Remediation Action Plan

Proposed Georges Cove Marina

Prepared for Benedict Industries Pty Ltd | 11 March 2016

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Remediation Action Plan

Final

Report J14149RP1 | Prepared for Benedict Industries Pty Ltd | 11 March 2016

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1 Introduction

1.1 Proposed Georges Cove Marina

Benedict Industries Pty Ltd (Benedict Industries) (who are acting for the landowner, Tanlane Pty Ltd (Tanlane)) propose to construct and operate a marina and related facilities on part of Lot 7 in DP 1065574 (referred to as "Lot 7" hereafter), 146 Newbridge Road, Moorebank, in the Liverpool City Council Local Government Area (LGA). The marina is proposed to be developed on the southern portion (approximately 13 ha) of Lot 7 (which is approximately 22 ha in total). Lot 7 (ie the combined northern section and marina site) has historically been used for sand extraction, dredging and recycling operations.

As referenced in this report, the 'site' only refers to the southern portion of Lot 7 (see Figure 1.1) on which is proposed to develop the marina.

The marina site comprises a dredge pond created by the existing extractive operations and surrounding banks that accommodate access roads and stockpiles.

During construction of the marina, a channel will be excavated through the bank of the Georges River, connecting the dredge pond/marina basin to the adjacent Georges River.

1.2 Contamination overview

Preliminary contamination investigations were undertaken in 2015 and 2016. These included analyses of historic information and specific sampling and analysis programs. The results are presented in the *Preliminary Investigation* report (EMM 2015a) and the *Supplementary Preliminary Investigation* report (EMM 2016). These preliminary contamination investigations identified varying degrees of soil, dredge pond sediment, dredge pond water and groundwater contamination. This contamination was related to the concentrations of some metals, polycyclic aromatic hydrocarbons (PAHs), ammonia and nutrients.

1.2.1 Land based risks

The benzo(a)pyrene (a PAH), copper and zinc concentrations measured in a small number of soil samples exceeded the applicable ecological guidelines. However based on the concentrations measured in the soils, these contaminants are considered to present a low and acceptable risk in the context of the operation of a commercial marina and for the potential residential uses associated with the marina development (EMM 2016).

1.2.2 Aquatic environment risks

Some metals, PAHs and ammonia concentrations in the groundwater, dredge pond water and dredge pond sediment present a potential ecotoxicological risk to the aquatic receiving environment, the Georges River. High nutrient concentrations in the groundwater, dredge pond water and dredge pond sediment present a potential eutrophication risk.

T:\Jobs\2014\J14149 - 146 Newbridge Road Moorebank\GIS\02_Maps\RAP001_SiteBoundary_20160311_01.mxd 11/03/2016

Marina site location and boundary

Georges Cove Marina Development
Remediation action plan

Figure 1.1

1.3 Regulatory framework

State Environmental Planning Policy No 55 – Remediation of Land (2014) (SEPP 55) provides a state-wide planning approach to the remediation of contaminated land, and aims to promote the remediation of contaminated land for the purpose of reducing the risk of harm to human and environmental health. Clause 7 of SEPP 55 requires contamination and remediation to be considered in determining development applications. Clause 7(4) of SEPP 55 specifies categories of land that have the potential to be contaminated via reference to Table 1 of the contaminated land planning guideline, *Managing Land Contamination Planning Guidelines: SEPP 55 – Remediation of Land* (DUAP and EPA 1998).

Two known potentially contaminating activities have been undertaken at the site: extractive industries and landfilling. Landfilling has occurred at the marina site and on the northern portion of Lot 7 immediately to the north. Other potentially contaminating activities undertaken at the site, but not listed in the *Managing Land Contamination Planning Guidelines*, include: historic land use as a dairy and the introduction of fill to assist in landform restoration (source and quantity is unknown). There is also evidence to suggest that parts of the site were used as a landfill between 1972 and 1993, most likely for construction and demolition waste.

The applicant is therefore required to carry out an investigation where the objective of the investigation is to provide a preliminary assessment of site contamination. If the land is contaminated it must be shown that the land is, or can be made, suitable in its contaminated or remediated state for the proposed development. A contamination investigation provides the planning authority with the information it needs to carry out its planning functions and the investigation is required to be undertaken in accordance with the contaminated land planning guidelines (DUAP and EPA 1998). The PI and SPI reports were prepared to satisfy the requirements of Clause 7 of SEPP 55.

1.4 Objectives

This remediation action plan (RAP) has been prepared to:

- outline the site-specific remediation goals;
- determine the extent to which remediation is required; and
- identify management and remediation actions.

1.5 Contamination assessment method

The contamination assessment and remediation program is in two parts, the preliminary contamination investigations (PI and SPI) and this RAP.

The PI and SPI (EMM 2015a and 2016) characterised the site, identifying:

- potential contaminants of concern in each medium based on:
  - *National Environment Protection (Assessment of Contamination) Measures* (ASC NEPM) (NEPC 2013) risk-based Health Investigation Levels (HIL);
  - ASC NEPM Health Screening Levels (HSL);
  - ASC NEPM Ecological Investigation Levels (EIL);

- ASC NEPM Ecological Screening Levels (ESL);
- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Water Quality Guidelines) (ANZECC and ARMCANZ 2000) water quality guidelines for the protection of freshwater and marine ecosystems;
- ANZECC and ARMCANZ (2000) sediment quality guidelines;
- *Guidelines for Managing Risks in Recreational Water* (NHMRC 2008);

- potential offsite and onsite sources of contamination;
- human health risks and ecological risks;
- management and further assessment recommendations; and
- the suitability of the site for the proposed uses.

The SPI confirmed the original conclusions of the PI, that contamination issues would not preclude the proposed future land use as a proposed marina development as well as for high-density residential dwellings with minimal opportunities for soil access.

The preliminary investigations found there is a risk that metals, ammonia and nutrients in the dredge pond water, and these contaminants plus PAHs in the sediment, may impact ecological values in the Georges River when the marina basin is first opened to the river (acute impacts) and/or during of marina operations (chronic impacts).

This RAP identifies actions to minimise risks to human health or ecology and provides the following:

- a summary of the PI and SPI findings (Chapter 2);
- development of a conceptual site model (CSM) (Chapter 3);
- identification of remediation goals (Chapter 4);
- examination of each feasible contaminant source, each pathways/mechanisms in the environment, the contaminant’s fate and potentially exposed populations (Chapter 5);
- identification of remediation options to reduce the exposure of populations, generally through interrupting the exposure pathways/mechanisms in the environment (Chapter 5);
- consolidation of the proposed remediation options into a RAP (Chapter 6); and
- identification of monitoring requirements (Chapter 6).

The implementation of the remediation actions will ensure that:

- risks to human health and ecology from onsite contaminant sources are reduced to an acceptable level;
- the site is suitable for the proposed uses; and

2 Overview of site contamination

2.1 Investigations

Historic, preliminary investigations (EMM 2015a and 2016) have assessed the contamination status of soil, dredge pond sediment, dredge pond water and groundwater within the site. Historic sampling, focusing on groundwater and surface water, commenced in 2002. Detailed site investigations undertaken in 2015, in support of the marina site development application, comprised sampling of site soil, dredge pond water and dredge pond sediment (PI), and groundwater (SPI).

The PI was submitted to Liverpool City Council (the Council) for review, with a follow up meeting held with the Council and the Environment Protection Authority (EPA) on 30 October 2015. It was agreed that further investigation should be undertaken to evaluate the nature and potential risk of ammonia in the dredge pond sediment and water. In addition, a higher sampling density for all mediums (soil, groundwater, dredge pond water and dredge pond sediment) was requested to definitively determine the sites suitability for its proposed use. The SPI reports the results of additional sampling to provide improved spatial and statistical confidence in the levels and distribution of potential contaminants on the site.

2.2 Contaminants and areas of potential concern

An overview of the contaminants of potential concern at the site and the mediums where contamination is observed is provided in the SPI and reproduced in Table 2.1 below. The table has been colour coded to identify the contaminants of highest concern in red; moderate concern in orange; and lowest concern in green.

Table 2.1 Contaminants of potential concern

Contaminant	Soil	Dredge pond sediment	Dredge pond water	Groundwater
			Assessment criteria/guideline exceedances	
Metals*				
Aluminium	-	-	Freshwater TV exceeded in 6 samples. Exceedances correlated with high TSS concentrations (>1 g/L). No exceedances in samples with low TSS concentrations (<1 g/L).	Freshwater TV exceeded by a factor of up to about 140 with the highest concentration in groundwater west of the basin. Low concentrations in groundwater adjacent to the Georges River.
Cadmium	-	-	-	Freshwater TV exceeded by a factor of about 20 and the marine TV (for protection of 99% if species) exceeded by a factor of about 6 in one sample from west of the basin. Lower concentrations in groundwater adjacent to the Georges River.
Copper	EIL exceeded in 2 samples by a factor of up to about 2.2.	ISQG-low exceeded in 10 samples but concentrations within range reported for the Georges River.	Freshwater and marine TVs exceeded in 1 sample.	Freshwater and marine TV exceeded by a factor of up to about 5 with the highest concentration in groundwater east of the basin. The highest concentration (0.005 mg/L) in groundwater is lower than the mean concentration in Georges River water (0.006 mg/L) (Marine Pollution Research 2010).
Lead	-	ISQG-low exceeded in 12 samples and the ISQG-high exceeded in 7 samples. Concentrations higher than in the main channel of the Georges River but within the range measured in bays and tributaries, where flow is lower and where there are historic contamination sources.	-	-

Table 2.1 Contaminants of potential concern

Contaminant	Soil	Dredge pond sediment	Dredge pond water	Groundwater
		Assessment criteria/guideline exceedances		
Manganese	-	-	-	Freshwater TV exceeded in one sample by a factor of about 1.4 with the highest concentration in groundwater west of the basin. Low concentrations (below Freshwater TV) in groundwater adjacent to the Georges River.
Nickel	-	-	-	Freshwater TV exceeded in one sample by a factor of about 5 with the highest concentration in groundwater west of the basin. Marine TV (for protection of 99% if species) exceeded by a factor of up to about 85 in one sample from west of the basin. Lower concentrations in groundwater adjacent to the Georges River.
Zinc	EIL exceeded in 3 samples by a factor of about 2.	ISQG-low exceeded in 10 samples but concentrations within range reported for the Georges River.	Freshwater and marine TVs exceeded. Concentrations correlated with TSS concentrations. Some exceedances (by a factor of about 2) in samples with low TSS concentrations (<1 g/L). However, these levels are similar to the mean concentration in the Georges River (Marine Pollution Research 2010).	Freshwater and marine TV exceeded by a factor of up to about 115 with the highest concentration in groundwater west of the basin.

