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File:	Mallina Gold Project – Baseline Aquatic Ecology Survey of the Turner and Yule Rivers, Flood Study Memorandum	Reviewed by:	Fiona Taukulis (Business Leader – Environment)
		Date:	January 24, 2023

Introduction and Background

De Grey Mining Limited (De Grey) are planning to develop the Mallina Gold Project (MGP) in the Pilbara region of Western Australia. The MGP comprises the large scale, high value, near surface Hemi Gold Deposit. Below water table (BWT) mining will be required to access part of the resource, with up 45 ML/day of surplus water to be discharged to the Turner River; a large, ephemeral river system located 14 km to the east of Hemi. Environmental impact assessment (EIA) of the Inland Waters key factor will be required as part of the approvals process submitted to the Environmental Protection Authority (EPA), under Part IV of the *Environmental Protection Act 1986* (EP Act).

A dual phase baseline study was completed by Stantec Australia Pty Ltd (Stantec), to provide information on the ecology of the Turner and Yule Rivers and associated permanent and semi-permanent pools. The study comprised a dual-phase (dry and wet season) aquatic ecology survey, however, wet season sampling was characterised by unusually dry conditions (Stantec 2022). This memorandum provides a summary of an additional opportunistic survey to assess the ecology of the Turner and Yule Rivers following heavy rainfall in the Pilbara region in July 2022 (the Survey), which led to high flow conditions, and supplements the dual phase baseline study findings.

Objective and Tasks

The objective of the Survey was to provide improved understanding of the aquatic ecology values of the Turner and Yule Rivers in the vicinity of the MGP, following high flow (flooding) conditions. The objective was achieved by undertaking the following tasks:

- completion of a single, opportunistic field survey, with systematic sampling of water and sediment quality, and aquatic biota;
- identification of all aquatic biota to genus or species level, where possible;
- assessment of the conservation status of species records;
- spatial and temporal analysis of abiotic and biotic data; and
- discussion of ecological values within a local and regional context, in relation to the hydrological regime.

Methods

Survey Rationale

The EPA has not developed prescriptive technical guidance for surveying Inland Waters in Western Australia. However, the National Water Quality Management Strategy (NWQMS) provides a framework for the management of water quality in Australia and New Zealand; the Water Quality Management Framework (WQMF) (ANZG 2018; Australian Government 2018). To protect the environmental values of waterways, the WQMF applies a weight of evidence approach to collect, analyse and evaluate qualitative, semi-quantitative or quantitative environmental and biological lines of evidence (LoE), typically comprising a range of ecological components across multiple trophic levels, to enable overall assessment (Australian Government 2018). The following LoE were sampled from each site during this Survey, to characterise and assess ecosystem condition:

- water and sediment quality;
- aquatic macrophytes (aquatic plants);
- phytoplankton (algae);
- periphyton (diatoms);
- aquatic invertebrates (zooplankton and macroinvertebrates);
- fish; and
- other vertebrate fauna (Pilbara olive python, frogs, reptiles and water birds).

At each site during the Survey, habitat characterisation was undertaken, to document the key hydrological, geological, and biological attributes of the waterway. Photographs were also captured to provide a record of site conditions at the time of each survey.

Survey Design and Team

The Survey was undertaken by suitably qualified aquatic Stantec Scientists from the 4th to the 7th of July 2022. Whilst there is no available data for June 2022 from the Bureau of Meteorology (BOM) station Indee (004016), in the months preceding the Survey (March to June 2022), conditions were typical of wet season conditions in the Pilbara region, notably with above average rainfall reported in late May (**Figure 1**). Prior to the Survey, high rainfall caused surface water flows, which rapidly ceased, resulting in a series of disconnected yet substantial-sized waterbodies during sampling (**Figure 2**). Most sites sampled during the Survey were comparable, albeit larger than the preceding dry season pools (**Table 1**).

Locations for sampling were selected based on accessibility, with sites previously visited/sampled during the dual phase baseline study revisited during the Survey. Subsequently, six sites were sampled during the Survey; four sites within the Turner River (including one site in Turner River East) and two sites in the Yule River. A summary of the sites sampled and survey design is provided in **Table 1**, with locations shown in **Figure 3**.

The field survey was led by Stantec Principal Aquatic Scientist Chris Hofmeester, assisted by Intermediate Scientist Joseph Laugharne. Theda Morrissey (De Grey Site Environmental Advisor) also provided field assistance during the Survey. Sampling was conducted under Department of Biodiversity, Conservation and Attractions (DBCA) Regulation 27 Fauna Taking (Biological Assessment) Licence BA27000526, and Department of Primary Industries and Regional Development (DPIRD) Fisheries Exemption 251002222. A range of abiotic and biotic components were assessed at each site, with the sampling regime summarised in **Table 2**.

In the laboratory, identification of aquatic biota was undertaken by relevant Stantec specialists. This included Dr Fiona Taukulis and Dr Erin Thomas for taxonomic resolution of algae (including diatoms) and macrophytes. Aquatic invertebrate identification was completed by taxonomists Emma Thillainath and Dr Erin Thomas. For some groups of microinvertebrates, additional taxonomic verification was required, outlined in more detail in the methods below. Technical reporting was completed by Emma Thillainath and Dr Fiona Taukulis of Stantec.

