pipeline while anchoring or trawling. Furthermore, natural processes such as quakes, storms, or underwater currents can sweep the sediment underneath the pipelines, causing some segments of the pipeline to become unsupported or be in a free-spanning condition (Choi, 2001). Free-span above the certain limits can lead to fatigue damage through vortex induced vibration dos Reis, Sphaier, Nunes, and Alves (2018). To avoid such disruptions to the pipelines, several methods have been developed for monitoring the subsea facilities, such as radiography and sonar mapping (Davis & Brockhurst, 2015; Ho et al., 2020).

Pertamina Hulu Mahakam, in collaboration with Elnusa performed the bathymetric measurements using Multibeam Echosounder for pipeline inspection installed on Unmanned Survey Vehicles. This study aimed to use sound navigation and ranging (sonar) technique to build a bathymetric map and detect the seabed anomalies in a very shallow water environment. The sonar system emits ultrasonic sound waves with a frequency over 20.000 Hz and listens to the returning echoes from seabed or underwater objects. During the survey, the echosounder generates sound pulses from a device called transducer. It then measured the time it took for a pulse to return to receiver and estimates the distance between the echosounder and the destination. A simple equation to convert the time needed for reflected waves back to the receiver into distance can be formulated as follows:

$$d = (\frac{TWT}{2}) * V \tag{1}$$

Where d (meter) is the distance between receiver and the seabed, or the object. TWT/Two-way travel time (ms) is the time needed for a wave to travel from its transducer to a given reflector/object back to the receiver. V is the velocity of the acoustic wave in water column (m/s). This velocity is measured daily via a device, known as the sound velocity profiler (or SVP), in the location of survey before and after the bathymetric measurements were conducted.

The echosounder is usually attached to the keel of a watercraft and typically used by hydrographic surveyors to determine the water depth and map the seabed. Echosounders are set up to make measurements from a watercraft in motion. The earliest echosounder sounding device was the singlebeam echosounder (SBES). In a single shot or ping, the SBES releases a pulse in a single, narrow beam and listens for the returning echo. During the bathymetric measurements, SBES only measured points directly below the watercraft which was not practical in producing an accurate

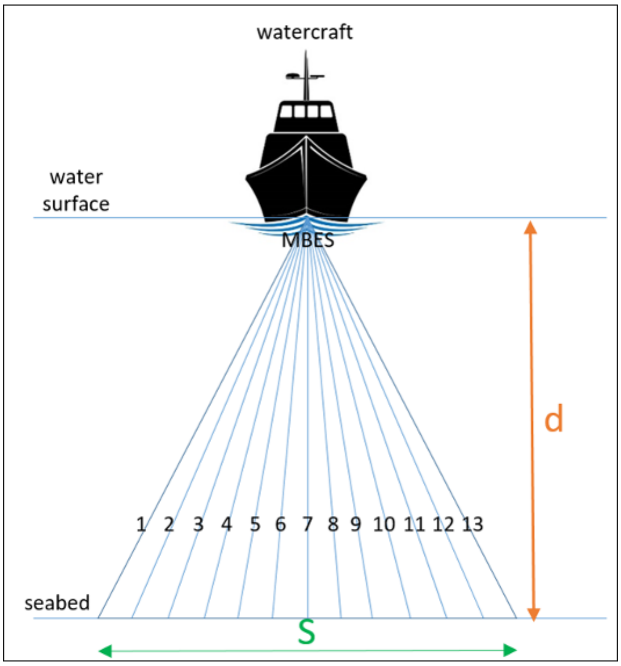

Figure 1. Illustration of sonar beams on bathymetric operation using Multibeam Echosounder (MBES). The MBES device attached at the keel of the watercraft releases 13 beams to the seabed and records the reflected beams from the seabed. S refers to swath width while d is the depth of water

image of the seabed morphology. To circumvent this, the latest echosounder equipment i.e. the multibeam echosounder (MBES) was utilised to map more than one point in a single shot. Multibeam echosounder sends multiple beams in a single ping to the area in a direction perpendicular to the path of the watercraft. This area is called a swath, illustrated on Figure 1

