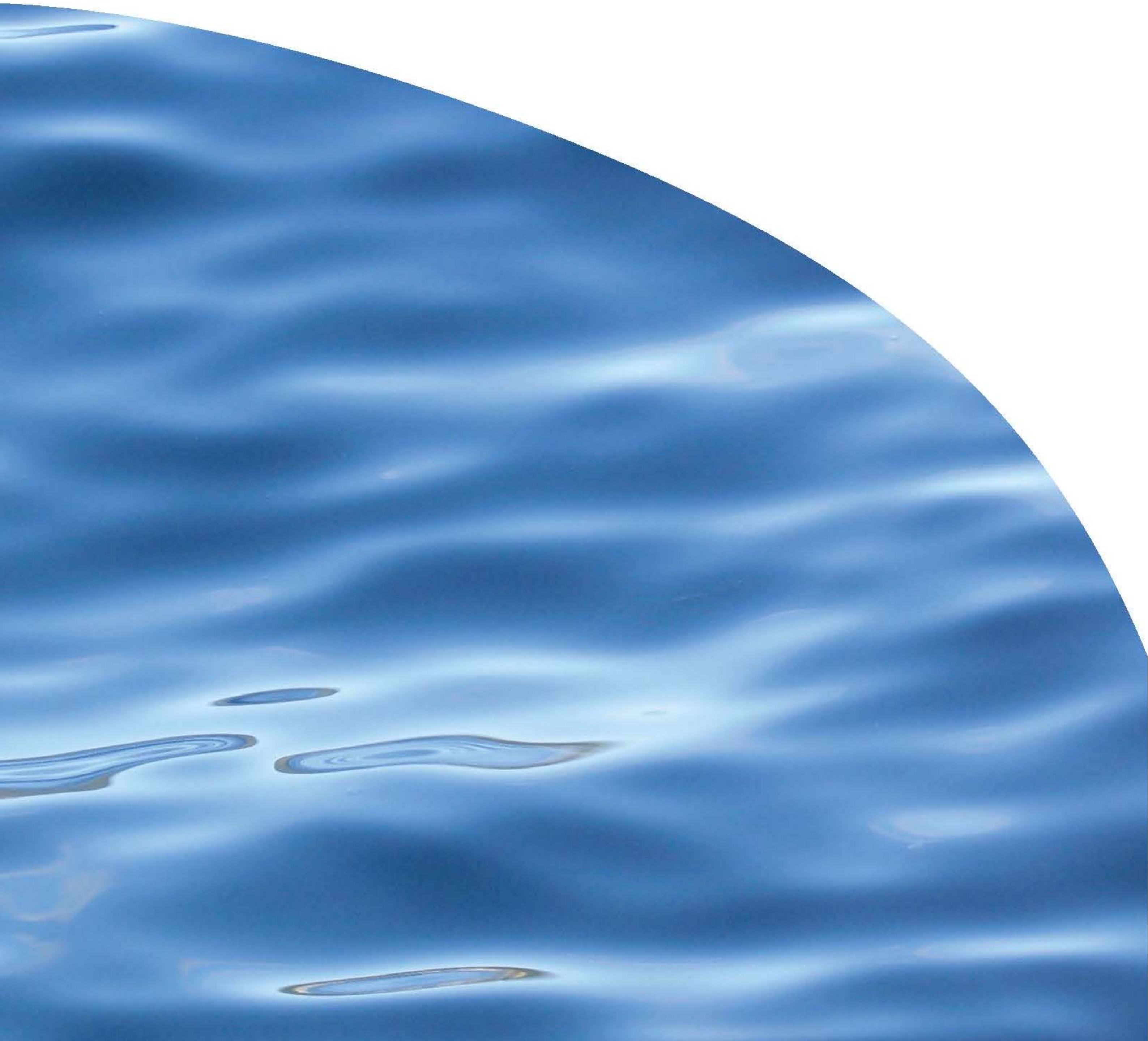
CAWTHRON
INSTITUTE

REPORT NO. 2015: ADDENDUM

EFFECTS ON WATER CLARITY IN TE AWAPARAHI BAY FROM RECLAMATION ACTIVITIES



EFFECTS ON WATER CLARITY IN TE AWAPARAHI BAY FROM RECLAMATION ACTIVITIES

ROSS SNEDDON

Prepared for Lyttelton Port of Christchurch Ltd

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Paul Barter

APPROVED FOR RELEASE BY:
Rowan Strickland

ISSUE DATE: 18 January 2012

RECOMMENDED CITATION: Sneddon R. 2015. Effects on Water Clarity in Te Awaparahi Bay from Reclamation Activities. Prepared for Lyttelton Port of Christchurch. Cawthron Report No. 2015: Addendum. 15 p.

1. INTRODUCTION

1.1. Background

Lyttelton Port of Christchurch Ltd (LPC) has approval, under Canterbury Earthquake (Resource Management Act Port of Lyttelton Recovery) Order 211, to use clean earthquake rubble from the city of Christchurch as fill material to build a 10 ha reclamation in Te Awaparahi Bay adjacent to its operations at Cashin Quay. Placement of this material within the sub-tidal zone adjacent to the shore has been occurring since April 2011, with this activity effectively becoming a continuous operation since 7 June. As a result of concerns regarding potential contamination of harbour waters from this material, Cawthron Institute (Cawthron) was contracted to implement a sampling survey and assessment of water, sediment and shellfish from points within and offshore from Te Awaparahi Bay during reclamation construction activities. The survey was carried out on 24 August 2011 over a high tide and the results of analyses for contaminants in water, sediment and shellfish samples were presented and interpreted in Cawthron Report 2015 (Sneddon 2011).

This addendum to Report N0. 2015 presents and interprets the results of the monitoring of parameters related to water clarity and suspended solids load.

