



UNSW
SYDNEY

Australia's
Global
University

School of Civil and Environmental Engineering
Water Research Laboratory

Narrabeen Lagoon Entrance Clearance Operation Design

WRL TR 2018/16 | August 2018

By T A Tucker, I R Coghlan, J T Carley and B M Miller



Water
Research
Laboratory
School of Civil and
Environmental Engineering

Narrabeen Lagoon Entrance Clearance Operation Design

WRL TR 2018/16 August 2018

By T A Tucker, I R Coghlan, J T Carley and B M Miller

Project details

Report title	Narrabeen Lagoon Entrance Clearance Operation Design
Authors(s)	T A Tucker, J T Carley and B M Miller
Report no.	2018/16
Report status	Final
Date of issue	August 2018
WRL project no.	2018050
Project manager	T A Tucker
Client	Northern Beaches Council
Client address	725 Pittwater Road Dee Why NSW 2099
Client contact	Duncan Howley Duncan.Howley@northernbeaches.nsw.gov.au
Client reference	2018/307438

Document status

Version	Reviewed by	Approved by	Date issued
Draft	I R Coghlan	G P Smith	23 July 2018
Final Draft	G P Smith	G P Smith	26 July 2018
Final	G P Smith	G P Smith	07 August 2018



**Water
Research
Laboratory**
School of Civil and
Environmental Engineering

www.wrl.unsw.edu.au

110 King St, Manly Vale, NSW, 2093, Australia

Tel +61 (2) 8071 9800 | ABN 57 195 873 179



This report was produced by the Water Research Laboratory, School of Civil and Environmental Engineering, University of New South Wales Sydney for use by the client in accordance with the terms of the contract.

Information published in this report is available for release only with the permission of the Director, Water Research Laboratory and the client. It is the responsibility of the reader to verify the currency of the version number of this report. All subsequent releases will be made directly to the client.

The Water Research Laboratory shall not assume any responsibility or liability whatsoever to any third party arising out of any use or reliance on the content of this report.

Executive summary

Narrabeen Lagoon is an intermittently open and closed lagoon located approximately 13 kilometres north of Sydney Harbour. The lagoon is managed by Northern Beaches Council. Historically, management of the lagoon has focused on flood risk, public amenity and lagoon water quality. These issues have been managed by the controlled opening and closing of the lagoon entrance.

Naturally, the entrance to the lagoon tends to close. This involves the infilling of the entrance to the lagoon with marine sands from North Narrabeen Beach. Once closed the water level in the lagoon will rise until it reaches a tipping point where it overflows the entrance berm at North Narrabeen and scours a channel across the beach causing a 'breakout' of the lagoon. If the beach berm height and infilling of the entrance are not managed, areas around the lagoon foreshore are at risk of severe flooding before 'breakout' occurs.

Northern Beaches Council have implemented a lagoon clearance operation program designed to clear the entrance from excess sand and allow for easier management of the lagoon entrance conditions. This operation also involves the replenishment of sand removed from Narrabeen Lagoon to the south end of Collaroy-Narrabeen beach. As of July 2018, the lagoon entrance channel is currently in a closed state and infilled with sand. Northern Beaches Council aims to reduce the sand currently located in the entrance of Narrabeen Lagoon and use it to replenish Collaroy-Narrabeen Beach.

This report outlines:

- A review of historical documentation and data from previous lagoon clearance operations;
- Criteria used in the development of cross-section profiles for the excavation of Narrabeen Lagoon;
- A procedure for excavation of sand from Narrabeen Lagoon;
- Timings for surveys to be conducted to determine the volume of sand removed from Narrabeen Lagoon; and
- Criteria recommended for the replenishment of Collaroy-Narrabeen Beach.

In total, it was determined that there is 39,100 m³ of sand available for beach replenishment of Collaroy-Narrabeen Beach to the south of Mactier Street. Thirty-one (31) cross-sections have been provided to describe the lagoon excavation limits. Historical documentation suggests that additional sand could be retrieved from the lagoon, however, there was no conclusive evidence of its suitability for beach replenishment. If additional excavation occurs, it may help alleviate erosion issues within the lagoon.

Contents

1	Introduction	7
1.1	Preamble	7
1.2	History of entrance works	8
1.3	Lagoon entrance behaviour	9
2	Review of survey data	12
3	Narrabeen Lagoon excavation	15
3.1	Preamble	15
3.2	Cross-section criteria	15
3.3	Excavation procedure	16
3.4	Bathymetric survey timings	19
4	Collaroy-Narrabeen Beach replenishment	20
4.1	Preamble	20
4.2	Beach replenishment criteria	20
5	Recommendations	25
5.1	Additional lagoon excavation	25
5.2	Beach replenishment survey	26
6	References	27
Appendix A	Narrabeen Lagoon excavation cross-sections	29

List of tables

Table 1: Past entrance clearance operations (adapted from Cardno, 2016)	9
Table 2: Survey technique uncertainty	14

List of figures

Figure 1: Narrabeen Lagoon entrance	8
Figure 2: Narrabeen Lagoon entrance infilling conceptual model (Morris, 2010)	10
Figure 3: Lagoon bathymetry maximum excavation survey limit	13
Figure 4: Lagoon bathymetry as surveyed from May to June 2018 (WRL, 2018)	14
Figure 5: Location of excavation cross-sections	18
Figure 6: Indicative replenishment profile overlain on a cross section taken at Narrabeen Street on 13 June 2018 with a volume of 55 m ³ /m	21
Figure 7: Indicative replenishment profile overlain on a cross section taken at Wetherill Street on 13 June 2018 with a volume of 115 m ³ /m	22
Figure 8: Erosion as seen from Mactier Street looking north on 13 July 2018	22
Figure 9: Erosion as seen from Wetherill Street looking north on 13 July 2018	23
Figure 10: Erosion as seen from Wetherill Street looking south on 13 July 2018	23
Figure 11: Beach replenishment location	24
Figure 12: Locations where the excavation limit could be lowered	26

1 Introduction

1.1 Preamble

The Northern Beaches Council (hereafter “Council”) is responsible for the management of Narrabeen Lagoon, which is classified as an intermittently closed and open lake or lagoon (ICOLL), located approximately 13 kilometres north of Sydney Harbour. Narrabeen Lagoon has an area of 2 km² and a total catchment area of approximately 55 km² (Morris, 2010).

Since Narrabeen Lagoon is an ICOLL, the state of the entrance to the lagoon has an impact on local area flood risk, lagoon water quality, and public amenity. Kulmar et al. (1989) specified that successful management of the lagoon requires:

- Lagoon water quality remaining above a level required for recreational amenity and ecology;
- Water level being controlled to reduce flood severity while ensuring survival of sea grass beds; and
- Recreational use of the lagoon foreshore should not be impacted by changes to the lagoon entrance.

Council has historically managed these requirements through mechanical breakout and closure of the lagoon entrance. When there is an increase in sand deposited at the entrance to the lagoon the effectiveness of mechanical breakout can be limited (Kulmar et al., 1989). To assist in the breakout of the lagoon, which is completed for flood management and increased water quality purposes, it is beneficial to remove additional sand from the lagoon entrance. Previously, this sand has been used to replenish areas of erosion along Collaroy-Narrabeen Beach (Morris, 2010, Cardno, 2011 and Cardno, 2016).

Council has requested the UNSW Sydney (University of New South Wales) Water Research Laboratory’s (WRL) assistance developing cross-sections for excavation of the Narrabeen Lagoon entrance and design criteria for the subsequent replenishment on Collaroy-Narrabeen Beach. This information will be used to assist the development of a Review of Environmental Factors (REF). The following report outlines the criteria for the development of cross-sections in addition to methodologies to be considered during excavation. Sand will be removed from two shoals located on the east and west side of Ocean Street bridge (Figure 1) and placed upon Collaroy-Narrabeen

Beach (see Figure 11 in Section 4.2). Criteria outlined in this report are pending any findings of the REF.



Figure 1: Narrabeen Lagoon entrance

1.2 History of entrance works

There have been several engineering modifications to the entrance of Narrabeen Lagoon which are designed to reduce transport of sand into the entrance area. These include (Morris, 2010 and Kulmar et al., 1989):

- 1928: Construction of the wooden Ocean Street bridge (upgraded to a concrete structure in the mid 1960's);
- 1975: Construction of the dune field known as Birdwood Park (on the southern side of the entrance); and
- 1982/83: Construction of a training wall on the northern side of the entrance.

Evidence has shown that these modifications have decreased how often the lagoon entrance closes, however, it has not prevented severe transport of marine sand into the entrance (Morris, 2010 and Kulmar et al., 1989). Measurements of the water levels within Narrabeen Lagoon indicated that the lagoon entrance is open approximately 75% of the time (Morris, 2010).

Early records indicate that dredging of Narrabeen Lagoon occurred as early as 1911 when sediment was used for land reclamation on the western side of the lagoon (Kulmar et al., 1989). Since 1979, Council has undertaken routine clearance operations to manage the sand within the entrance of Narrabeen Lagoon. Table 1 outlines the historic clearance operations and volumes of sand removed.

Table 1: Past entrance clearance operations (adapted from Cardno, 2016)

Year	Volume of sand (m ³)	Location in relation to Ocean Street bridge
1975	100,000	No data
1979	37,500	No data
1982/83	60,000	No data
1987	40,000	East
1990	30,000	East and west
1992/93	56,000	East and west
1995	27,500	East and west
1999	70,000	East and west
2002	40,000	East and west
2006	45,000	East and west
2011	36,000	East and west
2016	38,650	East and west

1.3 Lagoon entrance behaviour

Morris (2010) conducted an extensive study on the entrance to Narrabeen Lagoon and developed a conceptual model for the ingress of sand into the entrance. It highlighted that there were two shoals that are created; initially one developed to the east of the Ocean Street bridge which is proceeded by the development of a shoal on the western side of the bridge. These shoals develop through five (5) stages, the first four (4) of which are shown in Figure 2. The fifth stage involves the entrance to the lagoon becoming closed to the ocean. At the time of writing (August, 2018), the lagoon is in this fifth state with the eastern and western shoals fully developed.

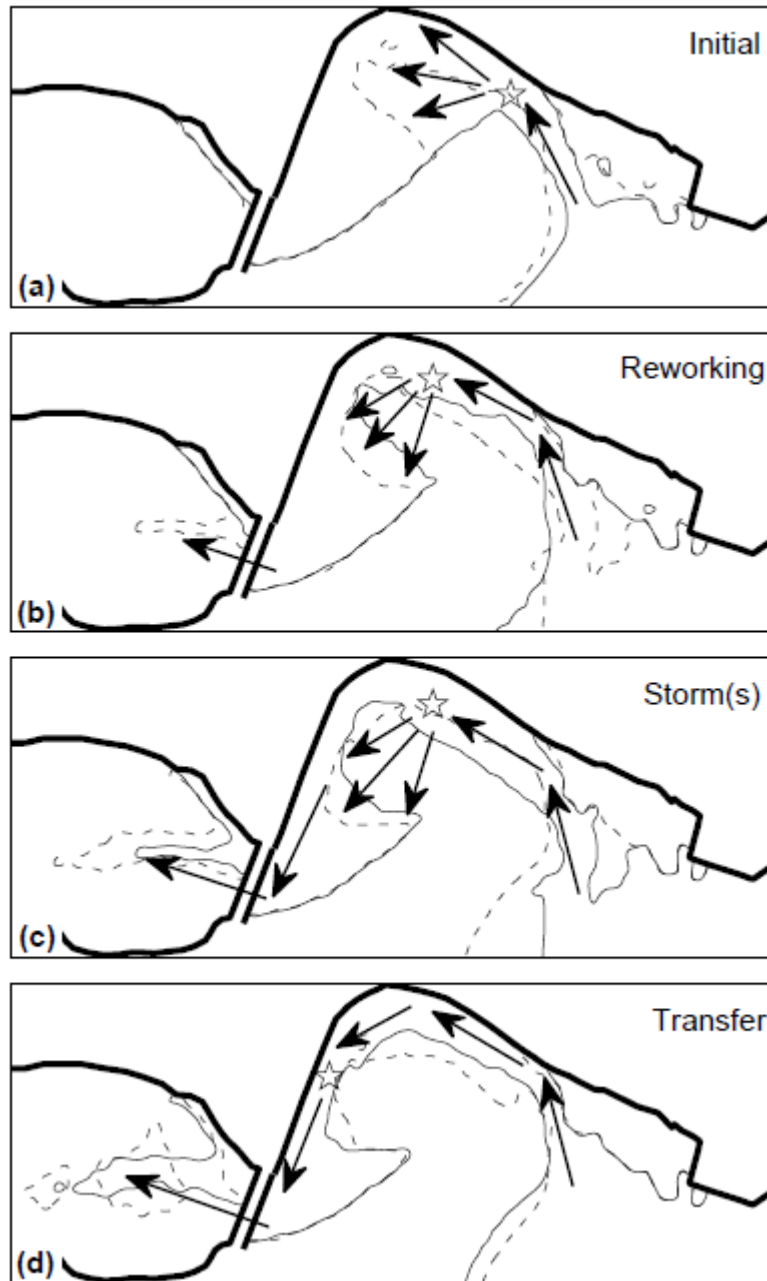


Figure 2: Narrabeen Lagoon entrance infilling conceptual model (Morris, 2010)

The morphodynamics of Narrabeen Lagoon are described in detail by Kumar et al. (1989). The lagoon morphology can be described by three (3) different scenarios:

1. Closure of the lagoon occurs when there is moderate to high wave energy forcing upon the lagoon entrance. This is generally associated with low lagoon water levels, neap tides, long shore (northward) transport of sand on Narrabeen Beach, and aeolian (wind blown)

transport of sand. Storm events with large wave conditions will contribute to closure of the lagoon entrance.

