# Swansea Sand Tracing Study – Highlighting the Processes

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## Abstract

The Swansea Channel has been significantly modified from its natural state from which the geomorphology of the channel continues to adjust. Changes include the construction of training walls at the ocean entrance in mid 1880s, construction of the Swansea Bridge and the extension of the channel (mid 1800s) to Marks Point (previously flowed westward from Naru Point) with spoil from the associated dredging activities sidecast as a continuous low lying island extending northward from Naru Point in front of Swan Bay  Sediment mobilised by the improved hydraulic efficiency of the entrance is propagated upstream in pulses by the dominant flood tide and is deposited in the upper region of the channel creating a navigation hazard for deep-keeled yacht and cruisers.

The NSW Department of Primary Industries (Lands) (DPI Lands) engaged Royal HaskoningDHV (RHDHV) and ETS to undertake a sediment tracing study to improve the understanding of sediment transport processes at Swansea Inlet, with particular emphasis on identifying the source/s of sand leading to the infill of the channel and growth of the flood tide delta.  The first step involved the deployment of different coloured fluorescent sand tracer material at five locations in the upper region of Swansea Channel. Over the next four months two sampling exercises were undertaken within the channel. The collected samples were subsequently analysed to assess the transport of the tracer material under the local coastal processes.

Clearly identifiable sediment transport pathways were identified from the analysis results. This provides an improved conceptual understanding of sediment transport processes at Swansea under natural conditions. Outcomes from the study are expected to be used for the development of a sand management strategy which may include installation of engineered features and/or dredging that is optimised and sustainable in the medium to long-term.

Sediment tracers provide unequivocal and tangible data on actual sediment transport on a site-specific basis.

## Introduction

The Swansea Channel (**Figure 1**) has been significantly modified from its natural state by construction of training walls at the ocean entrance, construction of the Swansea Bridge and the completion of a number of dredging campaigns to address navigation problems faced by waterway users. The adjustment of the Swansea Channel to training of the entrance has resulted in erosion of sand primarily from Salts Bay and scour of the outer channel. Sediment mobilised from these areas by the improved hydraulic efficiency of the entrance is propagated upstream in pulses by the dominant flood tide and is deposited upstream of Swansea Bridge creating a navigation hazard for deep-keeled yacht and cruisers.


**Figure 1: Aerial view of Swansea Channel**

The Swansea Channel has generally been dredged at irregular intervals on an "as-required" basis to relieve constraints to navigation in specific areas of shoaling. Recently, in February 2015, NSW Crown Lands undertook a large scale "once off" maintenance dredging campaign. This involved removing around 80,000 $m^3$ of sand from the Swansea Channel that was pumped 3 km to Blacksmiths Beach for dune nourishment.

The *Swansea Channel Dredging Review of Environmental Factors* (RHDHV, 2014) prepared for the February 2015 dredging works described the 'relatively short-lived benefits from previous dredging campaigns'. This highlighted the limited understanding of:

- the source/s and movement of sand in the area that contributed to the requirement to undertake the recent 'once-off' dredging campaign, and:
- the fate of material placed during previous smaller maintenance dredging campaigns.

The NSW Department of Primary Industries (Lands) (DPI Lands) engaged Royal HaskoningDHV (RHDHV) and ETS to undertake a sand tracing study to improve the understanding of sediment transport processes at Swansea Channel, with particular emphasis on identifying the source/s of sand leading to the infill of the channel and growth of the flood tide delta. Sand tracers provide unequivocal and tangible data on actual sediment transport on a site-specific basis.

***Summary of Existing Conceptual Understanding of Sediment Dynamics***

A brief summary of recent studies related to sediment transport in Swansea Channel is provided below. It is evident from the studies that sediment transport processes are highly complex and sedimentation mechanisms in the area are yet to be fully understood.

*Lake Macquarie Estuary Process Study (AWACS, 1995)*

AWACS (1995) assessed the estuarine hydraulics and sediment transport characteristics of Swansea Channel. A hydrodynamic model of Lake Macquarie was established as part of this study using the RMA-2 software, which adopts a two-dimensional finite element solution.

Continuing erosion of the Salts Bay foreshore was predicted, with the eroded sand being transported upstream and deposited at the entrance to Black Neds Bay and at the drop-overs to Lake Macquarie. This sedimentation will be a continuing cause of reduced navigability, particularly around Marks Point, and the requirement for maintenance dredging in the channel.

*Investigation into Hydraulics, Sediment Transport and Navigation in Swansea Channel and Swan Bay (WBM, 2003)*

A key recommendation of WBM (2003) was to implement full or partial closure of the southern entrance to Swan Bay to improve the stability of the dredged channel.

The RMA-2 hydrodynamic model of Lake Macquarie developed by AWACS (1995) was updated by WBM (2003), which also included a sediment transport model. WBM postulated that catchment sourced flooding is not dominant in Swansea Channel; the dominant hydraulic process is tidal and he most likely source for sediment into the study area has been the significant erosion of Salts Bay following training of the entrance.

*Improvement Works at the Swan Bay Southern Entrance: Design Assessment Report (WBM, 2004)*

WBM (2004) considered a range of options for partial closure of the southern entrance to Swan Bay with the preferred solution was found to be partial re-closure of the southern entrance, with an indicative gap width of 30 m. The developed solution was considered to best satisfy two criteria: optimising sediment transport in the main navigation channel and maintaining reasonable tidal flushing within Swan Bay.

Works were subsequently undertaken in 2006.

Sediment transport modelling results predicted that there would be an almost continuous corridor of erosion potential through the main navigation channel as a result of the works.

*Tidal Modelling of Lake Macquarie (WorleyParsons, 2010)*

WorleyParsons (2010) carried out a numerical modelling study of Lake Macquarie, including Swansea Channel, with the objective of characterising the lake's tidal response to projected sea level rise. This involved updating an existing MIKE hydrodynamic model system of Lake Macquarie, with addition of the MIKE 21 SW (Spectral Wave) and ST (Sand Transport) modules.

WorleyParsons (2010) presented morphological modelling results that supported the conclusion by Nielsen and Gordon (2008) that the channel is currently not in an equilibrium state and is instead tending towards increased hydraulic efficiency through erosion resulting in deepening of the channel.