1.2. Scope and limitations

Over the course of the 24 August 2011 survey, from 9:30 to 15:20 NZST, simultaneous readings of transmissivity and Optical Back-Scatterance (OBS) turbidity were continuously recorded as the survey vessel moved through the near-shore and offshore waters of Te Awaparahi Bay. This allowed the tracking of turbidity plumes propagating from the construction activity and evaluation of their relative strength and effect on water clarity. GPS tracking drifters were also deployed throughout the survey to indicate near-shore water movements within the bay over the changing tidal state. As was the case for water and sediment sampling, the work area was limited to outside the floating containment boom placed to prevent the escape of floating debris.

Since the placement of reclamation fill material will occur over a significant time period, consideration of the survey data carries the implicit assumption that the day of sampling was reasonably typical in terms of the nature of the fill material deposited and the level of construction activity.

2. METHODS

The fieldwork was carried out on Wednesday 24 August 2011 between 09:30 and 15:30 NZST. High tide occurred at 12:08 and was 2.1 m relative to chart datum. The monitoring work was undertaken from the University of Canterbury research vessel, *Rapaki*.

2.1. Near-shore current circulation

In order to gain an indication of water movement within Te Awaparahi Bay and to better track any sediment plumes associated with reclamation activities, GPS tracking drifters were periodically released at points near the containment boom.

A drifter (also called a drogue) is a device which drifts with water currents without being significantly influenced by surface winds. For this study, drogues of the 'holey-sock' type were used, consisting of a 425 mm cylindrical polyethylene tube reinforced with spiral steel rings. This cylinder had six to eight 80 mm diameter holes cut in the sides and was designed to hang at a discrete depth (in this case approximately 800 mm) beneath a low-profile float made from closed-cell foam to which it was attached by a short bridle. The floats were recessed to hold a Garmin® Foretrex 101 GPS which was set to continuously log its position at a 15 second time interval. After completion of the survey, the tracks could be plotted using GIS software.

2.2. Transmissivity (clarity) measurement

Water clarity within Te Awaparahi Bay and offshore were monitored continuously from the survey vessel using a 25 cm path length WetLabs C-Star^{TM} transmissometer (green 530 nm). This was deployed over the side of the vessel at a fixed depth of approximately 1 m while moving at idle speed throughout the survey area. Transmissivity data were collected in real-time at three second intervals and merged with vessel position using a GPS-linked data-logging system. To aid navigation, these data were simultaneously displayed on a monitor using ArcMap© GIS software.

Transmissivity gives a measurement (% transmittance) directly analogous to water clarity, so a record can be compiled which is immediately interpretable with respect to a quantifiable reduction in clarity.

2.3. Turbidity measurement

A logging Seapoint Optical Back-Scatterance (OBS) turbidimeter was mounted adjacent to the transmissometer to compile a simultaneous record of water turbidity along the track of the survey vessel. This was set to internally log turbidity (in Formazin Turbidity Units (FTU)), along with the vessel's GPS position, at two second intervals.

2.4. Suspended solids

Over the course of the five hours of the survey, nine discrete seawater samples were collected at various points offshore in Te Awaparahi Bay from approximately 0.5-1 m below water surface level. Locations for most of the samples were at points close to the floating boom (see Figure 1, Report 2015). However, two control samples were also collected at up-current locations further offshore. Sample timing was mostly predicated by changes in water turbidity (as measured by continuous logging equipment on the survey vessel) to ensure that the sample was influenced by sediment plumes generated by the placement of earthquake rubble.

As the samples were collected, field readings of nephelomentric (90° scatterance) turbidity were taken (Hach 2100 field turbidimeter) in addition to continuous recording of transmissivity and Optical Back-Scatterance (OBS) turbidity. The samples were kept on ice for transport back to the laboratory for the analysis of Total Suspended Solids (TSS) and nephelometric turbidity, as well as other water quality parameters.

3. RESULTS AND DISCUSSION

Due to the dynamic nature of conditions within Te Awaparahi Bay, principally due to the changing tidal state over the course of the survey, the collected data must be interpreted as discrete time intervals for which a degree of consistency in water movement and construction activity can be assumed. One hour was considered appropriate for this interval, giving five sets of conditions over the survey's duration.

The transmissivity data for each of the five intervals is shown spatially in Figures 1 to 5. Graduated size and colour coding of symbols has been arranged to emphasise areas of lower transmissivity, corresponding to water with higher turbidity. However, consistent preset ranges for the five transmissivity symbols have not been applied for the five plots. The principal reason for this was that background harbour water clarity was changing with tidal state throughout the survey period and variable ranges allow the plots to show more clearly where turbidity plumes were propagating and their intensity relative to background.

The tracks of the deployed logging drifters were used to interpret water movements within the bay. These indicated the presence of a circulating gyre which changed rotation with the tidal direction and effectively occupied the entire bay during full ebb and flood flows (Figures 1 and 5). The inferred propagation of turbidity plumes within the bay was also generally consistent with this water circulation regime. The interpretation of conditions giving rise to the results of each plot is presented in the caption to each figure.

It was noted during the survey that construction activity was sporadic before 11:30 NZST and distinct sediment plumes were not visible before mid-day; however, changes in transmissivity (relative to background) were detected near the containment boom and the eastern and western shorelines of the bay (Figures 1 and 2). Visible plumes were observed after 13:00 NZST, especially those associated with the edge tipping of brick rubble by bulldozer, but these were generally only conspicuous from sea level within the bay itself.

It appeared that the operation of the Te Awaparahi Bay gyre served to significantly limit the propagation of turbidity plumes out of the bay by internally recirculating water with high suspended solids and potentially resulting in significant redeposition within the bay. This is supported by the observation that water entering the bay along the northern shoreline in Figure 5 appears little affected by the turbidity plume circulating out of the bay at its southern end. Current velocity in the offshore edge of the gyre in Figure 5 was calculated from drifter speed at 0.2 m/s.