2. Constriction of the lagoon occurs when the entrance channel into the lagoon narrows and shoals, but does not close. This occurs during moderate to low wave conditions.
3. The lagoon will break out once the water level inside has significantly increased creating a large differential between the water level in the lagoon and the ocean. Once the berm at the entrance to the lagoon is overtopped, a channel forms and scours the sand away subsequently draining the lagoon. This can happen when there is a large rainfall event within the Narrabeen Lagoon catchment. Breakout events can be associated with significant transport of sand (approximately 30,000 m³) out of the lagoon. Alternatively, breakout can also be caused by mechanical means. The best conditions for breakout are a high lagoon water level combined with an ebbing (falling) tide. Once the sand has been scoured from the entrance, a rock weir is exposed with an elevation of 0.00 m AHD.

Currently the lagoon is in a closed state. It will require breakout, as described in the third scenario above, for this state to change. Should a breakout event naturally occur, this could result in significant loss of sand from the eastern end of the lagoon. This would reduce the amount available for replenishing sand on Collaroy-Narrabeen Beach.

Upon completion of excavation works, the Narrabeen Lagoon entrance will begin to infill again. The rate of this infilling is dependent upon the frequency of storm events and the amount of sand available at the entrance to the lagoon. Typically this has occurred over a three (3) year cycle, however, since it is dependent on storms, the period for closure has potential to occur quicker than this. By increasing the volume of sand excavated and removing features such as the eastern and western shoals, the open state of the lagoon can be prolonged.

2 Review of survey data

Excavation profiles have been created so that only recently deposited marine sand is removed to ensure that sand being excavated is of suitable quality for beach nourishment. Seven (7) datasets have been compared to determine suitable locations of sand for excavation. These surveys include:

- 1976 Manly Hydraulics Laboratory (MHL) survey of the rock weir;
- 2002 post excavation survey of the lagoon;
- 2011 excavation design cross-section and levels;
- 2015 CMS Surveyors survey of the rock weir;
- 2016 excavation design cross-section and levels;
- 2016 post excavation survey of the lagoon;
- 2018 WRL bathymetry survey.

Where survey data was digital, or able to be digitised, it was turned from point data into a surface using natural neighbour interpolation. A digital elevation model (DEM) showing the survey limit was then created by combining these datasets and extracting the lowest elevation. This is shown in Figure 3, which is comprised of data from:

- 1976 Manly Hydraulics Laboratory (MHL) survey of the rock weir;
- 2002 post excavation survey of the lagoon;
- 2015 CMS Surveyors survey of the rock weir;
- 2016 post excavation survey of the lagoon; and
- 2018 WRL bathymetry survey.

A DEM was also created for the existing bathymetry from the most recent 2018 survey (Figure 4) (WRL, 2018). Both DEM's were sampled at a 0.5 m interval for analysis.

The deepest excavation within the western shoal was found in the 2011 excavation plans where a minimum elevation of -1.05 m AHD was reached on the eastern side closest to the Ocean Street bridge. This excavation generally tapered up to an elevation of -0.4 m AHD on the western side of the shoal. Excavation footprints generally varied from year to year, dependent upon macroalgae and seagrass locations (Craig and Rhodes, 2002, Cardno, 2011 and Cardno, 2016).

Surveys undertaken for the eastern shoal showed a minimum elevation of -0.8 m AHD closest to Ocean Street bridge. This tapered up to a level of -0.5 m AHD closest to the entrance. There is a rock weir at approximately 0 m AHD that constricts flow and subsequently limits excavations at the point of Birdwood Park. Surveys on the downstream side of this rock weir showed that the rock shelf lowers again to below -1 m AHD.

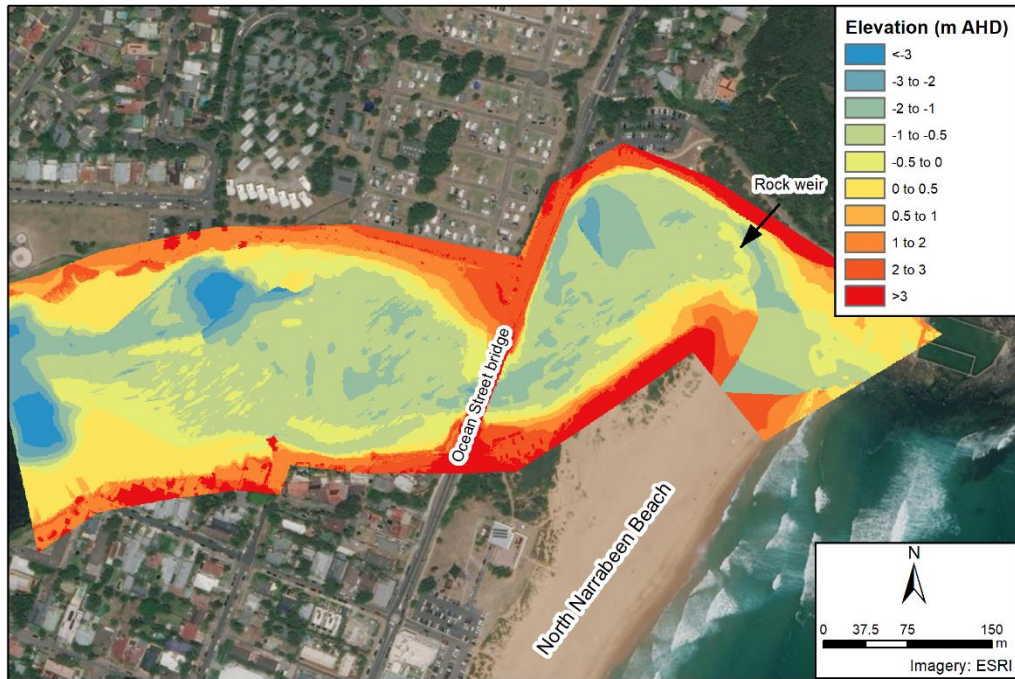


Figure 3: Lagoon bathymetry maximum excavation survey limit

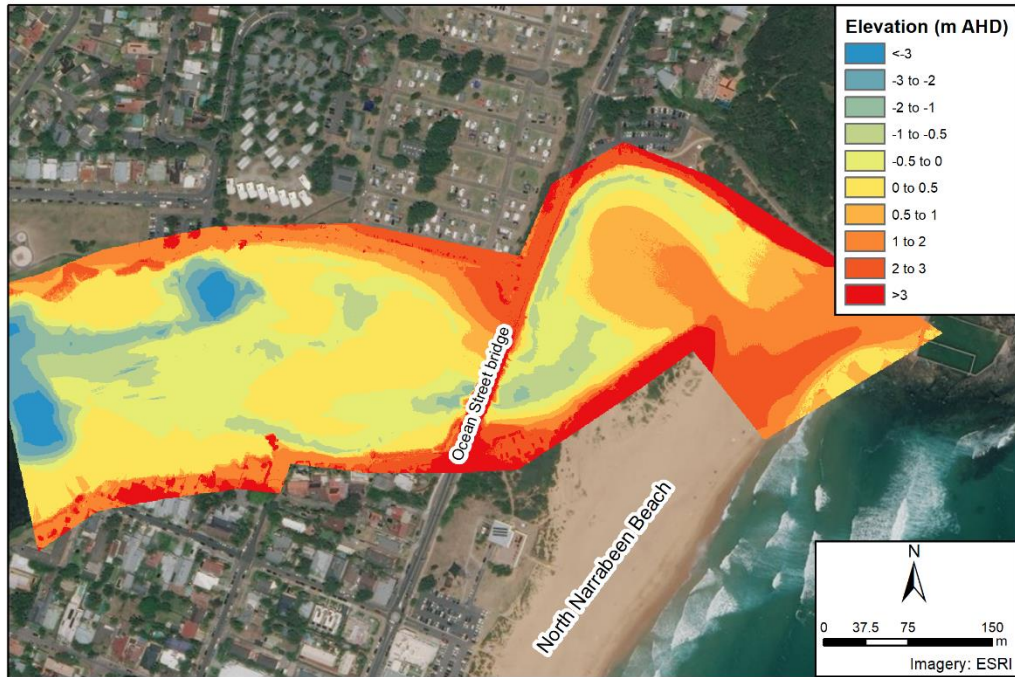


Figure 4: Lagoon bathymetry as surveyed from May to June 2018 (WRL, 2018)

Three different survey techniques were used to compile the DEM for the existing (2018) lagoon bathymetry:

1. Unmanned Aerial System (UAS) photogrammetry;
2. Standalone Real Time Kinetic (RTK) GPS surveys; and
3. Boat mounted echo sounding surveys corrected by RTK-GPS.

Each survey technique has a small error associated with its measurements. The specific root mean square (RMS) error for each technique is shown in Table 2. While the errors are small, the excavation footprint of the lagoon has a total area of almost 50,000 m² (see Section 3.2) meaning the total volume uncertainty is not insignificant. This area was separated into zones depending on how it was surveyed. The total uncertainty in volume was subsequently calculated to be $\pm 1,300$ m³ (< 3% of the total volume to be excavated).

Table 2: Survey technique uncertainty

Survey Technique	RMS error (\pm m)
UAS photogrammetry	0.020
Standalone RTK-GPS	0.021
RTK-GPS corrected echo sounder	0.033

3 Narrabeen Lagoon excavation

3.1 Preamble

Clearance of sand within the Narrabeen Lagoon entrance will prolong its open state (Kumer et al., 1989). This will reduce the risk of flood inundation to the local area and allow tidal flushing of the lagoon. Sand excavated from the lagoon entrance is required to be of suitable quality for the replenishment of Collaroy-Narrabeen Beach. Suitable material to be excavated consists of marine sand that is of similar grain size and colour to that existing at the replenishment site. Morris (2010) found that sand deposited in the lagoon entrance is sourced from the landward migration of sand from North Narrabeen Beach. It has therefore been assumed that sediment above the excavation limits only includes marine sand that has been transported into the lagoon entrance and is suitable for beach replenishment. The excavation limit has been determined as outlined in Section 2.

In total, 39,100 m³ of sand is available for beach replenishment. This includes 23,900 m³ of sand from the eastern shoal and 15,200 m³ of sand from the western shoal. Cross-sections shown in Appendix A outlining the volume to be excavated, were developed using the criteria outlined in the following section.

3.2 Cross-section criteria

A total of 31 cross-sections have been created to show the limits of where suitable sand material can be excavated from within Narrabeen Lagoon. For consistency, these cross-sections overlap with those from previous excavation operations. All cross-sections are displayed looking downstream (towards the ocean) with a chainage of zero at the left bank.

Excavation cross-sections were developed using the following criteria:

- All batter slopes are less than 1H:6V (1 vertical 6 horizontal) to be conservative when compared to the natural angle of repose of sand (Al-Hashemi and Al-Amoudi, 2018);
- The excavation is a minimum 10 m from the lagoon boundary (larger if practical and 20 m at any eroding banks);
- The excavation is a minimum 10 m from seagrass or macroalgae as defined by Eco Logical Australia (ELA, 2018) (some exceptions have been made for seagrass as outlined later in this section);
- The excavation footprint does not have holes or sharp bends that could lead to large morphologic change during system equilibration;
- The excavation footprint will not impact mechanical control of the lagoon entrance;
- Machinery access for excavation was considered when creating cross-sections; and
- All excavation levels are above historic levels as outlined in Section 2.

There was a large area of seagrass mapped in July 2018 at locations that had previously been excavated as part of prior lagoon entrance clearance operations (ELA, 2018, Craig and Rhodes, 2002, Cardno, 2011 and Cardno 2016). To maximise the area of available sand in 2018, areas of seagrass within the eastern shoal were not considered when defining the excavation limit (that is they are included within certain areas to be excavated). Additionally, the excavation limit to sparse seagrass on the western shoal was reduced from 10 m to 5 m. This report does not provide approval for removal or damage of any seagrass; this is subject to the REF for the Narrabeen Lagoon entrance clearance project.

3.3 Excavation procedure

It is recommended that excavation operations occur when Narrabeen Lagoon is in a closed state. As found in previous excavation operations, by having the lagoon closed, the turbidity created from the excavation operations can be limited (Cardno, 2012 and Cardno 2017). This should be done by creating a berm across the entrance to the lagoon. A berm elevation of 2 m AHD and 5 m wide will reduce overtopping during high tides and large swells. It is recommended that the entrance is monitored for the duration of construction works to ensure that the water level in the lagoon does not rise above flood levels. Mechanical breakout of the lagoon may need to occur during the construction period to reduce lagoon water levels and prevent flooding. Previous excavations have determined that a water level of 0.4 m AHD during excavation is acceptable for construction requirements (Cardno, 2012 and Cardno, 2017). Additionally, ELA (2018) have recommended a water level of 0.4 m AHD to limit the harm to seagrass and macroalgae.

