Tuggerah Lakes Black Ooze

Removal investigations and feasibility study

Prepared for
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Abbreviations

Abbreviation	Description
ALS	ALS Global Pty Ltd
BOD	Biological Oxygen Demand
COC	Chain of custody
COPC	Chemicals of potential concern
CSM	Conceptual site model
DDD	Dichloro diphenyl dichloroethane
DDT	Dichloro diphenyl trichloroethane
DQO	Data quality objectives
ELA	Eco Logical Australia Pty Ltd
EMP	Environmental Management Plan
ES	Environmental Strategies Pty Ltd
ESA	Environmental Site Assessment

Abbreviation	Description
GPS	Global Positioning System
GPT	Gross pollutant trap
HASP	Health and Safety Plan
LCS	Laboratory control sample
LOR	Limit of reporting
NATA	National Association of Testing Laboratories
OCC	Organochlorine
OCP	Organochlorine Pesticides
OEH	Office of Environment and Heritage
OPP	Organophosphate Pesticides
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated Biphenyls
QA/QC	Quality assurance and quality control
REF	Review of Environmental Factors
RPD	Relative percent difference
SAC	Site assessment criteria
SD	Standard Deviation
TBT	Tributyltin
TOC	Total Organic Carbon

Executive summary

Introduction and methods

The black ooze investigations and feasibility study is one of the activities to be delivered under the "Tuggerah Lakes Clean-up Project" funded by the Australian Government under the *National Landcare Programme*. This present study investigates the feasibility for Council to undertake a pilot black ooze removal program.

The aim of this study is to determine if it is feasible to undertake a pilot ooze removal program at a selection of study sites in Tuggerah Lake.

The objectives of this study are to:

- assess nearshore areas of Tuggerah Lake for suitability of black ooze removal (including desktop and field based assessment)
- analyse the physical and chemical composition of the ooze
- provide recommended methods and costings for the pilot removal of ooze from priority sites
- provide technical information that will feed into a future Review of Environmental Factors (REF).

To meet the above project aim and objectives the following scope of works was undertaken:

Literature review

In the preparation of this report Eco Logical Australia (ELA) and Environmental Strategies (ES) have undertaken a literature review of available documents and reports pertaining to the formation, removal and management of black ooze in Tuggerah Lakes.

Field survey

Fieldwork associated with this study which included ecological and sediment mapping, and sediment sampling, required techniques which were largely visual to locate the features on the lake bottom.

Sediment Characterisation and Assessment

Preliminary assessment of the site/s has specifically sought to characterise and assess black ooze and sediments encountered in potential trial and control sites within Tuggerah Lake. In order to provide this assessment both chemicals of potential concern (COPC) and geotechnical properties of the materials have been analysed.

Key findings and recommendations

Site characterisation and assessment

The works completed to date as discussed within this report represent the first two phases of a five step process of contaminant assessment. The five phases are as follows:

- **Phase I – evaluation of existing information**
- **Phase II – sampling and analysis of sediments**
- *Phase III – elutriate and bioavailability testing*
- *Phase IV – toxicity and bioaccumulation testing*
- *Phase V – where necessary in rare cases, a weight-of-evidence assessment.*

Requirement for further assessment

As COPC were detected above the site assessment criteria (SAC), this study has identified the need for resampling the ooze to undertake elutriate testing, where OCPs were detected, to assess the potential for leaching and bioavailability in sediment in these sites.

Sediment removal methodology

It is considered that either small scale hydraulic dredging or fixed arm (articulated) mechanical dredging methodologies using a closed-bucket system have the greatest potential to minimise impacts while at the same time maximising environmental and economic outcomes associated with the project.

Material treatment and waste disposal

Dredged ooze, underlying sediments and water collected with the sediments will need to be captured, treated and assessed prior to waste classification and appropriate disposal. As the dredged sediments will be saturated, dewatering and separation of the liquid and solid components of the dredged material will need to be completed before waste classification and disposal options could be considered.

Ongoing maintenance and monitoring

A monitoring program before, during and periodically after ooze removal is recommended to evaluate ooze accumulation and sediment ecological health using sediment depth measurements, benthic infauna counts and seagrass presence.

An annual inspection of the lake foreshore for ooze is recommended to evaluate whether ooze is continuing to develop, where and the rate at which that may be occurring.

Feasibility of black ooze removal

Based on the results of laboratory testing, the discussions provided within this study, ooze mapping completed to date and isolation from large seagrass beds, it is concluded that the targeted removal of black ooze from Tuggerah Lakes is technically and physically feasible.

Costing

The estimate provided in this report is exclusive of GST and it is recommended that a contingency of ±30% should be applied to the estimate.

It is estimated that an ooze removal trial could be completed for a total of $ 166,000.

The costing estimate is based on a three day trial estimating that a total volume of 30 m^3 of black ooze would be dredged, treated, classified and disposed of appropriately.

Conclusion

Whilst it is technically feasible to undertake a pilot ooze removal program at a selection of study sites in Tuggerah Lake, the cost/benefit may render it unsuitable. The removal program outlined in this report will only remove a small portion of ooze and will not prevent future formation of ooze. Therefore this is considered to be a short term, geographically restricted option for specific treatment areas.

Supplementary works such as foreshore reshaping, the establishment of saltmarsh and the installation and/or upgrading of gross pollutant traps is considered likely to impact the potential for the future creation of ooze.

Ongoing monitoring is recommended to evaluate whether ooze is continuing to develop and the rate at which that may be occurring. Based on the results and discussions provided in this report it is concluded that the objectives of the study have been met.

1 Introduction

Background

The black ooze investigations and feasibility study is one of the activities to be delivered under the "Tuggerah Lakes Clean-up Project" funded by the Australian Government under the *National Landcare Programme*. In June 2013, the NSW Office of Environment and Heritage (OEH) completed the Council commissioned report titled *Recommendations for management of ooze in Tuggerah Lakes*, which outlines a number of recommended strategies for removal or reduction of the sources or conditions that favour ooze production. Council has been undertaking these strategies in various parts of the estuary over recent years. OEH have recommended areas that may be favourable to manual removal of ooze.

This present study investigates the feasibility for Council to undertake a pilot black ooze removal program. This is achieved by providing information on the composition and depth of black ooze, recommended removal methods and associated costings for targeted ooze removal at a selection of study sites. Council would like to determine the feasibility of a black ooze removal pilot program, in order to:

- remove or minimise plumes at the end of stormwater treatment zones, thus allowing nutrient enriched stormwater to enter the deeper lake basins
- to enhance amenity of the nearshore zone of the lakes where primary contact with the lakes occurs for the majority of the community.

Aim

The aim of this study is to determine if it is feasible to undertake a pilot ooze removal program at a selection of study sites in Tuggerah Lake.

Objectives

The objectives of this study are to:

- assess nearshore areas of Tuggerah Lake for suitability of black ooze removal (including desktop and field based assessment)
- analyse the physical and chemical composition of the ooze
- provide recommended methods and costings for the pilot removal of ooze from priority sites
- provide technical information that will feed into a future REF.

2 Methods

2.1 Literature review

In the preparation of this report ES have undertaken a literature review of available documents and reports pertaining to the formation, removal and management of black ooze in Tuggerah Lakes. Specifically two reports have provided a significant proportion of the background information and data used in the preparation of this report.

NSW OEH, June 2013 – An Assessment of 'Tuggerah Lakes Restoration Project' as a shoreline restoration strategy.

The major conclusions relevant to this study which were drawn from the above report are:

Results show that there is little consistent pattern in the location of ooze with respect to the Tuggerah Lakes Restoration Project (TLRP) restored shores. Occurrence of ooze is determined by a number of local factors such as physical processes due to aspect and localised hydrology, high nutrient and sediment loads. It is most likely that differences between ooze accumulation at 'restored sites' across the three lakes can be attributed to the different physical conditions of intensity of catchment pressure.

OEH research has also shown that there are a suite of conditions that lead to ooze formation. Shorelines with the following conditions are considered to be 'hot spots' for ooze formation:

- In protected areas with limited wave energy
- In areas which receive high nutrient sediment loads from stormwater runoff
- In areas with large wrack accumulations that impede water flow

Water quality data from the different sites show the importance of lake mixing to the health of the near shore zone. The most heavily degraded sites along the western shores of Lower Tuggerah Lakes experience very little mixing with lake basin water which, combined with high nutrients and sedimentation loads fuels ooze formation.

Most sites in Tuggerah Lake were influenced by high nutrient and sediment loads coming from the three major tributaries. High nutrient and sediment loads from the upper catchment and fringing urban catchment have continued to flow into the near shore zone of the lakes over the last twenty years. The prevalence of black ooze and oozey sediment are a direct result of catchment inputs, combined with localised hydrology at the site. These two factors, rather than 'restoration' of the area during TLRP are most likely to be the primary drivers of ooze accumulation in Tuggerah Lakes today.

NSW OEH, June 2013 – Recommendations for Management of Ooze in Tuggerah Lakes.

The major conclusions relevant to this study which were drawn from the above report are:

General considerations

- Ooze is a very loosely defined term and is used to cover a wide range of sediment types found in the near shore. Some ooze sediment will contain higher concentrations of toxic or problematic materials, while others will consist largely of fine organic sediments. As such, the risk of adverse environmental impacts of removal should be assessed on a case by case basis by sampling and analysis of the material to be removed.

- Ooze sediments may also occur in areas supporting seagrass and macroalgal habitats. Any targeted removal should consider the direct disturbance of these communities and relevant permission should be obtained from NSW Fisheries.
- Ooze accumulations come and go around the lake on seasonal time scales. Targeted removal is only a short term fix (witness the very brief benefit of the TLRP in the early 1990s).
- The cost of targeted removal of ooze (short term treatment of symptoms) should be weighed against the cost of management measures aimed at reducing urban pollution to the near shore and strategic wrack harvesting (long term treatment of causes).

Management of targeted removal of ooze sediments

- Deployment of sediment booms maybe beneficial in reducing sediment plume impacts on neighbouring near shore habitats.
- Prevailing weather conditions at the time of removal will determine the fate of dredging plumes. It would be beneficial to carry out sediment removal when conditions allow for the rapid dispersion of dredge plumes that escapes sediment booms.
- There needs to be careful consideration given to the appropriate disposal of removed material. Due to its potentially high iron monosulfide, nutrient and heavy metal contaminant contents, removed spoil represents an environmentally hazardous material.
- Spoil that is allowed to drain on the shore, will be exposed to oxygen and become acidic, potentially causing the leaching of contaminants to the surrounding area and groundwater.

Chemistry of ooze

- Materials of concern in ooze sediments include hydrogen sulphides, iron monosulfides, high concentrations of nitrogen and phosphorous and fines.

2.2 Field survey

Fieldwork associated with this study which included ecological and sediment mapping, and sediment sampling, required techniques which were largely visual to locate the features on the lake bottom. As such, the fieldwork was reliant on the prevailing conditions being favourable to support the works. These conditions included:

- light winds or the study area being protected from the prevailing winds
- low wave action
- low turbidity within the lake.