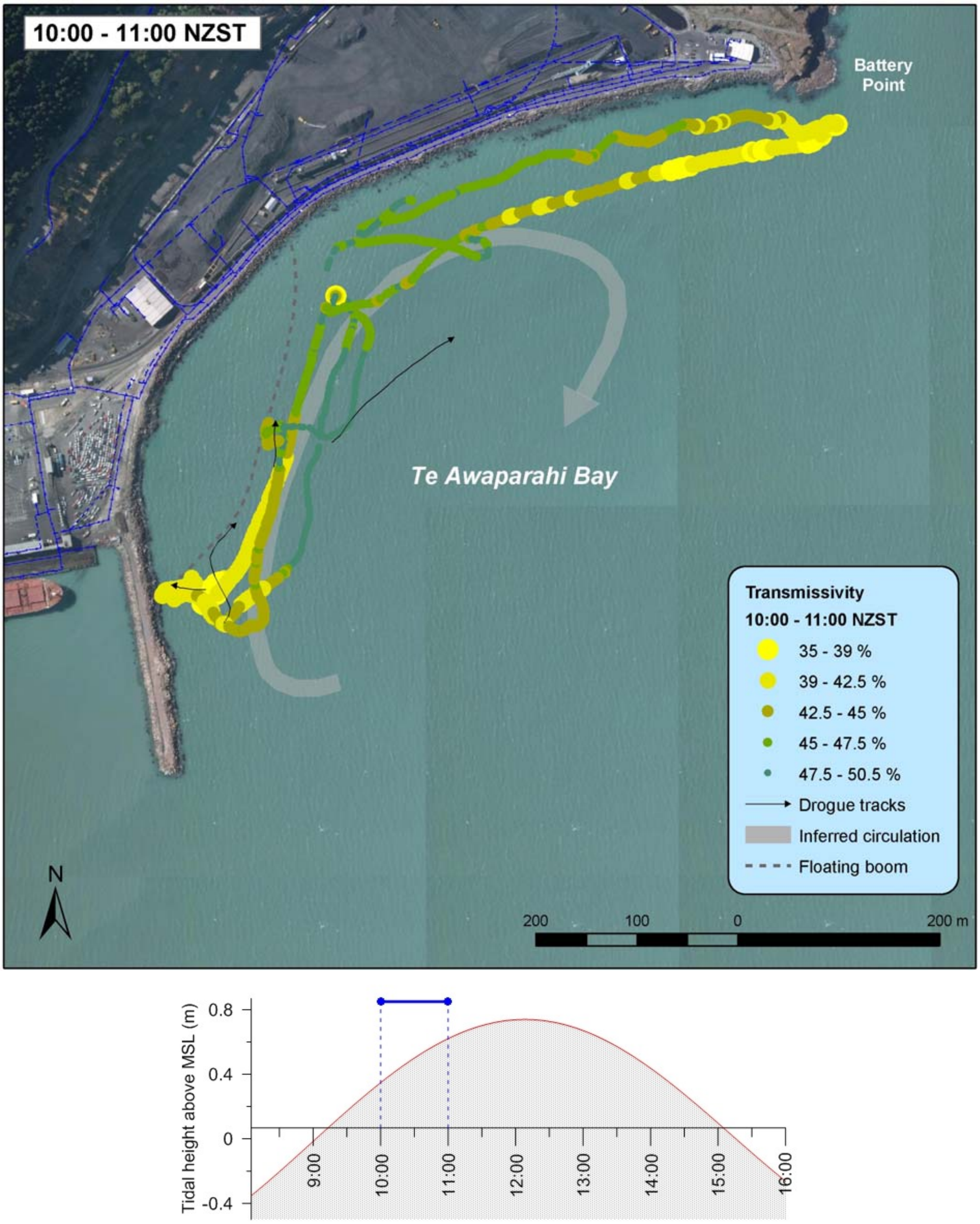


Figure 1 Tide incoming. Fully developed clockwise gyre in Te Awaparahi Bay. Water of lower clarity near Battery Point and Cashin Quay breakwater is not particularly turbid (minimum 35% transmissivity) and likely to be associated with current and surge resuspension of near-shore benthic sediments rather than reclamation activities.