From the sweep of the signal (the swath), the reflected ray-paths of sonar were obtained and calculated as real time water depth. Each spot of measured depth was assigned a position and corrected with tidal change with reference to the chart datum (CD). All the depth spots must be assigned a grid to produce an interpolated contour map and a coloured sun illuminated image. The maps were used for interpretation of the seabed morphology and to show if there was any anomaly around the pipeline. In this survey, several USV lines were ran on the pipeline vicinity to determine if the subsea pipelines were still buried or exposed/in free-span condition. In the case of anomaly, the length of spanning pipeline or exposure dimension should be measured. Furthermore, the bathymetric survey aims to investigate all objects around the pipelines.

The survey area for USV is located inside the Mahakam delta tributary (refer to Figure 2). Situated in an isolated area, the high density of vegetation resulted in limited accessibility due to its narrow path and very shallow water depth. The survey coverage was 50m x 300m centered at a 24 inches pipeline infrastructure, which could be found approximately 85 meters to the nearest facility (Gathering Transfer Station Platform). For safety reasons, and conforming to the HSSE COMPANY regulations, the USV was controlled and monitored from a manned vessel that was staying at the

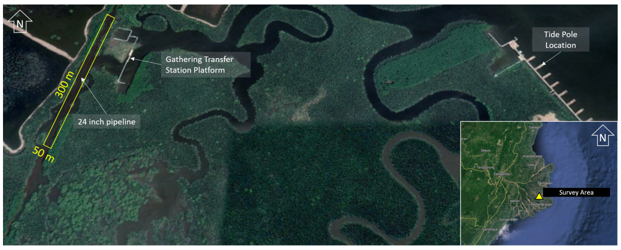

Figure 2. USV survey area within the Mahakam tributaries. The red-dashed line is the 24 inches pipeline from the database. The yellow box contains the survey area, acknowledged as an isolated and very shallow water environment.

Figure 3. USV Barelang deployed on site

Gathering Transfer Station Platform. The pipeline infrastructure in survey area was installed in the early 2000s and was buried 2m below the seabed. Thus, an update on the pipeline condition was imperative.

To accomplish the objectives, the table 1 below shows list of equipment deployed:

The USV deployed for data acquisition were the USV Barelang series (Figure 3), with dimensions of 1.8m in length, 0.95m in width and 0.8m in height (including the antenna radio link). She weighed at 50kg with the battery and Multibeam Echosounder (MBES) included. She was able to cruise at a speed of 3 knots with around 4 hours battery power. The distance of telemetry radio communication to pilot, based on local conditions, was approximately 200-300m due to dense vegetation on location.

2 DATA CORRECTIONS AND PROCESSING

Prior to the survey, all positioning and survey instruments were verified and calibrated. GPS Veripos LD 8 was used as positioning and gyrocompass system during the bathymetrical survey. The working datum was P2-Exc-T9 (Samboja – Gunung Segara) and the entire coordinates in this paper used reference from this datum. The integrity of the positioning system was verified to the reference survey station using known coordinates. DGPS verification to known point took 30 minutes and the mean results are summarised in Table 2.

Heading calibration was done by setting up two (2) GPS Veripos LD 8, located at the bow and stern of the USV. The