Table 2.1 Contaminants of potential concern

Contaminant	Soil	Dredge pond sediment	Dredge pond water	Groundwater
		Assessment criteria/guideline exceedances		
Mercury (total)	-	ISQG-low exceeded in 12 samples.	Freshwater and marine TVs exceeded by total mercury concentrations in 6 samples. All exceedances correlated with high TSS concentrations (>1 g/L). No exceedances in samples with low TSS concentrations (<1 g/L). Recreational guideline exceeded in 2 samples, both with high TSS concentrations (>58 g/L).	-
Nutrients				
Nitrate	-	-	Mean concentration exceeds TV for Lowland Rivers in 7 samples, by a factor of about 2.5.	-
Ammonia	-	-	Mean concentration exceeds TV for Lowland Rivers by a factor of about 400. Mean concentration exceeds freshwater and marine TVs by a factor of about 9.	Mean concentration exceeds TV for Lowland Rivers by a factor of about 120. Mean concentration exceeds freshwater and marine TVs by a factor of about 3. Lower concentrations in groundwater adjacent to the Georges River but still high.
Total nitrogen	-	Potential release of nutrients to water column and eutrophication risk.	Mean concentration exceeds trigger value for Lowland Rivers by a factor of about 95. Eutrophication risk.	Mean concentration exceeds trigger value for Lowland Rivers by a factor of about 10. Eutrophication risk.

Table 2.1 Contaminants of potential concern

Contaminant	Soil	Dredge pond sediment	Dredge pond water	Groundwater
		Assessment criteria/guideline exceedances		
Total phosphorus	-	-	Mean concentration exceeds trigger value for Lowland Rivers by a factor of about 370. Eutrophication risk	-
PAH				
Benzo(a) pyrene	ESL exceeded in two samples by a factor of about 1.6.	ISQG-low exceeded in 5 samples.	Recreational guideline value exceeded Exceedances correlated with high TSS concentrations (>1 g/L). No exceedances in samples with low TSS concentrations (<1 g/L).	-
Chrysene	-	ISQG-low exceeded in 3 samples.	-	-
Phenanthrene	-	Concentrations below the LOR in all but one sample. ISQG-low and -high exceeded in 1 sample.	-	-
Pyrene	-	ISQG-low exceeded in 8 samples and the ISQG-high exceeded in 1 sample.	-	-
Benzo(a) anthracene	-	ISQG-low exceeded in 4 samples.	-	-

Notes: ** Dissolved.*

EIL: environmental investigation level, and ESL: environmental screen level (NEPC 2013).

ISQG: interim sediment quality guidelines, high and low trigger values: (ANZECC and ARMCANZ 2000).

Freshwater & marine TVs: freshwater and marine trigger values for slightly to moderately disturbed ecosystems, generally for the protection of 95% of freshwater/marine species (ANZECC and ARMCANZ 2000).

River: default trigger values for South-east Australia Lowland Rivers (ANZECC and ARMCANZ 2000).

Recreational: recreational guideline (NHMRC 2008).

Eutrophication, no assessment criteria exceedance, but concentration high enough to consider a potential eutrophication risk.

2.2.1 Human health risks

The SPI (EMM 2016) found the following in relation to human health risks at the site:

> The SPI and PI did not identify soil contamination issues that are considered to present an unacceptable risk to human health in the context of the proposed future land uses.
>
> The elevated nutrient concentrations in the dredge pond water and the groundwater are not considered to represent a risk to human health as swimming in the pond water (leading to potential ingestion of pond water/groundwater) is unlikely in the context of a commercial marina.
>
> The elevated benzo(a)pyrene and total mercury concentrations measured in the dredge pond water were associated with very high TSS concentrations. The concentrations measured in the samples with low TSS concentrations are not considered to represent an unacceptable risk to human health. Therefore, these contaminants are not considered to represent an unacceptable risk to human health if sediment remains on the base of the marina and are not resuspended into the water column.

2.2.2 Ecological risks

The SPI (EMM 2016) found the following in relation to ecological risks at the site:

> While the ecological assessment criteria for benzo(a)pyrene, zinc and copper were exceeded in five soil samples, the exceedances are considered to present a low and acceptable risk in the context of the operation of a commercial marina. The marina design (ie locations of car parks, roads and buildings) will contribute to further reductions in the current risk level. No other ecological criteria applicable to soils were exceeded.
>
> The highest ecological toxicant risks contaminants in the groundwater, dredge pond water, dredge pond sediments are a result of:
>
> - lead and pyrene in the dredge pond sediment;
> - ammonia in the groundwater when the groundwater is discharging to the Georges River; and
> - total mercury and ammonia in the dredge pond water.
>
> The highest eutrophication risks are a result of:
>
> - ammonia in the groundwater; and
> - ammonia, total nitrogen and total phosphorus concentrations in the dredge pond water.

3 Conceptual site model

3.1 Approach to land based risks

Soil in the site contains fill which includes anthropogenic debris. Some locations have elevated benzo(a)pyrene, copper and zinc concentrations. Soil remediation will be relatively straight forward with contaminated soils removed or covered by impermeable surfaces. These will be managed through the remediation actions described in Section 6.1, including implementation of an unexpected finds protocol (see Section 6.1.2). Given the relative simplicity of the soil contamination, it has not been extensively considered in the CSM other than as a potential source of contamination to the aquatic environment.

3.2 Approach to aquatic environment risks

3.2.1 Conceptual site model overview

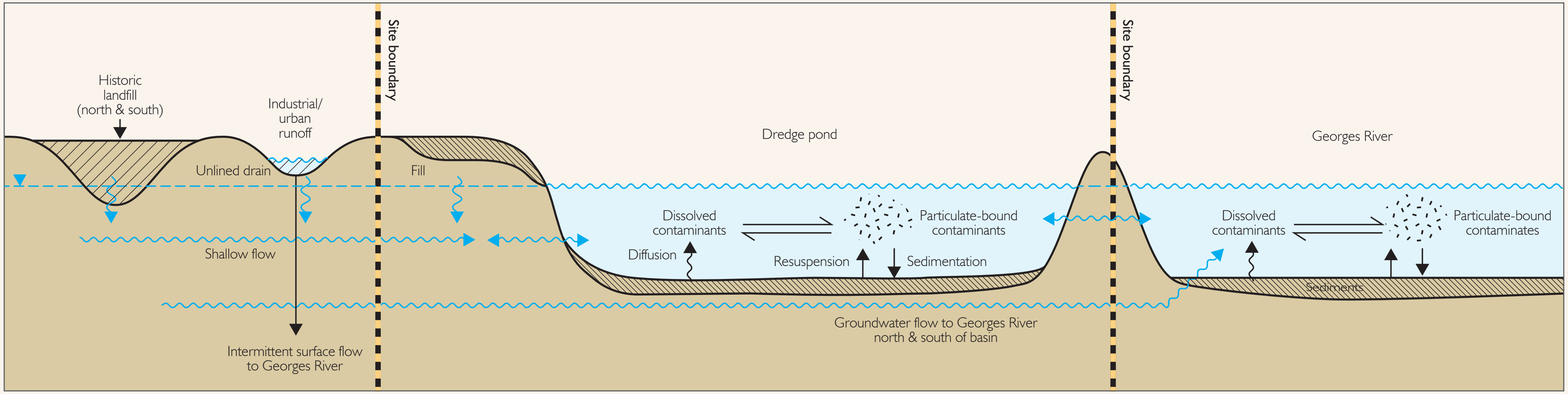
A CSM was developed to understand the potential contamination sources, the exposed populations and the pathways between these. The CSM reflects the complexity of the site and surrounding environment and includes:

- onsite and offsite environmental media;
- potential onsite and offsite contaminants sources;
- groups of contaminants with different chemical behaviour and partitioning;
- a range of potential physical and chemical transport mechanisms; and
- potentially exposed populations.

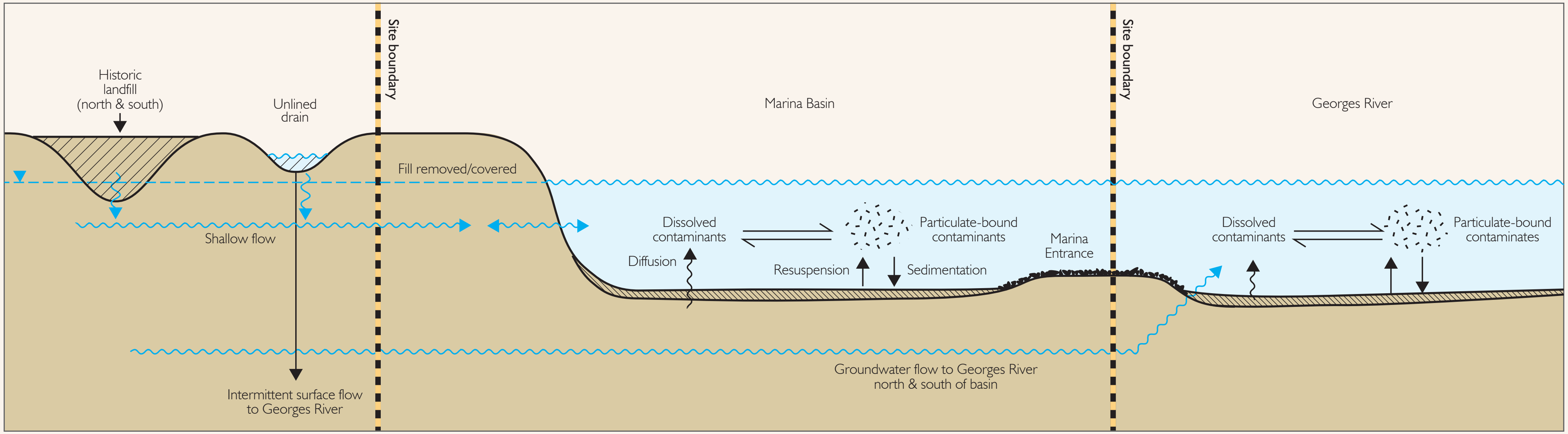
Some of the pathways will change when the use of the land is changed from a sand extraction operation to a marina. There are acute (ie short-term) risks when the marina basin is first opened to the Georges River and chronic (ie long-term) risks when the site operating as a marina.

