

Ludmilla Waste Water Treatment Plant Environmental Risk Assessment

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Executive Summary

The purpose of this document was to provide an update to the 2019 ERA. It is important to note the quality of the discharge and locations of the outfalls have not changed significantly since the last assessment and thus a number of the conclusions drawn are still relevant to the current assessment.

Three new assessments have been undertaken since the 2019 report to draw insights from. The 2018 toxicological assessment of the discharge, the 2021 ecological risk assessment (ERA) conducted by SLR focussed on receptors in Ludmilla Ck and 2020 CEE Pty Ltd report on the Benthic Infauna Monitoring and Management Plan (BIMMP) report. Also, since 2019, greater insights surrounding the black plume phenomena have been attained.

As part of the BIMMP imposed by the commonwealth, a 2020 cumulative report (including monitoring between 2017 and 2019) by CEE echoes the conclusions of the initial BIMMP monitoring report (2016). Sensitive species believed to live in the vicinity of the East Point Outfall (EPO) are not negatively affected by the discharge. Based upon these reports, the impact zone of the EPO on benthic infauna is no greater than 200m and seagrass has not been sighted within 300m of the outfall. Similarly, sensitive fauna has not been sighted during any sampling run.

Screening assessments identify human contact with pathogens as the highest risk posed by the discharge. Studies by researchers at Charles Darwin University (Neave et al 2014; Padovan et al 2017; Kaestli et al 2017, Padovan et al 2019) have identified microbiota as a sensitive environmental indicator even in the dynamic and complex environment that is Darwin Harbour. These studies have also identified that DNA associated with pathogenic bacteria is present in waterways subject to treated wastewater discharges, however the studies also found that the DNA was present in Darwin Region water ways to which there are no known wastewater of treated effluent discharges.

Black plume discharges, caused by low flows in the outfall rising main, have had an adverse effect on the visual amenity of the waters around East Point. This phenomena is classed as a risk to the cultural values and there has been no evidence that it has compromised the environmental values of the area.

Toxicant assessments show a marked improvement between the 2014 and 2018 due to the commissioning of the hydraulic plant upgrade in 2016. The toxicity of the effluent for organisms commonly found in the receiving environment has reduced by between 3 and 5 times. Based upon the results a dilution factor of 26 is required for 99% species protection though the estimated dilution factor at the East Point Outfall between SLuEP01 and 02 is 200.

The toxicant assessments, along with the Ludmilla Creek ERA conducted by SLR in 2021 identifies 3 chemicals of potential concern; ammonia, copper (both of which have the potential for toxicity and are found in high concentrations in the discharge) and zinc (included as it is a commonly identified toxicant in wastewater). Ludmilla Ck receptors were assessed against the concentrations of these chemicals in the discharge and their estimated toxic thresholds. Ammonia toxicity ranked as a possible risk to receptors whereas copper and zinc register a low or negligible rating following the semi-qualitative risk assessment. Though this is the case, these results were contingent on a 24hr continuous discharge which is rarity in wet season and even less likely in dry season.

The risk associated with sewage effluent discharges to Ludmilla Ck in the wet season is Low to Negligible due to the dilute nature of the effluent. The study also found, based upon water quality results comparing the sampling sites upstream and downstream of the discharge point, the wider Ludmilla Ck catchment has a larger influence on the characteristics of the creek than the discharge.

Although, largely, the risk profile of discharge from each point remains low, the need for maintenance and mitigation is important and ongoing. Current and ongoing mitigation measures to retain a low risk rating include:

- Routine water quality sampling including observations from samplers on a monthly basis,
- assessing the environmental outcomes of operational changes within the plant,
- maintenance of signage and other communication to reduce human activity and
- regular investigations to bolster PWC's understanding of the ever changing context of the receiving environment

Changes to the WDL were also recommended as part of the SLR assessment.

- Alterations to the flowrate qualifier for wet season discharges to Ludmilla Creek from 1000L/s inflow to 750L/s.
- The adjustment of site specific trigger values within Ludmilla Ck to more accurately take into account the upstream impact on water quality and, subsequently, gain a further understanding of the influence the WwTP discharge is having on the creek.
- Removal of the upstream monitoring sites SLuLC01 & SLuLC02. The water quality at these sites is more heavily influenced by the runoff from the catchment than the LWwTP discharge.

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1. Introduction

Power and Water Corporation and its predecessor organisations has operated the Ludmilla Wastewater Treatment Plant (LWwTP) at 21 Dick Ward Drive, Ludmilla for over 40 years. Power and Water Corporation operate the LWwTP to treat the sewage from the inner suburbs of Darwin (Figure 1). The treatment of sewage is designed to reduce the risks associated with the disposal of untreated sewage.

The LWwTP is a primary sewage treatment plant utilising gross pollutant and grit screening, odour control through chlorination and chemically assisted sedimentation (CAS) to treat the sewage from the Central Darwin sewage catchment which comprises central Darwin and the inner suburbs (Figure 1). The CAS tank supernatant is discharged to Darwin Harbour via the East Point Outfall (EPO). In periods of high inflow discharges can be made to Ludmilla Creek via a bypass drain.

The discharge of treated wastewater from the LWwTP (the Activity) is subject requirements specified by the Controller of Water Resources (the Regulator) as conditions associated with a Waste Discharge Licence (WDL) 150, issued under the Water Act 1992 (NT).

1.1. Risk Assessment Objectives

The objective of this risk assessment is to build on the knowledge gained through PWC's ongoing water quality and environmental monitoring programs to more effectively characterise the risks associated with the Activity (the discharge of treated wastewater from the Ludmilla Wastewater Treatment Plant) to the waters of Darwin Harbour and Ludmilla Creek.

The objectives of this ecological risk assessment are to:

- a. Use the Conceptual Site model to identify possible receptors and exposures.
- b. Assess the risks and identified pathways for source to receptors.
- c. Evaluate the risks
 - i) Estimate likelihood of impacts on receptors;
 - ii) Estimate consequence of impact on receptors.
- d. Identify mitigation measures for identified risks.
- e. Inform the development of monitoring programs to enable risks to be quantitatively assessed to ensure decisions relating to the impacts of the LWwTP discharge on the protection of Beneficial Uses are based on the most relevant local information.

This ERA builds on the information obtained in the previous risk assessment along with a 2021 risk assessment (SLR 2021) focussed on the impact of wet and dry season discharge to the Ludmilla Creek receiving environment. The main objective of the 2021 ERA was to evaluate the risk of harm to the ecology of Ludmilla Creek from wet and dry weather discharges from the treatment plant to Ludmilla Creek in instances when the volume in the LWwTP exceeds the capacity for discharge through the EPO. Additionally it sought to utilise the outcomes to further refine WDL conditions and site specific trigger values (SSTV) associated with the creek.

1.2. Framework

ANZG (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality

- This is a culmination and continuation of the ANZECC and ARMCANZ guidelines. It provides a Water Quality Management Framework for natural and semi-natural water resources in Australia and New Zealand along with region specific guideline values for toxicants and other chemical stressors.

NEPC (2013) Schedule B5a, Guideline on Ecological Risk Assessment

- This provides a best practice guide on how to conduct an Ecological Risk assessment

NHRMC (2008) Guidelines for Managing Risks in Recreational Water

- The primary purpose of this guideline is to protect human health, providing a best practice approach to quantifying and minimising the risks to human health in a marine context.

1.3. Scope and assumptions

The ERA addresses environmental risks associated with the discharge of treated sewage effluent from the Ludmilla Wastewater Treatment Plant. This assessment does not address any hazards or risks associated with the operation of LWwTP. Risks to the environment will be assessed in part according to the water quality monitoring data

Water quality sampling for the receiving environments are taken monthly and thus this risk assessment will deal with only long form data and overall trends within the environment.

2. Site Description

2.1. Ludmilla WWTP

The LWwTP, originally commissioned in 1977, is an advanced primary waste water treatment plant servicing the suburbs of Larrakeyah, The Gardens, Parap, Stuart Park, Fannie Bay, Ludmilla, Coconut Grove, Nightcliff and Winnellie (Figure 1). Following treatment, effluent is discharged via the East Point Rising Main to Darwin Harbour from the intertidal East Point Outfall (EPO). A chemical treatment and hydraulic upgrade completed in 2014 and commissioned in 2016 increased the capacity of the plant from ~9.5ML/d up to 17.5ML/d meeting the communities need until approximately 2030. The capacity upgrade has also greatly improved effluent quality by reducing nutrient and toxicant loads, although an unintended consequence has been the settling of sediment in the larger rising mains during periods of very low flow (night time) which is subsequently emitted as flows increase.

2.2. Ludmilla Creek

Ludmilla Creek lies to the north-east of the East Point Recreation Reserve and forms part of the north and east boundary of the reserve. A channel of the creek flows adjacent to the Ludmilla WwTP site.

The creek catchment extends to the east of Bagot Road where surface water runoff from the former air force housing estate of Eaton and the suburb of The Narrows is contained in storm water pipes with the pipes running under Bagot Road and surfacing in the parkland adjacent to Ludmilla Primary School. A westerly flowing creek is adjacent to Harvey Norman Stadium flowing under Dick Ward Drive, subsequently combining with a number of other channels that drain the tidal wetlands and mangrove swamp land to the east of Dick Ward Drive. A more defined water body, Ludmilla Creek, is evident to the west (downstream) of Dick Ward Drive.

The creek is bounded by a continuous, established mangrove wetland from the point where the creek enters Darwin Harbour at the Kulaluk mudflats to the park adjacent to Harvey Norman Stadium. Under the Northern Territory Planning Scheme, the mangrove forest is listed as 'conservation'. The surrounding land uses for Ludmilla Creek are most accurately characterised as recreational open space, environmentally significant tidal flats and mangroves which are environmentally sensitive receptors. The nearest housing is located at the Minmarama community which is adjacent to the creek to the north of the Ludmilla WwTP with direct access to the creek downstream of the weir discharge point into Ludmilla Creek.

The Pearl Retirement Resort in Fannie Bay is several hundred metres south of the creek and the Ludmilla community is close to the north-east upper reaches of the creek, upstream of the discharge impact zone and downstream of Bagot Road (SKM 2011).

The Ludmilla Creek riparian zone up and downstream of the Ludmilla WwTP is dominated by mangrove forest with tidal flats at the creek mouth. As an urban creek, Ludmilla Creek receives stormwater from the upstream and adjacent urban residential, infrastructure and open space environments surrounding the creek and the creek retains substantial environmental values as a mangrove ecosystem.

When inflow to the Ludmilla WwTP exceeds the plant's hydraulic capacity (typically during heavy wet season rainfall events) excess treated wastewater is directed via an open drain directly into Ludmilla Creek. Discharges into Ludmilla Creek during the dry season are limited to plant malfunctions and emergency shut downs and accounted for less than 1.6 % of the total dry season discharge and 0.4% of the total discharge during the period May 2012 to October 2014, the period following the redirection of flows from the Larrakeyah outfall to Ludmilla WwTP.

Other noteworthy discharges to Ludmilla Creek include storm water drains from the residential suburbs of Eaton, The Narrows and Ludmilla and runoff from the Darwin Turf Club and a small industrial area at Colivas Road which includes Spot on Marine (boat lifting, repairs and hard-stand storage).

2.3. East Point

Darwin Harbour is a macro-tidal (>7 metre) system in the monsoonal (wet/dry) tropics of northern Australia with the characteristics of an estuary during the wet season and an embayment in the dry season. In the wet/dry tropics, many of the smaller tidal creeks, such as Ludmilla Creek, have the characteristics of a tidal creek (estuary) in the wet season and a tidal inlet in the dry season.

Water quality in Darwin Harbour is not significantly impacted by human activities except within urban areas and where there are localised impacts from point source discharges (McKinnon et al. 2006).

The Darwin Harbour Water Quality Protection Plan Phase 1 Report indicates that, on a whole of harbour scale, catchment sources such as storm water runoff and point source sewage discharges are a minor contribution to the overall condition of the harbour (Fortune and Maly 2009). Investigations by Burford et al. (2008) into primary productivity within Darwin Harbour found that the major nutrient sources were from:

- Oceanic waters: 15,015 tonnes/year N (97%); 1,087 t/y P (95%);
- Atmospheric input from rainfall: 194 t/y N (1.3%);
- Storm water runoff catchment: 115 t/y N (0.74%); 12 t/y P (1.0%); and
- Sewage: 180 t/y N (1.2%); 49 t/y P (4.3%).

In 2019-20 Ludmilla Wastewater Treatment Plant discharged 150 t/y N (125 t/y $\text{NH}_3\text{-N}$): and 7.0 t/y P to Darwin Harbour, with approximately 99.4% of the annual discharge being via the EPO and 0.6% via Ludmilla Creek with 100% of dry season discharges via the EPO.

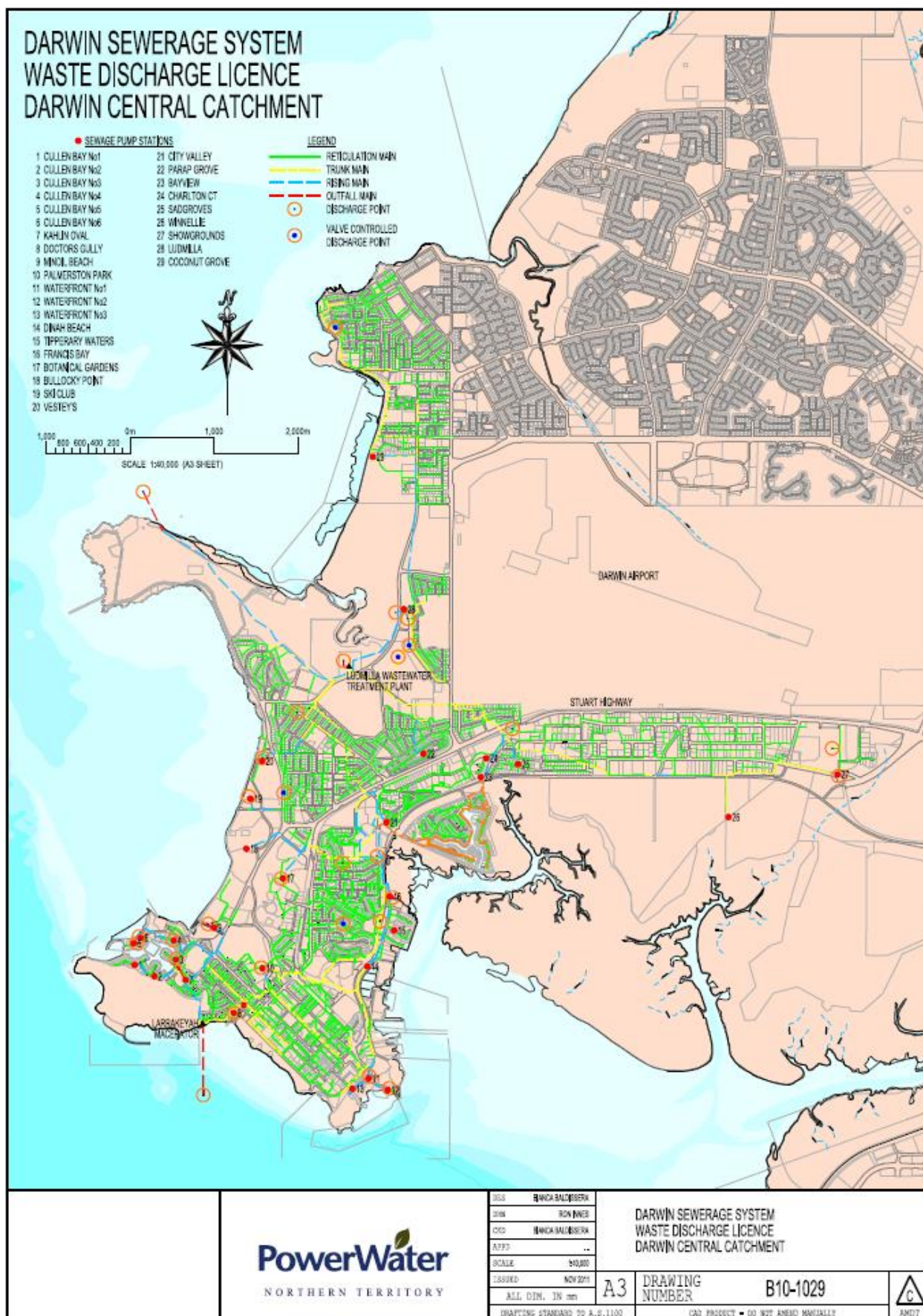


Figure 1: Ludmilla WwTP sewer catchment

2.4. Conceptual site model

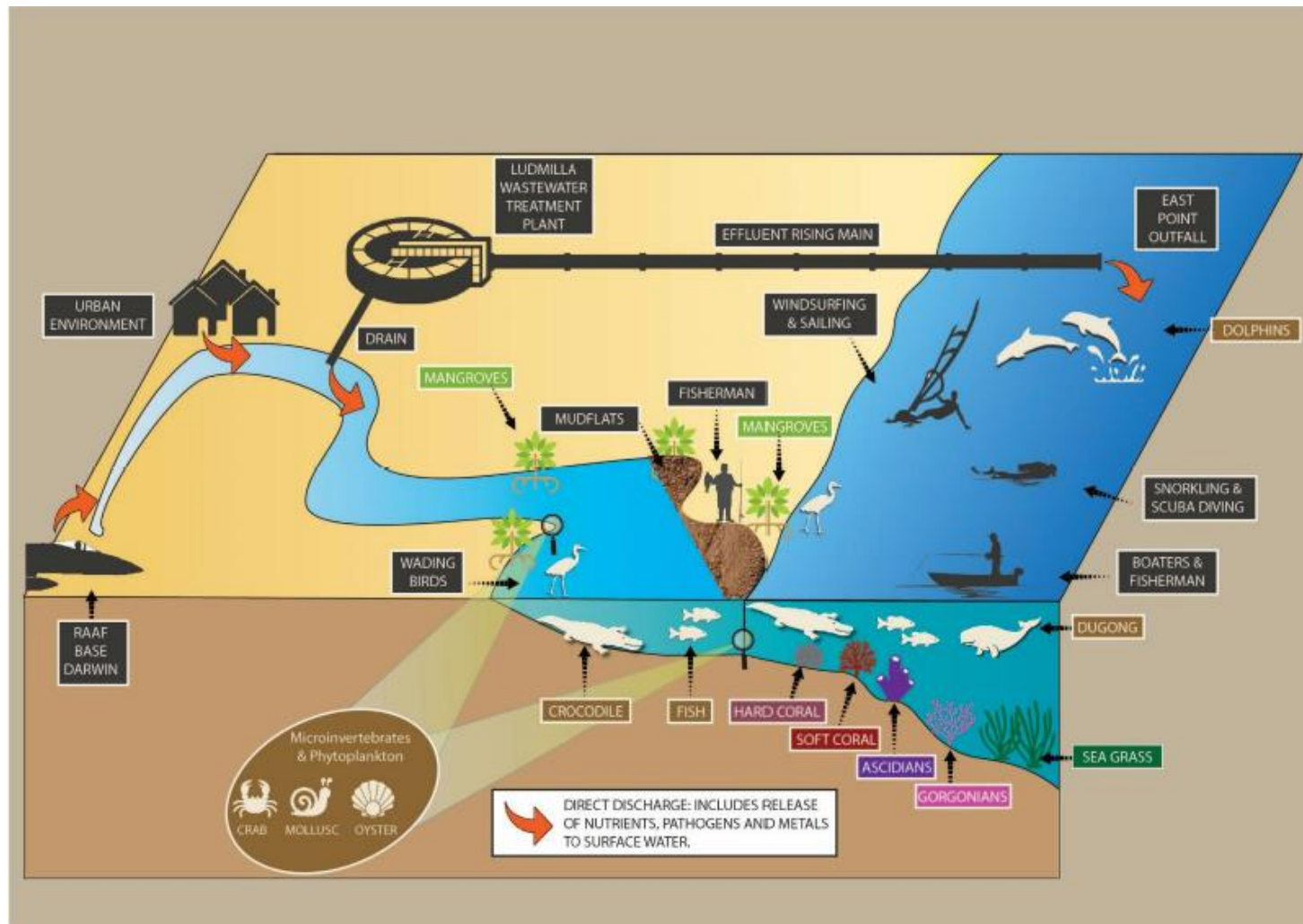


Figure 2: Conceptual site model

3. Risk Assessment

3.1. Overview

This ERA follows the 5 step process outlined in the 2013 National Environment Protection Measure – Assessment of site contamination and the EPA Victoria methodology for assessing the risk of discharges of wastewater to waterways:

- Problem Formulation – renamed Problem Identification in this report
- Data Collection and Evaluation – renamed Receptor Identification in this report
- Toxicity Assessment
- Exposure Assessment
- Risk Characterisation

Each of these steps will be applied for 3 levels of increasing detail:

- Level 1: screening assessment of discharge quality contaminant levels against appropriate guideline values (ANZG, WDL SSTVs)
- Level 2: Preliminary assessment of site specific factors of environmental components and using local stressor or toxicant modifying factors
- Level 3: A definitive, probabilistic or quantitative assessment using site specific receptor stressor and toxicity data and exposure pathway information to inform the risk assessment

Table 1: Screening level assessment of stressors associated with WwTP discharge

Stressor	Indicator	Potential symptom
Bacterial pathogens	Pathogen counts	Animal (fish) kills / disease Changed animal behaviour Decreased fishery productivity Human health impacts / illness Poor water quality Shellfish/ fisheries closures
Nutrients	TN / TP –water column TN / TP – sediments Chl-a Mangrove/ seagrass biomass epiphytes Mudflat benthic biomass	Algal blooms Anoxic events (algal bloom anoxia) Benthic biomass change Animal (fish) kills Nuisance plant growth e.g. epiphytes Phytoplankton blooms / toxic blooms Phytoplankton biodiversity decrease Poor water quality

		Seagrass loss
Toxicants Loads / Concentrations Bioavailability of pesticides, herbicides, organics, oils, hydrocarbons, metals, metalloids, organometallics etc.	Water soluble toxicants Toxicants in sediment Toxicants in biota Animal kills Occurrence of imposex	Animal kills Animal disease/ lesions/ mutations Animal behaviour /respiratory dysfunction / neurobiological change Changed animal physiology Biodiversity decrease Biota loss/ distribution change Habitat loss or distribution change Human health problems (skin irritation or disease) Poor water quality Sea food catch composition change Fishery closures or composition change
Organic matter	Dissolved oxygen Frequency of fish kills	Animal/ fish/ macro-benthos kills Anoxia and hypoxia Biodiversity decrease Poor water quality Species (plant/animal) composition change
Aquatic sediments	• Turbidity • Biodiversity • Habitat range	Poor water quality e.g. turbidity Decreased seagrass cover Sediment grain size distribution Water depth
Excess freshwater	Salinity	Animal (fish) kills Changed biodiversity Habitat loss or disturbance Species loss or disturbance Changed fish stocks Species (plant/animal) changes

3.2. Level 1 Assessment

Problem identification:

Treated effluent discharged from the Ludmilla WwTP may impact on the protection of declared Beneficial Uses.

Receptor identification:

The risk register for the LWwTP identifies that the discharge of untreated effluent poses risks of environmental or public health harm, see Table 2. The role of the treatment plant is to minimise the discharge of untreated effluent and therefore reduce this risk to an acceptable level.

The Public Environmental Report for the duplication of the East Point Rising Main and the extension of the East Point Outfall identified areas of impact for the ongoing operation of the LWwTP. The key risks associated with the discharges from the LWwTP were the future and cumulative increases in nutrients, turbidity, fine sediment and heavy metals entering the marine environment of Darwin Harbour causing impacts to fauna and flora at both the pollution point source and Harbour wide scale.

Exposure assessment:

The discharge via East Point Outfall occurs continuously and at extreme low tides may be the only source of water at the outfall making exposure to undiluted treated effluent a possibility at least monthly.

Toxicity assessment:

Historic water quality monitoring data indicates that copper, zinc and ammonia exceed the ANZG triggers and nutrient and bacteriological characteristics of the treated effluent may also exceed the threshold levels for stressors (nutrients) and for pathogen indicators and the effluent may pose a risk to the protection of the declared Beneficial Uses.

Risk characterisation

At the outfall copper and ammonia may be above the toxic threshold and pose a risk to the protection of the declared Beneficial Uses. The addition of freshwater and high levels of organic matter may also pose a risk to the protection of the benthic ecological communities in the vicinity of the outfall.

The effluent plume is black in colour reducing the aesthetic appreciation of the area. In low oxygen and low flow conditions the high total and dissolved iron in the effluent may be reduced from ferrous to ferric compounds in the East Point rising main resulting in a dark coloured effluent plume. This has the potential to impact on the aesthetic enjoyment of the area and discourage the use of the receiving waters for recreational purposes.

Table 2: Screening level risk register

Master Category	Assessment Category	Risk Name	Risk Description	Infrastructure/ Asset	Likelihood (I)	Consequence (I)	Risk Rating (I)	Likelihood (R)	Consequence (R)	Risk Rating (R)	Causes of Risk
Environment	Treated water disposal	Emissions to water	Increase in nutrient and contaminant load in receiving system' including black plumes from the East Point Outfall.	Sewerage system	Almost Certain	Moderate	High	Almost certain	Minor	Medium	Discharges of nutrients and pathogens to East Point outfall WDL monitoring New effluent chamber on line.
Environment	Inputs to treatment process - chlorine	Emissions to air	Damage to adjoining mangrove ecosystems	Sewerage system	Possible	Major	Very High	Unlikely	Moderate	Medium	Accidental discharges to atmosphere. Equipment likely to cause air discharges no longer used.
Environment	Sewage transfers involving illegal wastes	Emissions to water	Reduced wastewater quality Failure to comply with Wastewater Discharge Licence Surface water contamination;	Sewerage system	Possible	Moderate	High	Unlikely	Moderate	Medium	Illegal disposal of hazardous wastes (including trade waste) contaminating the sewerage system
Environment	Sewage treatment process	Emissions to air	Localised odour Public complaints	Sewerage system	Likely	Minor	Medium	Possible	Minor	Low	Treatment generates continuous odour discharge (including upset conditions).
Environment	Inputs to treatment process - lime, ferric chloride and polymer	Emissions to land and water	Soil contamination Storm water pollution Poor storage and handling of chemicals	Sewerage system	Likely	Moderate	High	Possible	Minor	Low	Loss of containment of chemicals due to plant failure or operator error

Master Category	Assessment Category	Risk Name	Risk Description	Infrastructure/ Asset	Likelihood (I)	Consequence (I)	Risk Rating (I)	Likelihood (R)	Consequence (R)	Risk Rating (R)	Causes of Risk
Environment	Sewage treatment bypass of raw sewage	Emissions to water	Increase in nutrient and contaminant load in creek system	Sewerage system	Likely	Moderate	High	Unlikely	Moderate	Medium	Bypass of raw sewage due to plant failure or wet weather inflows
Environment	Sewage treatment bypass of treated water	Emissions to water	Increase in nutrient and contaminant load in Darwin Harbour	Sewerage system	Almost Certain	Moderate	High	Possible	Minor	Low	Bypass of treated water due to plant failure or wet weather inflows
Environment	Sewage transfers	Emissions to water	Water pollution - pathogens and nutrients	Sewerage system	Likely	Minor	Medium	Possible	Minor	Low	Spill from sewage pump stations due to failure (electrical, mechanical or power supply failure)
Environment	Waste disposal (sludge)	Waste Management	Inappropriate disposal leading to soil contamination Localised odour Public complaints	Sewerage system	Almost Certain	Moderate	High	Possible	Minor	Low	Odour generation from prolonged retention on site
Environment	Waste disposal (screenings & grit)	Waste Management	Inappropriate disposal leading to soil contamination ,localised odour and public complaints	Sewerage system	Likely	Moderate	High	Possible	Minor	Low	Uncontrolled dumping of material containing leachate, sharps and pathogens

3.3. Level 2 Assessment

Problem Identification

The screening level risk assessment identified potential risks to the protection of the declared Beneficial Uses of the waters of Darwin Harbour associated with the discharge of treated wastewater from the Ludmilla Wastewater Treatment Plant via both the East Point Outfall and the overflow drain into Ludmilla Creek.

To more effectively characterise the risks an assessment of monitoring data for the effluent and the receiving waters has been conducted to characterise the risks.

Receptor identification

The declared beneficial uses for the saline waters of Darwin Harbour are the use of the waters of Darwin Harbour to sustain ecological, cultural and aquaculture values. The conceptual site model (Appendix 3) identifies the range of ecological and cultural values and uses that apply in the vicinity of the discharge.

The area in the vicinity of the East Point Outfall is not recognised as a swimming beach however both Ludmilla Creek and the Ludmilla Bay area are regularly used for the collection of shellfish and crabs by mixed age groups and as such water quality objectives relevant to the protection of shellfish for human consumption and for secondary contact recreation should be considered in assessing the risks to the protection of the declared Beneficial Uses.

No aquaculture is undertaken in the Ludmilla area however a disused mud crab pond system is present on the land at Minmarama Park, it is understood that the facility was constructed but has never been used for aquaculture.

Exposure Assessment

Appendix 6 includes an assessment of discharge loads and Appendix 7 is an assessment of the water quality data for the Ludmilla WWTP discharge and receiving environment and provides a preliminary (level 2) assessment of the risks posed to the protection of the declared beneficial uses resulting from the Activity (the discharge of treated effluent from the Ludmilla Wastewater Treatment Plant to Darwin Harbour and Ludmilla Creek via the authorised discharge points). Use of this beach at the outfall location for swimming, however, is rare as it is not a designated swimming beach and there are signs present warning of the risks of recreational activity around the EPO.

Toxicity Assessment

Toxicity assessments have been conducted twice over the last 10 years: once in 2014, before the commissioning of the plant capacity upgrades, and in 2018, several years after the commissioning of the upgrade.

