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PEI turbidity threshold workshop 11 June 2024

REPORT

I. General frame of the workshop

In the framework of the monitoring of the construction of Princess Elisabeth Island, one bottom lander with an ADCP was deployed at various locations and two monitoring buoys have been placed at about 2 km northeast (TME01) and southwest (TME02) of the future island. Equipped with an ADCP and EXO multiparameter probe, the measuring buoys provide real-time data on the currents, turbidity and chlorophyll concentrations in the water column surrounding the island. To ensure that the turbidity doesn't increase up to threatening levels for the environment, thresholds must be implemented in an alarm system to detect when mitigation measures must be taken. In that regard, the objectives of this workshop were (1) to update all parties on the advances of the construction works and monitoring results, (2) to agree on one or multiple turbidity threshold(s) for the summer and fall of 2024 and (3) to communicate on needs and missing information or actions to be taken on both sides. This report is intended to summarize the decisions related to the turbidity thresholds made by RBINS following this workshop.

II. Turbidity and SPM concentration thresholds

In this report, the focus will be on turbidity, which is less dependent on calibration with water samples than the SPM concentration. In addition to that, a small section will be devoted to ADCP data, which will later be used to establish thresholds for other depths in the water column. In the absence of precise calibration and consistent instruments, this section will remain minor, and the thresholds established will mainly be applied to the OBS installed on surface buoys. It is expected that further refined thresholds will be suggested for 2025 based on a more thorough analysis and on a larger dataset.

a. Turbidity thresholds in literature

It has been argued that water quality data must be linked to thresholds that connect physical pressures to biological responses, defining exposure conditions above which effects may occur (Jones et al., 2016). Multiple studies have sought these threshold values during marine extraction for various sensitive habitats. However, none have specifically examined the biological response of gravel bed habitats to sediment plume exposure (see further; b. Sensitivity study on the gravel beds). Nevertheless, the methodology of these studies can still be used to define relevant threshold values.

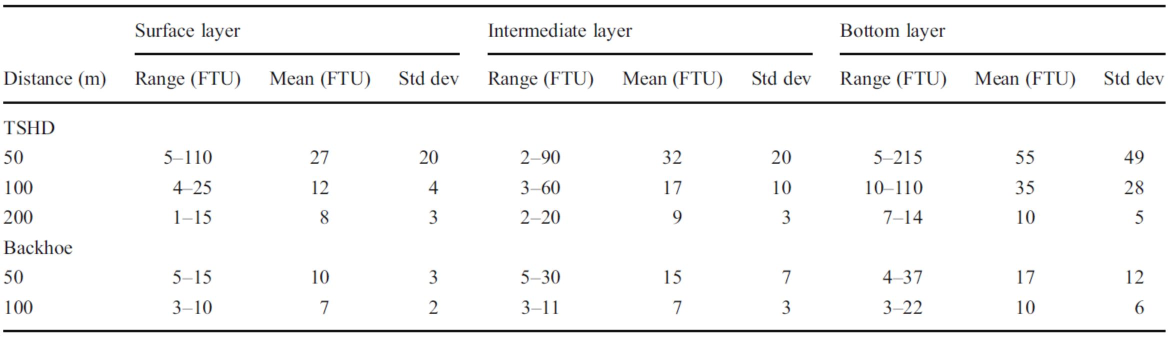
Typical damages associated with turbidity-generating activities can be divided into direct and indirect effects. Direct effects occur at the extraction site, involving substrate removal, and at disposal areas, involving burial. Indirect effects include sediment mobilization into the water column leading to physico-chemical changes (such as contaminant and nutrient release, elevated suspended sediment concentrations (SSCs), altered light quality and quantity, and sediment covering), and seabed smothering near the activities due to sediment dispersal. The sediment covering of organisms has the most significant biological impact (Jones et al., 2016).

Studies have shown that the coarser sediment fraction (sand) settles quickly within the first 10 to 20 minutes and does not travel far (Duclos et al., 2013). In contrast, the passive plume, composed of finer sediments (silt, mud) and lower SSCs, can extend for many kilometers and persist for several hours, depending on site-specific hydrodynamic conditions. Turbidity measurements during marine extraction have shown significant temporal variability, **with short-term turbidity levels spiking up to 20 times higher than the baseline, and long-term levels regularly exceeding the baseline by five times**. At the Barrow Island project, turbidity levels regularly exceeded 100 NTUs compared to baseline levels of around 20 NTUs. After a 2-year dredging program, Jones et al. (2016) observed a clear change in seafloor sediment composition, with increased silt content and decreased sand/gravel fraction, indicating seabed smothering.

Another study on dredging in the port of Genoa recorded turbidity values ranging between 1 and 215 FTU depending on the dredging method, water depth and distance to the activity (Table 1; Cutroneo et al., 2012). It should be noted that hydrodynamic conditions in a port differ significantly from those offshore, where sediment plumes are subject to stronger currents and can travel further from the extraction site. In Genoa, they defined **a threshold value of 30 NTU, combined with an outward current** (from port to sea) **greater than 20 cm/s lasting longer than 15 minutes**, to protect a seagrass habitat near the port (Cutroneo et al., 2012).