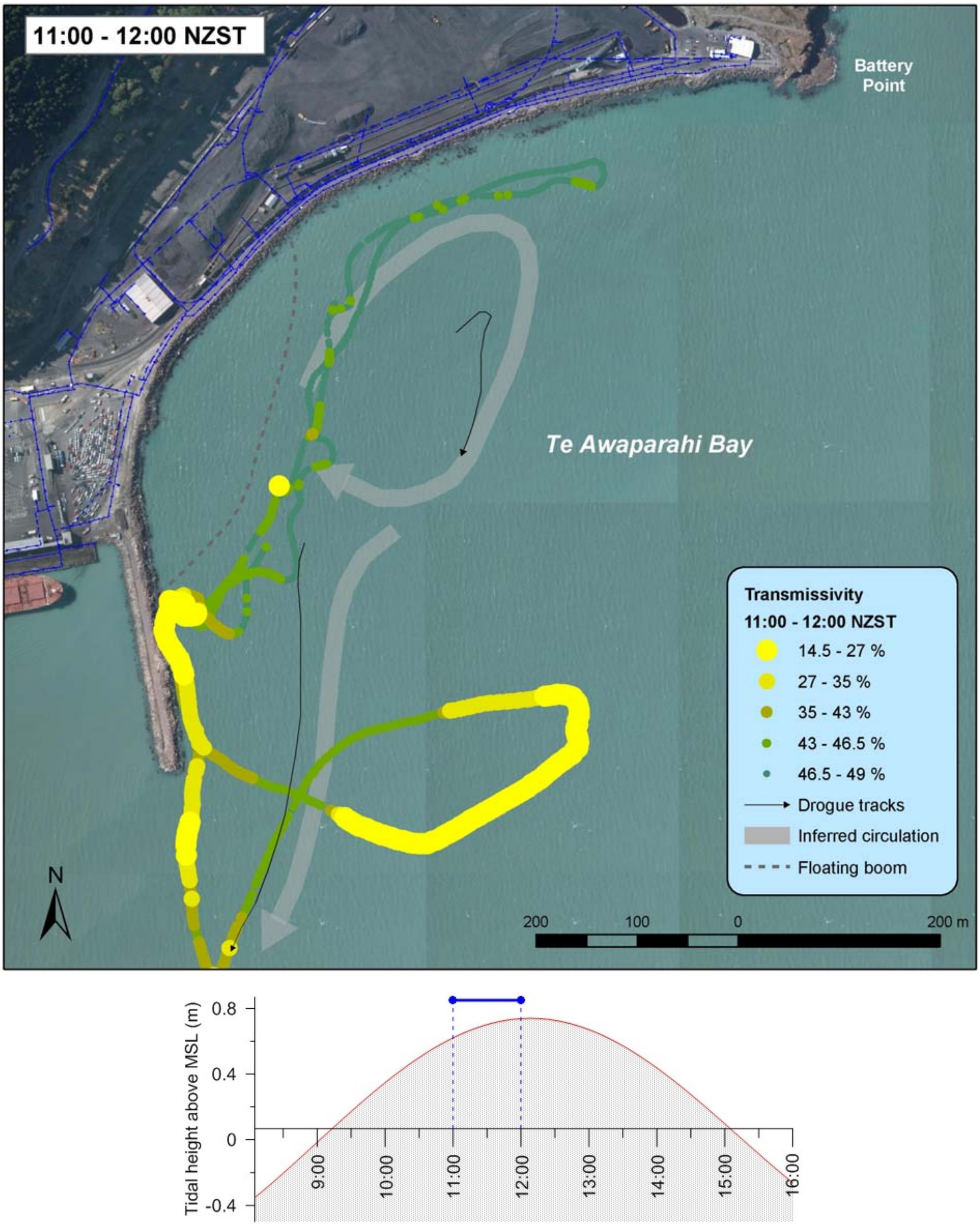


Figure 2 Last hour of incoming tide. The clockwise gyre had weakened and contracted in size. The patch of water of lower clarity offshore from Cashin Quay breakwater (transmissivity 20-27%) did not appear to have propagated from activities within Te Awaparahi Bay. However, low clarity near the floating boom and along the breakwater (min 14.5% transmissivity) was affected by construction plumes.

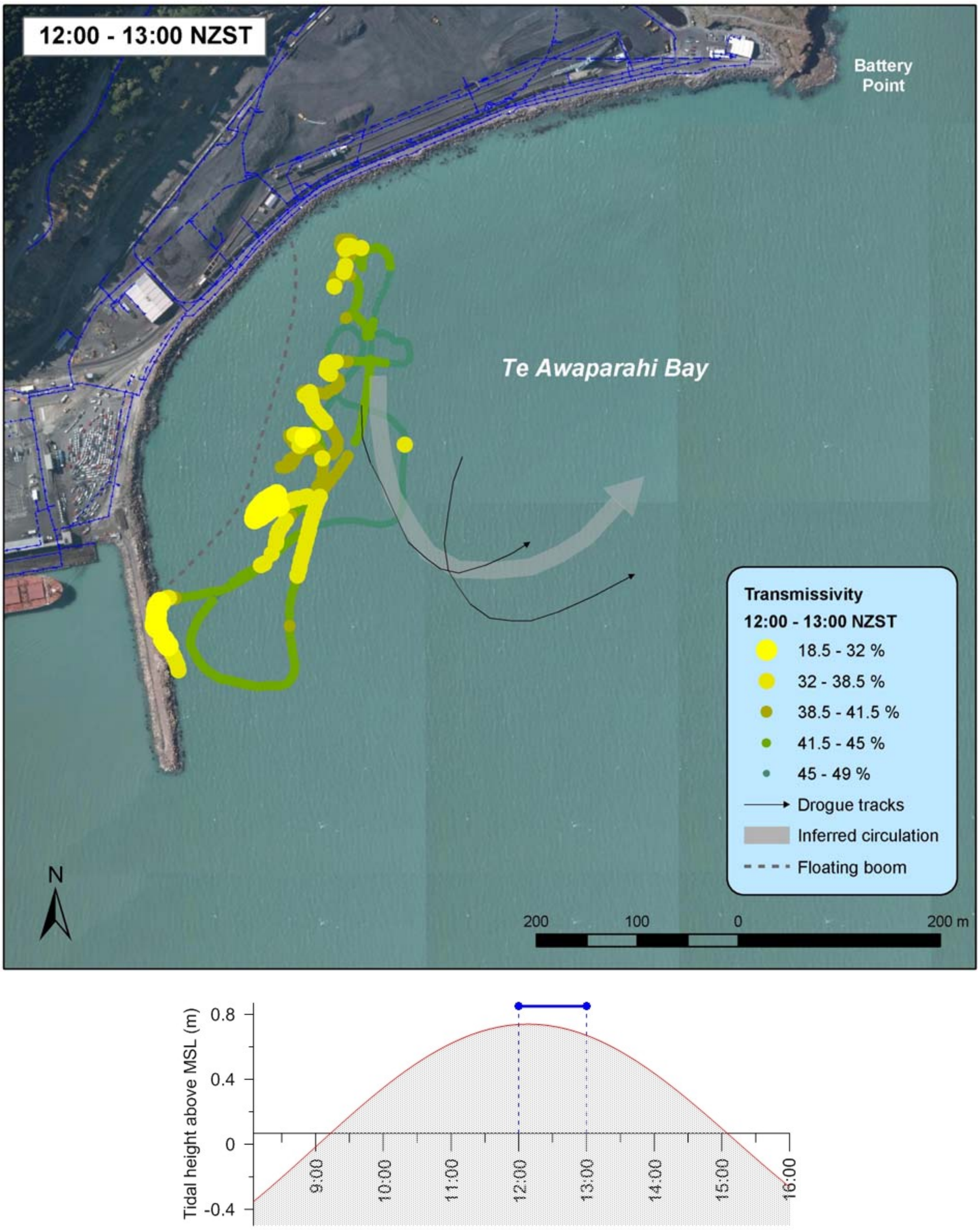


Figure 3 Turn of the tide at 12:08. The Te Awaparahi Bay gyre was no longer operating and the drogue tracks reflect a change in direction of the generalised water movement in the harbour. At this time, the placement of rubble within the bay by crane was proceeding without pause after an earlier delay. A resultant turbidity plume was consistent along the outside of the boom but the transmissivity record showed that this did not extend far out into the bay.