Fieldwork was scheduled to commence on 20 April 2015. This date coincided with the ‘super storm’ East Coast Low system which impacted the NSW central and northern coasts. A site visit undertaken by ELA and ES staff on 20 April 2015 to assess the prevailing conditions concluded that due to high winds, waves and turbidity within the lake caused by a combination of wave action and extremely high volumes of runoff received from the surrounding catchment, the fieldwork could not be successfully completed.

Over the ensuing period between the above site visit and fieldwork commencement, the lake was assessed on a number of occasions by both Council and ELA. Once the required conditions were assessed to have stabilised sufficiently fieldworks were rescheduled to commence. The revised commencement date for the fieldwork was 12 May 2015, and was completed over a seven day period from 12 to 18 May 2015.

A side effect of the storm conditions which occurred immediately prior to the fieldwork was that a fresh and visually uniform layer of silt was deposited into the lake. This fresh silt made visual differentiation of ooze from other sediments very difficult and required a revision of methods to locate the ooze, from a visual approach to a method based on physically probing the bottom sediments. This revision of methodology required more time and created greater disturbance of lake sediments, but the disturbance allowed ooze to be identified by gas emission and odour, as well as visually, largely overcoming any uncertainty in the extent of ooze formations.

As the extent of ooze formations was not as large and well defined as was expected from the literature review it is also likely the storm had some dispersing and mixing action on near-surface sediments across the lake, including ooze formations.

2.2.1 Weather

Weather conditions prevalent at the time of the storm activity as measured at the Norah Head AWS meteorological station (station number 61366) and which impacted the scheduling of fieldwork, can be summarised as follows:

- Rainfall – >180 mm over the four days from 20 to 23 April (shaded orange in **Table 1**). This is greater than the average total monthly rainfall for Norah Head in April (136.7 mm)
- Wind Speed – average wind speed for the same period was 87.5 km/h
- Temperature – this is not considered to have a significant effect on the fieldwork or the results obtained.

It should be noted that while the readings from Norah Head AWS are considered to be representative of the conditions at the Tuggerah Lake study sites, the Norah Head AWS is located further towards the coast (east) and to the north of the study sites. Thus, the conditions experienced at the study sites, which are located in a more protected area rather than directly on the coast, may have differed from the meteorological measurements summarised above.

Conditions experienced during the period of fieldworks (shaded green in **Table 1**) can be summarised as follows:

- Rainfall –7.8 mm over the seven days from 12 to 18 May
- Wind Speed – average wind speed for the same period was 41.3 km/h

Table 1: Weather conditions during survey from Norah Head AWS (61366) Lat. 33.28° S, Lon. 151.57° E. Sourced from BOM (2015)

Date	Min. temperature (°C)	Max. temperature (°C)	Max. wind speed (km/hr)	Rainfall (mm)
13th April	14.6	20.2	37	1.6
14th April	14.4	22.2	24	0
15th April	16.2	25.7	52	0
16th April	18.2	27.4	41	2.0
17th April	20.6	24.1	35	0
18th April	19.9	24.2	39	0
19th April	18.3	21.5	69	3
20th April	13.2	18.7	117	23.6
21th April	16.0	19.7	135	61.4
22th April	14.8	19.4	76	76.2
23th April	14.9	20.5	22	19.4
24th April	15.3	25.4	26	0

Date	Min. temperature (°C)	Max. temperature (°C)	Max. wind speed (km/hr)	Rainfall (mm)
25th April	16.4	25.9	65	0
26th April	12.3	18.0	39	22.4
27th April	12.6	18.1	39	0.6
28th April	13.0	18.6		0
29th April	12.5	18.1	46	
30th April	14.7	19.1	59	18.0
1st May	15.1	21.3	67	15.4
2nd May	16.6	21.9	48	5.6
3rd May	18.6	20.4	54	39.2
4th May	17.3	20.1	35	15.2
5th May	15.5	25.7	39	0.2
6th May	13.6	20.2	26	0.2
7th May	11.1	20.4	31	0
8th May	9.8	19.5	20	0
9th May	10	20.7	24	0
10th May	11.5	20.7	39	0
11th May	15.2	21	48	0
12th May	12.3	22.1	35	0
13th May	12.9	17.3	56	0
14th May	7.7	17.1	41	0
15th May	11.9	18.4	61	0
16th May	13.8	17.8	50	7
17th May	12.6	18.6	26	0.8
18th May	14.1	17.5	20	0
19th May	14.4	20	33	2.8
20th May	15.5	24.9	26	0
21th May	14.9	20.3	52	3
22th May	13.5	17.5	96	2.4
23th May	11.6	17.1	46	24.4
24th May	10.5	17.1	26	0.6
25th May	11.4	20.1	22	0
26th May	11	18.3	24	0

2.2.2 Site selection

The location and extent of ooze was not as apparent and widespread as expected. Vast lengths of near shore sediment lacked evidence of ooze. Very small patches occurred near most inflowing drainage channels. Other areas with accumulating wrack (dead seagrass and organic detritus) on shore, showed ooze-forming properties (smell and decomposing matter), but were not black ooze as had been characterised in OEH reports. The field team at first walked the near shore zone searching for ooze in Big Bay (March Street to Warner Ave, Tuggerawong) and Berkeley Vale. All patches of ooze were mapped with a *Getac* tablet with <1m GPS accuracy using *ArcPad* software, and transferred onto *ArcMap* desktop mapping software each night.

Given the initial lack of ooze, the field team switched from walking the near shore zone to a kayak-based probing technique. This technique involved probing the kayak's paddle deeply into the sediment to break into gaseous ooze. Bubbles emitted from the ooze were easily recognised using this method by their anoxic smell and duration of emission (the sediment would trickle-release bubbles for a short duration after being disturbed). Care was taken not to create bubbles from the paddle itself entering the water (those bubbles did not smell or last long). This was avoided by keeping the paddle blade submerged and using multiple jabs into the sediment.

Using the techniques above a map of ooze was developed. Discussions with Council during the survey period helped refine the site selection to eight locations: four trial sites, three control sites and one reference site. Trial sites were selected based on accessibility to trucks (usually Council gates and reserves) and workability of the foreshore (grassy land or car parks for dewatering activities). Control sites were selected based on proximity to trial sites, similar foreshore aspect and inaccessibility. The reference site had no ooze (except a very minor patch inside a small inflowing channel) and was selected because of its proximity to a group of trial/control sites.

2.2.3 Sediment sampling

Each sediment sampling area was inspected from the shoreline prior to measurement and sampling. Sampling and measurement of the black ooze / sediment was undertaken at a total of eight sites comprising four trial sites, three control sites and one reference site. At each site a total of four locations were sampled, representing a sampling regime of 16 trial samples, 12 control samples and four reference samples. In addition to the sampling and measurement of the ooze, the underlying sediments of the lake bed were sampled to allow assessment of the potential for the materials below the ooze-lakebed interface to be chemically impacted. Each sample location and the spatial extent of the ooze was recorded using a GPS. Ooze and reference sampling sites are shown in **Figure 1** and **Figure 2**.

Prior to sampling, identification of the ooze at each location was taken by probing the underlying sediments with a boat oar to release odorous gases from within the ooze. This method was required due to the difficulties in visually identifying ooze formations which have been discussed above in **Section 2.2**. Samples were collected from between the probing points so that the undisturbed surface of the ooze was subject to sampling.

The specialised sludge sampling equipment used is designed to retain samples from non-cohesive materials, including underwater sediment in shallow lakes, streams, and various types of impoundments with a capability of capturing an undisturbed sample. The equipment was used to take undisturbed samples up to 0.5 m thick in single use sealable plastic liners. This method of sampling ensures that the samples were to the extent possible undisturbed and were suitable for geotechnical and chemical analysis.

All samples were submitted to NATA accredited laboratories under chain of custody protocols. Chemical samples were submitted to ALS as the primary laboratory and geotechnical samples were submitted to SGS.

2.2.4 Seagrass mapping

Two scales of seagrass mapping were used. One aimed to find the nearest seagrass growing near the ooze sites. The second targeted the location of the largest, healthiest seagrass communities along the lake. Given the expansive area to cover, limited survey timeframe and shifting water clarity the seagrasses were mapped as broad zones depending on species, condition and cover, as deemed appropriate to what was present at the time.

Seagrass was identified at first by kayak with bathyscope underwater viewer- (in shallow or clear water), and pole-mounted underwater video camera (in deeper or turbid water). Seagrasses were identified to species, and characterised by their foliage cover and condition (shoot length, epiphyte growth and sedimentation). Seagrass patches growing close to the ooze sites were mapped on foot or kayak using a *Getac* tablet with <1m GPS accuracy. Larger seagrass communities further offshore were mapped as a near-shore boundary. Results were overlaid on aerial imagery and NSW Fisheries' *Marine Vegetation Map of Tuggerah Lake* (Creese et al. 2009) to identify common boundaries.

Seagrass mapping was challenging at times due to variable turbidity, which was heavily influenced by wind direction and speed. At times a clear water site quickly turned turbid as wind and wave direction shifted. Several sites were revisited during the survey period to complete seagrass mapping when water clarity improved.

2.2.5 Stormwater inflows

All stormwater inflow channels near the sites were mapped and photographed for background information. This study does not aim to investigate the relationship between catchment size, use or imperviousness with ooze formation. Rather the study is concentrated on the feasibility of targeted removal of the black ooze from defined areas within Tuggerah Lake.

2.2.6 Accessibility and workability

Access to a site was deemed suitable if there was a Council gate and cleared thoroughfare for a truck to drive to the shore. Most saltmarsh in the survey area was not considered a constraint to machinery access if alternative access was possible, or if it was narrow, slashed, weedy and comprised of hardy species (e.g. *Juncus kraussii*). Footpaths crossings were considered accessible to vehicles (except narrow or timber bridges) but we acknowledge paths may be damaged by the trucks.

Workability of a site was identified as an open space close to the site that could accommodate truck turning, sediment dewatering and other staging areas needed for ooze removal. Both access and workability were assessed and mapped on foot.

2.3 Sediment characterisation and assessment

2.3.1 Data quality objectives (DQO)

The DQO process is a systematic planning tool based on the scientific method for establishing criteria for data quality and for developing data collection designs. The DQO defines the experimental process required to test a hypothesis. The DQO process has been developed to ensure that efforts relating to data collection are cost effective, by eliminating unnecessary, duplicative or overly precise data whilst at the same time, ensuring the data collected is of sufficient quality and quantity to support defensible decision making.

It is recognised that the most efficient way to accomplish these goals is to establish criteria for defensible decision making before data collection begins and develop a data collection design based on these criteria. By using the DQO process to plan the investigation effort, the relevant parties can improve the effectiveness, efficiency and defensibility of a decision in a resource and cost effective manner.

The DQO process consists of seven steps, which are designed to clarify the study objectives, define the appropriate type of data and specify tolerable levels of potential decision errors.

The DQOs for this Environmental Site Assessment (ESA) are provided in **Table 2** and were derived in accordance with AS 4482.1-1997.