The ideal excavation procedure should start with cross-sections E01 to E015 (Figure 5 and Appendix A). This will reduce the impact of any turbidity created during excavation to the area east of the Ocean Street bridge. This should be followed by excavation of the western shoal. To facilitate movement of machinery, the western shoal should be cleared from west to east. Finally, cross-sections E16 to E19 should be cleared from west to east. Once completed, the lagoon should be mechanically opened. In summary, it is recommended that cross-sections are excavated in the following order:

1. E01 to E015;
2. W01 to W12; then
3. E16 to E19.

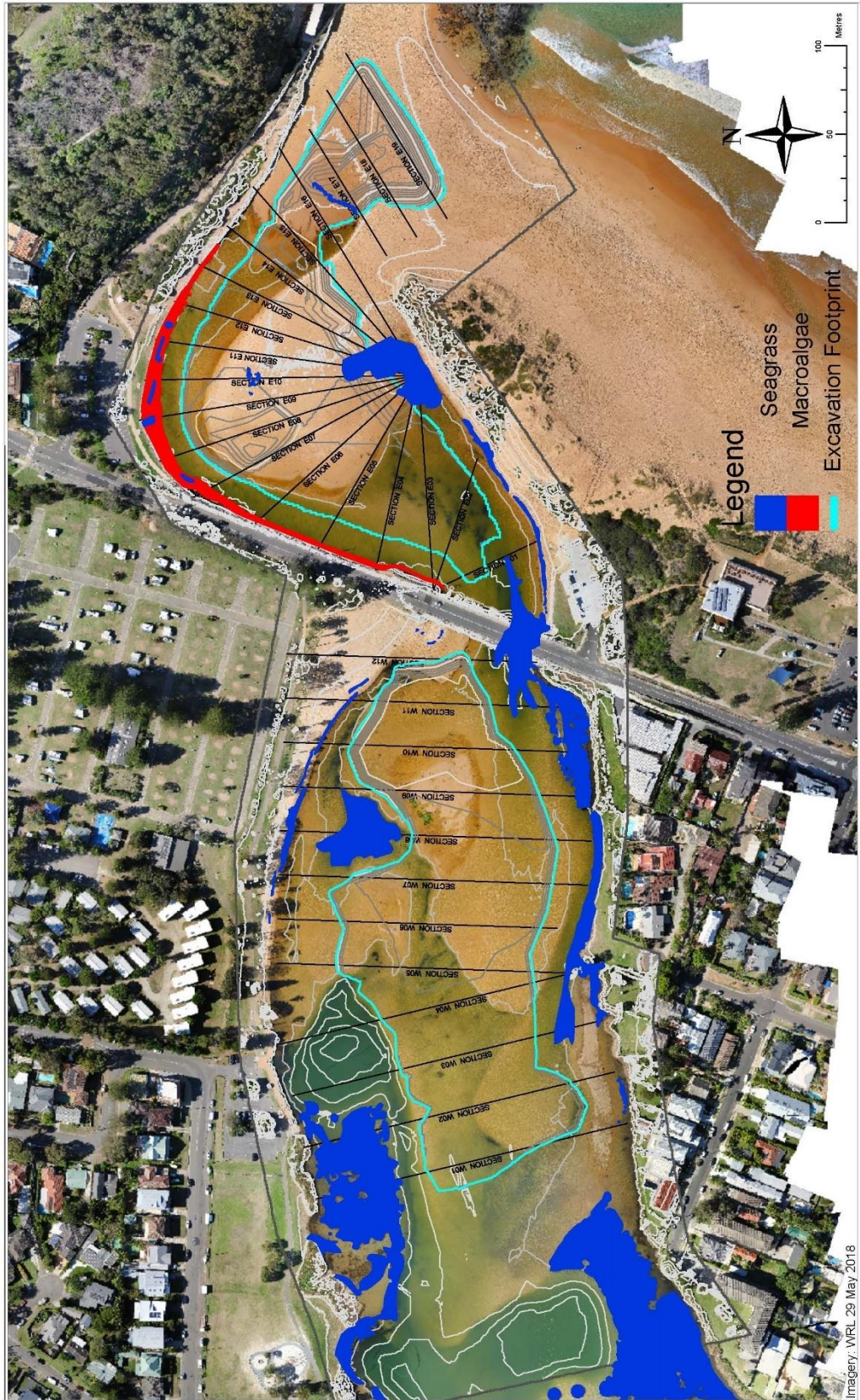


Figure 5: Location of excavation cross-sections

3.4 Bathymetric survey timings

Surveys of the lagoon bathymetry are to be completed to determine the total volume of sand removed from Narrabeen Lagoon once excavation is completed. The lagoon is a dynamic system and different forces act to change the shape of the bathymetry. There are three main drivers for displacement of sand within the lagoon (Kumar et al., 1989):

1. Aeolian transport of sand from North Narrabeen Beach;
2. High flow velocities likely to transport sand out of the lagoon; and
3. Large waves causing overtopping of the lagoon entrance and increasing the sand volume within the lagoon.

The previous two (2) clearance operations of the lagoon took between two (2) and three (3) months to complete (Cardno, 2012 and Cardno, 2017). During the 2011 excavation, which took three (3) months, it was observed that a berm elevation of 1.5 m AHD with a width of 5 m was not enough to prevent overtopping during high tides and storm events (Cardno, 2012). To decrease the likelihood of this, as outlined in Section 3.3, it is recommended the temporary berm height be increased to 2 m AHD.

Breakout of the lagoon is likely to move sand within the lagoon (Kumar et al., 1989). By mechanically opening the lagoon during clearance operations the bathymetry would change and potentially result in less sand available for excavation. The previous two (2) clearance operations have both had to stop and open the entrance to the lagoon to alleviate flood risk during operations (Cardno, 2012 and Cardno, 2017).

To ensure the volume of sand removed is calculated correctly, it is recommended that surveys be undertaken at the completion of each stage, including:

- The end of excavating sections E01 through to E15;
- The end of excavating sections W1 through to W12; and
- The end of excavating sections E16 through to E19.

Additionally, it is recommended that surveys be undertaken before and after opening of the lagoon entrance. This would determine if any sand is lost or moved while the entrance is open. It is important that the requirement for surveys does not delay opening of the lagoon entrance if there is a risk of flooding. For this reason it is recommended that surveys be conducted pre-emptively.

4 Collaroy-Narrabeen Beach replenishment

4.1 Preamble

The sand on Collaroy-Narrabeen Beach is highly mobile and the shape of the beach can vary significantly within a short timeframe (Philips et al., 2017). Due to this high variability, any cross-sections created for beach replenishment would likely be made redundant by natural changes in beach morphology within a matter of weeks. For this reason, this section of the report outlines criteria for the design of suitable beach replenishment cross-sections. The criteria outlined here can be used to determine the suitable placement of sand excavated from Narrabeen Lagoon at the correct locations on Collaroy-Narrabeen Beach.

4.2 Beach replenishment criteria

Design of beach replenishment should consider the following criteria:

- The top of the profile should start just below the bank elevation closest to property boundaries to reduce the probability of wind-blown sand being transported into private property and roads;
- The length of beach nourished should have a smooth longshore profile (that is no individual sections protruding seaward) to minimise the development of concentrated erosion and rip currents;
- The top surface of the profile should be wide enough to allow construction vehicles to move along it while allowing a smooth longshore profile;
- For public safety the shoreward face of the profile should have a batter slope no greater than 1V:4H which is conservative when compared to the angle of repose of dry sand (Al-Hashemi and Al-Amoudi, 2018);
- Locations below 2 m AHD should have an additional a 1V:10H batter slope extending to below 0 m AHD to reduce the likelihood of excessive steepness in the ambient swash zone;
- Replenishment profiles and their placement should consider safety to beach users; and
- Replenishment profiles should be placed in a way to minimise the costs of construction.

Indicative cross-section profiles are shown in Figure 6 and Figure 7. These figures were created from profiles surveyed on 13 June 2018 (as described in Turner et al., 2016) and do not show the most recent erosion that has occurred on Collaroy-Narrabeen Beach. As of 13 July 2018, there are rocks and seawalls exposed at numerous locations along the beach (Figure 8 to Figure 10). At some locations replenishment profiles will extend below 2 m AHD and be exposed to active wave

conditions. It is important that for these profiles, an additional 1H:10V profile is extended to 0 m AHD to prevent a large vertical scarp developing and posing risks to beach user safety.

The alongshore location where Collaroy-Narrabeen Beach should be replenished is shown in Figure 11. Replenishment should be completed so that the limit of the profile closest to the shore along the length of the replenished area has a smooth embayed shape. Having areas which protrude could lead to rip currents developing and increased concentrated erosion adjacent to these areas. During summer and autumn there is likely to be prevailing conditions that would lead to longshore transport to the south (Harley et al., 2011). Additionally, access to Collaroy-Narrabeen Beach for replenishment is limited to Mactier Street. For this reason replenishment should start at Mactier Street and continue south until excavated materials runs out. If there is enough sand, areas to the north of Mactier Street can be replenished.

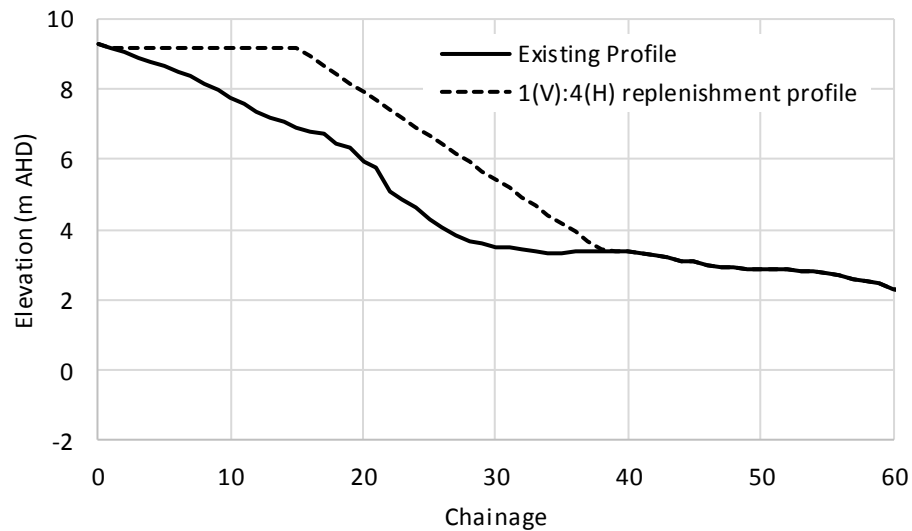


Figure 6: Indicative replenishment profile overlain on a cross section taken at Narrabeen Street on 13 June 2018 with a volume of 55 m³/m

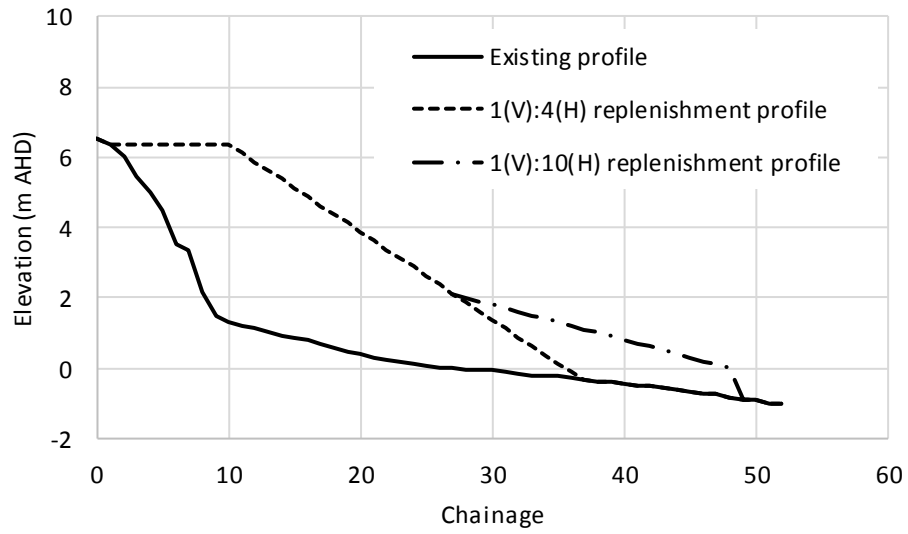


Figure 7: Indicative replenishment profile overlain on a cross section taken at Wetherill Street on 13 June 2018 with a volume of 115 m³/m



Figure 8: Erosion as seen from Mactier Street looking north on 13 July 2018



Figure 9: Erosion as seen from Wetherill Street looking north on 13 July 2018



Figure 10: Erosion as seen from Wetherill Street looking south on 13 July 2018



Figure 11: Beach replenishment location

5 Recommendations

5.1 Additional lagoon excavation

Council has expressed an aspirational excavation target of 50,000 m³ from Narrabeen lagoon. In order to increase the volume of sand excavated within Narrabeen Lagoon from 39,100 m³ to 50,000 m³ it is feasible that the excavation limit could be lowered at specific locations as shown in Figure 12. It is estimated that approximately 15,000 m³ of sand is available in these locations. Higgs (1977) found that marine sand was deposited to a depth below the bed of 1.5 m west of Ocean Street bridge and 1.2 m to the east. Core samples taken as a part of this investigation did not have the spatial resolution to determine if sand was of acceptable quality for large scale excavation. Ideally, sand samples in these areas would be obtained prior to any excavation to ensure they are suitable for beach replenishment. To expedite the process, a suitably qualified coastal engineer could supervise the excavation of sand in these areas to ensure its quality. There is potential for suitable sand to be excavated on the east of Ocean Street bridge to an elevation of -1 m AHD and to an elevation of -2 m AHD on the west (see Figure 12). On the east where additional excavation is suggested to an elevation of -1 m AHD, there is a high likelihood that rock could be encountered. For this reason suitable checks should be conducted, alongside the inspection of sand quality, prior to excavating this area. These works would need to be in compliance with the REF. It is recommended that detailed surveys be undertaken to benefit future clearance operations should additional excavations be completed.

Excavation of a channel on the western side of Ocean Street bridge (As shown in Figure 12) will help alleviate erosion to the southern bank by redirecting flow through the centre of the lagoon. However, due to the nature of Narrabeen Lagoon being an ICOLL, the channel will infill as the lagoon tends to closure. Maintenance will be required to ensure the channel remains free from sand.

