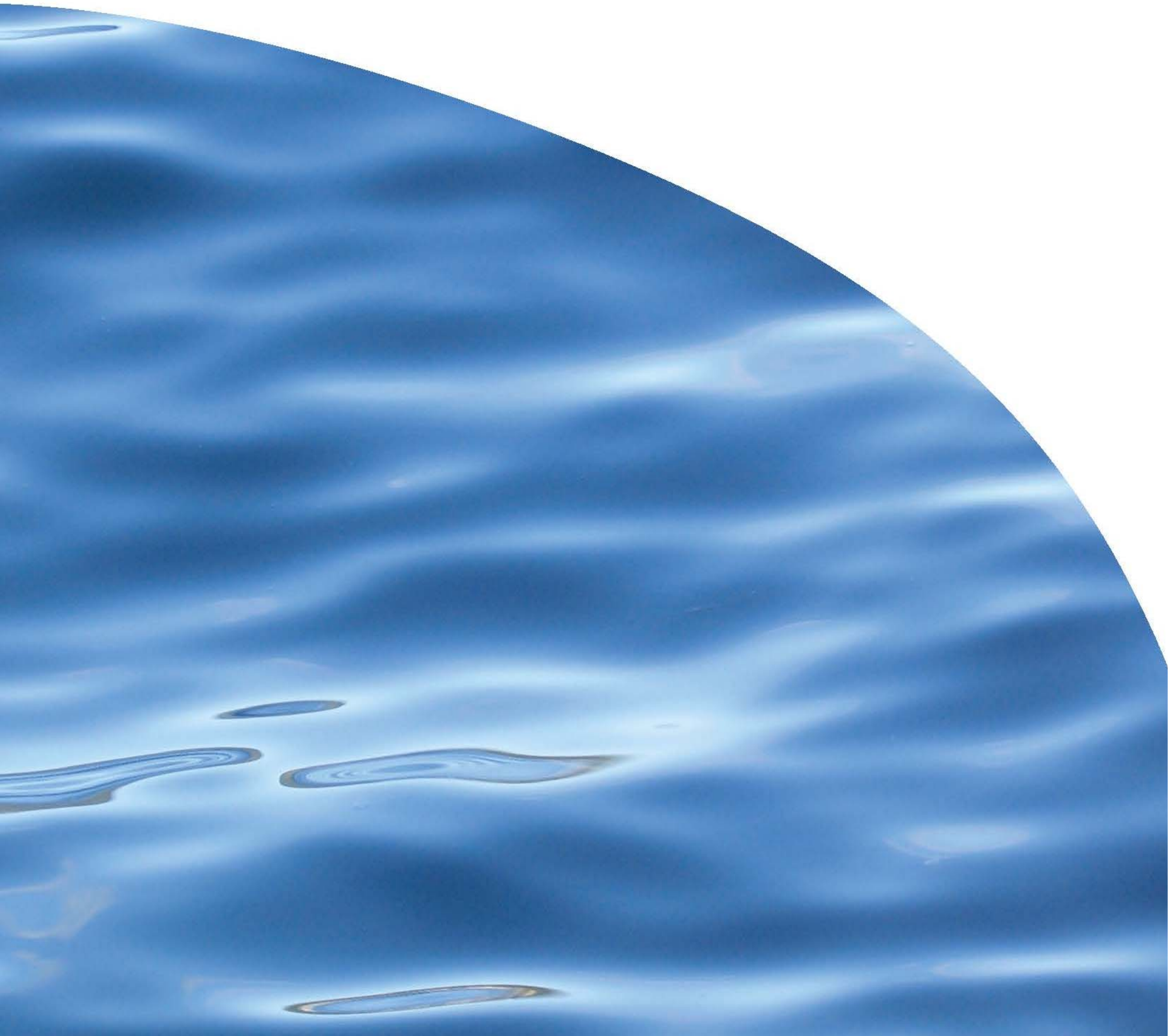
REPORT NO. 2693A

SUMMARY OF TURBIDITY DATA FOR OTAGO HARBOUR: ADDENDUM TO CAWTHRON REPORT NO. 2693



SUMMARY OF TURBIDITY DATA FOR OTAGO HARBOUR: ADDENDUM TO CAWTHRON REPORT NO. 2693

DRAFT FOR CLIENT REVIEW

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EXECUTIVE SUMMARY

Port Otago Ltd (POL) has resource consents granted by Otago Regional Council (ORC) to permit dredging operations in Otago Harbour. As a requirement, turbidity levels are monitored within Otago Harbour.