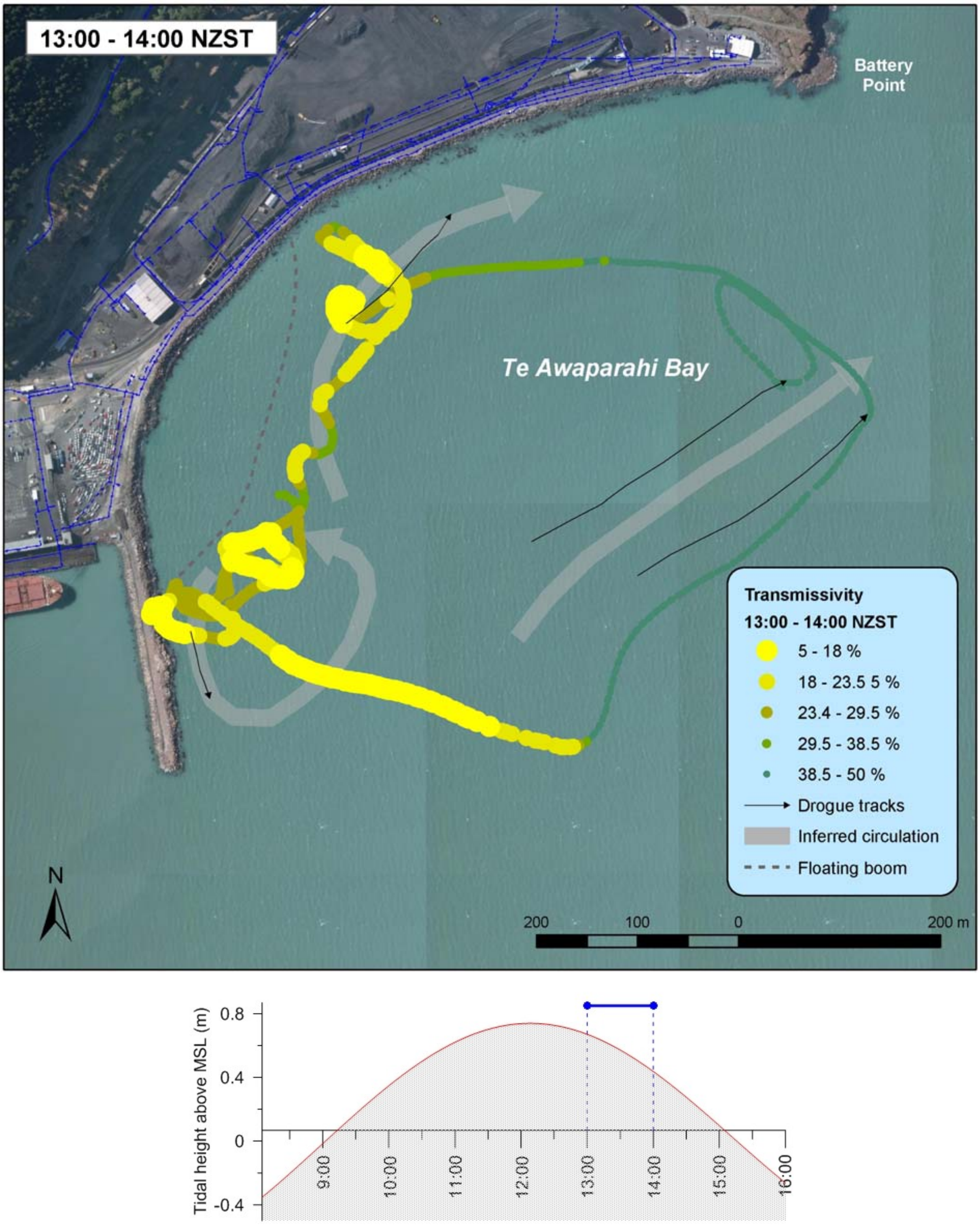
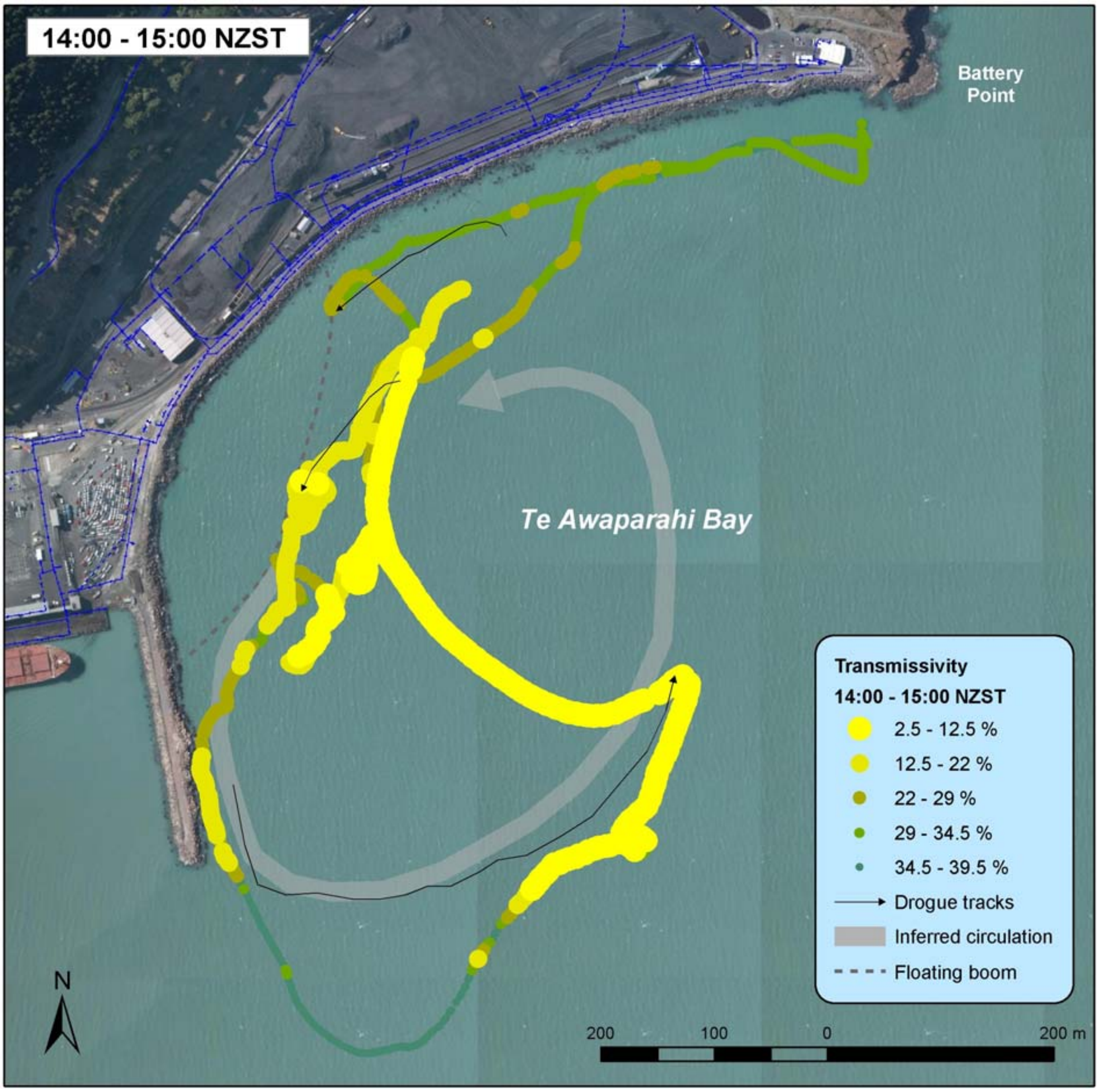