A study in the Bay of Seine, with tidal conditions, bathymetry, and SSC similar to the offshore Belgian part of the North Sea (BPNS), recorded the overflow characteristics of a trailer suction hopper dredger (TSHD). The TSHD had an overflow discharge of 3150 m^3/h, an SSC of 3-13 g/l, and sediment composition of 55.3% sand, 30% silt, and 17.7% clay. The subsurface plume diluted substantially, decreasing from several hundred mg/l to 20 mg/l within 10 minutes and disappearing after two hours. The plume extended up to 600 m during slack conditions and up to 8.5 km during ebb or flood periods, with a width of 100 m. In their case, they **defined the plume as the mean of the background SSC plus two times the standard deviation** (Duclos et al., 2013).

Table 1 Turbidity values measured around the trailer suction hopper dredger (TSHD) and backhoe; while for the TSHD typical turbidity values of the port are reached at 200 m, for the backhoe these values are reached by 100. (Cutroneo et al., 2012).



	Surface layer			Intermediate layer			Bottom layer		
Distance (m)	Range (FTU)	Mean (FTU)	Std dev	Range (FTU)	Mean (FTU)	Std dev	Range (FTU)	Mean (FTU)	Std dev
TSHD									
50	5–110	27	20	2–90	32	20	5–215	55	49
100	4–25	12	4	3–60	17	10	10–110	35	28
200	1–15	8	3	2–20	9	3	7–14	10	5
Backhoe									
50	5–15	10	3	5–30	15	7	4–37	17	12
100	3–10	7	2	3–11	7	3	3–22	10	6

b. Sensitivity study on gravel beds

In the framework of the designation of the new area for marine renewable energy in the BPNS, a sensitivity study has been carried out to investigate the possible reactions of organisms to different levels of burial (Zupan et al., 2023). The foreseen area is located near the Natura 2000 zone hosting protected gravel bed habitats. The sensitivity of four species representative of the diversity of the gravel bed epifauna community was tested in laboratory experiments for 2, 5 and 7 cm of burial and for durations of 2 and 10 days. Their results showed that some species (*Buccinum undatum* and *Metridium senile*) remained unaffected by high burial (7 cm) while others could only cope with light or short-term burial (*Asterias rubens* and *Alcyonium* *digtatum*). Based on these experiments and confirmed by literature findings, the authors indicated that tolerance to burial is very variable and mainly species-specific.

c. Definition of turbidity thresholds based on statistical analyses and natural background values

In view of the results of the sensitivity study of species present in the gravel bed habitats, it became evident that a single threshold could not be defined for many different species, given their diverse reactions to different burial and turbidity levels (Zupan et al., 2023). Therefore, a precautionary approach was chosen instead, using statistical analysis to determine thresholds based on deviations from the natural background. Duclos et al. (2013) used this method to define a threshold as the mean plus two times the standard deviation. However, in our case, using that definition still left 3.35 % and 1.46 % of the natural data above that threshold for TME01 and TME02 respectively, unintentionally setting off 70 false alerts every month. By trial and error, and with the aim of reducing the number of false alarms below the statistical value of one per month, the threshold was defined as the mean plus five times the standard deviation.

One could argue that the defined turbidity thresholds are low, however, the offshore environment is characterized by a naturally low turbidity, in comparison to traditional dredging areas more commonly located in turbid coastal waters. Data collected at W08 (about 13 km southwest of the PEI area) in the framework of another monitoring project (BGCMonit) confirm that. During that project, water samples were taken close to the bottom and to the surface using Niskin bottles mounted on a rosette and were collected monthly between 2018 and 2023. These samples were then filtrated on board for SPM concentrations and turbidity was measured using a portable Hach turbidity meter. Three replicates were taken each time.

At the surface, the mean SPM over 2018-2023 is 4.2 mg/L with only four peaks above 15 mg/L, while the mean close to the bottom is 5.4 mg/L. The SPM concentration shows some small intra-annual variability with all months displaying values below 15 mg/L except for April when a peak is visible (Figure 1). The latter can be explained by the phytoplankton bloom.