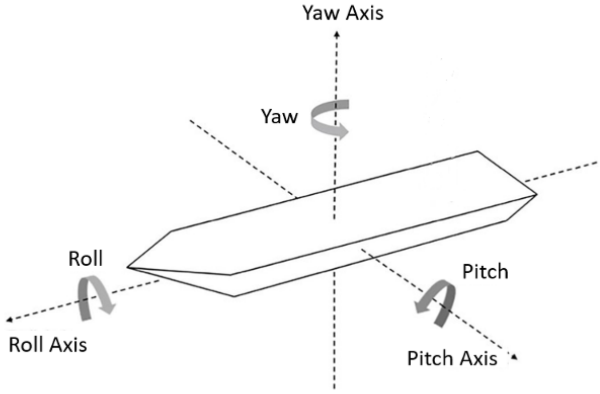

Figure 4. Illustration of USV's movement on water surface

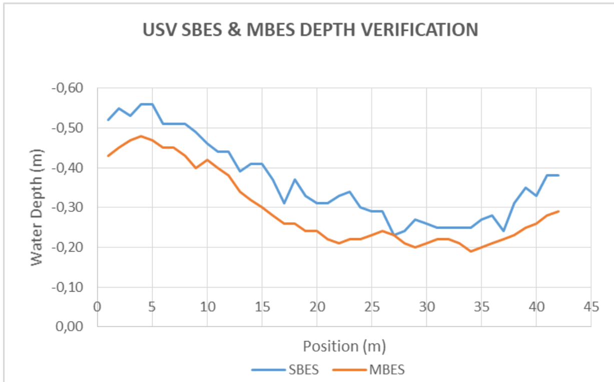

Figure 5. Depth profile from SBES (blue line) and MBES USV (red line) with a difference of 0.07 meter (average)

USV was then headed to the reference point where correction values were measured by comparing the observed to the calculated heading values. Gyro calibration took 3 hours and 30 minutes and the results are shown in Table 3.

The MBES system was mounted on the watercraft and experienced all motions consisting of rotation around the front-to-back axis (roll), rotation around the side-to-side axis (pitch), and rotation around the vertical axis (yaw) (Figure 4). It means that the motions of the watercraft would affect the MBES reading and should be measured. Calibration was mandatory in finding the mounting angle errors (roll, pitch and yaw) for the MBES system. The values for roll, pitch, and yaw were then used as correction to produce an accurate, calibrated data set (Table 4).

To verify the reads of water depth at MBES USV, the system was calibrated with reference to the SBES at the mother vessel which had completed its bar-check. To do this, the MBES USV had to be located as close as possible to the Echosounder transducer of the mother vessel. The method assumed that both Echosounder transducers (of the USV and mother vessel) would echo the same reflection point on the seabed. The water depth read from the mother vessel echosounder and MBES at the same location displayed a reliable difference 0.07m in average (Figure 5)

Tidal changes were observed in order to apply corrections to the bathymetric reading due to changes in sea levels over time affecting different reading values of the

Table 1. Vessel and Equipment List

Equipment	**Version**	**Description**
DGPS	Veripos LD8	Positioning System
Heading System	Veripos LD8	Gyro Compass
Navigation System	EIVA Navisuite	Data Recorder
USV	Barelang	Unmanned Survey Vehicle
MBES	R2 Sonic 2020	Multi beam System
Motion Sensor	Advanced Navigation	Dynamic Motion Sensor
Tidal monitoring	Measuring Poles	Manual at 3m marking
Sound Velocity	AML Micro X and Valeport Mini SVP	Valeport mini SVP attach on MBES
Vessel	Long Sedulang	Sea Truck/Manned Vessel

Table 2. DGPS verification to known point result

Mean C-O Easting (m)	0.17	Mean C-O Northing (m)	-0.24
Std Dev C-O Easting (m)	0.25	Std Dev C-O Northing (m)	0.08

Table 3. Gyro Calibration result

Gyrocompass System	C-O Gyrocompass	
	Mean	Std Dev
2 GPS Veripos LD8	0.3999	0.095

Table 4. MBES Calibration Results

Calibration Type	Std Dev	Average	Median
Pitch Std Deviation Calculation Basis	0.006m	0.005m	0.004m
Roll Std Deviation Calculation Basis	0.007m	0.007m	0.005m
Yaw Std Deviation Calculation Basis	0.007m	0.005m	0.004m

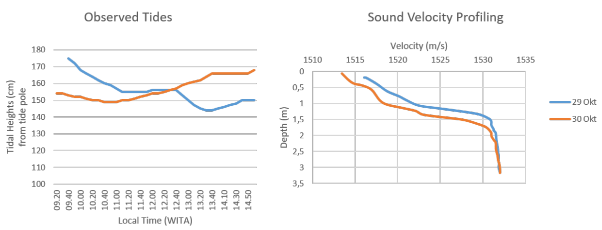

Figure 6. Observed tide data (left) and sound velocity data on water column (right) on day 1 (29 October 2021) (blue line) and day 2 (30 October 2021) (red line).