The ecotoxicity assessment of the effluent conducted in 2014 found that for all tests conducted the effluent remained toxic even at high dilution (Table 3)

Table 3: 2014 Ecotoxicity results

Test	Bioassay	EC ₁₀ (% discharge)	EC ₅₀ (% discharge)	Toxicant Sensitivity
Chronic toxicity tests				
<i>Heliocidaris tuberculata</i>	1 hr. sea urchin fertilisation:	<0.8	1.1	Ammonia
<i>Heliocidaris tuberculata</i>	72 hr. sea urchin larval development	6.6	8.2	Ammonia
<i>Saccostrea echinata</i>	48 hr. larval development: milky oyster	3.4	5.0	Metals, ammonia, petroleum, hydrocarbons
<i>Isochrysis aff. galbana</i>	72 hr. marine algal growth	1.8	2.4	Metals including copper
<i>Ecklonia radiata</i>	72 hr. macroalgal germination	6.6	9.2	Copper
Acute toxicity tests				
<i>Parvocalanus crassirostris</i>	48 hr. acute copepod survival	1.3	1.9	Metals including copper
<i>Lates calcarifer</i>	7 day fish imbalance	21.8	26.8	Ammonia
<i>Lates calcarifer</i>	7 day fish biomass toxicity	13.2	32.5	Ammonia

Table 4: 2014 Ecotoxicity effluent water quality

Site	ANZG Guideline	SLu080 (test effluent)	SLuEP10 (diluent water control)
Date collected	-	23 January 2014	23 January 2014
pH	7.0 to 8.5	8.1	8.0
Salinity	-	0.2‰	32.5‰
Total ammonia (mg/L)	0.91 (95% protection)	6.4 (8.3 mg/L NATA certified)	<2.0 (0.0025 mg/L NATA certified)
Temperature on receipt	-	15	Room temperature
Copper (µg/L)	1.3 (95% protection)	17.9 µg/L (NATA certified)	<1.0 µg/L (NATA certified)

The sea urchin fertilisation bioassay was the most sensitive to the discharge with an EC50 of 1.1% discharge.

Table 5: 2018 Ecotoxicity Results

Test species	Bioassay	EC ₁₀ (% discharge)	EC ₅₀ (% discharge)
<i>Amphibalanus amphitrite</i>	4-day barnacle larval development	13.5	16.6
<i>Nassarius dorsatus</i>	7-day dog whelk larval growth	6.5	7.1
<i>Tisochrysis lutea</i>	3-day microalgal population growth	17.4	24.5
<i>Nitzschia closterium</i>	3-day microalgal population growth	8.4	11
<i>Heliocidaris tuberculata</i>	3-day sea urchin larval development	11.1	14.3
<i>Saccostrea glomerata</i>	2-day oyster larval development	10.1	13.1
<i>Hormosira banksii</i>	3-day macroalgal cell germination	>25	>25

In contrast to the 2014 bioassays, the 2018 results show that the mollusc (dog whelk) larval development was the most sensitive bioassay with an EC50 of 7.1%.

Risk Characterisation

Based upon the toxicity assessments an estimate of the dilution factor required for increasing levels of species protection, shown in

Table 6.

Table 6: Required dilution factors

2014 (PWC 2014)			2018 (van Dam 2018)	
Protection level	% discharge	Dilution Factor	% discharge	Dilution Factor
99%	0.82	122	3.8	26
95%	1.6	63	5.7	18
90%	2.2	46	6.8	15

80%	3.0	33	8.4	12
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As indicated, the effluent used in the 2018 study requires a far lower dilution factor to ensure a level of species protection. Based upon this study the potential toxicity of the effluent has been reduced by the plant upgrade by ~3-5x. The ANZG water quality guidelines are exceeded for copper, zinc and ammonia although only at the immediate discharge point

Table 7 & Table 8 detail a screening level risk assessment conducted on the environmental values and cultural and aquacultural values of East Point Outfall and Ludmilla Ck. Pathogen risk to human health is the highest rated risk due to the harm which may come about from recreation in or around the east point outfall and the consumption of shellfish found in the area which may contain pathogens. Although this is the case the likelihood of swimming or wading in the area is rare as it is not a designated swimming beach and there are signs warning of the outfall hazard. Boating is only possible at high tide when the discharge is diluted, reducing the possibility of coming into contact with raw effluent.

This assessment was completed for the 2019 ERA though, since the outfall conditions and effluent quality have not changed significantly, the findings are still appropriate.

Table 7: Conceptual site model receptor identification and screening level risk assessment for East Point Outfall and Ludmilla Creek (Environmental Values)

Beneficial Use surface water	Receptor	Pathway	Hazard	Consequence for beneficial uses of Ludmilla Creek/ Darwin Harbour	Likelihood	Estimated Exposure Duration
Environment						
	Seagrass	water	Sediment	Smothering/ shading	Possible	moderate
		water	Nutrients	Excessive growth ephiphytes	Unlikely	low
		water	Toxicants	Reduce grazing on ephiphytes	Possible	moderate
	Mangroves	water	Sediment	Smothering	Unlikely	Low
		water	Nutrients	Excessive growth	Possible	Moderate
		water	toxicants	Impact on key fauna	Unlikely	Low
	Corals (soft/ hard) Ascidians/ Bryozoans Gorgonians	water	Sediments	Smothering / shading	Possible	Low
		water	Nutrients	Excessive algal growth	Unlikely	Low
		water	toxicants	Impact on key fauna	Possible	Low
	Dugongs/ Turtles	water	Toxicants	Illness/ death - Bioaccumulation	Rare	Moderate
		water	pathogens	Illness/death - pathogens	Rare	Moderate
	Dolphins	water	Toxicants	Illness/ death – Bioaccumulation	Unlikely	Moderate
		water	pathogens	Illness / death - Pathogens	Unlikely	Moderate
	Fish e.g. barramundi	water	Toxicants	Illness /death – Bioaccumulation	Possible	Moderate
		water	pathogens	Illness/ death - Pathogens	Possible	Moderate
	Crustaceans e.g. mud crabs	water	Toxicants	Illness/ death – Bioaccumulation	Unlikely	Moderate
		water	pathogens	Illness/ death - Pathogens	Unlikely	Moderate
	Molluscs - grazers and filter feeders	water	Toxicants	Illness – Bioaccumulation	Possible	Moderate
		water	pathogens	Illness - Pathogens	Possible	Moderate
	Predators e.g. crocodiles	Water/ food	toxicants	Illness/death – Bioaccumulation	Rare	Moderate
		Water /food	Pathogens	Illness/ death	Rare	Moderate
	Birds - wading	Food	Toxicants	Illness/ death	Rare	Moderate
		bioaccumulation		reproductive success	Rare	Moderate
			pathogens	Illness /death	Unlikely	Moderate
			Toxicants	illness	unlikely	Moderate
	Birds of prey	Bioaccumulation		Reproductive success	unlikely	Moderate
		food	Pathogens	Illness / death	unlikely	Moderate

Table 8: Conceptual Site Model Receptor Identification and Screening Level Risk Identification for East Point Outfall and Ludmilla Creek (Cultural and Aquaculture Values)

Surface water	Receptor	Pathway	Hazard	Consequence for beneficial uses	Likelihood	Estimated Exposure Duration
Cultural Recreational Use						
Primary contact	Swimming	Water	Pathogens	Illness - human	Possible	High
			toxicants	Illness - human	Unlikely	Moderate
East Point Ludmilla Creek	Swimming	Water	Pathogens	Illness - human	Rare	Moderate
			Toxicants	Illness - human	Rare	Moderate
Secondary contact	Boating or wading	Water	pathogens	Illness - human	Possible	High
			Toxicants	Illness - human	Rare	Moderate
		sediment	pathogens	Illness - human	Possible	Moderate
			Toxicants	Illness - human	Unlikely	Moderate
Aesthetics	Enjoyment of environment reduced	water	odour	Aesthetics and illness	Possible	Moderate
		water	colour	Aesthetics (reputational and legal risk – black plume under effluent low flow conditions)	Possible	Moderate
Indigenous cultural use	Intact healthy system	Water	Nutrients	Algal blooms	Possible	Low
			Toxicants	Fish kills	Possible	Moderate
			Pathogens	Illness - human	Possible	High
	Toxicants and pathogens for food collection	Sediment	Nutrients	Anoxic sediments	Possible	Low
			Toxicants	Uptake and toxicity to infauna	Unlikely	Moderate
			Pathogens	Uptake in infauna	Possible	Moderate
		Food	Nutrients	Algal blooms	Possible	Moderate
			Toxicants	Illness - human	Unlikely	Moderate
			Pathogens	Illness - human	Possible	High
Aquaculture						
	Crop (e.g. mud crabs)	Water -	toxicants	Animals Fail to thrive	Unlikely	Low
			pathogens	Animals Fail to thrive	Unlikely	Low
	Human consumers	meat	toxicants	Illness - human	Unlikely	Moderate
pathogens			Illness - human	Unlikely	Moderate	
Beneficial Uses: Ground water						
No listed uses	Creek environment	Shallow groundwater to creek	Nutrients	Eutrophication	Rare	Low
			Toxicants	Fish kills	Rare	Low
			Pathogens	Illness	Rare	Low

3.4. Level 3 Assessment

Problem Identification

The level 2 assessment went into further detail around the potential site specific risks presented by the LWwTP discharge. Further to this, the level 3 assessment will provide more context to the potential receptors and toxicity and exposure assessments by delineating wet and dry season discharges, better understanding recreational and cultural uses along with observations of receptor diversity.

SLR consultants (2021) completed a level 3 risk assessment of the discharge to Ludmilla Creek and the potential for adverse effects on the Ludmilla Creek catchment. This assessment determined that wet season flows over the weir to Ludmilla Creek pose negligible risk to the receiving environment. This is evidenced by the fact that the upstream monitoring sites, in most instances, have higher concentrations of chemicals of potential concern (Copper, Zinc, Ammonia, Total Nitrogen, Total Phosphorus) than the sites downstream of the outfall. This suggests runoff and other contamination sources within the Ludmilla Ck catchment (which includes the RAAF base) have a greater influence over the water quality within Ludmilla Ck than the treated effluent. The treated effluent will also make up a much smaller proportion of the total flows during wet season.

Receptor Identification

The BIMMP has identified, through routine monitoring (CEE 2020), that there has been no changes to the ecology of the outfall environment beyond 200m of the outfall with differences in species composition and abundance also detected between dry and wet seasons. The benthic infauna results indicate that impacts on abundance and species composition beyond 200 m from the outfall are negligible and no documented seagrass beds occur closer than 350 m from the outfall, the closest recorded between 2017 and 2019 were 500m from the outfall (CEE 2020).

The East Point Aquatic Reserve is a marine reserve of approximately 1.5 km² off-shore and abutting East Point (Power and Water Corporation 2011). The Reserve contains fringing coral reef developed on a laterite rock platform and was established under provisions of the *Fisheries Act 1998* to protect the marine biological assemblages in the area of East Point and Dudley Point, which were threatened by collectors in the early 1980s.

The reef is a dynamic marine environment subjected to prolonged exposure during spring low tide and high levels of turbidity during high tides. Adjoining the marine reserve is a large area of subtidal sponge and gorgonian beds. The offshore coral reef is regularly exposed during low spring tides and is unique in the Darwin area as it is the only accessible major reef on the Darwin side of the harbour. This proximity has made it a collection site for a number of marine organisms including the 160 species of sponges and 63 shrimp species. The purpose of the 1993 declaration of the East Point Aquatic Life Reserve was to protect the ecology of this unique area by prohibiting the harvest of sedentary animals and juvenile fish within the reserve.

The reserve is located ~300m from the EPO and thus, based upon prior investigations it is not noticeably impacted by the discharge.

An ecological survey of Ludmilla creek has not been conducted although a list of potential ecological receptors has been compiled based upon organisms present in other mangrove forests in Darwin Harbour. Table 9 shows the trophic levels of the relevant ecological receptors only and not the individual species.

Table 9: Receptor trophic levels considered to be of relevance to Ludmilla Creek System (SLR 2021 Table 3-2)

Trophic Level	Description	Considered further?
<u>Terrestrial Receptors</u>		
Plants	Terrestrial plants are those not inundated at high tide.	No. Terrestrial plants are not found within the mangrove forest in the area of Ludmilla Creek associated with the LWwTP discharge.
Invertebrates	Insects form a part of the diet for several species associated with mangrove forests including for fish, reptiles, and birds.	No. Terrestrial invertebrates are generally associated with the canopy and trunks of the mangroves and are unlikely to be exposed to the LWwTP discharge.
Vertebrates (Mammals)	Bats use the upper canopy of the mangroves.	No. Bats are unlikely to use the supratidal, tidal or sub-tidal zones as habitat.
Vertebrates (Avian)	Nectivorous, insectivorous and fructivorous birds use the canopy for feeding.	No. Canopy feeding birds are unlikely to use the supratidal, tidal or subtidal zones as habitat.
Vertebrates (Reptiles)	Lizards and snakes prey on the small crustaceans and fish residing in the mangrove forest.	Yes. Potential impacts on prey will also potentially adversely impact predators.
<u>Aquatic Receptors</u>		
Plants	This group includes photosynthetic organisms found growing on the surface of waterbodies or immersed within the water column.	Yes. Assessment of direct toxicity to aquatic plants has been undertaken by quantitative comparison of surface water and sediment concentrations against aquatic assessment criteria.
Invertebrates	This includes benthic invertebrates, burrowing crustaceans and molluscs and bottom dwelling filter feeders.	Yes. Assessment of direct toxicity to aquatic invertebrates has been undertaken by quantitative comparison of surface water and sediment concentrations against aquatic assessment criteria.
Vertebrates (fish)	This includes pelagic herbivores, benthic omnivores and carnivorous Fish.	Yes. Assessment of direct toxicity to aquatic vertebrates has been undertaken by quantitative comparison of surface water concentrations against aquatic assessment levels in Ludmilla Creek
Vertebrates (reptiles)	This includes crocodiles that may forage within the mangrove forest.	No. Crocodiles are unlikely to obtain a significant portion of their diet from the area surrounding Ludmilla Creek.
Vertebrates (avian)	Migratory shorebirds and wading birds using the Ludmilla Creek sandflats (adjacent sampling point SLuLC04) at low tide.	Yes. Assessment of direct toxicity to benthic infauna (prey species of foraging shore birds) has been undertaken by quantitative comparison of surface water and

Trophic Level	Description	Considered further?
		sediment concentrations against aquatic assessment criteria.

Fish kill observations

No fish kills have been observed or reported in relation to Ludmilla Creek or the East Point Outfall.

Environment –Eutrophication and primary production in mangroves

Mangrove productivity is a key driver of biodiversity as the organic matter produced by mangroves ultimately supports a wide variety of aquatic animals such as molluscs, crabs and worms and subsequently secondary and tertiary level consumers. Temperature and humidity are key drivers of productivity in Darwin mangroves with productivity declining during the dry season. The influence of increased primary production can be measured through standing biomass and litter-fall. Anecdotal, enhanced regrowth of mangroves following physical disturbance by cyclones in the transition zone have also been observed but not quantified. Historical data comparing enriched versus unenriched systems in Darwin, found a two-fold enrichment in TN and TP in sediment and mangrove leaves in the enriched system (Clough et al. 1983). An assessment of $\delta^{15}\text{N}$ in *Rhizophora stylosa* in Ludmilla Creek and in the vicinity of the East Point Outfall leaves found evidence of substantial uptake of WwTP derived N by Ludmilla Creek mangroves (AIMS 2014).

Primary production impacts on biodiversity in mangrove ecosystems

Increased growth of mangroves can provide further habitat areas for roosting and breeding for arboreal species to exploit in these tidal ecosystems. Leaf biomass is predated by insects that are eaten by fish and birds. Increases in mangrove flowers/fruit can provide food opportunities for birds, bats and turtles. Mangrove litter ultimately support multiple levels of both inshore and offshore consumers.

The positive impacts of nutrient enrichment and increased primary production in mangrove ecosystems reflects that highly disturbed ecosystems can have values that also need to be recognised.

A before and after control versus impact study in Victoria, demonstrated statistically significant reductions in time spent feeding by eight water bird species following the implementation of regulatory nitrogen load reductions at the Western Treatment Plant (Hepworth and Hamilton 2001; Hamilton 2002; Hamilton et al. 2002; Mustoe and Waugh 2006; Mustoe 2009 in Murray and Hamilton 2010). The significance of the area to birds implies that these values cannot be ignored when assessing the impacts of the discharge in Ludmilla Creek.

Areas at the mouth of Ludmilla Creek (very close to the sampling point SLuLC04 downstream of the discharge) and the claypan adjacent to Spot on Marine are considered to be areas of significance for migratory birds. (PWC 2011)

Other impacts of the discharge on biodiversity in mangrove ecosystems

The establishment of bio-indicators in estuaries is acknowledged to be very difficult due to criteria such as sensitivity, timeliness, cost-effectiveness and ultimately that you require a response that is caused by the source and not by natural factors or other sources (ANZG 2018). It is well established that mangrove assemblages naturally shift across landward to seaward zones as does the concentration gradient

associated with the discharge.

Invertebrate fauna such as polychaete worms, gastropods and grapsid crabs have been found to be responsive indicators of environmental change/urbanisation/stormwater inputs in mangroves (Metcalf 2007) but are non-specific to the discharge.

Benthic Infauna Risks due to effluent exposure

Previous investigations (SKM 2015) identified that there was no detectable impact on benthic infauna in Ludmilla Creek resulting from the discharge of treated effluent. Following the approval of the Benthic Infauna and Water Quality Monitoring and Management Plans by the Commonwealth Department of the Environment in June and July 2016 commissioning of the augmented East Point rising main, the volume of treated effluent discharged to Ludmilla Creek has decreased. The Benthic Infauna Monitoring and Management Plan report (CEE 2016) focuses on the area potentially impacted by the increased discharge from the east Point Outfall directly to Darwin Harbour (Figure 3).

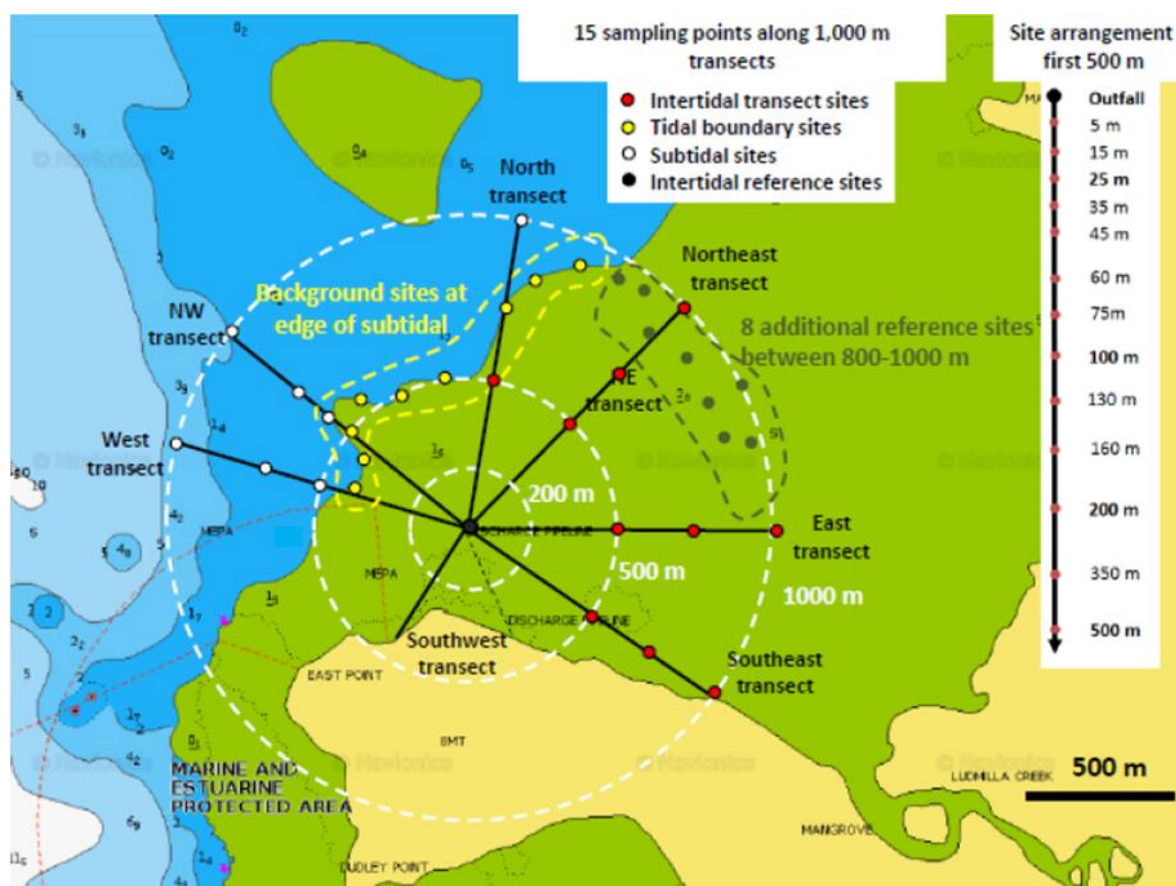


Figure 3: Benthic Infauna Monitoring and Management Plan

The approved BIMMP adopted an effluent exposure gradient design. In 2017 (CEE 2020) seabed condition indicator species were sampled along effluent exposure gradients and at reference sites to assess ecosystem condition of foraging areas (seagrass beds) for inshore dolphins, turtles and dugongs in the bay north of East Point (Kulaluk tidal flats/ Ludmilla Bay).

Infauna monitoring sites were positioned along 1,000 m long transects radiating at to 45 degrees from the point of discharge. Sites were arranged intensely along the first 200 m of the transects, with greater distances between sites beyond 200 m. Seagrass was monitored at subtidal and intertidal areas in parts of the Bay where it was mapped in previous studies.

The Commonwealth approved BIMMP was implemented in 2017 and season survey was completed in April and August/September 2017 respectively (CEE 2020).

Infauna were sampled a total of 106 intertidal and subtidal infauna monitoring sites in the 2017 Wet Season survey and at 107 sites in the 2017 Dry Season survey. The results of the infauna survey showed that the composition of the intertidal infauna community was different from the subtidal community. The analysis focussed on the intertidal community where the effect of the present East Point discharge is most likely to be expressed.

The intertidal survey results showed substantial differences in the characteristics of the infauna and seagrass communities between the 2017 Wet and Dry Season surveys.

Infauna were more abundant in the Dry Season with an average of 111 individuals per square metre, compared to the Wet Season with an average of 64 individuals per square metre within 1 km of discharge. There were more infauna species (identified to family level) present in the Dry Season with an average of 13 species per square metre, compared to the Wet Season with an average of 7 species per square metre within 1 km of discharge.

Two species of seagrass were present at most seagrass monitoring sites during the Dry Season survey; but were totally absent during the Wet Season survey. Seagrasses were sparse, short and dusted with sediment during the Dry Season survey and did not form obvious meadows.

- Intertidal infauna numbers were highest at sites within 100 m of the East Point outfall compared to sites from 350 m to 1000 m from the discharge. Infauna numbers were elevated at some sites between 100 m and 200 m from the discharge compared to reference sites, while others were similar to reference sites. The pattern of higher abundance close to the outfall was stronger in the Dry Season compared to the Wet Season survey, when abundances were generally lower across all sites. Some species showed a pattern of higher abundance beyond 50 m from the outfall and this pattern was generally strongest northward (offshore) from the outfall. This is likely to reflect the predominant direction of effluent dispersal due to wind (particularly during the Dry Season) and gravity at low tide.
- The infauna community across the study area comprised a range of burrowing worms, crustaceans, molluscs and echinoderms. No infauna taxa were consistently absent from within 200 m from the discharge compared to sites elsewhere on the intertidal bank.

Burrowing polychaete worms were the most common group and certain species showed strong correlation of elevated abundance with proximity to the point of discharge. Three species of polychaete worm showed consistently strong correlation of elevated abundance with proximity to the point of discharge (positive indicators) in the Wet Season survey and a further three species (six in all) were identified as positive indicators in the Dry Season. Polychaete worms are commonly found in elevated abundance in organically enriched environments (positive indicators).

Although some polychaete worm abundance showed a positive correlation with proximity to the East Point discharge, there was no evidence of organic enrichment of the sediments. Total organic carbon concentration, sediment particle size and pH at the outfall sites were similar to those at distant and reference sites elsewhere in Kulaluk tidal flats (Ludmilla Bay).

Crustaceans were the second most abundant infauna across the sampling sites; but were more diverse than polychaetes worms. Crustaceans were sparse or patchy in abundance. No crustacean species showed consistent strong positive or negative distributions in relation to the position of the East Point discharge. One crustacean group in the Wet Season survey and two groups in the Dry Season survey showed possible mild positive abundance distributions in relation to the position of the outfall.

One mollusc species – a predatory snail - showed a strong and consistent pattern of high abundance at sites within 200 m of the East Point discharge compared to other sites. The pattern was strongest in the Dry Season, but also was present in the Wet Season when abundances were lower.

Sea urchin-like Sand dollars were consistently found at sandy sites between the East Point discharge and the edge of the reef inshore of the outfall. They were present at very few other sites. Sand dollars in the sampling area seem to have a primary preference for the physical habitat at sites near the reef edge, but the proximity of the discharge may also be a factor in their distribution.

Overall, the infauna community showed a strong seasonal pattern of more species and more individuals in the Dry Season compared to the Wet. The effect of the East Point discharge on the benthic infauna community was expressed in both seasons as an increased abundance of infauna individuals within 200 m, and particularly within 50 m, of the discharge. Certain polychaete worms showed the strongest and most consistent patterns, sand dollars and a species of predatory snail also showed strong and consistent patterns.

Seagrass

The Benthic Infauna Monitoring and Management plan report (CEE 2016) was designed to detect impacts on listed species (inshore dolphins, turtles and dugong) either directly or through impacts on critical food sources such as benthic infauna or on critical habitat such as seagrass. In 2017 seagrass was surveyed using a towed video technique at 17 sites in areas previously known to provide habitat for seagrasses during the Dry Season (CEE 2020). The Wet Season towed-video survey detected a seabed generally bare of epifauna or macrophytes, including seagrass. Some biota communities were observed including benthic microalgal crust (microphytobenthos or MPB), fan worms, sand-dollars, heart urchins and the entrances to tube worm burrows. The mounds of other burrowing infauna were also observed. Sparse evidence or remnants of seagrass were observed at some sites near the intertidal/subtidal boundary, but no whole, healthy seagrass plants were recorded (CEE 2020).

The Dry Season survey of seagrass sites found widely distributed seagrasses, albeit in low abundances. The most abundant and widespread species was *Halophila ovalis* while *Halodule* was found at only a few intertidal sites and was generally very sparse.

These seagrasses are likely to provide some food source for grazing turtles (observed in the general area in August/September 2017) and dugong.

No exceedances of reportable triggers were detected during the survey indicating that during the study period the discharge of treated effluent from the Ludmilla WwTP posed a low risk to the protection of the critical food and habitat for the listed species and no direct impacts on listed species were observed.

Aquaculture

Aquaculture is a declared beneficial use for the saline waters of Darwin Harbour and while it is not a current use in either Ludmilla Creek or in the vicinity of East Point it is an expectation that the water quality is protected to a level that it is suitable for use for the beneficial use of aquaculture.

Exposure Assessment

While swimming is not recommended in Darwin's urban creeks (Campbell et. al. 2012); the northern shoreline of East Point, in the vicinity of the East Point Outfall, includes a specific exclusion zone for swimming and the collection of shellfish (Ports Regulation 5), these activities are identified as Beneficial Uses and may occur within the area influenced by the discharge and incidental or secondary contact may occur in the vicinity of East Point and within Ludmilla Creek due to boating, fishing and shell fish collection.

Primary Contact Recreation

The 2012 report into the sources and pathways of bacteria affecting Darwin Harbour Beach indicated that water quality at swimming beaches was impacted by multiple sources of bacterial pollution. This study found that while there were few, if any incidences of gastrointestinal illness outbreaks in Darwin that can be linked to swimmer exposure to bacteria in beaches and waterways, dangerous animals, particularly Box Jellyfish and crocodiles present a greater risk to people and cause hospitalisations. (Campbell 2012).

Figure 4 identifies recognised swimming beaches in Darwin Harbour and the nearest recognised 'swimming beaches' to the East Point outfall are located on the southern side of East Point and to the north at Nightcliff. Both sites are well beyond the zone of influence identified for the discharge from the treatment plant either at the East Point Outfall or via the bypass to Ludmilla Creek.