The CSM is illustrated in Figure 3.1 and is described below.

Conceptual site model - sand extraction (current)



Conceptual site model - marina (future)



EMM

Conceptual site model
Remediation action plan
Georges Core Marina Development
Figure 3.1

3.2.2 Environmental media

The CSM includes the following environmental media:

- Groundwater: generally from offsite and moving through the site towards the Georges River. The groundwater flow is expected to be influenced by surface water inputs and the Georges River water level that changes due to river flow and tides (depending on the distance from the river).

- Surface water:

  - largely from offsite but particularly the unlined stormwater drain running along the western boundary of the site that drains stormwater from the Chipping Norton industrial area to the north of Newbridge Road. It is separated from the site by a levee running from Newbridge Road to the southern end of the site. This water discharges to the un-named creek the Georges River immediately south of the site. As the drain is unlined adjacent to the site, there is expected to be some seepage to groundwater. Contaminant concentrations is this drain will be highly variable and will depend on many factors including flow, period since last rain, rainfall intensity, and rainfall duration. It would be extremely difficult to characterise the average concentrations (or loads) in such a highly variable system.

  - Basin (dredge pond) water is currently used as part of processing operations to the north of the site (see Section 3.2.3). This flow has been considered in the surface water compartment. Process water is sourced from the basin and is returned to the basin after use. The water is used to wash concrete, bricks, glass and excavated geological materials, including soils with a high organic fraction.

  - Surface water runoff from north of the site drains to the basin. This includes water that has been in contact with stockpiled materials.

- Basin water: the dredge pond is currently about 6 ha and about 2.9 m deep. A cutter suction dredge is used to recover material from the basin as part of the sand extraction operations. Presently, there is no opening between the dredge pond and the Georges River. The water in the dredge pond is brackish with a mean salinity of 8.7 g/L (salinity of seawater is 35 g/L) and is generally well mixed (Marine Pollution Research 2010). The dredge pond will form the marina basin which will open to the river. It is estimated that up to 40 to 60% of the water in the marina basin will be exchanged between each peak and trough of a tidal cycle (Worley Parsons 2010).

- Basin sediments: the base of the basin is covered by fine sediments. The operating dredge resuspends these sediments into the water column. When the marina is opened, the basin sediments will be contiguous with Georges River sediments.

- Georges Cove River water: the site is toward the top of the estuarine section of the Georges River. The river adjacent to the site carries stormwater runoff from highly urbanised sub catchments upstream, including wet weather sewage discharges from three Sewage Treatment Plants (STPs): Glenfield, Liverpool and Fairfield. The *Georges River Catchment Built Environment and Foreshore Access Study* (DIPNR 2004) states that in the section of the river between Liverpool Weir and Sandy Point Bridge "Water quality is generally poor and affected by urban influences including discharge from sewage treatment plants, sewage overflows, discharge from industrial activities and contaminated run-off." River ecosystems include mangroves, benthos (ie organisms living in or on the sediment in the base of the river) and nekton/plankton (ie free-swimming/drifting organisms within the water column).

- Georges Cove River sediment: as described in the SPI, Georges River sediments have elevated copper, lead and zinc concentrations. As reported in Marine Pollution Research (2015):

  > Ecological Risk Assessment for the estuarine section of the Georges River downstream of Chipping Norton sewerage overflow [upsteam of the site] showed that there was potential risk to aquatic life from exposure to chemicals in sewer overflow and stormwater. Twenty-five chemicals were identified as COPCs [chemicals of potential concern] following chronic exposures and 5 COPCs were identified for acute exposures. Detailed risk evaluation indicated that processes such as degradation and the settling of particle bound chemicals reduced the number of chemicals of potential concern. However risks were still predicted from 3 acute COPCs and 9 chronic COPCs.
  >
  > In practice, Sydney Water (1998) found that whilst preliminary sampling of sediments undertaken in 1996 identified arsenic, cadmium, chromium, copper, iron, nickel, lead, zinc, a & b-BHC, endosulphan, DDT, Chlordane, chloropyrifos as chemicals of potential concern, no toxicity was found in a sediment bioassay taken downstream of the overflow.

- Site soils: the site soils contain fill, some of which extends at least 4 m below ground level. This is primarily construction and demolition waste (SPI Table 4.1). There is the potential that the dredge pond contains some of this fill as a result of the excavation of the pond.

The dredge pond, stormwater drain and un-named creek and the Georges River adjacent to the site are described in detail in Marine Pollution Research (2010), with an update provided in Marine Pollution Research (2015).

3.2.3 Contaminant sources

The CSM includes the following potential contaminant sources:

- Urban runoff: largely in the unlined stormwater drain west of the site that is expected to contain metals, ammonia, nutrients and PAHs with some seepage to groundwater.

- Fill to the north of the site: an old landfill that may contribute metals, ammonia, nutrients and PAHs to the basin and Georges River through groundwater seepage.

- Fill to the south of the site: an old landfill to the immediate south of the site that is a potential source of contamination (metals, ammonia, nutrients and PAHs), contributing to contamination of groundwater and the dredge pond sediments at the site (see SPI Section 5.5.2 for further details).

- Fill on the site: generally inert fill (bricks, rubble, etc. but with some anthropogenic debris such as plastics) may generate some leachate or may have been introduced to the dredge pond as the pond was excavated. Therefore the fill may have contributed metals, nutrients and PAHs to the groundwater and dredge pond.

- Runoff and process water from north of the site: materials such as concrete, bricks and glass are recycled in the area north of the site. This includes sorting, crushing, washing and stockpiling. Material is washed using pond water that is returned to the pond while runoff from the site also reports to the pond. Given that the waste materials are inspected prior to being accepted by the recycling facility, there is a low risk of these activities being a source of metal or organic chemical contaminants. However, these activities have the potential to introduce ammonia and nutrients to the dredge pond.

- Georges River Water, suspended sediment, and bed sediment: as described in Section 3.2.2.

3.2.4 Transport mechanisms

The CSM includes the following physical and chemical transport mechanisms:

- seepage of surface water containing dissolved contaminants to groundwater (onsite and offsite);
- groundwater flow containing dissolved contaminants with discharge to the basin (onsite);
- groundwater flow containing dissolved contaminants with discharge to the Georges River (onsite and offsite);
- seepage of basin water containing dissolved contaminants to groundwater (onsite);
- suspended particles with adsorbed contaminants settling to the sediments on the base of the basin or the Georges River (onsite and offsite);
- resuspension of sediments into the water column (onsite and offsite);
- adsorption of contaminants onto particles suspended in the water column (onsite and offsite);
- desorption of contaminants from suspended particles to the dissolved phase in the water column (onsite and offsite);
- direct discharge of stormwater in the unlined drain containing dissolved and particulate contaminants to the Georges River (offsite);
- formation of ammonia from organic matter in sediments (onsite and offsite);
- diffusion of contaminants from the bed sediment (onsite and offsite);
- Georges River water flow (offsite);
- sediment movement along the bed of the river (offsite); and
- overland flow during floods (offsite).

3.3 Existing arrangement, construction and operations

The CSM considers three periods:

- Existing arrangement: sand extraction on the site using the dredge. The basin is not connected directly to the Georges River but there is groundwater flow between the basin and the river.
- Marina construction, in particular opening the marina basin to the Georges River (acute risks): the marina basin will be completed to the greatest possible extent with the marine entrance channel partially excavated. The bank will only be opened if the water quality in the basin is similar to, or better than, that in the Georges River (based on the site-specific water quality assessment criteria described in Section 6.2.2).
- Marina operations (chronic risks): once the access channel is constructed, the marina will remain open for the foreseeable future with 40 to 60% of the water within the basin exchanged every tidal cycle (Worley Parsons 2010).

3.4 Chemical behaviour

The chemical behaviour of a contaminant will determine the pathways it will follow in the environment and the potential toxicity to biological receptors. The CSM considers the following chemical behaviours:

- Dissolved metals and PAHs concentrations measured in the dredge pond water as part of the SPI were generally correlated with TSS concentrations, with low metal and PAH concentrations in samples that had a low TSS concentration. Adsorption of these contaminants onto suspended particles followed by settling of the particles is expected to decrease the concentration of these contaminants in the water column. The contaminants remaining in the water column will be partitioned between the dissolved and particulate phases. Dissolved contaminants are generally considered to be more bioavailable, and hence of greater toxicity risk, than particulate-bound contaminants.

- Ammonia is highly soluble and predominantly occurs in the dissolved phase. In the SPI dredge pond water results, there was little correlation between TSS and ammonia concentrations at lower TSS concentrations. This is consistent with ongoing elevated ammonia concentrations across the dredge pond (see Section 6.2.2i). The samples with the highest TSS concentrations and had the highest ammonia concentrations suggesting that mobilisation of dredge pond sediments adds additional ammonia to the water column. Most of the ammonia in the environment comes from the natural breakdown of manure and dead plants and animals. Anthropogenic sources include fertiliser, sewage, breakdown of waste.

- Nutrients (measured as total nitrogen and total phosphorus in unfiltered samples) are generally associated with organic matter and may be transported as solids or in the dissolved phase. There was a good correlation between TSS and nutrient concentrations in the SPI dredge pond water results indicating that nutrients are being remobilised with the sediment by dredging.