Table 2: Project Data Quality Objectives

State the Problem	To assess feasibility of targeted removal of black ooze accumulations within the confines of Tuggerah Lake.
Identify the Decision	If black ooze was identified on the site: • What is the extent of the ooze? • Does any contamination within the ooze occur at concentrations that pose or may pose an unacceptable liability or risk to the environment and/or human health? • Do methodologies exist which would enable the targeted removal of black ooze within the anticipated setting?
Identify the Inputs to the Decision	Key data required to resolve the project problem included: • Concentrations of contaminants of concern exceeding the adopted screening criteria in the sediment collected in the study area. • The presence or otherwise of sensitive ecological communities in the study area. • Identifying appropriate areas for staging potential removal works. • Establishing the physical properties of the material being targeted for removal. Based on the desktop searches, the site history and the current site condition the contaminants of concern were identified as per **Section 2.3.2** of this assessment This study has applied the Australian Government – National Assessment Guidelines for Dredging (2009), NAGD 2009 to the site assessment criteria to assess the sediment results.
Define the Study Boundaries	The intrusive ESA was limited to sediments within the physical site boundaries of a total of four trial sites, three control sites and one reference site, as shown in **Figure 1** and **Figure 2**. The vertical extent of the study boundaries was limited to a maximum depth of 0.1 m below the maximum depth of black ooze encountered. The temporal boundaries of the study were limited to the date that the investigation was undertaken (12 to18 May 2015).
Develop a Decision Rule	If the concentrations of contaminants in soil and groundwater are reported to be below the relevant adopted guidelines, then the soil will be deemed suitable to remain on site for the proposed land use. If, however, the concentration of one or more contaminants is greater than the guidelines, then further investigation will be required to laterally and vertically delineate the extent of the contamination and recommendations made for the management of the contamination to make the site suitable for the proposed use.
Specify Tolerable Limits on Decision Errors	The acceptable limits for sediments without elutriate are as follows: • Recovery of matrix spikes and surrogate spikes is as per the laboratory's Quality Assurance targets accepted under their National Association of Testing Authorities (NATA) accreditation. Precision is measured using the standard deviation 'SD' or Relative Percent

	Difference '%RPD'. Replicate data for field duplicates of organics is expected to be as follows: • RPD criteria of 50% or less, for concentrations > or = 10 times Limit of reporting (LOR) • RPD criteria of 75% or less, for concentrations between 5 and 10 times the LOR • RPD criteria of 100% or less, for concentrations < 5 times LOR. Replicate data for field duplicates for inorganics, including metals is expected to be as follows: • RPD criteria of 30% or less, for concentrations > or = 10 times LOR • RPD criteria of 75% or less, for concentrations between 5 and 10 times the LOR • RPD criteria of 100% or less, for concentrations < 5 times LOR. Where acceptable limits for field duplicates were not met, a discussion on low biased error will be provided.
Optimise the Design	Sediment samples were collected using a systematic approach to optimise the design for efficient and representative sampling. Once ooze was identified and the extent mapped, sample locations were selected to provide an even distribution across the trial site.

Preliminary assessment of the site/s has specifically sought to characterise and assess black ooze and sediments encountered in potential trial and control sites within Tuggerah Lake. In order to provide this assessment both COPC and geotechnical properties of the materials have been analysed. The following sections provide details of the chemical analytical suite and geotechnical testing regime adopted for the study.

2.3.2 Chemical analytes

Based on a review of the documents listed in **Section 2.1** and sediment screening guidance from Australian Government (2009), samples collected during the study were analysed for the following analytes:

- Metals (mg/kg dry wt)
    - Antimony, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Silver, Zinc
- Metalloids (mg/kg dry wt)
    - Arsenic
- Organometallics
    - Tributyltin
- Organics
    - Acenaphthene, Acenaphthalene, Anthracene, Fluorene, Naphthalene, Phenanthrene, Benzo(a)anthracene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Chrysene, Fluoranthene, Pyrene
- Organochlorine and Organophosphate Pesticides (OCC/OPP)
- Polychlorinated Biphenyls (Total PCBs)
- Ammonia
- Sulphate

- Nutrients (Phosphate/Nitrate)
- Coliforms (Faecal and Total)
- Biological Oxygen Demand (BOD)
- Organic carbon content

2.3.3 **Geotechnical properties**

In addition to the above physio/chemical parameters at least one sample from each site was submitted for the following geotechnical analyses to assess the physical properties of the material in order to determine the most appropriate method of sediment removal/handling during any removal program:

- dispersivity
- bulk density
- particle size distribution
- moisture content.

Figure 1: Sediment sample locations (Map 1)

Figure 2: Sediment sample locations (Map 2)

3 Quality assurance

3.1 Field quality assurance

3.1.1 Details of sampling team

All sediment sampling was conducted by experienced ES Environmental Scientists, Ryan Wells and Greg Sheehan.

3.1.2 Decontamination procedures carried out between sampling events

New disposable nitrile gloves were used at each sample location. New disposable push tube sleeves inside the sampling device were used at each borehole location.

3.1.3 Chain of custody details

Sediment samples were transported to the laboratory under a chain of custody (COC). Information on the COC included the sampler, sample identifier, sample matrix, collection date, analyses to be performed, sample preservation method, sample release date and sample received date. COCs are provided in **Appendix A** along with the laboratory reports.

3.1.4 Sample splitting techniques

Sediment samples were split by collecting representative samples of the sediment at the same depth interval. Due to the potential loss of volatiles, samples were not mixed and separated, but replicate samples were collected.

3.1.5 Statement of duplicate frequency

ES collects field QA/QC samples at a rate of at least 1:20 samples.

For this project, the following QA/QC samples were collected:

- DUP1O_ (13/05/2015) was intra-laboratory duplicate of ooze sample BV24O
- Trip1O_(13/05/2015) was inter-laboratory duplicate of ooze sample BV24O
- DUP2_ (14/05/2015) was intra-laboratory duplicate of ooze sample BV31O
- DUP3_ (14/05/2015 was intra-laboratory duplicate of ooze sample BV44O.

QA/QC samples were collected at a rate of 1:8. Overall the QA/QC sample collection rate is greater than the target collection rate and is considered for the purpose of the study to be in accordance with the Australian Standard Field procedures (AS1482.1 1997).

3.1.6 Rinsate sample results

Rinsate samples were not collected during the field work. ES considers that the use of dedicated, single use, sampling equipment, best practice sampling methods and appropriate decontamination methods were adequate to minimise the potential for cross contamination to occur. Therefore ES does not consider the dataset to be compromised due to the lack of a rinsate sample.

3.1.7 Trip blank

Trip blanks were not used for this investigation. All samples were collected within laboratory supplied sample jars/bottles, fitted with Teflon® seals and stored and transported within an ice-chilled cooler box, fitted with a closable lid to prevent the loss of volatile compounds. ES does not consider the integrity of the dataset to be compromised.

3.1.8 Trip spike results

Trip spikes were not used for this investigation. All samples were collected within laboratory supplied sample jars/bottles, fitted with Teflon® seals and stored and transported within an ice chilled cooler box, fitted with a closable lid to prevent the loss of volatile compounds. ES does not consider the integrity of the dataset to be compromised.

3.2 Laboratory QA/QC

The laboratory results were subject to a detailed quality assurance and checking process. The results are summarised in **Appendix B**. The RPD calculations are provided as a separate file contributing to **Appendix B**.

Based on the review of QA/QC provided, ES considers the data is of acceptable quality for the purposes of this study.

4 Results

4.1 Site details

Eight sites were sampled in this study, comprised of four trial sites, three control sites and one reference site. Each site varied in size dependant on extent of ooze, ranging from 357 to 2,113 m^2. The reference site (with no ooze) was sampled to cover a similar area as the larger ooze patches.

Stormwater drains entering the lake at Berkeley Vale are abundant, ranging from small excavated channels draining a few properties, to large urban catchments. All study sites had at least one stormwater drain in or adjacent to the survey area. Only two gross pollutant traps (GPT) were observed.

Trial sites are all accessible via Council easements and gates (limited to small trucks), and have adequate open space on lawns/car parks for staging areas. Nearly all foreshore areas have a narrow band of saltmarsh, adjacent to either mown open space or small vegetated areas. Saltmarsh can be traversed by small machinery by laying wrack on top or sticking to weedy patches.

Site details for sampling locations at Berkeley Vale are presented in **Table 3** and **Figure 3.** Additional mapping of ooze extent (not sampled) will be presented in **Figure 4** and **Figure 5**.

Table 3: Site description, access and workability

Site No.	Date	Treatment	Ooze surface area (m^2)	Location to stormwater drains	Stormwater treatment devices	Shoreline type	Adjacent landuse	Accessibility	Workability of foreshore
BV1	12/05/15	Trial	1,489	One drain 5 m to north of ooze patch	No GPT	One-third car park, two-thirds rehabilitated saltmarsh (20 m wide)	Jetty access (car park), footpath and vegetated	Gravel road on Lot 121 DP27299 to jetty (opposite Panorama Pde, Berkeley Vale)	Car park on Lot 7307 DP1146702 suitable for staging area
BV2	13/05/15	Trial	1,673	Two drains at north and south boundary of ooze patch	No GPT	Saltmarsh (4 m wide)	Open space grass reserve and footpath	Access easement next to channel in Lot 108 DP28859 (opposite Bluebell Ave, Berkeley Vale). Need to remove small garden rockery	Grass foreshore on Lot 7307 DP1146702 suitable for staging area (away from saltmarsh fringe)
BV3	14/05/15	Control	885	One drain at centre of ooze patch	No GPT	Saltmarsh (11 m wide) and reeds	Vegetated and footpath	Not required, but accessible through Lot 12 DP27299, or on foot from jetty car park (opposite Panorama Pde, Berkeley Vale)	Not required
BV4	14/05/15	Control	2,113	One drain in centre, and one minor drain at southern boundary of ooze patch	GPT at centre drain	Saltmarsh (2 m wide) and Casuarinas	Vegetated and footpath	Not required, but accessible through Lot 170 DP27302 (opposite Emerald Pl, Berkeley Vale)	Not required
BV5	15/05/15	Trial	652	One large creek covering ooze patch	No GPT	Large creek with fringing Casuarinas, adjacent to saltmarsh (3-6 m wide)	Open space grass reserve and footpath	Access easement in Lot 319 DP222243 (opposite Wombat St, Berkeley Vale)	Grass foreshore on Lot 7307 DP1146702 and surrounds suitable for staging area (away from

Site No.	Date	Treatment	Ooze surface area (m^2)	Location to stormwater drains	Stormwater treatment devices	Shoreline type	Adjacent landuse	Accessibility	Workability of foreshore
									saltmarsh fringe)
BV6	15/05/15	Control	357	One large creek covering ooze patch	GPT	Large creek with fringing Casuarinas, adjacent to saltmarsh (1-3 m wide)	Open space grass reserve, footpath and vegetated	Not required, but accessible on foot from Lot 63 DP31935 (317 Lakedge Ave, Berkeley Vale)	Not required
BV7	18/05/15	Trial	1,611	One minor drain in centre and one small drain at northern boundary of ooze patch	Small GPT at northern end (sump only, no rack)	Saltmarsh (2-7 m wide), grass and scattered trees	Open space grass reserve, footpath and scattered trees	Access easement in Lot 403 DP28398 (opposite Erin Ave, Berkeley Vale)	Grass foreshore on Lot 7308 DP1146699 suitable for staging area (away from saltmarsh fringe)
RS1	15/05/15	Reference	0	One minor drain in centre, and one small drain at southern boundary of reference site (small ooze patches within channels)	No GPT	Saltmarsh (3 m wide) and Casuarinas at drains	Open space grass reserve and footpath	Not required, but accessible on foot from Lot 63 DP31935 (317 Lakedge Ave, Berkeley Vale)	Not required

Figure 3: Map of ooze sites, extent, seagrass and accessibility in Berkeley Vale

Figure 4: Map of ooze extent in Tuggerawong (Big Bay).