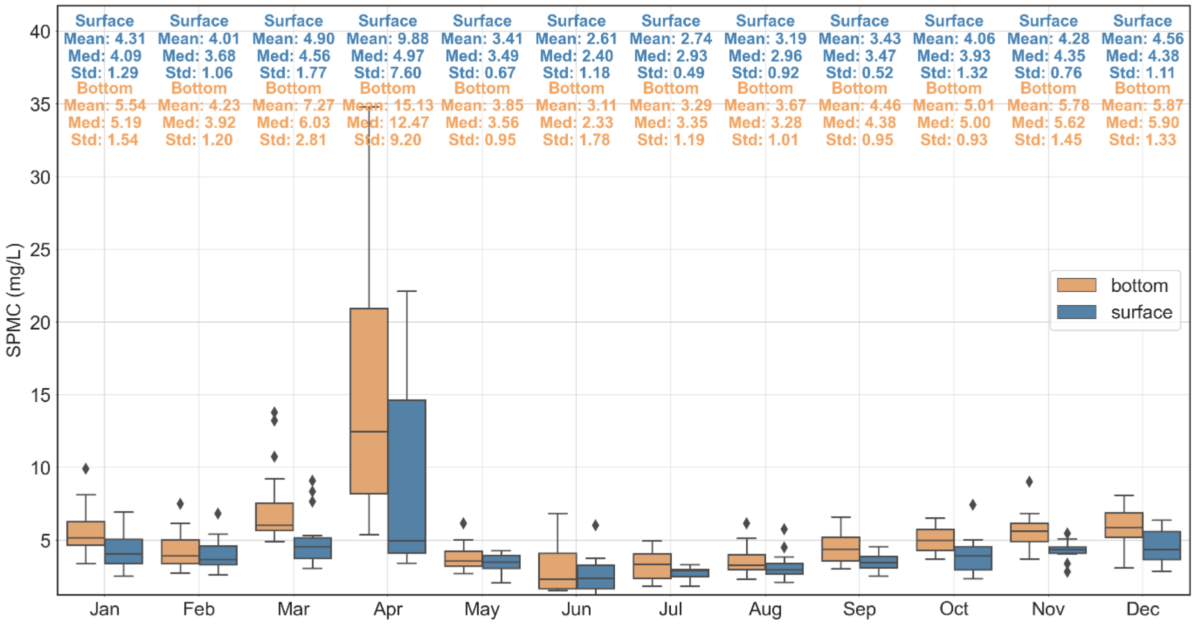


Figure 1. Monthly distribution of the SPM concentration (mg/L) measured at the bottom and at the surface at W08 between 2018 and 2023.

The mean surface turbidity over 2018-2023 is 1.7 NTU with only two peaks above 5 NTU, while the mean for the bottom is 2.2 NTU. The turbidity also shows some intra-annual variability with higher values measured in winter and lower in summer (Figure 2). The increase in SPM concentration observed in April is also visible in the turbidity, although to a lesser extent.

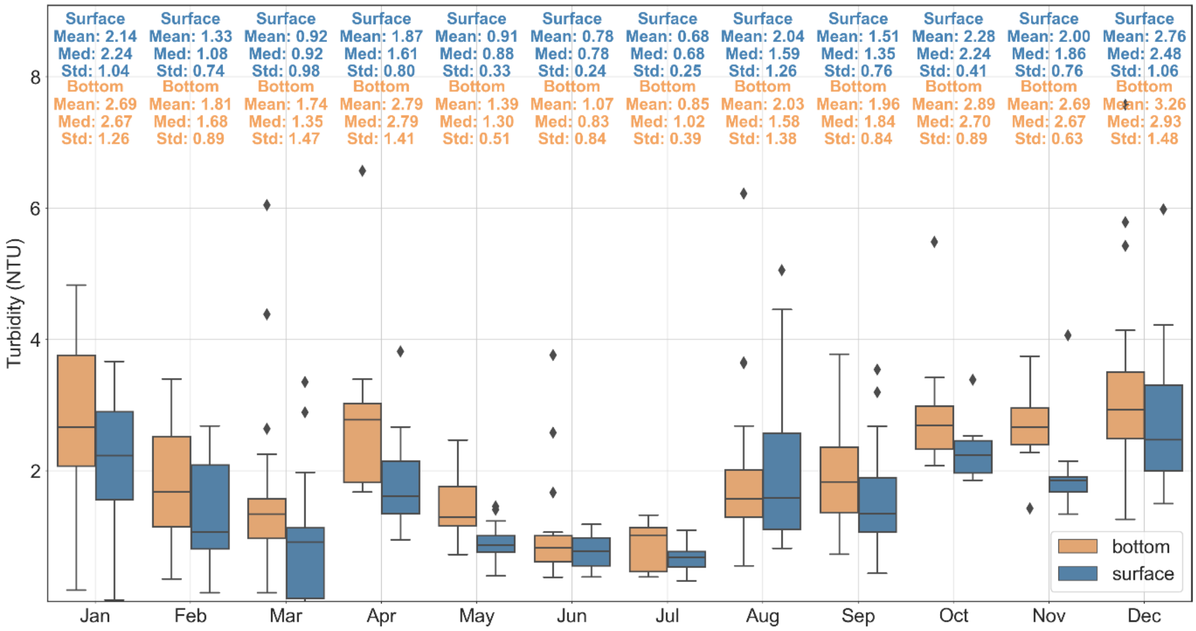


Figure 2. Monthly distribution of the turbidity (NTU) measured at the bottom and at the surface at W08 between 2018 and 2023.

Relatively low turbidity and SPM thresholds are further justified by the large distance between the buoys and the island (i.e. 2 km) and the narrow width of the plume (i.e. ± 100 m) which both make its detection challenging.

In order to reduce the risk of false alarm generated by single outliers (e.g. isolated fish or dirt passing over the sensor), it was decided to set up the alarm system using two thresholds:

- ***Warning threshold***: This threshold corresponds to 80% of the alarm value. Its purpose is to inform the two parties (i.e. RBINS and TME) of any abnormal increase in turbidity in one or two buoy(s). A warning is sent if this threshold is exceeded three consecutive times and an investigation of possible reasons for this increase should then be done by TM Edison.
- ***Alarm threshold***: If this threshold is exceeded, mitigation measures should be taken by TM Edison.

Although the current setup records data once every thirty minutes, we strongly emphasize the need to increase this frequency to at least every 10 or 15 minutes. This will not only reduce the risk of missing the plume but will also make it easier to distinguish outliers from real alerts, something that can also be further improved by measuring in bursts. This requested increase in measurement frequency is also supported by the studies conducted by Jones et al. (2016) and Cutroneo et al. (2012).

d. Initial turbidity thresholds suggested for spring 2024

The pre-construction dredging phase was done during the first two weeks of April 2024. To enable real-time environmental monitoring during this work, initial turbidity thresholds were determined based on data collected by the OBS placed on the buoys from November 2023 to

March 2024. **Warning and alarm thresholds were respectively set at 3.4 NTU and 4.2 NTU for TME01, and 3.8 NTU and 4.7 NTU for TME02** (Figure 3 & 4; Table 2), resulting in only 0.06 % and 0.05 % of the data naturally above the alarm threshold for TME01 and TME02. That means such a threshold should statistically trigger a false alarm less than once a month at each buoy.