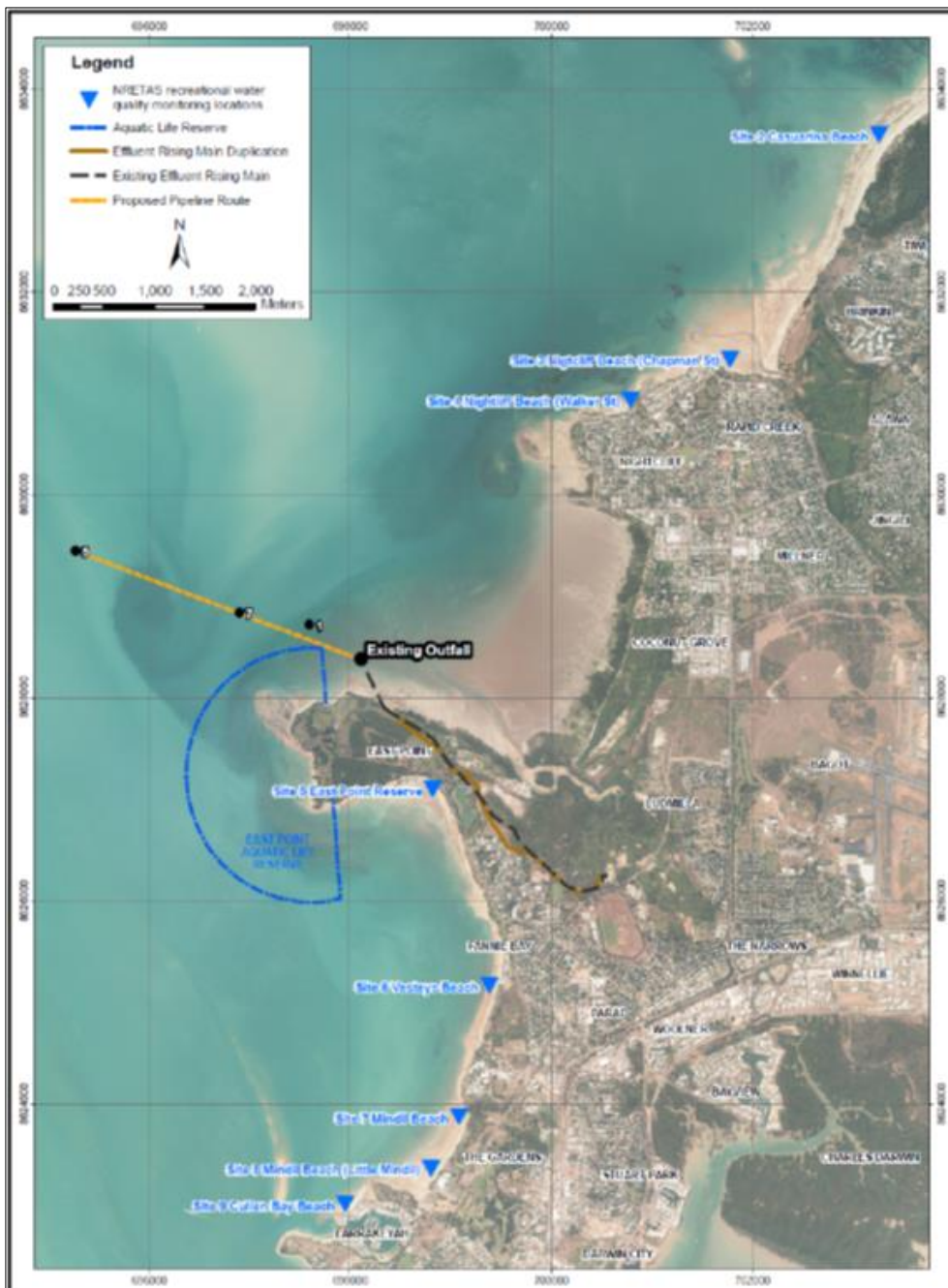


Figure 4:Recreational Beaches listed for Darwin Harbour’s Monitoring Program(from Campbell 2012: Figure 2-2 NRETAS Recreational Water Quality Monitoring Sites)

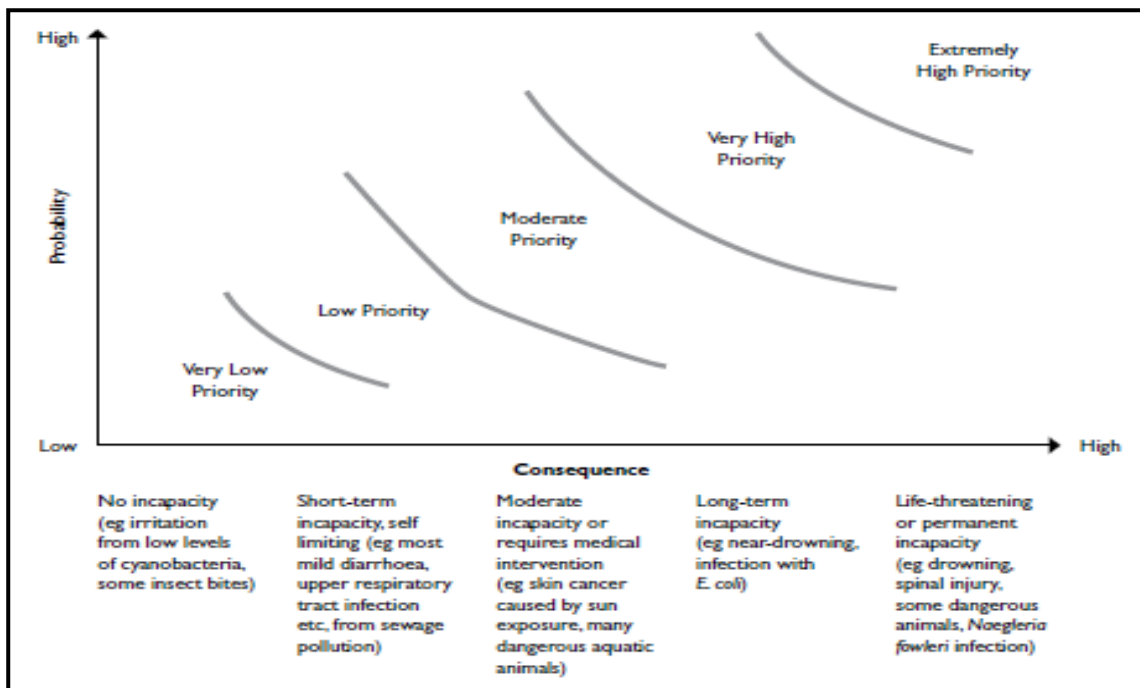


Figure 5: Schematic comparison of health hazards encountered during recreational water use (NHMRC 2008)

The report into factors affecting beach water quality (Campbell 2012) also noted that there were multiple sources of bacterial pollution on Darwin Harbour beaches and that a range of measures to target the different sources were required. While the report monitored tidal creeks for public health indicators it stated that, 'with the exception of Rapid Creek', tidal creeks are not generally considered recreational water bodies in the Darwin area (Campbell 2012). The study also found that tidal creeks are likely to be significant contributors of elevated bacterial levels on adjacent beaches. The study found that the National Health and Medical Research Council Guidelines for Managing Risks to Recreational Waters were seldom met in Darwin's tidal creeks, especially in the wet season.

Figure 4 indicates the beaches considered to be Darwin's swimming beaches.

The PWC/CDU Aquatic Foods monitoring program (Padovan and Gibb 2016) identified a number of virulent strains of *Vibrio* species in animals collected from urban creeks, including Micketts, Rapid and Ludmilla Creeks and it is summited that these pathogenic species are both endemic, and contained in sewage discharges indicating that, as with the DoH warnings, swimming in tropical estuarine creeks in the wet season may be a health hazard (DoH 2016).

Secondary contact recreation – Reduced visual amenity

Reductions in visual amenity are mostly considered to have a low level impact in terms of consequence i.e. insignificant; however, when the concentration of recreational users or sensitive receptors increase then the consequence increases to minor or in the case of highly visible impacts, such as the occasional black plume discharged from the East Point Outfall the risk rating increases to moderate as the events are most commonly associated with low flow conditions more common in the dry season.

Following a comprehensive assessment into the causes of the black plume, 2 primary causes were identified:

1. Low flow and the use of ferric dosing appears to be producing an anaerobic black sludge which is building up throughout the plant and can only be removed manually

2. Night time flows are seldom above the required velocity to prevent settling leading to discharges of settled material as velocities increase throughout the morning.

The highest risk ranking for reduced visual amenity relates to the visibility of the East Point Outfall at low tide and the slight odour that occurs in at the outfall.

The outfall is highly visible at low tide and while the typical discharge is evident primarily due to the freshwater layer on the surface of the more saline Darwin Harbour waters (Figure 6), at times the discharge can be a highly visible black plume (Figure 7) which may have a detrimental impact on the amenity values of the area.



Figure 6: Typical effluent discharge at East Point Outfall



Figure 7: Black plume due to iron compounds in effluent following retention in main

The concentration of recreational users is low however the area is of cultural and tourist significance for the Darwin Region.

Secondary contact recreation –Public health

There are two mechanisms by which secondary contact recreation may present an assessable risk to public health under current NHMRC guidelines (NHMRC 2008). These are when:

- Secondary contact recreation by children (i.e. exploratory activities and wading) is assessed as primary contact recreation in terms of pathogen exposure; and
- Secondary contact recreation exposes people to blooms of toxin producing species through incidental contact.

Based on the PWC water quality monitoring data the risk ranking for the East Point Outfall (SLuEP01) is listed as a hazard factor of 9.9 (Table 17) for swimming which is a moderate health risk, for swimming in the immediate vicinity of the outfall.

The health hazards of these exposures are typically considered minor and short-lived and of 'Low Priority' in terms of probability and consequence compared to the life-threatening or permanent incapacity associated with the hazard posed by dangerous aquatic animals. The Darwin Harbour Beach Water Quality Taskforce (Campbell 2012) indicated that 'tidal creeks are generally not considered recreational water bodies in the Darwin area' and that dangerous aquatic animals were considered a greater risk to human health than bacterial load for example.

'We need to keep this problem in perspective as a threat to human health, in that few if any incidental incidences of gastrointestinal illness outbreaks in Darwin can be linked to swimmers' exposure to bacteria in beaches and waterways, whereas dangerous aquatic animals particularly Box Jellyfish and crocodiles, present a greater risk to people and cause hospitalisation in the Northern Territory every year.'

Key finding, Campbell 2012)

The risks associated with secondary or incidental contact recreation are lower than for primary contact recreation however to ensure people make informed decisions relating to exposure to the treated effluent warning signs have been erected at East Point overlooking the outfall and adjacent to Ludmilla Creek, the sign at Ludmilla Creek recommends the wearing of footwear and the covering of cuts and wounds to reduce the risks associated with bacteria from either wastewater or natural sources that may be present in the waterway.

This is consistent with NT DOH issuing precautionary advice with respect to the hazards posed by marine stingers in the wet season and the 'no tolerance' management plan of NT Parks and Wildlife with respect to crocodile management. While crocodiles are known to inhabit Ludmilla Creek cases of them stalking recreational users are not unknown but considered to be rare in Darwin Harbour.

Secondary contact recreation by children - Pathogens

The first question that should be asked before proceeding with these assessments is whether the water body is used for exploratory activities and wading by children in accordance with the simplified framework for microbial quality assessment of recreational water (NHMRC 2008). Given that this is a sensitive receptor (children), usage will be assumed and considered under likelihood of exposure in this risk characterisation.

The indicator group enterococci are used for assessment purposes not because it is considered to be the causative agent but due to correlation with disease outcomes (NHMRC 2008).

Enterococci are the only pathogen indicator that meets all of the suitability requirements for regulatory parameters to assess faecal pollution, defined in Section 5.3.5 of the NHMRC Guidelines (NHMRC 2008). Further testing to confirm origin of the indicator organism is recommended (NHMRC 2008) and various approaches to source tracking have been applied in the Darwin context (Naeve et al. 2014). Research generally indicates that the distance from the discharge is a moderating factor in the sanitary inspection category. No sanitary survey has been conducted for Ludmilla Creek and the Northern shore of East Point as it is not considered a recreational area and East Point Outfall has a designated exclusion zone under the Ports Act (and is marked on marine survey maps). The discharge is via a short outfall and is chemically assisted sedimentation and chlorinated primary treated effluent and is therefore considered to be a high risk category, which if the area were considered to be a recreational area would require a more intensive monitoring schedule of 20 samples across the swimming season at four locations and on five occasions as well as verification of the effectiveness of management actions. Power and Water monitors the outfall and adjacent sites on a monthly basis however this is not a recreational water quality survey.

Based on the assessment principals outlined by the NHMRC 2008 Guidelines for Managing Recreational Waters the presence of a short outfall for an advanced primary treatment plant indicates a high to risk human health if the area was to be used for primary contact recreation.

Microbial water quality assessment categories derived for enterococci based on epidemiological studies relate to the protection of healthy adult bathers exposed to marine water in temperate north European waters (10 minutes bathing involving three immersions). There is some uncertainty with respect to:

- how relative inactivation of enterococci viruses under Tropical Australian conditions might mitigate these dose response assessments;
- how risk of exposure may be overestimated by an indicator that is non-specific to human sources due to the species-barrier and can undergo in-situ proliferation independent of source inputs;
- how the dose response for enterococci is modified in the case of incidental contact by children as opposed to whole-body immersion primary contact with a more meaningful risk of ingestion; and
- the dose response may not be protective of children, the elderly or immunocompromised people.

The application of these assessment categories is subsequently considered 'worst-case' in most cases, in light of these uncertainties. The end-points for the dose response categories are risk of gastrointestinal illness (GI) and acute febrile respiratory illness (AFRI). In addition to the impact of the East Point Outfall the microbial quality of recreational waters may also be strongly influenced by catchment rainfall due to a range of factors:

- environmental factors such as reduced salinity and resuspension of sediment bound pathogens affecting bacterial community profiles;
- increased WwTP discharge;
- WwTP and or sewer networks can be overwhelmed resulting in overflows of partially or un-treated waste to the environment (i.e. in the interests of protecting public health versus the environment)
- increased catchment derived indicator inputs of both animal and human origin; and
- re-suspension of sediment bound pathogens.

Effective management of water borne pathogens in wastewater treatment to safe levels is critical to protect human health and the environment, Treatment processes can be effective through physical removal or pathogen inactivation without physical removal (such as through disinfection processes), the Ludmilla WwTP utilises both physical removal through chemically assisted sedimentation and inactivation through chlorination.

WwTPs are considered a barrier to the direct contamination of the receiving environment by fresh faecal material of human origin (public health benefit). This is consistent with the NHMRC Microbial Quality of Recreational Water Guideline i.e. protects against direct contamination. The influence of the discharge on pathogen indicator risk can be considered cumulative with the impact of other sources particularly in the wet season and requires separate assessment). Neap ebb tide sampling data from routine monitoring was used to determine potential for increased consequence (higher rate of illness risk meaning more people could get sick if exposed. The classification of the recreational environment for faecal pollution that these were based on is provided in NHMRC. Any 'Poor' – 'Very Poor' grading for any recreational water body does trigger Red Action Mode under the short-term alert level framework.

This would indicate that 'the local authority and health authorities should warn the public that the water body is considered to be unsuitable for primary and secondary contact' (NHMRC 2008). While GI and AFRI end-points are typically considered to be examples of 'short-term' incapacity i.e. of 'minor' consequence, as the illness risk increases and more people would be likely to be affected if exposed then the consequence was upgraded to 'moderate'.

However, this consequence is moderated by the likelihood that children would be exposed in the first place. Likelihood of exposure in the northern shore of East Point or the tidal estuary of Ludmilla Creek is considered possible in the outer zones of the creek in the dry season and unlikely in the wet season. Likelihood was moderated on a seasonal basis with an assumption that less children would be permitted to undertake exploratory wading in the wet season when marine stingers are present. The risk posed by exposure through recreational contact is subsequently mostly 'Low' for these end-points in the dry season in areas where secondary contact recreation by children may possibly occur (the lower transition and outer zones). In the wet season the risk increases to 'medium' for these end-points in these zones.

Secondary contact recreation – Toxic Blooms

Naturally occurring blooms of cyanobacteria such as *Lyngbya majuscula* (maiden's tresses) and *Trichodesmium* spp. (sea sawdust or red tides) are common in Darwin Harbour from later in the dry season (September – November) when light intensity in the water column is higher and water temperatures increase. The actual colour of these 'red tides' can in reality be green to yellow-brown. These red tides were first observed in Australia by Captain Cook in the 1700s.

The blooms can cover extensive areas and can wash up onto the Darwin Harbour coastline including at East Point (Bennett 2013). Oceanic inputs of TP are considered dominant in Darwin Harbour as discussed previously, with phosphorous and iron considered key drivers for *Lyngbya majuscula* bloom formation in Darwin Harbour. These cyanobacteria have both been associated with skin irritation through dermal contact. *Trichodesmium* has the ability to fix atmospheric nitrogen and blooms of this species can also be an important food source for a variety of invertebrates and fish, including whale sharks and manta rays

(NRETAS Media Release 16 October 2009). For example, the mesozooplankton *Microstella* is adapted to feeding on *Trichodesmium* in Darwin Harbour (McKinnon et al. 2006).

Secondary contact recreation in waters subject to an algal bloom can result in dermal contact, inhalation of aerosols and possible ingestion through incidental contact during secondary contact recreation. The organisms that can present a hazard through these secondary contact exposures are summarised in NHMRC recreational water guidelines, key species and symptoms are listed in Table 10.

Table 10: Organisms that can cause adverse effects through dermal contact, inhalation or ingestion during secondary contact recreation

Organism	Syndrome	Toxin	Exposure	Symptoms
<i>Pfisteria piscicida</i> - dinoflagellate	Estuary syndrome	Unknown	Dermal or inhalation	Dizziness, eye irritation, headache, gastrointestinal, respiratory (wheezing, coughing, shortness of breath), dermatological symptoms (less frequent), cognitive effects
<i>Lyngbya majuscula</i> - cyanobacteria	Swimmers Itch	Debromoaplysiatoxin and Lynbyatoxin A	Dermal	Severe inflammatory irritation (eye, respiratory, skin)
<i>Trichodesmium spp.</i> - cyanobacteria	Skin irritation and Trichodesmium Fever	Unknown (specific species can contain a neurotoxin)	Dermal	Skin irritation, respiratory difficulties
<i>Karenia brevis</i> (also known as <i>Gymnodinium breve</i>) - dinoflagellate	Respiratory irritation	Brevetoxins	Inhalation	Severe irritation of conjunctiva and mucous membranes followed by coughing/sneezing and tingling of lips
<i>Nodularia spumigena</i> - cyanobacteria	Hepatotoxicity	Nodularin	Ingestion of water or scum	Hepatotoxicity

The risk analysis and characterisation for secondary contact exposures to the blooms that develop in Ludmilla Creek and East Point reveals a 'Low' risk ranking. This is based on a suitability for recreation classification of 'Good' – 'Very Good' based on a high susceptibility to algal contamination but an algal history category of A-B (Table 7.4 and 7.5 of NHMRC 2008) and the mainly irritant end-points associated with these exposures. *Lyngbya majuscula* does occur at bloom levels in Darwin Harbour including in the vicinity of the East Point outfall however this is a natural phenomenon and is not the result of the Ludmilla WwTP discharge, the maximum cells per millilitre at sites in the vicinity of the LWwTP was 22 cells/ml at the Ludmilla Creek upstream site (SLuLC01) on 2 October 2014. This is below the threshold likely to result in a bloom or symptoms following exposure.

To advise the public of potential risks associated with exposure to treated effluent discharged via the East Point Outfall or via the overflow weir into Ludmilla Creek, PWC, in consultation with key stakeholders has erected warning signs at East Point and at major access points to Ludmilla Creek (Figure 8 & Figure 9).

The current signs do not account for members of the public who may approach the East Point Outfall discharge point from the water and as such the deployment of a buoy for the offshore outfall was attempted however the intertidal location proved unsuitable with the asset destroyed in the first heavy weather.

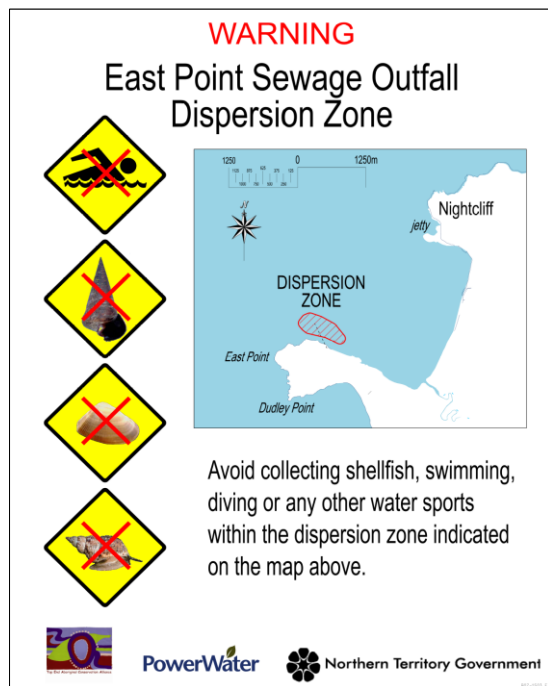


Figure 8: Warning sign at East Point identifying dispersion zone

Figure 9: Treated effluent warning sign at Ludmilla Creek

Cultural use of aquatic foods:

There is considerable evidence of the collection of a wide variety of shellfish and other aquatic animals as food by both the local indigenous community and other groups within the vicinity of Ludmilla Creek and the East Point Outfall. As shown in Figure 17, in addition to fish and mud crabs a variety of molluscs and mangrove worms are collected, cooked over a low temperature camp fire and eaten.



Figure 10: Sorting the shellfish at East Point for a Christmas feast. Photo Stephen Roper December 2015

Public health consequence

There are two main mechanisms by which cultural use of aquatic foods (harvest and then consumption) may present a public health risk. These mechanisms include:

- Shellfish and fish may bioaccumulate toxins produced by toxin producing microalgae/phytoplankton; and
- Seafood that is harvested and consumed may be contaminated by pathogens.

The first mechanism could occur indirectly through eutrophication and bloom formation if toxin producing species were present in sufficient numbers. Natural inputs of Fe and silica and nutrients from catchment surface and groundwater inflows and increasing temperatures can also facilitate blooms in the wet season.

The second mechanism can be directly attributed to the source although there are other pathogen sources in this catchment particularly in the wet season therefore confirmation of association with source is required.

Toxicity Assessment

Discharge Characteristics

Wastewater characteristics at Ludmilla WwTP are influenced by both the influent sewage and the treatment processes within the treatment plant. The chemical characteristics of both the influent and effluent are detailed in Tables 11, 12 and 13.

This assessment is conservative as it uses data that is no longer typical of Ludmilla WwTP discharge; the plant upgrade has improved the discharge quality.

Table 11: Inflow Characteristics LWwTP

Period			
Parameter	2014- 2016 (financial years)	2016- 2018 (financial years)	2018-2021 (financial years)
Ave Volume ML/year	5980.168	7043.748	5956.91
Input to LWwTP t/y			
BOD	915.25	754.80	726.765
TSS	1194.5	1340.24	1244.8
TP	30.94	34.70	33.155
FRP	23.19	24.03	23.46
TN	277.88	290.77	261.87
NH3 (free)	210.73	226.56	165.2
Metals input to LWwTP kg/yr			
Hg	0.33	0.35	0.296
Cu	1133	1409	1331
Ni	24.99	14.1	11.91
Zn	683	775	716
Pathogen Input to LWwTP organisms/yr			
E. coli	5.1×10^{17}	9.15×10^{17}	7.16×10^{17}
Enterococci	2.7×10^{16}	5.27×10^{16}	3.68×10^{16}

Table 12: Outflow Characteristics LWwTP

Quantity	East Point Outfall			Ludmilla Ck discharge		
Financial Years	2014-2016	2016-2018	2018-2021	2014-2016	2016-2018	2018-2021

Vol ML/yr	5416.311	6232.87	5333.21	427.93	117.66	21.73
Input to Darwin Harbour t/y						
BOD	482.18	416.03	470.33	23.11	5.58	1.91
TSS	213.05	247.73	195.51	12.15	4.2	0.79
TP	6.98	9.98	9.76	0.29	0.13	0.04
FRP	2.74	5.85	4.174	0.16	0.08	0.02
TN	182.52	159.08	193.86	8.85	1.96	0.79
NH₃-N (Free)	147.33	136.61	150.2	7.03	1.78	0.61
Input to Darwin Harbour kg/y						
Mercury	0.693	0.698	0.757	0.055	0.013	0.003
Copper	65.54	168.9	147.89	5.18	3.19	0.60
Nickel	12.99	11.22	13.38	1.03	0.21	0.05
Zinc	19.5	24.31	42.45	1.54	0.45	0.17
Arsenic	4.33	4.36	7.83	0.34	0.08	0.03
Input to Darwin Harbour organisms/y						
E. coli	7.58x10 ¹²	9.35x10 ¹¹	9.39x10 ¹³	5.99x10 ¹¹	1.76x10 ¹¹	3.83x10 ¹¹
Enterococci	1.95x10 ¹²	6.23x10 ¹¹	2.47x10 ¹²	1.54x10 ¹¹	1.18x10 ¹⁰	1.01x10 ¹⁰

Based upon the water quality of the discharge and their penchant for toxicity in marine flora and fauna, 3 chemicals of potential concern have been identified as ammonia, dissolved copper and dissolved zinc

Ammonia

Ammonia is highly soluble and its speciation is affected by a wide range of environmental factors including pH, temperature and ionic strength (CCME 2010). Ammonia is in equilibrium in the environment between unionised (NH₃) and ionised (NH₄⁺) forms in aquatic systems. The amount of ammonia in a system is generally termed total ammonia which includes the sum of NH₃ and NH₄⁺ and is referred to total ammonia-N (CCME 2010). Ammonia aquatic toxicity needs to take into account the temperature and pH of the water. National guidelines incorporate these aspects to create a range of guideline values which can be used to derive a guideline specific to a site (ANZG 2018). The toxicity of ammonia is primarily attributed to NH₃ which exists at higher pH than NH₄⁺ (ANZG 2018). Therefore, ammonia will exhibit higher toxicity in tropical marine systems than in freshwater systems. It is important to note that ammonia is non-persistent and non-accumulative in aquatic biota, therefore indirect toxicity (e.g. exposure via ingestion of biota) is not a relevant consideration when assessing the potential risk of harm from ammonia exposure. Ammonia-N

toxicity (range of LC50s (Median lethal concentration with 50% of exposed population survival)) to marine organisms for short term exposures is shown below:

- Fish: 8.8 mg/L to 21.4 mg/L (44-68 hours);
- Molluscs: 7.7 mg/L to 42.8 mg/L (48-96 hours); and
- Crustaceans: 18.7 mg/L to 264 mg/L (24 – 96 hours) (ANZG 2018).

No observed effect concentrations (NOEC) for long term toxicity (20-day exposure) for fish were 6.3 mg/L (mortality) and 3.6 mg/L (growth) (ANZG 2018). ANZG (2018) states that invertebrates are generally more tolerant to ammonia than fish with vascular plants being more tolerant again (ANZG 2018). There is a lack of information in the literature on ammonia toxicity to aquatic plants, however, Korner et al. (2001) showed that a 14-day exposure of freshwater duckweed to ammonia resulted in zero growth at 8 mg/L $\text{NH}_3\text{-N}$.

Dissolved copper

Copper is a naturally occurring element in aquatic systems and is an essential trace element for most aquatic organisms and the internal concentration is under tight homeostatic control. It is generally assumed that the free copper ion (Cu^{2+}) and the copper hydroxy species are the most toxic copper species to aquatic organisms (ANZG 2018). Due to the chemical speciation of copper, the presence of dissolved organic matter will reduce its toxicity. Suspended material will adsorb copper; copper complexing is increased with increasing pH and increasing salinity which in turn will reduce copper toxicity (ANZG 2018). Copper toxicity ranges to marine organisms for long term (5 – 28 days LC_{50}) exposures are shown below (ANZG 2018):

- Fish: 30 $\mu\text{g/L}$ to 260 $\mu\text{g/L}$;
- Crustaceans: 8.5 $\mu\text{g/L}$ to 42 $\mu\text{g/L}$;
- Molluscs: 0.4 $\mu\text{g/L}$ to 20,000 $\mu\text{g/L}$;
- Annelids: 17 $\mu\text{g/L}$ to 68 $\mu\text{g/L}$; and
- Algae: 2 $\mu\text{g/L}$ to 1,000 $\mu\text{g/L}$.

Dissolved zinc

Similarly, as with copper, zinc is an essential element required for growth and development commonly found in low concentrations in most aquatic systems (ANZG 2018). Also, the toxicity of zinc is related to the free ion (Zn^{2+}) which is also affected by increasing dissolved organic carbon, suspended solids, pH and salinity. Zinc toxicity ranges to marine organisms for long term (7 – 28 day NOEC) exposures are shown below (ANZG 2018):

- Fish: 10,400 $\mu\text{g/L}$;
- Crustaceans: 15 $\mu\text{g/L}$ to 2,100 $\mu\text{g/L}$;
- Echinoderm: 460 $\mu\text{g/L}$;
- Molluscs: 15 $\mu\text{g/L}$ to 27,500 $\mu\text{g/L}$;
- Annelids: 70 $\mu\text{g/L}$ to 3,260 $\mu\text{g/L}$;
- Algae: 13 $\mu\text{g/L}$ to 796 $\mu\text{g/L}$.

Cultural use of aquatic foods – Accumulation of natural toxins

Natural toxins produced by marine phytoplankton/microalgae can result in toxic syndromes in humans when shellfish is consumed. There does not need to be a visible bloom present in order for shellfish to accumulate toxins to unsafe levels. Filter feeders are considered particularly susceptible to toxin accumulation as they filter large volumes of water. Unlike pathogens, cooking of shellfish does not mitigate

the risk from consumption and may even create more potent breakdown products. Once harvested shellfish cannot naturally depurate the toxins.

Marine biotoxin management plans are in place in many states of Australia to protect shellfish harvest areas. There is currently no shellfish quality assurance program that includes biotoxins in the Northern Territory. The power to suspend harvesting and close a shellfish growing area due to biotoxin contamination does exist under the NT *Fisheries Act 1988*. The NT Fisheries Division of DPIF was unaware of any cases of shellfish poisoning having been reported in the NT (ASQAAC 2001).

Several micro-algal species capable of production of toxins that can cause PSP (Pyrodinium sp.), ASP (*Pseudo-nitzschia* sp.) or DSP (*Dinophysis* sp.) are present in Northern Territory waters (ASQAAC 2011). In the East Arm of Darwin Harbour, four genera containing potentially toxic species have been identified (*Dinophysis* sp., *Prorocentrum* sp., *Plankothrix* (*Oscillatoria*) and *Pseudo-nitzschia*) during baseline surveys between 2010 and 2012. These taxa were found to be in low concentrations that 'do not pose a human health concern' and were considered a 'natural component of the phytoplankton composition' (Dostine 2013). No differences in phytoplankton group dominance could be determined between creeks with and without sewage N inputs in Darwin Harbour, based on HPLC pigment analysis (Burford et al. 2012).

A risk analysis and characterisation (Table 13) indicates that the consequence of exposure to biotoxins in shellfish are likely to be at most 'Moderate' due to the confirmed presence of potential toxin producers. Toxin production of *Pseudo-nitzschia* spp. in Darwin Harbour has not been confirmed to our knowledge. However, the toxin produced is an irreversible neurotoxin that if present could result in death in elderly consumers i.e. Severe Consequence. While death would be considered a 'Rare' consequence, the overall risk ranking is 'High'. This risk ranking is likely to apply equally to all shellfish harvest areas in Darwin Harbour due to the natural presence of low levels of potential toxin producers.

Table 13: Risk analysis and characterisation of exposure to biotoxins through cultural use of aquatic foods

Hypothesis	Zone	Consequence		Likelihood		Risk Ranking
Blooms of toxic species could occur that present a risk to public health through consumption of aquatic foods	Ludmilla Creek downstream of discharge point and East Point where shellfish harvest occurs	Species potentially capable of toxin production present in Ludmilla Creek and East Point as they are elsewhere in Darwin Harbour. Presence in the wet season may not be directly attributable to the discharge due to the influence of other catchment sources and freshwater inflows at this time. End-points associated with biotoxins considered Minor, Moderate, Long-term and even Life-threatening i.e. Severe (GI illness, short-term memory loss, death). Sensitive populations: indigenous harvesters and > 50 year old people more likely to display Moderate or Long-term (neurological) consequences, while death in >68 year olds possible based on a case in Canada in the 1980s. Consequence – Severe (albeit discharge is not only contributor to consequence in this catchment)	5	Considered – Rare (An event could occur only in exceptional circumstances i.e. once every 10 years or greater)	1	High

PWC has conducted algal species and algal toxin production monitoring in Ludmilla Creek and at East Point since 2014 and during this period no harmful microalgal species for this exposure pathway have been identified at levels sufficient to cause harm or detectable toxic producing levels in Ludmilla Creek or in the waters adjacent to East Point. Commercial harvesting is the typical focus of biotoxin management plans; however, the same principles apply to cultural use of aquatic foods.