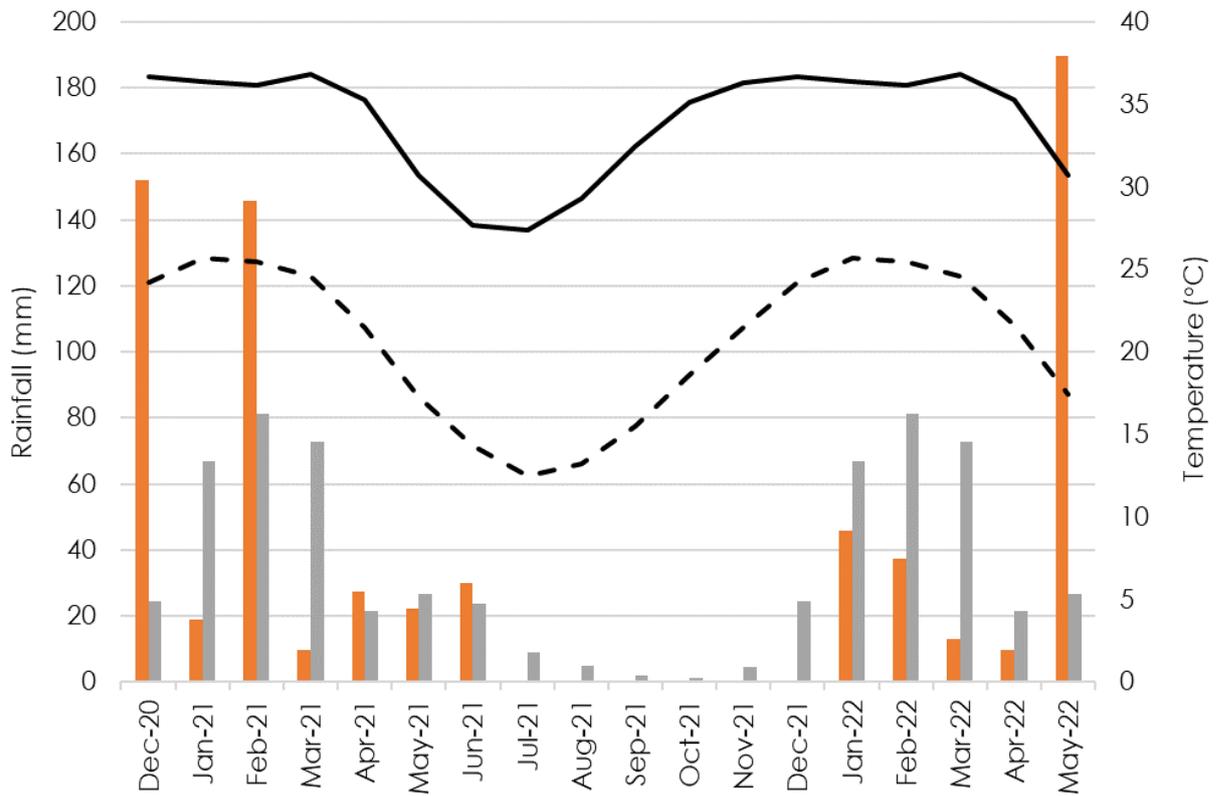


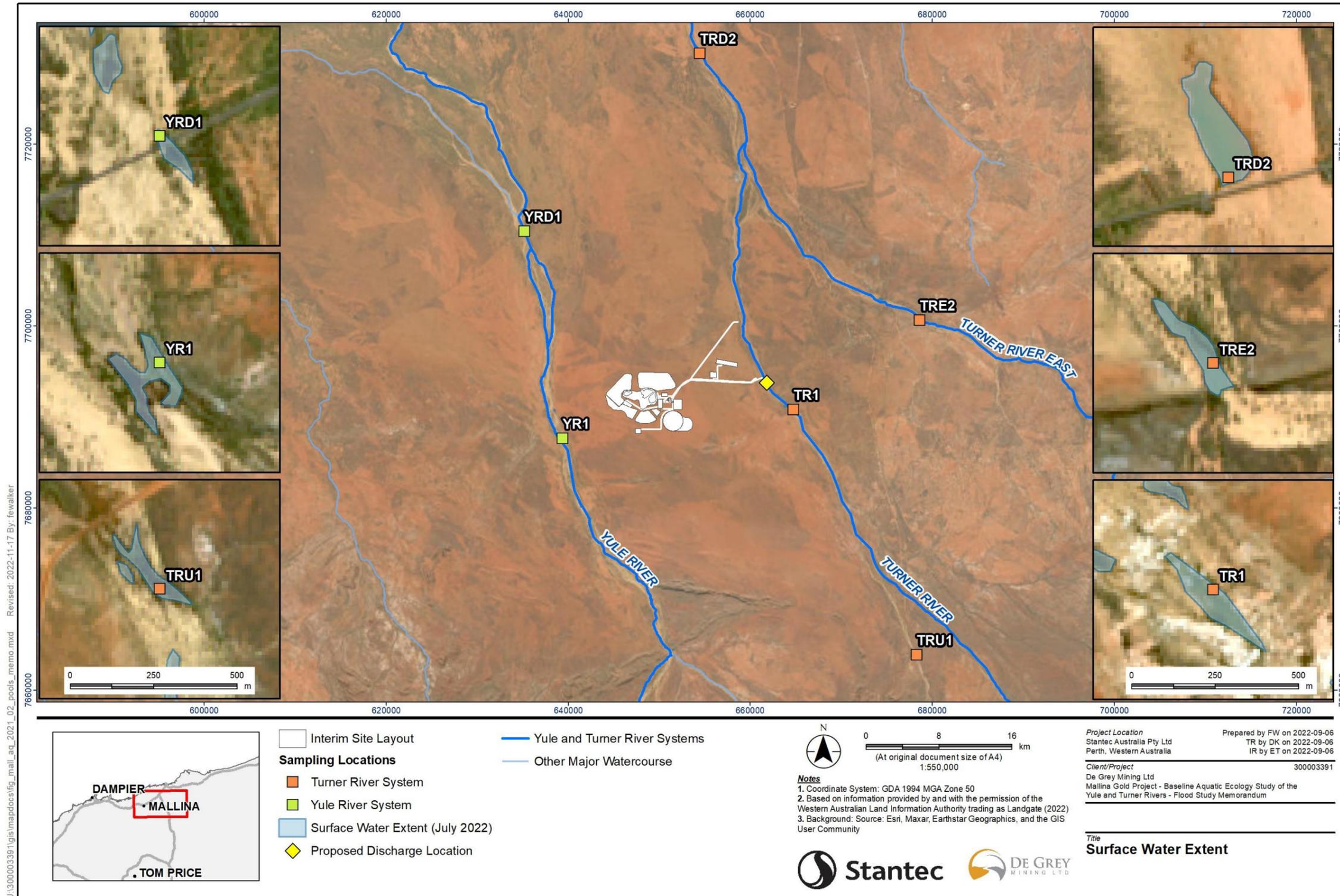
Figure 1: Monthly rainfall December 2020 to May 2022 (■), and mean monthly rainfall (■) and mean minimum (---) and mean maximum (—) temperatures (1909 to 2022), recorded from Indee 004016 (Bureau of Meteorology 2022).

Table 1: Summary of sites visited during the Survey (July 2022).

System	Site	Easting	Northing	Location	Description	Site Photograph		
						Dry Season Survey (November 2021)	Wet Season Survey (May 2022)	Post-flood Survey (July 2022)
Turner River	TRE2	678598	7700634	Within MGP tenement on the eastern branch of Turner River (Turner River East), ~5 km upstream of TRE1.	<p>During the Survey, site TRE2 comprised a large (200 m length, 50 m width) deep (>1.5 m) relatively turbid pool located at the base of a rocky gorge on the eastern branch of the Turner River. Similar to the dry season of November 2021. Instream habitat was complex and comprised large woody debris, submerged and emergent macrophytes, detritus, and overhanging vegetation. During the wet season, the water body had contracted substantially to a pool approximately 30 m long and 10 m wide, with a maximum depth of 1.2 m, with instream habitat more limited. Riparian vegetation was healthy but scattered, primarily comprising <i>Melaleuca argentea</i> and flooded gum. Substrate primarily comprising coarse sand, with some silty clay on the pool's margins.</p>			
	TRU1	678264	7663877	~30 km upstream (south) of the MGP tenement and proposed discharge	<p>During the Survey, the pool comprised a large (100 m length, 30 m width), deep (>1.5 m) relatively clear pool located in the centre of the Turner River main channel. Similar to the dry season of November 2021. Instream habitat was complex and comprised large woody debris, submerged and emergent macrophytes, detritus, and overhanging vegetation. Substrate primarily comprised coarse sand, with some silty clay on the pool's margins. During the wet season, surface waters had reduced to a series of very small (1 m x 1 m, <0.2 m deep) pools, which were heavily impacted by cattle. Subsequently, substrates were dominated by anoxic, silty clay. During both seasons, riparian vegetation was healthy but scattered, primarily comprising <i>Melaleuca argentea</i> and flooded gum.</p>			