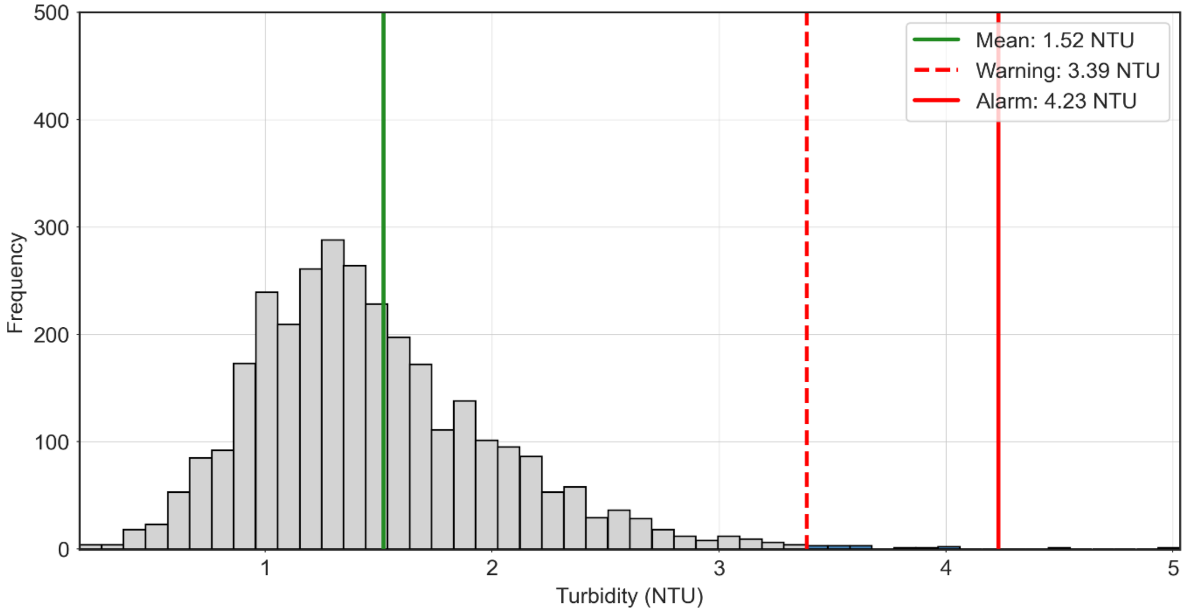


Figure 3. Distribution of the baseline turbidity values collected at TME01 between November 2023 and March 2024. The mean is represented by the green line; the warning threshold is the red dotted line, and the alarm threshold is the red full line.

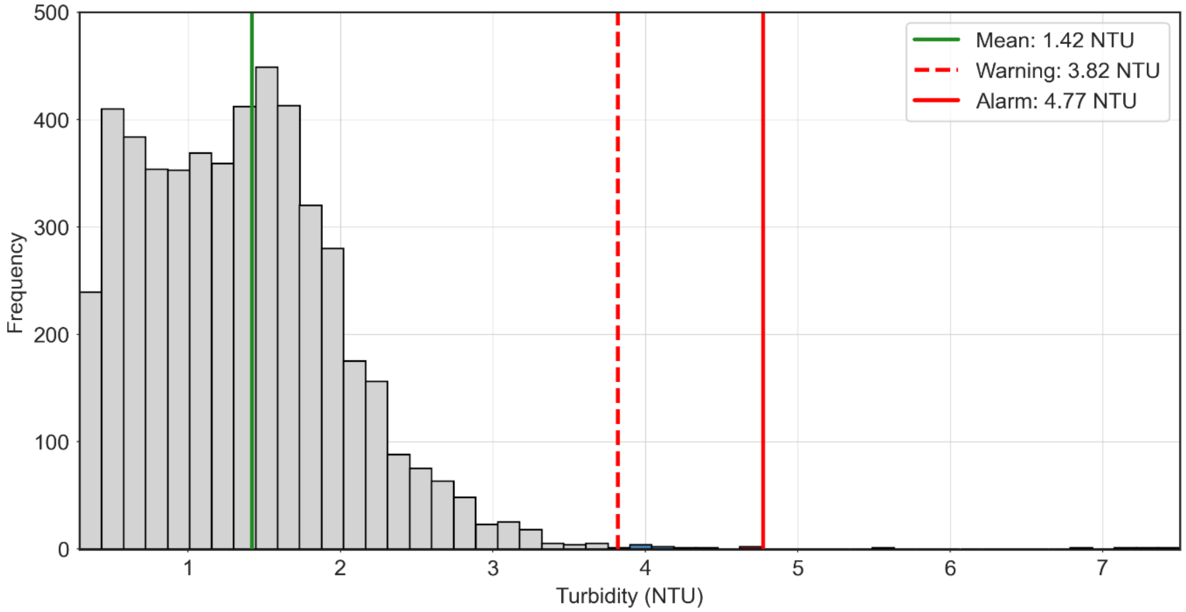


Figure 4. Distribution of the baseline turbidity values collected at TME02 between November 2023 and March 2024. The mean is represented by the green line; the warning threshold is the red dotted line, and the alarm threshold is the red full line.

e. Updated turbidity thresholds suggested for summer and fall 2024

In order to cover the following stages of the construction in summer and autumn 2024, the temporary thresholds defined in March 2024 were refined using the data until April 2024

(Figure 5, Figure 6). As several unexplained and isolated outliers were observed at TME01, values above 5 NTU were removed for the threshold calculations. **Warning and alarm thresholds need to be set at 3.6 NTU and 4.5 NTU for TME01, and 3.8 NTU and 4.7 NTU for TME02** (Figure 5 & 6; Table 2), resulting in only 0.04 % and 0.05 % of the data naturally above the alarm threshold for TME01 and TME02 respectively. These thresholds should statistically trigger a false alarm less than once a month at each buoy.