3.5 Exposed population

Three exposed populations have been considered in the CSM:

- Humans: the Georges River adjacent to the site is used for recreational boating, including power boats, jet skis and kayaks. The recreational contact guidelines are calculated by multiplying the *Australian Drinking Water Guidelines* criterion by 10, assuming that water ingested during recreational activity is approximately 10% (200 mL) of that assumed for daily drinking water intake (2 L). Ingestion of 200 mL of water is far more likely when swimming than boating.

- Nekton and plankton: nekton are actively swimming aquatic organisms (eg fish) while plankton are passive organisms carried along by the current. The risk to these organisms has primarily been considered using the ANZECC and ARMCANZ (2000) water quality guidelines for slightly to moderately disturbed ecosystems.

- Benthos: the benthos is the community of organisms living in or on the bed sediment. The risk to these organisms has primarily been considered using the ANZECC and ARMCANZ (2000) sediment quality guidelines.

4 Remediation goal

The remediation goal is to ensure that:

- the site is suitable, from a contamination perspective, for the proposed uses — this will be achieved through the remediation of contaminated soil of the site, including unexpected finds (see Section 6.1.2);
- the risks to human health and ecology from onsite contaminant sources are reduced to an acceptable level — this will be achieved through the management and remediation actions during construction and operation of the marina basin (see Section 6.2); and
- the marina development does not increase the risks to the environment from offsite contaminant sources — this will be achieved through management and remediation actions during construction of the marina (see Section 6.2).

5 Potential pathways from sources to populations

The CSM was used to identify each feasible pathway between contaminant sources and exposed receptors. Each of these pathways is presented in Table A.1 in Appendix A.

High metals, PAHs and nutrients concentrations present ecotoxicity risks, while high nutrient concentrations present eutrophication risks. The Georges River is the main receptor of mobile onsite and offsite contaminants. The CSM focuses on pathways to the Georges River where there are ecotoxicity or eutrophication risks.

Generally, the exposure pathways from the primary source to the receptors include secondary sources. The form of the contaminant (eg dissolved or particulate) and the media (eg basin water or river water) for each secondary source are identified in Table A.1. The fate of the contaminant (form and medium) is identified based on the available transport mechanisms. Each fate may form a further secondary source, may result in exposure to a receptor, or both. Table A.1 lists whether each pathway is existing and whether the pathway needs to be considered when the marina channel between the basin and the Georges River is first opened and/or needs to be considered as part of ongoing marina operations.

Remediation options to reduce the exposure of populations, generally through interrupting the pathways/mechanisms in the environment, are listed for each pathway.

6 Remediation actions

6.1 Land based remediation

The general sequence for land based remediation works will comprise:

1. Prior to commencing any remediation works the dredge infrastructure will be removed. Any signs of contamination (notably staining and petroleum odours) observed during this process will be recorded. If unexpected areas of potential contamination are identified, the unexpected finds protocol (Section 6.1.2) will be implemented.

2. The need for excavation and/or the introduction of fill for the site will be determined prior to the start of construction.

3. The existing soil stockpiles in the north of the site and the soil mound in the south of the site will be removed with validation soil samples taken from the stockpile footprints. As described in the SPI, it is considered unlikely that gross contamination would be encountered within or under the mound or stockpiles that would render the site unsuitable for the proposed uses. The unexpected finds protocol (Section 6.1.2) will be implemented if required.

4. Areas where soil has been identified as having exceedances of the soil acceptance criteria will be:

    a) remediated through the removal and appropriate disposal of soil and fill; or

    b) will be covered with an impermeable surface.

5. Any material proposed for offsite disposal or reuse will be characterised for waste classification in accordance with the NSW EPA (2014) *Waste Classification Guidelines, Part 1: Classifying Waste*, or with regard to a relevant resource recovery order and exemption issued under the *Protection of the Environment Operations Act 1997* (POEO Act).

6. A validation survey of areas where soils will remain exposed will be conducted by a qualified environmental consultant following the completion of the landform. This will determine if contamination has been adequately removed, remediated and/or managed and no longer presents an unacceptable risk to human or environmental health.

6.1.1 Materials used for construction fill

Soils from the site or imported materials may be used as fill during construction.

Any material from the site that is proposed for reuse and that will not be covered by an impermeable surface will need to meet the ASC NEPM *Schedule B1: Guideline on Investigation Levels for Soil and Groundwater* (NEPC 2013) health-based and ecological investigation and screening levels for soil and soil vapour.

Any fill imported onto the site will need to be validated by a qualified environmental consultant, or certified by the supplier, as being suitable for the proposed land use. Virgin excavated natural material (VENM), with an appropriate VENM validation certificate, will be assumed to be suitable for importation without further assessment.

There must be no aesthetic issues associated with any fill (eg visible debris, staining or odours) that may be exposed when the marina site is operating.

6.1.2 Unexpected finds protocol

Given the inherent heterogeneity of fill material present at the marina site, an unexpected finds protocol with clear instructions for identifying and managing potential undiscovered contamination issues during development is required.

The appropriate management of unexpected finds will minimise human health and environmental risk from the disturbance of potential contaminated materials, and will ensure the material is managed in accordance with the *Contaminated Land Management Act 1997*.

Unexpected finds at the site could relate to buried finds and/or volatile contaminants, including (but not limited to):

- oil/diesel/tar/petrol sheens, free product, odours or impacted soils;
- buried structures, such as storage tanks, drums, disused pipe work, tyres or waste;
- asbestos pieces, fibre cement sheets, fibres (although this is considered highly unlikely due to the lack of development at the site);
- discoloured or odorous soil; and
- acid sulfate soils (ASS) or potential ASS, appearing as grey, gluggy soils with rotten egg smell.

The following procedures will be implemented if suspected contamination is discovered during construction:

1. Upon discovery of suspected contamination, all construction works in the vicinity are to cease, the site foreman is to be notified and the area barricaded.
2. The potentially contaminated material is to be removed and disposed of in accordance with the Waste Classification Guidelines. This may include removal of a buffer zone around the potentially contaminated material, based on field observations or volatile detections with a photoionization detector. The notification and engagement of a qualified environmental consultant will be required to assess the nature and degree of potential contamination and classification.
3. If the find is suspected to be asbestos material, the area is to be kept wet and management practices implemented in accordance with the NSW *WorkCover How to Manage and Control Asbestos in the Workplace, Code of Practice* (WorkCover 2011). If appropriate, the material will be covered to prevent dust generation, pending final management.
4. If the find is actual ASS or potential ASS, a suitably qualified consultant is to be engaged to manage the ASS in accordance with the *National Guidance for the Management of Acid Sulfate Soils in Inland Aquatic Ecosystems* (EPHC and NRMMC 2011).
5. If there is large scale exceedance of the assessment criteria it may be more practical to remediate the contamination rather than remove the source. An environmental consultant will establish and document a tailored remediation process, and will likely undertake sampling to confirm the type and extent of contamination. This is most likely for instances of potential and actual ASS.

6. Unexpected finds will be documented throughout the unexpected finds process. This will include: date(s), location(s), persons involved and remedial actions.

7. Once the site is remediated and validated, construction works will recommence.

Any required remediation will be directed by the Site Manager with supervision from a qualified Environmental Consultant depending on the type and extent of contamination.

6.2 Aquatic environment remediation

6.2.1 Consolidated management actions

The actions identified for each pathway in Table A.1 have been consolidated into management and remediation actions that will address the range of contaminants and pathways related to the marina basin and the aquatic environment.

The actions and monitoring to manage marina construction risks are described in Section 6.2.2 and those to manage marina operations risks are described in Section 6.2.3.

6.2.2 Marina basin construction

The marina construction management actions and monitoring are provided in Table 6.1 and described in further detail below. These will be implemented up to the time that the marina basin is opened to the Georges River.

Table 6.1 Management and remediation actions - construction

Potential source and mechanism	Construction actions	Construction monitoring
Direct water flow of water containing elevated metals, ammonia, nutrients and PAHs from secondary contaminant sources (groundwater, surface flows to basin and basin sediments) from the basin to the river.	Actions: • Cease dredging. • Complete all marina construction activities that may result in sediment resuspension and then allow time for metals to be adsorbed and for particles in the water column to settle to the bed sediments. • Monitoring of basin water prior to opening basin - only open basin once concentrations in the basin are in the range occurring in the river as determined by site-specific water quality assessment criteria. • Use silt curtains to minimise high TSS water entering the river surface water discharge from marina basin to river. Contingencies: • If required, treatment to remove ammonia and nutrients from the water column, eg flocculent addition.	Basin (prior to opening to the river): • pH, temperature, EC, DO and turbidity • TSS • Dissolved Al, Cd, Cu, Ni, Pb and Zn • Total and dissolved Hg • PAHs • Ammonia, total P and total N • BOD and COD River upstream/downstream of the site to provide a contemporary baseline: • pH, temperature, EC, DO and turbidity • TSS • Dissolved Al, Cd, Cu, Ni, Pb and Zn • Total and dissolved Hg • PAHs • Ammonia, total P and total N • BOD and COD

Table 6.1 Management and remediation actions - construction

Potential source and mechanism	Construction actions	Construction monitoring
Seepage of water containing elevated metals, ammonia and nutrients from the offsite unlined stormwater drain to groundwater followed by groundwater flow discharge to basin. Ongoing offsite source that has contributed contaminants to the basin.	Management through managing water quality in the basin prior to opening it to the river. Slow process - source will not contribute significant contaminants to the basin over the period which the basin will be opened to the river.	See basin/river water construction monitoring above.
Seepage from historic landfills north and south of the site to groundwater followed by groundwater flow discharge to basin. Ongoing offsite sources that may have contributed contaminants to the basin.	Management through managing water quality in the basin prior to opening the basin to the river. Slow process - sources will not contribute significant contaminants to the basin over the period which the basin will be opened to the river.	See basin/river water construction monitoring above.
Direct surface water discharge to the basin from north of the site. Historic offsite source that has contributed contaminants to the basin.	Cease processing to north of site. Prevent surface water runoff from offsite running directly into the basin.	See basin/river water construction monitoring above.