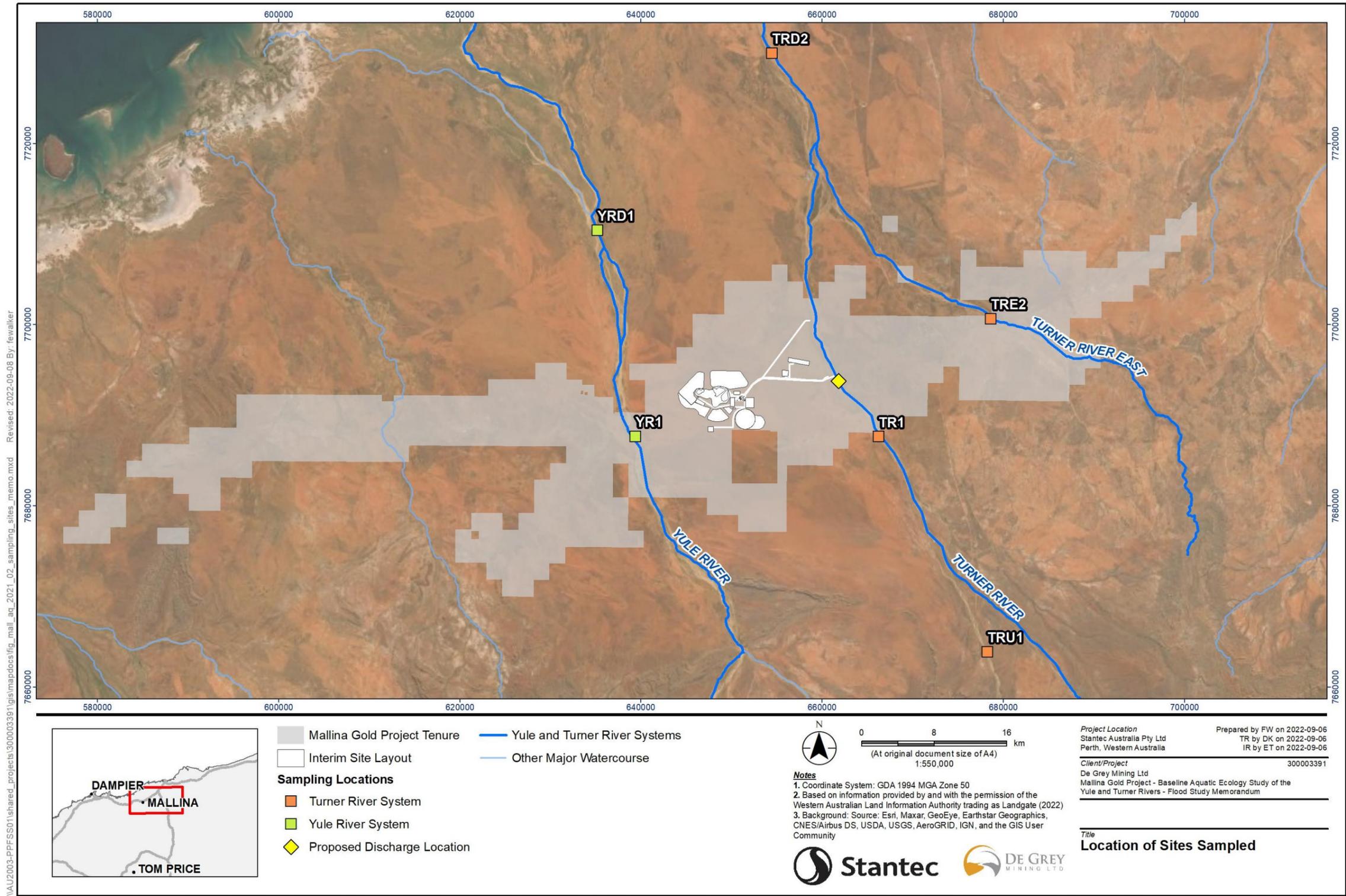
System	Site	Easting	Northing	Location	Description	Site Photograph		
						Dry Season Survey (November 2021)	Wet Season Survey (May 2022)	Post-flood Survey (July 2022)
	TR1	665044	7690772	Within the MGP tenement (southernmost border), upstream of proposed discharge.	<p>During the Survey, TR1 consisted of a large (100 m length, 30 width) deep (>1.5 m) rockpool, which had previously been documented during subsequent wet and dry seasons as a series of small (3 x 3 m, 0.2 cm deep) to moderately sized (20 x 10 m, 0.5 m deep) rockpools located at the centre of the Turner River main channel. Instream habitat was very limited, with some submerged macrophytes (charophytes) present. Riparian vegetation was notably absent. Substrate comprised sand overlying bedrock. Pool size and depth between dry and wet seasons only reduced slightly, due to surface waters likely being perched atop the bedrock base, with limited infiltration. Also known as Red Rock.</p>			
	TRD2	654441	7729971	~40 km downstream of MGP tenement and Mallina proposed discharge outlet.	<p>During the Survey, TRD2 comprised a broad (>100 m length, 50 m width), mixed depth (ranged from 0.5 m to 1.5 m) semi-permanent clear pool situated beneath the Great Northern Highway bridge. Similar to the dry season of November 2021. Instream habitat was limited to a few scattered boulders, with no aquatic macrophytes or riparian vegetation. Substrate comprised primarily sand, with silty clay at the pool's margins, which was anoxic during the wet season survey. Surface waters contracted substantially during the wet season, with only a small (15 m x 5 m), shallow (0.4 m) pool remaining, with turbid waters from blooming algae/cyanobacteria and fouled with deceased fish.</p>			

System	Site	Easting	Northing	Location	Description	Site Photograph		
						Dry Season Survey (November 2021)	Wet Season Survey (May 2022)	Post-flood Survey (July 2022)
Yule River	YR1	639367	7687647	Within MGP tenement, adjacent approximately 7.5 km from proposed site infrastructure	Large (>500 m length, 15 m width), deep (>1.5 m) permanent pool situated on the eastern edge of the Yule River main channel. Water relatively turbid. Steep, incised banks with sediments comprising silty clay, gravel and cobbles on the edges, with a bedrock base. Dense aquatic macrophyte growth suggesting high productivity, including emergent <i>Typha domingensis</i> and <i>Schoenoplectus subulatus</i> beds throughout the pool. Highly complex instream habitat included the macrophyte beds, as well as overhanging (draping) vegetation, tree roots, large woody debris, boulders, and detritus. Fringed with a narrow zone of dense <i>Melaleuca argentea</i> and flooded gums (particularly on the western edge) indicative of water permanency. Limited change in pool size or depth between the dry and wet seasons.			
	YRD1	635191	7710393	~15 km downstream (north) of the MGP tenement; pool beneath the NW Coastal Highway bridge	Large (>100m length, 30m width), deep (>1.5 m) and slightly turbid permanent pool, situated on the eastern edge of the Yule River main channel beneath the NW Coastal Highway bridge. Complex instream habitat including large woody debris, detritus, aquatic macrophytes and boulders present at the pool's margins, with relatively open habitat in the centre of the pool. Benthic substrates exclusively comprised coarse sand. Sparse to moderately dense (pool fringes) riparian zone primarily comprising <i>Melaleuca argentea</i> and flooded gum. Pool size receded slightly between the dry and wet season surveys.			



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Figure 2: Surface water extent of pools sampled during the Survey (July 2022).



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Figure 3: Location of sites sampled during the Survey (July 2022).

Table 2: Summary of sampling methods employed at each site during the Survey (July 2022).

System	Site	Water Quality	Sediment Quality	Macrophytes	Phytoplankton and Diatoms	Aquatic Invertebrates	Fish	eDNA Sampling (Filtered)	eDNA Sampling (Passive)	Other Vertebrates (Opportunistic Observation)
Turner River	TRE2	✓	✓	✓	✓	✓	✓			✓
	TRU1	✓	✓	✓	✓	✓	✓			✓
	TR1	✓	✓	✓	✓	✓	✓			✓
	TRD2	✓	✓	✓	✓	✓	✓			✓
Yule River	YR1	✓	✓	✓	✓	✓	✓			✓
	YRD1	✓	✓	✓	✓	✓	✓			✓

Water Quality

During the Survey, at each site, *in situ* readings of pH, salinity (electrical conductivity; EC), dissolved oxygen and water temperature were recorded using a YSI Pro-Plus portable water quality meter. Additionally, water samples were collected from the water column for the analysis of nutrients, ionic composition, and dissolved metals (**Table 3**), using sterilised bottles provided by the NATA-accredited Australian Laboratory Services (ALS), containing preservative where required. Water samples collected for metals analysis were filtered through a 0.45 µm Millipore filter, with samplers wearing nitrile gloves to avoid contamination. Bottles were sealed and kept cool prior to being couriered to ALS (Wangara) for the analysis.

Table 3: Analytical suite for water samples collected during the Survey.