Table 14: Assessment of dominant marine phytoplankton in Ludmilla Creek and East Point

Date	Location	Dominated by	Comments
21 July 2015	SLuLC01	<i>Thalassiosira</i> (diatom) 5×10^2 cells/mL	Not harmful to public health
8 November 2016	SLuEP01	<i>Chaetoceros</i> – 7.1×10^3 cells/L (diatoms) <i>Pseudo-nitzschia</i> 14 cells/ml	Not harmful to public health Very low levels of the diatom <i>Pseudo-nitzschia</i> (well below alert levels and not relevant to this pathway – i.e. can produce amnesic shellfish toxin domoic acid)
10 December 2017	SLuEP03	<i>Chaetoceros</i> spp. 2.9×10^3 cells/L (diatom)	The species present are not generally considered toxic or harmful species in the marine environment.
22 September 2015	SLuLC01	<i>Gyrodinium</i> spp. 3.17×10^2 cells/L	Not harmful to public health
13 Nov 2018	SLuLC03	<i>Peridinium</i> cf. <i>quinquecorne</i> 1.16×10^4 (dinoflagellate)	Not harmful to public health

A risk analysis and characterisation indicates that the while the possible consequence of exposure to biotoxins in shellfish is high due the potential for death, the actual risk ranking is likely to be at most 'low' due to no confirmed presence of toxin producing *Psuedo-nitzschia* or other species at levels that have been demonstrated to be capable of producing domoic acid or other toxins in the receiving waters of the LWwTP discharge Harbour at East Point or in Ludmilla Creek.



Figure 11: *Trichodesmium* in receiving waters of East Point Outfall discharge – photo taken 30/09/2019

Blooms of the cyanobacteria *Trichodesmium* spp (Figure 11) have been identified in the vicinity of East Point however the source of these blooms is oceanic and unlikely to be associated with the East Point Outfall or discharges from Ludmilla Creek.

Table 15: Risk analysis and characterisation of secondary contact recreation exposures to blooms observed in Ludmilla Creek or East Point - marine phytoplankton

Hypothesis	Zone	Consequence	Likelihood		Risk Ranking	
Blooms of toxic species could occur that present a risk to public health through secondary contact recreation exposure	Ludmilla Creek and East Point	Suitability for Recreation Classification is 'Good' based on identification of species present in in-situ blooms to date (Green Surveillance Mode). Consequences are considered 'Minor' due to the Algal History Category and mainly irritant end-points that could occur.	2	Considered - Unlikely (Event not expected based on algal history but possible that one could occur)	2	Low

Cultural use of aquatic foods – Accumulation of pathogens

Larakia traditional owners have had concerns that some shellfish harvest areas near sewage discharges may be 'suspect' as opposed to 'safe' to eat areas. The concerns of traditional owners were principally with respect to elevated metals and pathogen levels in shellfish. Power and Water's routine monitoring data focuses water quality indicators of potential pathogen contamination, the assessment of this data is included in Table 17 to Table 22 of this report.

The impact of contamination in waterways has been the focus of a number of recent studies to assess the correlation between water quality indicators and the impact on the declared beneficial uses, especially in relation to artisanal collection of aquatic foods.

A Healthy Marine Harvest study (Padovan et al. 2013) was conducted on behalf of traditional owners in the Darwin Harbour Region for Territory Natural Resource Management Inc, further investigations by Neave et al 2014; Padovan et al 2017 and Padovan et al 2019 have concluded that there are distinct microbiological signatures for effluent and catchment runoff however faecal indicator species were present in waters collected near discharge sites but also from areas with no known effluent discharges, particularly during the rainy season suggesting that food should not be collected from creeks and estuaries during the rainy season (Padovan et al 2019).

In the original study (Padovan 2013) Site selection was undertaken in consultation with traditional owners and included Ludmilla Creek and East Point shellfish harvest area (200 m upstream of the boat ramp) in the transition zone as a 'suspect' site. Reference sites were included from Woods Inlet and One Fella Creek on the Cox Peninsula. This study focussed on targeting four species (long bum, mud whelk (*Terebralia palustris*), periwinkle and oyster (*Saccostrea cucullata*) that may be expected across most sites. Oysters and the mud whelk species selected were found at East Point and Ludmilla Creek. However, it was noted that traditional owners do not discriminate between these periwinkle species. Overall, eight commonly eaten species were identified by traditional owners inclusive of the above species but also, *Marcia hiantina* (smooth cockle), *Polymesoda erosa* (mud mussel), *Bactronophorus thoracites* and *Banka australis* (mangrove worms). It is not clear whether all species are present or potentially targeted by traditional owners at Ludmilla Creek. The findings with respect to Ludmilla Creek are therefore based on the long bum and periwinkle species that were present and collected at this location. It is however important to choose a target species that can be used to assess and compare multiple locations. Microorganisms in shellfish were identified using DNA sequencing (16S rRNA) based on operational taxonomic units (OTU). While high throughput and each OTU is theoretically a distinct species, this is not confirmed through culturing. Samples were harvested over four weeks between April and May in 2012.

In 2013 and 2014 Power and Water Corporation conducted a separate investigation of bioaccumulation and pathogen levels in Telescopium and oysters in Ludmilla creek and around East Point.

The Foods Standard Code (FSANZ 2005) of 2.3 MPN *E. coli*/g of flesh with a standard plate count of 100,000 organisms/g was adopted as a standard in edible tissue in the DHWQO to protect consumption of aquatic foods derived from aquaculture, recreational, commercial or indigenous food gathering in Darwin Harbour (NRETAS 2010). Alternatively, a median guideline for water in shellfish growth harvest areas of 14 MPN Faecal coliforms/ 100 mL can be applied to the consumption of aquatic foods. Shellfish harvesting is

assumed to occur mainly at low tide from downstream of Dick Ward Drive to the mouth of the Creek. The 1983 land use field study for the Kulaluk area found different communities collected different species across most of the creek (Henderson 1983).

An assessment of the faecal coliform data indicates the DHWQO guideline is complied with at downstream Ludmilla Creek site and at all sites except the East Point Outfall in the dry season. In the wet season all Ludmilla Creek sites exceed the DDWQO and both the East Point Outfall and site SLuEP02, approximately 250 metres North West of the outfall exceed the DHWQO for shellfish for human consumption. It should be noted that there is a NT Government declared exclusion zone of approximately 350 metres around the East Point Outfall which prohibits the collection of shellfish (see figure x above) the zone is declared by regulation under the Ports Act. The WHO (2010) has indicated that the reliability of this indicator (faecal coliforms in water) is poor due to a lack of correlation between this indicator and bacterial or viral pathogens in shellfish flesh. Given the multitude of sources in the wet season, more specific markers are also required to be developed and/or applied to assist with source tracking for these exposures when data becomes available in flesh i.e. similar to recreational contact exposures. While there is limited data from 1983 and from the Healthy Harvest study of 2012 it is largely also unknown, how these resources are seasonally exploited by indigenous harvesters at present and in the interim it is assumed harvesting and consumption is consistent across seasons.

The lack of data specific to the 'bush foods' collected in Darwin Harbour limited the previous risk assessment. To address this data gap PWC commissioned Charles Darwin University (CDU) researchers to conduct an aquatic foods monitoring program. The preliminary results are discussed below.

Concerns have been raised regarding the suitability of the current water quality pathogen guidelines when considering indigenous collection of aquatic foods from an urban waterway. The guidelines were developed for consumers of filter feeding organisms and may not be relevant to grazing species such as *Telescopium*; however they were not designed to protect consumers who may always collect their food from the same environmental area, and may be exposed to more localised contamination. To address these uncertainties in the risk assessment PWC commissioned researchers from Charles Darwin University to investigate water quality indicators of pathogen contamination and contaminant concentrations in the flesh of a range of indigenous collected aquatic food organisms collected from the Darwin area including Ludmilla and Rapid Creeks, Darwin Harbour near the East Point Outfall and East Point outside any potential influence of the outfall (Padovan and Gibbs 2016).

While wastewater treatment plants provide a barrier to reduce the public health risks associated with the disposal of domestic and industrial wastewater. They provide a partial barrier to pathogen exposure, the treatment reduces the pathogen load present in the effluent however the effectiveness of the barrier depends on the nature of the treatment process and the dispersal of the effluent.

Access to the treated effluent discharge via the intertidal East Point Outfall has signage however there is only a limited barrier as the near shore discharge is exposed at low tide and forms a 'creek' of undiluted treated effluent on low spring tides.

The exposed inshore location of the East Point Outfall enables direct access to the treated effluent, resulting in the potential for direct exposure to pathogens remaining following the treatment process and

consequently health impacts for both the collection of aquatic food and paddling in the water. The NHMRC assessment category is high risk for recreational uses.

The 95th percentile for pathogen indicators are outside the range considered acceptable for the protection of the Beneficial Uses of aquaculture; primary contact recreation; and the human consumption of aquatic foods (Figure 12).

The assessment considered the exposure pathways for aquaculture and primary contact recreation to be weak for both Darwin Harbour on the northern intertidal zone at East Point and for Ludmilla Creek. The exposure pathway for the collection of aquatic foods is strong in Ludmilla Creek with the collection of mud crabs, shellfish and fishing considered to be common activities, with local communities collecting from one primary area. The collection of food in the direct vicinity of the East Point Outfall is not as common due to the lack of appropriate habitat however oysters are collected from the rock shelf at East Point and tissue samples collected in 2013 indicated elevated levels of pathogens and the metals zinc and copper, indicating probable exposure to treated effluent from the East Point Outfall.

The Healthy Harvest investigation by Padovan et al. (2013) found that while overall there were elevated levels of metals in shellfish at sites near discharges there was no evidence to indicate that shellfish collected from near sewage outfalls and industrial areas in Darwin Harbour contained higher concentrations of metals than shellfish from reference sites.

The principal findings from this study were that:

Faecal indicators in water in the Ludmilla Creek discharge zone (drain proximal to the outfall) were not significantly higher than concentrations in Mickett Creek or Rapid Creek control sites;

Coastal sites generally had lower faecal indicators in water than tidal creek sites;

Criteria for *E.coli* in shellfish (FSANZ 2016) were only exceeded in the wet season.

Criteria for *E.coli* in shellfish (FSANZ 2016) were exceeded in the control zones in Mickett and Rapid Creeks;

No *E.coli* exceedances occurred in oysters (*Saccostrea cucullate*) including from East Point.

Vibrio parahaemolyticus was detected in 81% of samples collected in the wet season and 48% of samples in the dry season, there was no difference between samples collected from discharge, potential impact and control sites.

No *E.coli* exceedances occurred in cooked Mud crabs.

There was no significant relationship between *E.coli* or faecal coliforms in water and *E.coli* in *N. balteata* or *T.telescopium*.

Sewage pathogens, salmonella and norovirus were rarely detected.

The human faecal marker *Bacteroides*, was not detected in any of the samples.

There was no relationship between *E.coli* and sewage-derived pathogens in shellfish from this study therefore it is likely that faecal indicators are most likely from environmental sources and/or responding to environmental conditions.

It can be concluded that for the East Point and Ludmilla Creek areas the discharge of treated effluent does not materially alter the risks associated with the consumption of shellfish collected from urban waterways.

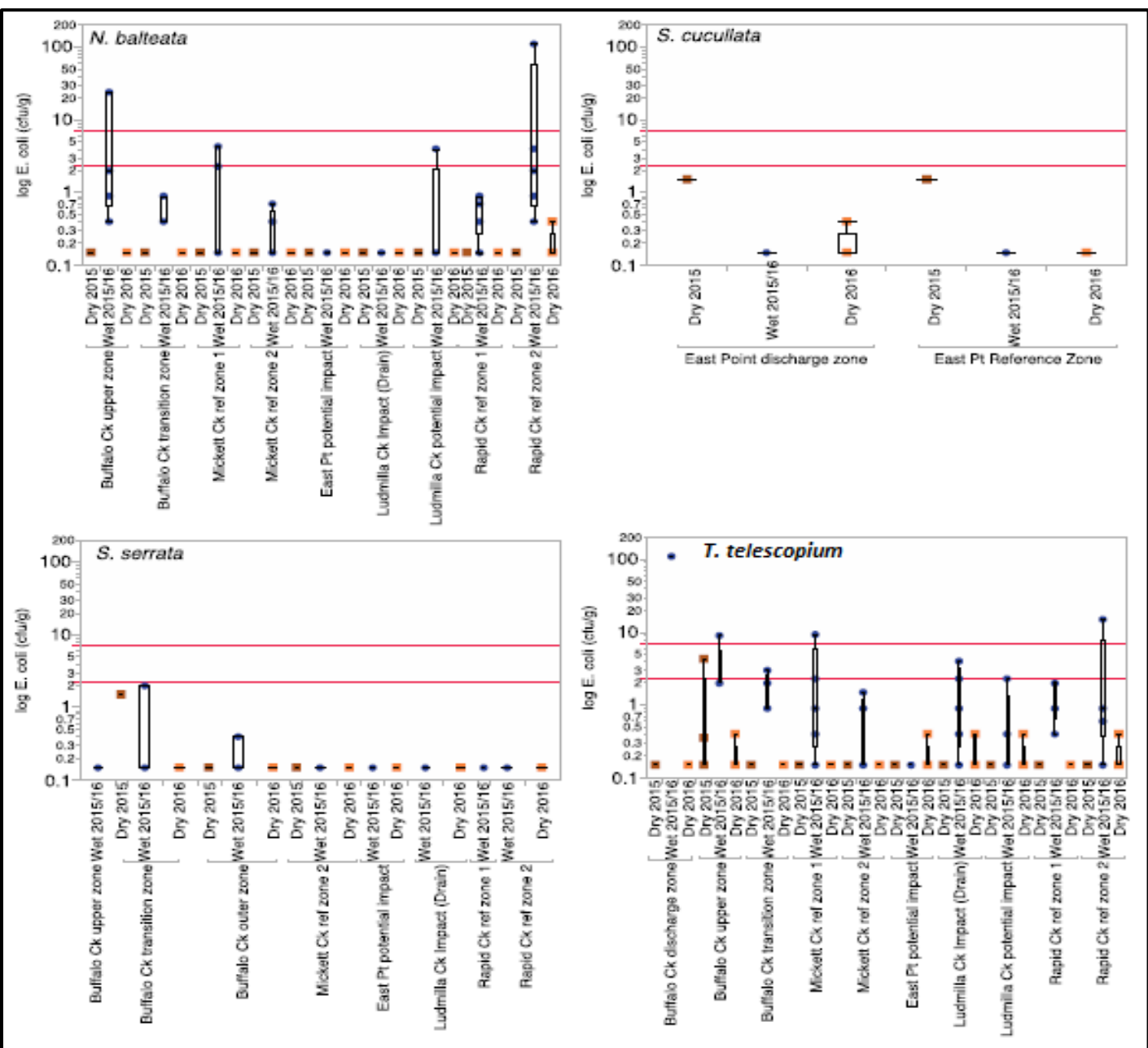


Figure 12: An assessment of *E. coli* in shellfish and mud crabs in Ludmilla Creek and East Point compared to control creeks
[Source – Figure 6 Padovan and Gibb 2016]

Emerging Chemicals of Concern for Aquatic Foods and Ecosystems (PFAS)

In addition to hazards associated with pathogens and identified contaminants in sewage, emerging chemicals of concern are regularly reviewed for the potential hazards associated with the discharge of treated effluent from the Ludmilla WwTP.

Persistent organic pollutants have a long history of environmental impacts due to their persistence and the potential for bioaccumulation through the food chain. Once such group of chemicals are per and poly fluoroalkyl substances (PFAS), internationally they been identified as of potential concern and in 2009 they were listed under the Stockholm Convention on Persistent Organic pollutants (DoEE 2017), the Commonwealth is consulting on Australian ratification of listing.

PFAS chemical have been identified in sewage effluent due to their intake and excretion (Thompson et al 2011; Gallen 2015). These ubiquitous chemicals have been widely used due to their properties including as oil and water repellent surface coatings for packaging and textiles and in fire-fighting foam (Thompson et al 2011), their effectiveness in relation to fuel fires has resulted in their association with airports and defence activities. Their chemical and thermal stability has raised concerns relating to their long term environmental and health impacts.

The Northern Territory Government has a structured, risk based assessment program to evaluate PFAS risks based on addressing issues of high public health risks as the first priority, within this framework the NT Government's investigations have focused on drinking water sources and high priority sources including defence facilities and airports.

The location of the Darwin Airport and Airforce base in the upper catchments of Rapid and Ludmilla Creeks indicate the potential for a contaminant pathway. Investigations conducted for the Northern Territory Department of Health (Munksgaard N. C et. al. 2017) found that per and poly fluoroalkyl substances (PFAS) were present in aquatic foods (longbums, periwinkles, crustaceans and fish) collected from Ludmilla and Rapid Creek however those foods can be eaten without exceeding the recommended dietary intake of 0.02 µg/kg_{bw}/day PFOS/PFHxS or 0.16 µg/kg_{bw}/day due to existing guidance on mercury exposure.

The same study confirmed that PFAS levels in the sediments indicate that with respect to PFAS the sediments are classified as being in 'good' condition.

In addition to the high priority site investigations for drinking water quality PWC has also analysed the influent and effluent from seven wastewater treatment facilities, including the Ludmilla WwTP (PWC 2018). Ludmilla WwTP influent and effluent has been analysed for PFOS, PHHxS and PFOA. Table 6 indicates the PFOS, PFHxS and PFOA levels in Ludmilla WwTP influent and effluent and the results are below the levels proposed for protecting environmental uses and values in the National Environmental Management Plan (HEPA 2020) and in the NSW EPA proposed trigger points (NSW EPA 2016).

Table 16: Average Concentrations (µg/L) PFAS derivatives in Ludmilla Influent and Effluent

Ludmilla WwTP	Average Concentration (µg/L)		
NEMP Guideline/marine	0.13	0.13	220
Recreational Waters	0.7	0.7	5.6
Influent onsite	0.010	0.005	0.016
Effluent offsite	0.0044	0.0016	0.0012
NSW EPA Trigger Points	Description: PFOS or PFOA in surface waters		Value

Trigger Point 1	Elevated contamination	10 µg/L
Trigger Point 2	Current screening guideline	0.1 µg/L
Trigger Point 3	Low level of contamination	0.05 µg/L
Trigger Point 4	Limits to analytical methodologies	**0.01 µg/L

The results indicate the current level of PFAS chemicals in the Ludmilla WwTP's treated effluent discharge poses a low risk to the protection of the beneficial uses.

Risks Associated with the Consumption of aquatic organisms

The PID Desktop Environmental Assessment identified the human consumption of aquatic foods collected in the vicinity of the East Point Outfall and in Ludmilla Creek as one of the highest risks associated with the discharge of treated effluent via the East Point Outfall and the overflow weir into Ludmilla Creek.

Ludmilla Creek is used for the collection of mud crabs, shellfish and other bush foods and contact with the water occurs during these activities.

In 2015 PWC commissioned CDU to conduct an aquatic foods monitoring program. The focus of the monitoring program was on waterways that receive discharges from Ludmilla WwTP and Leanyer-Sanderson and similar water ways that do not receive discharges of wastewater from the treatment plants.

The objectives of the Plan were:

3. To sample water and shellfish at key locations in receiving waters and reference sites; the specific shellfish species are *Telescopium telescopium* (longbums), *Nerita balteata* (periwinkles), *Saccostrea cucullata* (rock oysters), *Marcia hiantina* (smooth cockles or pipis) and *Scylla serrata* (mud crab);
4. To test water and shellfish for faecal indicators (*E. coli*, faecal coliforms, enterococci, *Bacteroides*) and pathogens (norovirus, *Vibrio* spp. and *Salmonella* spp.);
5. To optimise protocols for the molecular detection of *Vibrio* spp., *Salmonella* spp. and *Bacteroides* spp.;
6. To develop associated standard operating procedures (SOPs); and
7. To report to PWC after each seasonal sampling.

The focus area for the aquatic foods monitoring program are shown in Figure 13 and Figure 14, with the monitoring sites relevant to the discharge from the Ludmilla WwTP grouped in Ludmilla Creek, to identify impacts from discharges via the overflow weir into Ludmilla Creek and in Darwin Harbour in the vicinity of the East Point Outfall.

Two 'reference' areas, not impacted by the discharge from the Ludmilla WwTP were also included in the monitoring program to identify background conditions for the urban catchments of Ludmilla Creek and Darwin Harbour at East Point.

The monitoring program commenced in the 2015 dry season and sampling has been conducted in two dry and one wet season. Interim sampling event reports have been received.

A summary of the findings of the various monitoring events is presented below.

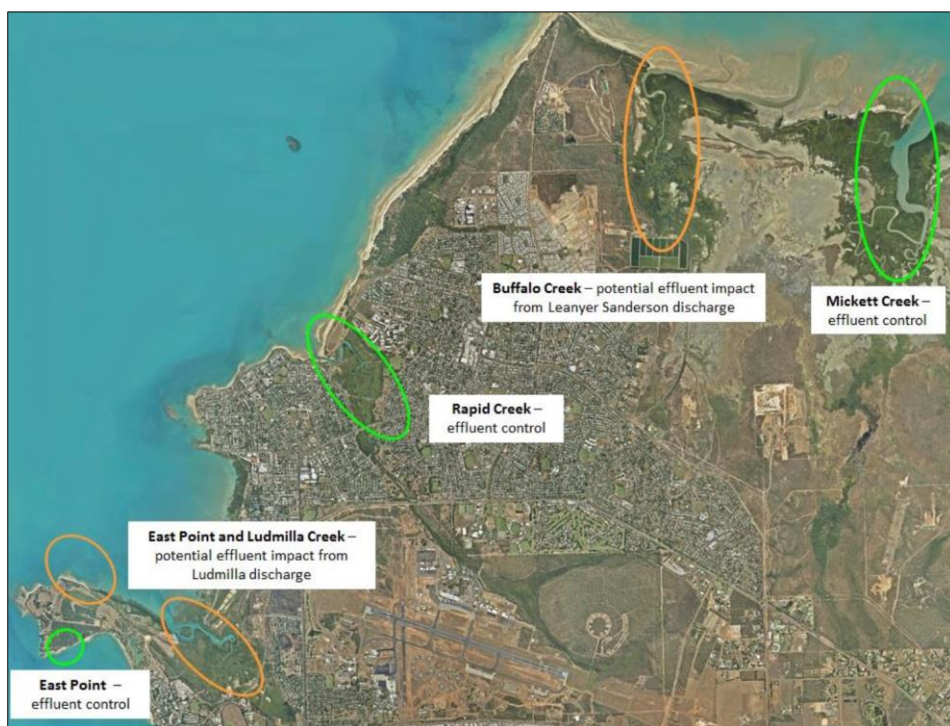


Figure 13: Aquatic Food Study monitoring sites

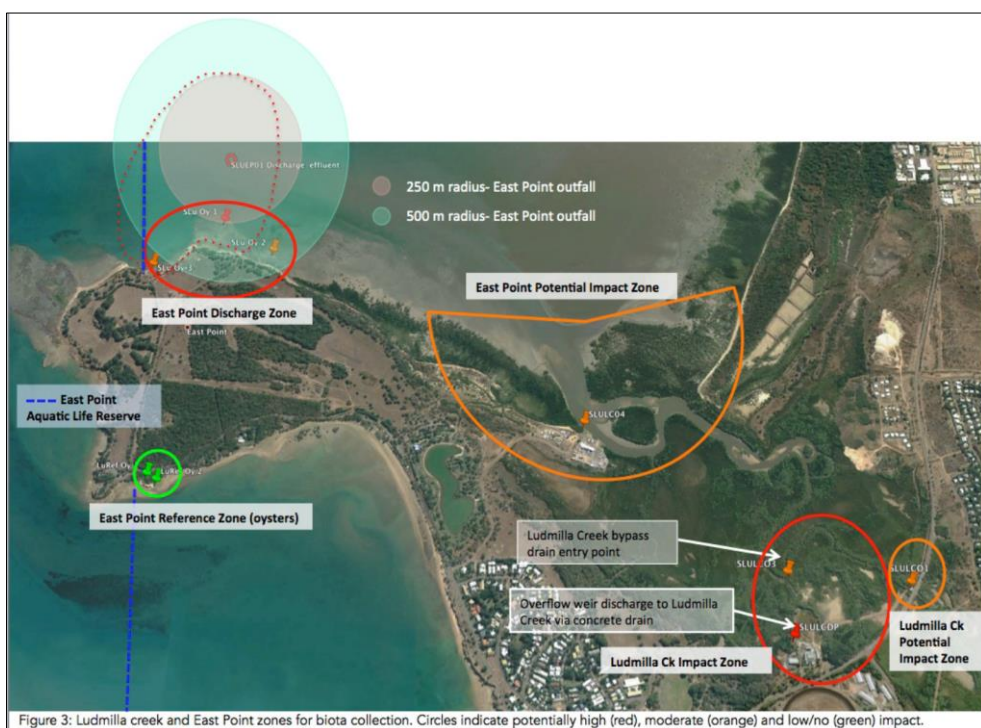


Figure 14: Ludmilla WwTP monitoring sites

The study investigated water, shellfish and mud crabs collected from receiving waters and reference sites (Figure 14), and the subsequent tests for faecal indicators and pathogens.

Concentrations of the faecal coliforms in water exceeded the Australia Shellfish Quality Assurance Program (ASQAP) trigger value for approved bivalve harvesting areas (ASQAP 2016) at 8 sites, including the

reference areas Rapid Creek, but not at the, East Point discharge zone or the East Point reference zone. In the 2015/2016 wet season, ASQAP trigger values were exceeded at 9 sites.

E. coli constituted most of the faecal coliforms at these sites except at the Ludmilla Creek impact (drain) site and Rapid Creek reference sites 12 (mouth).

During the dry 2015 and 2016 dry seasons lower faecal coliform concentrations were detected compared to the 2015/16 wet season except for the East Point potential impact zone where concentrations were 3 times higher than the previous wet season. At Rapid Creek, faecal coliform concentrations were lower than in the 2015/16 wet season but higher than the 2015 dry season.

E. coli concentrations in biota were all lower than the Australia New Zealand Food Standards Code (Microbiological Limits in Foods) acceptable level for *E. coli* in bivalve molluscs of 2.3 /g, with most below the limit of detection. No correlation was found between faecal coliform or *E. coli* concentrations in water and *E. coli* concentrations in biota.

Norovirus (genogroup II), *Salmonella* and *Bacteroides* were not detected in any biota samples. *Vibrio parahaemolyticus* and *V. vulnificus* were detected in 48% and 24% of biota samples respectively, which is less than for the previous wet season. Vibrios were more prevalent in the Ludmilla Creek/East Point and Rapid Creek samples, than at other creeks investigated in the program.

Of the 16 cooked crab samples, one was positive for *V. parahaemolyticus*.

Two virulent strains of *V. parahaemolyticus* were identified, one from a Rapid Creek *Telescopium telescopium* sample containing the *tdh* gene, and one from a *T. telescopium* sample from the Ludmilla Creek potential impact site (SLULC01) containing virulence genes, *tdh* and *trh*. Vibrios occur naturally in marine and estuarine water, but they can also be present in effluent and thrive in nutrient rich water.

Figure 15 displays water quality monitoring data from the 2015 and 2016 dry seasons and the 2015/16 wet season for all sites in the monitoring program. Only data relevant to Ludmilla discharge and the related reference sites will be discussed in this report.

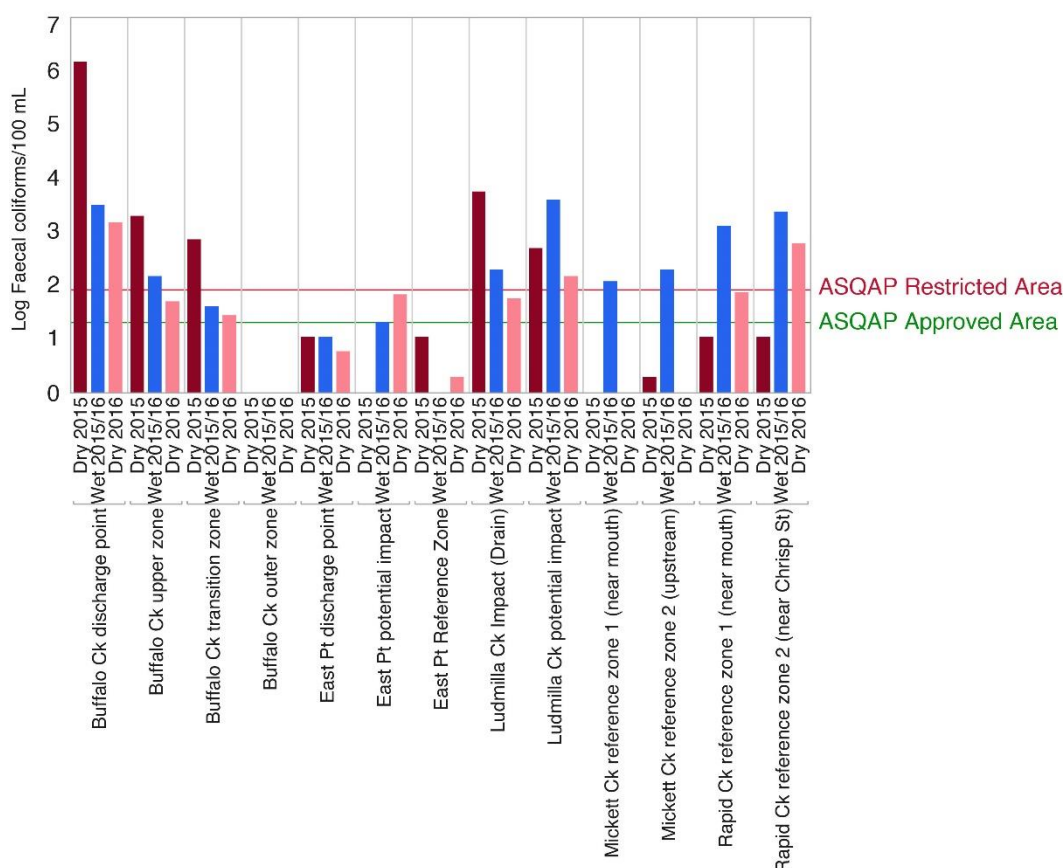


Figure 15: Faecal coliform concentrations in water samples across all sites during the 2015 dry season (■), 2015/2016 wet season (■) and 2016 dry season (■). (From Padovan 2016b)

During the recent 2016 dry season, all sites recorded lower faecal coliform concentrations compared to the previous wet season 2015/16 except for the East Point potential impact zone where concentrations were 3 times higher than the previous wet season. At the Rapid Creek sites, faecal coliform concentrations were lower than the previous wet season but higher than the 2015 dry season (Figure 15).