EC: electrical conductivity, DO: dissolved oxygen, TSS: total dissolved solids, Al: aluminium, Cd: cadmium, Cu: copper, Ni: nickel, Pb: lead, Zn: zinc, Hg: mercury, PAHs: polycyclic aromatic hydrocarbons, total P: total phosphorus, total N: total nitrogen, BOD: biological oxygen demand, COD: chemical oxygen demand.

i Cease dredging

The ammonia concentration in the dredge pond water generally decreased between September 2015 and January 2016 (Figure 6.1).

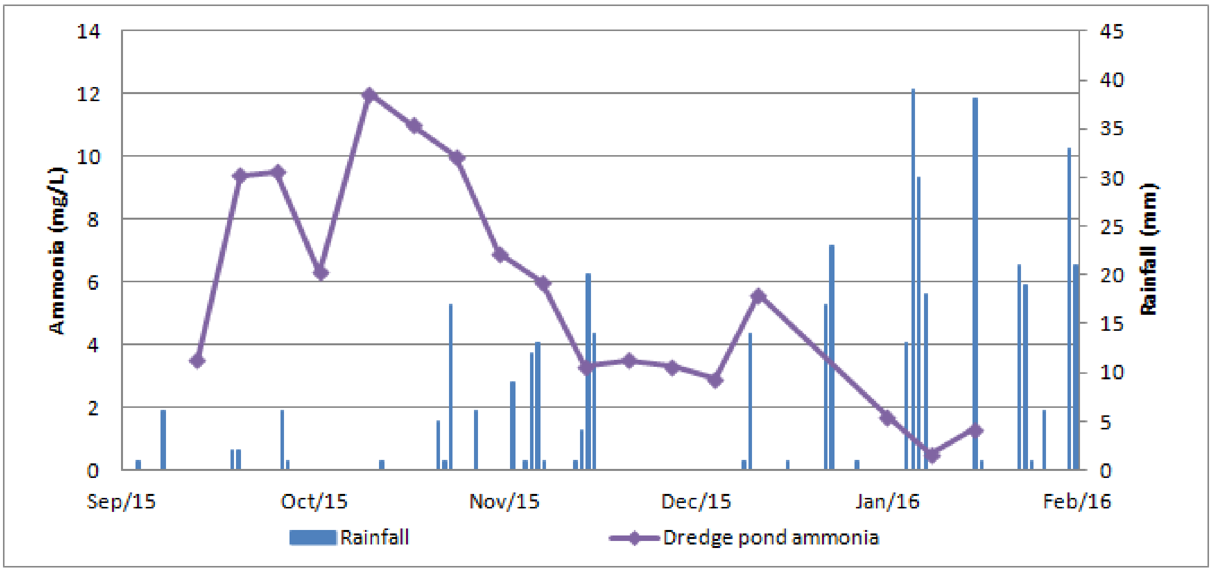


Figure 6.1 Ammonia results in the dredge pond water

The decreasing ammonia concentration has coincided with decreasing dredging activity in the pond. It may have also been reduced by dilution following rainfall. However, the decrease from October 2015 started before there was any appreciable rainfall.

Dredging within the pond as part of sand extraction activities was completed in February 2016. This has allowed suspended particles to settle. Since the completion of dredging, preliminary results indicate that the ammonia concentration in the pond has been measured to be 0.1 mg NH_3-N mg/L. There was little rainfall in this period. This preliminary concentration is below the ANZECC and ARMCANZ (2000) freshwater/marine trigger values for the protection of slightly to moderately disturbed ecosystems (0.90 NH_3-N mg/L / 0.91 NH_3-N mg/L). Monitoring is continuing.

It is anticipated that metals, PAHs and nutrient concentrations in the dredge pond water will also decrease as particulates in the water column settle and the bed sediments are no longer resuspended. Water sampling and analyses are underway to test this.

Ammonia concentrations below 0.90 NH_3-N mg/L will not result in an unacceptable ecotoxicologial risk. On the basis that metals and PAHs concentrations in pond water with low TSS concentrations were below trigger values (see Section 3.4), these contaminants are not expected to result in an ecotoxicologial risk to nekton/plankton or a recreational risk to humans when TSS levels are low as will be the case once particle settling is complete.

Given that dredging is believed to mobilising nutrients from the sediments into the dredge pond water (see Section 3.4), the risk of eutrophication is expected to reduce by orders of magnitude now that dredging has ceased. This would be further reduced as basin water is diluted with the far great volume of water in the Georges River.

While risks are expected to be reduced to acceptable levels, monitoring is required (see below) to confirm that metals, PAHs, ammonia and nutrient concentrations will not result in ecotoxicologial or eutrophication impacts. As the basin will not be opened to the river until assessment criteria are met, there is no change of an unacceptable risk to environment from water quality during construction.

ii Preventing surface flow to basin

The use of basin water for washing material to the north of the site will start prior to the start of marina construction. This will remove a historic contamination source.

Drains will be constructed at the start of the marina construction phase that prevent surface water runoff from the area north of the site running directly into the basin.

iii Marina basin and entrance construction

The *Georges Cove Marina, Moorebank, Environmental Impact Statement* (EMM 2015b) describes construction of the marina basin (EIS Section 2.10.3):

> The marina basin will be formed by filling parts of the existing quarry basin to shape it to the final landform using the existing quarry dredge and land-based earth moving machinery. This has been largely completed as part of recent quarry operations although final rehabilitation of the basin has not yet started.
>
> Excavated sand and other suitable materials will be used to form the entrance channel and associated land areas required for the marina. As described in Section 1.3 [of the EIS], some VENM (but no other waste materials) and rock will be imported to assist with shaping the marina basin.

> Modification of the quarry basin to form the marina basin and entrance channel will commence on the landward (eastern) side of the basin wall prior to breaking through the banks to the river. The breakthrough to the river will be undertaken as the last activity in the construction of the marina basin after the water quality in the basin has stabilised and is suitable for discharge to the river. In this way, works in the basin will not impact on river water quality.

This sequencing will allow sediments that have been resuspended during construction to settle to the bed sediments and allow time for the majority of dissolved metals in the water column to be adsorbed onto these settling particles. Absorption of dissolved metals in the basin water onto suspended particulates followed by sediment deposition will reduce concentrations in the water column and reduce contaminant mobility.

As for the cessation of dredging, allowing any suspended particulates to settle is expected reduce contaminant concentrations in basin water to levels where risks are acceptable. While risks are expected to be reduced to acceptable levels, monitoring is required (see below) to confirm that metals, PAHs, ammonia and nutrient concentrations will not result in ecotoxicologial or eutrophication impacts.

iv Silt curtains

Silt curtains are required in the river when the basin entrance is opened. These will prevent visible surface silt plumes entering the Georges River and will assist any suspended particles to settle to the bed of the Georges River by reducing the current and turbulence at the marina entrance.

v Water quality monitoring

A water quality monitoring program is required to confirm that the water from the basin is suitable for discharge when the marina channel is opened. The following parameters need to be measured in the basin (prior to opening to the river):

- pH, temperature, EC, DO and turbidity;
- TSS;
- dissolved Al, Cd, Cu, Ni, Pb and Zn;
- total and dissolved Hg;
- PAHs;
- ammonia, total P and total N; and
- BOD and COD.

Approximately five samples could be taken one to two days apart following the completion of construction activities that may disturb the water in the basin. Samples will take three to five days to analyse. Therefore this program should commence approximately two weeks before it is planned to complete the channel. Real-time measurements (pH, temperature, EC, DO and turbidity) could be used as an indicator that the water quality was stable immediately prior to commencing works to open the marina to the river.

The same parameters would be measured in the river upstream and downstream of the site to provide a contemporary baseline of river water quality. Up to ten weekly samples should be collected during marina construction.

vi Assessment criteria

The basin should not be opened unless the site-specific water quality assessment criteria are achieved.

Water quality in the Georges River varies according to rainfall events in the catchment and flow. The basin will be flushed with approximately 40 to 60% of the water exchanged each tide. Therefore when the basin is first opened, the majority of water in the basin will be flushed into the river by the first two tides. This is a short-duration event and assessment criteria for determining whether the basin can be opened to the river should reflect this.

The ANZECC and ARMCANZ (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* recommend the use of site-specific water quality data where possible when developing trigger values. Single trigger values should be derived statistically from a site-specific water quality dataset.

The site-specific Georges River water quality data collected prior to determining whether to open the basin would be used to determine site-specific assessment criteria. Given that the opening of the basin, and the subsequent flushing of the basin will occur within about 24 hours, it is appropriate that the assessment criteria reflect conditions that occur in the river frequently but not all of the time. The use of the 90th-percentile of the baseline data as the assessment criteria would achieve this goal. Assuming that the baseline data are reasonably representative of daily water quality over a year, the assessment criteria levels would be expected to be exceeded on 35 days per year regardless of marina construction. In reality, it is unlikely that the baseline sampling would capture the days when the water quality in the river was poorest so use of the 90th-percentile values for assessment criteria would be conservative.

vii Validation monitoring

Validation monitoring upstream and downstream in the river 24 hours after the basin is first opened is required. The same parameters should be measured as prior to opening the basin.

viii Contingencies

The management measures described above are expected to reduce the risks to exposed nekton/plankton and human populations to acceptable levels during construction. However, chemical treatment options are available as a contingency should contaminant concentrations not reduce to below the assessment criteria over an acceptable period to allow the marina basin to be opened to the river.

As described above, sufficient time will be allowed for suspended sediments in the basin water to settle to the basin bed sediments prior to opening the marina basin to the river. This will reduce the concentrations of metals and PAHs in the water column. If required, a non-toxic flocculent may be added to increase settling rates of fine particles (ie clay-sized particles). The capacity of a particle to adsorb contaminants increases with increasing particle surface area. The smallest particles have the highest surface area to mass ratio so addition of a flocculent is likely to further decrease contaminant concentrations if the water is turbid. Alternatively or in combination, the addition of coagulants (clarifying agents) can cause colloids to come out of suspension in the form of flocs or flakes.