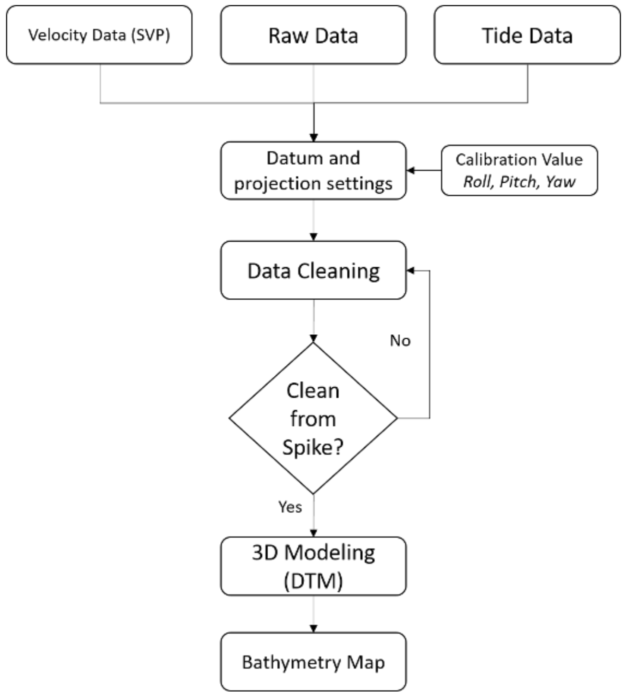

Figure 7. Bathymetry data processing flow chart

echosounder. In order to have an exact reference of datum elevation, the PHM chart datum was used by means of recording the elevation control networks at a Gathering Transfer Station Platform point marker. Sound velocity profiling was conducted to obtain a tradeoff depth and time value. This activity had been performed daily before the data acquisition in the survey vicinity to obtain in situ readings of sound velocity. The observed tide and velocity data is shown on Figure 6.

The sound velocity measurement data, taken from sound velocity profiling activity, were used as input in the processing software as a ray tracing correction in the water column and for conversion of time to depth on the seabed. The workflow of bathymetric data processing is shown on Figure 7

The first step was to input all raw data, velocity data, and observed tide data into the bathymetry processing software. The projected coordinate system used during data processing was UTM Zone 50S and datum P2Exc-T9 (Samboja - Gunung Segara). All elevation was expressed with reference to PHM Chart Datum (CD), defined as 1.58m below Mean Sea Level (MSL). MBES calibration values were then loaded before data cleaning. The processing stage included tidal correction, ray-path refractions (by input SVP data), sensor attitudes (roll, pitch, yaw, and latency) offset-patch corrections and manual cut/cleanings. All data had to be cleaned from outsider or spike noise manually before modeling the seabed. At this stage, the optimal grid was also determined from the obtained data in order to be interpolated. The bathymetric grids were exported from the processing software with a grid resolution of 0.05x0.05 meter.

Figure 8. Screen shot from camera 360 multi beam echo sounder USV

3 BATHYMETRIC RESULTS & SEABED FEATURES

Bathymetric data were collected using the R2Sonic 2020 MBES system. The system provided narrow beam widths at 700 kHz operation which allowed a 2° x 2° beam width. The USV was equipped with a 360-degree camera attached to the top part of the vehicle. The camera helped the pilot keep the USV on a straight path (Figure 8). Acquired MBES data were recorded in Eiva Software as well as online navigation data, and then processed using offline Eiva Software at the office. The processed bathymetric results are presented in a color chart on the bathymetric image as shown on (Figure 9).

The bathymetry of the survey area appeared to be relatively flat with steep sloping (12°-13°) to the center of the river, or far from the shoreline. Close to the shoreline, the water depth is shallower, ranging from -1.2 to -0.2 meter CD, increasing gradually to 2.5 meter in the middle of the river. In total, the pipeline covered a length of 109 m from the North point to the South point survey coverage. No pipeline exposure or free-span anomaly was observed. However, few pockmarks close to the pipeline area were detected from the bathymetric data.