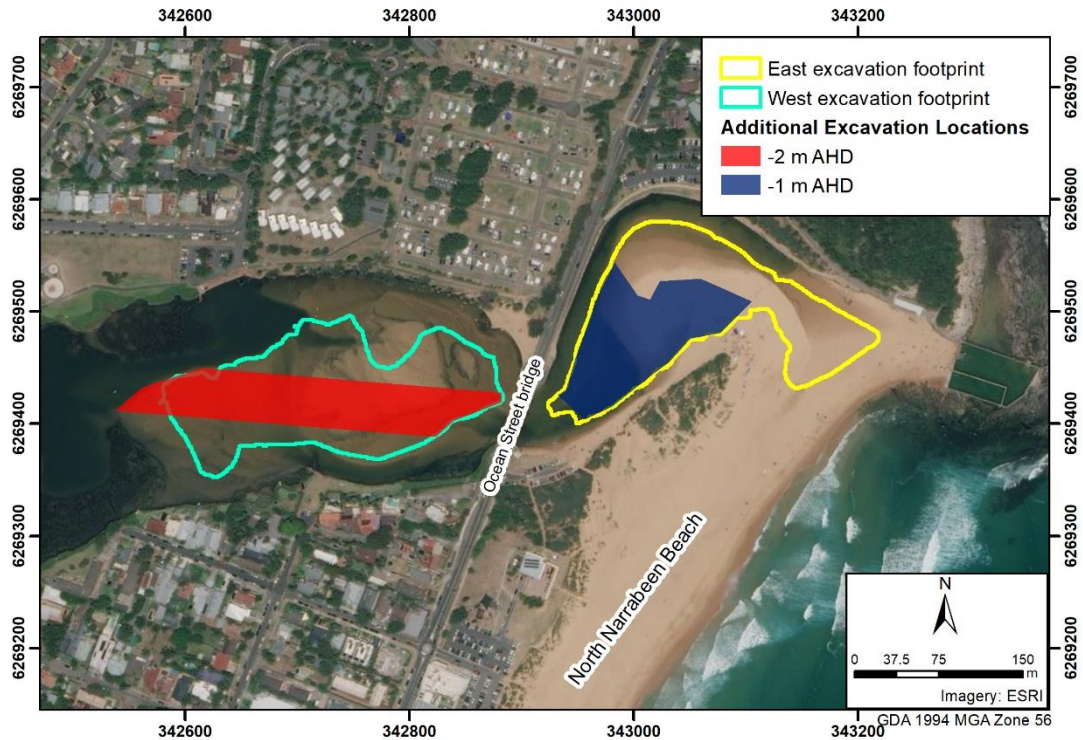


Figure 12: Locations where the excavation limit could be lowered

5.2 Beach replenishment survey

It is recommended that a survey of Collaroy-Narrabeen Beach be conducted immediately prior to any replenishment works. This data can then be used to accurately determine the volume of sediment needed for replenishment at each location along the beach.

6 References

Al-Hashemi, H.M.B. and Al-Amoudi, O.S.B., 2018. A review on the angle of repose of granular materials. Powder Technology.

Cardno, 2011. Narrabeen Lagoon entrance Clearance Works Review of Environmental Factors. Prepared for Warringah Council, February 2011.

Cardno, 2012. Narrabeen Lagoon Entrance Clearance Post Completion Report. Prepared for Warringah Council, February 2012.

Cardno, 2016. Narrabeen Lagoon entrance Clearance Works Review of Environmental Factors. Prepared for Warringah Council, January 2016.

Cardno, 2017. Narrabeen Lagoon Entrance Clearance Post Completion Report. Prepared for Warringah Council, February 2017.

Craig and Rhodes, 2002. Bathymetric survey data of Narrabeen lagoon. Craig and Rhodes surveyors, engineers, planners.

Eco Logical Australia (ELA), 2018. Seagrass Mapping and Validation – Narrabeen Lagoon entrance.

Harley, M.D., Turner, I.L., Short, A.D. and Ranasinghe, R., 2011. A reevaluation of coastal embayment rotation: The dominance of cross-shore versus alongshore sediment transport processes, Collaroy-Narrabeen Beach, southeast Australia. Journal of Geophysical Research: Earth Surface, 116(F4).

Higgs, K., 1977. Narrabeen Lagoon: A preliminary assessment of the suitability of Narrabeen Lagoon bed material for nourishment of Narrabeen and Collaroy Beaches. WRL Technical Report 2017/09.

Kulmar, M. A., Hurst, A. M., Gordon, A. D., 1989. Narrabeen Lagoon Entrance Study. Manly Hydraulics Laboratory, Public Works Department, N.S.W., Technical report. MHL552.

Morris, B.D., 2010. Infilling and sedimentation mechanisms at intermittently open-closed coastal lagoons.

Phillips, M.S., Harley, M.D., Turner, I.L., Splinter, K.D. and Cox, R.J., 2017. Shoreline recovery on wave-dominated sandy coastlines: the role of sandbar morphodynamics and nearshore wave parameters. *Marine Geology*, 385, pp.146-159.

Turner, I.L., Harley, M.D., Short, A.D., Simmons, J.A., Bracs, M.A., Phillips, M.S. and Splinter, K.D., 2016. A multi-decade dataset of monthly beach profile surveys and inshore wave forcing at Narrabeen, Australia. *Scientific data*, 3, p.160024. <http://dx.doi.org/10.1038/sdata.2016.24>.

WRL, 2018, WRL Letter Report: Survey and Analysis of Narrabeen Lagoon Entrance Shoal, WRL Ref: WRL2018034 LR20180615, 15 June 2018.

Appendix A Narrabeen Lagoon excavation cross-sections

Narrabeen Lagoon Clearance Operation 2018



Imagery: WRL 29 May 2018

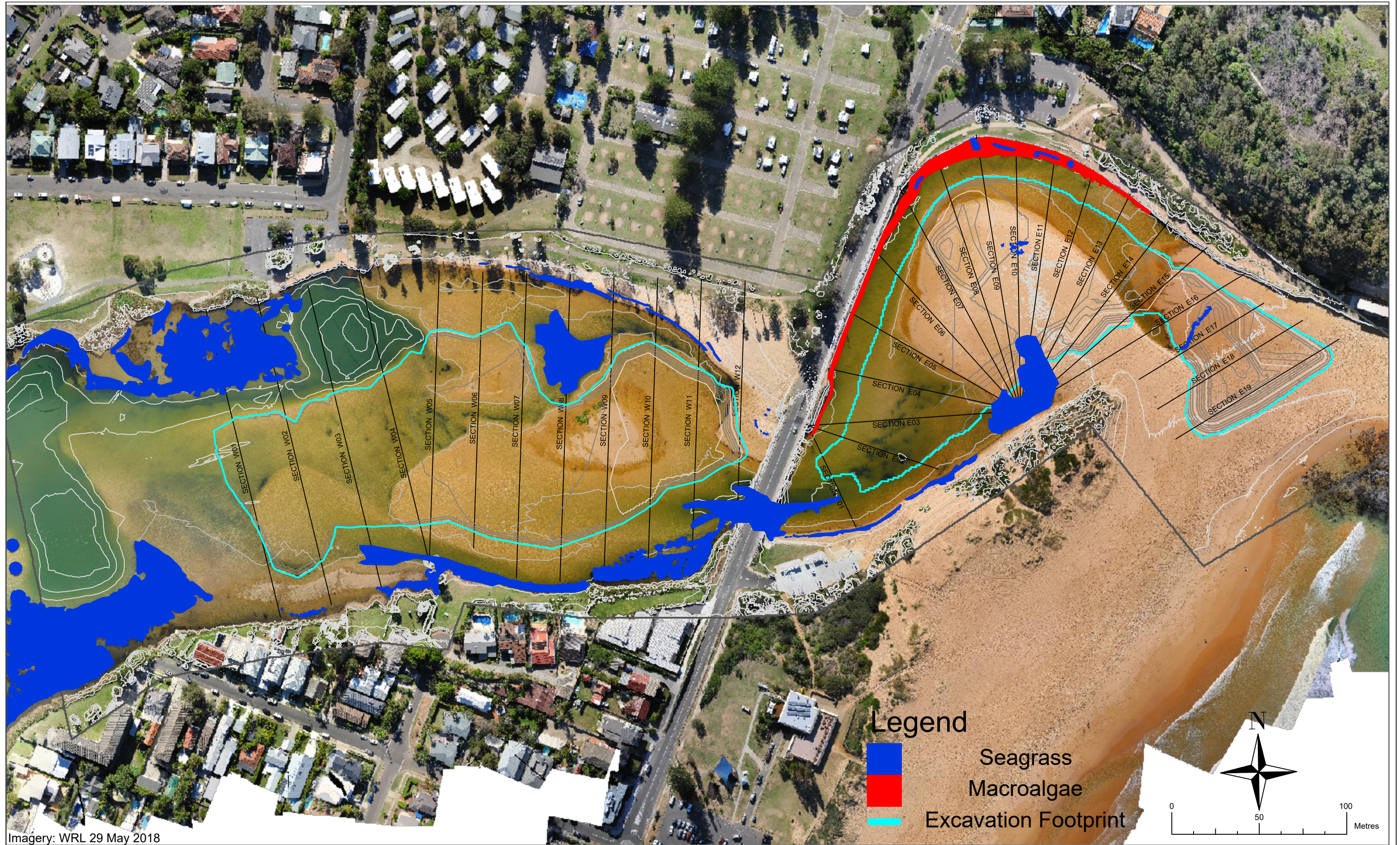
1. All drawings should to be read alongside WRL Technical Report 2018/16
2. All elevations are in metres Australian Height Datum
3. It is the contractors responsibility to ensure that all sediment removed is of suitable quality for beach replenishment
4. Cross-sections east of the Ocean Street bridge are close to the rock shelf and pre-excavation checks should be conducted to ensure the rock shelf is not damaged
5. Calculated excavation volume has been taken from previously excavated areas and is assumed to be comprised of sediments deposited in the lagoon from Narrabeen Beach
6. Volumes have been calculated from a fit-for-purpose bathymetric survey undertaken between May 29, 2018 and June 13, 2018. Sediment may have moved since this survey altering cross-section profiles
7. There is seagrass within the footprint of the excavation to the east of Ocean Street bridge. This document does not provide approval for damaging or removing this seagrass
8. Any requirements of a review of environmental factors should be considered alongside these drawings
9. All cross-sections are displayed left bank to right bank looking downstream towards the sea

Revision notes:

Rev:	Date:	Notes:
1	16/07/2018	Draft for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT	Project: Narrabeen Lagoon entrance clearance operation
Client: Northern Beaches Council	Drawing Title: WRL2018050Cover

Page: 1 of 25
Vertical Scale @ A3: N/A
Horizontal Scale @ A3: N/A



Imagery: WRL 29 May 2018

Revision notes:		
Rev:	Date:	Notes:
1	16/07/2018	Draft cross-section plan for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-section plan for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT	Project: Narrabeen Lagoon entrance clearance operation
Client: Northern Beaches Council	Drawing Title: WRL2018050PLAN

Page: 2 of 25	Vertical Scale @ A3: N/A
Horizontal Scale @ A3: 1:2000	

UNSW SYDNEY
Water Research Laboratory
School of Civil and Environmental Engineering

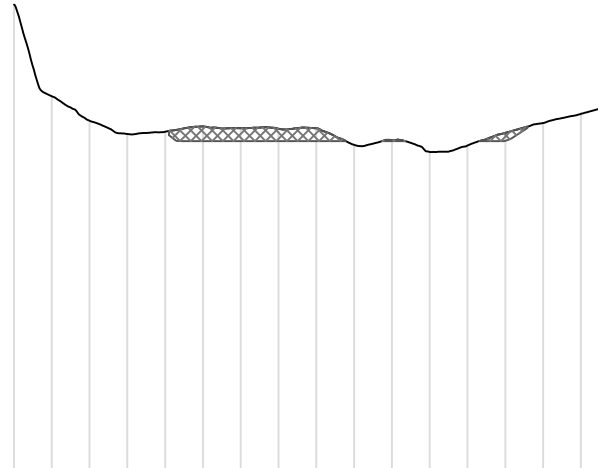
Section E01



Datum = -10 m AHD

Existing	2.74	0.31	-0.48	-0.45	-0.44	-0.57	-0.71	-0.87	-0.94	-0.88	-0.54	-0.30	0.08
Excavation					-0.77	-0.80	-0.80						
Difference					0.34	0.23	0.09						
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60

Section E02



Datum = -10 m AHD

Existing	2.81	0.38	-0.26	-0.61	-0.55	-0.41	-0.46	-0.47	-0.46	-0.90	-0.77	-1.09	-0.92	-0.58	-0.32	-0.08
Excavation						-0.80	-0.80	-0.80	-0.80					-0.79		
Difference						0.39	0.34	0.33	0.34					0.21		
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area

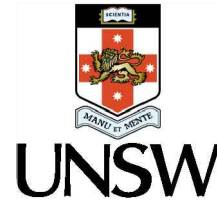
Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