Basic Parameters and Nutrients	Anions and Cations	Dissolved Metals	
pH	Chloride (Cl)	Aluminium (Al)	Iron (Fe)
Electrical Conductivity (EC)	Bicarbonate (HCO ₃)	Arsenic (As)	Mercury (Hg)
Total Dissolved Solids (TDS)	Carbonate (CO)	Barium (Ba)	Manganese (Mn)
Turbidity	Sulphate (SO ₄)	Boron (B)	Molybdenum (Mo)
Suspended Solids (SS)	Sodium (Na)	Cadmium (Cd)	Nickel (Ni)
Nitrite + Nitrate (NO _x)	Magnesium (Mg)	Chromium (Cr)	Selenium (Se)
Total Kjeldahl Nitrogen (TKN)	Calcium (Ca)	Cobalt (Co)	Uranium (U)
Total Nitrogen (TN)	Potassium (K)	Copper (Cu)	Vanadium (V)
Total Phosphorus (TP)		Lead (Pb)	Zinc (Zn)

Surface water pH was classified according to the system developed by Foged (1978), comprising acidic (4.5 to 6.5), circumneutral (6.5 to 7.5), and alkaline (>7.5) conditions, while salinity levels were categorised according to Hammer (1986), as freshwater (>5,000 µS/cm) and hyposaline (>5,000 µS/cm to 30,000 S/cm). Analytical water quality results were compared to the Australian and New Zealand (ANZG 2018) Default Guideline Values (DGVs) for freshwaters. Basic parameters and nutrients were compared against stressor DGVs for slightly-moderately disturbed ecosystems in tropical northern Australia, while dissolved metals were compared against toxicant DGVs at the level of 95% species protection (except for some potentially bioaccumulating metals, whereby 99% species DGVs were applied).

Sediment Quality

Sediment samples were collected from each site during the Survey from along the margins of the watercourses using sterilised glass jars (provided by ALS), with samplers wearing nitrile gloves to prevent incidental contamination. All sediment samples were sealed and kept cool for the duration of the field survey, and then couriered to ALS in Wangara for the analysis of a range of parameters including ionic composition, nutrients, and metals (**Table 4**).

Table 4: Analytical suite for sediment samples collected during the Survey.

Basic Parameters and Nutrients	Anions and Cations	Metals	
pH	Chloride (Cl)	Aluminium (Al)	Iron (Fe)
Electrical Conductivity (EC)	Bicarbonate (HCO ₃)	Arsenic (As)	Mercury (Hg)
Total Soluble Salts (TSS)	Carbonate (CO)	Barium (Ba)	Manganese (Mn)
Moisture Content	Sulphate (SO ₄)	Boron (B)	Molybdenum (Mo)
Total Organic Carbon (TOC)	Sodium (Na)	Cadmium (Cd)	Nickel (Ni)
Nitrite + Nitrate (NO _x)	Magnesium (Mg)	Chromium (Cr)	Selenium (Se)
Total Kjeldahl Nitrogen (TKN)	Calcium (Ca)	Cobalt (Co)	Uranium (U)
Total Nitrogen (TN)	Potassium (K)	Copper (Cu)	Vanadium (V)
Total Phosphorus (TP)		Lead (Pb)	Zinc (Zn)

Sediment pH was also classified according to Hazelton and Murphy (2007), ranging from very strongly acidic (<5.0) to very strongly alkaline (>9.0). Analytical sediment quality results were compared to the ANZG (2018) Guideline Values (GVs) including GV-High concentrations; levels that are potentially toxic to aquatic biota.

Macrophytes

Macrophytes (emergent and submerged forms) were opportunistically photographed and collected during the Survey, where observed at sites. Macrophyte samples were examined under a dissecting microscope in the laboratory and identified to genus or species level (where possible) based on morphological and reproductive features, using relevant literature and keys.

Phytoplankton

Phytoplankton was collected with a 20 µm mesh net during the Survey, towed through the water column (rinsed between sites to prevent cross-contamination), over an approximate 30 m reach at each site. The resultant samples were transferred into a 70 mL vial and kept cool to preserve algal structure. In the laboratory, three representative slides from each sample were mounted on glass microscopy slides and examined under a compound microscope at 40x magnification. The relative abundance of algal taxa from the phytoplankton samples was recorded, and was calculated per cell, colony, or filament, dependent on morphological form. Taxa were identified to genus and species level by Stantec's experienced algal taxonomists, using appropriate taxonomic literature.

Periphyton (Diatoms)

Periphyton (diatoms) were collected in the form of twigs, sediments, rocks, debris and macrophytes from the shallow waters of each site during the Survey. Samples were placed in 50 mL polycarbonate containers and kept cool for preservation. In the laboratory, diatoms were treated in 70% nitric acid to remove organic material, and permanent slides were prepared. Three replicate slides were made from each sample, with enumeration and identification carried out at 100x magnification under a compound microscope. A maximum of 100 diatoms were counted from each site, to provide a representation of community structure. Taxa were identified to species level, with verification provided by Stantec's experienced diatom taxonomists, using relevant taxonomic guides.

Aquatic Invertebrates

Microinvertebrates (zooplankton) were sampled using a 53 µm plankton net swept through the water column over a standardised (50 m) longitudinal reach at each site during the Survey. Samples were placed into 250 ml polycarbonate containers and preserved in 100% ethanol. Aquatic macroinvertebrates were sampled at each site using a 250 µm D-frame dip net using a kick/sweep motion over approximately 50 m, targeting all available habitat types including riffles, detritus, woody debris, open water column, benthic sediments and submerged and emergent macrophytes. Material retained in the D-frame net was emptied into 1.5 L polycarbonate containers and preserved in 100% ethanol.

Micro and macroinvertebrate samples were processed under a dissecting microscope, with specimens separated into their broad taxonomic groups (family level). Following this, specimens were identified to the lowest taxonomic rank possible (typically species-level) using dissecting or compound microscopes by Stantec specialists. For several microcrustacean groups, specialist identification was also required (**Table 5**).

Table 5: Aquatic invertebrate taxonomy specialists utilised during the Survey.

Group	Personnel	Affiliation
Ostracoda	Dr Stuart Halse	Bennelongia Environmental Consultants
Copepoda and Cladocera	Jane McRae	Bennelongia Environmental Consultants

Fish

Fish were sampled using several integrated methods during the Survey, consisting of beach seine, gill netting (where deemed safe and appropriate to do so), fyke netting and visual observation. Gill nets of 10 mm, 13 mm, 19 mm and 25 mm mesh were deployed for a set time of 20 minutes at each site, with nets constantly checked and cleared to ensure fish are not placed under undue stress. Two beach seine hauls were conducted at each site to target smaller bodied/juvenile species. Two fyke nets (comprising a single hooped funnel and 5 m “wings”; mesh size 6 mm) were also deployed overnight at site YR1 during the Survey. All captured fish were placed in a 20 L container, identified, measured for standard length (from the tip of the snout to the posterior end of the last vertebra) and released back into the waterway. Fish nomenclature followed that of Allen *et al.* (2002).

Other Vertebrate Fauna

Opportunistic observations of other vertebrate fauna (frogs, freshwater turtles and waterbirds) utilising the waterways at were recorded during the Survey. These fauna were identified to species level, where possible in the field, by Stantec specialists.

Results and Discussion

Water Quality

The surface water pH of the Turner River during the Survey ranged from 7.4 (circumneutral) at TRE2, to 8.9 (alkaline) at TR1 (Foged 1978) (**Table 6**). In the Yule River, pH ranged from 7.7 (alkaline) at YRD1, to 7.8 (alkaline) at YR1 (Foged 1978) (**Table 6**). While surface water pH was above the upper ANZG (2018) DGV (8.0) at two Turner River sites during the Survey (TR1 and TRD2) (**Table 6**), pH was generally lower than the dual phase baseline study (Stantec 2022), likely due to the recent high flows. These results are considered typical of semi-permanent river pools and spring fed pools throughout the Pilbara and is consistent with previous surveys of the Turner and Yule Rivers (Masini 1998; Pinder *et al.* 2010; Stantec 2022). The pH of surface waters in the Pilbara region can vary according to factors such as surface runoff, the presence of organic matter, primary productivity and local catchment geology (Boulton and Brock 1999).