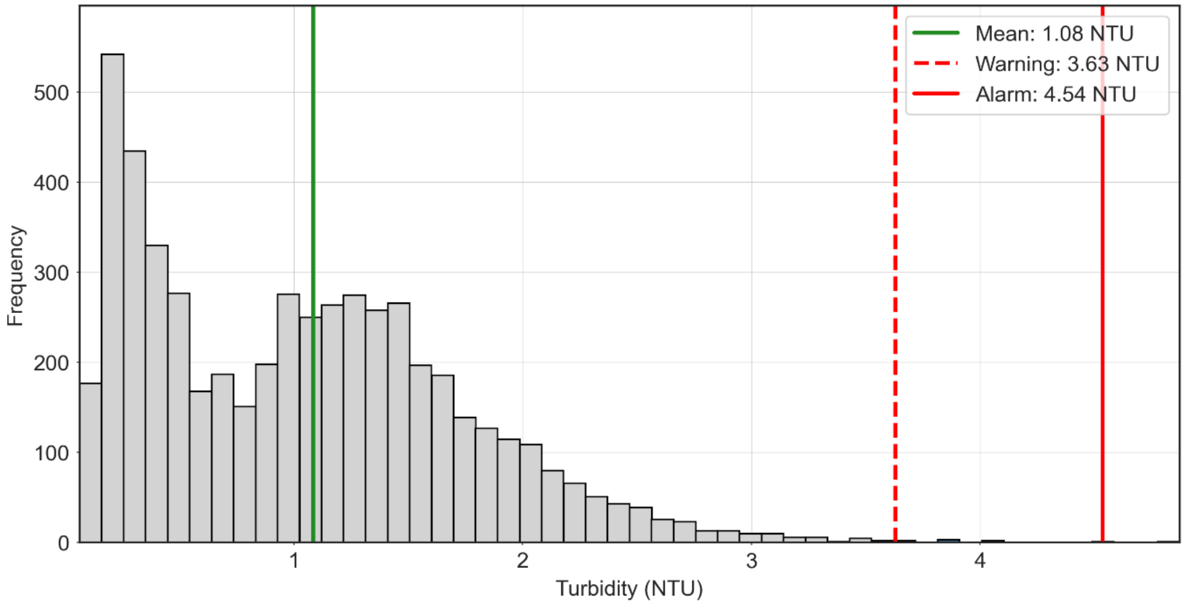


Figure 5. Distribution of the baseline turbidity values collected at TME01 between November 2023 and April 2024. The mean is represented by the green line, the warning threshold by the red dotted line and the alarm threshold by the red line.

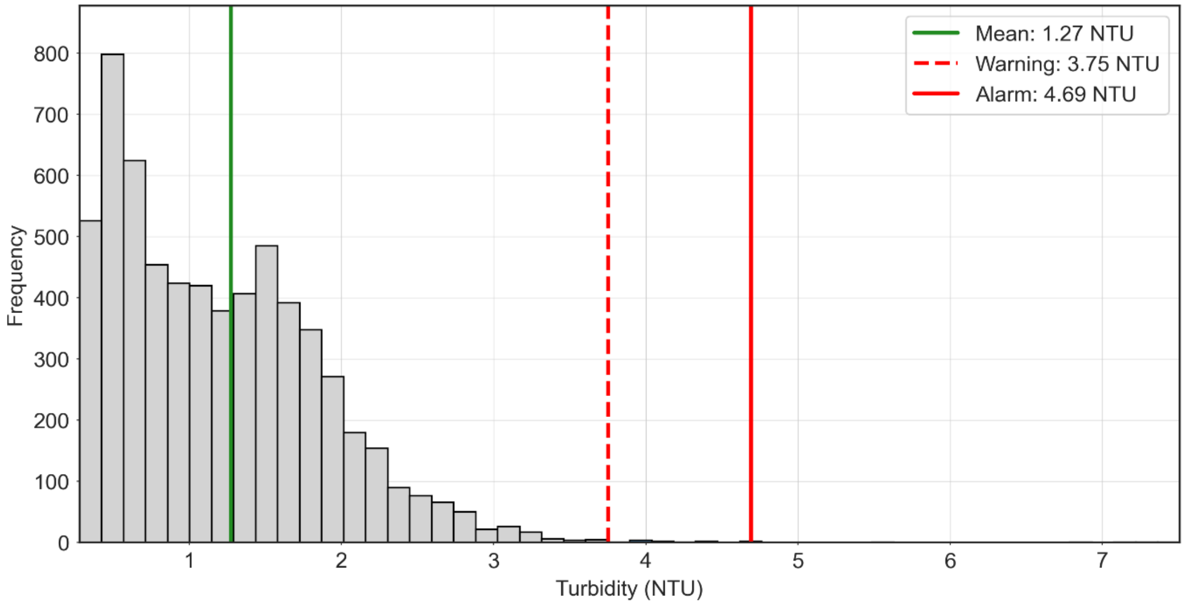


Figure 6. Distribution of the baseline turbidity values collected at TME02 between November 2023 and April 2024. The mean is represented by the green line, the warning threshold by the red dotted line and the alarm threshold by the red line.