Another option, if necessary, would be the use of in-situ biological reactors within the pond that promote the growth of ammonia oxidising bacteria (AOB). This is accomplished through the installation of high surface area fixed growth media that allow for water flow through the media (essentially, a metal frame structure wrapped with a material similar to a fine fish net). The system includes air diffusers which provide the oxygen required for AOB growth and for the nitrification of dissolved ammonia. These systems are suitable for reducing a one-off nutrient load in a pond, as well as managing continuous loading if relevant.

Water treatments options are also available using external fixed bed reactors to remove nutrients if required.

There will be no risk from the development of the marina before the basin is opened. Benedict Industries has committed to only opening the marina basin to the Georges River once the water quality is similar to the Georges River. The contingency measures outlined above are unlikely to be required to achieve this goal. However, there are a range of options available to reduce contaminant concentrations if required to meet the water quality assessment criteria prior to opening the pond. There will be as much time as needed to investigate and implement contingency actions if they are required.

6.2.3 Marina operations

The marina operations management actions and monitoring are provided in Table 6.2 and described in further detail below.

Table 6.2 Remediation options - operations

Potential source and mechanism	Operations remediation options	Operations monitoring
Direct water flow of water containing elevated metals, ammonia, nutrients and PAHs from secondary contaminant sources (groundwater, surface flows to basin and basin sediments) from the basin to the river.	• The marina basin is designed to promote frequent flushing (40–60% per tidal cycle), preventing contaminant accumulation in the water column and increasing contaminant concentrations. • Prevent basin sediment resuspension from propeller wash by: o providing adequate under keel clearance; and o enforcing speed limit (4 knots). • Ongoing chemical treatment of basin/river water is not viable.	River upstream/downstream of the site to provide a contemporary baseline: • pH, temperature, EC, DO and turbidity • TSS • Dissolved Al, Cd, Cu, Ni, Pb and Zn • Total and dissolved Hg • PAHs • Ammonia, total P and total N • BOD and COD
Seepage of water containing elevated metals, ammonia and nutrients from the offsite unlined stormwater drain to groundwater followed by groundwater flow discharge to basin. Ongoing offsite source that will continue to contribute contaminants to the basin.	No viable remediation options. Unlined stormwater drain transports runoff from the industrial area north of Newbridge Road to the Georges River. It is likely that the majority of the contaminant load from the drain is delivered to the Georges River by direct surface water discharged through the un-named creek south of the site rather than through groundwater seepage to the basin. Lining the drain would change the pathway (less flow/contaminant movement via groundwater and more via surface flow) but not the fate of contaminants in drain (discharge to river).	See basin/river water operations monitoring.

Table 6.2 Remediation options - operations

Potential source and mechanism	Operations remediation options	Operations monitoring
Seepage from historic landfills north and south of the site to groundwater followed by groundwater flow discharge to basin. Ongoing offsite sources that will continue to contribute contaminants to the basin.	Contaminants need to be managed at the source. The marina development will not change the contribution of contaminants from the historic land fill to the north of the site to the river. The land fill to the north is an offsite source that cannot be rectified as part of the marina development. However, this area will be remediated to the required standard as part of developing the Georges Cove residential estate. The marina development will not change the contribution of contaminants from the historic land fill to the south of the site to the river. There is no known proposal to remediate this area as it is currently approved to be used as a recycling facility for which no remediation works were required. Any measures to redirect this groundwater around the site would not reduce the total contaminant loads to the river.	See basin/river water operations monitoring.
Direct surface water discharge to basin from north of the site. Historical source that has contributed contaminants to the basin.	Cease processing to the north of site. Prevent surface water runoff from offsite running directly into the basin. Direct surface runoff to treatment area in north-west of basin to minimise solids, organic matter and nutrients entering the basin.	See basin/river water operations monitoring.
Movement of sediment along the bed of the basin to the river.	The marina entrance will be excavated to a depth that leaves a 'lip' at the entrance that extends above the base of the basin and river. The lip will be armoured with rock to prevent erosion by water moving into and out of the basin.	Upstream and downstream river sediment survey: • Fraction <63 µm • Cd, Cu, Hg, Ni, Pb and Zn concentrations • PAHs concentrations.
Desorption of metals or PAH from bed sediment and diffusion to overlying water column.	Ongoing chemical treatment of basin/river water is not viable.	See basin/river water operations monitoring.
Formation of ammonia in the sediments from organic matter and/or release of nutrients and diffusion to overlying water column.	Minimise input of solid organic matter to the basin by directly flow though treatment ponds.	See basin/river water operations monitoring.

i Marina flushing

The marina basin has been designed to promote frequent flushing (40–60% per tidal cycle), preventing contaminant accumulation in the water column and increasing contaminant concentrations.

ii Sediment resuspension prevention

The management described in Section 6.2 aim to ensure that there no unacceptable risks from water quality in the basin. In general, contaminants in the water column will be carried to the sediments. Given that the resuspension of sediments are believed to be a source of contaminants in water column, the settling of particles is not expected to increase contaminant levels in the sediment. Conversely, resuspension of contaminated sediments in the basin and subsequent transport to the Georges River is a potential long-term risk.

The marina will be a relatively low energy environment compared to the Georges River channel so particulates are more likely to settle in the basin than in the marina. Over the very long-term this will cap, or at least dilute, contaminants in the basin sediments.

The majority of the boats using the marina will be less than 15 m long. There will be four berths for boats between 15 m and 20 m long and no berths for boats more than 20 m long. Power boats 15 to 20 m long have draughts of up to 2.0 m (JBA Planning 2008). An under keel clearance of 0.3 m plus half the significant wave height is required to allow safe boat movement (JBA Planning 2012) where the bed is soft sediment. The marina basin will be 2.92 m deep at low tide and there will be no waves. Therefore there will be 0.92 m clearance for the longest boats using the marina at low tide. A speed limit of 4 knots will be enforces and significant propeller induced sediment resuspension is unlikely.

iii Treatment of surface flow to basin

The marina will be constructed to prevent uncontrolled surface run-off to the marina basin except from the immediately adjacent areas, eg walk ways and landscaped areas. Most storm water runoff from the marina site will be directed to the stormwater drain along the western boundary of the site.

As described in EIS Sections 3.4.6 and 6.1.7, the marina basin will incorporate a large constructed wetland to the north-west of the marina basin for polishing and treatment of storm water runoff from the development. The wetland will minimise solids (and associated contaminants such as metals), organic matter and nutrients from entering the basin.

iv Lip on floor of basin opening

There will be the potential for sediment to move horizontally between the base of the basin (2.92 m below the low tide level) and the base of the Georges River if the bottom basin entrance is at the same level. Rather, a 'lip' will be left at the base of the entrance. This will minimise the horizontal movement of basin sediment. The lip will be covered by rock armouring to prevent it being eroded by the overlying water movement in and out of the marina.

Over time, sediments in the basin are expected to further consolidate following the completion of dredging and become less mobile.

Monitoring of sediments in the Georges River prior to opening the basin (as a baseline) and quarterly for a year and then annual for five years is required. Sediments should be analysed for:

- fraction <63 µm;
- Cd, Cu, Hg, Ni, Pb and Zn concentrations; and
- PAHs concentrations.

The concentrations of contaminants in the sediments, most notably lead and pyrene (see Table 2.1), are elevated to levels where there are ecotoxicological risks to the benthos. However, these risks will be largely confined to the marina basin.

v Offsite contaminant sources

It is not proposed to implement management measures to control the following offsite contaminant sources identified in the CSM as the proponent will not be taking actions that will alter these sources and the project will not exacerbate the risks to receptors as a result of these sources:

- seepage to groundwater (offsite) and direct discharge to Georges River north and south of basin;
- offsite urban runoff discharge directly to river from the unlined storm water drain;
- leachate from landfills to north and/or south of the site entering the groundwater and direct discharge to Georges River north and south of basin;
- dissolved and particulate contaminants in the Georges River upstream of the site;
- dissolved and particulate contaminants in overland flow during flooding of the Georges River of the site; or
- contaminants in the Georges River sediments upstream of the site Georges River upstream of the site.

7 Conclusions and recommendations

7.1 Site suitability

A marina development is proposed on the site. The PI and SPI (EMM 2015a and 2016) characterised the site. These preliminary investigations found there is a risk that metals, ammonia and nutrients in the dredge pond water, and these contaminants plus PAHs in the sediment, may impact ecological values in the Georges River when the marina basin is first opened to the river (acute impacts) and/or during of marina operations (chronic impacts).

This RAP identifies a range of actions to minimise risks to human health or ecology within the marina basin and adjoining George River (see Section 7.2).

The land is suitable in its contaminated state (or will be suitable, after remediation) for the proposed future land use as a proposed marina development as well as for high-density residential dwellings with minimal opportunities for soil access.

7.2 Management actions

This RAP identifies the following management actions to ensure that the risks to human health or ecology within the marina basin and adjoining George River are minimised:

- During marina construction:
  - Cease dredging to allow suspended particulates in the dredge pond to settle. (Dredging ceased in February 2016).
  - Complete all marina construction activities that may result in sediment resuspension and then allow time for metals to be adsorbed and for particles in the water column to settle to the bed sediment.
  - Monitor basin water prior to opening basin. Only open basin once concentrations in the basin are in the range occurring in the river.
  - Monitor Georges River water quality to establish a contemporary baseline and establish site-specific water quality assessment criteria.
  - Use silt curtains to minimise water with high TSS concentrations entering the river surface water from the marina basin.
  - If required, investigate contingencies to reduce contaminant concentrations in the basin to meet site-specific water quality assessment criteria.
- During marina operations:
  - The marina basin is designed to promote frequent flushing, preventing contaminant accumulation in the water column and increasing contaminant concentrations.
  - Prevent basin sediment resuspension from propeller wash by: providing adequate under keel clearance (2.9 m low tide water depth) and enforcing the speed limit within the marina basin (4 knots).