Attention should be paid to the possible gas seepages and pockmarks interpreted from the multi beam bathymetric data. The gas seepages were located within the pockmarks area and suspected bubbles were noted from backscatter multi beam data at water column. Figure 10 shows the coverage area and interpretation of processed bathymetric data from MBES USV. The black square box is the location where anomalies were captured. The zoomed in image is shown in Figure 11.

Seven possible gas seepages were interpreted from the MBES data. During the MBES data processing, the backscatter multi beam data were found in the water column area. These backscatters were interpreted as suspected bubbles coming out from the pockmarks (seepages); refer to Figure 13, Figure 14, Figure 15, and Figure 16. The red circles indicate the suspected bubbles reflection feature. The origin of the possible gas seepages is not known yet and further visual investigations will need to be conducted to gain insight in how these pockmarks were formed. These possible gas seepages are charted and tabulated in Table 5. Summary of pockmarks and possible gas seeping location

To verify the aforementioned anomalies, bathymetry data from the Single Beam Echo Sounder (SBES) were examined. The SBES data were acquired separately from MBES data acquisition. It turned out that anomaly G4 was detected from recorded SBES data (red circle in Figure 12) while other anomalies were not detected. Other anomalies were not visible from SBES recorded, since the SBES USV did not pass above the pockmarks position. The suspected bubble at G-4 from SBES recorded data confirms that the anomaly was not an artifact from the MBES bathymetry processing sequence.

The bathymetry data, as shown in Figure 10 and Figure 11, is a combination of data acquired on 2 different dates (October 29 & 30, 2021). To confirm that the anomalies were captured on both dates, all data were examined. Figure 13 shows suspected bubbles at G-1, G-2, and G-3 during the MBES data that were acquired on day 1 and Figure 14 shows suspected bubbles at G-4, G-5, G-6 and G-7 on day 1. Figure 15 shows suspected bubbles at G-1, G-2, and G-3 during the MBES data acquired on day 2, while Figure 16 shows suspected bubbles at G-4, G-5, G-6 and G-7 on the second day of data acquisition

Another examination was conducted in order to check if the suspected bubbles or other objects were seen on the water surface from images produced by UAV drone and USV camera. However, none of the images shows the suspected bubbles or other objects (i.e. trash or plants) at the water surface. It can therefore be interpreted that the suspected bubbles had already burst and were unable to reach the water surface.

4 CONCLUSIONS AND RECOMMENDATION

The project described within this paper demonstrated the practical feasibility of the Unmanned Surface Vehicle (USV)'s operation in a very shallow water environment, where the location is isolated and access by sea truck or manned vessels was difficult. The pipeline, in the bathymetric survey—in total—covered a 109 m length from the North point to the South point. No pipeline exposure was able to be observed, although several pockmarks with suspected bubbles were noticed during MBES data processing and interpretation stage. The dimensions of the anomalies in the surveyed area were less than 1 meter in diameter and depth. Hence, it was important to process, output, and interpret the bathymetric data at the smallest grid (0.05x0.05 meter) for the highest accuracy. Interpretation was done to bathymetry data acquired on two (2) different dates to ensure that the anomalies were not mere reflections of moving objects such as animals. Both data showed similar reflection patterns from floating objects above the position of the pockmarks. The origin of the possible gas seepages is still unknown, and further investigation is required to understand how pockmarks are formed near the pipeline. The bathymetric data acquisition using Multibeam Echsounder installed on an Unmanned Survey Vehicle at a very shallow water depth area (0.5-2m) for pipeline inspection and investigation on seabed features was successfully and safely conducted. In the future, this operation might be able to be applied for other Oil and Gas operators (K3S) in Indonesia, which have similar environments.