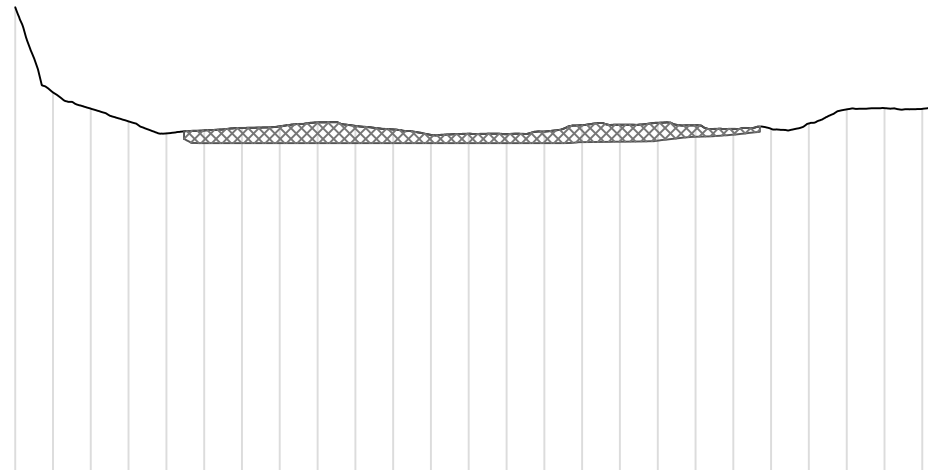
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS1

Page: 3 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



Water Research Laboratory
School of Civil and Environmental Engineering

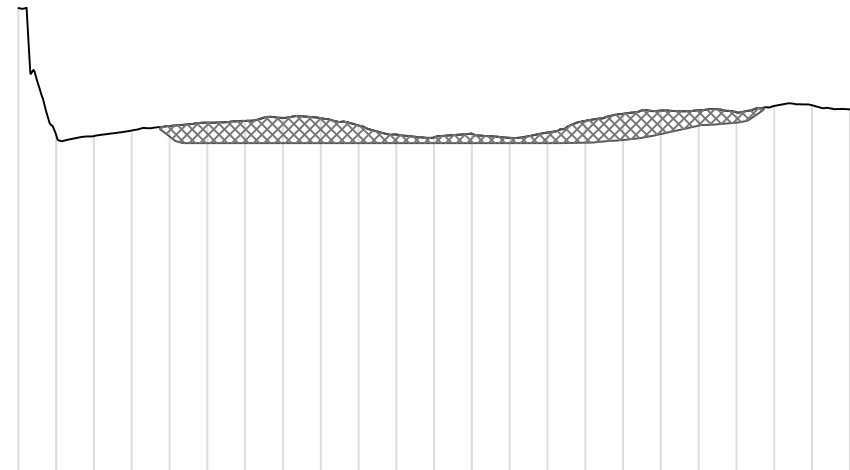
Section E03



Datum = -10 m AHD

Existing	2.79	0.54	0.11	-0.23	-0.54	-0.80	-0.46	-0.40	-0.36	-0.25	-0.34	-0.44	-0.58	-0.55	-0.56	-0.50	-0.33	-0.31	-0.26	-0.33	-0.42	-0.42	-0.28	0.09	0.12	0.10
Excavation						-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.78	-0.76	-0.74	-0.63	-0.58					
Difference						0.34	0.40	0.44	0.55	0.46	0.36	0.22	0.22	0.25	0.24	0.30	0.45	0.45	0.47	0.30	0.15					
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	

Section E04



Datum = -10 m AHD

Existing	2.77	-0.59	-0.61	-0.47	-0.35	-0.26	-0.21	-0.13	-0.14	-0.33	-0.58	-0.65	-0.55	-0.66	-0.52	-0.21	-0.03	0.06	0.07	0.02	0.18	0.20	0.09	
Excavation					-0.62	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.79	-0.72	-0.56	-0.34	-0.26				
Difference					0.28	0.54	0.59	0.67	0.66	0.47	0.22	0.15	0.25	0.14	0.28	0.58	0.69	0.62	0.41	0.27				
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area


Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

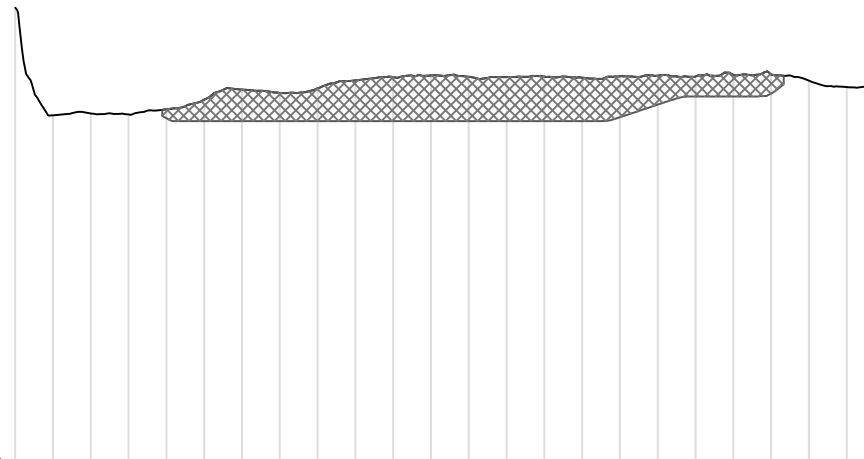
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS2

Page: 4 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



Water Research Laboratory
School of Civil and Environmental Engineering

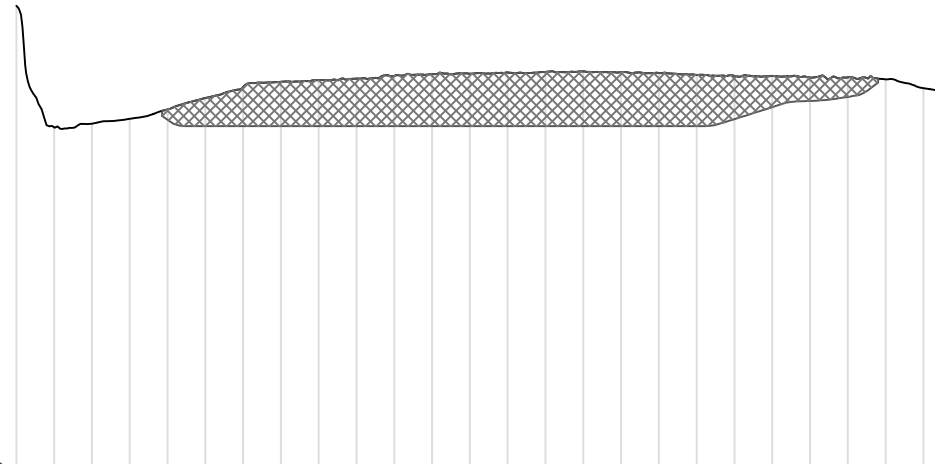
Section E05



Datum = -10 m AHD

Existing	2.20	-0.65	-0.60	-0.62	-0.49	-0.23	0.03	-0.05	0.06	0.28	0.36	0.41	0.37	0.37	0.35	0.39	0.40	0.38	0.42	0.44	0.27	0.10	
Excavation					-0.72	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.70	-0.36	-0.15	-0.15	-0.07			
Difference					0.24	0.57	0.83	0.74	0.86	1.08	1.16	1.21	1.17	1.17	1.15	1.08	0.77	0.53	0.57	0.51			
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110

Section E06



Datum = -10 m AHD

Existing	2.38	-0.83	-0.74	-0.60	-0.36	-0.06	0.23	0.37	0.42	0.46	0.53	0.58	0.58	0.62	0.63	0.65	0.63	0.61	0.55	0.53	0.49	0.49	0.44	0.20	
Excavation					-0.63	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	
Difference					0.27	0.74	1.03	1.17	1.22	1.26	1.33	1.38	1.38	1.42	1.43	1.45	1.43	1.41	1.35	1.15	0.62	0.30	0.35	0.20	
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area

Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

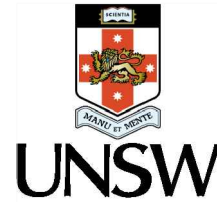
Revision notes:

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

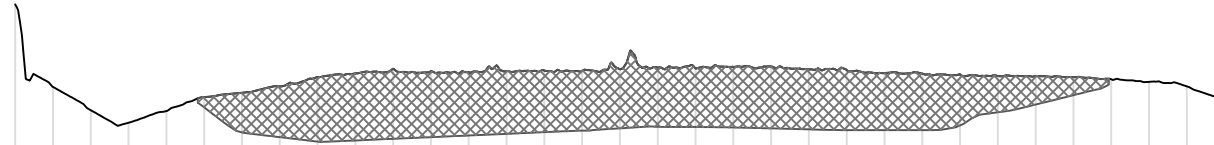
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS3

Page: 5 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



Water Research Laboratory
School of Civil and Environmental Engineering

Section E09



Datum = -10 m AHD

Existing	2.53	0.34	-0.27	-0.60	-0.30	0.07	0.19	0.35	0.60	0.70	0.82	0.76	0.74	0.76	0.78	0.76	0.81	0.85	0.83	0.87	0.88	0.81	0.79	0.71	0.70	0.67	0.63	0.63	0.60	0.54	0.48	0.36
Excavation						-0.20	-0.86	-0.99	-1.10	-1.07	-1.03	-0.99	-0.94	-0.90	-0.85	-0.81	-0.75	-0.71	-0.72	-0.73	-0.75	-0.78	-0.80	-0.80	-0.80	-0.79	-0.68	-0.33	-0.12	0.12		
Difference						0.27	1.05	1.34	1.70	1.77	1.85	1.74	1.68	1.66	1.63	1.58	1.56	1.57	1.55	1.60	1.64	1.59	1.59	1.51	1.50	1.35	0.96	0.75	0.48	0.36		
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area


Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

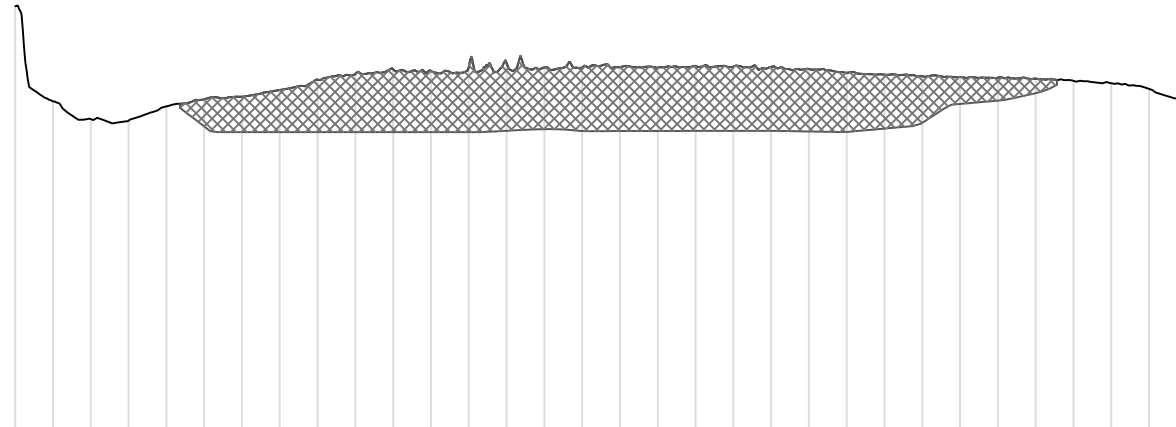
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS5

Page: 7 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



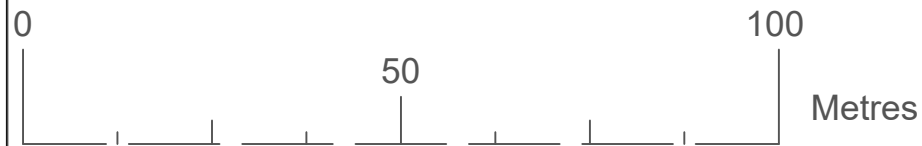
Water Research Laboratory
School of Civil and Environmental Engineering

Section E10



Datum = -10 m AHD

Existing	2.53	0.01	-0.46	-0.49	-0.12	0.07	0.14	0.31	0.59	0.74	0.86	0.82	0.92	1.03	0.91	0.91	0.92	0.91	0.94	0.93	0.93	0.87	0.77	0.68	0.66	0.64	0.61	0.56	0.49	0.34		
Excavation						-0.65	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.77	-0.72	-0.77	-0.77	-0.77	-0.77	-0.77	-0.77	-0.78	-0.80	-0.71	-0.55	-0.06	0.03	0.23				
Difference						0.72	0.94	1.11	1.39	1.54	1.66	1.62	1.72	1.79	1.63	1.68	1.69	1.68	1.71	1.70	1.70	1.65	1.57	1.43	1.23	0.71	0.61	0.38	0.61	0.56	0.49	0.34
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area


Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

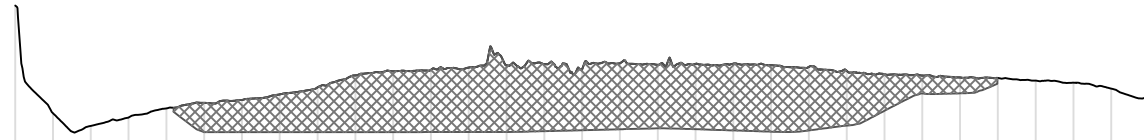
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS6