Worley Parsons also suggested there is strong evidence to suggest that the most likely source of sediment contributing to shoaling in the upper reaches of Swansea Channel is ongoing scour of the main channel upstream of the bridge, rather than erosion of Salts Bay.

## Sand Tracing Study Methodology

### *Background Sampling*

Background sampling and analysis was carried out before the commencement of the tracer deployment in order to determine whether there was any background fluorescent material present in the natural sediment that may interfere with analysis of the introduced tracer. The background samples were collected before any tracer mixing or release took place.

All the collected samples were shipped to the ETS ISO 9001 certified laboratory in the UK. All samples were analysed for fluorescent particle counts, which were then converted into particle counts per square metre of the grab area.

From analysis of the background samples it was observed that there was no natural fluorescence in the samples which could interfere with the analysis of the introduced fluorescent tracer particles used in this study.

### ***Tracer Manufacture***

In order for the sand tracers to behave in the same way as the target sediment, it was important to ensure that the tracer particles had similar physical characteristics to the native sediment. This involved analysis of Particle Size Distribution (PSD) data previously collected in the study area prior to the manufacture of tracer material.

A comprehensive sediment sampling and analysis program was undertaken in the study area in May 2014 as part of the investigations for the February 2015 dredging works.

ETS' EcoTrace fluorescent sediment particle tracers were used for the study. They are designed to be transported like natural sediment, thus assimilating the processes of tidal currents, wind and waves to give an integrated assessment of sediment transport. The tracers are a solid solution of fluorescent dyes in a thermoplastic polymer base.

The tracers are whole tracer particles and fluorescent throughout rather than a coating on natural sediment grains from the environment. Coated sediment grains can be abraded reducing recoverability and detection, whereas the ETS EcoTrace particles remain highly fluorescent and can be detected over long timescale projects in high energy environments even after some abrasion.

### ***Tracer Deployment***

The sand tracer material was deployed in November 2015 at the locations shown in **Figure 2** below. Weather during the deployments was fine, followed by a late thunderstorm, with light to moderate northerly winds prevailing throughout the deployments.

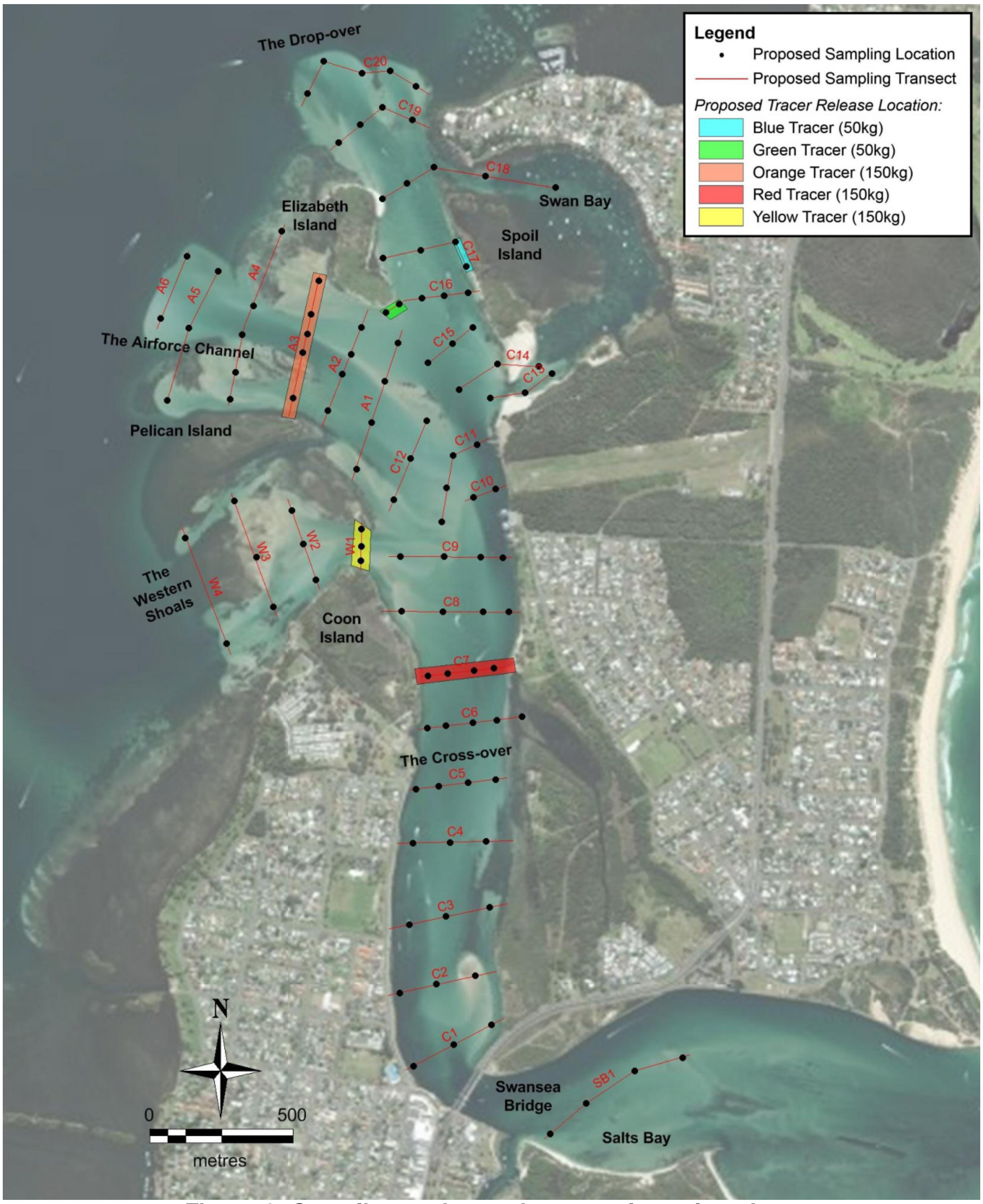

**Figure 2: Sampling region and tracer release locations**

***Sampling***

*Sampling Exercise 1*

Sampling exercise 1 was undertaken in December 2015. A total of 112 samples were collected during Sampling Exercise 1. The objective of the first tracer sampling exercise was to assess movement of the tracer particles over the short term, i.e. one complete spring-neap tidal cycle (28 days) following tracer deployment.