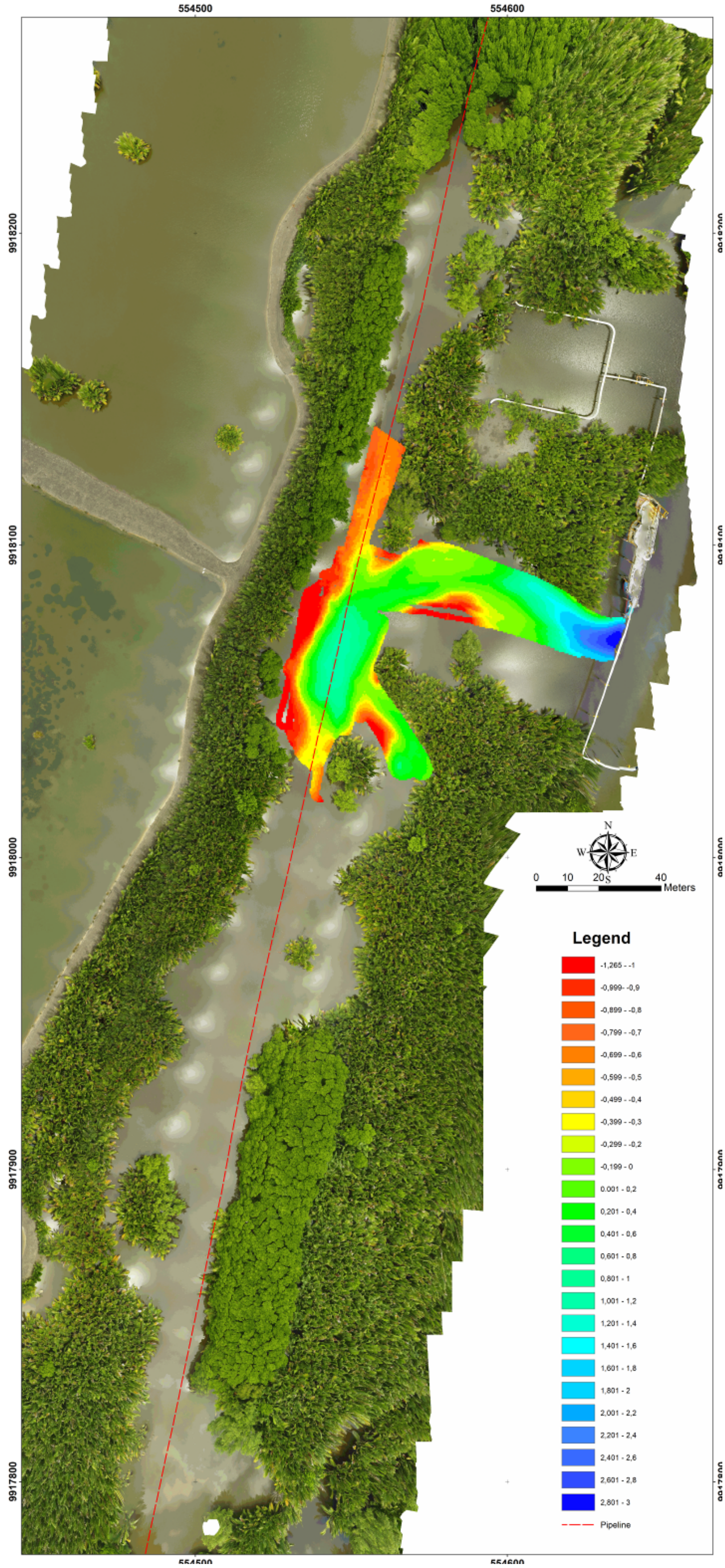

Figure 9. Depth contours from MBES data. The red dashed line is the pipeline position from database