Salinity, measured as electrical conductivity (EC), was classified as freshwater (<5,000 $\mu\text{s}/\text{cm}$) (Hammer 1986) at all sites during the Survey (**Table 6**). In the Turner River, salinity ranged from 259 to 428 $\mu\text{s}/\text{cm}$, while the Yule River ranged from 392 to 811 $\mu\text{s}/\text{cm}$ (**Table 6**). Salinities across both waterways were more uniform compared to the dual phase baseline study, with maxima greater than 5,000 $\mu\text{s}/\text{cm}$ recorded during the baseline study reflecting reduced pool sizes due to evapoconcentration during prolonged dry conditions (Stantec 2022). Similar ranges have been recorded in previous studies, driven by seasonal variation (Masini 1988; Masini and Walker 1989; Morgan *et al.* 2009; Pinder and Leung 2009). In addition, although salinity exceeded the ANZG (2018) DGV of 250 $\mu\text{s}/\text{cm}$ during the Survey (**Table 6**), this is considered typical of Pilbara riverine systems (Pinder *et al.* 2010).

Ionic composition at all sites was dominated by Na, followed by Ca, Mg and K during the Survey (**Table 6**). The pattern of anions was also uniform across sites, dominated by HCO_3^- , followed by Cl (**Table 6**). These results were more homogenous compared to the dual phase baseline study, where sites showed considerable variation due to the isolated, retracted nature of the pools. The ionic composition of waterbodies in the Pilbara can vary markedly (Pinder *et al.* 2010), and is typically influenced by factors such as catchment geology, groundwater influence and evapoconcentration effects (Hart and McKelvie 1986).

Surface waters in both waterways were clear during the Survey, with turbidity below the ANZG (2018) DGV (15 NTU) (**Table 6**), likely attributed to the settling of suspended solids following recent high flows. In contrast, during the dual phase baseline study, some pools of the Turner and Yule Rivers exhibited high turbidity levels, created by the suspension of fine sediments from livestock (Stantec 2022). During previous surveys, turbidity in the Yule River has exceeded 20 NTU (Masini 1988; Masini and Walker 1989), however, throughout Pilbara waterbodies, levels are known to frequently exceed 150 NTU (Pinder *et al.* 2010).

During the Survey, concentrations of total nitrogen (TN) were comparable between the Turner and Yule Rivers, with an average of 0.4 mg/L and 0.35 mg/L, respectively. At Turner River sites, TN had a maximum of 0.9 mg/L at TRU1, while at Yule River sites, the maximum was 0.5 mg/L at YR1 (**Table 6**), exceeding the ANZG (2018) stressor (eutrophication) DGV (0.3 mg/L) at several sites (**Table 6**). Nitrogen levels were typically higher during the dual phase baseline study, related to evapoconcentration. Total phosphorus (TP) concentrations were largely comparable across sites and rivers, ranging between 0.01 mg/L and 0.03 mg/L (**Table 6**). Similar to TN, TP also exceeded the ANZG (2018) stressor (eutrophication) DGV (0.01 mg/L) at most sites (**Table 6**), although levels were comparable to the dual phase baseline study (Stantec 2022). Elevated TN and TP can be common in Pilbara riverine pools, reflecting nutrient enriched groundwaters and unrestricted livestock access (Boulton and Brock 1999; Jakowyna *et al.* 2000).

The majority of dissolved metals were below respective analytical limits of reporting (LOR) and the ANZG (2018) DGVs during the Survey (**Table 6**). There were some minor exceedances of DGVs comprising:

- Zn, which exceeded the 95% DGV (0.008 mg/L) at all sites with the exception of Turner River site TR1; and
- Numerous sites in both rivers, which exceeded the freshwater low reliability trigger value for U, which is considered indicative only (0.0005 mg/L).

Similar exceedances occurred during the dual phase baseline study, indicating naturally elevated concentrations of Zn in the catchment, which is common in Pilbara surface waters (WRM 2009;2015;2017). It also appears that natural U enrichment is a characteristic of surface and groundwaters in the local area.

Table 6: Water quality data recorded from the Turner and Yule Rivers, in comparison to ANZG (2018) DGVs.

Water Quality Parameters	LOR	Turner River				Yule River		ANZG (2018)		
		TRE2	TRU1	TR1	TRD2	YR1	YRD1	Stressor DGV	Toxicant DGV	
Basic	pH (unit)		7.36	7.51	8.9	8.25	7.8	7.67	6.5 - 8.0	-
	Total Dissolved Solids	1	168	179	278	217	527	255	-	-
	Dissolved Oxygen								-	-
	Dissolved Oxygen (%)								90	120
	Electrical Conductivity (µS/cm)	1	259	275	428	334	811	392	250	-
	Total Suspended Solids	5	<5	<5	<5	<5	<5	<5	-	-
	Turbidity (NTU)	0.1	10.4	1	0.5	2.3	1.5	1.4	15	-
Ions	Sodium	1	29	38	65	34	115	52	-	-
	Magnesium	1	5	5	9	9	16	9	-	-
	Calcium	1	18	12	15	24	36	31	-	-
	Potassium	1	2	3	4	4	4	3	-	-
	Chloride	1	36	42	71	38	128	34	-	-
	Sulphate	1	6	20	22	12	9	14	-	-
	Bicarbonate	1	78	58	83	143	267	155	-	-
	Carbonate	1	<1	<1	12	<1	<1	<1	-	-
Nutrients	Total Nitrogen	0.1	0.2	0.9	0.3	0.2	0.5	0.2	0.3	-
	Total Phosphorus	0.01	0.03	0.03	0.02	0.01	0.03	0.02	0.01	-
	Total Kjeldahl Nitrogen	0.1	0.2	0.4	0.3	0.2	0.5	0.2	-	-
	Nitrite + Nitrate	0.01	0.02	0.48	<0.01	0.04	<0.01	<0.01	0.7 ^E	2.1 ^T
Metals & Trace Elements	Aluminium	0.005	<0.005	0.007	<0.005	<0.005	<0.005	<0.005	-	0.055
	Arsenic	0.0002	0.0006	0.0006	0.001	0.0007	0.001	0.0004	-	0.024
	Barium	0.0005	0.0976	0.0521	0.0507	0.0632	0.137	0.0928	-	-
	Boron	0.005	0.023	0.032	0.068	0.033	0.125	0.046	-	0.94
	Cadmium	0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	-	0.002
	Chromium	0.0002	<0.0002	<0.0002	0.0005	0.0005	<0.0002	<0.0002	-	0.001
	Cobalt	0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0001	<0.0001	-	-
	Copper	0.0005	0.0007	0.0013	0.0009	0.0009	<0.0005	<0.0005	-	0.0014
	Iron	0.002	0.026	0.042	0.003	0.006	0.112	0.018	-	0.7
	Lead	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	0.0034
	Manganese	0.0005	0.0079	0.0028	0.001	0.0251	0.0493	0.0055	-	1.9
	Molybdenum	0.0001	0.0005	0.0004	0.0012	0.0008	0.0012	0.0009	-	-
	Mercury	0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	-	0.00006
	Nickel	0.0005	0.0005	0.0005	0.0005	0.0008	0.0006	<0.0005	-	0.011
	Selenium	0.0002	<0.0002	0.0003	0.0003	<0.0002	<0.0002	<0.0002	-	0.008
	Uranium	0.00005	0.00121	0.00077	0.00348	0.00248	0.00242	0.00225	-	-
	Vanadium	0.0002	0.0006	0.0006	0.0034	0.0024	0.0008	0.0026	-	-
Zinc	0.001	0.033	0.02	0.007	0.016	0.023	0.018	-	0.008	

Note: Red shading indicates exceedance of ANZG (2018) DGVs, while bold text indicates exceedance of low reliability freshwater trigger value. E = Eutrophication DGV. T = Toxicity DGV. * indicates low reliability freshwater trigger value only of 0.0005 mg/L (considered indicative only).

Sediment Quality

During the Survey, sediment pH at the Turner River from 6.7 (circumneutral) at TRD2 to 8.2 (moderately alkaline) at TR1, while sediment pH at the Yule River ranged from 6.6 (circumneutral) at YRD1 to 10 (very strongly alkaline) at YR1 (Hazelton and Murphy 2007) (**Table 7**). Sediment pH was lower in the Turner River compared to the Yule River during this Survey, with similar trends observed during the dual phase baseline study. Sediment pH is strongly influenced by changes in the hydroperiod, redox reactions and fluctuations in the concentration of carbonates and organic matter (Connell 2005; Reddy and DeLaune 2008).