Cawthron Report No. 2693 analysed baseline turbidity data from seven monitoring stations within Otago Harbour and briefly discussed the influence of external factors such as weather, roadworks and tides on turbidity. To build on these findings, this addendum report further explored the relationship between weather and turbidity by focusing on one weather event and describing in detail the effects of wind speed, wind direction and rainfall on turbidity throughout the harbour.

Key findings of this report are as follows.

- The weather event from 13–18 April 2015 was characterised by increased wind speed and rainfall. Wind directions were sustained for several days predominantly from the west/southwest and the north/northeast/east.
- Turbidity was elevated at all stations during the weather event.
- Overall turbidity was higher at Roseneath, Acheron Head, Aramoana and Portobello Harwood, and lower at Pudding Island, Portobello Bay and Omate Beach.
- A peak in turbidity was delayed at the Omate Beach and Aramoana stations closer to the harbour entrance.
- Different turbidity patterns were displayed at different stations, *e.g*. Aramoana and Acheron Head exhibited short sharp peaks possibly mediated by tidal currents.
- Elevated turbidity was retained for longer at Roseneath and Pudding Island, stations closest to the inner harbour.
- Wind speed, wind direction and rainfall were all likely to have influenced turbidity responses.
- The magnitude and timing of the turbidity response varied at the different stations, likely due to a range of factors including: the relative shelter provided to the station from the prevailing wind and resulting fetch; the depth of the station and its proximity to the main channel and harbour entrance; and the timing of tidal currents.

1. INTRODUCTION, BACKGROUND AND METHODS

Port Otago Ltd (POL) has resource consents, granted by Otago Regional Council (ORC), to permit dredging operations in Otago Harbour. The conditions specified in ORC 2010.195 and the objectives of the Project Next Generation Environmental Management Plan (EMP), require that turbidity levels are monitored within Otago Harbour.

Baseline turbidity data for March 2014–April 2015 from seven monitoring stations within Otago Harbour (positions shown in Figure 1) were analysed in Cawthron Report No. 2693 (Berthelsen & Barter 2015). The influence of external factors such as weather, roadworks and tides on turbidity was also briefly discussed. Key findings from this report are summarised below.

1.1. Summary of Cawthron Report No. 2693

- Median turbidity values for all monitoring stations ranged between 0.78–1.45 Nephelopmetric Turbidity Units (NTU) which has been calibrated to correspond to 1.95–3.63 Suspended Sediment Concentration (SSC).
- Portobello Bay, the control and reference station, had the lowest median turbidity value. Acheron Head, situated close to the main channel, had the highest median value followed by Roseneath and Pudding Island, positioned closest to the inner harbour.
- Large turbidity spikes, typical of automated turbidity data, were present in data from all stations.

1.1.1. Weather

- Weather events appeared to have a strong influence on turbidity, and periods of increased rainfall and wind strength were usually associated with elevated turbidity at all stations.
- Wind and rain events often occurred simultaneously making it difficult to separate out their effects, however:
  - elevated turbidity associated with increased wind strength, but limited rainfall, was observed to occur.
  - stronger winds and rainfall, and therefore higher turbidity levels, were generally associated with westerly and southwesterly winds.

1.1.2. Tides

- Slight daily fluctuations in turbidity suggested a likely influence of tidal activity. The timing of daily patterns in turbidity varied amongst stations and dates.

- Large turbidity spikes occurred at both mid- and slack tides. It was unlikely these were being driven solely by tidal cycles as they did not display a regular tidal pattern.
- No noticeable patterns were observed between turbidity levels and tidal cycles occurring over time periods larger than the daily cycle (*e.g.* neap and spring tides).

1.1.3. Roadworks

- Turbidity spikes that did not appear to be associated with weather events or replicated across distant stations occurred at stations close to roadwork activities.

1.1.4. Other factors

- Some turbidity spikes appeared to be unexplained by the weather, tide and roadwork data. Many of these were inconsistent across all stations, indicating that they were likely caused by localised factors at or near specific stations.