- Cease processing to the north of site.
- Prevent surface water runoff from offsite running directly into the basin.
- Direct surface runoff to the treatment area in north-west of the basin to minimise solids, organic matter and nutrients entering the basin.
- Excavate the marina entrance to a depth that leaves a 'lip' at the entrance that extends above the base of the basin and river. Armour the lip with rock to prevent erosion by water moving into and out of the basin.
- Monitor Georges River water quality and sediment quality for five years to validate that marina operations are not an unacceptable risk to the ecology of river or to recreational users.

7.3 Conclusion

There are a range of offsite sources contributing contaminants to the Georges River in the vicinity of the site. These contaminants enter the river directly though surface water flow (eg urban runoff) and indirectly through seepage to groundwater followed be discharge of groundwater to the river. Development of the marina would not materially change these inputs.

The identified contamination on the site is largely associated with the basin, particularly bed sediments and suspended particulate matter.

There will be no ecological or recreational contact risk from the development of the marina before the basin is opened. There are a range of active and passive management measures that will reduce contaminant concentrations in the basin water before it is opened to the river. Benedict Industries has committed to only opening the marina basin to the Georges River once the water quality is similar to the Georges River.

Ecological or recreational contact risks in the river during marina operations will be generally associated with the movement of sediment along the bed or as a result of sediment resuspension. There are a range of management measures that will reduce these risks to acceptable levels.

Monitoring during marina construction, following opening the marina basin and during marina operations will be required to confirm that risks are acceptable based on established and site-specific criteria.

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Appendix A

Contaminant pathways and management

ID	Primary source	Secondary source		Mechanism	Fate		Risk to potential receptors			Notes	Existing?	Future?		Management options	
		Form	Media		Form	Media	Benthos (including bottom feeding nekton)	Nekton/plankton	Humans (recreational contact)			Acute	Chronic	Maqrina construction (acute risk)	Marina operations (chronic risk)
Metals															
1	Surface water: urban runoff in unlined drain seeps to groundwater	Dissolved metals	Groundwater												
2		Dissolved metals	Groundwater	Seepage to groundwater (offsite) and direct discharge to Georges River north and south of basin	Dissolved metals	River water	-	Levels above baseline/ANZECC TVs - potential toxicity	Levels exceed recreational guidelines	Off-site source. Marina development will not change source or pathway. Lining the drain would change the pathway (less via groundwater, more via surface flow) but not the fate (discharge to river)	y	y	y	None	None
3		Dissolved metals	River water	Absorption to suspended particulates	Particulate bound metals	River water	-	Levels above baseline/ANZECC TVs - potential toxicity Risk lower than for dissolved metals	Levels exceed recreational guidelines	-	y	y	y	None	None Ongoing chemical treatment of basin/river water is not viable
4		Particulate bound metals	River water	Particle settling	Particulate bound metals	River sediment	Levels above baseline/ANZECC ISQGs - potential toxicity	-	-	-	y	y	y	None	None
5	Surface water: urban runoff in unlined drain seeps to groundwater	Dissolved metals	Groundwater												
6		Dissolved metals	Groundwater	Seepage to groundwater (offsite) and discharge to basin.	Dissolved metals	Basin water	-	Levels above baseline/ANZECC TVs - potential toxicity	Levels exceed recreational guidelines	Risk only when basin is contiguous with river Off-site source. Marina development will not change source or pathway. Ongoing input so redirection (eg in-ground barriers) would not change fate (flow to Georges River).	y	n	y	See basin water management	None
7		Dissolved metals	Basin water	Absorption of metals to suspended particulates	Particulate bound metals	River water	-	Levels above baseline/ANZECC TVs - potential toxicity Risk lower than for dissolved metals	Levels exceed recreational guidelines	Risk only when basin is contiguous with river	y	y	y	Basin water management: - allow time for metals to be adsorbed. - basin water monitoring of prior to opening basin - open basin only when site-specific water quality assessment criteria acheived - contingency water treatment if required (eg flocculent)	None Ongoing chemical treatment of basin/river water is not viable
8		Particulate bound metals	Basin water	Particle settling	Particulate bound metals	Basin sediment	Levels above baseline/ANZECC ISQGs - potential toxicity	-	-	Risk only when basin is contiguous with river Metals most immobile and generally lowest risk when associated with the sediment	y	n	y	None	None
9		Particulate bound metals	Basin sediment	Resuspension of sediments by dredge or propellers	Particulate bound metals	Basin water	-	Levels above baseline/ANZECC TVs - potential toxicity Risk lower than for dissolved metals	Levels exceed recreational guidelines	Risk only when basin is contiguous with river Small number of boats 15-20 m long and no boats more than 20 m long	y	n	y	See basin water management	Prevent sediment resuspension from prop wash by providing adequate clearance and enforcing speed limit (4 knots)
10		Particulate bound metals	Basin water	Desorption of metals from suspended particulates	Dissolved metals	Basin water	-	Levels above baseline/ANZECC TVs - potential toxicity	Levels exceed recreational guidelines	Risk only when basin is contiguous with river	y	y	y	See basin water management	Prevent sediment resuspension
11		Particulate bound metals	Basin sediment	Desorption of metals from sediment and diffusion to overlying water column	Dissolved metals	Basin water	-	Levels above baseline/ANZECC TVs - potential toxicity	Levels exceed recreational guidelines	Risk only when basin is contiguous with river Slow chemical processes that may be accelerated by bioturbation. Metals likely to remain largely adsorbed on particles	y	n	y	See basin water management	None
12	Surface water: urban runoff in unlined drain - surface flow discharges directly to river	Dissolved metals and particulate bound metals	River water												

Table A.1 Contaminant pathways and management

ID	Primary source	Secondary source		Mechanism	Fate		Risk to potential receptors			Notes	Existing?	Future?		Management options	
		Form	Media		Form	Media	Benthos (including bottom feeding nekton)	Nekton/plankton	Humans (recreational contact)			Acute	Chronic	Maqrina construction (acute risk)	Marina operations (chronic risk)
13		Dissolved metals and particulate bound metals	River water	Direct surface water discharge to river when drain is flowing	Dissolved metals and particulate bound metals	River water	-	Levels above baseline/ANZECC TVs - potential toxicity	Levels exceed recreational guidelines	Historic discharge. Drain and discharge point to river off-site.	y	n	y	None	None
14	Leachate from landfills to north and/or south of the site	Dissolved metals	Groundwater												
15		Dissolved metals	Groundwater	Seepage to groundwater (offsite) and direct discharge to Georges River north and south of basin	Dissolved metals	River water	-	Levels above baseline/ANZECC WQTVs - potential toxicity	Levels exceed recreational guidelines	Need to be managed at the source. Measures on site could only redirect flows. A contamination assessment for area north of the site is underway. No remediation was required during recent approcal of site to the south	y	n	y	None	None
16		Dissolved metals	Groundwater	Seepage to groundwater (offsite) and discharge to basin	Dissolved metals	Basin water	-	Levels above baseline/ANZECC TVs - potential toxicity	Levels exceed recreational guidelines	Risk only when basin is contiguous with river	y	n	y	See basin water management	None. Ongoing chemical treatment of basin/river water is not viable
17	Process water/surface water runoff from north of the site	Dissolved metals and particulate bound metals	Surface water												
18		Dissolved metals and particulate bound metals	Surface water	Direct surface water discharge to basin	Dissolved metals and particulate bound metals	Basin water	-	Levels above baseline/ANZECC TVs - potential toxicity	Levels exceed recreational guidelines	Risk only when basin is contiguous with river Basin water will cease to be used for processing at the cessation of recycling facility activities north of the site.	y	y	y	Cease processing to north of site Prevent surface water runoff from offsite running directly into basin Direct surface runoff to treatment area in north-west of basin See basin water management	Prevent surface water runoff from offsite running directly into basin Direct surface runoff to treatment area in north-west of basin
19		Dissolved metals	Basin water	Direct water flow to river	Dissolved metals	River water	-	Levels above baseline/ANZECC TVs - potential toxicity	Levels exceed recreational guidelines	Risk only when basin is contiguous with river	n	y	y	See basin water management	Marina designed to promote frequent flushing (40-60% per tidal cycle), preventing dissolved and particulate metal accumulation and increasing concentrations.
20		Particulate bound metals	Basin water	Direct water flow to river	Particulate bound metals	River water	-	Levels above baseline/ANZECC TVs - potential toxicity Risk lower than for dissolved metals	Levels exceed recreational guidelines	Risk only when basin is contiguous with river	n	y	y	See basin water management	None
21		Particulate bound metals	Basin sediment	Movement of sediment along bed to river	Particulate bound metals	River sediment	Levels above baseline/ANZECC ISQGs - potential toxicity	-	-	-	n	n	y	-	Leave an armoured lip on the base on the marina entrance
22		Dissolved metals	Basin water	Infiltration to groundwater	Dissolved metals	Groundwater	-	-	-	-	y	n	y	-	-
23	Georges River upstream of the site	Dissolved metals and particulate bound metals	River water												
24		Dissolved metals and particulate bound metals	River water	River flow	Dissolved metals and particulate bound metals	River water	-	Levels above baseline/ANZECC TVs - potential toxicity	Levels exceed recreational guidelines	-	y	y	y	None	None Ongoing chemical treatment of basin/river water is not viable
25		Dissolved metals	River water	Absorption to suspended particulates	Particulate bound metals	River water	-	Levels above baseline/ANZECC TVs - potential toxicity Lower risk than for dissolved metals	Levels exceed recreational guidelines	-	y	y	y	None	None Ongoing chemical treatment of basin/river water is not viable