Comparing the turbidity values measured by the buoys around the island between November 2023 and April 2024 with the data collected at W08 from 2018 to 2023, it seems that the two zones are comparable, and that the data collected in five months around PEI are slightly lower but still representative of the background (Figure 7). Given this result, the proposed thresholds can be expected to be slightly underestimated (Table 2). However, since turbidity values are generally lower from May to September (Figure 2, Figure 7) and that these thresholds are determined for the summer and autumn of 2024, this underestimation is unlikely to have any significant impact on the number of false alarms triggered.

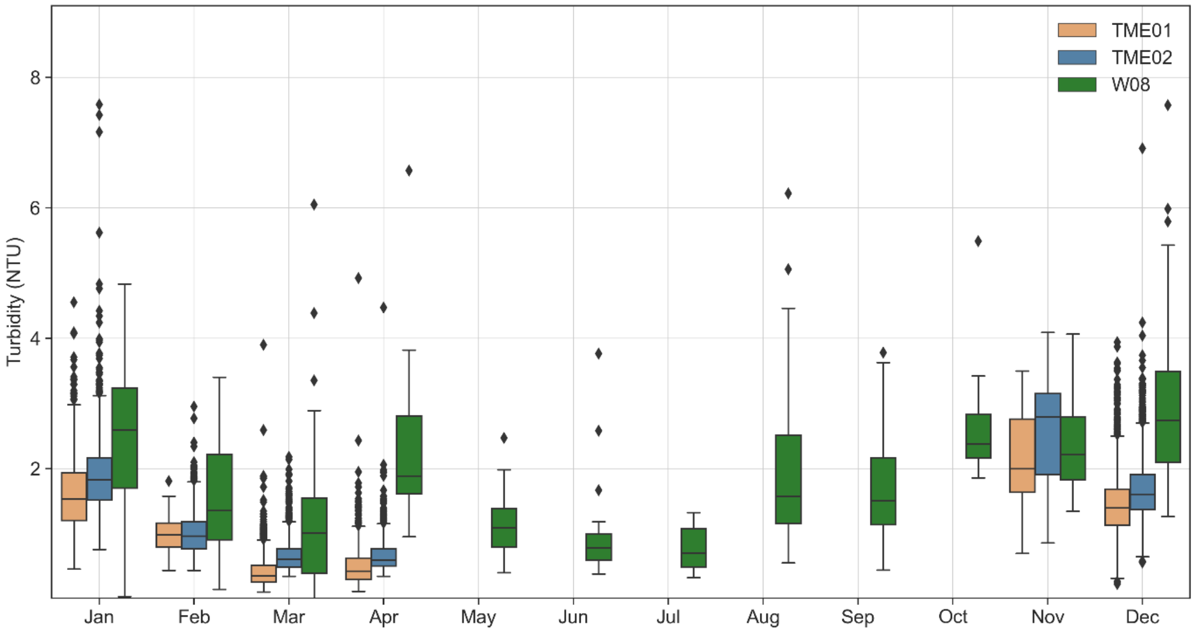


Figure 7. Monthly boxplots of the baseline turbidity values at TME01, TME02 and W08.

In the Table 2 below, the thresholds for SPM concentrations were determined by converting turbidity from the OBS installed on the buoys using the following equation:

$$SPMc = turbidity * 2.6$$

In which the turbidity is expressed in NTU. The conversion factor (2.6) was determined by the linear relationship (through the origin) between the filter-weighted water samples and the corresponding NTU value during sampling. This factor is based on the EXO water sampling campaign 1 (November 2023); however, from the other two sampling campaigns we obtained factors 3.9 and 6.6 (February and April 2024 respectively). The latter is highly likely influenced by the biological particles during the spring phytoplankton bloom. To continue working with mg/L values, caution is advised.

Table 2 Turbidity thresholds.

	Nov-March		Nov-April		2018-2023
	TME01	**TME02**	**TME01**	**TME02**	**W08**
Turbidity (NTU)					
Warning Alarm	3.4 4.2	3.8 4.7	3.6 4.5	3.8 4.7	6.3 7.8
SPM (mg/L)					
Warning Alarm	8.8 11	9.8 12.2	9.4 11.8	9.8 12.2	8.6 10.7

f. Turbidity thresholds for 2025

From the end of November 2023 until the end of April 2024, both the TME01 and TME02 buoys were equipped with a downward looking 600 kHz ADCP (Aanderaa). A direct linear relationship between the buoy EXO-OBS data (log-form) and the ADCP backscatter dB data close to the sea surface was found (Figure 8) and considered applicable for turbidity estimation (derived from the ADCP bins) for most of the water column. The latter considers the sound losses due to the distance away from the ADCP, including spherical ADCP beam spreading and water attenuation. Attenuation due to SPM is ignored here, as the SPM concentration is too low. The entire acoustic inversion and calibration procedure described by Kim et al. (2004) is followed in this study.