*Sampling Exercise 2*

Sampling exercise 1 was undertaken in December 2015. The objective of the second tracer sampling exercise was to assess movement of the tracer material over the medium term. Sampling Exercise 2 was undertaken around five spring-neap tidal cycles (20 weeks) following tracer deployment. The tracer results for Sampling Exercise 2 can therefore be used to identify the key depositional areas and, importantly, likely source locations for these areas.

### *Dredging Activities*

Two minor dredging campaigns were undertaken in the study area during the study period. These works were carried out to improve navigation through the channel in the vicinity of the southern entrance to Swan Bay. The timing and dredge quantity for each campaign was as follows:

- December 2015 - 2,000 $m^3$ (approximately); and,
- January 2016 - 4,000 $m^3$ (approximately).

Dredged material for both campaigns was placed onto Spoil Island above the waterline.

The dredging campaign in December 2015 was undertaken after Sampling Exercise 1, so the results from this sampling exercise are not influenced by dredging activities.

However, both dredging campaigns were carried out prior to Sampling Exercise 2, which means that the results from this sampling exercise should be assessed considering that 6,000 $m^3$ of material had been removed from the key depositional area opposite the southern entrance to Swan Bay. This made it more difficult to assess the likely sources of material and sediment transport pathways that are responsible for the growth of this problematic shoal. This was partly addressed by collecting several samples from the dredged material stockpile on Spoil Island during Sampling Exercise 2 on the basis that any tracer material present in these samples had previously been deposited on the shoal.

## Tracer Results

Plots of the sediment tracer counts are provided on **Figure 3** to **Figure 7** below.