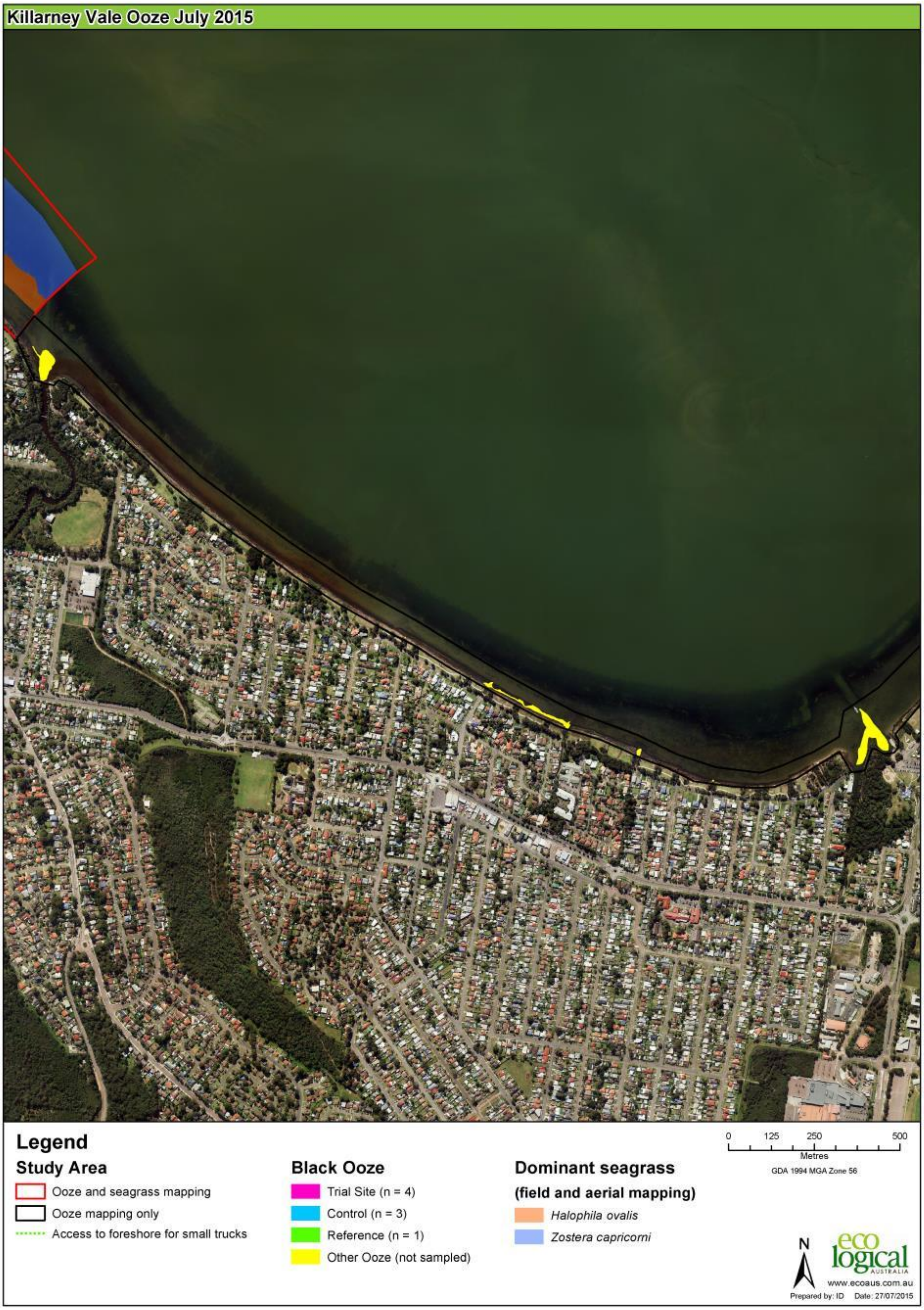

Figure 5: Map of ooze extent in Killarney Vale

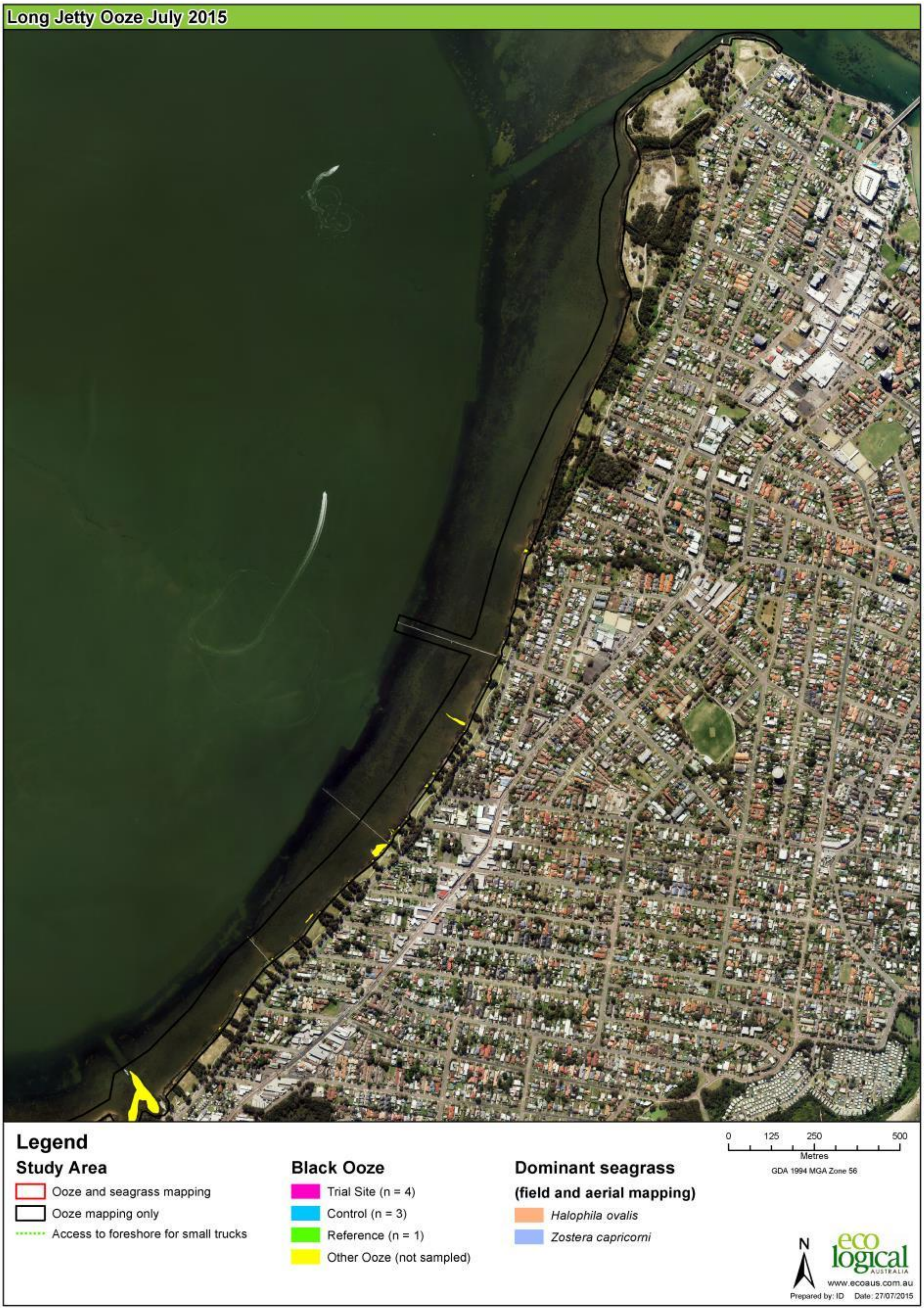

Figure 6: Map of ooze extent in Long Jetty

4.2 Results of laboratory analyses

4.2.1 Results of chemical analyses

The following section provides a summary of the results of chemical analyses undertaken on the collected samples. For definition of SAC see **Table 2**.

Chemicals of potential concern (COPC)

Metals

Metals were detected in the majority of samples submitted for analyses, the concentrations were generally low, with no results exceeding the SAC in any sample.

- Antimony - *no results detected, all <limit of reporting (LOR)*
- Cadmium - *32 of 40 samples (not including QA/QC), no results >site assessment criteria (SAC)*
- Chromium - *38 of 40 samples (not including QA/QC), no results >SAC*
- Copper- *38 of 40 samples (not including QA/QC), no results >SAC*
- Lead - *39 of 40 samples (not including QA/QC), no results >SAC*
- Mercury - *35 of 40 samples (not including QA/QC), no results >SAC*
- Nickel - *35 of 40 samples (not including QA/QC), no results >SAC*
- Silver - *22 of 40 samples (not including QA/QC), no results >SAC*
- Zinc - *40 of 40 samples (not including QA/QC), no results >SAC*

Metalloids

Arsenic was detected in all of the samples submitted for analyses, the concentration were generally low, with no results exceeding the SAC in any sample.

- Arsenic - *40 of 40 samples (not including QA/QC), no results >SAC*

Organometallics

Tributyltin (TBT) was not detected in any of the composite samples submitted for analyses.

- TBT - *no results detected, all <LOR*

Organics

Polycyclic aromatic hydrocarbons (PAH) were detected in the majority of samples submitted for analyses. Generally concentrations were low with only one sample marginally exceeding the SAC.

Concentrations of PAH in samples collected from the reference area (no ooze) were mainly below detection limits with only a few results recorded marginally above the LOR, whereas concentrations of PAHs in sub-ooze samples were similar to the concentrations detected in the ooze. This indicates that the ooze is likely to be the main source of the PAHs detected and that PAHs from the ooze are likely to be impacting the underlying sediments.