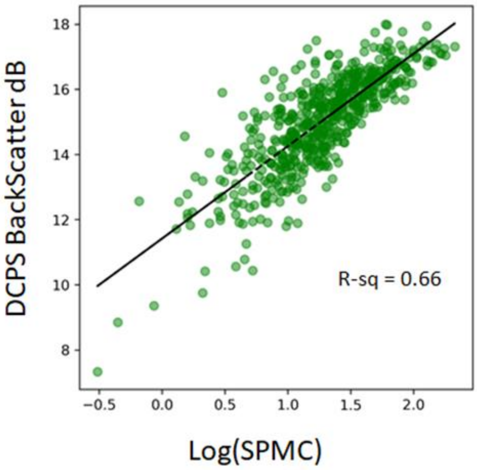


Figure 8: Linear relationship between the log form of the EXO-OBS and the Aanderaa acoustic backscatter.

When approaching the seafloor, caution is required as the SPM may become subtly coarser resulting in an overestimation of the ADCP-derived turbidity as the ADCP is relatively more sensitive towards coarser grains compared to the OBS.

In figure 9 and as an example, the mid-water column NTU dataset at TME01 derived from the ADCP backscatter in bin n°12 is shown. The data were tidally grouped (black curves) and averaged (green curve) starting and ending at low water (LW).

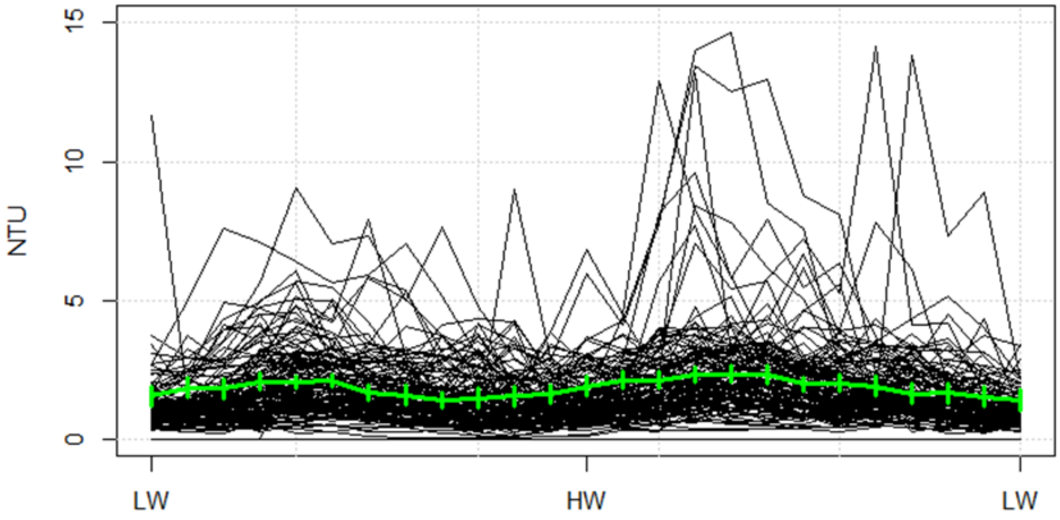


Figure 9: Tidally grouped ADCP-derived NTU data (TME01). Green line is the mean NTU with standard error bar.

For the different buoy measurement periods, buoy maintenance together with Aanderaa ADCP replacements (not ideal for bulk data-analysis as such a calibration is instrument-specific) took place. It was also noted that the gain level settings were changed once resulting in data being easily saturated.

Turbidity thresholds could be set, but not shown during the workshop nor used on the real-time acoustic data (alert set-up) because, from the end of April 2024 onwards, the Aanderaa ADCPs were replaced by Nortek Signature 1000 kHz ADCPs. This imposes a thorough revision of the acoustic inversion method for this type of ADCPs. Once enough Nortek data (~ 6 months) are collected, summary statistics will be calculated allowing us to provide ADCP threshold values.

An inter-comparison is also envisaged for understanding the ADCP's frequency dependency (600 vs. 1000 kHz), thanks to the overlapping buoy measurements at the TME02 location. When the dependency is judged minor, then the Aanderaa ADCP backscatter can be combined with the Nortek datasets and thus re-used for statistical analysis.

The datasets from the AWAC bottom lander (in the vicinity of the TME02 buoy) (March-April 2024) consisted of a Nortek ADCP (Signature 1000 kHz) and an EXO-OBS and provided us with interesting insights on the near-bed SPM dynamics. A stronger tidal (ebb-flood, spring-neap) variability in NTU (Figure 10a) was observed that co-varies with the tidal elevation (range) shown in Figure 10c. The acoustic data (Figure 10b) from bin n°1 (black) and bin n°10 (red) also readily shows this pattern. For the SPM type, the relationship between ADCP and OBS makes it possible to calculate a sediment composition index (SCI) (Figure 10d); this index (Pearson et al. 2021) is a subtraction between the log form of the OBS NTU data and the acoustic dB data. When the SCI becomes more negative, during the more energetic spring tide conditions, the coarser the SPM tends to be for example, and vice versa. The last 14 days of April, the SCI fluctuates around a (less negative) constant value implying finer SPM in transportation (unless biofouling on the ADCP transducers reduced the recorded backscatter). The same SCI method will be applied on the near-surface EXO-OBS and backscatter data, which may help in detecting when the SPM type deviates from the natural variability.