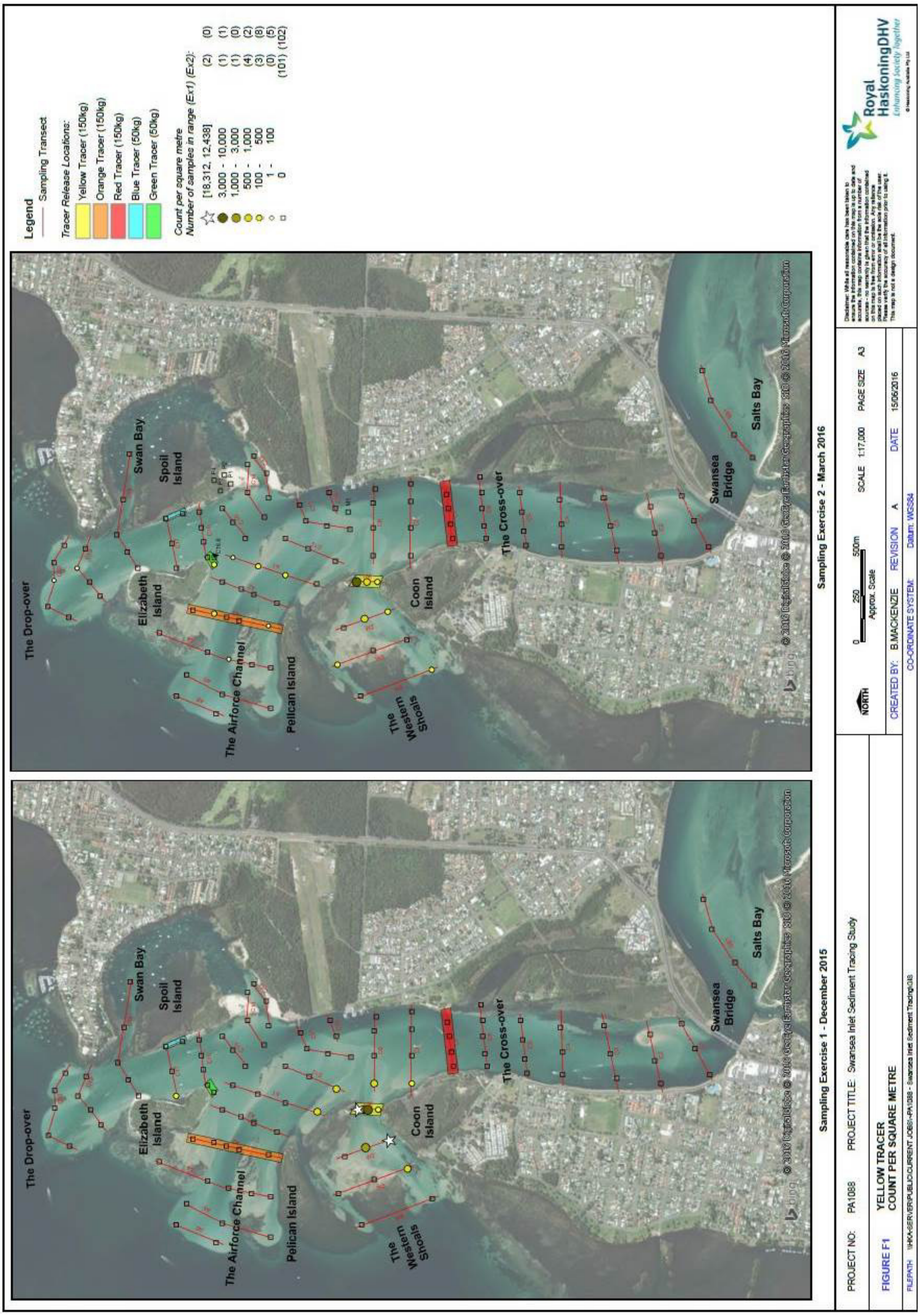


**Figure 3: Yellow tracer results - counts per square metre**

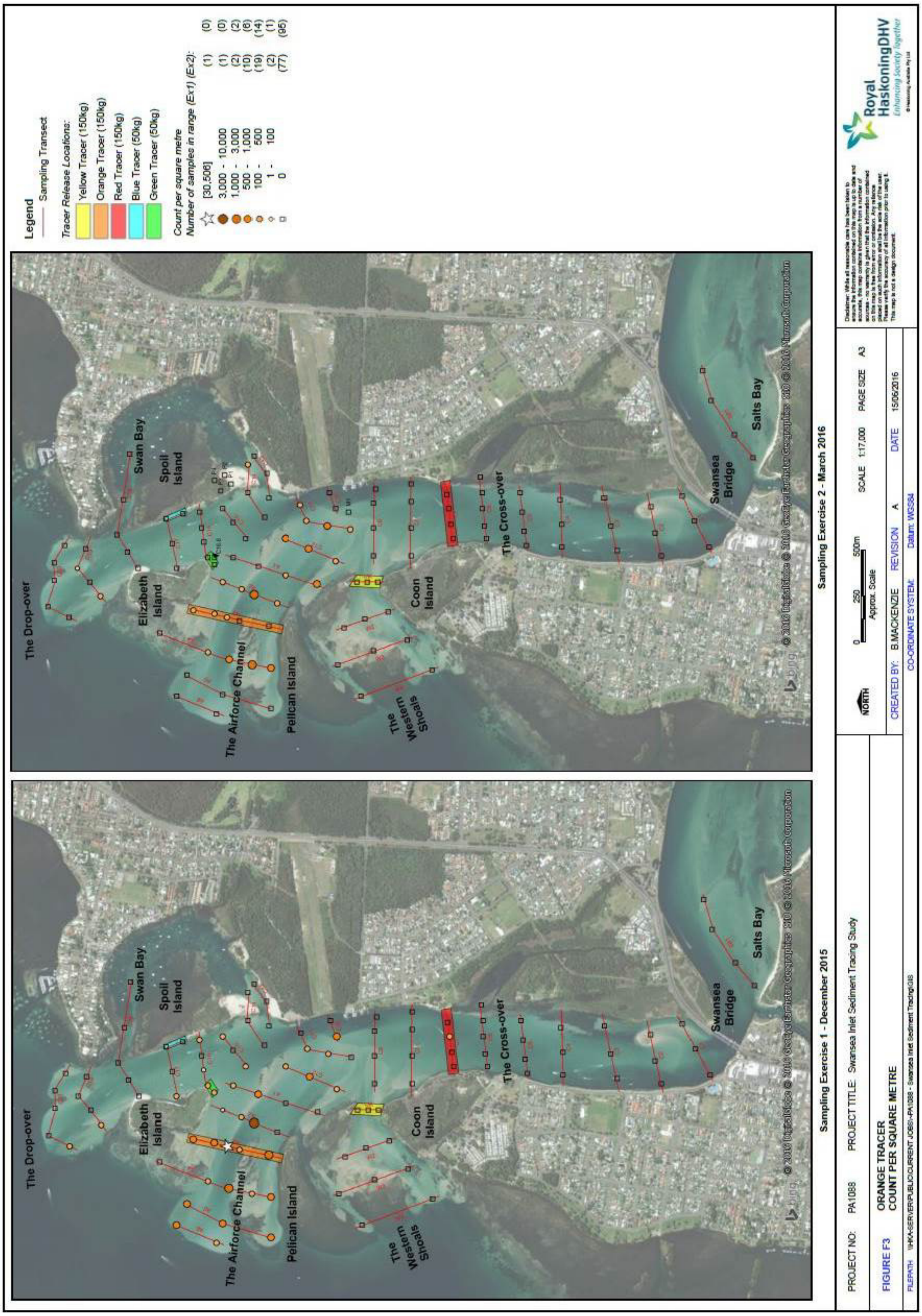


**Figure 4: Orange tracer results - counts per square metre**

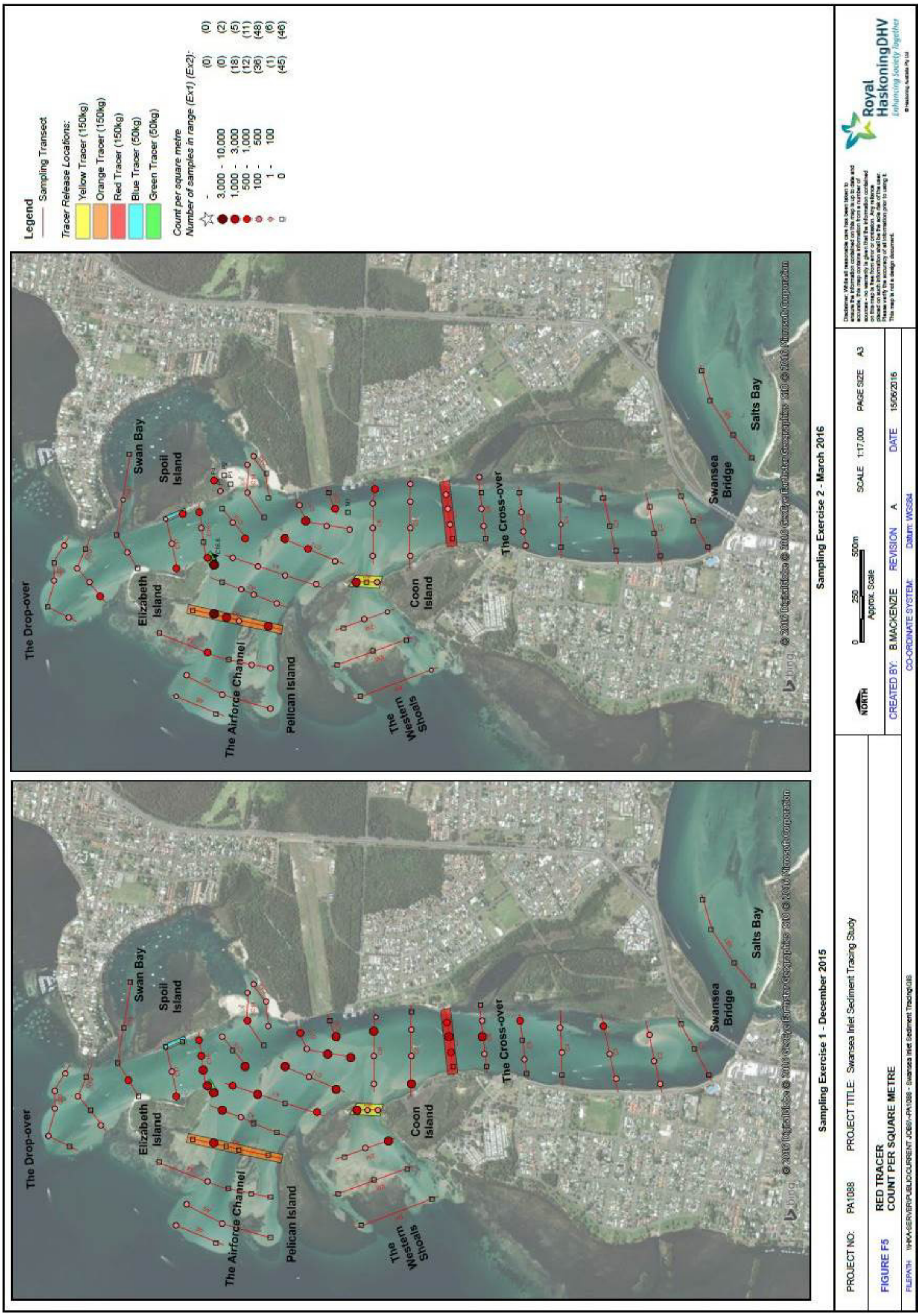


**Figure 5: Red tracer results - counts per square metre**

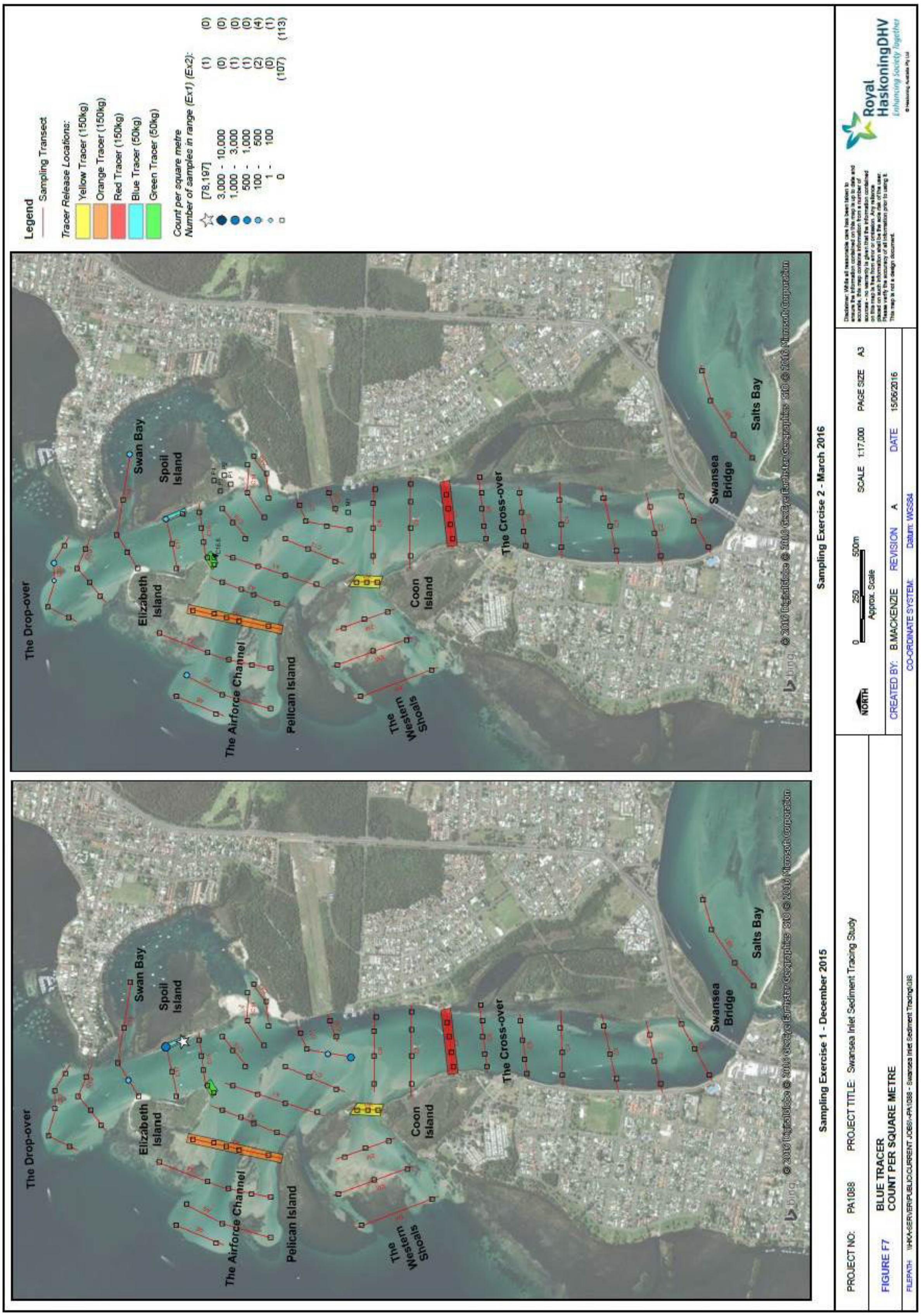


**Figure 6: Blue tracer results - counts per square metre**

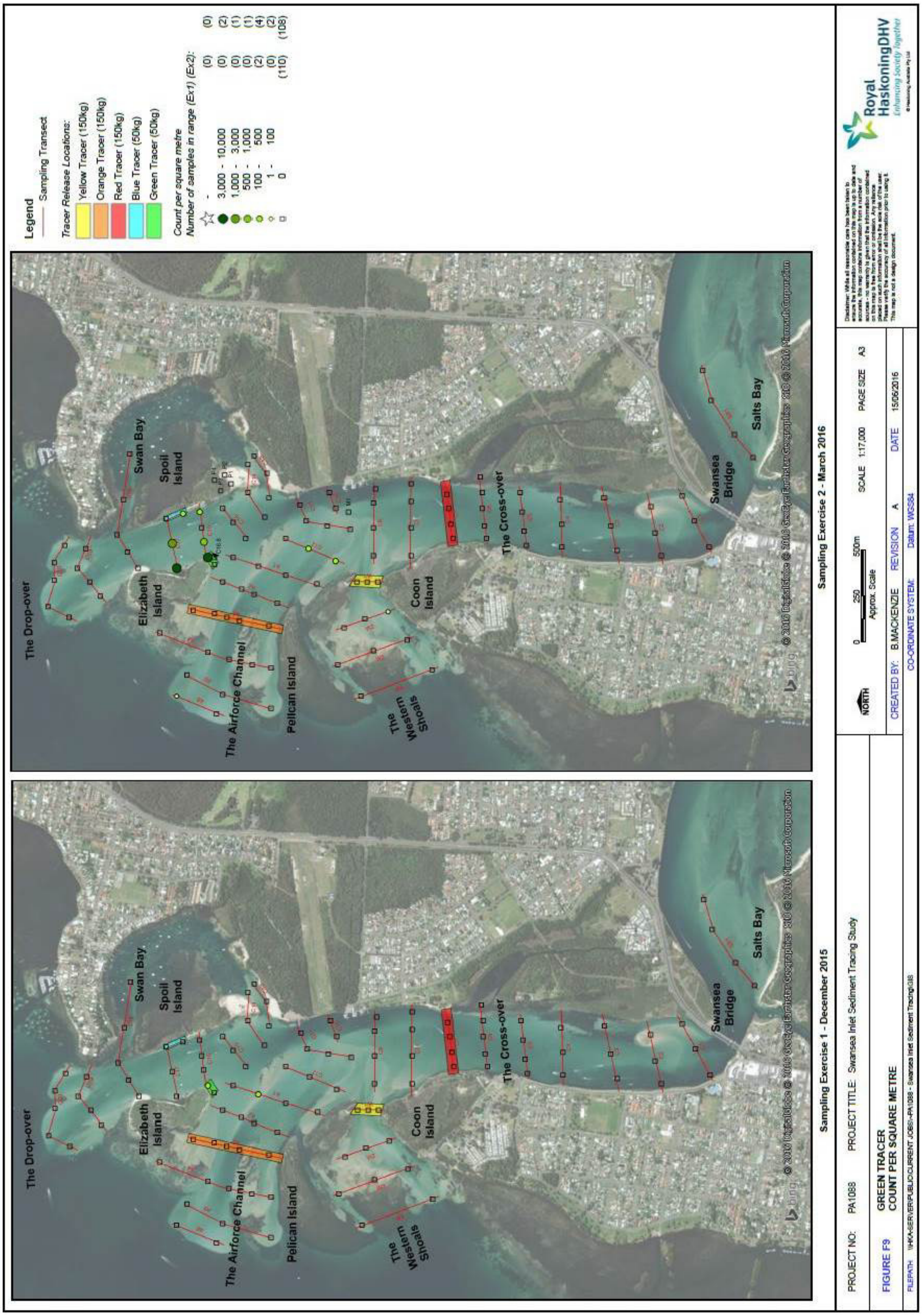


**Figure 7: Green tracer results - counts per square metre**

## Discussion on Sediment Transport Processes

### *Sampling Exercise 1*

The tracer results for Sampling Exercise 1 can be related to sediment transport processes that may occur in Swansea Channel during a typical tidal cycle (28 days), including:

- Deposition of material within the upper reaches of Swansea Channel appears to be primarily related to scour of the main channel. Sediment transport from the main channel near the Cross-over is flood tide dominated, with depositional areas including the following key regions:

    - shoals opposite the former Pelican Marina site;
    - shoals opposite the southern entrance to Swan Bay;
    - inside the southern entrance to Swan Bay;
    - shoals within the Airforce Channel;
    - adjacent to Elizabeth Island; and,
    - the outer extremities of the study area where Swansea Channel enters Lake Macquarie, including the drop-over and at the western end of the Airforce Channel.

- Ebb tide transport and deposition of sediment from the main channel is less significant than flood tide transport, however this transport was observed to extend over a distance of approximately 1.1 km to a location around 350 m upstream of Swansea Bridge. Transport of sediment from the main channel downstream of the bridge and into Salts Bay was not observed for the study period considered herein, however it is likely that this would become evident over slightly longer timescales.