With *E. coli* accounting for a major component of faecal coliforms at all sites, the seasonal trends are very similar to that of the faecal coliforms.

The final report for the AQFMP identified that while the discharge from the various wastewater treatment plants may impact on the suitability of the environment for the protection of the declared beneficial use of the cultural use of aquatic foods however it also identified that for the Ludmilla treatment plant discharge to Ludmilla Creek the faecal coliform levels were not significantly different to the levels detected in reference creeks and that no impact was detected associated with the East Point Outfall. It is also clear that the treatment plant discharges are not the only factors that result in a high risk for this activity in Darwin's urban creeks as a number of the virulent pathogenic strains identified in the tissue of the aquatic food species occur naturally in the catchment and particularly in the wet season are present in the aquatic food collected.

At sites located further from effluent discharge, the concentrations of faecal coliforms (and *E. coli*) in water samples were lower in the 2015 and 2016 dry seasons in comparison to the 2015/16 wet season, indicating a seasonal affect. Nevertheless, faecal concentrations at eight out of thirteen sites this dry season were still above the ASQAP trigger value for bivalve harvest – these sites are in creeks and near urban areas, and include both Rapid Creek reference sites. Sites located in more open water and away from urbanisation had low faecal coliform concentrations including the East Point reference zone.

E. coli was rarely detected in biota samples during the 2015 and 2016 dry seasons, with no samples exceeding the ANZFS value.

There was no correlation between faecal coliform or *E. coli* concentrations in water and flesh, suggesting current ASQAP guidelines for water quality may not accurately reflect flesh quality. During the 2015 and 2016 dry seasons enterococci concentrations were below detection for *T. telescopium* collected in the Ludmilla Creek area.

The targeted pathogens associated with faecal pollution, salmonella and norovirus were not detected in any biota, suggesting they are present at very low concentrations in flesh, and/or are not accumulated by the shellfish tested.

Potential for Cu toxicity – Surface water

Bioavailable Cu-F exceeds the ANZG (2019) SMD chronic toxicity trigger value of 1.3 µg/L in discharge and within the immediate vicinity of the East Point Outfall; however following the 2013 upgrade to the treatment plant there has been a decrease in the copper loads discharged to the harbour.

Copper exposures are unlikely to be sustained over the long term based on the detection frequency or in the short-term across the course of the tidal cycle. Historically the discharge of treated wastewater was likely to be the dominant source of Cu to the Ludmilla Creek estuary. Marine fish and gastropods are considered relatively tolerant of copper while marine bivalves and invertebrates (crustaceans) are considered more sensitive. Because Cu is an essential trace element required by most aquatic organisms it can be a fine line between growth stimulation and potential for toxicity in some species and between potential for chronic and acute effects.

Table 17: 5 year pathogen risk assessment (April 2017 - April 2022)

Pathogen Indicators Water Quality Assessment									
parameter	E. coli		Enterococci	Likelihood		Hazard Consequence			Risk Rating
Unit	cfu/100 mL								
1 DHWQO Aquatic food 2 NHMRC primary contact recreation	14 ¹	43 ¹	40 ²						
Assessment criteria percentile	Aquatic food:		Primary Recreation	Aquatic Food collection and food production (aquaculture)	Primary Contact Recreation	Aquatic Food collection and production (aquaculture)	Primary Contact Recreation	Aquatic food collection and aquaculture	Primary Contact Recreation
	50th	90th	95th						
SLu080	24.0	2630.0	219.0						
SLuLC03 ²	25.0	94.0	190.0						
SLuLC01 ²	53.0	680.0	981.0						
SLuLC02 ²	63.0	1090.0	3430.0						
SLuLC04 ²	3.0	13.0	66.0						
SLuEP01 ¹ outfall	1.0	10.0	8.0						
SLuEP02 ¹	1.0	1.0	6.0						
SLuEP03 ¹	1.0	2.0	9.0						
Hazard Assessment for pathogen indicators (enterococci and E. coli). Assessment for the suitability of the waters for swimming and the collection of organisms for consumption and the use of the water for aquaculture.									
SLu080	1.7	61.2	5.5	Almost certain	Almost Certain	Moderate (GI illness requiring medical attention or hospitalisation)	> 10% Moderate (GI illness requiring medical attention or hospitalisation)	Extreme (no pathway for use)	Extreme (no pathway for use)
	Aquatic food	10 Recreation (swimming)							
Ludmilla Creek									
SLuLC03	1.8	2.2	4.8	Almost certain	Almost certain (Swimming rare)	Moderate (GI illness requiring medical attention or hospitalisation)	> 10% GI illness requiring medical attention or hospitalisation- moderate	High	Very High
SLuLC01	3.8	15.8	24.5						Very High
SLuLC02	4.5	25.3	85.8						
SLuLC04			1.7	Possible Risk <10%	Likely (Swimming rare)	Moderate (GI illness requiring medical attention)	> 10% GI illness requiring medical attention or hospitalisation- moderate	Moderate: high results following rain	Moderate: high results following rain
East Point Outfall									
SLuEP01				Unlikely	Possible	Minor (illness short term inconvenience)	<1% minor (illness short term inconvenience)	Low Sewerage outfall exclusion zone advice	Low
Darwin Harbour in the vicinity of East Point									
SLuEP02				Unlikely	Possible	Minor (illness short term inconvenience)	<1% minor (illness short term inconvenience)	Low	Low
SLuEP03				Unlikely	Possible	Minor (illness short term inconvenience)	<1% minor (illness short term inconvenience)	Low	Low

Table 18: 5 year toxicant risk rating (April 2017 - April 2022)

Toxicants Water Quality Assessment							
parameter	pH	NH3-N	Cu (D)	Zn (D)	Likelihood	Consequence	Risk Rating
Unit	pH units	µg/L	µg/L	µg/L			
DHWQO Outer Estuary ¹ Mid Estuary ²	7.0 - 8.5 ¹ : 6.5 - 8.5 ²						
ANZG level of species protection	7.0 – 8.5	910 - 2840 pH dependent	1.3 –SMD 3.0 –D* 8.0- HD	15- SMD			
Assessment criteria percentile	50th	95th	95th	95th			
SLu080*	8.13	41200.0	59.44	12.20			
Discharge to receiving waters: Ludmilla Creek , discharge upstream and downstream of discharge							
SLuLC01 ²	7.33	120.9	0.55	7.20			
SLuLC02 ²	7.48	71.2	1.10	3.05			
SLuLC03 ²	7.86	63.6	1.10	5.20			
SLuLC04 ²	8.10	20.0	1.00	6.00			
East Point Outfall within Darwin Harbour receiving waters							
SLuEP01 ¹ –outfall*	8.15	1997.0	2.15	5.00			
Darwin Harbour receiving waters							
SLuEP02 ¹	8.14	200.9	0.63	8.25			
SLuEP03 ¹	8.15	40.2	1.00	4.25			
Hazard Assessment:							
SLu080		82.7	7.4		Almost Certainly toxic Ammonia and copper	Toxicity confirmed by ecotoxicology testing. Localised within LWwTP Ammonia likely to be present as mono chloramines due chlorination of ammonia contaminated effluent and median pH 8.59.	Very high
Ludmilla Creek							
SLuLC01					Toxicity Unlikely	insignificant	Low
SLuLC02			0.8		Acute Toxicity Unlikely	Meets Cu 90% species protection	Medium
SLuLC03			0.8		Acute Toxicity Unlikely	Meets Cu 90% species protection	Low
SLuLC04					Toxicity Unlikely	insignificant	Low
East Point Outfall							
SLuEP01		3.3			Almost certain NH3 toxic levels Cu meet D; exceeds SMD levels	Moderate impact Localised to less than 250 m (verified by infauna monitoring)	high
Darwin Harbour in the vicinity of East Point							
SLuEP02					Toxicity Unlikely	insignificant	Low
SLuEP03					Toxicity Unlikely	insignificant	Low

Table 19: 5 year Nutrient risk rating (April 2017 - April 2022)

Nutrient Water Quality Assessment following commissioning of Ludmilla WwTP upgrade June 2014 onwards									
Indicator Type	Nutrient Indicators						Likelihood	Consequence	Risk Rating
parameter	FRP	TP	NH3-N	TN	NOx	Chl-a			
Unit	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L			
SSTV		20 ¹		270 ¹	17 ¹	2 ¹			
Outer Estuary ¹	5 ¹	30 ²	20	300 ²	20 ²	4 ²			
Mid Estuary ²	10 ²								
ANZG level of species protection	5	20	15	250	30	2			
Assessment criteria percentile	50 th	50 th	50 th	50 th	50 th	50 th			
Discharge point and treated effluent (receiving water quality guidelines is not directly applicable);Colour code for comparison: Compliant to ANZG 2000 and Darwin Harbour Water Quality Objectives (DHWQO): light green ≤ guideline; yellow exceeds DHWQO, not ANZG objectives; ANZG trigger values pale orange exceeds slightly to moderately (SMD); orange exceeds all objectives and disturbed (D) triggers.									
SLu080	716	1655	29400	37130	173.5	0.58			
Discharge to receiving waters: Ludmilla Creek , discharge upstream and downstream of discharge									
SLuLC01 ²	9	63	2.5	540	3	2.5			
SLuLC02 ²	12	71.5	2.5	500	1.5	2.655			
SLuLC03 ²	8	51.5	2.5	355	1.5	3.78			
SLuLC04 ²	5	37	2.5	255	1.5	0.72			
East Point Outfall within Darwin Harbour receiving waters									
SLuEP01 ¹ -outfall	8	64	439	940	5	0.58			
Darwin Harbour receiving waters									
SLuEP02 ¹	5	39	2.5	220	1.5	0.565			
SLuEP03 ¹	4	36	2.5	210	3	0.67			
Hazard quotient: Ratio of test statistics to guideline where < 1 indicates the assessment statistic is compliant with the guideline and > 1 indicates exceedance of the guidelines: Ranked by Green <1.0 Pink (low) ≥1.0 to ≤1.5; Orange (moderate) exceeds by a factor >1.5 to 10; Red (high) exceeds by factor >10							Hazard assessment risk of eutrophication		
SLu080	72	55	1470	124	9		Almost certain	Moderate impact low dissolved oxygen localised within the plant	high
Hazard Quotient Applied to Receiving Waters and Ludmilla Creek Discharge Point									
Hazard Quotient Applied to Receiving Waters: Ludmilla Creek									
SLuLC01		2.1		1.8		1.3	likely	Localised low DO may be natural	medium
SLuLC02	1.2	2.4		1.7		1.3			medium
SLuLC03		1.7		1.2			likely	Localised elevated chl-a and low DO	medium
SLuLC04		1.2					possible	DO above DHWQO range insignificant	low
Hazard Quotient Applied to Discharge at East Point Outfall									
SLuEP01		3.2	22.0	4.6			possible	Nutrients above DHWQO range no impact on Chl-a - insignificant	low
Hazard Quotient Applied to Receiving Waters - Darwin Harbour									
SLuEP02		2.0					possible	insignificant	low
SLuEP03		1.8					possible	insignificant	low

Table 20: Primary contact recreation risk rating, seasonal breakdown using Hazen percentiles

Enterococci Results sheet for Hazen calculator: Primary Contact Recreation Assessment Guideline Values : NHMRC Guidelines for managing risks in recreational waters 2010 95 th percentile values E. coli is not recommended as no causal link to illness risk. Primary contact defined as 10 minutes swimming with at least 3 full body immersions.						Guideline	Category			Illness Risk							
						< 40	A			Gastrointestinal illness (GI) <1%			Acute Febrile Respiratory illness (AFRI) <0.3%				
						41-200	B			GI 1-5%			AFRI 0.3 – 1.9%				
						201-500	C			GI 5-10%			AFRI 1.9-3.9%				
						>500	D			GI >10%			AFRI >3.9%				
Site	SLUEP01	SLUEP02	SLUEP03	SLUEP04	SLUEP05	SLUEP06	SLUEP07	SLUEP08	SLUEP09	SLUEP10	SLUEP11	SLUEP12	SLULC01	SLULC02	SLULC03	SLULC04	SLU080
Post Commissioning of LWwTP upgrade (June 2014-July 2019)																	
Number data points	103	103	103	103	103	103	103	103	103	103	103	69	113	not enough data	113	111	127
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	2	not enough data	0	1	0
Data maximum	880	100	19	25	32	20	23	18	13	4	6	9	9200	not enough data	2000	520	4300
Hazen result 95 th percentile (Full)	297	16.6	11.9	4.95	9.85	11.85	5.85	5.95	3.85	2.9	3.85	8.25	2770	not enough data	704	129.5	1980
Hazen result 95 th percentile (Wet)	310	9	12	13	27	16	7	11	6	3	4	7.35	3870	not enough data	908	176	1680
Hazen result 95 th percentile (Dry)	356	50.2	8.6	2	2	1	0	1	1	1	0.4	1	790	not enough data	158	16.8	2360
Period since last risk assessment (July 2019 - Current)																	
Number data points	29	27	27	27	27	27	26	26	26	26	26	26	27	28	27	29	28
Data minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	12.0	0.0	0
Data maximum	660.0	7.0	6.0	33.0	250.0	4.0	5.0	12.0	3.0	12.0	0.0	1.0	3.0	3900.0	3400.0	2900.0	66
Hazen result 95 th percentile	204.0	5.3	6.0	8.3	40.9	2.3	3.4	5.6	2.2	3.2	0.0	0.2	2.1	1263.0	1224.0	449.0	36.3
Dry Season Period since last risk assessment (July 2019 - Current)																	
Number data points	13	12	11	11	11	11	11	11	11	11	11	11	11	11	11	12	11
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	8	15	0	0
Data maximum	180	2	6	33	250	0	1	12	1	0	0	0	1	93	110	59	8
Hazen result 95 th percentile	178	2	6	31	238	0	1	11	1	0	0	0.0	1.0	92	109	57	7.9
Wet Season Period since last risk assessment (July 2019 - Current)																	
Number data points	16	15	16	16	16	16	15	15	15	15	15	15	16	17	16	17	17
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	26	12	17	0
Data maximum	660	7	6	4	4	4	5	4	3	12	0	1	3	3900	3400	2900	66
Hazen result 95 th percentile	510	6.5	4.5	3.4	3.7	3.4	4.5	3.5	2.8	9.3	0.0	0.8	2.7	2874	2632	1997	54

Table 21: Secondary contact recreation risk rating seasonal breakdown (indicative only) using Hazen percentiles

Enterococci Results sheet for Hazen calculator: Secondary Contact Recreation Assessment Guideline Values (NHMRC, 2019)								Meets all criteria									
								Median <230 org/100 mL									
								80th percentile (4 of 5 results) <450 org/100mL									
								Category B Water Quality NHMRC Guideline 95th%ile ≤200 org/100 mL									
Site	SLUEP01	SLUEP02	SLUEP03	SLUEP04	SLUEP05	SLUEP06	SLUEP07	SLUEP08	SLUEP09	SLUEP10	SLUEP11	SLUEP12	SLULC01	SLULC02	SLULC03	SLULC04	SLU080
Post Commissioning of LWwTP upgrade (June 2014-July 2019)																	
Number data points	103	103	103	103	103	103	103	103	103	103	103	69	113	not enough data	113	111	127
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	2	not enough data	0	1	0
Data maximum	880	100	19	25	32	20	23	18	13	4	6	9	9200	not enough data	2000	520	4300
Hazen result: Median	2	0	0	0	0	0	0	0	0	0	0	0	78	not enough data	50	7	8
Hazen result: 80th%ile	28.8	3.6	2.5	1	1	1	0.3	1	0.1	0.3	0	0	356	not enough data	124	26.1	360
Hazen Result 95th%ile	356	50.2	8.6	2	2	1	0	1	1	1	0.4	1	790	not enough data	158	16.8	2360
Period since last risk assessment (July 2019 - Current)																	
Number data points	29	27	27	27	27	27	26	26	26	26	26	26	27	28	27	29	28
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	8	12	0	0
Data maximum	660	7	6	33	250	4	5	12	3	12	0	1	3	3900	3400	2900	66
Hazen result: median	0.65	0	0	0	0	0	0	0	0	0	0	0	56.5	48	34	2.5	1.0
Hazen result: 80th %ile	1.0	0.1	1.0	1.1	0.1	0.3	0	0	0	0	0	0.1	93.9	160.0	61.1	12.9	27.0
Hazen Result 95th%ile	204	5.3	6.0	8.3	40.9	2.3	3.4	5.6	2.2	3.2	0	0.2	2.1	1263	1224	449	36.3
Dry Season Period since last risk assessment (July 2019 - Current)																	
Number data points	13	12	11	11	11	11	11	11	11	11	11	11	11	11	11	12	11
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	8	15	0	0
Data maximum	180	2	6	33	250	0	1	12	1	0	0	0	1	93	110	59	8
Hazen result: median	0.425	0	0	0	0	0	0	0	0	0	0	0	41	42	18.5	0	1
Hazen result: 80th %ile	0.7	0.3	0.6	1.3	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.3	75.2	62.7	37.4	4.6	27.4
Hazen Result 95th%ile	1.9	6	31	238	0	1	11	1	0	0	0	1	92	109	57	8	178
Wet Season Period since last risk assessment (July 2019 - Current)																	
Number data points	16	15	16	16	16	16	15	15	15	15	15	15	16	17	16	17	17
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	26	12	17	0
Data maximum	660	7	6	4	4	4	5	4	3	12	0	1	3	3900	3400	2900	66
Hazen result: median	0.9	0	0	0	0	0	0	0	0	0	0	0	64	70.5	42	3	4
Hazen result: 80th %ile Dry Season	1.7	0.3	1.0	1.3	1.3	1.0	0.0	0.5	0	0	0	0.6	502.0	489.0	81.2	24.6	44.0
Hazen Result 95th%ile	510	6.5	4.5	3.4	3.7	3.4	4.5	3.5	2.8	9.3	0	0.8	2.7	2874	2632	1997	54.4

Table 22: Cultural use of food pathogen risk rating seasonal breakdown using Hazen percentiles

Faecal coliforms (as E. coli) Results sheet for Hazen calculator: Guidelines for Cultural Use of Aquatic Food; food derived from aquaculture, recreational, commercial or indigenous food gathering									Meets Guideline Values (Water Quality Objectives for the Darwin Harbour Region – Background Document February 2010)								
									Median ≤14 org/100 mL								
									90 th percentile ≤43 org/100mL								
Site	SLUEP01	SLUEP02	SLUEP03	SLUEP04	SLUEP05	SLUEP06	SLUEP07	SLUEP08	SLUEP09	SLUEP10	SLUEP11	SLUEP12	SLULC01	SLULC02	SLULC03	SLULC04	SLU080
Post Commissioning of LWwTP upgrade (June 2014-July 2019)																	
Number data points	51	51	51	51	51	51	51	51	51	51	51	34	56	not enough data	56	55	63
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	not enough data	2	0	0
Data maximum	51000	2100	90	15	60	20	16	9	12	30	40	6	8000	not enough data	5600	310	160 000
Hazen result: Median	1.0	0	0	0	0	0	0	0	0	0	0	0	59.0	not enough data	26.0	3.0	15.0
Hazen result: 90 th ile	45.6	6.2	5.2	3.4	2.4	3.8	1.0	1.0	0.4	0	0	2.0	2130	not enough data	660	65	27 200
Post Commissioning of LWwTP upgrade (June 2014-July 2019)																	
Number data points	29	29	29	29	29	29	29	29	29	29	29	21	31	not enough data	31	31	31
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	not enough data	2	0	0
Data maximum	370	18	9	15	30	16	16	9	12	2	10	6	8000	not enough data	5600	310	160 000
Hazen result: Median	2.00	0	0	0	0	0	0	0	0	0	0	0	200	not enough data	35	5.0	4.0
Hazen result: 90 th ile	43.6	3.4	3.6	5.8	3	5.6	4.6	2.8	1.6	1	0.6	2	3880	not enough data	672	107	25000
Post Commissioning of LWwTP upgrade (June 2014-July 2019)																	
Number data points	22	22	22	22	22	22	22	22	22	22	22	13	25	not enough data	25	24	32
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	1	not enough data	4	0	0
Data maximum	51000	2100	90	10	60	20	2	1	0	60	40	1	500	not enough data	900	80	100 000
Hazen result: Median	0.5	0	0	0	0	0	0	0	0	0	0	0	15.0	not enough data	25.0	1.0	190
Hazen result: 90 th ile	238	8.6	9.1	1.3	0	1.0	0	1.0	0	0.3	0	1	80.0	not enough data	60.0	60.0	28800
Period since last risk assessment (July 2019 - Current)																	
Number data points	25	27	27	28	27	26	26	26	26	26	26	26	26	27	27	28	28
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	0
Data maximum	6200	5500	6	2.39	9	1	10	3	39	1	1	1	2	2800	2400	450	36
Hazen result: Median	2.0	0	0.6	0	0	0	0	0	0	0	0	0	42.0	50.0	24.5	4.5	41.0
Hazen result: 90 th ile	22.8	1.0	1.2	2.6	0	1.0	1.0	1.0	0	0	0	1.0	728	1040	97.6	20.5	220
Dry Season Period since last risk assessment (July 2019 - Current)																	
Number data points	13	10	10	12	10	10	10	10	10	10	10	10	10	10	10	11	10
Data minimum	2	0	0	0	0	0	0	0	0	0	0	0	0	1	2	6	0
Data maximum	6200	5500	2	0.69	9	1	0	1	1	1	1	1	1	740	72	90	22
Hazen result: Median	3.0	0	0.4	0	0	0	0	0	0	0	0	0	14	7	22	3	51
Hazen result: 90 th ile	2761	1.5	0.675999985	5	0	0	0.5	0.5	0.5	0.5	0.5	0.5	399	68.5	86.99999809	17.5	1639.998913
Wet Season Period since last risk assessment (July 2019 - Current)																	
Number data points	18	18	17	18	17	17	17	17	17	17	17	17	17	18	17	18	12
Data minimum	0	0	0	0	0	0	0	0	0	0	0	0	8	7	4	0	0
Data maximum	73	6	2.39	3	1	10	3	39	1	0	0	2	2800	2400	450	36	150
Hazen result: Median	2	0	1	0	0	0	0	0	0	0	0	0	75	94.5	26	4.5	22
Hazen result: 90 th ile	58	4.5	2.2	3.0	1.0	9.2	2.6	32.2	0.8	0	0	1.8	936	2130	124	20	90

Risk Characterisation

The highest ranked risk to environmental harm is the high risk to the well-being of humans from pathogens in the waterway with or without WwTP discharges. The Rapid Creek monitoring data confirms that it is unlikely that the suitability of Ludmilla Creek for primary contact recreation or for aquaculture and food collection can be significantly improved.

Ecosystem risks are ranked as medium and the hazards identified include ammonia, copper and Zinc as toxicants and nutrients levels promoting excessive phytoplankton growth.

Assessment procedure

In accordance with the procedure recommended by NHMRC 2008 the pathogen hazard quotient assessment used the Hazen method to calculate the 95th percentile; the same methodology was used to calculate the median and 90th percentiles for the assessment of the cultural uses of the collection of food.

Dissolved oxygen was assessed using both the 20th percentile and the 95th percentile of the data set to reflect the low and high values included in all the guidelines. All physico-chemical and nutrient indicator assessments were made by comparing the median values of the data set for nutrients to the DHWQO guideline (NRETAS 2010) and the 95th percentile of the toxicant data set to the ANZG guideline, using the data from the last 5 years of sampling

Pathogens

Pathogen indicators (*E. coli* and enterococci) results are outside the acceptable range for primary contact recreation (swimming) for all receiving water sites in the vicinity of discharge points. The East Point Outfall (SLuEP01) and all Ludmilla Creek sites (SLuLC01, 03 and 04) indicated a high hazard quotient for both *E. coli* and enterococci and SLuEP02 has a medium hazard quotient risk based on the enterococci results. Receiving water sites SLuEP03 to 06 and SLuEP08 all indicated a medium to low hazard for primary contact recreation.

The exposure pathway is weak for primary contact recreation however there is a hazard and a potential exposure pathway requiring further evaluation. Primary contact recreation is an unlikely use of the waters of Ludmilla Creek due the hazards associated with estuarine crocodiles; however, primary contact recreation in the vicinity of East Point is possible, although this is also subject to hazards associated with dangerous or venomous creatures (estuarine crocodiles and stingers). Contact recreation is not observed to be occurring at any point in the creek during routine monitoring.

The exposure pathway is weak for aquaculture however there is a hazard and a potential exposure pathway requiring further evaluation. The aquaculture beneficial use is declared for the area and while there is no aquaculture in the vicinity of the discharge there is an assessment criterion for water quality to protect shellfish for human consumption based on a median 14 org/100 mL and a 90th percentile of 43 org/100ml. This is exceeded at all sites within Ludmilla and Rapid Creeks and at the East Point Outfall however, reliable stocks of filter feeding shellfish are not present within the vicinity of East Point or Ludmilla Creek. There are no established guidelines for water quality to protect the harvesting of the estuarine gastropod *Telescopium telescopium* which is practised by the local indigenous community. The DHWQO objectives, based on the ANZECC guidelines for the harvesting of filter feeding shellfish have been applied as a conservative indicator of risk.

Concerns regarding water quality at Darwin Harbour beaches in 2010 prompted an investigation into the sources and pathways of bacteria affecting water quality on Darwin Harbour beaches and waterways (Campbell A. 2012). The key findings of the study were;

- There were no instances of gastrointestinal illness outbreaks in Darwin that can be linked to swimmer exposure to bacteria in beaches or waterways;
- Dangerous aquatic animals e.g. Box jellyfish and crocodiles pose a greater risk to people and have caused hospitalisation and death;
- People should be advised against swimming in urban areas in the days after heavy rainfall;
- People should avoid swimming next to stormwater drains or downstream of sewage outfalls, e.g. water volumes in stormwater drains pose a greater risk to people and have caused deaths ; and
- People should avoid putting their head under or swallowing the water if they are unsure of the quality.

The report indicates that with the exception of Rapid Creek, which includes some deep water holes, tidal creeks in Darwin Harbour are not considered recreational water bodies. Charles Darwin University researchers undertook bacterial source investigations which included monitoring of tidal creeks around Darwin Harbour and found them likely to be significant contributors to elevated bacteria levels recorded at the beaches where they discharge.

The nearest beaches to the East Point Outfall are East Point beach, the water quality at this beach is listed as good, with the possible impacts being from the adjacent toilet blocks and boats moored offshore. The second beach, Nightcliff beach, is listed as poor, with the assessment concluding that the poor water quality may be due to the impact of swimming pool backwash from the Nightcliff pool and potentially its proximity to Rapid Creek.

Supplementary assessment based on the aquatic foods monitoring program identified a poor correlation between water quality indicators (E. coli and enterococci) in the water column and the presence of either indicator species (E. coli) or genetic biomarkers of pathogenic species in the tissue of aquatic food species.

The report of the aquatic food monitoring program (Padovan and Gibb 2016) found that it was not possible to determine whether genetic biomarkers for *Vibrio* species containing virulence genes were due to catchment or effluent sources, irrespective of the source it suggests that in the wet season urban creeks, such as Micketts, Rapid and Ludmilla Creeks may not be suitable for primary contact recreation or for the collection of aquatic foods for human consumption.

Nutrients

Nutrients results indicate a high hazard quotient at the East Point Outfall (SLuEP01) for the nutrient indicators (FRP, TP, NH₃-N and TN) and a moderate to low hazard quotient for (FRP, TP and TN) at Darwin Harbour receiving water sites (SLuEP02 to 11). As a stressor, the approach is to identify the potential hazard and then determine whether local environmental factors result in the hazard translating into an environmental impact that poses a risk to the protection of the beneficial uses. In the case of Darwin Harbour, a nitrogen limited macro- tidal estuary, the exceedances of the nutrient stressor indicators does not translate into a hazard for the primary indicator, Chlorophyll-a (a measure of excessive phytoplankton biomass) or dissolved oxygen at any of the Darwin Harbour receiving waters monitoring sites, indicating that the hazard is not progressing to an environmental risk, as a link in the pathway for phytoplankton bloom development is not present.

Ludmilla Creek data indicates a moderate hazard level for nutrients (TP and TN) at the point where the bypass discharge drain enters the creek (SLuLC03) and a moderate hazard rating for the primary indicator chlorophyll-a, indicating that the pathway between the hazards associated with nutrient enrichment and excessive

phytoplankton growth is realised for the receiving waters where the bypass drain enters Ludmilla Creek. The Ludmilla Creek receiving waters upstream site (SLuLC01) has a moderate hazard rating for the nutrient indicators (TP, NH₃-N, TN and NO_x), however, the primary indicator chlorophyll-a is below the hazard assessment threshold. The Ludmilla Creek downstream site (SLuLC04) has a low hazard quotient rating for TN and is below the threshold for all other nutrient indicators.

Dissolved oxygen, the DHWQO range is 80 to 100% saturation low DO levels within Ludmilla Creek upstream (SLuLC01) and at the discharge point (SLuLC03) are identified as a moderate hazard.

All Darwin Harbour sites exceeded the DHWQO range but are within the ANZECC 2000 range for tropical estuaries. The upper range results are assessed as a low level hazard requiring no further evaluation as elevated levels are not associated with an elevated hazard rating from phytoplankton blooms (measured as Chl-a).

Approximately 80% of the total nitrogen discharge from the East Point Outfall is present as total NH₃-N. This represents all forms of ammonia and includes the mono-chloramine form which is not readily available to support plant growth.