Page: 8 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



Water Research Laboratory
School of Civil and Environmental Engineering

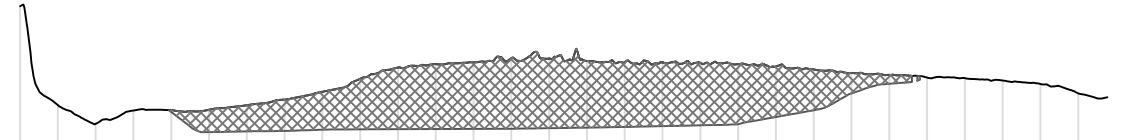
Section E11



Datum = -10 m AHD

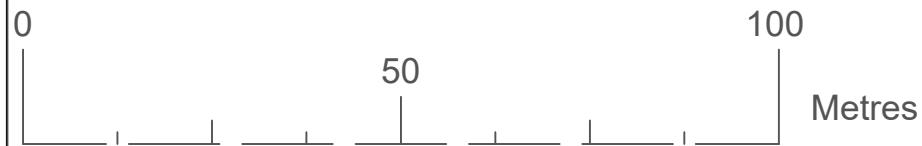
Existing	2.55	-0.30	-0.64	-0.41	-0.17	-0.03	0.05	0.20	0.38	0.70	0.81	0.85	0.91	0.96	1.00	0.86	1.02	0.98	1.00	0.73	0.64	0.63	0.56	0.51	0.35					
Excavation						-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.80	-0.78	-0.75	-0.73	-0.70	-0.72	-0.72	-0.76	-0.79	-0.75	-0.63	-0.24					
Difference						0.77	0.85	1.00	1.18	1.50	1.61	1.65	1.71	1.76	1.77	1.61	1.75	1.68	1.73	1.76	1.76	1.68	1.56	1.45						
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145

Section E12



Datum = -10 m AHD

Existing	2.53	-0.09	-0.58	-0.23	-0.22	-0.21	-0.09	0.06	0.27	0.61	0.91	1.00	1.04	1.15	1.15	1.08	1.05	1.04	1.03	1.00	0.94	0.86	0.77	0.71	0.64	0.62	0.56	0.47	0.22	
Excavation					-0.27	-0.80	-0.78	-0.77	-0.74	-0.73	-0.72	-0.72	-0.71	-0.71	-0.70	-0.68	-0.66	-0.64	-0.62	-0.59	-0.59	-0.40	-0.22	-0.22	-0.48	-0.48	-0.48	-0.48	-0.47	-0.22
Difference					0.05	0.59	0.69	0.83	1.00	1.34	1.63	1.72	1.76	1.86	1.85	1.76	1.71	1.68	1.65	1.59	1.59	1.50	1.08	1.08	1.24	1.24	1.24	1.24	1.24	
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area

Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Revision notes:

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

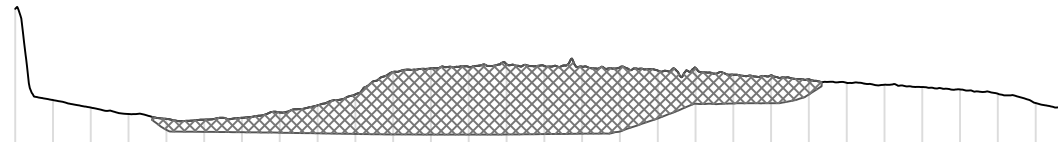
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS7

Page: 9 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



Water Research Laboratory
School of Civil and Environmental Engineering

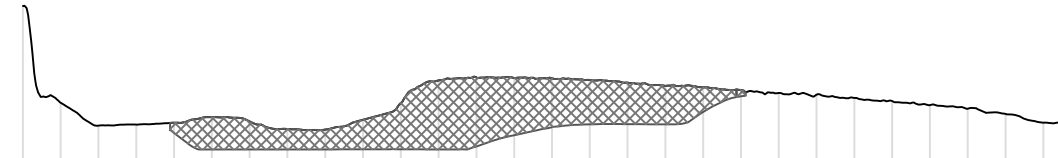
Section E13



Datum = -10 m AHD

Existing	2.69	0.29	0.09	-0.08	-0.21	-0.23	-0.18	-0.04	0.14	0.43	1.03	1.12	1.16	1.24	1.19	1.17	1.15	1.07	1.14	0.96	0.94	0.83	0.74	0.69	0.63	0.57	0.45	0.21
Excavation					-0.50	-0.56	-0.57	-0.58	-0.59	-0.61	-0.62	-0.63	-0.63	-0.63	-0.62	-0.60	-0.54	-0.20	0.19	0.19	0.20	0.20	0.43					
Difference					0.29	0.32	0.38	0.53	0.74	1.04	1.65	1.75	1.79	1.86	1.80	1.77	1.69	1.27	0.95	0.77	0.74	0.40						
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135

Section E14



Datum = -10 m AHD

Existing	3.19	0.64	0.03	0.06	0.11	0.26	0.14	-0.06	-0.07	0.19	0.63	1.23	1.31	1.29	1.28	1.24	1.17	1.08	1.04	0.97	0.90	0.85	0.76	0.68	0.58	0.48	0.34	0.11	
Excavation					-0.16	-0.60	-0.60	-0.59	-0.59	-0.60	-0.60	-0.60	-0.52	-0.22	-0.01	0.07	0.07	0.07	0.07	0.39	0.81								
Difference					0.27	0.86	0.74	0.54	0.52	0.78	1.22	1.82	1.82	1.51	1.29	1.21	1.17	1.10	1.02	0.65	0.17								
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area

Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

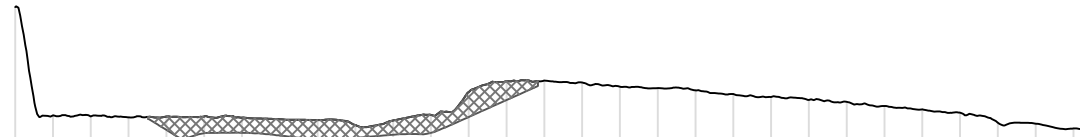
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS8

Page: 10 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



Water Research Laboratory
School of Civil and Environmental Engineering

Secion E15



Existing	Excavation	Difference	Chainage
3.33			0
0.46			5
0.44			10
0.41			15
0.43	0.08	0.35	20
0.43	-0.01	0.44	25
0.40	0.00	0.40	30
0.36	-0.07	0.43	35
0.34	-0.19	0.53	40
0.20	-0.14	0.34	45
0.33	-0.05	0.38	50
0.47	0.00	0.47	55
1.08	0.42	0.66	60
1.36	0.87	0.50	65
1.38			70
1.33			75
1.22			80
1.18			85
1.12			90
1.03			95
0.95			100
0.87			105
0.82			110
0.71			115
0.62			120
0.53			125
0.27			130
0.24			135
0.12			140

Section E16



Existing	Excavation	Difference	Chainage
1.69			0
0.70			5
0.67			10
0.64			15
0.57	-0.05	0.62	20
0.62	-0.18	0.80	25
0.60	-0.08	0.68	30
0.54	0.00	0.54	35
0.52	0.00	0.52	40
0.48	0.00	0.48	45
0.46	0.11	0.35	50
0.38			55
-0.09			60
0.20			65
1.32			70
1.48			75
1.51			80
1.43			85
1.25			90
1.19			95
1.08			100
0.96			105
0.91			110
0.82			115
0.76			120
0.64			125
0.51			130
0.38			135
0.16			140
0.14			145
0.11			150



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area

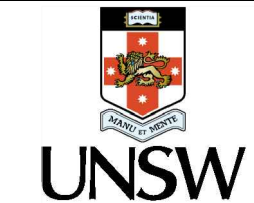
Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

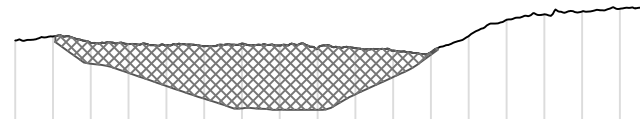
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS9

Page: 11 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000

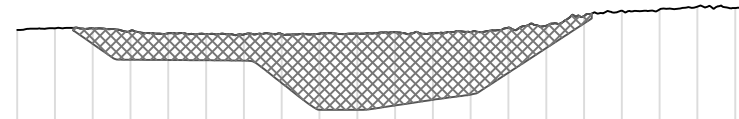


Water Research Laboratory
School of Civil and Environmental Engineering

Section E17



Section E18



Datum = -10 m AHD

Existing	0.93	1.04	0.87	0.84	0.80	0.78	0.85	0.80	0.73	0.73	0.67	0.62	1.05	1.48	1.63	1.70	1.77
Excavation		0.55	0.32	0.08	-0.27	-0.60	-0.86	-0.90	-0.90	-0.49	-0.03	0.56					
Difference		0.55	0.32	0.08	-0.27	-0.60	-0.86	-0.90	-0.90	-0.49	-0.03	0.56					
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80

Datum = -10 m AHD

Existing	1.22	1.26	1.25	1.19	1.13	1.10	1.09	1.11	1.12	1.12	1.16	1.13	1.16	1.28	1.33	1.58	1.72	1.76	1.83	1.80
Excavation		0.41	0.85	0.43	0.42	0.41	0.40	-0.19	-0.90	-0.90	-0.78	-0.63	-0.50	0.08	0.74	1.39				
Difference		0.41	0.85	0.43	0.42	0.41	0.40	-0.19	-0.90	-0.90	-0.78	-0.63	-0.50	0.08	0.74	1.39				
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area

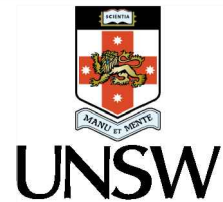
Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

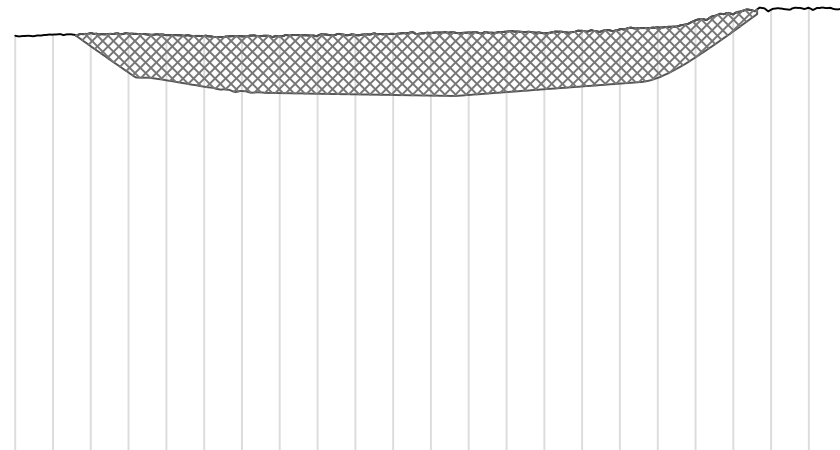
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS10

Page: 12 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



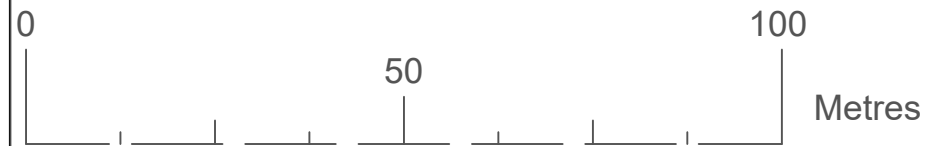
Water Research Laboratory
School of Civil and Environmental Engineering

Section E19



Datum = -10 m AHD

Existing	1.51	1.54	1.58	1.57	1.53	1.51	1.50	1.49	1.51	1.53	1.56	1.59	1.59	1.62	1.58	1.64	1.68	1.73	1.92	2.08	2.20	2.25
Excavation		0.35	0.53	0.33	0.16	0.05	-0.01	-0.02	-0.04	-0.06	-0.07	-0.05	0.02	0.09	0.17	0.24	0.40	0.94	1.63			
Difference																						
Chainage	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area


Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

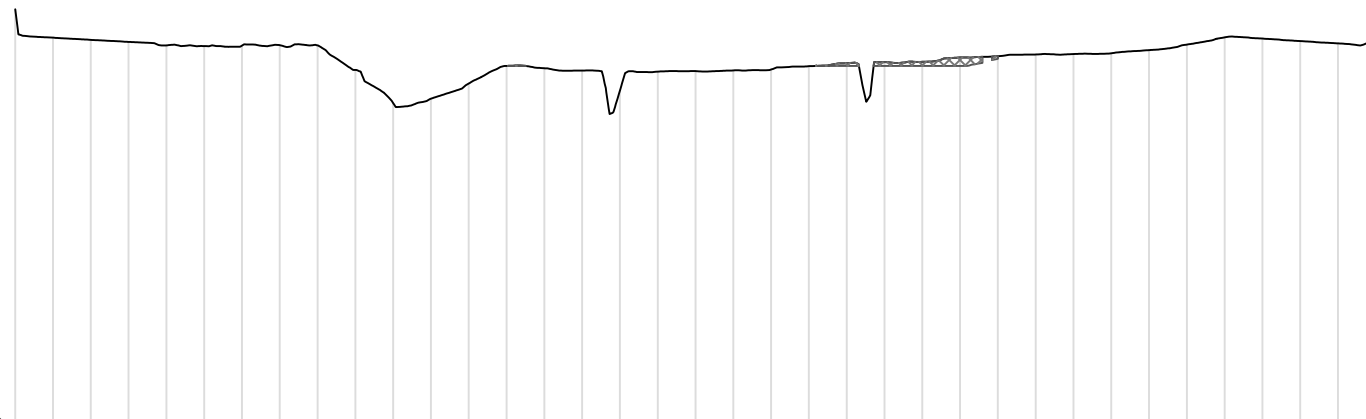
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS11

Page: 13 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



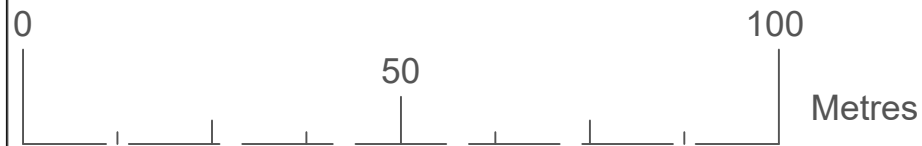
Water Research Laboratory
School of Civil and Environmental Engineering