Figure 4 The ebb flow gains momentum. A small anti-clockwise gyre had begun in the lee of the Cashin Quay breakwater, resulting in the propagation of a construction turbidity plume from the southern end of Te Awaparahi Bay out into Lyttelton Harbour. South-east of the breakwater, this became entrained within the main ebb flow. Edge tipping of brick rubble by bulldozer had commenced at 13:00, producing a visible increase in turbidity within the boomed area. Inshore turbidity along the outside of the boom had intensified, with plumes in the range 5-18% transmittance. The absence of a vessel track close to the northern shore means that propagation of the plume along this shoreline has not been detected.



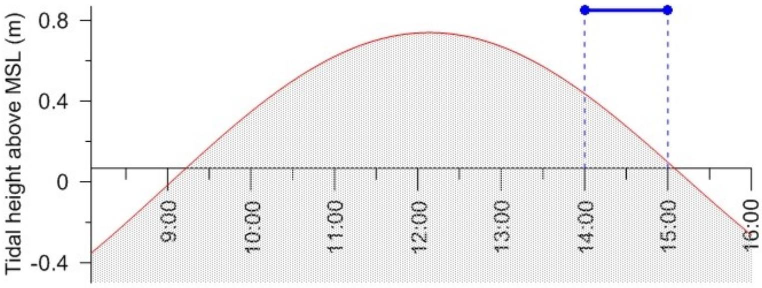


Figure 5 Full ebb flow established with an anti-clockwise gyre occupying the whole of Te Awaparahi Bay. Areas of high turbidity (2.5-12.5% transmittance) associated with reclamation activities were essentially contained within the gyre with only limited propagation into the main tidal flow. With the gyre filling the entire bay, the northern shoreline is relatively unaffected by suspended sediment. Note that background clarity of the Lyttelton Harbour water has decreased to 35-40% transmittance with the outgoing tide compared to 45-50% on the incoming tide (10:00-12:00 NZST, Figures 1 and 2).

Field observations of reclamation activity suggested that a significant proportion of the suspended sediment contributing to visible turbidity plumes came from disturbance of the seabed by deposited rubble rather than from entrained fine sediment within the rubble itself. The benthic sediments of the bay are predominantly fine, with the silt and clay fraction being generally greater than 50%, and as high as 99% in areas more than 150 m offshore (Sneddon & Barter 2009).

The range of turbidity, suspended solids and clarity measures carried out for water samples collected during the survey is presented in Table 1. Locations for these samples and timing relative to tidal state are presented in Figures 1 and 2, respectively, of Cawthron report 2015 (Sneddon 2011). Due to the relatively 'noisy' OBS turbidity data, the values listed in Table 1 were generated as averages of measurements taken at sample collection ± 15 seconds. It should be noted also that OBS turbidity and transmissivity readings, while being coincident with sampling, were not measurements made of the water samples themselves.

Table 1 Water quality parameters associated with clarity for the nine samples collected during the survey. All were measured within the water sample itself except for OBS turbidity and transmissivity, which are derived from readings taken simultaneously with sample collection. Control samples, collected away from the influence of reclamation activities, are shaded green.