Mangrove sediment

Monitoring of the sediments in the vicinity of the East Point Outfall and within Ludmilla Creek indicates that the mangrove sediments in the creek act as a net sink for dissolved inorganic nitrogen and particulate nitrogen (Alongi, 1996; SKM 2014).

Seagrasses

Benthic surveys have identified that there are several sparse seagrass beds within the vicinity of the East Point Outfall which colonise the tidal sand banks during the late dry season and are exposed on extremely low tides. Stable isotope analysis indicates that there is some uptake of sewage sourced nitrogen into the seagrass (AIMS 2014).

Exchange of marine waters

Typically, moderate quantities of nitrogen are exported to the marine environment due to the large exchange of seawater and lack of a constricted entrance. Export is more significant during extreme flood events, when large quantities of total nitrogen and other organic material are moved offshore. This assists in limiting the environmental impact in the inshore waters.

Toxicants

The risk assessment identifies three toxicants of concern in the discharge, ammonia, copper and zinc. These results are consistent with the findings of the multi species ecotoxicology assessment undertaken in 2018. (van Dam 2018).

The findings of this assessment show a vast improvement over the prior study completed in 2014 (Ecotox. Services Australasia 2014).. While the effluent, collected from monitoring site SLu080, proved toxic to all bar 1 tested bioassay, the dilution factor required to ensure a 99% species protection has reduced from 1:122 to 1:26. This indicates the discharge has reduced in toxicity by up to 5x. The organisms tested displayed sensitivity to copper zinc and ammonia.

The PWC Darwin Harbour monitoring program data indicates that a 1:200 dilution is achieved for both copper and ammonia by monitoring site SLuEP02, indicating a low risk beyond the immediate discharge point at the East Point Outfall.

The monitoring data indicates that mixing and dilution in Ludmilla Creek is less effective and consequently during discharges to the creek the level of species protection is reduced in the immediate vicinity of the discharge drain's entry to the creek. As a more persistent toxicant elevated levels of copper may result in a lower level of species protection within the creek.

Exposure point concentrations have been derived to better estimate the likelihood of toxicity occurring after discharges to Ludmilla Ck. Since discharges are so rare, gaining an accurate profile during or immediately after a discharge is difficult and so a conservative dilution of 5 is applied to maximum outlet concentrations from the plant SLu080 to simulate the possible concentrations at SLuLC03 during dry season discharges (SLR 2021)

Analyte	SLuLC03 Dry season measured maximum	SLu080 (Discharge) Dry season measured maximum	SLuLC03 dry season estimate during discharge
NH₃-N (mg/L)	0.069	52	10.4
Bioavailable Copper (µg/L)	3	76	15.2
Bioavailable Zinc (µg/L)	16	16	3.4

Ferric sulphate is added in the treatment process to assist with sedimentation, total iron is elevated in the discharge indicating the need for further assessment of the risk, however, the assessment of the filtered (bioavailable) fraction indicates iron in receiving water samples to be below the hazard threshold at all Darwin Harbor sites, including the East Point Outfall and is not considered to be an environmental risk. The elevated iron at the Ludmilla Creek sites is considered to be from sources other than the LWwTP such as naturally occurring iron in sediments as the up and downstream sites are higher than the bypass discharge point.

Ammonia

Ammonia as a toxicant is indicated as a high hazard level in the undiluted effluent (SLU080) and a moderate hazard in the receiving waters at the East Point Outfall (SLuEP01) and at the bypass drain entry into Ludmilla Creek (SLuLC03).

As a chlorinated discharge it is expected that the majority of the total ammonia measured in the discharge is in the form of chloramine species. As the pH of the discharge is close to pH 8 (median 7.99) and the receiving waters for the Darwin Harbour are above pH 8 the major species of chloramine present will be in the form of mono-chloramine. Mono-chloramine is an effective disinfectant and toxicant however it requires a longer contact time for effect compared to chlorine or ammonia.

Chloramines are less toxic than either the ammonia or chlorine species however their persistence makes them a more effective disinfectant with lower risks in relation to public health or occupational health and safety. The key toxicants identified copper and the non-metallic inorganic toxicant ammonia which is likely to be largely present in the form of mono chloramine due to the ammonia rich sewage. Investigations have found no evidence of petroleum hydrocarbons, polycyclic aromatic hydrocarbons, pesticides or herbicides in the discharge.

The following table is taken from SLR 2021 - -Ludmilla Creek WwTP Ecological Risk Assessment and addresses the likelihood of direct toxic effects of Ammonia on preceptors in the Ludmilla Ck catchment

Table 23: Likelihood of ammonia toxicity within Ludmilla Creek - SLR 2021

Receptor	EPC ¹	Criteria ²	Likelihood of direct toxic effects
<u>Aquatic receptors</u>			
Plants	Dry season discharge 10.4mg/L NH ₃ -N	1.2mg/L NH ₃ -N	Possible. ANZG (2018) states that plants are more tolerant to ammonia than other organisms. Toxicity of ammonia to plants will likely occur at concentrations >7.7 mg/L (lowest LC ₅₀ from Level 3 toxicity assessment). This is supported by research by Korner et al.(2001) that showed zero growth in freshwater duckweed after a 14 day exposure to 8 mg/L NH ₃ -N in sewage. Therefore, short term exposures (i.e. <24 hours) are unlikely to result in adverse impacts on marine plants. This is supported by the Chl-a concentrations at SLuLC03 which show that the growth of microalgae is not adversely impacted at that location (Burford et al. 2012).
Invertebrates			Possible. Toxicity data in Level 3 Toxicity assessment indicates that an ammonia concentration of 7.7 mg/L NH ₃ -N can result in 50% mortality after 48 hours exposure to a sensitive mollusc species. However, as dry weather discharges are generally less than 24 hours, acute toxicity may not occur.
Vertebrates (Fish)			Possible. Toxicity data in Level 3 Toxicity assessment shows that an ammonia concentration of 8.8 mg/L NH ₃ -N can result in a 50% mortality after 44 hours exposure to sensitive fish species. However, as dry weather discharges are generally less than 24 hours, acute toxicity may not occur.
Vertebrates (Avian)			Negligible. Migratory shorebirds are known to frequent Ludmilla Creek downstream of monitoring site SLuLC04 as discussed in Table 9. The maximum ammonia concentration at that site was measured at 0.119 mg/L NH ₃ -N in the dry season and 0.83 mg/L NH ₃ -N in the wet season. Both concentrations are below the screening criteria. The concentration of ammonia in any dry season discharge is likely to be lower at SLuLC04 than SLuLC03 due to mixing with Ludmilla Creek water and therefore will also be below the screening criteria. The sediment and pore

			water results for SLuLC04 support this conclusion (Appendix 8)
Terrestrial receptors			
Vertebrates (Reptiles)	Dry season discharge 10.4mg/L NH ₃ -N	1.2mg/L NH ₃ -N	Negligible. If aquatic invertebrate prey are adversely affected as discussed above, reptiles will be able to move to an area that has not been impacted by the discharge to obtain prey.
[1] – Exposure point concentrations discussed in Toxicity assessment			
[2] – Site Specific Trigger Value from WDL 150-08			

Copper

Copper as a toxicant is assessed as a moderate hazard in the Darwin Harbour receiving waters at the East Point Outfall (SLuEP01) and also at the most downstream site in Ludmilla Creek (SLuLC04). As upstream sites in Ludmilla Creek are below the hazard threshold this may indicate that following heavy rain impacting on site SLuLC04 sources other than the LWwTP discharge may contribute to an increase in the hazard rating.

Table 24: Likelihood of copper toxicity in Ludmilla Creek - SLR 2021

Receptor	EPC	Criteria ¹	Likelihood of direct toxic effects
Aquatic receptors			
Plants	Dry season 3µg/L Dry season discharge 15.2µg/L	1.3µg/L	Low. The dry season maximums are only slightly above the screening criteria with a median of 0.5 µg/L during the dry seasons. Unicellular algae can be sensitive to copper, however, the Chl-a concentrations (Table 17) indicate that unicellular algae are present at SLuLC03 where the presence of nitrogen may be acting as a nutrient, promoting algal growth as evidenced by the 2018 ecotoxicity tests (Table 5). Adverse impacts from short-term exposure to the estimated dry season discharge copper concentration is unlikely since toxicity observed at these low concentrations were the result of long-term exposures (e.g. unicellular alga 5 day exposure day (ANZG 2018)) (see Level 3 Toxicity assessment).
Invertebrates			Low – dry season discharge. The dry season maximum is only slightly above the screening criteria with a median of 0.5 µg/L during the dry seasons, therefore risks of harm during the dry season are considered low. Annelids do not exhibit adverse effects from copper exposures at the

			measured and estimated concentrations, however crustaceans and molluscs are sensitive to long-term exposures (ANZG 2018). Likelihood of adverse impacts from the short-term exposure to the estimated dry season discharge copper concentration is low since toxicity observed at these concentrations were the result of long-term exposures (crustaceans 10-14 days and molluscs 30 day (ANZG 2018)) (see Level 3 Toxicity assessment).
Vertebrates (Fish)			Negligible. The dry season maximum is only slightly above the screening criteria with a median of 0.5 µg/L. Fish do not exhibit adverse effects from copper exposures at these low concentrations (ANZG 2018). Adverse effects from short-term exposure to the estimated dry season discharge copper concentration are unlikely since the lowest concentrations that can cause toxicity to fish are higher (>30 µg/L) than the estimated discharge (15.2 µg/L) and occurred after longterm exposures (fish 5-28 days on sensitive life stages (ANZG 2018)) (see Level 3 Toxicity assessment). In addition, pelagic fish are able to swim away from unfavourable water quality and obtain prey organisms elsewhere.
Vertebrates (Avian)			Negligible. Migratory shorebirds are known to frequent Ludmilla Creek downstream of monitoring site SLuLC04 as discussed in Table 9. The maximum copper concentration at that site was measured at 1.0 µg/L in the dry season and the wet season. Both concentrations are below the screening criteria. The concentration of copper in any dry season discharge to the creek is likely to be lower at SLuLC04 than SLuLC03 due to mixing with Ludmilla Creek water and will also be below the screening criteria. The sediment and pore water results for SLuLC04 support this conclusion (Appendix 8)
<u>Terrestrial receptors</u>			
Vertebrates (Reptiles)	Dry season 3µg/L Dry season discharge 15.2µg/L	1.3µg/L	Negligible. If aquatic invertebrate prey are adversely affected as discussed above, reptiles will be able to move to an area that has not been impacted by the discharge to obtain prey.

[1] – 95% species protection (ANZG 2018)

Many toxicants reaching estuaries have a high affinity for fine-grained sediment. The concentrations of some toxicants are therefore controlled to a certain extent by processes governing sediment transport and deposition. In tide-dominated waterways (e.g. deltas, estuaries and tidal creeks), flanking environments are the main traps for fine sediments, and these include mangroves, saltmarshes and intertidal flats. Sediment monitoring in Ludmilla Creek and at East Point has found no evidence of elevated levels of contaminants other than nutrients.

Modelling undertaken in 2012 indicated that for an atypical (95th percentile) discharge the impact zone for copper, as a conservative tracer to return to background is a zone that reaches to within the boundary of the East Point Aquatic Life Reserve, (see Figure 16). This modelling was based on the discharge quality prior to the upgrade of the treatment plant and more recent monitoring indicates the impact zone is most likely to have reduced to within 250 metres.

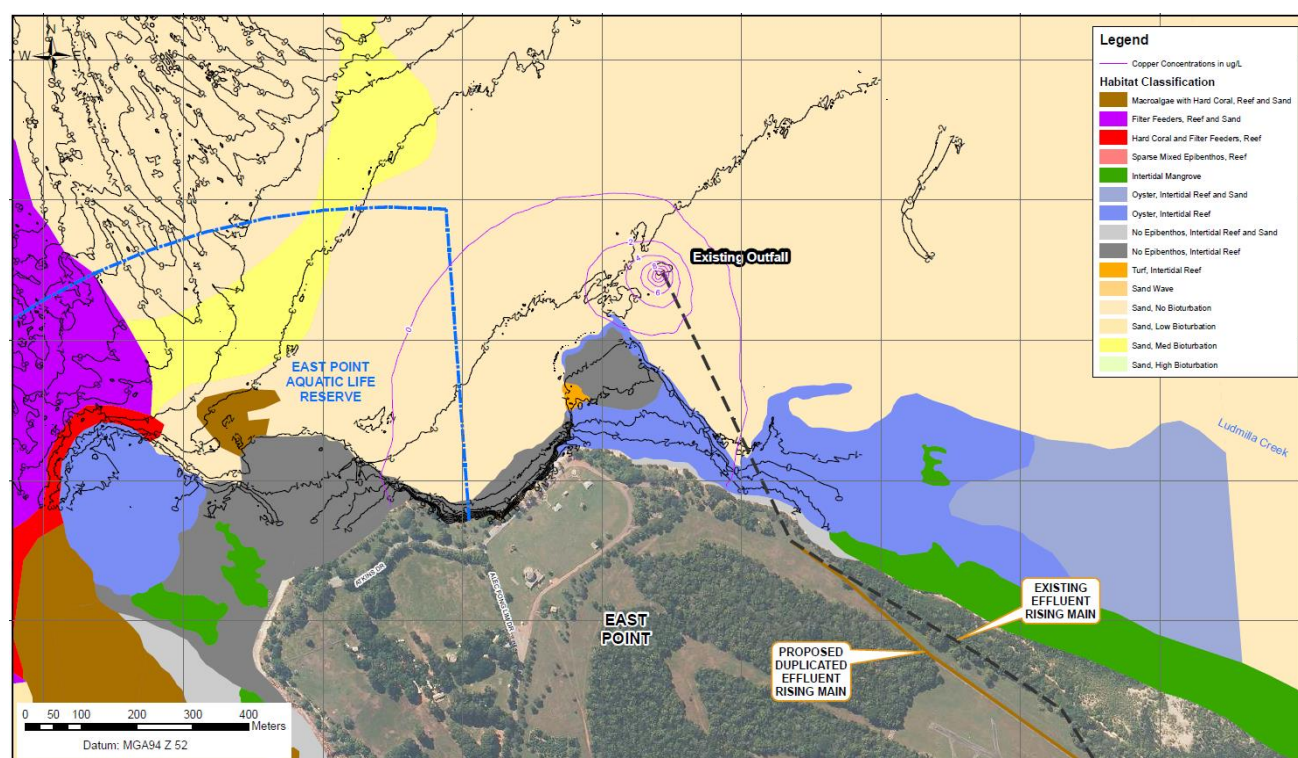


Figure 16: LWwTP Modelled impact zone for copper (atypical discharge)

Zinc

Although bioavailable zinc does have the propensity for toxicity in many of the organisms found in the vicinity of the EPO, the available water quality data shows it does not come in sufficient quantities to have a lasting impact. Coupled with the immediate dilution of the discharge, it is apparent the risk the LWwTP discharge poses to the surrounding environment in terms of zinc toxicity is negligible. This assertion is echoed by the Ludmilla Creek WwTP Ecological Risk Assessment completed by SLR:

“The maximum zinc concentration measured during the dry season at the Ludmilla Creek downstream site, SLuLC03, was the same as the maximum measured at the upstream site, SLuLC01 and the estimated zinc concentration in the dry season discharge is below the selected criteria (Table 5-5). Therefore, it is unlikely that zinc concentrations measured downstream in Ludmilla Creek are directly linked to the discharge from the LWwTP. Consequently, the risk of exposure of ecological receptors to zinc from the LWwTP is negligible. Furthermore, adverse effects from exposure to zinc originating at upstream sites by downstream ecological receptors are considered unlikely to occur since concentrations of zinc causing toxicity in marine species range from 190 µg/L (fish) to 320,000 µg/L (mollusc) (ANZG 2018). These concentrations are much higher than the measured and estimated maximum EPCs in this ERA (i.e. 3.4-16 µg/L).” – SLR 2021

Discharges to Ludmilla Creek

Ludmilla Creek receives inputs from a number of sources including the bypass discharge from the LWwTP, runoff from the Darwin Turf Club and Spot-On Marine which is located downstream of the drain receiving the LWwTP discharge and upstream of the Ludmilla Creek sampling site SLuLC04.

Preliminary modelling of the impact zone using copper as a conservative tracer and an atypical (95th percentile discharge) continuous for more than three days to Ludmilla Creek indicate that the zone of influence for a substantial dry season discharge to Ludmilla Creek would have a zone of influence reaching upstream of Dick Ward Drive (PWC monitoring site SLuLC01) and downstream into Darwin Harbour close to the East Point Outfall, this takes in the area covered by PWC monitoring sites SLuLC01, SLuLC03 and SLuLC04.

Figure 17 indicates a worst case scenario for pathogen indicators relating to an atypical discharge on an incoming spring tide during the dry season, while there is limited information on flow rates within the creek on tides greater than 6 metres there is movement upstream beyond Dick Ward Drive and therefore the potential for movement of contaminants both up and downstream from the discharge point, which is represented as the red section in Figure 17. The figure uses the distribution of copper (a conservative tracer) and a similar distribution pattern is likely for the distribution of pathogens and nutrients. The upgrade of the hydraulic capacity of the East Point rising main indicates that such a discharge is highly unlikely (rare) occurring on less than a once in 10 year frequency (Figure 17), however the impact of the entire discharge being directed to Ludmilla Creek for a number of days would have a widespread impact within Ludmilla Creek that may result in temporary damage and would most likely result in considerable community concern however the impact would moderate over time (Table 22) resulting in a medium level risk (level 8).

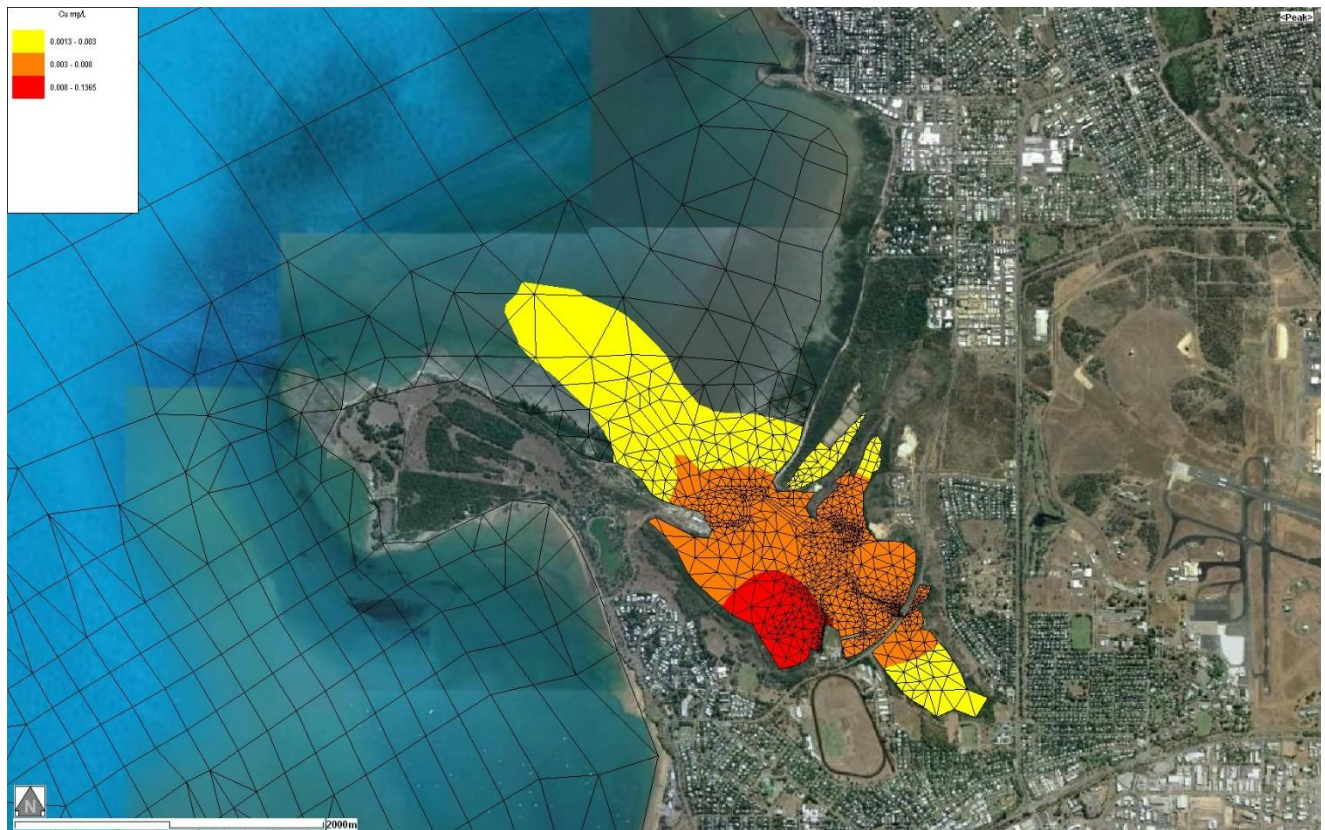


Figure 17: Atypical bypass discharge to Ludmilla Ck (Proudfoot et al 2012)

Discharges of Emerging Chemicals of Concern (PFAS/PFOS)

The location of Rapid and Ludmilla Creeks with the Darwin RAAF base and Darwin Airport in the upper catchments indicate the potential for a contaminant pathway. Investigations conducted for the Northern Territory Department of Health (Munksgaard N. C et. al. 2017) found that per and poly fluoroalkyl substances (PFAS) were present in aquatic foods

4. Risk Mitigation and Further Actions

- Following commissioning of the augmented East Point rising main, the majority of the Ludmilla WwTP discharge is via the East Point Outfall 97.6% of the total discharge and 100% of the dry season discharge, the exception is during high flow (wet season) events. However the impact of the wet season water quality associated with the LWwTP discharges and catchment inputs on the suitability of the creek for the declared beneficial uses is evident in the risk assessment.
- To more fully characterise the impacts to Beneficial Uses of Ludmilla Creek associated with the discharge PWC has developed further understanding of the risks associated with recreational and human consumption of aquatic food collection uses of the receiving environment through the aquatic foods investigations. This program indicated that the Ludmilla WwTP posed a low risk to the collection of aquatic food however the water quality in the urban creeks such as Ludmilla Creek is generally not suitable for the protection of this Beneficial Use.
- The upgrading of the Ludmilla WwTP has increased the plant's capacity through the expansion of the existing CAS process with dedicated coagulation and flocculation facilities with sufficient design capacity for

projected demand growth to 2030. The upgraded plant has a treatment capacity of 5 times average dry weather flow (ADWF) which has reduced the occurrence of discharge to Ludmilla Ck. The increased capacity has reduced the risk of the 90th percentile limits being breached other than exceptionally wet years.

- Commissioning of the upgraded LWwTP commenced in early 2013 and was completed in mid-2014; monitoring data from June 2014 onwards indicates that there has been an improvement in the quality of the discharge following the commissioning however the updated risk assessment uses data from the completion of the commissioning of the upgraded treatment process in May 2014 to July 31 2018.
- To accommodate the increased discharge requirements the augmentation of the East Point Rising Main was the subject of a Public Environmental Report. The construction works, completed in the second half of 2014 were followed by a commissioning phase requiring Commonwealth Department of Environment approval of monitoring and management plans for receiving water quality and benthic infauna protection, designed to ensure the protection of listed species.
- Augmentation of the East Point rising main has resulted in a decrease in the volume of wastewater discharged to Ludmilla Creek, with an increase in hydraulic capacity to approximately 800 L/sec which remains below the design expectation of 1000 L/sec.
- Monitoring data from Rapid Creek indicates that removing the Ludmilla WwTP discharge from Ludmilla Creek to other than extreme rainfall events is unlikely to result water quality suitable for the protection of all the declared Beneficial Uses of the creek and that a significant improvement in the hazard classification for Ludmilla Creek to suitable for primary contact recreation or for aquaculture and food collection is unlikely as catchment and effluent discharges both contribute to the poor water quality in the creek.
- Since 2008 an exclusion zone has existed under Section 5A of the Port Services Act, this is in the vicinity of the East Point Outfall. Signage is in place to advise the community.
- Signage warning of the potential for the Ludmilla WwTP to discharge treated effluent to Ludmilla Creek has been installed at the unofficial boat ramp (Colivas Road). The signs advise the community of the presence of the discharge and warn against the collection of shellfish and swimming or paddling in waters affected by the discharge.
- PWC has installed the signs and advised community members via portable signage when discharges occur and a community engagement strategy advises key users of the creek of the risks associated with collection of food following discharges to the creek. While swimming is not a common occurrence in Ludmilla Creek, secondary contact due to fishing, bait collection and the collection of mud crabs and molluscs including pipis and Telescopium spp is common and as children may be involved immersion contact is possible.
- Further risk mitigation can only be achieved through significant changes to treatment within the plant (to reduce ammonia) or relocation of the East Point Outfall to a sub-tidal location, although the latter has been investigated and since been abandoned.
- Ongoing water quality sampling of the environmental sites in Ludmilla creek and East Point will ensure any concerning trends in water quality can be addressed as they arise and the risk be adjusted accordingly
- This environmental assessment was conducted in response to Condition 30 of WDL150-08 which required the existing risk assessment to be updated a minimum of 60 Business days prior to the end of the licence, the previous assessments have been supplemented with additional information and data collected in the current licence period.

SLR 2021 has recommended, based upon the findings regarding Ludmilla Ck, some amendments to the current WDL:

Condition 20 in WDL 150-08 currently states:

“Discharges from Authorised Discharge Point SLuLCDP must only occur when average inflows to the WwTP during the discharge period to SLuLCDP exceed 1000 L/second during wet weather events”

The results of water quality monitoring in Ludmilla Creek during the wet season presented in this ERA show that maximum CoPC concentrations measured during discharges to the creek are unlikely to pose a risk to the ecology of Ludmilla Creek, however, dry weather discharges should be allowed for in the WDL.

Recommended wording for Condition 20 for WDL 150-09:

Discharges during the wet season from Authorised Discharge Point SLuLCDP must only occur when outflows from effluent pumps are above 750L/s and/or east point influent pumps are engaged.

Recommended to change Site specific trigger values for SLuLC03 (Ludmilla Ck Discharge point) to account for the upstream influence (calculate based on water quality dta from SLuLC01 & 2).

Recommend to remove SSTVs altogether for SLuLC01 & 2 due to the influence of the catchment on those sites.

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6. Appendices

Appendix 1: Power and Water's Corporate Risk Assessment Methodology

Table 25: Power and Water's Consequence Assessment Matrix

Area of Impact	Impact Rating				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Severe (5)
Health & Safety	Minor event with or without injury; and/or No on-going impact to health.	Injuries requiring first aid treatment; and/or Minor short term inconvenience.	Medical Treated injury; and/or Short term reversible disabling effect to human health; and/or Lost Time Injury <1 week lost.	Hospitalisation; and/or Injuries resulting in Lost Time Injury > 1 week lost; and/or Long term (chronic) chemical health exceedance or short term chemical exceedance of chemical with acute health impacts; and/or Long term aesthetic exceedance with health impact on supply.	One or more fatalities; and/or One or more persons seriously injured (includes long term disabling effect); and/or Widespread release of untreated water (eg due to disinfection failure).
Financial (Impact on EBITDA)	Loss less than \$500K.	Impact between \$500K-\$2M.	Impact between \$2m-\$10m.	Impact between \$10m-\$40m.	Impact greater than \$40m.
Legal/ Regulation	Legal issues managed by corporate procedures or practices; and/or Breach of internal policies or procedures without the need for formal investigation.	Matter requires legal advice to address issues; and/or Internal breach of policies or procedures requiring a formal investigation.	Required to operate under limited regulatory restrictions or orders; and/or Incident which requires legal representation resulting in court proceeding.	Required to operate under significant regulatory restrictions or orders; and/or Government inquiry/ intervention.	Criminal charges / civil litigation against the Corporation and/or Officers; and/or Operating licences revoked.

Area of Impact	Impact Rating				
Environmental	Localised low level damage controlled but no remedial action required.	Localised low level damage controlled and remedied with minimal resources.	Widespread temporary damage with extended resources to remedy.	Long-term detrimental effect on environment and once controlled results in minor permanent damage.	Substantial permanent damage to widespread and sensitive areas.
Service Delivery (external customers only)	Category 1 loss of service (refer to Appendix C of ERM Standard).	Curtailment or loss of service, restored within expected timeframes (<=2 hours). Category 2 loss of service (refer to Appendix C of ERM Standard).	Short term curtailment or loss of service outside of expected timeframes (<=12 hours). Category 3 loss of service (refer to Appendix C of ERM Standard).	Long term curtailment or loss of service with extended resources required to remedy (>12 hours< 24 hours). Category 4 loss of service (refer to Appendix C of ERM Standard).	Complete and indefinite loss of service (=>24 hours). Category 5 loss of service (refer to Appendix C of ERM Standard).
Reputation	No media attention; and/or Isolated community or individual issue-based concern; and/or Localised dissatisfaction which is managed by normal business processes; and/or Short term aesthetic exceedance.	Occasional once-off negative media attention; and/or Localised community impacts and customer concerns; and/or Localised staff dissatisfaction which requires Human Resources in resolution; and/or Long term aesthetic exceedance.	Brief adverse media attention and/or community/customer condemnation (days); and/or Limited, localized loss of confidence by the community; and/or Localised staff dissatisfaction with localised impacts to service deliver; and/or Short term chemical health exceedance.	Prolonged adverse media attention and/or community/customer condemnation (weeks); and/or Prolonged, widespread community/ customer loss of confidence (weeks); and/or Widespread dissatisfaction and loss of confidence by staff resulting in temporary service delivery issues.	Sustained adverse media attention and/or community/customer condemnation (months); and/or Irreconcilable community/ customer loss of confidence; and/or Loss of stakeholder confidence in Board and/or Management; and/or Widespread dissatisfaction by staff resulting in sustained service delivery issues.