Sediment salinity (measured as total soluble salts; TSS) in the Turner River ranged from 90 mg/kg at TRD2, to 241 mg/kg at TRE2, while at the Yule River, ranged from 142 mg/kg (YRD1) to 1,800 mg/kg (YR1) (**Table 7**). Salinities were also slightly lower than the dual phase baseline study. Ionic composition followed water quality, with Na and HCO₃ typically dominant at most sites (**Table 7**). The salinity and ionic composition of arid zone waterbodies in Western Australia displays high spatial heterogeneity (Simpson *et al.* 2005), depending on the hydroperiod (Boulton and Brock 1999; McComb and Qui 1998) and catchment geology (Gregory 2008; Hart and McKelvie 1986).

Concentrations of TN were highly variable between sites across the two rivers, with the highest concentration recorded in Yule River site YR1 (720 mg/kg), followed by Turner River site TRU1 (180 mg/kg) (**Table 7**). TP was more homogenous although was once again highest at Yule River site YR1 (146 mg/kg) (**Table 7**). Elevated TN concentrations are most likely associated with livestock and associated animal waste (**Table 7**). Similar trends were also found during the dual phase baseline study (Stantec 2022), with higher TN and TP concentrations in the Yule River compared to the Turner River. Nutrient concentrations in these river systems can also be influenced by microbial activity and sediment mineral composition (Reddy and DeLaune 2008).

The concentrations of all metals were below analytical detection limits or where detected, were below ANZG (2018) GVs/GV-High in the Turner and Yule River sediments during the Survey, attributed to widespread flooding prior to the Survey. There were also few exceedances of GVs during the dual phase baseline study, with the exception of Cr and Ni, which reflects natural background mineralization in the catchment (Stantec 2022).

Table 7: Sediment quality data recorded from the Turner and Yule Rivers, in comparison to ANZG (2018) GVs/GV-High. All units are in mg/kg unless specified otherwise.

Sediment Quality Parameters	LOR	Turner River				Yule River		ANZG (2018)		
		TRE2	TRU1	TR1	TRD2	YR1	YRD1	GV	GV-High	
Basic	pH (unit)	0.1	8.1	7.1	8.2	6.7	10	6.6	-	-
	Electrical Conductivity (µS/cm)	1	71	34	68	27	529	42	-	-
	Total Soluble Salts	5	241	117	233	90	1800	142	-	-
	Moisture Content (%)	1	21.3	18.9	17.1	19.9	25	17.7	-	-
	Total Organic Carbon (%)	0.5	0.9	1.2	0.9	1.2	1.7	0.6	-	-
Cations and Anions	Sodium	10	20	30	40	10	660	20	-	-
	Magnesium	10	<10	<10	10	<10	<10	<10	-	-
	Calcium	10	30	<10	30	10	20	20	-	-
	Potassium	10	<10	10	<10	<10	10	<10	-	-
	Chloride	10	10	20	20	10	80	<10	-	-
	Sulfate	10	<10	10	<10	<10	50	<10	-	-
	Bicarbonate	5	185	58	152	47	1480	82	-	-
	Carbonate	5	<5	<5	<5	<5	1120	<5	-	-
Nutrients	Total Nitrogen	20	100	180	130	20	720	40	-	-
	Total Phosphorus	2	57	77	49	20	146	35	-	-
	Total Kjeldahl Nitrogen	20	100	180	130	20	720	40	-	-
	Nitrite + Nitrate	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	-	-
Metals and Trace Elements	Aluminium	50	1550	1560	1910	1330	1240	1320	-	-
	Arsenic	5	<5	<5	<5	<5	<5	<5	20	70
	Barium	10	<10	<10	<10	<10	<10	<10	-	-
	Boron	50	<50	<50	<50	<50	<50	<50	-	-
	Cadmium	1	<1	<1	<1	<1	<1	<1	2	10
	Chromium	2	2	4	6	4	3	3	80	370
	Cobalt	2	<2	<2	<2	<2	<2	<2	-	-
	Copper	5	<5	<5	<5	<5	<5	<5	65	270
	Iron	50	3300	3510	1300	3670	2990	3000	-	-
	Lead	5	<5	<5	<5	<5	<5	<5	50	220
	Manganese	5	<5	15	<5	7	12	7	-	-
	Mercury	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.15	1
	Molybdenum	2	<2	<2	<2	<2	<2	<2	-	-
	Nickel	2	<2	<2	<2	<2	<2	<2	21	52
	Selenium	5	<5	<5	<5	<5	<5	<5	-	-
	Uranium	0.1	<0.1	0.2	0.8	0.1	0.1	0.1	-	-
Vanadium	5	<5	7	8	<5	<5	<5	-	-	
Zinc	5	<5	<5	<5	<5	<5	<5	200	410	

Note: red shading indicates values exceeding ANZG (2018) GV; bold text indicates values exceeding GV-High.

Macrophytes

During the Survey, a total of nine aquatic macrophyte species belonging to seven different families were recorded, comprising both submerged and emergent forms (**Table 8**). Among the submerged macrophytes, Hydrocharitaceae was the most well represented family (two taxa), with the remaining families (Characeae, Potamogetonaceae, Ruppiaceae and Haloragaceae) comprising one taxon each (**Table 8**). Emergent macrophyte families included Cyperaceae (two taxa) and Typhaceae (one taxa) (**Table 8**).

Of the submerged macrophytes, *Najas marina* was the most common taxon, recorded at three sites (TRE2, YR1 and YRD1) (**Table 8**). This is a cosmopolitan species known to inhabit waterbodies of fresh to low salinities, often with alkaline pH, and occupies a variety of depths (Sainty and Jacobs 2003). It is also among the most common macrophytes in the Pilbara region (Lyons 2015; Pinder *et al.* 2010), and was prevalent during the dual phase baseline study. *Typha domingensis* was the most widespread emergent macrophyte taxon, recorded at both Yule River sites, and from TRE2 on Turner River East (**Table 8**). This species typically dominates the emergent vegetation of rivers and creeklines throughout the Pilbara, forming dense beds along banks within shallower areas (Lyons 2015; Pinder *et al.* 2010). Macrophyte species composition recorded during the Survey was comparable to the dual phase baseline study, and typically related to water levels and habitat availability, with highly ephemeral sites dominantly on the Turner River exhibiting lower macrophyte diversity.

Between sites, the highest macrophyte diversity occurred at Yule River site YR1 (six taxa), YRD1 (four taxa) and Turner River East site TRE2 (four taxa) (**Table 8**). The higher diversity at these sites was likely associated with increased water permanency, which is known to favour the colonisation and persistence of submerged and emergent macrophytes (Lyons 2015). In comparison, macrophytes were absent from Turner River site TRD2 (**Table 8**), which represented a wide, dominantly shallow pool which was reported during the dual phase baseline study as being heavily reduced, highly ephemeral and depauperate of any complex habitats. During the dual phase baseline study, macrophytes were limited in the Turner River, reflecting the ephemeral nature of this watercourse. This river is predominantly dry, and when rarely flowing is subject to high flows, which are considered unfavourable for colonisation by macrophytes (Lyons 2015).

The macrophytes of the Turner and Yule Rivers comprise a suite of common, ubiquitous taxa, that have been previously recorded during the dual phase baseline study (Stantec 2022) and/or are known to occur more broadly in the Pilbara region (Loomes and Braimbridge 2010; Masini and Walker 1989; Pinder and Leung 2009; van Dam *et al.* 2005). These taxa provide important structural habitat in the water column for aquatic larvae with mobile adult stages, such as dragonfly larvae (Gooderham and Tsyrlin 2002; Pinder and Leung 2009), as well as foraging and nesting habitat for waterbirds (Sainty and Jacobs 2003).

Table 8: Summary of aquatic macrophytes recorded from the Turner and Yule Rivers during the Survey (July 2022).