Water sample	**Time** (NZST)	**TSS** (Lab)	**Turbidity** (Lab)	**Turbidity** (Field)	**OBS Turbidity** (Field)	**Xmiss*** (Field)
Units		mg/L	NTU	NTU	FTU	%
WQU01	10:49	10	2.1	-	36	48
WQU02	11:32	18	7.9	7.6	70	20
WQU03 (Cntl1)	11:44	16	9.7	8.9	52	25
WQU04	13:34	20	10	11.2	80	19
WQU05	13:47	31	22	16.5	73	17
WQU06	14:04	31	16	15.5	97	9
WQU07	14:09	37	22	21.3	82	6.5
WQU08 (Cntl2)	14:51	8	3.4	5.1	49	39
WQU09	15:05	25	13	12.7	88	16.5

* Transmissivity.

Comparison of the continuously recorded transmissivity and (OBS) turbidity data showed good agreement in terms of sensitivity to changes in water clarity within the bay, however, as noted above, the transmissivity record produced a cleaner plot with less noise (Figure 6).

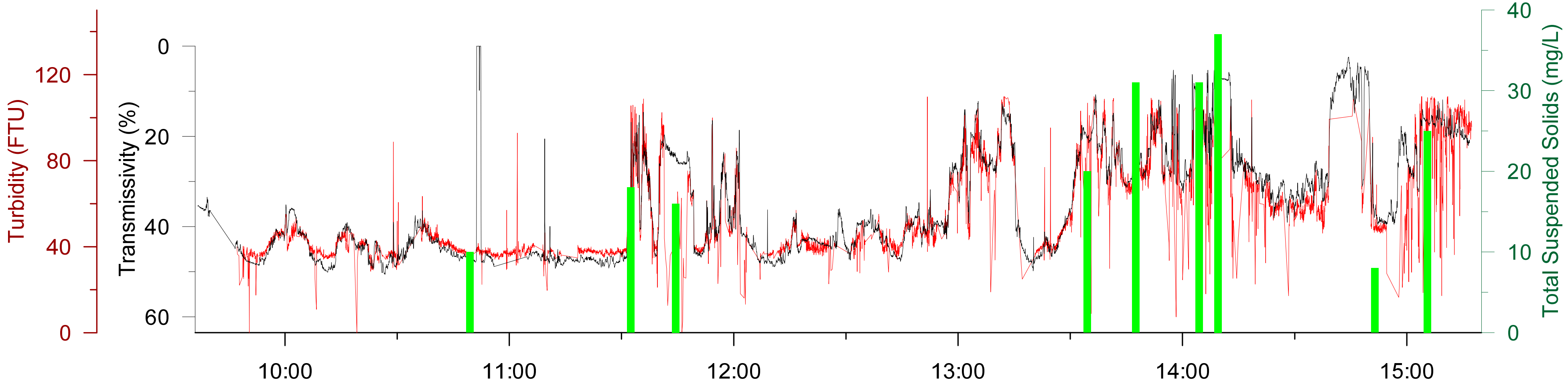


Figure 6 Timeline of the water clarity (turbidity and transmissivity) record as measured by the survey vessel throughout the monitoring period, showing the total suspended solids (TSS) concentrations of water samples taken at various points (green bars). The axes have been scaled to superimpose the simultaneously recorded OBS turbidity (red) and transmissivity (black) plots. Over this period, the vessel was moving in and out of Te Awaparahi Bay and through both background- and reclamation-associated turbidity plumes (see tracks, Figs 1-5). Placement of rubble in bay waters was sporadic before 11:30 NZST and construction-related plumes were not distinct before this time. There is some indication of a change in background clarity of Lyttelton Harbour waters occurring after 13:30 NZST believed to result from the ebb flow from the upper harbour (see also Figure 5).

Turbidity is a measure of the optical properties of a water body; specifically the scattering of light caused by particulate matter suspended in the water column. As such, values can vary significantly with the measurement method used. Turbidity measured as Nephelometric Turbidity Units (NTU) specifically calls for measurement of scattering at 90° to the incident light whereas that expressed in FTU is typically non-descriptive of measurement angle and can be made at any angle of detection; however, calibration to formazin standards is common to both. Turbidity measured as Optical Back-Scatterance (OBS) is measured at 180° to the incident light. Because of the sensitivity and particle selectivity aspect of different scatter angles and the unique design of various individual turbidity instruments, correlations between instruments of different measuring techniques, or different manufacturers, are difficult and often impossible.

Due to the nature of turbidity measurement, it is difficult to assess levels measured over the course of the survey in the context of sparse historical records. However, Lyttelton Harbour is an area of frequently elevated turbidity. Fine benthic sediments, which are easily resuspended by disturbance and natural wave shear, result in the occurrence of sometimes very high benthic turbidity. Nephelometric turbidity exceeding 30 NTU is likely in the surface waters of Lyttelton harbour during run-off and wave-resuspension events. Similarly, background levels of TSS levels exceeding 50 mg/L would also be expected of such events, especially for near-shore areas and more generally in the upper harbour.

3.1. Implications of survey results for monitoring of turbidity effects

In terms of continuous monitoring of water column clarity, the logging of turbidity data is the simplest and most cost-effective approach. While a good correlation with suspended solids levels was displayed for nephelometric turbidity (Figure 7), the in-line arrangement of light source and detector in OBS measurement lends itself better to continuous *in situ* measurement for monitoring purposes. However, the data plotted in Figure 7 indicates a poorer correlation for the OBS readings[1]. Consequently, collection of OBS turbidity data via an instrument deployment in bay waters may have limitations in accurately reflecting the suspended solids load in turbidity plumes, especially as the source-specific nature of turbidity may render background plumes less than comparable. Interpretation of the data may also be difficult unless such instrumentation is replicated at a control location.

---

[1] The poorer correlation with OBS turbidity may also partly result from measurement of Te Awaparahi Bay waters *in situ* rather than being of the individual samples (though measurement was coincident with their collection). That is, it may arise from variation in turbidity at small spatial scales.