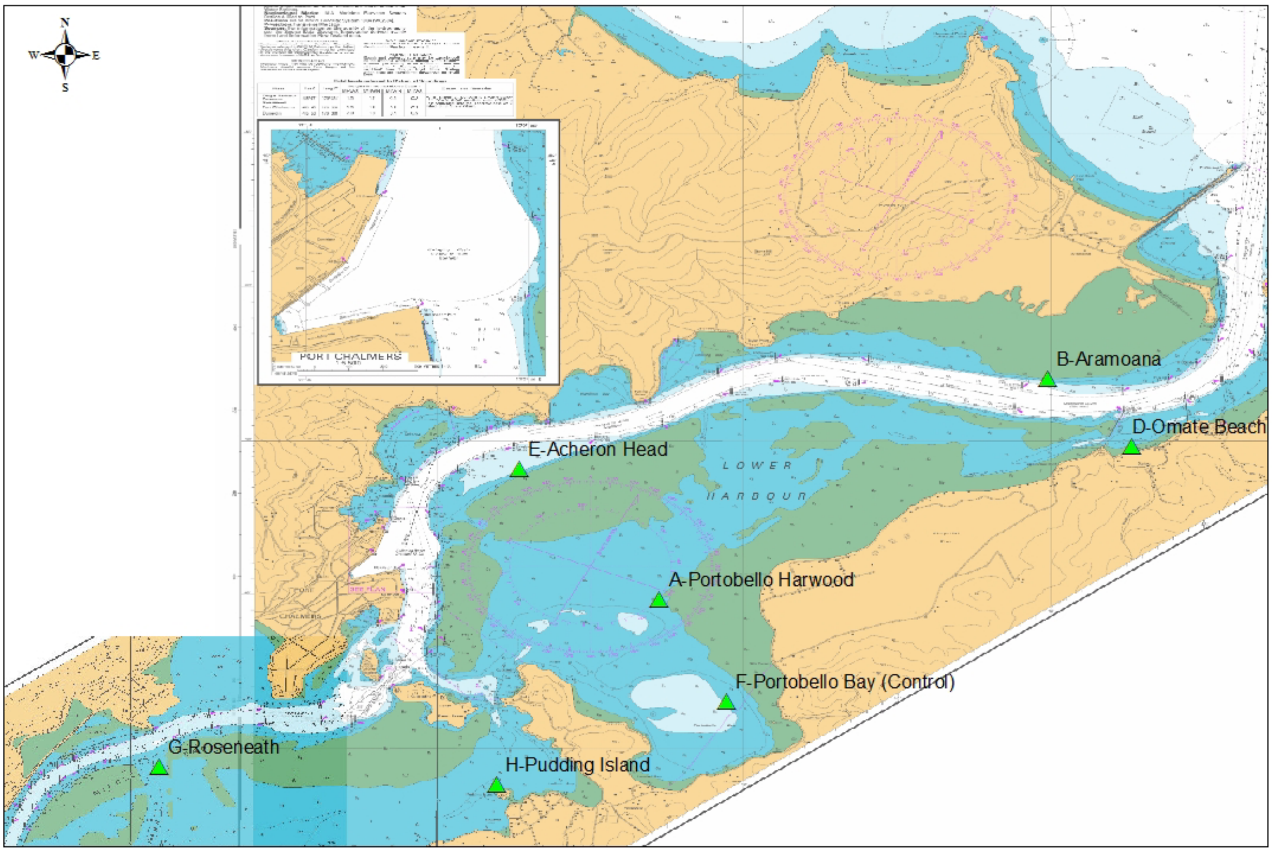

Figure 1. Map showing the site locations of turbidity stations (green triangles) within Otago Harbour.

1.2. Aim

To build on the findings of Cawthron Report No: 2693 (Berthelsen & Barter 2015), POL requested further exploration of the relationship between weather and turbidity within the harbour. To investigate this, focus was placed on one weather event and the effects of wind speed, wind direction and rainfall on turbidity throughout the harbour were described in detail. Berthelsen & Barter (2015) should be referred to for a description of the turbidity monitoring stations, information regarding the collection and clean-up of turbidity data, and a description of weather data.