Table 26: Likelihood Assessment Matrix

Likelihood rating	Expected Likelihood	
(E) Almost Certain	Event is expected to occur on a regular basis. One or more times per annum.	Not Applicable
(D) Likely	An event is expected to occur from time to time. Once every 1 – 3 years	Probability of occurring is greater than 33%
(C) Possible	An event should occur at some time. Once every 4 – 10 years.	Probability of occurring is greater than 10% up to 33%
(B) Unlikely	An event could occur at some time. Once every 11 to 30 years	Probability of occurring is greater than 3% up to 10%
(A) Rare	An event not expected but possible. Less than once in 30 years	Probability of occurring is up to and including 3%

Table 27: Risk Rating Matrix

Consequence					
Likelihood	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Severe (5)
Almost Certain (E)	Medium	High	Very High	Extreme	Extreme
Likely (D)	Low	Medium	High	Very High	Extreme
Possible (C)	Low	Low	Medium	High	Very High
Unlikely (B)	Low	Low	Medium	High	High
Rare (A)	Low	Low	Low	Medium	Medium

Appendix 2: Monitoring Site Locations



Figure 18: Sampling locations used for WDL Monitoring

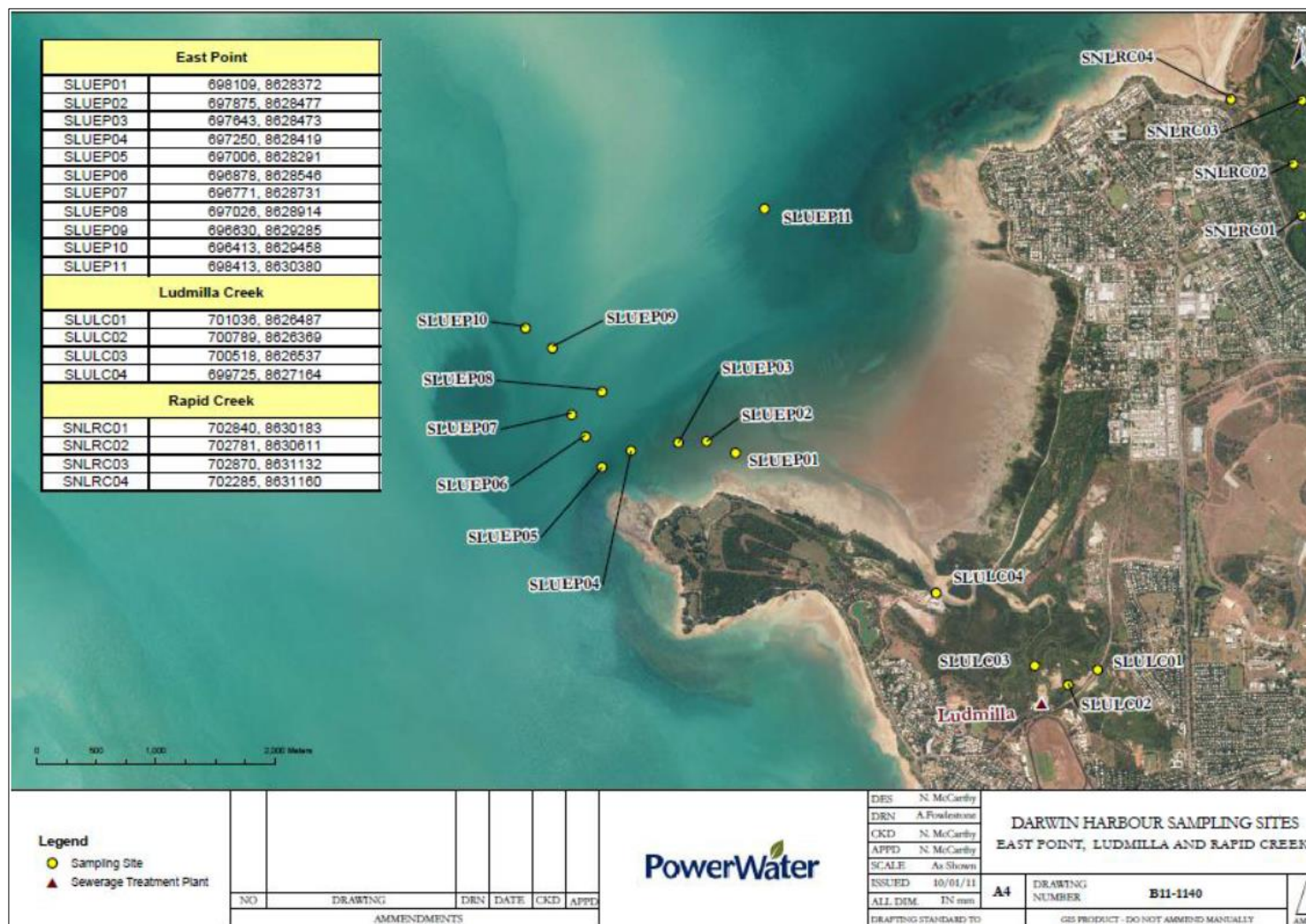


Figure 19: Expanded set of sampling locations

Appendix 3 Conceptual Site Model: Receptor Identification

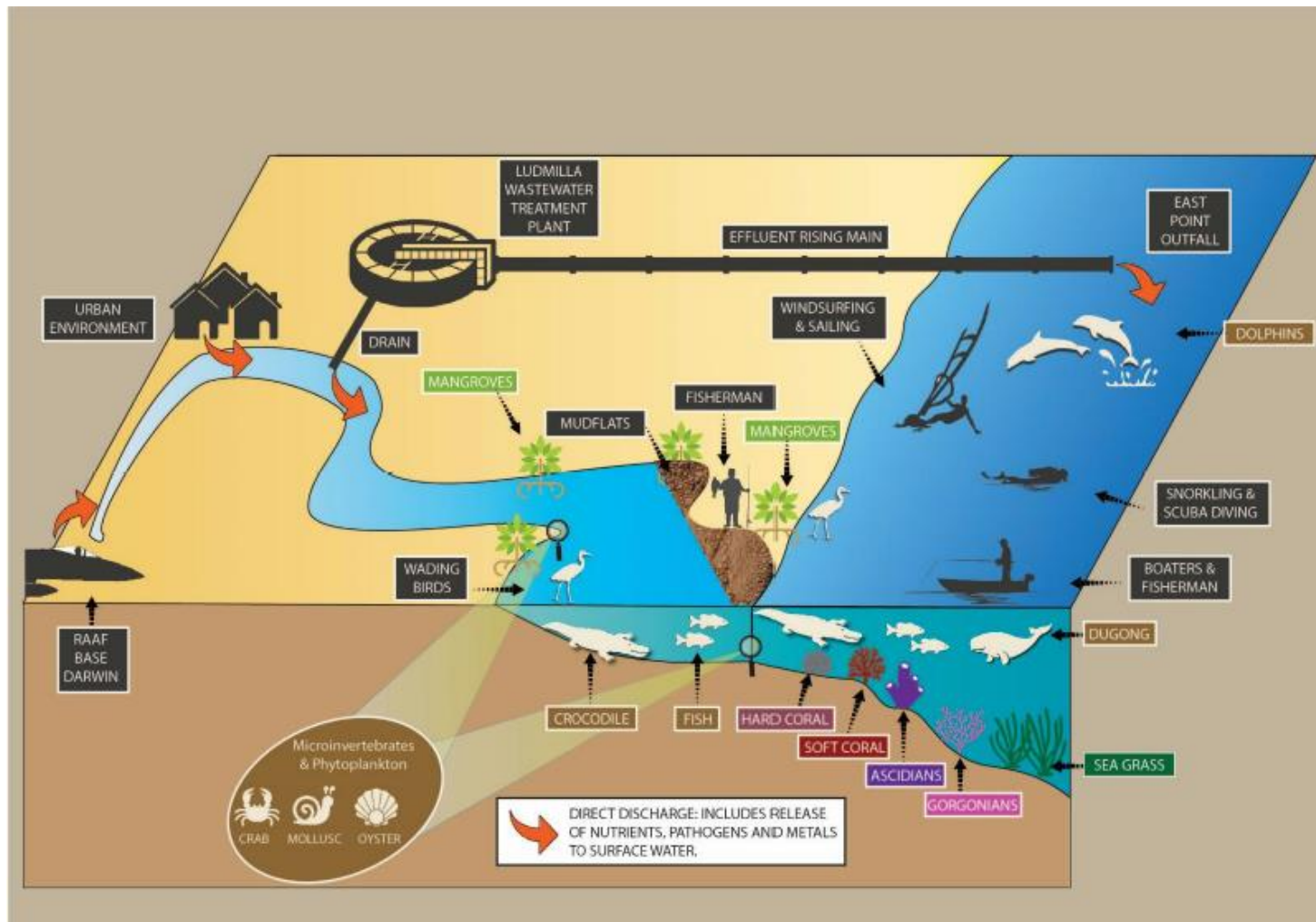


Figure 20: Conceptual model of the LWwTP and receiving environment

Appendix 4: Trophic Model and Fish Dietary Composition

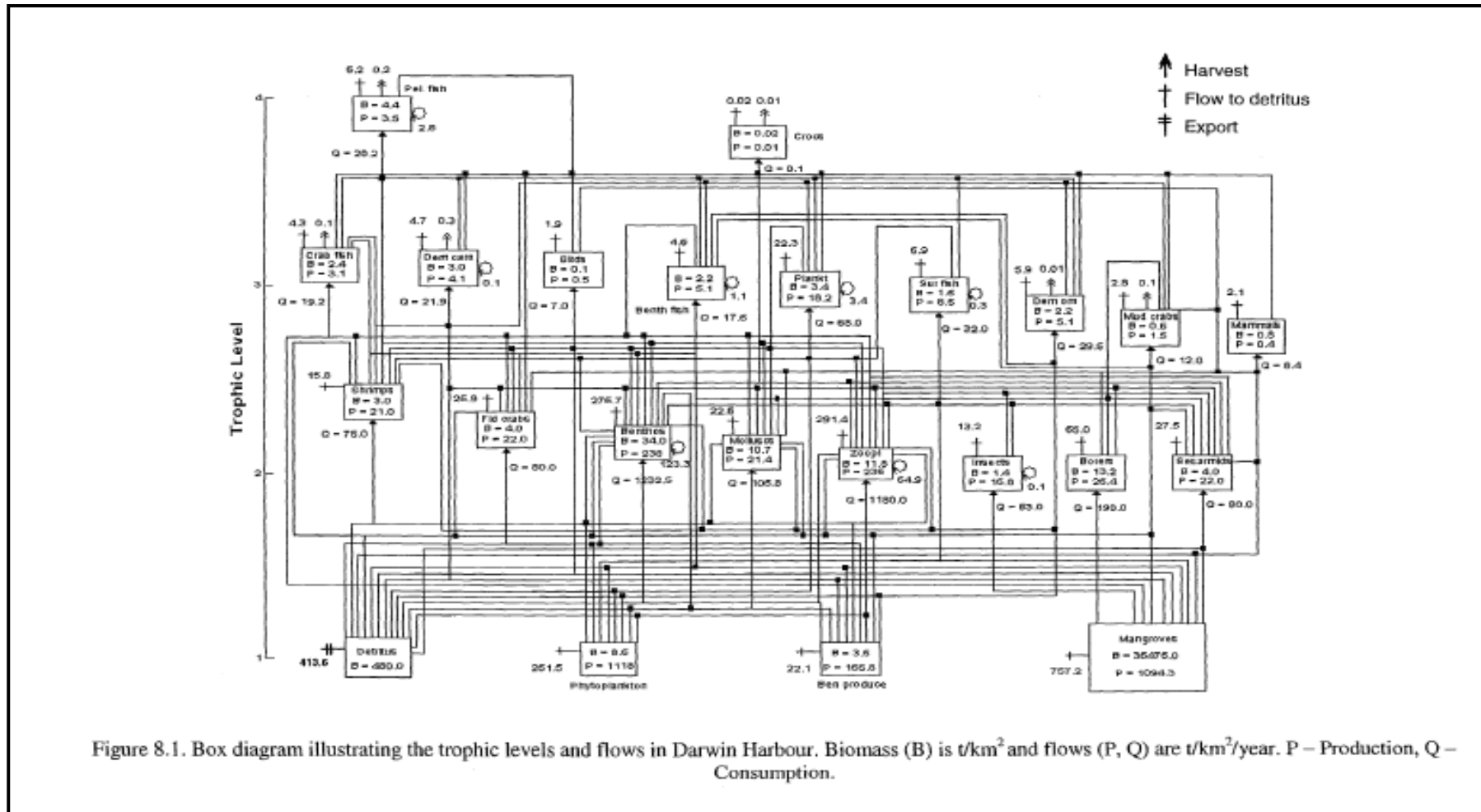


Figure 8.1. Box diagram illustrating the trophic levels and flows in Darwin Harbour. Biomass (B) is t/km^2 and flows (P, Q) are $\text{t}/\text{km}^2/\text{year}$. P – Production, Q – Consumption.

Figure 21: Trophic levels and flows in Darwin Harbour (Martin 2005)

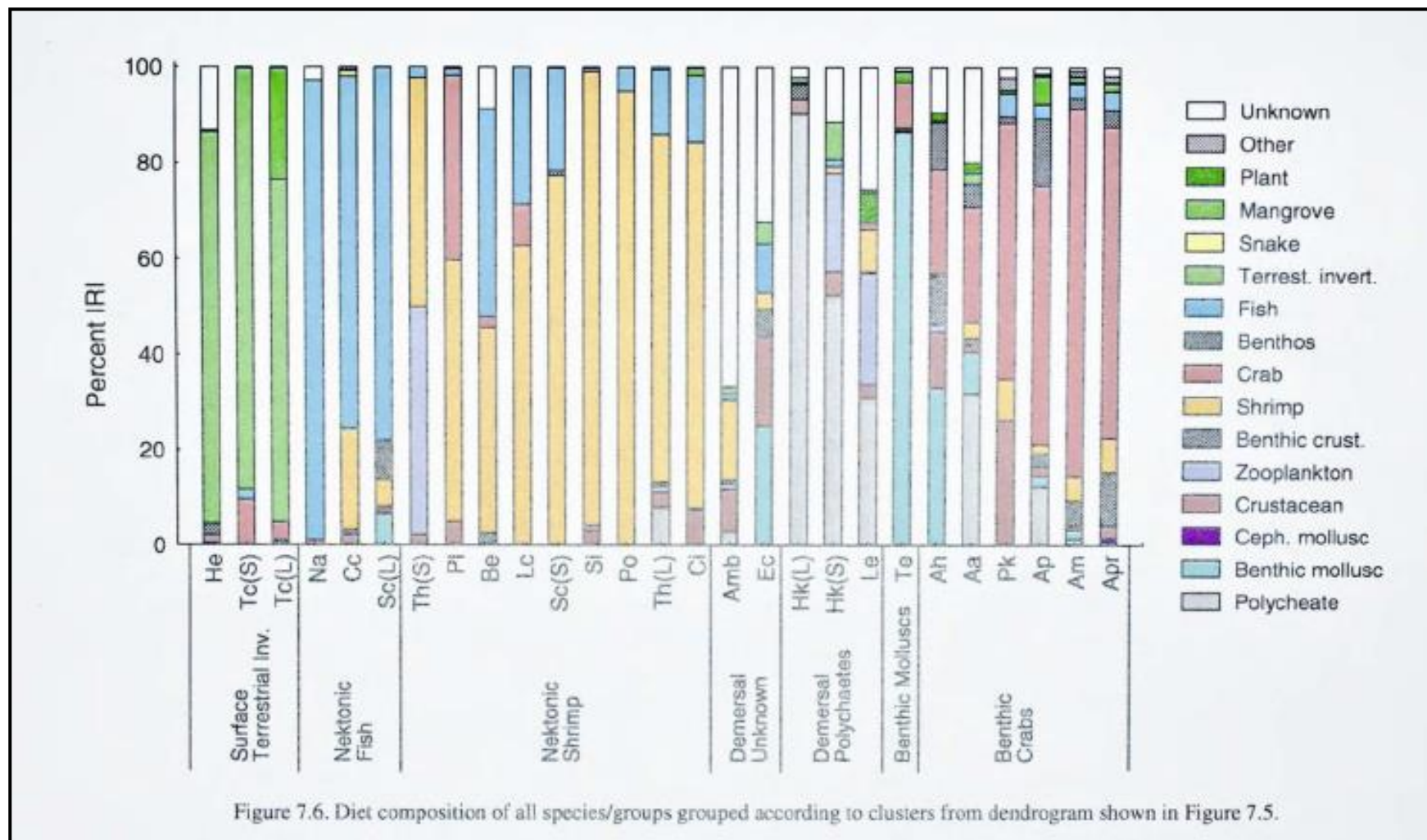


Figure 22: Illustration of fish dietary composition in Darwin Harbour mangrove habitats based on similarities for feeding mode and prey group (Martin 2005)

Appendix 5: Ludmilla Inflow and outflow graphs 2015 to 2022

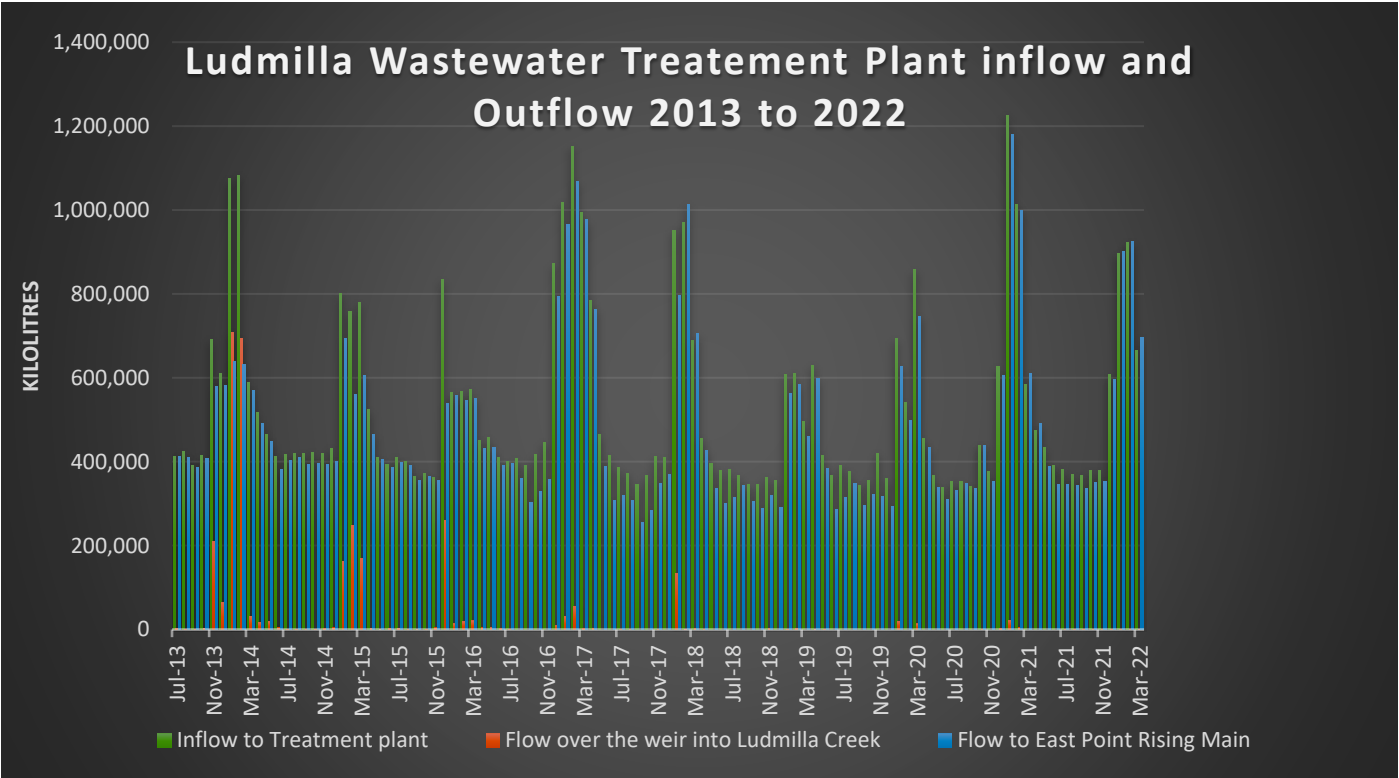


Figure 23: Long term monthly inflows and outflows to and from LWwTP

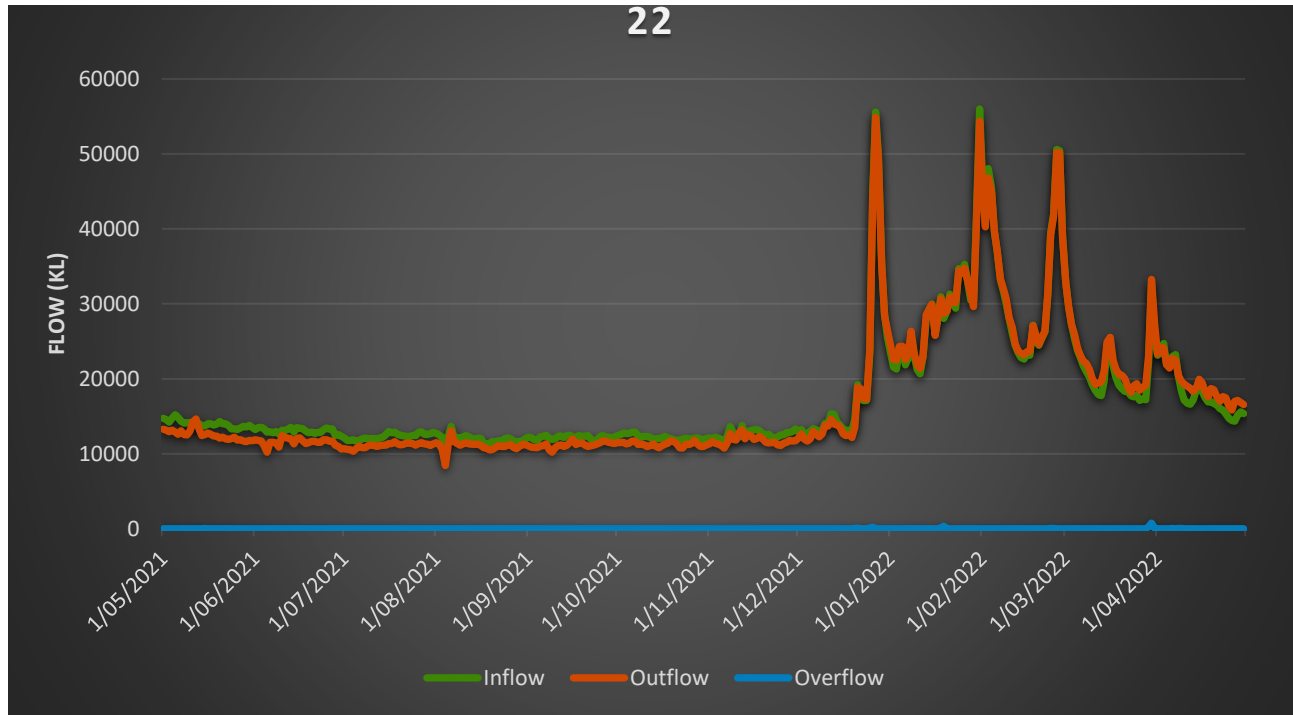


Figure 24: Medium term daily inflows and outflows to and from LWwTP

Appendix 6: Inflow and Outflow contaminant loads 2013-14 to 2020-21 financial years

Table 28: Mass loads of key nutrients

		Biochemical Oxygen Demand BOD (tonnes/yr)	Chemical Oxygen Demand COD (tonnes/yr)	Nitrogen-ammonia Free NH3-N Free (tonnes/yr)	Nitrogen-ammonia Organic NH3-N Organic (tonnes/yr)	Nitrogen oxide NOX - N (tonnes/yr)	Total Nitrogen (tonnes/yr) Calculations	Phosphorus P_Reactive High (tonnes/yr)	Phosphorus P_Total High Level (tonnes/yr)	Suspended Solids SS (tonnes/yr)	Volatile Suspended Solids VSS (tonnes/yr)	Reporting Period	Annual Rainfall
150 Ludmilla	Inflow	876.65	2,696.82	194.33	65.56	0.50	252.82	21.62	32.70	1276.3	1184.5	2020-21	1833
	Discharge to East Point Outfall	390.72	1,046.99	145.05	32.72	1.96	176.85	3.35	8.79	242.0	185.2		
	Outflow to Ludmilla Ck	0.46	1.60	0.32	0.08	0.01	0.38	0.01	0.02	0.7	0.5		
	Harbour	391.18	1,048.59	145.38	32.80	1.97	177.22	3.36	8.81	242.7	185.7		
	Mass removed prior to discharge	485.47	1,648.23	48.96	32.76	(1.47)	75.60	18.25	23.89	1033.6	998.8		
	Percentage removed prior to discharge	55%	61%	25%	50%	-296%	30%	84%	73%	81%	84%		
150 Ludmilla	Inflow	849.64	2519.38	182.66	63.16	0.49	246.31	21.67	30.93	1337.38	1246.61	2019-20	1228.3
	Discharge to East Point Outfall	356.23	901.92	121.74	28.76	1.23	151.10	2.70	6.55	175.29	139.77		
	Outflow to Ludmilla Ck	1.09	3.38	0.51	0.15	0.01	0.67	0.01	0.03	0.68	0.42		
	Harbour	357.32	905.30	122.25	28.90	1.24	151.77	2.71	6.58	175.97	140.19		
	Mass removed prior to discharge	492.33	1614.08	60.41	34.26	-0.74	94.54	18.95	24.35	1161.42	1106.41		
	Percentage removed prior to discharge	57.94%	64.07%	33.07%	54.24%	-151.24%	38.38%	87.47%	78.73%	86.84%	88.75%		
150 Ludmilla	Inflow	642.48	2271.02	177.11	54.98	0.27	232.36	18.80	27.98	1032.32	967.73	2018-19	1156.2
	Discharge to East Point Outfall	402.28	894.96	110.00	22.70	0.88	133.59	3.51	6.88	192.99	155.23		
	Outflow to Ludmilla Ck	0.21	0.50	0.07	0.01	0.00	0.08	0.00	0.00	0.14	0.11		
	Harbour	402.49	895.46	110.07	22.71	0.88	133.67	3.51	6.88	193.13	155.34		
	Mass removed prior to discharge	239.99	1375.57	67.04	32.27	-0.61	98.69	15.29	21.10	839.19	812.40		
	Percentage removed prior to discharge	37.35%	60.57%	37.85%	58.69%	-227.95%	42.47%	81.33%	75.41%	81.29%	83.95%		
150 Ludmilla	Inflow	692.78	2503.61	213.09	55.12	0.48	268.69	23.25	32.92	1387.38	1267.49	2017-18	1956.3
	Discharge to East Point Outfall	359.51	952.98	125.72	25.36	0.93	136.53	4.39	8.70	190.94	149.14		
	Outflow to Ludmilla Ck	6.88	17.81	2.12	0.42	0.04	2.04	0.06	0.13	3.30	2.36		
	Harbour	366.39	970.79	127.84	25.78	0.96	138.57	4.45	8.83	194.25	151.49		
	Mass removed prior to discharge	326.39	1532.82	85.25	29.34	-0.49	130.12	18.80	24.09	1193.13	1116.00		
	Percentage removed prior to discharge	47.11%	61.22%	40.01%	53.23%	-102.69%	48.43%	80.87%	73.19%	86.00%	88.05%		
150 Ludmilla	Inflow	816.81	2559.90	240.02	72.37	0.47	312.85	24.80	36.47	1293.1	1207.9	2016-17	2653.2
	Discharge to East Point Outfall	465.66	1133.22	137.38	36.35	1.86	175.59	7.25	11.12	301.2	238.7		
	Outflow to Ludmilla Ck	4.28	10.28	1.44	0.40	0.03	1.87	0.10	0.12	5.1	4.3		
	Total Outflow from Ludmilla into Darwin Harbour	469.94	1143.49	138.82	36.75	1.89	177.47	7.35	11.24	306.3	243.0		
	Mass Removed Prior to Discharge	346.87	1416.41	101.20	35.62	-1.42	135.38	17.45	25.23	986.8	964.9		
	Percentage removed prior to discharge	42.47%	55.33%	42.16%	49.22%	-302.13%	43.27%	70.36%	69.18%	76.31%	79.88%		
150 Ludmilla	Inflow	868.91	2538.60	190.41	65.92	0.49	256.81	22.45	29.00	1129.2	1044.4	2015-16	1384.4
	Discharge to East Point Outfall	466.79	1095.66	141.15	34.15	0.85	176.15	2.69	6.60	209.5	169.3		
	Outflow to Ludmilla Ck	20.20	57.11	5.16	1.22	0.16	6.54	0.11	0.22	9.7	6.2		
	Total Outflow from Ludmilla into Darwin Harbour	487.05	1152.94	146.34	35.38	1.01	182.72	3.71	6.81	219.4	175.5		
	Mass Removed Prior to Discharge	381.86	1385.66	44.07	30.54	-0.52	74.09	18.74	22.19	909.8	868.9		
	Percentage removed prior to discharge	43.95%	54.58%	23.14%	46.33%	-106.12%	28.85%	83.47%	76.52%	80.57%	83.20%		
150 Ludmilla	Inflow	961.58	2571.51	231.05	68.10	0.31	299.45	23.92	32.87	1457.6	1344.5	2014-15	1463.1
	Discharge to East Point Outfall	497.56	1079.57	153.50	30.81	0.55	184.88	2.78	7.35	216.6	177.7		
	Outflow to Ludmilla Ck	26.02	60.86	8.90	2.14	0.10	11.15	0.21	0.37	14.6	9.7		
	Total Outflow from Ludmilla into Darwin Harbour	523.58	1140.43	162.40	32.95	0.65	196.03	3.78	7.72	231.1	187.4		
	Mass Removed Prior to Discharge	438.00	1431.08	68.65	35.15	-0.34	103.42	20.15	25.15	1226.4	1157.0		
	Percentage removed prior to discharge	45.55%	55.65%	29.71%	51.62%	-110.72%	34.54%	84.21%	76.51%	84.14%	86.06%		
150 Ludmilla	Inflow	1,019.31	2,668.83	228.77	71.26	0.37	300.39	24.54	38.11	1456.8	1329.7	2013-14	2156.3
	Discharge to East Point Outfall	515.15	1,254.31	154.79	30.37	0.86	186.03	4.54	12.58	304.7	240.6		
	Outflow to Ludmilla Ck	78.41	231.96	25.38	8.09	0.37	33.89	0.73	2.19	72.0	53.1		
	Total Outflow from Ludmilla into Darwin Harbour	593.55	1,486.27	180.17	38.46	1.23	219.92	6.03	14.77	376.8	293.7		
	Mass Removed Prior to Discharge	425.75	1,182.57	48.60	32.80	(0.86)	80.47	18.51	23.34	1080.1	1036.0		
	Percentage removed prior to discharge	42%	44%	21%	46%	-231%	27%	75%	61%	74%	78%		