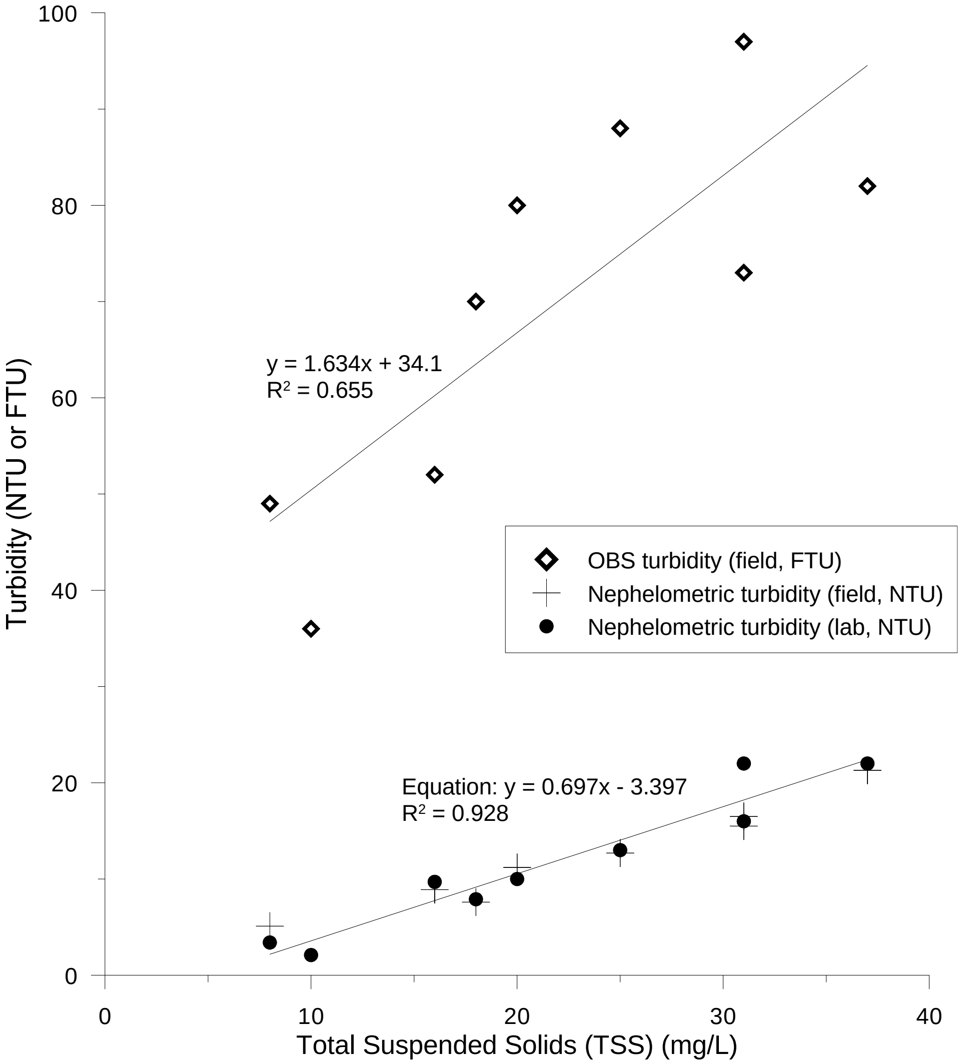


Figure 7 Total suspended solids (as analysed from discrete samples) matched to field and lab readings of nephelometric turbidity (90° scatterance) and to levels of Optical Back-scatterance (OBS) turbidity (units FTU) from continuous recording in Te Awaparahi Bay. The trend line for nephelometric turbidity is fitted to the laboratory results (*n* = 9).

4. SUMMARY AND CONCLUSIONS

The tracks of deployed logging drifters indicated the operation of a circulating gyre which changed rotation with the tidal direction and effectively occupied the entire bay during full ebb and flood flows. The inferred propagation of turbidity plumes within the bay was also generally consistent with this water circulation regime.

Suspended sediment contributing to plumes from reclamation activities are likely to derive mainly from resuspended seabed sediments with only a small proportion due to fine material entrained with the reclamation fill.

While turbidity plumes extending out into Lyttelton Harbour from Te Awaparahi Bay could be discerned visually on the ebb tide during the 24 August survey, these were not highly conspicuous from a sea-level perspective and were of a similar level to background variations in water colour. Hence it is unlikely that these would be considered conspicuous visual effects pursuant to Section 107 of the Resource Management Act. The tidal gyre operating within Te Awaparahi Bay appears to limit the propagation of construction-associated turbidity plumes out of the bay into the wider harbor area.

Overall, the levels of turbidity detected within Te Awaparahi Bay during reclamation activities did not appear to exceed those which may be expected from natural events such as storm run-off and wave resuspension. The sediment load carried by such plumes is expected to have a negligible effect upon sediment transport and deposition processes operating within Lyttelton Harbour. It is considered that any ecological effects resulting from construction turbidity plumes will be limited to Te Awaparahi Bay itself and immediately adjacent waters.

While it would be possible to monitor turbidity levels in waters adjacent to the reclamation activity over intermediate time-frames (*e.g.* months), such data would likely be limited in interpretability. On the basis of the current survey data indicating the generation and propagation of plumes of relatively low intensity, such a monitoring programme does not appear warranted.

5. REFERENCES

Sneddon R, Barter P. 2009. Assessment of benthic ecological and water quality effects for a proposed reclamation in Te Awaparahi Bay, Lyttelton. Prepared for Lyttelton Port of Christchurch Ltd. Cawthron Report 1509. 54p plus appendices.

Sneddon R 2011. Contaminant Monitoring for Reclamation Activities in Te Awaparahi Bay, Lyttelton Harbour. Prepared for Lyttelton Port of Christchurch. Cawthron Report No. 2015. 24 p plus appendices.