2. RESULTS AND DISCUSSION

2.1. Selection of weather event

A weather event that occurred during 13–18 April 2015 was chosen as the focus of this investigation because:

- It was relatively significant in terms of rainfall and wind strength and direction as shown by the following features
    - The average daily rainfall was 4.8 mm. In comparison, the average daily rainfall from March 2014–April 2015 (including all weather events) was 1.68 mm.
    - The average hourly wind speed was 4.9 m/s (17.6 km/h). In comparison, the average wind speed from March 2014–April 2015 (including all weather events) was 3.4 m/s (12.2 km/h).
    - 8.3% of hourly wind speeds exceeded 8 m/s (28.8 km/h). In comparison, 2.6% of hourly wind speeds from March 2014–April 2015 (including all weather events) exceeded 8 m/s.
    - Winds were sustained for several days predominantly from two general directions: west/southwest and north/northeast/east.
- Coincident data were available from all seven monitoring stations over this period.
- To our knowledge, there was no nearby roadwork activity during this period although dredging did occur near three of the monitoring stations.
- Elevated turbidity was evident at all stations during the weather event.

The start and end dates of the weather event were defined largely by the two rainfall peaks on 14 and 18 April. The start date was extended forward to include 13 April as average hourly wind speeds on this date were relatively high (6.1 m/s). Prior to this on 12 April, average hourly wind speeds were lower (3.6 m/s) and there was no rainfall.

2.2. Weather event

The wind direction, wind strength and rainfall associated with the weather event over 13–18 April 2015, as well as tidal heights, are displayed in the top four graphs in Figure 2. The 19th of April was also included due to the possible lag in response time of the turbidity to the weather event. Turbidity at all harbour monitoring stations during the weather event are displayed in the bottom seven graphs in Figure 2. Gaps in the turbidity data represent either extremely high turbidity readings (> 100 NTU)[1] that were removed during data clean-up, or periods when no data was collected (see Berthelsen & Barter 2015). Time is on the horizontal axis (x-axis) for all graphs. The seven turbidity graphs have varying scales on the vertical axis (y-axis) in order to

[1] Two high singular turbidity readings of 92.1 and 72.8 NTU were also removed during the current study from the Omate Beach and Roseneath datasets respectively.

visually determine the relative magnitude of changes in turbidity at each station. This variation in scale must be considered when making comparisons between stations.