- Total PAH - *38 of 40 (not including QA/QC), no results >SAC*
    - Acenaphthene - *5 of 40 (not including QA/QC), no results >SAC*
    - Acenaphthalene - *35 of 40 (not including QA/QC), **1 result >SAC (BV41O)***
    - Anthracene - *35 of 40 (not including QA/QC), no results >SAC*

- Fluorene - *10 of 40 (not including QA/QC), no results >SAC*
- Fluoranthene - *36 of 40 (not including QA/QC), no results >SAC*
- Naphthalene - *34 of 40 (not including QA/QC), no results >SAC*
- Phenanthrene - *35 of 40 (not including QA/QC), no results >SAC*
- Benzo(a)anthracene - *36 of 40 (not including QA/QC), no results >SAC*
- Benzo(a)pyrene - *36 of 40 (not including QA/QC), no results >SAC*
- Dibenzo(a,h)anthracene - *18 of 40 (not including QA/QC), no results >SAC*
- Chrysene - *35 of 40 (not including QA/QC), no results >SAC*
- Fluoranthene - *36 of 40 (not including QA/QC), no results >SAC*
- Pyrene - *37 of 40 (not including QA/QC), no results >SAC*

Organochlorine Pesticides (OCP)

Concentrations of OCPs were generally low with the majority of samples having no detectable OCPs. The exceptions were two samples which returned results exceeding the SAC. One of these samples had a sub-ooze sample collected from directly below, which did not return detectable concentrations of OCPs. Likewise, none of the samples collected from the reference site returned detectable concentrations of OCPs. This indicates that although the ooze is the source of the OCPs detected, concentrations exceeding the SAC are isolated and do not appear to be impacting the underlying sediment.

- 4,4-DDE - *1 of 40 (not including QA/QC), 1 result >SAC (BV33O)*
- Chlordane - *no results detected, all <LOR*
- Chlordane (cis) - *no results detected, all <LOR*
- DDD - *3 of 40 (not including QA/QC), 1 result >SAC (BV33O)*
- DDT - *2 of 40 (not including QA/QC), 2 results >SAC (BV33O, BV72O)*
- Dieldrin - *no results detected, all <LOR*
- Endrin - *no results detected, all <LOR*
- g-BHC (Lindane) - *no results detected, all <LOR*

Organophosphate Pesticides (OPP)

OPPs were not detected in any sample submitted for analyses.

- OPPs - *no results detected, all <LOR*

Polychlorinated Biphenyls (Total PCBs)

PCBs were not detected in any sample submitted for analyses.

- no results detected, all <LOR

Environmental indicators (No SAC)

Ammonia in sediments typically results from bacterial decomposition of natural and anthropogenic organic matter that accumulates in sediment. Ammonia is especially prevalent in anoxic sediments because nitrification (the oxidation of ammonia to nitrite [NO2-] and nitrate [NO3-]) is inhibited.

Concentrations of ammonia were generally an order of magnitude less in samples collected from the reference site compared to those from the ooze sites. Concentrations in sub-ooze samples were generally lower than those recorded in ooze samples. This indicates that the ooze is the main source of the ammonia detected and may be influencing ammonia formation in the underlying sediments.

- Ammonia - *40 of 40 (not including QA/QC)*

As per the discussion above the low levels of nitrite and nitrate detected in the ooze samples combined with ammonia concentrations detected, which were generally an order of magnitude or more than the background levels (from the reference site), are strong indicators of anoxic sediments.

- Nitrate and Nitrite - *8 of 40 and 2 of 40 respectively (not including QA/QC)*

Concentrations of iron were generally an order of magnitude less in samples collected from the reference site compared to those from the ooze sites. Concentrations in sub-ooze samples were generally similar to those recorded in ooze samples. This indicates that the ooze is the main source of the iron detected and that iron in ooze is impacting underlying sediments. The high iron concentrations detected in the ooze and underlying sediments are likely to be stable under the prevailing anoxic conditions. Should the sediments be disturbed or exposed to oxygen during any proposed removal or treatment works, consideration should be given to the high potential for the iron within the sediments to oxidise and act as a catalyst for acid sulphate generation.

- Iron - *40 of 40 (not including QA/QC)*

Concentrations of sulphate were generally an order of magnitude less in samples collected from the reference site compared to those from the ooze sites. Concentrations in sub-ooze samples were generally similar to those recorded in reference samples. This indicates that the ooze is the main source of the sulphate detected but that sulphate in ooze is having limited impact on underlying sediments. As discussed above the sulphate concentrations detected in the ooze are likely to be stable under the prevailing anoxic conditions. Should the sediments be disturbed or exposed to oxygen during any proposed removal or treatment works, consideration should be given to the high potential for the iron within the sediments to oxidise and react with the sulphate present to generate acid sulphates.

- Sulphate - *40 of 40 (not including QA/QC)*

Phosphorus was detected in less than half the samples submitted for analyses. Detectable concentrations of phosphorus were not detected in the samples collected from the reference site. In contrast to other analytes, concentrations of phosphorus were generally higher in sub-ooze samples than in the ooze. This indicates the ooze is not the predominant source of detected phosphorus in the sediments.

- Phosphorus - *14 of 40 (not including QA/QC)*

The concentrations of both faecal and total coliforms varied significantly both across and within the sites. Concentrations detected in samples collected from the reference site were generally at the lower end of the range, however, similar low levels or non-detects were detected on the ooze sites often in close proximity to coliform concentrations several orders of magnitude greater. This indicates that coliforms although present in the ooze are likely to be location-specific and may be the result of proximity to potential inputs such as stormwater outfalls.

- Coliforms

  - Faecal - *21 of 40 (not including QA/QC)*
  - Total - *39 of 40 (not including QA/QC)*

Total Organic Carbon (TOC) refers to the amount of organic matter preserved within sediment. TOC percentages within the ooze were generally an order of magnitude greater than those detected in the reference site and sub-ooze samples. This indicates that the formation of ooze is likely to have a strong correlation with the breakdown of organic matter under anoxic conditions.

- TOC - *40 of 40 (not including QA/QC)*

4.2.2 Results of geotechnical analyses

The following section provides a summary of the results of the geotechnical characteristics of the sediments encountered based on the analyses undertaken on the collected samples.

Dispersivity – Emerson Class

The results of dispersivity testing on a select number of samples assessed as being representative of the study sites.

All Emerson Class results were Class 8, indicating that the ooze is not likely to slake or swell. Slaking is the breakdown of a lump of soil into smaller fragments on wetting. It is caused when clay swells and the trapped air bursts out. Soils, or in this case sediments which exhibit slaking or swelling characteristics are more likely to be dispersive than those that do not. It the case of the ooze samples the low likelihood that the material will slake or swell is a good indicator that the ooze will not disperse easily if disturbed. It also indicates that the fines within the material are more likely to be organic than mineral, as materials with high organic content typically have low slake/swell characteristics.

The exception was the sample collected from Site BV3, which returned an Emerson Class 4, indicating that the material was non-dispersive but that carbonate or gypsum were present in the material.

Overall, based on the Emerson Class results the dispersion potential of the ooze could be characterised as low to very low. This indicates that the ooze material is likely to occur in discrete areas with little potential to spread through the lake by dispersion mechanisms.

Moisture content

Moisture content in the sample collected from the reference site (37%) was approximately half to almost a full order magnitude lower than the moisture contents recorded for the ooze samples (118-296%). This indicates that the clay and silt fractions within the ooze are absorbing moisture and that consideration of appropriate dewatering methods will be an important part of the planning for any proposed remediation or removal works.

Particle density

Particle densities recorded from the ooze samples were generally lower than that recorded for the reference site. This is expected due to the lower density of the organic materials which constitute a greater proportion of the ooze than in the reference site sediments.

Particle density for the reference site was 2.63 tonnes per cubic metre and for the ooze ranged from (2.43 to 2.63 t/m^3).

Particle size distribution

The particle size distribution for the reference size indicated that the sediments are predominantly silty sands whereas the samples collected from the ooze sites could be characterised as silty sands or sandy silts. As a result there is little differentiation between the particle size distribution of the ooze and of the reference site sediments. The main physical differentiator appears to be not the size of the particles but rather the nature, with the clays and silts in the reference sites likely to have been derived from more mineral based sources where the ooze is derived from more organic sources.

4.3 Seagrass surveys

Two species of seagrass were observed in the survey area. The Fisheries Management Act requires a permit to gather, cut, pull up, destroy, poison, dig up, remove, injure, prevent light from reaching or otherwise harm seagrasses (DPI 2007). A common pattern emerged where *Halophila ovalis* (Paddleweed) occupied the shallow nearshore zone (20 – 140 m from shore), followed by a large *Zostera capricorni* (Eelgrass or ribbonweed) population in deeper water (120 – 400 m from shore). No seagrass occurred within the ooze or reference patches.

H. ovalis was generally scattered with sparse foliage cover; and showed signs of disturbance from sedimentation and dense epiphyte growth which reduces sunlight reaching its leaves (**Figure 7**). The densest *H. ovalis* patches (site BV5) were near a large creek outlet within or surrounded by a mass of wrack and fine woody debris (leaves and sticks) (right image, **Figure 7**). *H. ovalis* is known to occupy higher nutrient areas and may take advantage of sediment stabilised by the settled debris.

Z. capricorni was abundant in deeper water, possibly more sheltered from wave disturbance and associated turbidity. A close inspection of *Z. capricorni* in shallower areas found these plants to be detached and resting on top of the sediment, a likely result of the severe storm events in the preceding month. Underwater footage of the *Z. capricorni* beds show the cover is moderately dense, with some epiphyte growth on leaves (**Figure 8**). Other areas had patches of bare sediment and uprooted plants settled to the floor.

Results from the site survey were compared to historic aerial photos and the NSW Fisheries Estuary Vegetation Maps (Creese et al 2009). Results roughly match the Fisheries mapping, but this study found more *H. ovalis* closer to shore (**Figure 9**). A distinctive dark band of seagrass can be seen on most aerial images, although its boundary appears dynamic, possibly a result of seasonal growth, sedimentation and storm disturbance. This variability in the seagrass boundary over years and existing disturbed conditions may add a degree of complexity and uncertainty if attempting to monitor potential impacts of ooze removal. Any noticeable impact to seagrass would need to be rather expansive and have a proven association with a point source disturbance.

Details of seagrass condition and approximate extent are shown in **Table 4** and **Figure 3**.