- Relatively extensive transport and deposition of sediment within the Airforce Channel occurs in both upstream and downstream directions, with depositional areas including the following key regions:

    - shoals opposite the former Pelican Marina site;
    - the western end of the Airforce Channel where Swansea Channel enters Lake Macquarie
    - the western side of the channel near Spoil Island; and,
    - the eastern side of the channel between Elizabeth Island and the drop-over.

- Relatively limited transport of sediment from within the Western Shoals to other parts of Swansea Channel could be inferred from the Sampling Exercise 1 tracer results. Furthermore, there appeared to be slight flood tide dominated transport in the Western Shoals. This indicates that the Western Shoals are not a significant source of material contributing to growth of the problematic shoals opposite the former Pelican Marina site and the shoals near the southern entrance to Swan Bay.

- Negligible transport of material from the shorelines of Elizabeth Island and Spoil Island to other parts of Swansea Channel occurred during the one month period between tracer deployment and Sampling Exercise 1. This indicates that these locations were not active erosional areas over the timescale investigated.

- While fine-sized sediment was generally transported further distances than medium[1] sized sand, the medium sized sand experienced reasonably extensive transport over distances of up to around 2 km within the relatively short timeframe considered herein (one month).

***Sampling Exercise 2***

The tracer results for Sampling Exercise 2 can be related to sediment transport processes that may occur in Swansea Channel over the medium term (i.e. around four months).

In general, greater dispersion of each colour tracer occurred over time evidenced by the results of Sampling Exercises 1 and 2, as expected. In particular, the red tracer material dispersed throughout the entire upper channel, providing further evidence that scour of the main channel is the dominant source of material contributing to sedimentation further upstream.

Furthermore, the red tracer results confirm that sediment transport from the main channel in the area studied is flood tide dominated. This is likely to have led to some burial over time of the other four tracers due to deposition of sand scoured from the main channel.

The key depositional areas for material eroded from the main channel identified from the Sampling Exercise 1 results were also evident in the Sampling Exercise 2 results. In particular, relatively significant deposition occurred along the spur that runs along the north-eastern edge of the Airforce Channel, which indicates that this sand feature became more pronounced during the study period. This is consistent with the observed bathymetric change between October 2015 and June 2016.

Over the medium term, transport and deposition of sediment within the Airforce Channel appears to be predominantly confined to this channel only. However, the wider dispersion of orange tracer evident in the Sampling Exercise 1 results suggests that material from the Airforce Channel is transported throughout the upper channel. Therefore, it is likely that the ongoing upstream deposition of material eroded from the main channel resulted in burial of orange tracer material initially transported to these wider areas.