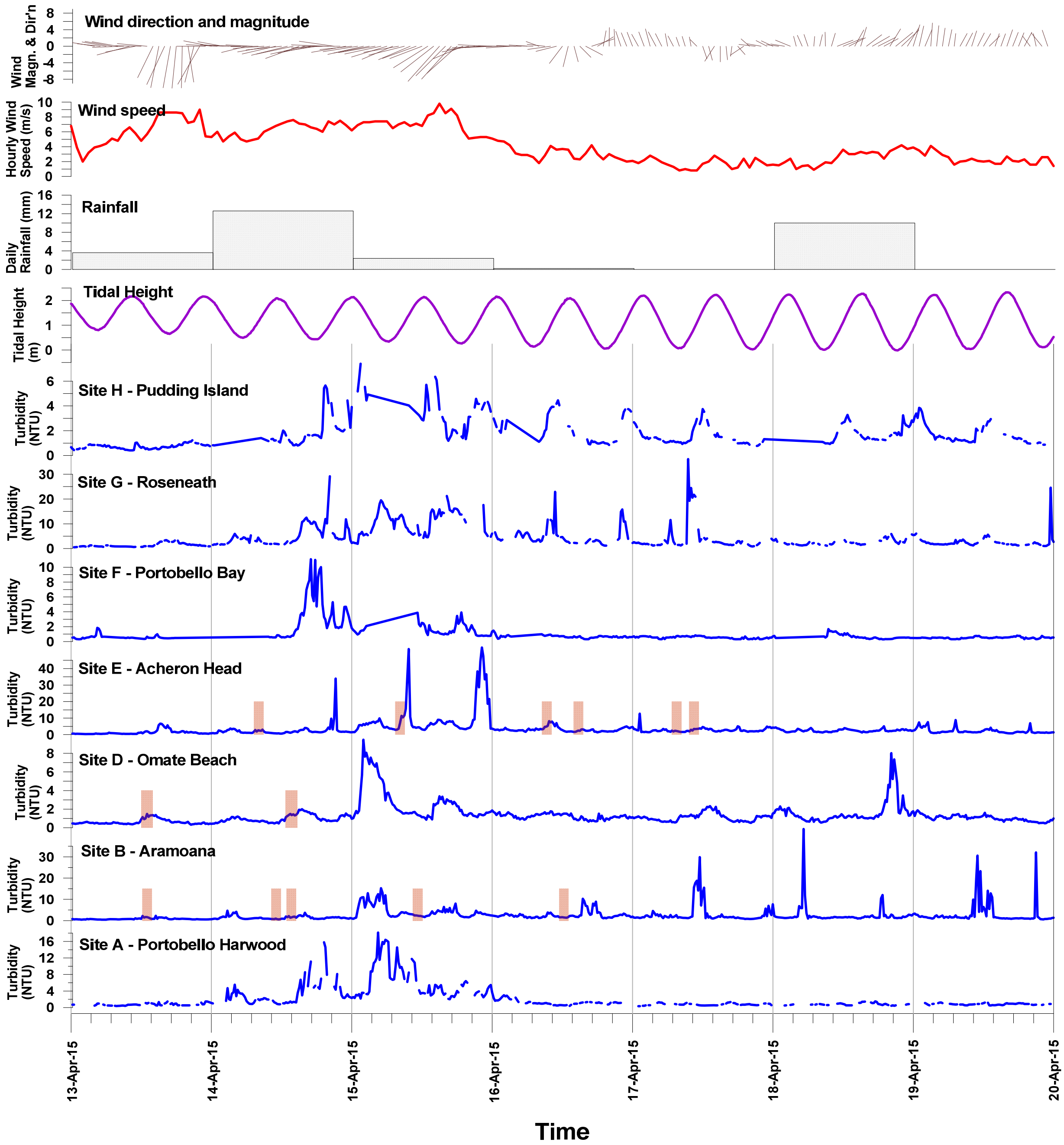

Figure 2. Turbidity readings (NTU) at each of the stations within the Otago Harbour from 13–19 April 2015 (bottom seven graphs). Wind speed and direction, rainfall and tidal height graphs are also included at the top of the figure. Dates and approximate times during which dredging activity occurred at or near a station are depicted as orange bars. Note that the different scales on the vertical axis (y-axis) of turbidity graphs should be considered when making between-station comparisons. Wind angles indicate the direction that the wind is travelling from.

2.2.1. Comparison of turbidity between stations

Overall, turbidity at the Pudding Island, Portobello Bay and Omate Beach stations was noticeably lower in comparison to all other stations (Figure 2). These three stations are located on the edge of the southern side of the harbour (Figure 1), and therefore were probably not subject to the impact of waves[2] likely caused by the westerly/southwesterly winds that blew consistently during the first four days of the weather event. Omate Beach is a relatively shallow site and therefore may be more susceptible to elevated turbidity due to resuspension of benthic sediments by wind waves. However its sheltered position from the prevailing winds in this case appears to have reduced the potential for this.

Roseneath, Acheron Head, Aramoana and Portobello Harwood were the most turbid. These stations are located on the northern side of the harbour (near the main harbour channel) and more exposed to the initial prevailing westerly/southwesterly winds, with the exception of Portobello Harwood which is closer to the southern side of the harbour. However Portobello Harwood is positioned at a relative distance from the land and therefore will be more exposed to westerly/southwesterly conditions than stations positioned closer to the southern shoreline. Roseneath is located in the inner harbour and is likely subject to reduced tidal flushing that, coupled with the proximity to the surrounding land and potential for higher levels of runoff, increase the potential for turbid conditions at this station.

2.2.2. Comparison of turbidity within stations

Reponse to weather on 13–15 April

From 13-15 April, the wind direction was westerly/southwesterly (Figure 2). From 13-15 April, relatively high wind speeds averaging 6.5 m/s (23.4 km/h) were sustained with peaks occurring on 13 April (9 m/s, 32.4 km/h) and 15 April (9.8 m/s, 35.5 km/h). Rainfall occurred from 13-15 April with the majority of this falling on 14 April (12.6 mm).