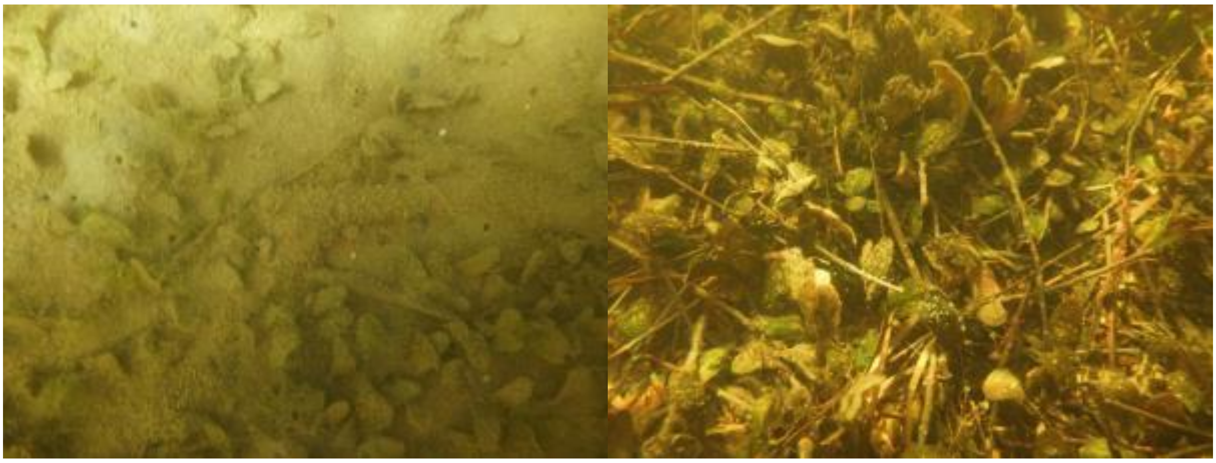

Figure 7: Typical condition of *Halophila ovalis*: Left – sparse cover with sediment and epiphyte growth on leaves; Right –small patches amongst wrack and fine woody debris from stormwater drain

Figure 8: Typical condition of *Zostera capricorni* with tall leaves (20-40 cm), moderate density with some epiphyte growth

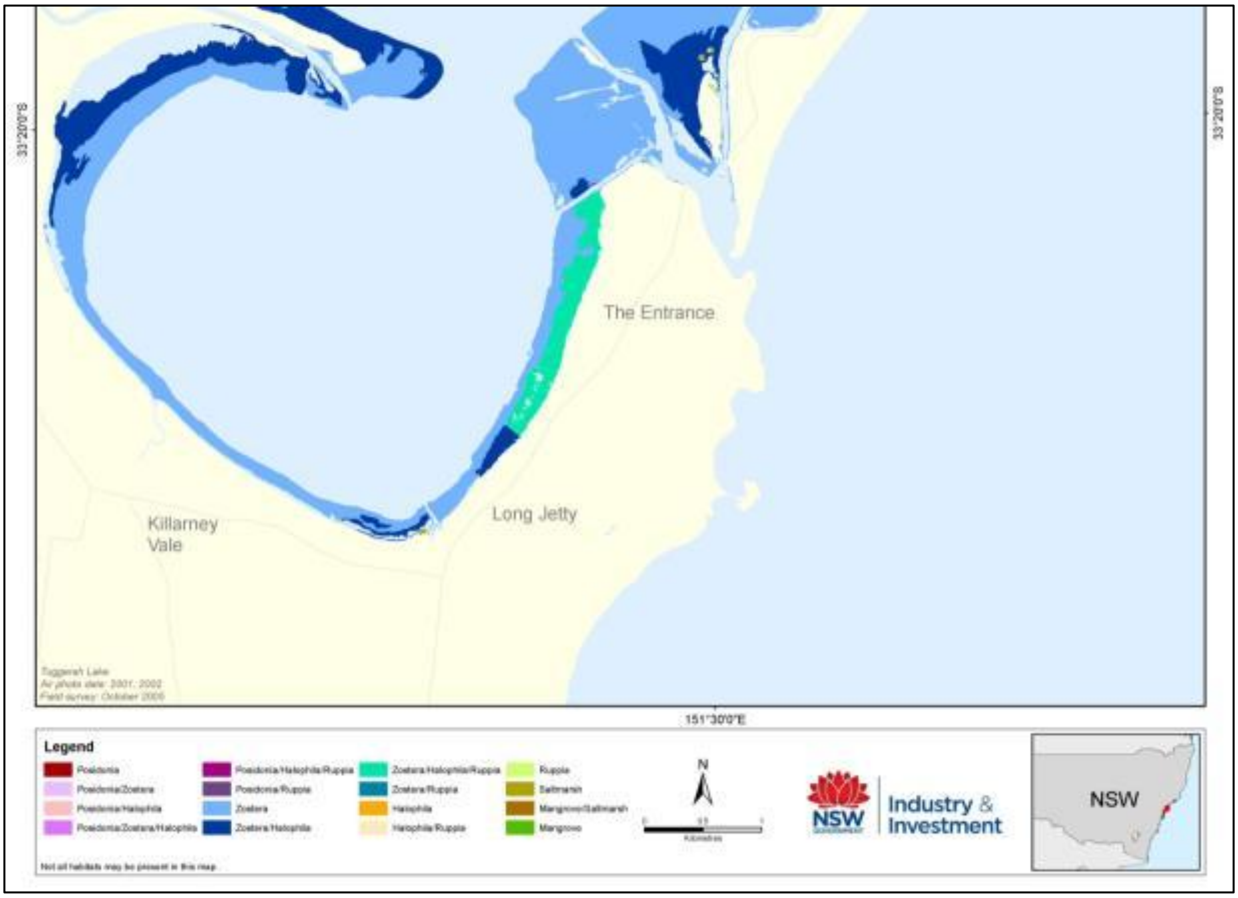

Figure 9: Portion of NSW Fisheries seagrass map for Tuggerah Lake

Table 4: Seagrass condition near survey sites

Site No.	Survey Date	Treatment	Nearest seagrass bed to ooze	Seagrass species (Dominant)	Seagrass species (Sub-dominant)	Seagrass cover	Seagrass height	Seagrass epiphytes	Seagrass condition	Seagrass disturbance
BV1	12/05/15	Trial	100 m	*Zostera capricorni*	*Halophila ovalis*	Moderate to dense (30-60% cover) in expansive patch	20-40 cm	Moderate	Moderate	Disturbed by severe storm, uprooting and sedimentation
BV2	13/05/15	Trial	100 m	*Zostera capricorni*	*Halophila ovalis*	Moderate to dense (30-60% cover) in expansive patch	20-40 cm	Moderate	Moderate	Disturbed by severe storm, uprooting and sedimentation
BV3	14/05/15	Control	100 m	*Zostera capricorni*	*Halophila ovalis*	Moderate to dense (30-60% cover) in expansive patch	20-40 cm	Moderate	Moderate	Disturbed by severe storm, uprooting and sedimentation
BV4	14/05/15	Control	54 m	*Halophila ovalis*	None	Very sparse (<5% cover), in scattered patches, mostly bare sediment	2 cm	Moderate	Poor	Disturbed by sedimentation
BV5	15/05/15	Trial	6 m	*Halophila ovalis*	None	Moderate to dense (30-60% cover), in small scattered patches, mostly bare sediment	2 cm	Abundant	Poor	Disturbed by sedimentation and fine woody debris from creek
BV6	15/05/15	Control	6 m	*Halophila ovalis*	None	Very sparse (<5% cover), in scattered patches, mostly bare sediment	2 cm	Abundant	Poor	Disturbed by sedimentation from creek

Site No.	Survey Date	Treatment	Nearest seagrass bed to ooze	Seagrass species (Dominant)	Seagrass species (Sub-dominant)	Seagrass cover	Seagrass height	Seagrass epiphytes	Seagrass condition	Seagrass disturbance
BV7	18/05/15	Trial	7 m	*Halophila ovalis*	*Zostera capricorni*	Very sparse (<5% cover), in scattered patches, mostly bare sediment	3 cm	Moderate	Poor	Disturbed by sedimentation and fine woody debris
RS1	15/05/15	Reference	3 m	*Halophila ovalis*	None	Very sparse (<5% cover), in scattered patches, mostly bare sediment	2 cm	Moderate	Poor	Disturbed by sedimentation

5 Impact assessment

When determining the feasibility of any sediment control, management or removal process it is critical to have a clear understanding of the potential impacts of the proposed works. For a dredging programme of the scale indicated to be required by black ooze mapping within the setting of Tuggerah Lakes, impacts are likely to fall within four main categories:

- Environmental
    - Impacts to the treatment site/s as a direct result of the works including
        - Ecological communities and changes to biodiversity
        - Physical changes to the site from
            - Staging of works
            - Treatment of materials
            - Generation of waste
    - Impacts to the surrounding environment as a secondary result of the works
        - Ecological communities and changes to biodiversity
        - Physical changes to surrounding environs as a direct result of the works
        - Impacts to surrounding environs due to waste transport and disposal requirements
- Human Health
    - Impacts to site workers and visitors during the works
    - Impacts to people residing, working, visiting and/or using the surrounding environs
    - Impacts to people residing, working and/or visiting waste transport and disposal routes and sites
    - Impacts to people consuming edible aquatic species
- Societal
    - Impacts to the social value and amenity of the treatment sites
- Material
    - Cost of the capital dredging works including controls and monitoring
    - Cost of ooze treatment and waste disposal
    - Cost of ongoing maintenance and monitoring requirements
    - Cost of additional supplementary works intended to enhance outcomes.

5.1 Environmental impacts

The use of appropriate controls to limit the potential for impacts to extend beyond the specific treatment area will be a primary management strategy in limiting potential impacts to the environment. Such controls could include but not necessarily be limited to:

- Creation of a comprehensive conceptual site model (CSM) based on
    - Accurate mapping of sediments to be removed from treatment zones
    - The presence of sensitive ecological communities within and around treatment zones
    - Appropriate characterisation of material/s to be removed or disturbed

- Creation a comprehensive Environmental Management Plan (EMP) providing detail on various control, management and monitoring including but not limited to
  - The deployment of containment measures such (as silt curtains).
  - Ensuring the dredging method employed is assessed during the works as remaining appropriate to the setting.
  - Monitoring of physical, ecological and chemical outcomes pre, during and post works.

The controls listed above are all part of a suite of management which would be required to be applied during any ooze removal works. None of the above are considered to be appropriate to be employed in isolation. Rather the controls are part of an overall risk assessment process which seeks to identify and control risks to human health and the environment and to provide methods of quantifying what those risks may be pre, during and post works. The actual controls to be employed for any sediment removal trial would be based on the methodology employed for the trial and would be developed within the EMP.

5.2 Human health Impacts

Human health impacts associated with any programmed works would be managed through the development of:

- a Health and Safety Plan
- adherence to the requirements of the EMP
- appropriate community liaison and stakeholder engagement.

5.3 Socio-economic impacts

As the underlying objective of any programme of ooze removal works is to improve the environmental outcomes and amenity of the treatment sites and therefore Tuggerah Lakes overall it is considered that socio-economic impacts will be limited to the loss of amenity of some publicly accessible areas in and around the treatment sites during the staging of the works. There are likely to be positive, long term impacts of the proposed project. It is considered that this impact could best be managed through an inclusive process of community liaison and stakeholder engagement.

5.4 Material impacts

Other than environmental impacts, the material impacts of any targeted dredging programme are generally the most critical to the overall success of the works. A number of factors need to be considered which have potential to significantly impact the materials costs associated with the works, including:

- Interactions with regulators
  - Funding
  - Approvals
  - Further assessment
- Location, management and access of the land based operations
- Dredging methods
  - Control measures required
  - Monitoring requirements
- Treatment methods

    - Ongoing treatment, maintenance and monitoring costs
    - Wastes generated
    - Waste transportation and disposal
- Maintenance and monitoring
- Community liaison and stakeholder engagement
- Contingency.
- Potential rebound after removal of ooze once the lake has reached a new equilibrium without assessing the primary source conditions from upgradient catchments.

Management of risks to material costs associated with the proposed works can be achieved through:

- Pre-works site characterisation and assessment
- Development of a CSM
- Development and adoption of a EMP
- Development of a REF.

6 Discussion and recommendations

6.1 Site characterisation and assessment

The characterisation and assessment of sediments as part of this study have been guided by the Australian Government National Assessment Guidelines for Dredging 2009 (Australian Government 2009). Although NAGD 2009 is most applicable to larger scale capital dredging programmes, with special focus on the requirements for sea dumping, the general processes and contaminant screening and assessment guidance are considered the most applicable for dredging works of all types within the Australian context.