Table 5. Summary of pockmarks and possible gas seeping location

No	Anomaly ID (Pockmarks)	From Outer Pipeline		Remarks d = diameter of pockmark deep = deep of pockmark
		Distance (m)	Direction (deg)	
1	G-1	Above the pipeline		d= 0.3m, deep= 0.06m. Possibly gas seepage
2	G-2	0.4	75.3	d= 0.43m, deep= 0.06m. Possibly gas seepage
3	G-3	1	76.3	d= 0.5m, deep= 0.12m. Possibly gas seepage
4	G-4	Above the pipeline		d= 0.52m, deep= 0.2m. Possibly gas seepage
5	G-5	0.2	259.3	d= 0.29m, deep= 0.18m. Possibly gas seepage
6	G-6	1.3	78.3	d= 0.34m, deep= 0.1m. Possibly gas seepage
7	G-7	0.6	79.3	d= 0.54m, deep= 0.2m. Possibly gas seepage

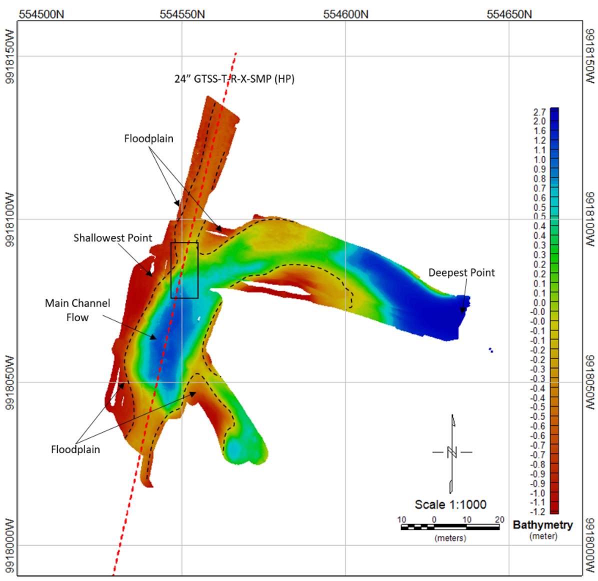

Figure 10. Multi beam bathymetric map of the 24 inches Pipeline USV survey area. The red dashed line is the pipeline's position from the database

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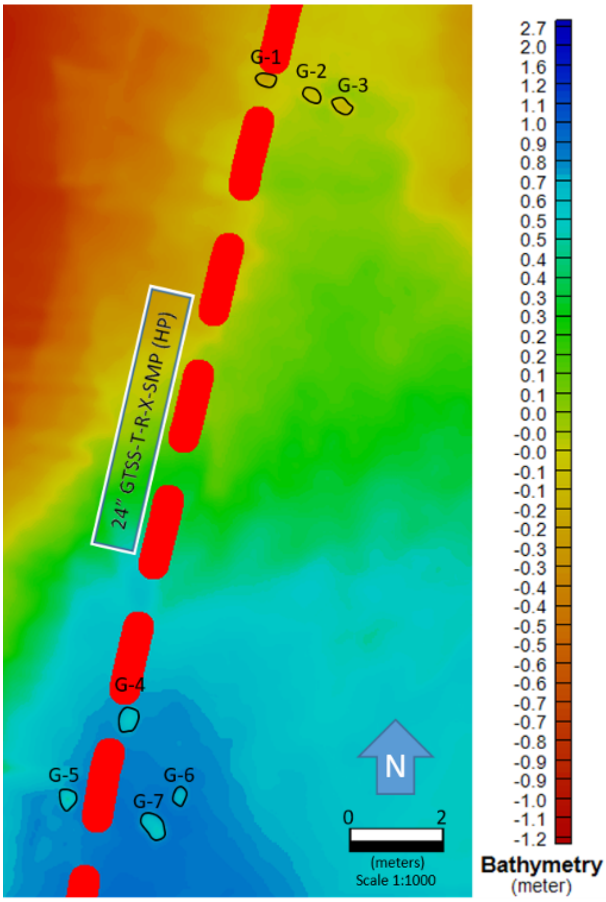

Figure 11. A zoomed in image of anomalies near the 24 inches pipeline area. The red dashed line is the pipeline's position from the database