Turbidity increases occurred at all stations between 14-15 April, likely in response to the increased wind strength and rainfall and the westerly/southwesterly wind direction (Figure 2). Relative to within-station turbidity variation, turbidity peaks occur first at Pudding Island, Roseneath, Acheron Head, Portobello Bay and Portobello Harwood on 14 April and somewhat later at Omate Beach and Aramoana on 15 April. Omate Beach and Aramoana are positioned closest to the harbour mouth and the extended time taken to reach a peak in turbidity may be explained by the flushing of cleaner ocean water past these stations by the incoming tide.

[2] These can be caused from a combination of wind speed and fetch, where fetch is the distance of open water over which a given wind has blown. Longer fetch and higher wind speeds can increase the size of waves produced.

The pattern of elevated turbidity is variable between stations. At Acheron Head and Aramoana, large, relatively short turbidity peaks are present. These two stations are situated next to the main channel in the harbour and it is possible that stronger tidal currents at these stations contribute to the large turbidity peaks. At most other stations (*e.g*. Pudding Island and Roseneath), elevated turbidity was more sustained over time.

Tailing off response from 15–17 April

From 15–17 April, average hourly wind strength and daily rainfall decreased to 1.8 m/s (6.5 km/h) and 0 mm respectively on 17 April (Figure 2). From 16–17 April, wind direction became variable and swung between all quarters.

In a likely response to decreased wind strength and rainfall, turbidity declined at all stations. Relative to the within-station turbidity variation that occurred in the initial response, turbidity remained elevated at Roseneath and Pudding Island until 17 April. This relatively long lag time could be due to the inner harbour location of these stations, where reduced tidal flushing is likely to result in the retention of turbid water. A reduction in turbidity occurred earlier (15 April) at all other stations, although turbidity at Aramoana and Acheron Head still exhibited some peaks on 16 and 17 April.

Response to weather on 18 April

On 18 April, another peak in daily rainfall occurred (10 mm) in conjunction with northerly/northeasterly/easterly winds (Figure 2). Average hourly wind speed was relatively low (2.5 m/s, 9 km/h).

There was no noticeable relative elevated turbidity response at Portobello Harwood. This station is relatively far from the shore and may be consequently less responsive to runoff from the land. Slight elevations in relative turbidity occurred at Roseneath and Portobello Bay on 18 April and Acheron Head on 19 April. A larger relative elevation in turbidity occured at Pudding Island and Omate Beach on 18 April. At Aramoana elevated turbidity occurred as four relatively high peaks between 18–19 April. The regularity of these suggests the possibility that they are tidally mediated.

It was difficult to separate out the effects of wind speed and direction on turbidity as changes in these two variables often occurred together. However, the limited turbidity response to relatively low wind speeds and high rainfall on 18 April, in comparison to the larger magnitude of response to the higher wind speed, west/southwest winds and the similarly high rainfall on 15 April, suggests that wind speed/direction has a strong effect on turbidity within the harbour. The response (although smaller) of turbidity to the rainfall event on 18 April indicates that rainfall is also likely to influence turbidity within the harbour.

Tailing off response from 18–19 April

No rain fell on 19 April and wind strength was relatively low (2.4 m/s, 8.6 k/h) (Figure 2). The predominant wind blew from a northerly/northeasterly/easterly direction.

The elevated turbidity at the stations mentioned in the previous section peaked and then declined rapidly within a 24 hour period, with the exception of Pudding Island where elevated turbidity was sustained for a longer period. There were further unexplained turbidity peaks at Aramoana and Roseneath, and to a lesser extent at Acheron Head, on 19 April.

2.2.3. Further investigation

This study described in detail the turbidity response at the seven monitoring stations to one weather event. It is likely that weather events characterised by differing environmental parameters (*e.g*. high wind strength and no rainfall) would trigger a different turbidity response at the various stations. Further investigation of turbidity responses to a range of weather events would complement the findings of this study. Interactions between turbidity and the environment are very complex and limitations in the data restricted the conclusions that could be drawn. For example, rainfall is averaged over a 24 hour period and the impact of shorter more intense rainfall events could not be differentiated from longer periods of light rain.

3. ACKNOWLEDGMENTS

Thank you to Rebecca McGrouther from Port Otago Ltd. for supplying further information on dredging activity.

4. REFERENCES

Berthelsen A, Barter P 2015. Summary of turbidity data for Otago Harbour: 2014/15. Prepared for Port Otago Ltd. Cawthron Report No. 2693. 14 p. plus appendix.