Macrophyte Taxa	Turner River				Yule River	
	TRE2	TRU1	TR1	TRD2	YR1	YRD1
Submerged Macrophytes						
Characeae						
<i>Chara sp./Nitella sp.</i>			✓			
Potamogetonaceae						
<i>Potamogeton sp.</i>	✓				✓	
Hydrocharitaceae						
<i>Vallisneria sp.</i>					✓	✓
<i>Najas marina</i>	✓				✓	✓
Haloragaceae						
<i>Myriophyllum sp.</i>	✓	✓				
Ruppiaceae						
<i>Ruppia sp.</i>					✓	
Emergent Macrophytes						
Typhaceae						
<i>Typha domingensis</i>	✓				✓	✓
Cyperaceae						
<i>Schoenoplectus subulatus</i>					✓	
<i>Cyperus vaginatus</i>						✓
Diversity	4	1	1	0	6	4
Total Diversity	5				7	

Phytoplankton

A total of 31 planktonic algae were recorded during the Survey, from five different phyla (**Table 9**). Bacillariophyta (diatoms; 12 taxa) and Chlorophyta (green algae; 12 taxa) were prevalent, followed by Cyanophyta (blue-green algae; 4 taxa), Euglenophyta (euglenoids; two taxa) and Dinophyta (dinoflagellates; one taxa). Five planktonic taxa were recorded during the Survey which had not been recorded during previous surveys, however these species and the taxa identified were considered common and ubiquitous, known from inland waters and rivers throughout Australia (Entwisle *et al.* 1997) and globally (Bellinger and Sigeo 2010).

The diversity of phytoplankton recorded during the Survey was comparatively lower (31 taxa) than the preceding seasons of the dual phase baseline study (Stantec 2022), likely attributed to recent flows, which are unfavourable for planktonic algae (Townsend *et al.* 2002). Typically, however, site diversity ranged from 14 to 16 taxa in the Yule River and from two to 17 taxa in the Turner River (**Table 9**), although the highest site diversity occurred in the previous dry season survey (Stantec 2022). Differences in site diversity between seasons and rivers is likely driven by water availability and water quality (Cooper 1996). Increased water volumes in these waterways may also indicate a possible dilution effect causing an initial decline in phytoplankton during flooding (Zalocar de Domitrovic 2003).

During the Survey, phytoplankton abundance was driven by the diatom species *Synedra ulna*, which was also widespread, and identified in most sites (collected from five of the six sites). More than 400 cells of this species were recorded in Turner River site TR1 and Yule River site YR1 (**Table 9**). *Synedra ulna* is a globally distributed freshwater taxon, which is also common throughout Australia (John 1998). The freshwater Chlorophyta species *Pediastrum* sp., which is known to occasionally form blooms, was also recorded in high abundance in the Yule River (>500 cells in site YRD1) (**Table 9**). This species has a preference for standing waters (Entwisle *et al.* 1997), corresponding to the large permanent pools of the Yule River.

Cyanophyta contributed to a minor proportion of the phytoplankton assemblage, which were frequently recorded in the Turner River sites (**Table 9**). *Lyngbyna* sp. was the most prevalent taxa, with >100 cells recorded from site TRU1 (**Table 9**). The Turner River sites also exhibited higher nutrient concentrations exceeding trigger values (ANZG 2018) (**Table 6**), which favours cyanobacteria growth (Bothe 1982; Gordon *et al.* 1981). However, cyanobacterial abundance had decreased compared to the dual phase baseline study. More broadly, the planktonic composition of sites during the Survey was considered representative of freshwater systems throughout Australia (Entwisle *et al.* 1997).

Table 9: Phytoplankton taxa recorded from the Turner and Yule Rivers during the Survey (July 2022).

Phytoplankton Taxa	Turner River				Yule River	
	TRE2	TRU1	TR1	TRD2	YR1	YRD1
Bacillariophyta						
<i>Cyclotella stelligera</i>					12	54
<i>Cymbella aspera</i>	5				6	
<i>Encyonema minutum</i>		6	6			
<i>Gyrosigma balticum</i>					3	
<i>Hantzschia amphioxys</i>			15		9	
<i>Hantzschia</i> sp. aff. <i>baltica</i>		6	12			6
<i>Mastogloia elliptica</i>			3			
<i>Navicula radiosa</i>	17	177			45	384
<i>Navicula viridula</i>	5	9				2
<i>Nitzschia closterium</i>			6			
<i>Nitzschia palea</i>			24			
<i>Synedra ulna</i>	8	102	462		468	105
Chlorophyta						
<i>Botryococcus</i> sp.			18			
<i>Chlamydomonas</i> sp.			165	2		
<i>Closterium</i> sp.		126				3
<i>Coelastrum</i> sp.					15	
<i>Cosmarium</i> sp.	1		51		6	9
<i>Dictyosphaerum</i> sp.						24
<i>Oedogonium</i> sp.	4	1	45			
<i>Oocystis</i> sp.		3	6			21
<i>Pediastrum</i> sp.				1	138	546
<i>Rhizoclonium</i> sp.		9				
<i>Scenedesmus</i> sp.		30			6	24
<i>Staurastrum</i> sp.		42	198		3	30
Cyanophyta						
<i>Chroococcus</i> sp.			66		7	
<i>Lyngbya</i> sp.		15				
<i>Merismopedia</i> sp.			30		9	
<i>Spirulina</i> sp.			6			
Dinophyta						
<i>Peridinium</i> sp.	12	4	48		24	3
Euglenophyta						
<i>Phacus</i> sp.					3	9
<i>Trachelomonas</i> sp.		30			57	
Abundance	52	560	1161	3	811	1220
Diversity	7	14	17	2	16	14

Periphyton (Diatoms)

A total of 38 diatom taxa were identified from the periphyton during the Survey (**Table 10**) and were abundant throughout both rivers. The most speciose genera, comprising *Nitzschia* (eight taxa) and *Navicula* (five taxa) (**Table 10**), are common inhabitants of inland waters throughout Western Australia (John 1998; Taukulis 2007). The diversity was comparable to the dual phase baseline study across seasons (Stantec 2022).

The site diversity of diatoms recorded during the Survey ranged from 13 to 16 taxa (**Table 10**), with differences in composition likely reflecting habitat heterogeneity and substrate composition (John 2000). The maximum diversity (16 taxa) occurred in Turner River East site TRE2 and Yule River site YR1 (**Table 10**), both of which comprised large, deep pools with dense submerged macrophytes, and fine clay/silt substrates, which provide ample attachment sites for diatoms to colonise (Krejci and Lowe 1986).

The most widespread and abundant diatom taxa recorded during the Survey were common freshwater species including *Nitzschia palea* (>290 frustules), with *Encyonema minutum*, and *Synedra ulna* also relatively common (>40 frustules) (**Table 10**). These species were typically found in both rivers, except for *Encyonema minutum*, which was only identified from the Turner River. *Nitzschia palea* is common in freshwater systems and is also associated with nutrient rich environments (John 1998), consistent with the elevated nutrient concentrations at Turner River site TRU1 (**Table 6**). The *Encyonema* genus is considered a discriminating freshwater diatom taxon known from lakes and streams throughout Western Australia (Taukulis 2007) and is also frequently associated with macrophytes. In comparison to the dual phase baseline study, there was a high degree of overlap in species found in both river systems, with dominant species found during the Survey also recorded during the dual phase baseline study.

The diatom assemblage during the Survey was consistent with the composition known from freshwater streams and rivers in Western Australia (John 1998; 2000), with the taxa recorded also having a cosmopolitan distribution throughout Australia and globally.

Table 10: Diatom taxa recorded from the Turner and Yule Rivers during the Survey (July 2022).