Sediment transport within the Airforce Channel occurs in both upstream and downstream directions, although there is stronger evidence of downstream (ebb tide driven) transport compared to upstream (flood tide driven). This may be related to increased runoff associated with the significant rainfall in January 2016, which would have resulted in increased ebb tide discharges through this channel and a greater potential for ebb tide driven sediment transport. Notably, the downstream transport extends to the shoals opposite the former Pelican Marina site.

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As per the Sampling Exercise 1 observations, relatively limited transport of sediment from within the Western Shoals to other parts of Swansea Channel could be inferred from the

*Sampling Exercise 2 Results*

Again, there appeared to be slight flood tide dominated transport in the Western Shoals, although the presence of yellow tracer in other areas of the upper channel indicates that some ebb tide driven transport occurs from this region. Nevertheless, it appears that the Western Shoals are not a significant source of material contributing to growth of the problematic shoals opposite the former Pelican Marina site and the shoals near the southern entrance to Swan Bay.

While greater dispersion of the green tracer was evident in the Sampling Exercise 2 results (compared to Sampling Exercise 1), this transport was generally limited to within approximately 300 m of the release site. Similarly, very limited dispersion of the blue tracer was observed to occur. These results provide further evidence that the foreshores of Elizabeth Island and Spoil Island were not active erosional areas during the study period.

Transport of the coarser size fractions was generally limited to near the respective release sites, with the exception of the red tracer which was recorded throughout the Airforce Channel and also through the main channel extending upstream to the drop-over. This indicates that the strong and turbulent flows through the main channel are capable of transporting coarse sand fractions significant distances upstream. The finer size fractions placed at each release site were observed to be transported throughout the entire upper channel where tracer material was recorded.

## Linkages with Hydrodynamic Model Outputs

The WorleyParsons (2010) hydrodynamics numerical model of Lake Macquarie and Swansea Channel was updated as part of the sand tracing study. The model was successfully calibrated and run for the study period reported herein (November 2015 to March 2016) to inform assessment of the tracer results.

It should be noted that the model was updated for hydrodynamics only, enabling linkages to be derived between sediment transport and the modelled current and discharge data.

Key observations from the hydrodynamic model results which may influence sediment transport processes in the upper channel included:

- Tidal velocity asymmetry occurs throughout the upper channel, with peak flood currents exceeding peak ebb tide currents. Furthermore, the critical velocity for initiating sediment transport is exceeded to a greater degree (in terms of both magnitude and duration) for flood tide conditions compared with ebb tide conditions. These results provide strong evidence of flood tide dominated sediment transport, which is generally consistent with the tracer results, particularly the red tracer material deployed in the main channel.

- Discharges through the Western Shoals are very minor in comparison to the Airforce Channel and the main north-south channel, while current speeds are also lower. As such, the sediment transport potential through this region is likely to be relatively minor compared to other parts of the channel. This is consistent with the relatively limited transport of yellow tracer from within the Western Shoals to other parts of Swansea Channel.

- Discharges through the main north-south channel are strongly flood tide dominated, while the analysis of current speeds also indicated that sediment transport through this channel is strongly flood tide dominated. This is particularly evident at the drop-over where it is only flood tidal currents that are strong enough to initiate sediment transport. This is the likely mechanism for the lakeward growth of these shoals, which was supported by ongoing deposition of tracer material in this area during the study period.

- Net discharge through the Airforce Channel shows ebb tide dominance, while the analysis of current speeds indicated that sediment transport through this channel is likely flood tide dominated. Nevertheless, it is clear that the Airforce Channel is an important pathway for directing ebb tide flows into Swansea Channel, and sediment transport would occur in both directions across this relatively shallow region. This is apparent in the tracer results, particularly for the orange and red tracers which dispersed across the entire length of the Airforce Channel.

- Peak current speeds on both the eastern foreshore of Elizabeth Island and the western foreshore of Spoil Island are relatively low, with higher velocities occurring through the channel proper. This provides further evidence of the relative stability of these areas which are not considered to be active erosional areas. This was consistent with the observation of relatively limited transport for the green and blue tracer materials.

## Key Observations

Sediment transport processes experienced in Swansea Channel during the study period have been inferred from the tracer results, the hydrodynamic modelling, and comparison of bathymetric surveys undertaken in October 2015 and June 2016. A conceptual description of the key sediment transport processes identified from the study is presented in **Figure8** below and is summarised as follows:

- Significant ongoing scour of the main channel is the primary cause of sedimentation in the upper channel. This was evidenced by the very wide dispersal of red tracer material, which is likely to have led to some burial over time of the other four tracers due to deposition of sand scoured from the main channel

- Based on the above, it is evident that sediment transport from the main channel is flood tide driven. This process occurs largely as a result of the tidal velocity asymmetry, with higher flood tide currents likely dominating sediment transport fluxes.

- Furthermore, given that water levels and tidal currents are in phase in the channel, peak flood currents act over a larger cross-sectional channel area compared with ebb tides. This includes active shoal areas that are typically exposed around low tide. This means that flood flows generally dominate the shoal areas.

- North of the former Pelican Marina site, there is a natural tendency for the development of an east-west braided channel resulting in a more defined (deeper) Airforce Channel over time. In particular, this was demonstrated by:

  - bathymetric change during the study period, including deepening of the Airforce Channel and concurrent growth of the sand spur that runs along the north-eastern edge of the Airforce Channel; and,
  - deposition of the red and orange tracer throughout the Airforce Channel, particularly on the spurs/shoals running along either side of the channel.

- Similarly, there is a natural tendency for the main channel to deflect to the west at Naru Point as part of this braided channel. The diversion of flood tide flow into the southern entrance to Swan Bay results in accretion of sand just outside the entrance at Naru Point as flow velocities slow down. This accretion was particularly evident in the bathymetric data, although this was not clearly demonstrated in the tracer results, possibly due to burial of tracer during the study period. It is noted that this accretion process would reinforce development of an east-west channel.

- Flow discharge through the Airforce Channel is ebb tide dominated, and this would be accentuated in response to significant rainfall and flooding of Lake Macquarie. While net sediment transport in this channel is inferred by modelling to be flood tide dominated (as per the entire upper estuary), there is a high potential for significant ebb tide driven transport in this relatively shallow channel. As described above for flow discharge, the ebb tide sediment transport potential may be similarly accentuated during major rainfall events reversing the inferred flood tide dominated net sediment transport regime. This was evident in the results for the orange and red tracer, which dispersed across the entire length of the Airforce Channel.