The works completed to date as discussed within this report represent the first two phases of a five step process of contaminant assessment. The five phases are as follows:

- **Phase I – evaluation of existing information**
- **Phase II – sampling and analysis of sediments**
- *Phase III – elutriate and bioavailability testing*
- *Phase IV – toxicity and bioaccumulation testing*
- *Phase V – where necessary in rare cases, a weight-of-evidence assessment.*

It should be noted that requirement for the final three phases of assessment is entirely dependent on the findings of the first two phases and in particular Phase II. The staging of the final three phases in conjunction with the first two has potential to significantly increase study costs and has a high likelihood of the proponent incurring additional costs which may have little or no value to the overall assessment of treatment and /or disposal methods.

6.1.1 Requirement for further assessment

The Phase II assessment is used to identify COPC which may be present in excess of the adopted screening criteria for the site (SAC). In the case of the Tuggerah Lakes study sites COPC detected in concentrations greater than the SAC were found to be:

- Organics – PAH (Acenaphthalene)
- Organochlorine Pesticides (OCP) - 4,4-DDE, DDD and DDT.

As COPC were detected above the SAC, a further Phase III assessment should be completed to assess the potential for leaching and bioavailability in sediment in these sites. A Phase III assessment would require the collection of a limited number of additional samples from the impacted sites and submission for total concentration and elutriate analyses for specific COPC to assess leachability and bioavailability. Should the analyses indicate that the COPC despite exceeding the SAC are not prone to leaching from the sediment and/or not bioavailable, further analytical assessment will not be required. However, should analyses prove that COPC may be bioavailable and/or prone to leaching, a Phase IV assessment to establish the toxicity and bioaccumulation potential of the chemical/s is recommended.

6.2 Sediment removal methodology

There are two main types of sediment removal methodologies in general usage globally. These are:

- Excavation (the area is dewatered and then the target material is removed)
- Dredging (the target material is removed from the water body without dewatering the area), via three main methods

- o Mechanical (i.e. without dewatering and excavation)
- o Hydraulic
- o Pneumatic.

Of these methods, mechanical and hydraulic dredging are the most commonly employed. The *US EPA Contaminated Sediment Remediation Guidance for Hazardous Waste Sites, December 2005, Chapter 6 –Dredging and Excavation*, provides a detailed examination of excavation and dredging methodologies and a critique of the advantages, disadvantages and suitability ratings for most commonly used sediment removal methods. This reference has been used as the basis for the preliminary sediment removal methodology assessment which follows.

The setting in which the *Tuggerah Lakes black ooze - Removal investigations and feasibility study* is taking place and the targeting of a specific type of sediment, separate the study sites from the majority of 'typical' sediment removal scenarios. The shallow water, proximity to shore and relatively thin layer of sediment (ooze) being targeted preclude the use of many methods which would normally be strongly considered for the majority of sediment removal projects. Specifically the use of either hydraulic or pneumatic dredging techniques is considered to have little potential in this context, primarily due to the shallowness of the water. Typically even small hydraulic dredging systems have difficulty operating in depths of less than 1 m of water, while pneumatic dredging systems operate best at a depth of around 5 m. In the case of this study and potential treatment sites, most of the ooze lays in water less than 1 m deep. Therefore, most hydraulic and pneumatic dredging techniques can immediately be discounted as being viable methodologies for the purposes of this study. An exception may be the use of very small scale equipment to undertake hydraulic dredging. An example of the type of technology which might be employed would be an amphibious vehicle (such as a Truxor®) fitted with a screw feed hydraulic dredge head. Such a system would allow targeted hydraulic dredging in very shallow water >0.3 m depth. An added advantage is the light weight and amphibious nature of such a vehicle as it would require a minimum of staging to deploy and could be secured on land at the end of every day.

Other than small scale hydraulic dredging excavation, the various methods of mechanical dredging and excavation are still to be considered. Excavation has been employed extensively within the Tuggerah Lakes to remove sediments, wrack,- seagrass, algae and re-contour the foreshore as part of the Tuggerah Lakes Restoration Project. The methodology was applied over large sections of dewatered, near-shore lake bed at a number of prominent locations around the circumference of Tuggerah Lake. The methodology was very successful in initially removing the targeted material from all sites and Council also have a demonstrated technical ability to successfully undertake works of this nature. However, the conditions created as a result of entirely removing all sediments and vegetation over large sections of the lake bed down to bare sand, and reusing this material for adjacent foreshore reclamation created poor environmental outcomes and led to massively accelerated seagrass and macro algal re-population of the areas, actually lessening the amenity of the lake. The methodology was deemed viable due to the large scale of the areas being treated, as the piling and dewatering systems required becomes cheaper due to economies of scale. For the ooze removal sites the relatively small size of the sites compared to the sites in the Tuggerah Lakes Restoration Project and the proven poor environmental outcomes of excavation in the Tuggerah Lake setting, means that excavation (accessed via dewatering sections of the lake) should be discounted as a potential sediment removal methodology on both economic and environmental grounds.

Mechanical dredging techniques are considered to be more likely than excavation to be successful for the black ooze removal sites both in terms of protecting the environmental setting and due to economic considerations. The types of mechanical dredging methodologies which might be employed can be separated into two types:

- Wire supported methods, including clam shell and enclosed buckets
- Articulated mechanical methods, including backhoe designs, clam-type enclosed buckets, hydraulic closing mechanisms, all supported by articulated fixed arm.

When considering the above methods it is important to consider the relatively thin layer, generally <0.5 m thick, of sediment (ooze) being targeted. This characteristic of the site setting means that a methodology should be adopted which has a high vertical operating accuracy. This is the ability to position the dredge head at a desired depth or elevation for the cut and maintain or repeat the vertical position during the dredging operation. Although positioning instrumentation is accurate to within a few centimetres, the design of the dredge and the linkages between the dredgehead and the positioning system will affect the accuracy attainable. Fixed arm (articulated) equipment holds some advantages over wire supported systems in maintaining vertical operating accuracy.

Of the fixed arm options a clam-bucket with sealable lid which can be closed either hydraulically or mechanically is considered to have advantages over open bucket designs. The closed bucket minimises to the extent possible the potential for sediments to be dispersed from the bucket as it is being drawn to the surface, this reduces the impacts of the project and the likelihood that additional levels of control may need to be implemented after works commence.

Based on the discussions above it is considered that either small scale hydraulic dredging or fixed arm (articulated) mechanical dredging methodologies using a closed-bucket system, have the greatest potential to minimise impacts while at the same time maximising environmental and economic outcomes associated with the project. In terms of a trial scenario it is likely that small scale hydraulic dredging would be the more cost effective option. Whether such a method would remain cost effective for a full scale removal programme would depend largely on the ultimate scale of the programme. This is because mechanical dredging methodologies are likely to become more cost effective as the size of the programme increases due to economies of scale and rates of dredging production. For the purpose of this study, a removal trial based on small scale hydraulic dredging is recommended due to the relatively lower cost of this method in a trial setting compared to mechanical dredging options.

6.3 Material treatment and waste disposal

Dredged ooze, underlying sediments and water collected with the sediments will need to be captured, treated and assessed prior to waste classification and appropriate disposal. As the dredged sediments will be saturated, dewatering and separation of the liquid and solid components of the dredged material will need to be completed before waste classification and disposal options could be considered.

A number of potential treatment systems may be capable of removing suspended solids and some dissolved contaminants from the waste stream. Field trials of potential treatment systems are recommended to assess the efficacy of potential treatment options.

Two active technologies commonly used within NSW for this purpose are:

- An activated air flotation system which is designed to remove volatile components and suspended material from the waste stream. This unit can be provided within a shipping container but would require a crane and three phase power to be provided for the trial.
    - The individual components of this system are a residence tank, vertical gravity separator, a venturi aeration system with skimmer as well as final polishing using a modular air stripper and finally activated carbon. This type of system is generally rated at 3,000 litres per hour and is at the bottom end of the acceptable discharge.

    - In the context of the ooze removal works the low discharge rate may not prove problematic as the preferred dredging methodology is not anticipated to generate large volumes of saturated sediments per hour.
- A hydrocyclone system which operates by applying several centrifugal forces (gravities) to the water by spinning the water through a vortoil with the ultimate objective of removing suspended solids and some dissolved and emulsified droplets. A hydrocyclone is typically rated at around 20,000 litres per hour and is, therefore easily capable of meeting the discharge volumes anticipated well within the efficiency of the unit.
    - This type of system is normally efficient when utilised with high volume dredging methods such as hydraulic or pneumatic systems, but can just as easily be used in low volume settings.

A cost effective alternative to active dewatering systems is passive dewatering. This can be achieved in a number of ways but the most recent, proven method is through the use of permeable geofabric bags. In this method sediments are pumped into the geofabric bags the side of which are fine enough to contain the sediment but sufficiently permeable as to allow water to seep out of the sediments under gravity. To collect and potentially treat the seepage water the bags would require to be placed in a bunded area on an impermeable surface (such as an HDPE liner). The bunded area would need to be designed so as to have a collection point or sump into which a pump could be inserted in order to transfer the seepage into a secondary collection tank, to allow for any further treatment or filtering to occur before releasing the water back into the environment. This method is very cost effective in terms of the costs to purchase and deploy the geofabric bags but does require that a significant area may need to be quarantined to stage the dewatering, which may take up to several weeks depending on the characteristics of the sediment and the setting. This method differs from the previous shore based dewatering of ooze through the use of an impermeable barrier and collection tank to prevent either sediment or water leeching back into the lake in an uncontrolled manner. Sediment that is exposed to oxygen during this process will become more acidic.

Following separation of the liquid and solids, sampling of each matrix for waste classification purposes would be required. Based on the results of the analyses the materials would be classified as wastes and appropriate disposal options considered. Secondary treatment of the materials could also be considered at this time and may prove to be a cost effective method of reducing waste classification of the material. Reduction of the waste class of the material increases the options for disposal and may lead to significant reductions in waste management and disposal costs. Secondary treatment options should be considered if elutriate results indicate that COPC in the ooze and underlying sediment are likely to leach or be bioavailable.

6.4 Ongoing maintenance and monitoring

As some of the conditions which have led to the creation of black ooze will be largely unchanged even after the ooze is removed, a periodic inspection of the lake is recommended to monitor the build-up of black ooze. Inspections should aim to rapidly assess soft sediment and indicators of sediment ecological health using the following schedule:

- Before sediment removal works
    - measure depth of soft sediments (if any) using steel measuring probe at four 'treatment types'
        - removal site
        - adjacent to removal site

        - control site (as sampled in this study)
        - reference site (as sampled in this study)
    - observe/smell gas emission (if any) after physical probing of four treatment types listed above (to confirm presence of ooze)
    - assess benthic infauna community of four treatment types listed above. This could include key indicators of health measured per 100 g of sediment sampled
        - invertebrate biomass (as total number of animals)
        - invertebrate richness (identification to order or family)
    - photograph and map the presence or colonisation of seagrass at four treatment types listed above, and note the extent, approximate density, and apparent condition
- During removal works
    - map approximate extent of any sediment plume that develops
    - monitoring of dissolved oxygen concentration, pH and turbidity of lake water
- Immediately post sediment removal
    - repeat measurements of soft sediments depth (if any) using steel measuring probe within removal site
- Annually after removal
    - repeat the 'before' survey program at four treatment types listed above to measure improvement in ecological health
- Opportunistically after extreme storm/flood events
    - repeat the 'before' survey program at four treatment types listed above to measure any severe sediment scouring or deposition

In the case of no sediment removal, annual inspection can apply the methods outlined above without the treatment replicates and on an annual basis.