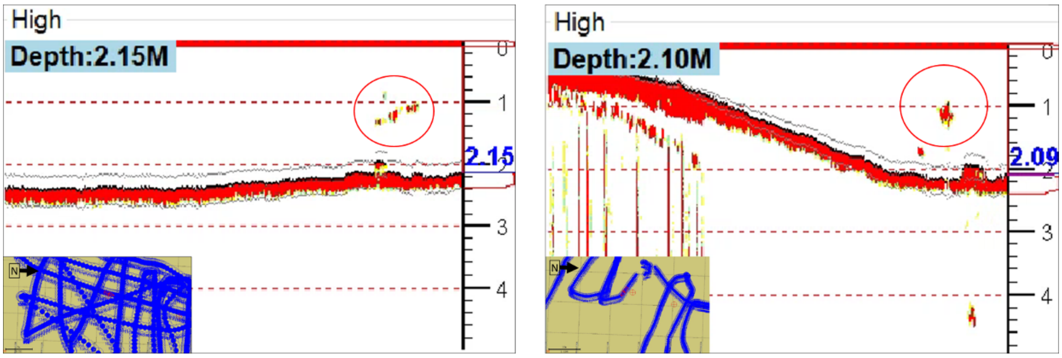

Figure 12. Suspected bubbles (red circle) at G-4 from SBES recorded data (left image is line track North to South and right image is line track West to East)

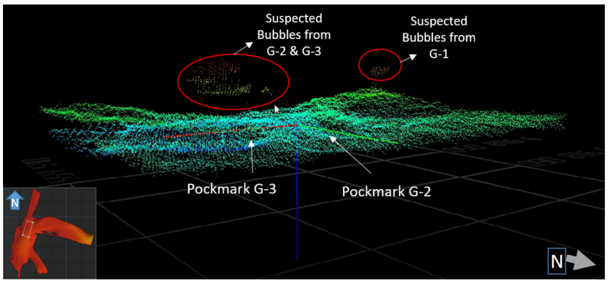

Figure 13. Suspected bubbles around G-1, G-2, G-3 location on day 1 (October 29, 2021) during MBES data processing

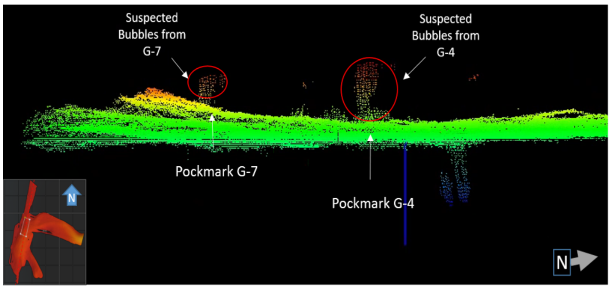

Figure 14. Suspected bubbles around G-4 and G-7 location on day 1 (October 29, 2021) during MBES data processing

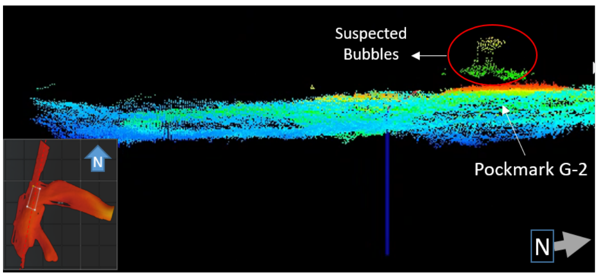

Figure 15. Suspected bubbles around G-1, G-2, G-3 location on day 2 (October 30, 2021) during MBES data processing

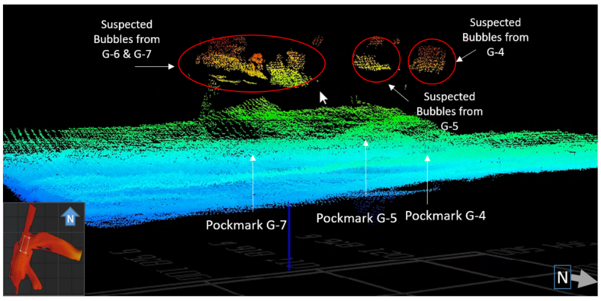

Figure 16. Suspected bubbles around G-4, G-5, G-6, G-7 location on day 2 (30 October 2021) during MBES data processing

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