Table A.1 Contaminant pathways and management

ID	Primary source	Secondary source		Mechanism	Fate		Risk to potential receptors			Notes	Existing?	Future?		Management options	
		Form	Media		Form	Media	Benthos (including bottom feeding nekton)	Nekton/plankton	Humans (recreational contact)			Acute	Chronic	Maqrina construction (acute risk)	Marina operations (chronic risk)
26		Particulate bound metals	River water	Particle settling	Particulate bound metals	River sediment	Levels above baseline/ANZECC ISQGs - potential toxicity	-	-	-	y	y	y	None	None Ongoing chemical treatment of basin/river water is not viable
27	Georges River upstream of the site	Particulate bound metals	River sediment												
28		Particulate bound metals	River sediment	Movement of sediment along the river bed	Particulate bound metals	River sediment	Levels above baseline/ANZECC ISQGs - potential toxicity	-	-		y	y	y	None	None (current boat use of river will continue).
29	Overland flow during flooding	Dissolved metals and particulate bound metals	River water												
30		Dissolved metals	River water	Absorption to suspended particulates	Particulate bound metals	River water	-	Levels above baseline/ANZECC TVs - potential toxicity Lower risk than for dissolved metals	Levels exceed recreational guidelines	-	y	y	y	None	None Ongoing chemical treatment of basin/river water is not viable
31		Particulate bound metals	River water	Particle settling	Particulate bound metals	River sediment	Levels above baseline/ANZECC ISQGs - potential toxicity	-	-	-	y	y	y	None	None (current boat use of river will continue).
Ammonia															
32	Surface water: urban runoff in unlined drain seeps to groundwater	Ammonia	Groundwater												
33		Dissolved ammonia	Groundwater	Seepage to groundwater (offsite) and direct discharge to Georges River north and south of basin	Dissolved ammonia	River water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	Off-site source. Marina development will not change source or pathway.	y	y	y	None	None Note: lining the drain would change the pathway (less via groundwater, more via surface flow) but not the fate (discharge to river)
34		Dissolved ammonia	Groundwater	Seepage to groundwater (offsite) and discharge to basin	Dissolved ammonia	Basin water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	Risk only when basin is contiguous with river .	y	y	y	See basin water management	None
35		Dissolved ammonia	Basin water	Direct water flow to river	Dissolved ammonia	River water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	May occur when basin first opened to the river. Could be a ongoing pathway for movement of ammonia to the river.	n	y	y	See basin water management	Marina designed to promote frequent flushing, preventing ammonia accumulation increasing concentrations.
36		Organic matter	Basin sediment	Formation of ammonia in the sediments from organic matter and diffusion to overlying water column	Dissolved ammonia	Basin water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	Risk only when contiguous with river	y	n	y	See basin water management	Minimise input of solid organic matter to the basin by directly flow though treatment wetland.
37	Surface water: urban runoff in unlined drain - surface flow discharges directly to river	Ammonia	Groundwater												
38		Dissolved ammonia	Groundwater	Direct surface water discharge to river when drain is flowing	Dissolved ammonia	River water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	Historic discharge. Drain and discharge point to river off-site	y	n	y	None	None
39	Leachate from landfills to north and/or south of the site	Dissolved ammonia	Groundwater												
40		Dissolved ammonia	Groundwater	Seepage to groundwater (offsite) and direct discharge to Georges River north and south of basin	Dissolved ammonia	River water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	-	y	n	y	None	Needs to be managed at the source. Measures on site could only redirect flows. Contamination assessment for area north of the site are underway.
41		Dissolved ammonia	Groundwater	Seepage to groundwater (offsite) and discharge to basin.	Dissolved ammonia	Basin water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	Risk only when contiguous with river	y	n	y	See basin water management	Ongoing chemical treatment of basin/river water is not viable None as part of this development
42	Process water/surface water runoff from north of the site	Dissolved ammonia	Surface water												

Table A.1 Contaminant pathways and management

ID	Primary source	Secondary source		Mechanism	Fate		Risk to potential receptors			Notes	Existing?	Future?		Management options	
		Form	Media		Form	Media	Benthos (including bottom feeding nekton)	Nekton/plankton	Humans (recreational contact)			Acute	Chronic	Maqrina construction (acute risk)	Marina operations (chronic risk)
43		Dissolved ammonia	Surface water	Direct surface water discharge to basin	Dissolved ammonia	Basin water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	Risk only when contiguous with river Basin water will cease to be used for processing at the cessation of recycling facility activities north of the site.	y	n	y	See basin water management	Minimise input of ammonia to the basin by directly flow though treatment ponds.
44		Dissolved ammonia	Basin water	Direct water flow to river	Dissolved ammonia	River water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	Risk only when contiguous with river	n	y	y	See basin water management	None
45		Dissolved ammonia	Basin water	Infiltration to groundwater	Dissolved ammonia	Groundwater	-	-	-	-	y	n	y	-	-
46	Georges River upstream of the site	Dissolved ammonia	River water												
47		Dissolved ammonia	River water	River flow	Dissolved ammonia	River water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	-	y	n	y	None	None Current process unrelated to operation of the site
48	Georges River upstream of the site	Dissolved ammonia	River sediment												
49		Organic matter	River sediment	Formation of ammonia in the sediments from organic matter and diffusion to overlying water column	Dissolved ammonia	River water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	-	y	n	y	None	None Current process unrelated to operation of the site
50	Overland flow during flooding	Dissolved ammonia	River water												
51		Dissolved ammonia	River water	River flow	Dissolved ammonia	River water	-	Levels above baseline/ANZECC TVs - potential toxicity. Eutrophication risk.	-	High organic loads may occur due to flooding and overflow of upstream sewage treatment plants	y	n	y	None	None Current process unrelated to operation of the site
Nutrients															
52	Surface water: urban runoff in unlined drain seeps to groundwater	Nutrients	Groundwater												
53		Nutrients	Groundwater	Seepage to groundwater (offsite) and direct discharge to Georges River north and south of basin	Nutrients	River water	-	Eutrophication risk.	-	Off-site source. Marina development will not change source or pathway.	y	y	y	None	None
54		Nutrients	Groundwater	Seepage to groundwater (offsite) and discharge to basin	Nutrients	Basin water	-	Eutrophication risk.	-	Risk only when basin is contiguous with river .	y	y	y	See basin water management	None
55		Nutrients	Basin water	Direct water flow to river	Nutrients	River water	-	Eutrophication risk.	-	May occur when basin first opened to the river. Could be a ongoing pathway for movement of nutrients to the river.	n	y	y	See basin water management	Marina designed to promote frequent flushing, preventing nutrient accumulation and increasing concentrations.
56		Nutrients	Basin sediment	Release of nutrients from the sediments from organic matter and diffusion to overlying water column	Nutrients	Basin water	-	Eutrophication risk.	-	Risk only when contiguous with river	y	n	y	See basin water management	Minimise input of solid organic matter to the basin by directly flow though treatment ponds.
57	Surface water: urban runoff in unlined drain - surface flow discharges directly to river	Nutrients	Groundwater												
58		Nutrients	Groundwater	Direct surface water discharge to river when drain is flowing	Nutrients	River water	-	Eutrophication risk.	-	Historic discharge. Drain and discharge point to river off-site	y	n	y	None	None
59	Leachate from landfills to north and/or south of the site	Nutrients	Groundwater												
60		Nutrients	Groundwater	Seepage to groundwater (offsite) and direct discharge to Georges River north and south of basin	Nutrients	River water	-	Eutrophication risk.	-	-	y	n	y	None	Needs to be managed at the source. Measures on site could only redirect flows. Contamination assessment for area north of the site are underway.

ID	Primary source	Secondary source		Mechanism	Fate		Risk to potential receptors			Notes	Existing?	Future?		Management options	
		Form	**Media**		**Form**	**Media**	**Benthos (including bottom feeding nekton)**	**Nekton/plankton**	**Humans (recreational contact)**			**Acute**	**Chronic**	**Maqrina construction (acute risk)**	**Marina operations (chronic risk)**
61		Nutrients	Groundwater	Seepage to groundwater (offsite) and discharge to basin.	Nutrients	Basin water	-	Eutrophication risk.	-	Risk only when contiguous with river	y	n	y	See basin water management	None
62	Process water/surface water runoff from north of the site	Nutrients	Surface water												
63		Nutrients	Surface water	Direct surface water discharge to basin	Nutrients	Basin water	-	Eutrophication risk.	-	Risk only when contiguous with river - see river row Basin water will cease to be used for processing at the cessation of recycling facility activities north of the site.	y	n	y	See basin water management	Minimise input of ammonia to the basin by directly flow though treatment ponds.
64		Nutrients	Basin water	Direct water flow to river	Nutrients	River water	-	Eutrophication risk.	-	Risk only when contiguous with river	n	y	y	See basin water management	None
65		Nutrients	Basin water	Infiltration to groundwater	Nutrients	Groundwater	-	-	-	-	y	n	y	-	None
66	Georges River upstream of the site	Nutrients	River water												
67		Nutrients	River water	River flow	Nutrients	River water	-	Eutrophication risk.	-	-	y	n	y	-	None Current process unrelated to operation of the site
68	Georges River upstream of the site	Nutrients	River sediment												
69		Nutrients	River sediment	Formation of ammonia in the sediments from organic matter and diffusion to overlying water column	Nutrients	River water	-	Eutrophication risk.	-	-	y	n	y	-	None Current process unrelated to operation of the site
70	Overland flow during flooding	Dissolved metals and particulate bound metals	River water												
71		Nutrients	River water	River flow	Nutrients	River water	-	Eutrophication risk.	-	High organic loads may occur due to flooding and overflow of upstream sewage treatment plants	y	n	y	-	None Current process unrelated to operation of the site

1. Metals of concern:
High risk: lead in sediment (high risk), total mercury in basin water (high risk)
Medium risk: aluminium (groundwater), cadmium (groundwater), mercury (basin sediment), nickel (groundwater), zinc (basin water and groundwater)
Low risk: aluminium (basin water), copper (basin sediment, basin water and groundwater), manganese (groundwater), zinc (basin water)
2. It is assumed that ammonia will occur predominantly as dissolved ammonia.
3. Nutrients measured as total nitrogen and total phosphorus.
4. PAH are expected to partition between the dissolved and particulate phases and are a toxicity risk. The same pathways and mechanisms are expected to occur as for metals. Measures to manage metals will also manage PAHs.

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