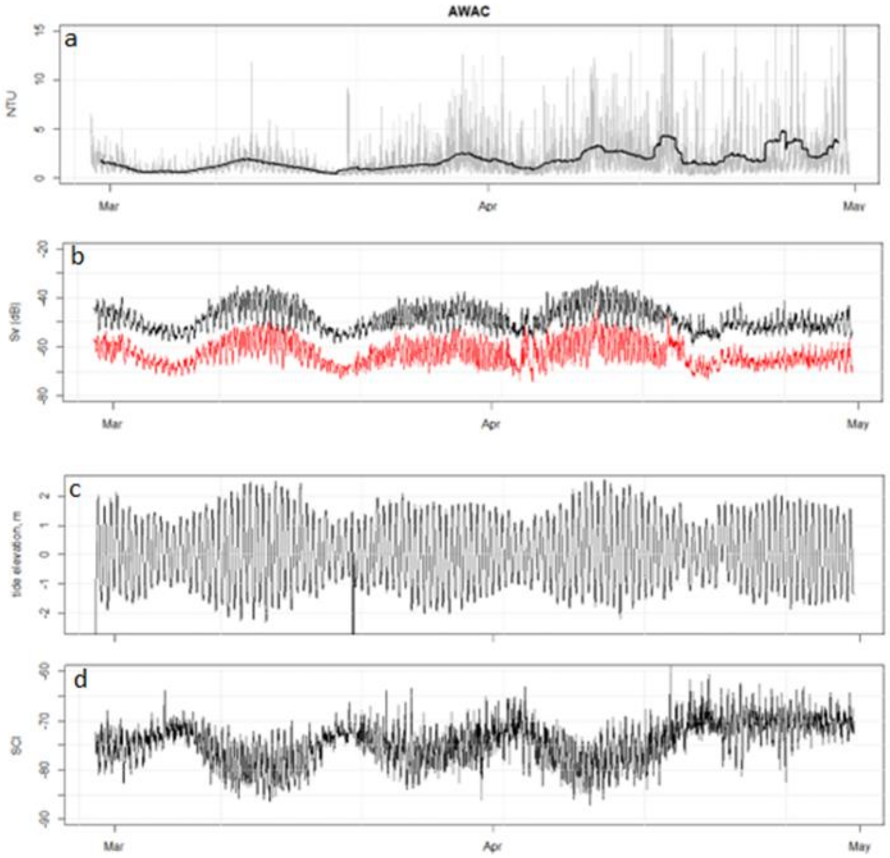


Figure 10: a, the EXO-OBS NTU time-series with moving average (bold line); b, Nortek Signature (1000) bin n°1 and n°10 (dB); c, tidal elevation and d, SCI (sediment composition index).

III. Combining real-time turbidity measurements with remote sensing

On 7 and 9 May, sediment plumes were detected at the water surface via satellite data from Sentinel 2 (Figure 11; source: https://terrascope.be/). Further research is currently ongoing to interpret these data and to integrate them into the sediment dispersal section. Is the processing of these data compatible with the processing of data from the survey buoys and bottom lander? Is the distribution of these sediment plumes consistent with the sediment plume models? What is causing the sediment plumes? What is the range of uncertainty? How is the conversion to SPMc done? The coming months will be dedicated to gaining a better understanding of how the use of satellite images can be combined with in-situ measurements to improve the detection and understanding of the sediment plumes generated by the construction of the Princess Elisabeth Island.

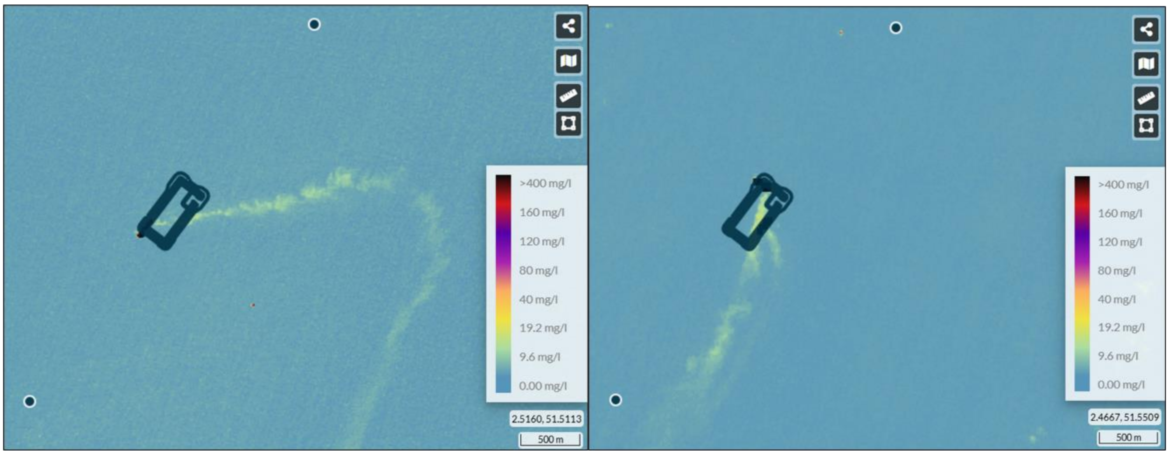


Figure 11. Sediments plumes detected in the area of Princess Elisabeth Island by satellite images viewed on the Terrascope online platform. The SPM concentration is derived from Sentinel 2 images. These images were taken on 7 May and 6 June 2024 respectively.

IV. References

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