- Furthermore, the orange tracer results indicated that ebb tide discharges (accentuated by catchment flows on an event basis) through the Airforce Channel contribute to the growth of the problematic shoals located opposite the former Pelican Marina site. Sedimentation on these shoals may also occur during flood tides with deposition of material scoured from the main channel.

- Sand scoured from the main channel appears to be the primary source of material resulting in the observed growth of the problematic shoals located opposite the southern entrance to Swan Bay.

- Flood tide dominated discharges and sediment transport occur in the main north-south channel (i.e. north of the southern entrance to Swan Bay). However, the development of intermittent shoals along this section of the channel during the study period, as evidenced in the bathymetric data and also deposition of red tracer material, suggests that this section of the channel was not self-scouring and is therefore becoming less defined.  Notable areas of shoaling included the area opposite the northern entrance to Swan Bay and on the outer edge of the drop-over.

- Discharges through the Western Shoals are very minor in comparison to the Airforce Channel and the main north-south channel, while current speeds are also lower.  As such, the sediment transport potential through this region is likely to be relatively minor, as demonstrated by the yellow tracer results.

- The relatively limited transport of the green and blue tracer materials suggests that the eastern foreshore of Elizabeth Island and the western foreshore of Spoil Island are not active erosional areas.  In particular, the eastern foreshore of Elizabeth Island is a key depositional area in the upper channel.

- The strong and turbulent flows through the main channel are capable of transporting coarse sand fractions significant distances upstream, as demonstrated by the wide dispersal of the large sized red tracer particles.  The finer size fractions placed at each release site were observed to be transported throughout the entire upper channel where tracer material was recorded.

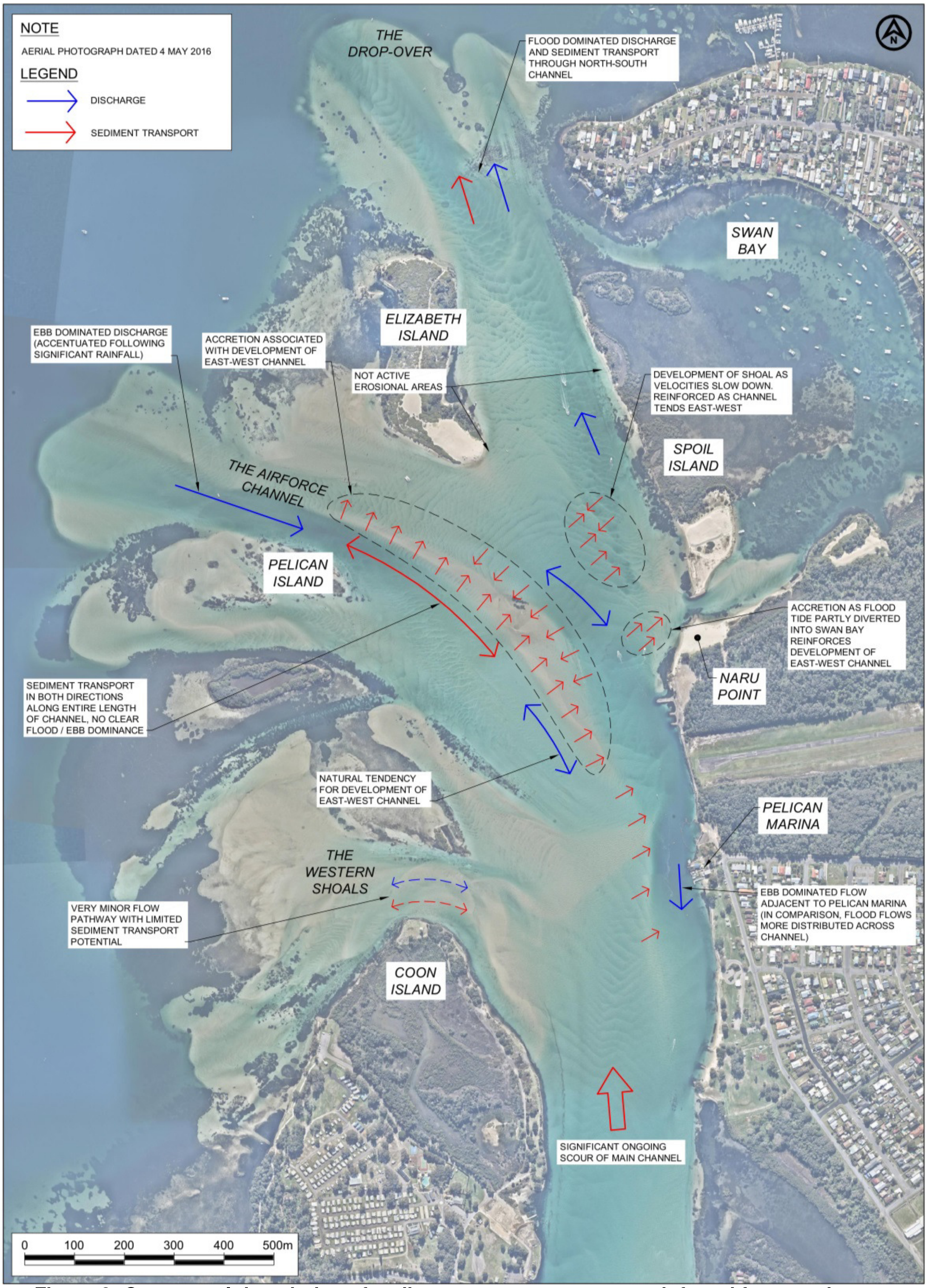


**Figure 8: Conceptual description of sediment transport processes inferred from study findings**

## Conclusion

These observations may have implications for future dredging activities in Swansea Channel. Detailed physical and/or numerical modelling investigations would be required to investigate these and other options in greater detail. In this regard, it should be noted that the tracer results could be used to verify a numerical sediment transport model of the site. A dedicated sediment transport model coupled with the hydrodynamic model to locate and verify sediment transport hotspots. An improved understanding of the sediment transport will allow the issues at the site to be managed more effectively. In the short-term results from the study will be used inform and optimize future dredging campaigns.

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