Benthic infauna monitoring of untreated ooze sites is not required. It is unlikely that the anoxic ooze can support benthic fauna populations. If the ooze is treated, it is likely that there will be some impact on the sub ooze sediements and adjacent areas that may support benthic infauna. Therefore benthic monitoring is recommended in the event of ooze removal at the extraction site, surrounding area and receiving area if applicable. Due to the dynamic nature of the lake mixing, any benthic infauna sampling should be done immediately prior to pilot ooze removal and annually after treatment to identify recovery trends post disturbance. A paired sampling regime is recommended to monitor benthic infauna diversity at reference and non reference sites to identify normal variations in populations of benthic infauna.

Supplementary works such as foreshore reshaping, the establishment of saltmarsh and the installation and/or upgrading of gross pollutant traps is considered likely to impact the potential for the future creation of ooze. Complimentary catchment works will improve the conditions that effect ooze formation and this will reduce the rate at which ooze is likely to develop.

6.5 Feasibility of black ooze removal

The results of geotechnical analyses indicate that the ooze has a low potential for dispersion. This supports the mechanical dredging option, which is normally considered to have high potential to disperse sediments due to the direct contacted and repetitive nature of the equipment causing a stirring effect. The mechanical dredging option is also capable of working in shallow water and removing thin layers of sediment such as those being targeted.

The particle size distribution results show the predominant fractions present in the ooze are silt and sand. As a result it is likely that the material will respond well to dewatering. However, it is also likely that the material may be prone to leaching of some or all COPC as the contaminants are less likely to be bound within the material, than if the ooze contained a high clay content. This means that while primary dewatering and treatment is likely to have a high probability of success, the material/s generated, and in particular the liquids, are likely to require secondary treatment either on-site or at an appropriately licensed facility prior to disposal. Consideration will need to be given to the management of the generation of acid sulphates due to the oxidation of high concentrations of iron within the ooze.

The site setting means there are a number of options to Council and contractors for staging of the works. Council have previously staged works in a number of similar settings around Tuggerah Lake as part of the Tuggerah Lake Restoration Project. This has been possible due to large areas of readily accessible foreshore immediately adjacent to the proposed treatment areas. These areas are, however, accessible to the public and as previously adopted, appropriate controls, security and accommodation for workers and equipment would be needed for any future works to minimise risk to the public, workers and the project. Typically these issues would be addressed within the EMP and Health and Safety Plan (HASP).

Based on the results of laboratory testing, the discussions provided above, ooze mapping completed to date and isolation from large seagrass beds, it is concluded that the targeted removal of black ooze from Tuggerah Lakes is technically and physically feasible.

The laboratory analysis indicates that the ooze tested is relatively benign. Although it is considered technically feasible to remove black ooze from Tuggerah Lake, the need to do so may be predominantly aesthetic.

7 Costing

Based on the findings and recommendations of this study, this section provides an indication of the material costs likely to be incurred as part of an ooze removal programme in Tuggerah Lakes. It should be noted that the costing is provided as guidance to allow Council to evaluate the potential economic feasibility of any ooze removal programme only. The costing is neither a proposal to complete the works nor a guarantee that works can and will be achieved within the indicated limits. The costing which has been created based on the experience and understanding of ES and limited supplier feedback, has not been subjected to any competitive or tendering process.

The costing estimate has been based on a dredging time of ten days to remove the ooze from a trial area. This is based on one of the larger study areas being subject to the trial removal. It is considered that this timing is conservative and that the main dredging works should be completed within this window. The estimate provided in this report is exclusive of GST and it is recommended that a contingency of ±30% should be applied to the estimate.

It is estimated that an ooze removal trial could be completed for a total of $ 166,000.

As this is a trial estimate it is envisaged that the costings of any removal programme proper would benefit from the proof of the methods and technologies proven during the trial and by economies of scale. A breakdown of the costing is provided in **Appendix C.**

8 Conclusion

The aim of this study was to determine if it is feasible to undertake a pilot ooze removal program at a selection of study sites in Tuggerah Lake. As part of this study, the extent of ooze in Tuggerah Lakes has been mapped (May-July 2015).

The data obtained from combined mapping and sediment sampling the black ooze identified within Tuggerah Lake indicates that it can be differentiated spatially and chemically from surrounding sediments. This study has found the physical characteristics of the ooze appear favourable to handling and treatment. Based on the location, chemical and physical characteristics of the ooze, it is concluded that it is technically feasible to undertake a pilot ooze removal program at a selection of study sites in Tuggerah Lake.

This study has identified the need for resampling the ooze to undertake elutriate testing, where OCPs were detected, to assess the potential for leaching and bioavailability in sediment in these sites. The results of this further analysis will inform the potential for pesticides to leech into the lake if sediments are handled.

Whilst removal of ooze is technically feasible, the cost/benefit may render it unsuitable. The removal program outlined in this report will only remove a small portion of ooze and will not prevent future formation of ooze. Therefore this is considered to be a short term, geographically restricted option for specific treatment areas. This study was not designed to assess the relative benefits of other ooze management options.

Ongoing monitoring is recommended to evaluate whether ooze is continuing to develop and the rate at which that may be occurring. The information provided by this feasibility study may inform Council's future management of ooze in Tuggerah Lake.

References

ARMCANZ/ANZECC 2000. *Australian and New Zealand Guidelines for Fresh and Marine water Quality – Interim Sediment Quality Guidelines.*

Australian Government 2009. *National Assessment Guidelines for Dredging.*

Creese RG, Glasby TM, West G and Gallen C 2009. *Mapping the habitats of NSW estuaries. Industry & Investment NSW Fisheries Final Report Series 113*. Port Stephens, NSW, Australia.

DPI 2007 Primefact 629 Seagrasses. NSW Department of Primary Industries.

OEH 2013a. *An assessment of 'Tuggerah Lakes Restoration Project' as a shoreline restoration strategy.* Prepared for Wyong Shire Council. Office of Environment and Heritage, NSW.

OEH 2013b. *Recommendations for management of ooze in Tuggerah Lakes*. Prepared for Wyong Shire Council .Office of Environment and Heritage, NSW.

US EPA 2005. *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites.*

Appendix A Laboratory Results

Refer to separate file “Appendix A”

Appendix B Chemistry Quality Checks

Refer to separate file for RDP calculations

Laboratory QA/QC

Holding times

All holding times were reported as being within specified ranges.

Two extraction time exceedences were recorded for sample batch ES1521758. All analyses for this batch were completed within the required holding time.

Laboratory accreditation for analytical methods used

The primary laboratory used was ALS Pty Ltd. ALS are accredited by NATA to ISO 17025, accreditation number 825.

Percent recoveries of spikes and surrogates

Laboratory QA/QC is provided on the laboratory reports in **Appendix A**. All spikes and surrogates were within acceptable ranges.

Exceptions to the above was that MS recovery for Ammonia in all sample batches submitted could not be determined as the background levels were ≥4 times the spike level.

Standard solution results

All ALS standard solution (or LCS – laboratory control sample) were within acceptable ranges.

LCS were below the required laboratory frequency for total sulphur for all sample batches submitted.

Laboratory duplicate results

All ALS laboratory duplicates were within acceptable ranges with the exception of Tributyltin (TBT). The RPD for TBT exceeded laboratory criteria in four of the five batches submitted. It is noted that the laboratory RPD requirement was significantly lower, due to the raised LOR as a result of compositing the TBT samples.

Laboratory duplicates were below the required laboratory frequency for total sulphur and sulphate for all sample batches submitted.

Laboratory blank results

All ALS laboratory blank results were within acceptable ranges.

Method blanks were below the required laboratory frequency for total sulphur and sulphate for all sample batches submitted.

QA/QC data evaluation

Evaluation of the QA/QC information compared to the DQOs

Documentation completeness:

Sample logs and chain of custody forms were completed and appropriate.

Data completeness:

All samples were received by the laboratories and analytical results reported including laboratory QA/QC.

Data comparability:

ES standard operating procedures, Australian Standards (AS 4482.1-2005 and AS 4482 2-1999) and industry best practice were followed during soil sampling.

Consistent field conditions and staff were used during sampling.

Standard analytical methods were used by the laboratories for all analyses.

The limits of reporting are appropriate and consistent from each laboratory.

Data representativeness:

Rinsate samples were not collected, however dedicated sampling equipment was used.

The frequency of laboratory blanks was acceptable and the results were within specified ranges, with the exception of Total Sulphur and Sulphate.

Precision:

Field duplicate/triplicates were collected at a rate of 1:8. These rates are within the Australian Standard (AS 1482.1 1997) and ES QA frequency ranges.

Laboratory duplicates were collected at acceptable frequencies (Australian Standard 1482). The laboratory duplicate RPDs were within acceptable ranges.

Data comparability

All sediment samples were collected using the same method. The weather conditions remained stable for the duration of the sampling.

All samples analysed by ALS used the same methodologies for each respective analyte.

Relative percentage difference

Precision of analytical techniques is measured by the RPD between duplicate results. Acceptance targets for field duplicates (intra-laboratory and inter-laboratory samples) are dependent on matrix type, analyte type and analyte concentrations and are as follows.

- Replicate data for field duplicates of organics is expected to be as follows:
    - RPD criteria of 50% or less, for concentrations > or = 10 times LOR
    - RPD criteria of 75% or less, for concentrations between 5 and 10 times the LOR
    - RPD criteria of 100% or less, for concentrations < 5 times LOR.
- Replicate data for field duplicates for inorganics, including metals is expected to be as follows:
    - RPD criteria of 30% or less, for concentrations > or = 10 times LOR
    - RPD criteria of 75% or less, for concentrations between 5 and 10 times the LOR
    - RPD criteria of 100% or less, for concentrations < 5 times LOR.

A summary of the RPD calculations is provided in separate document titled '**Appendix B'**.

A number of RPD exceedences, that is results returned outside of the above acceptance criteria were noted during the review of QA/QC data. In summary three duplicate samples and one triplicate returned some RPD exceedences:

- BV24O / Dup 1O – 7 exceedences (RPDs 31 – 88%)
- BV 24O / Trip 1O – 1 exceedences (RPD – 33%)
- BV31O / Dup 2 – 6 exceedences (RPDs 43 – 88%)
- BV44O / Dup 3 – 5 exceedences (RPDs 39 – 58%).

As has been previously discussed the duplicate samples collected were not split samples but separate samples collected from a sampling location immediately adjacent the original sample. As a result the RPDs returned by the duplicate sample pairs above considered to be most likely due to the effects of material heterogeneity rather than due to the inability of the laboratories to analyse the samples to more accurate repeatability.

Appendix C Costing

Refer to separate file “Appendix C”.

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