Section W01



Datum = -10 m AHD

Existing	1.10	0.35	0.29	0.24	0.14	0.13	0.14	0.15	0.15	-0.51	-1.38	-1.26	-0.86	-0.40	-0.46	-0.52	-1.05	-0.55	-0.54	-0.52	-0.49	-0.41	-0.33	-0.30	-0.29	-0.18	-0.14	-0.10	-0.08	-0.07	0.02	0.17	0.36	0.32	0.26	0.20	0.30		
Excavation																																							
Difference																																							
Chainage	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180			



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area

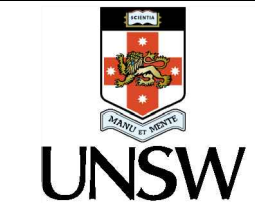
Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

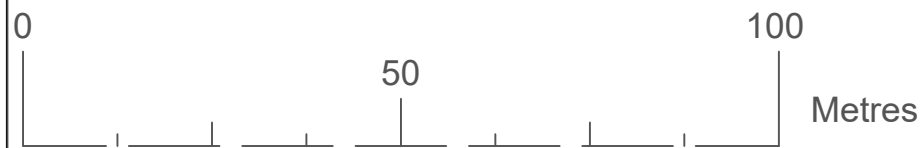
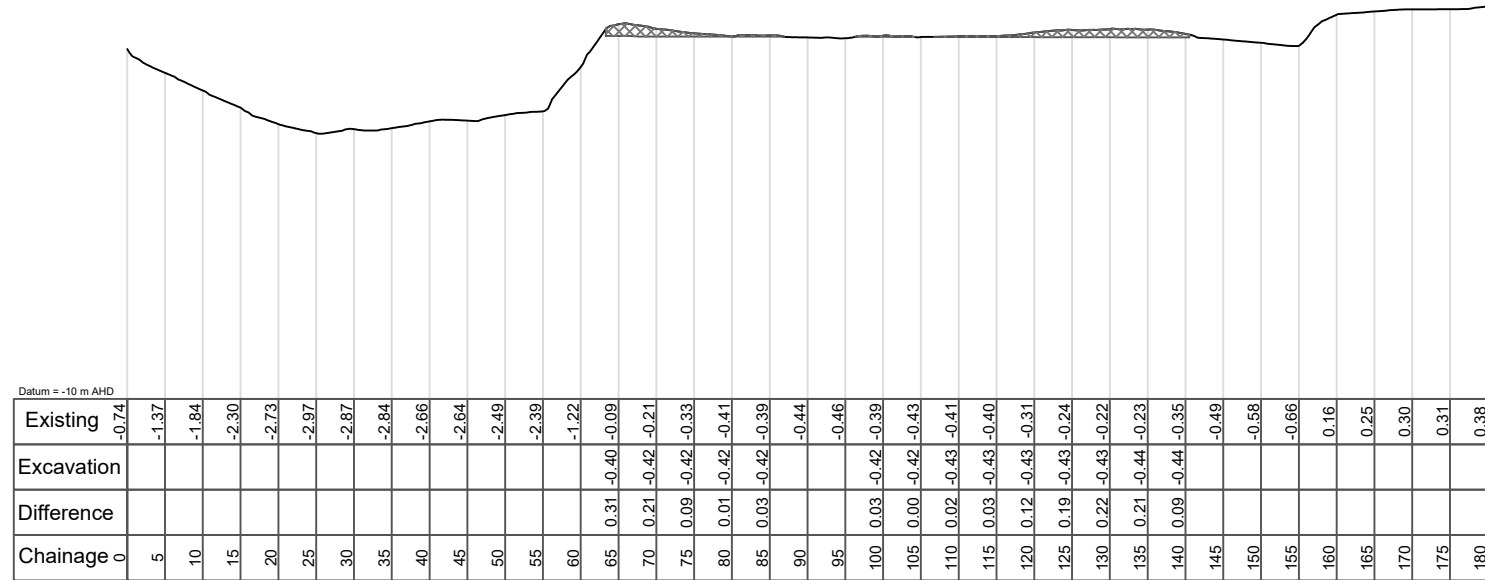
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS12

Page: 14 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



Water Research Laboratory
School of Civil and Environmental Engineering

Section W03



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area


Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Revision notes:		
Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

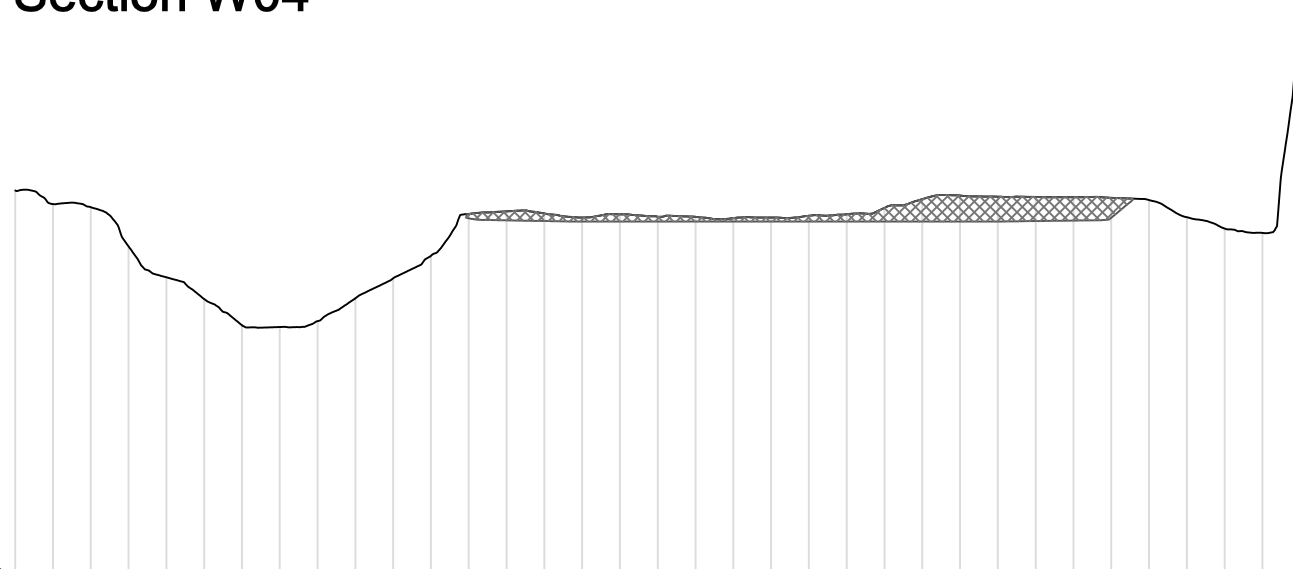
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS14

Page: 16 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



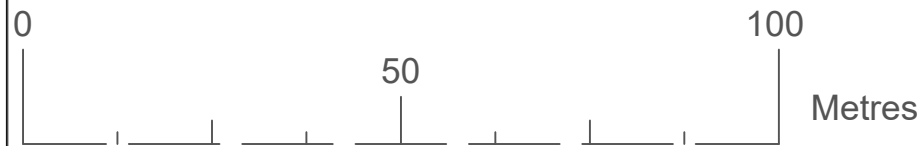
Water Research Laboratory
School of Civil and Environmental Engineering

Section W04



Datum = -10 m AHD

Existing	Excavation	Difference	Chainage
0.27			5
-0.09			10
-0.17			15
-1.21			20
-2.02			25
-2.60			30
-3.29			35
-3.34			40
-3.18			45
-2.58			50
-2.05			55
-1.45			60
0.12	-0.46	-0.35	65
0.24	-0.52	-0.28	70
0.20	-0.53	-0.34	75
0.11	-0.55	-0.44	80
0.19	-0.55	-0.36	85
0.13	-0.55	-0.42	90
0.12	-0.55	-0.42	95
0.09	-0.55	-0.45	100
0.11	-0.55	-0.44	105
0.15	-0.55	-0.39	110
0.19	-0.55	-0.36	115
0.36	-0.55	-0.19	120
0.59	-0.55	0.04	125
0.69	-0.55	0.14	130
0.66	-0.55	0.11	135
0.64	-0.53	0.10	140
0.62	-0.52	0.10	145
0.53	-0.45	0.08	150
0.02			155
-0.43			160
-0.73			165
-0.85			



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area


Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

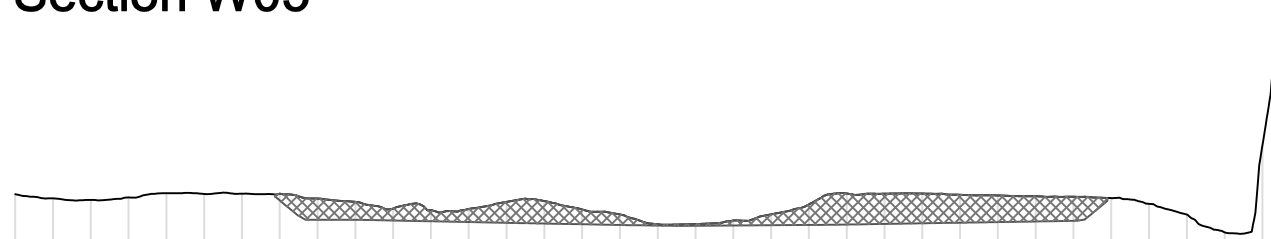
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS15

Page: 17 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



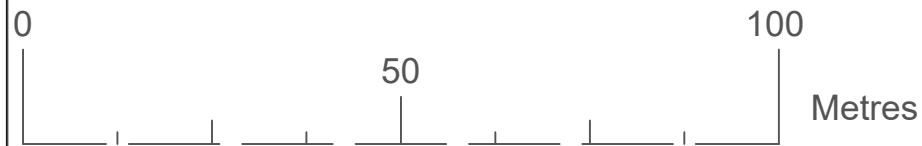
Water Research Laboratory
School of Civil and Environmental Engineering

Section W05



Datum = -10 m AHD

Existing	0.18	0.07	0.02	0.09	0.20	0.18	0.19	0.19	0.01	0.19	0.06	0.03	0.20	0.24	0.21	0.03	0.00	0.23	0.36	0.09	0.19	0.19	0.16	0.14	0.12	0.11	0.07	0.08	0.36	0.83	1.47			
Excavation									0.01		-0.50	-0.50	-0.52	-0.54	-0.56	-0.58	-0.60	-0.62	-0.64	-0.65	-0.63	-0.61	-0.59	-0.56	-0.55	-0.53								
Difference									0.18	0.19	0.56	0.53	0.52	0.54	0.56	0.55	0.60	0.62	0.64	0.65	0.63	0.61	0.59	0.56	0.55	0.53								
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area


Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

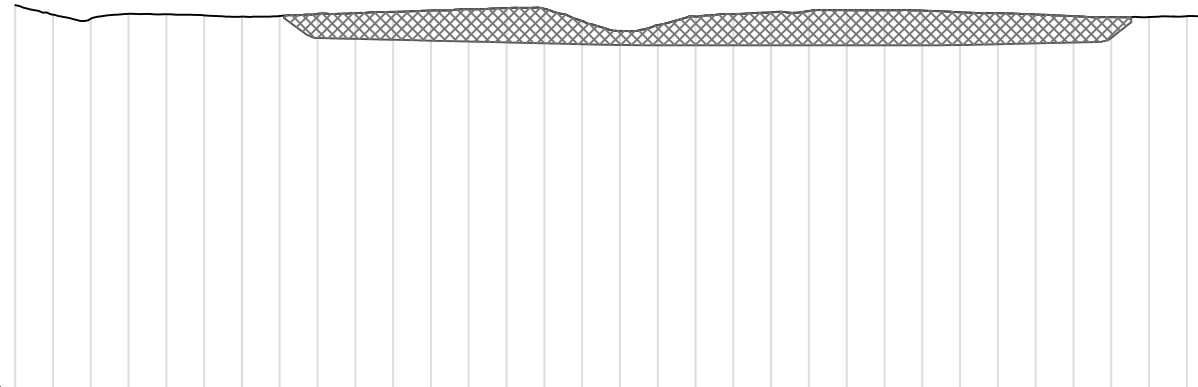
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS16

Page: 18 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



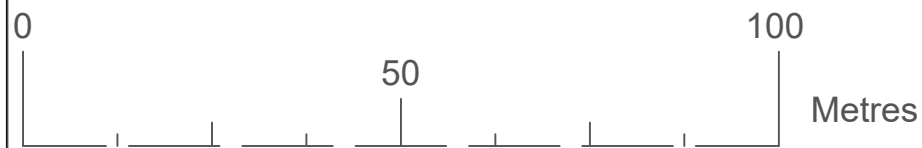
Water Research Laboratory
School of Civil and Environmental Engineering

Section W06



Datum = -10 m AHD

Existing	0.36	0.11	0.00	0.13	0.12	0.09	0.06	0.08	0.13	0.15	0.19	0.22	0.25	0.29	0.27	0.06	0.32	0.17	0.21	0.23	0.23	0.22	0.17	0.15	0.12	0.07	0.04	0.05	0.07		
Excavation									-0.51	-0.53	-0.55	-0.58	-0.60	-0.62	-0.65	-0.67	-0.69	-0.70	-0.70	-0.70	-0.70	-0.70	-0.69	-0.67	-0.65	-0.63	-0.50				
Difference									0.64	0.68	0.74	0.80	0.85	0.91	0.91	0.61	0.37	0.53	0.76	0.83	0.87	0.91	0.93	0.92	0.87	0.77	0.70	0.55			
Chainage	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area

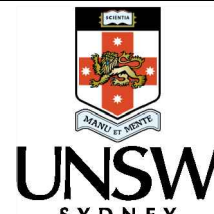
Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