Appendix 7: Water Quality Monitoring Assessment and Hazard Identification

Table 29: Water Quality and Hazard Assessment 2019-2022

Water Quality Monitoring Assessment: Ludmilla WwTP Discharge and East Point Receiving Waters, Comparison against Guidelines to 28/03/2022																												
Indicator type	Pathogen indicators			Physico-chemical indicators						Nutrient Indicators							Toxicant indicators											
parameter	E. coli		Enterococci	pH	EC	DO		Turbidity	TSS	BOD	Chl-a	FRP	TP	NH3-N	TN	NOx	NO2	NO3	NH3-N	As (D)	Cd	Cr	Cu (D)	Fe	Hg (D)	Ni (T)	Pb (D)	Zn (D)
Unit	cfu/100 mL			pH units	µS/cm	% sat		Ntu	mg/L	mg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
DHWQO	14	43	50	7.0 - 8.5 ¹		80	100						0.02	0.02	0.27	0.17	0.17	0.17	0.91	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range 0.39-2.6
SMD							110				2	0.01	0.03		0.3	0.02	0.02	0.02		1.0 – 3.3	0.02-0.7	0.01- 0.1	0.06-1.3	0.14 to 13.7	0.0007- 0.003	0.13- 0.5	0.006- 0.03	
ZOI				6.5 - 8.5 ²		50	110				4								1.2									
ANZG level of species protection	Not applicable		40 (NHMRC)	8 – 8.4	54,100	80	120																1.3 –SMD			7.0 - pristine 70-SMD		
Assessment criteria	Aquatic food: ^h		Primary Contact Rec ⁿ	50 th	50 th	Low	High	50 th	50 th	95 th	50 th	50 th	50 th	50 th	50 th	50 th	50 th	50 th	95 th	95 th	95 th	95 th	95 th	SMD 95%	SMD	95 th	95 th	95 th
percentile	50 ⁱ	90 ⁱ	95 th			20 th	80 th																	95 th				
Discharge point and treated effluent (receiving water quality guidelines is not directly applicable); ³ PER approved treatment plant design criteria, no guideline values for receiving waters <2 is desirable for rivers and marine waters, no guidance available for estuaries due to natural dissolved organic matter availability; ⁴ ANZECC Low Reliability																												
Trigger Values, Section 8 of ANZECC/ARMCANZ Guidelines for Fresh and Marine Waters.																												
Colour code: (Green) - Meets National and Darwin Harbour Water Quality Objectives (DHWQO) ≤ guideline; (Orange) exceeds DHWQO, Exceeds national (ANZECC/NHMRC) trigger or control stat exceeded; (red) exceeds all objectives and disturbed (D) triggers by 3x.																												
Assessment against SSTVs: Discharge SLu080 Effluent within the treatment plant (discharges to Ludmilla Creek (overflow) and East Point Outfall via the East Point Rising Main																												
SLu080:Effluent	39	219	176	7.74	1023	40.66	48.86	32.30	38.00	96	0.58	0.707	1.845	29.300	37.13	0.229	0.0925	0.127	33.232	1.60	0.50	44.08	45.98	732.20	0.15	3.50	0.50	12.43
Assessment against SSTVs: East Point Outfall (intertidal outfall) within Darwin Harbour receiving waters																												
SLuEP01 ¹ outfall (discharge)	2	22	1	8.09	51850	86.38	92.46	4.83	4.00	1	0.63	0.0085	0.063	0.401	0.93	0.0045	0.0015	0.003	0.0298	6.50	0.50	2.95	2.50	10.00	0.15	2.91	0.50	5.60
Assessment against SSTVs: Darwin Harbour receiving waters Zone 1 (sites between 220 and 500 metres of outfall – impact zone – exceedance of triggers due to discharge low likelihood)																												
SLuEP02 ¹	0	1	6	8.10	52800	83.14	92.2	3.19	2.00	1	0.60	0.006	0.04	0.003	0.145	0.0015	0.0015	0.003	0.005	7.60	0.50	1.00	0.80	2.50	0.15	2.00	0.50	6.95
SLuEP03 ¹	1	1	5	8.09	53000	85.42	92.52	2.86	1.50	1	0.67	0.004	0.039	0.003	0.17	0.0015	0.0015	0.003	0.005	6.20	0.50	1.00	0.77	3.20	0.15	3.00	0.50	5.00
Assessment against SSTVs: Darwin Harbour Zone 2 (sites between 500 and 1000 metres of outfall- secondary impact zone – impact unlikely)																												
SLuEP04 ¹	0	3	16	8.10	52950	85.16	95	2.68	2.00	1	0.72	0.005	0.033	0.003	0.145	0.0015	0.0015	0.003	0.005	6.00	0.50	1.00	1.00	2.50	0.15	2.75	0.50	6.70
SLuEP12 ¹	0	0	2	8.10	52900	86.26	92.46	3.55	4.00	1	0.66	0.005	0.0375	0.003	0.11	0.0015	0.0015	0.003	0.005	5.45	0.50	1.00	1.00	2.50	0.15	2.00	0.50	5.00
Assessment against SSTVs: Darwin Harbour Zone 3 (sites between 1000 and 2000 metres of outfall – tertiary impact zone – impact highly unlikely)																												
SLuEP05 ¹	0	0	2	8.11	53000	88	94.2	3.29	2.00	1	0.72	0.0055	0.0325	0.003	0.145	0.0015	0.0015	0.003	0.005	5.00	0.50	0.50	0.50	6.00	0.36	2.80	0.50	4.70
SLuEP06 ¹	0	2	1	8.11	52900	87.88	94.8	3.28	2.00	1	0.66	0.0045	0.034	0.003	0.145	0.0015	0.0015	0.003	0.005	5.70	0.50	0.57	0.50	3.20	0.15	3.00	0.50	6.75
SLuEP07 ¹	0	1	5	8.11	53050	87.26	93.8	4.83	3.00	1	0.66	0.005	0.037	0.003	0.08	0.0015	0.0015	0.003	0.005	5.65	0.50	2.00	1.75	8.00	0.15	3.00	0.50	6.00
SLuEP08 ¹	0	2	1	8.12	53000	87.18	93.86	4.12	2.00	1	0.70	0.0055	0.039	0.003	0.1	0.0015	0.0015	0.003	0.005	6.00	0.50	1.00	1.00	6.00	0.15	2.00	0.50	7.00
SLuEP09 ¹	0	0	2	8.12	53000	88.12	94.88	3.42	2.00	1	0.76	0.005	0.039	0.003	0.08	0.0015	0.0015	0.003	0.005	5.00	0.50	1.00	1.00	5.20	0.15	3.00	0.50	5.00
SLuEP10: Control Site	0	0	0	8.13	52900	88.34	94.12	4.76	2.00	1	0.68	0.0055	0.032	0.003	0.085	0.0015	0.0015	0.003	0.005	5.00	0.50	0.55	0.50	2.50	0.23	3.80	0.50	6.70
SLuEP11 ¹	0	0	0	7.89	52900	90.3	97.092	4.49	4.00	1	0.60	0.006	0.037	0.003	0.08	0.0015	0.0015	0.003	0.005	6.65	0.50	1.00	1.00	5.10	0.15	2.00	0.50	5.70
SLuEP10 Control Assessment	0		1	8.40	60358	98.45		12.80	7.00	1	0.95	0.01	0.04	0.01	0.47	0.00	0.00	0.00	0.01	7.13	0.55	0.79	0.50	5.91	0.06	1.53	0.50	3.25
Assessment against SSTVs: Catchment Inflow to Darwin Harbour receiving waters: via Ludmilla Creek																												
SLuLC01up-stream	42	766	970	7.33	41000	37.32	50.12	9.98	9.00	1	2.85	0.01	0.07	0.007	0.55	0.016	0.0015	0.003	0.005	5.00	0.50	0.50	0.53	63.40	0.15	4.00	0.50	9.60
SLuLC02 (up-stream)	44	1140	968	7.45	54700	32.96	49.4	9.80	12.00	1	2.33	0.0125	0.0715	0.003	0.54	0.00525	0.0015	0.003	0.005	1.50	0.50	4.90	0.53	61.50	0.15	1.02	0.50	3.20
SLuLC03 (at inlet drain)	26	100	968	7.83	52000	62.78	78.48	11.45	10.00	1	3.48	0.008	0.0465	0.003	0.43	0.004	0.0015	0.003	0.005	5.30	0.50	1.00	1.00	9.80	0.15	2.00	0.50	5.40
SLuLC04 ² (down-stream)	3	26	308	8.13	52000	85.52	93.6	3.82	4.00	1	0.81	0.005	0.041	0.003	0.24	0.0015	0.003	0.003	0.005	5.00	0.50	0.00	0.00	5.65	0.15	3.00	0.50	6.00

Table 30: Hazard quotient determination for LWwTP discharge

Water Quality Monitoring Assessment: Ludmilla WwTP Discharge and East Point Receiving Waters Hazard Quotient Determination to 28/03/2022																													
Indicator type	Pathogen indicators			Physico-chemical indicators					Nutrient Indicators								Toxicant indicators												
parameter	<i>E. coli</i>		Enterococci	pH	EC	DO		Turbidity	TSS	BOD	Chl-a	FRP	TP	NH3-N	TN	NOx	NO2	NO3	NH3-N	As (D)	Cd	Cr	Cu (D)	Fe	Hg (D)	Ni (T)	Pb (D)	Zn (D)	
Unit	cfu/100 mL			pH units	µS/cm	% sat		Ntu	mg/L	mg/L	µg/L	mg/L	mg/L	mg/L	mg/L	µg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	
DHWQO	14	43	50	7.0 - 8.5 ¹		80	100						0.02	0.02	0.27	0.17	0.17	0.17	0.91	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	Natural estuary range	
SMD											2	0.01	0.03	0.02	0.3	0.02	0.02	0.02		1.0 – 3.3	0.02-0.7	0.02- 0.1	0.06-1.3	0.14 to 13.7	0.0007- 0.003	0.13- 0.5	0.006- 0.03		
ZOI				6.5 - 8.5 ²							4								1.2										
ANZECC level of species protection	Not applicable		40 (NHMRC)	8.0 – 8.4	54,100	80	120				2	2.5	0.005	0.015	0.015	0.1	0.03	No criteria so NOx used to assess	0.91	2.3	5.5	4.4	1.3	300	0.4	7	4.4	8	
																							3			70			
																							8						
Assessment criteria	Aquatic food: ^h		Primary Contact Rec ⁿ	50 th	50 th	Low	High 80 th	50 th	50 th	95 th	50 th	50 th	50 th	50 th	50 th	50 th	50 th	50th	50th	95 th	95 th	95 th	95 th	95 th	SMD 95%	SMD	95 th	95 th	95 th
percentile			95 th			20 th																			95 th				
Hazard quotient: Ratio of test statistics to guideline where < 1 indicates the assessment statistic is compliant with the guideline and > 1 indicates exceedance of the guidelines: Ranked by - Green (low) <1.5, 1.5 < Orange (moderate) < 10, Red (high) exceeds by factor >10																													
Hazard Quotient applied to treated effluent and discharge point; however the correlation is not directly relevant. While aquaculture and primary contact recreation is assessed the use is not permitted in the vicinity of East Point Outfall under the Port Bylaw Section 5A.																													
SLu080	2.75	5.09	3.52							48.00	0.29	70.70	61.50	1465.00	123.77	11.45			27.69	0.70	0.09	10.02	5.75	2.44	0.38	0.05	0.11	1.55	
Hazard Quotient Applied to Receiving Waters: Darwin Harbour and Ludmilla Creek																													
Declared Beneficial Use	Aquatic food		1 ^o Recreation	Ecosystem protection: Stressors - Physico - chemical. (No cell value indicates no applicable guideline value)					Ecosystem Protection: Nutrient Indicators (No cell value indicates no applicable guideline value)								Ecosystem Protection: Toxicants												
Hazard Quotient applied to East Point Outfall discharge																													
SLuEP01	0.11	0.51	0.03							0.50	0.31	1.70	4.20	26.70	9.30	0.23			0.03	2.83	0.09	0.67	0.83	0.03	0.38	0.42	0.11	0.70	
Hazard Quotient applied to receiving waters: Darwin Harbour Zone 1 (sites between 220 and 500 metres of outfall – impact zone)																													
SLuEP02	0.00	0.03	0.12							0.50	0.30	1.20	2.67	0.17	1.45	0.08			0.01	3.30	0.09	0.23	0.27	0.01	0.38	0.29	0.11	0.87	
SLuEP03	0.05	0.03	0.11							0.50	0.34	0.80	2.60	0.17	1.70	0.08			0.01	2.70	0.09	0.23	0.26	0.01	0.38	0.43	0.11	0.63	
Hazard Quotient applied to receiving waters: Darwin Harbour Zone 2 (sites between 500 and 1000 metres of outfall- secondary impact zone – impact unlikely)																													
SLuEP04	0.00	0.07	0.33							0.50	0.36	1.00	1.10	0.17	1.45	0.08			0.01	2.61	0.09	0.23	0.33	0.01	0.38	0.39	0.11	0.84	
SLuEP12	0.00	0.00	0.04							0.50	0.33	1.00	1.25	0.17	1.10	0.08			0.01	2.37	0.09	0.23	0.33	0.01	0.38	0.29	0.11	0.63	
Hazard Quotient applied to receiving waters: Darwin Harbour Zone 3 (sites between 1000 and 2000 metres of outfall – tertiary impact zone – impact highly unlikely)																													
SLuEP05	0.00	0.00	0.04							0.50	0.36	1.10	1.08	0.17	1.45	0.08			0.01	2.17	0.09	0.11	0.17	0.02	0.90	0.40	0.11	0.59	
SLuEP06	0.00	0.05	0.03							0.50	0.33	0.90	1.13	0.17	1.45	0.08			0.01	2.48	0.09	0.13	0.17	0.01	0.38	0.43	0.11	0.84	
SLuEP07	0.00	0.02	0.10							0.50	0.33	1.00	1.23	0.17	0.80	0.08			0.01	2.46	0.09	0.45	0.58	0.03	0.38	0.43	0.11	0.75	
SLuEP08	0.00	0.04	0.02							0.50	0.35	1.10	1.30	0.17	1.00	0.08			0.01	2.61	0.09	0.23	0.33	0.02	0.38	0.29	0.11	0.88	
SLuEP09	0.00	0.00	0.04							0.50	0.38	1.00	1.30	0.17	0.80	0.08			0.01	2.17	0.09	0.23	0.33	0.02	0.38	0.43	0.11	0.63	
SLuEP10	0.00	0.00	0.00							0.50	0.34	1.10	1.07	0.17	0.85	0.08			0.01	2.17	0.09	0.12	0.17	0.01	0.58	0.54	0.11	0.84	
SLuEP11	0.00	0.00	0.00							0.50	0.30	1.20	1.23	0.17	0.80	0.08			0.01	2.89	0.09	0.23	0.33	0.02	0.38	0.29	0.11	0.71	
Darwin Harbour Control Assessment (Site SLuEP10; 2000 metres north west of outfall, outside the influence of the outfall and of catchment impacts)																													
Control StatSLuEP10+	0.02		0.01							0.50	0.48	2.41	1.35	0.47	4.66	0.14			0.01	3.10	0.10	0.18	0.17	0.02	0.16	0.22	0.11	0.41	
Ludmilla Creek catchment input sites																													
SLuLC01(up-stream)	3.00	17.81	19.40							0.50	1.43	2.00	2.33	0.47	5.50	0.80			0.01	2.17	0.09	0.11	0.18	0.21	0.38	0.57	0.11	1.20	
	3.14	26.51	19.36							0.50	1.17	2.50	2.38	0.17	5.40	0.26			0.01	0.65	0.09	1.11	0.18	0.21	0.38	0.15	0.11	0.40	
SLuLC03 (at inlet drain)	1.86	2.33	19.36							0.50	1.74	1.60	1.55	0.17	4.30	0.20			0.01	2.30	0.09	0.23	0.33	0.03	0.38	0.29	0.11	0.67	
SLuLC04 ² (down-stream)	0.21	0.60	6.16							0.50	0.41	1.00	1.37	0.17	2.40	0.08			0.01	2.17	0.09	0.00	0.00	0.02	0.38	0.43	0.11	0.75	
*no criteria compare to control site statistic of 80 th percentile for nutrients and bio stimulants and 95%ile+ standard deviation for toxicants calculated for site SLuEP10.																													
Arsenic assessment is against the ANZECC low reliability trigger, arsenic is naturally occurring and there is no signal from the Ludmilla discharge (within the treatment plant or at the outfall); only one site (SLuEP12 exceeds the statistical assessment for the control site As 95%ile + standard deviation at a hazard level of 1.1 and is therefore low risk. It is likely that the arsenic is naturally occurring in the Northern Territory soil).																													

Appendix 8: Sediment and pore water quality for ammonia, copper and zinc.

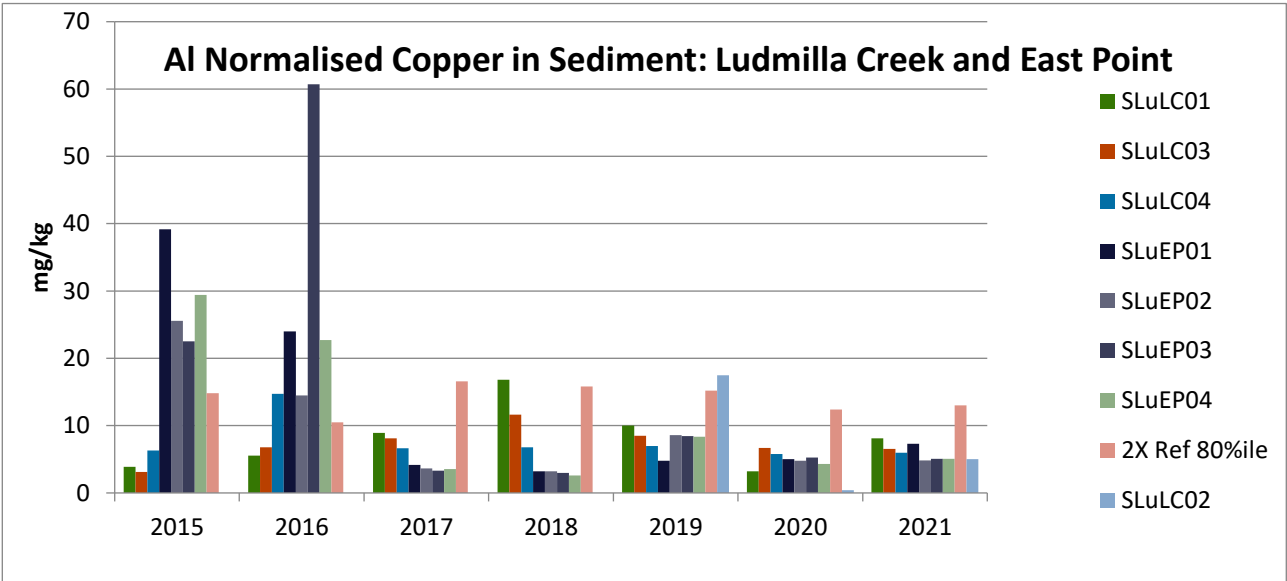


Figure 25: Al Normalised Copper in Sediment

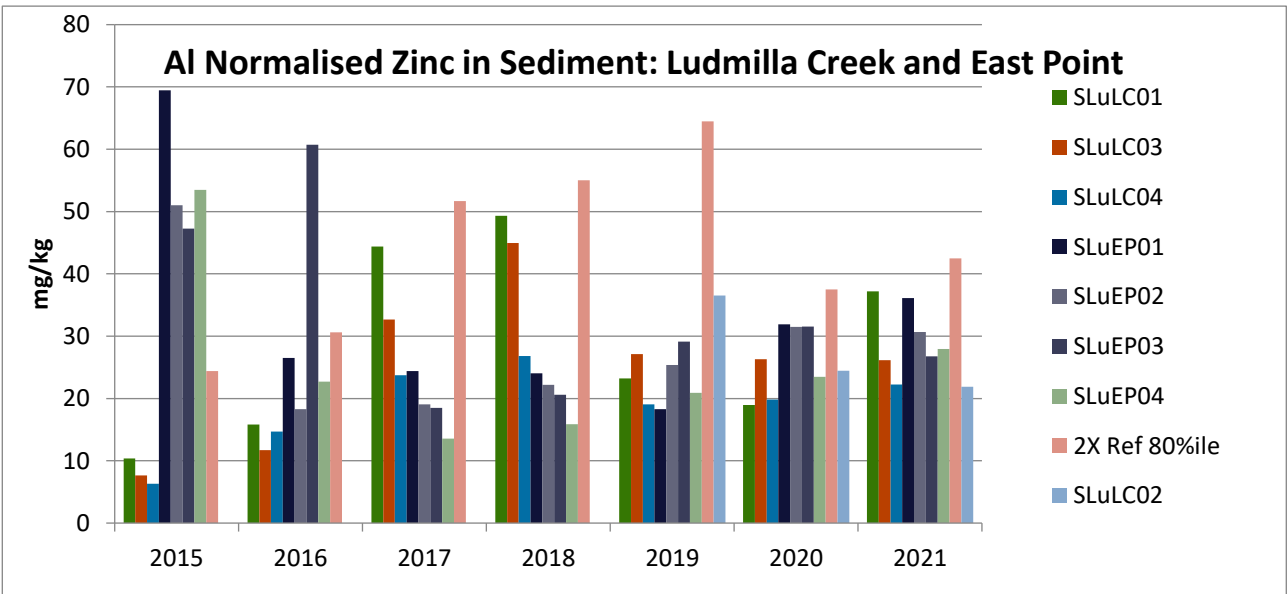


Figure 26: Al Normalised Zinc in Sediment

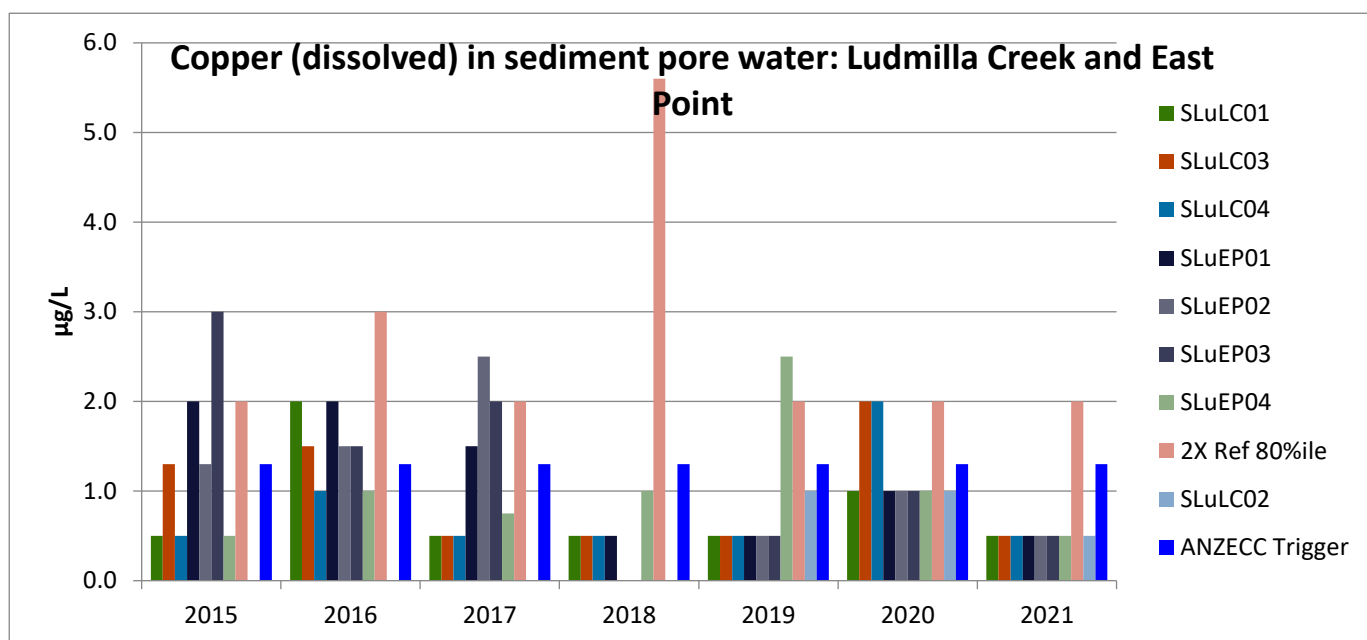


Figure 27: Dissolved Copper in Pore Water

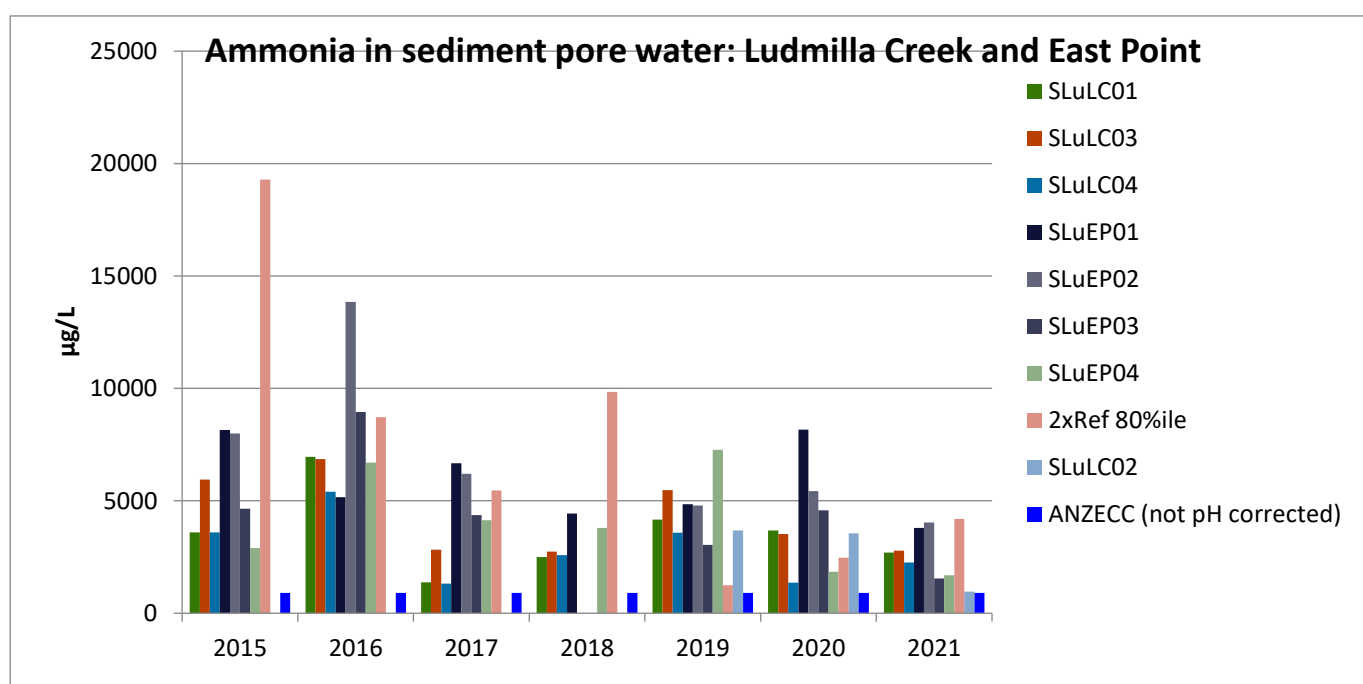


Figure 28: Ammonia in Pore Water

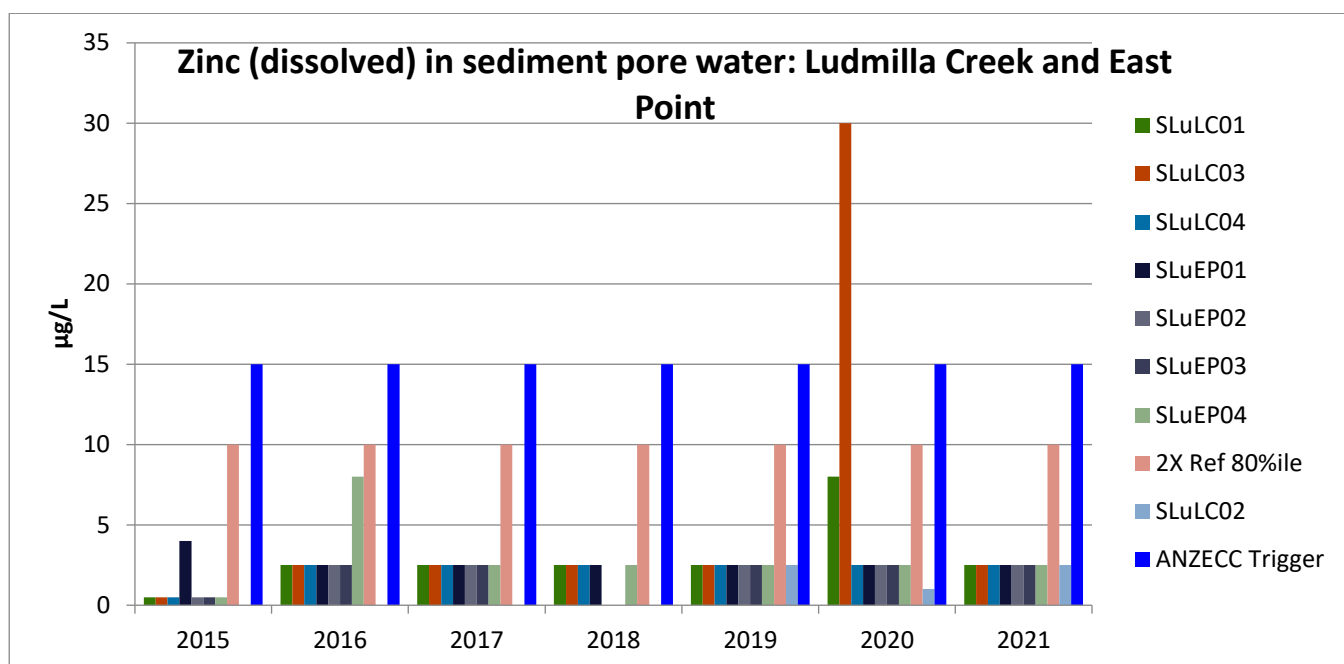


Figure 29: Dissolved Zinc in Pore Water

Contact

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