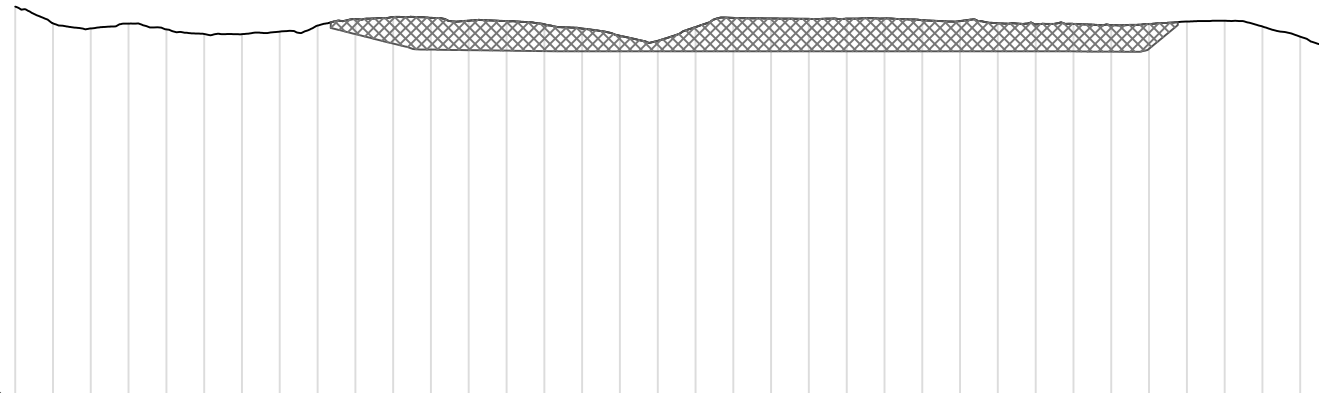
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS17

Page: 19 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



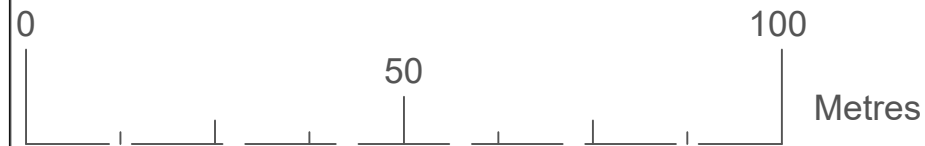
Water Research Laboratory
School of Civil and Environmental Engineering

Section W07



Datum = -10 m AHD

Existing	0.48	0.04	-0.10	0.03	-0.12	-0.24	-0.25	-0.18	-0.02	0.15	0.21	0.18	0.11	0.10	0.01	-0.10	-0.29	-0.42	-0.06	0.18	0.17	0.16	0.16	0.17	0.12	0.10	0.04	0.01	0.03	-0.01	0.02	0.09	0.11	-0.04	-0.31	
Excavation										-0.24	-0.50	-0.65	-0.67	-0.68	-0.69	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.70	-0.71	-0.63						
Difference										0.40	0.70	0.84	0.78	0.78	0.71	0.60	0.41	0.28	0.64	0.88	0.87	0.86	0.86	0.87	0.82	0.80	0.74	0.71	0.70	0.66	0.66	0.63	0.09	0.11	-0.04	-0.31
Chainage	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170		



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area

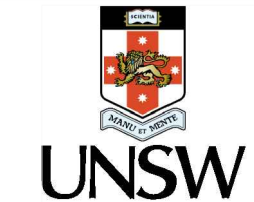
Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

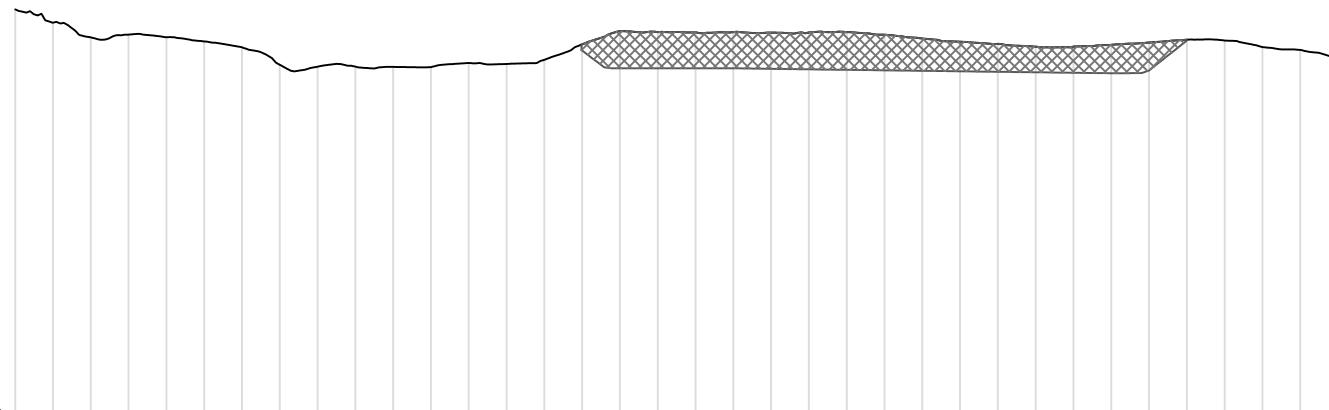
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS18

Page: 20 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



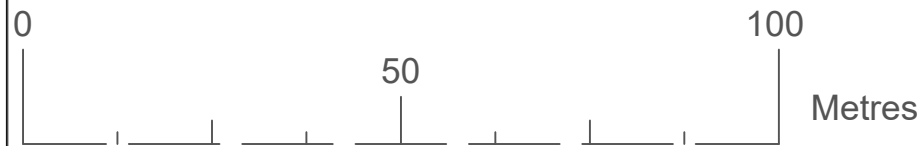
Water Research Laboratory
School of Civil and Environmental Engineering

Section W08



Datum = -10 m AHD

Chainage	Existing	Excavation	Difference
5	0.86		
10	0.51		
15	0.12		
20	0.19		
25	0.12		
30	0.01		
35	-0.14		
40	-0.61		
45	-0.66		
50	-0.66		
55	-0.67		
60	-0.56		
65	-0.59		
70	-0.47		
75	0.17	-0.23	-0.07
80	0.98	-0.70	0.28
85	0.96	-0.70	0.26
90	0.95	-0.70	0.25
95	0.96	-0.70	0.26
100	0.96	-0.71	0.24
105	0.97	-0.73	0.25
110	1.00	-0.74	0.26
115	0.94	-0.75	0.19
120	0.85	-0.77	0.09
125	0.78	-0.78	0.00
130	0.74	-0.79	-0.05
135	0.68	-0.80	-0.13
140	0.69	-0.82	-0.13
145	0.75	-0.83	-0.08
150	0.74	-0.76	-0.02
155			0.06
160			0.04
165			-0.14
170			-0.21
175			-0.46



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area


Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

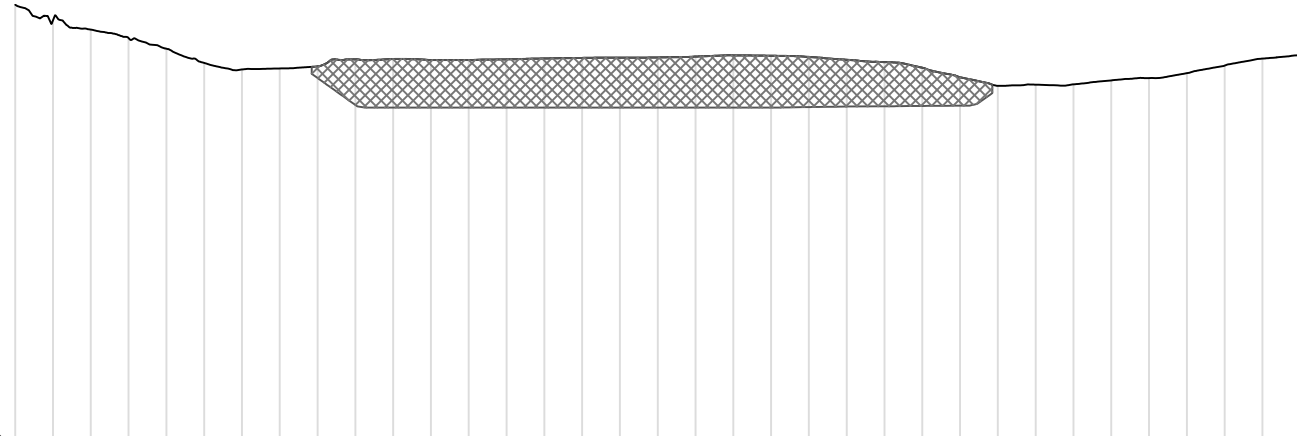
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS19

Page: 21 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



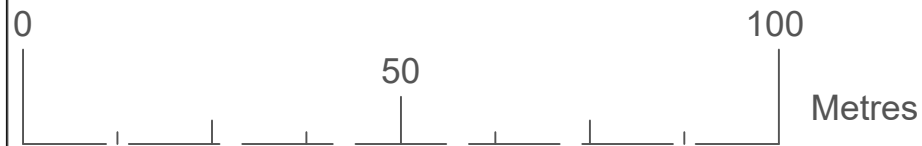
Water Research Laboratory
School of Civil and Environmental Engineering

Section W10



Datum = -10 m AHD

Chainage	Existing	Excavation	Difference
5	1.67		
10	1.26		
15	1.01		
20	0.79		
25	0.51		
30	0.13		
35	-0.04		
40	-0.02		
45	0.04		
50	0.23		
55	0.23		
60	0.21		
65	0.21		
70	0.23		
75	0.25		
80	0.26		
85	0.27		
90	0.28		
95	0.30		
100	0.33		
105	0.32		
110	0.29		
115	0.21		
120	0.15		
125	0.00		
130	-0.25		
135	-0.47		
140	-0.44		
145	-0.44		
150	-0.33		
155	-0.27		
160	-0.14		
165	0.06		
170	0.24		
170	0.34		



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area

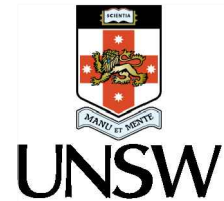
Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

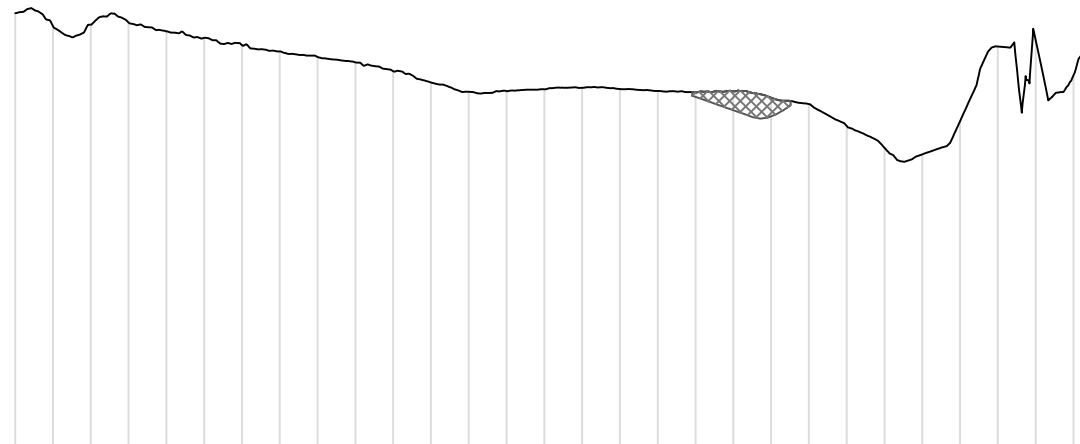
Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS21

Page: 23 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



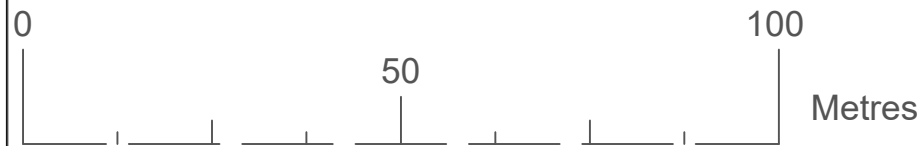
Water Research Laboratory
School of Civil and Environmental Engineering

Section W12



Datum = -10 m AHD

Existing	2.53	2.19	2.23	2.28	2.05	1.88	1.68	1.52	1.37	1.23	1.00	0.70	0.45	0.47	0.52	0.56	0.52	0.47	0.44	0.47	0.30	0.13	-0.45	-1.03	-1.20	-0.32	1.65	1.82	0.88
Excavation																			0.12	0.32	0.44								
Difference																													
Chainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140



Cross-sections are displayed from left bank to right bank looking downstream toward the ocean

Legend

— Existing surface

▨ Excavated area


Slopes are a maximum 1(V):6(H) and less where not perpendicular to the batter

Rev:	Date:	Notes:
1	16/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018
2	20/07/2018	Draft cross-sections for Narrabeen Lagoon clearance operation 2018 - New vegetation criteria
3	25/07/2018	Draft for Narrabeen Lagoon clearance operation 2018 - Updated colour scheme
4	31/07/2018	Drawings for Narrabeen Lagoon clearance operation 2018 issued with the Final Technical Report - No changes

Drawn by: TAT
Client: Northern Beaches Council

Project: Narrabeen Lagoon entrance clearance operation
Drawing Title: WRL2018050XS23

Page: 25 of 25
Vertical Scale @ A3: 1:200
Horizontal Scale @ A3: 1:1000



Water Research Laboratory
School of Civil and Environmental Engineering