Diatom Taxa	Turner River				Yule River	
	TRE2	TRU1	TR1	TRD2	YR1	YRD1
<i>Achnantheidium exiguum</i>	4					3
<i>Achnantheidium minutissimum</i>	1	4			1	
<i>Amphora ovalis</i>			3	1		
<i>Anomoeoneis sphaerophora</i>						1
<i>Craticula cuspidata</i>		1	1	1	1	
<i>Cymbella turgida</i>	5			7		
<i>Diploneis subovalis</i>			4			
<i>Encyonema minutum</i>			33	10		
<i>Fallacia tenera</i>						1
<i>Gomphonema parvulum</i>	2		2		1	1
<i>Gomphonema undulatum</i>				1	4	
<i>Hantzschia amphioxys</i>	1					
<i>Hantzschia disinctipunctata</i>		1				
<i>Hantzschia virgata</i>		2	2	1		
<i>Luticola mutica</i>	2	1	2	1		
<i>Mastigloia elliptica</i>			1	6	1	6
<i>Mastogloia smithii</i>				2		
<i>Navicula cryptocephala</i>	1	3	8	2	21	4
<i>Navicula radiosa</i>					2	
<i>Navicula rhynchocephala</i>	4		3	1		2
<i>Navicula tripunctata</i>		3				
<i>Navicula viridula</i>					8	4
<i>Nitzschia amphibia</i>	1	3	2	2	6	
<i>Nitzschia closterium</i>					1	
<i>Nitzschia gracilis</i>	4					
<i>Nitzschia linearis</i>			12	1	2	
<i>Nitzschia microcephala</i>	2	1				3
<i>Nitzschia palea</i>	61	66	11	62	32	61
<i>Nitzschia schroeteri</i>					2	
<i>Nitzschia sigma</i>			1			
<i>Pinnularia gibba</i>		1			3	
<i>Pinnularia microstauran</i>	1					
<i>Pinnularia subcapitata</i>	1					
<i>Pinnularia vividis</i>		2				
<i>Sellaphora pupula</i>				2		5
<i>Synedra ulna</i>	9	11			14	6
<i>Tabularia fasciculata</i>		1	15			
<i>Tryblionella calida</i>	1				1	3
Abundance	100	100	100	100	100	100
Diversity	16	14	15	15	16	13

Aquatic Invertebrates

A total of 1,313 aquatic invertebrate specimens representing 93 taxa from nine higher order groups were recorded during the Survey (**Table 11**). These included Insecta (insects), Gastropoda (aquatic snails and limpets), Hydrozoa (solitary cnidarians), Arachnida (aquatic mites), Oligochaeta (aquatic worms), Monogononta (rotifers) and the crustacean groups Branchiopoda (comprising Cladocera; water fleas), Maxillopoda (comprising copepods) and Ostracoda (seed shrimp) (**Table 11**). Of these, insects were the dominant group, comprising 734 specimens and 65 taxa, followed by the Maxillopoda, with 322 specimens and six taxa, all of which were copepods (**Table 11**). Branchiopoda (including species belonging to the suborders Cladocera and Spinicaudata) were also relatively diverse (9 taxa, 217 specimens), while the remaining groups typically comprised less than 15 specimens and four taxa each (**Table 11**).

The aquatic invertebrate community during the Survey was generally consistent with previous studies of river systems in the Pilbara and to the dual phase baseline study (Stantec 2022), where insects are prevalent (Pinder and Leung 2009; Pinder et al. 2010; WRM 2009;2015;2017). Insects during the Survey comprised Diptera (true flies), Coleoptera (aquatic beetles), Ephemeroptera (mayflies), Hemiptera (true bugs), Odonata (dragonflies and damselflies) and Trichoptera (caddisflies) (**Table 11**). Of these, Diptera and Coleoptera were dominant, accounting for >60% of all insect taxa and >70% of all specimens recorded. All insect groups were considered transient or opportunistic taxa, and have mobile winged adult stages, which allow them to readily disperse and rapidly colonise newly created aquatic habitats (Gooderham and Tsyrlin 2002).

There was lower taxa diversity and specimen abundance recorded during the Survey compared to the dual phase baseline study. Strong flows and higher water volumes are known to displace resident aquatic invertebrates and alter habitats through scouring (Death 2008; Lake 2000). Following these high flow events and once initial flows reduce and pools remain, recolonisation of these waterbodies will occur over time (minimum of two weeks for early colonising species (Tronstad et al. 2007)).

The majority of aquatic invertebrate taxa recorded were common, ubiquitous species with distributions spanning the Pilbara, northern Australia or the Oceania region. The most widespread taxon comprised the chironomid (non-biting midge) *Procladius* spp. and the Ephemeroptera (mayfly) species *Cloeon* sp. *Red Stripe*, which was recorded from every site during the Survey (**Table 11**). The most abundant taxa were the copepod *Mesocyclops notius* (176 specimens), the cladoceran *Moina micrura* s.l. (130 specimens) and the chironomid *Procladius* spp. (125 specimens) (**Table 11**). The prevalence of the cladoceran *Moina micrura* s.l. (Santangelo et al. 2008) and chironomids, during the Survey reflects the ephemeral nature of the waterways, with emergence likely triggered by flooding (Panarelli et al. 2020). Chironomids often constitute the most common and abundant invertebrate taxa in freshwaters worldwide, due to their tolerance to a range of environmental conditions, including low oxygen, high temperatures, high salinity, nutrients, and desiccation (Armitage et al. 2015, Cornette et al. 2015; Thorat and Nath 2015).

During the Survey, aquatic invertebrate diversity was highest in Turner River East site TRE2 (40 taxa) followed by Yule River site YRD1 (35 taxa) (**Table 11**). The lowest diversity was recorded in Turner River site TRU1 (23 taxa), followed by Turner River site TRD2 (27 taxa). The range of taxa recorded in Turner River sites (23 to 40 taxa) was comparable to Yule River sites (32 to 35 taxa). Although taxa diversity was generally lower than the dual phase baseline study (Stantec 2022), this was likely driven by high flows displacing aquatic invertebrates, coupled with the settlement time of returning/resetting aquatic biota, which can be between two and six months following high flow/flooding conditions for certain species (Kroon and Ludwig 2010).

Aquatic invertebrate abundance was relatively uniform during the Survey. In the Turner River, abundance ranged from 196 (TRU1) to 251 specimens (TRD2), while in the Yule River, abundance ranged from 164 specimens (YR1) to 251 specimens (YRD1) (**Table 11**). While abundance was generally higher during the dual phase baseline study, abundances across sites during this Survey were more uniform, likely reflecting more homogenous water quality and habitats across both waterways.

Eodiaptomus lumholtzi (copepod) is a common and broadly distributed species across the Pilbara region (Pinder et al. 2010), having been previously recorded from the Fortescue River, Coondiner Creek, Kalgan Creek, Gudai-Darri Spring, Cane River and from Papua New Guinea, with a pan tropical distribution (Vlaardingerbroek 1989; WRM 2020). This species is listed as Vulnerable on the IUCN Red List of Threatened Species (Reid 1996). However, its status requires updating, with the species having been recorded widely across Northern Australia since its IUCN listing in 1996. It was found from Turner River East site TRE2 (25 individuals) and Yule River site YRD1 (two individuals) during

this Survey, in addition to having been recorded from multiple sites (TRE2, TRU1, TRD2, TR1-A, YR2, YR3 and YRD1) during the dual phase baseline study (Stantec 2022).

One Pilbara endemic species; the damselfly *Eurysticta coolawanyah*, was recorded during the Survey from site TRE2 (Turner River East) (**Table 11**). *E. coolawanyah* is currently listed as Vulnerable on the IUCN Red List of Threatened Species (Dow 2019) and has a restricted range (extent of occurrence of less than 20,000 km²). This species inhabits streams, rivers and riverine pools in the Pilbara, with key threats to persistence including habitat alteration (declining water levels) due to development and climate change (Dow 2019). However, *E. coolawanyah* has been recorded from over 15 locations throughout the region (Pinder and Leung 2009; Pinder *et al.* 2010), suggesting it is more broadly distributed. *E. coolawanyah* has previously been recorded from site TRE2 (Turner River East) and sites YRU1-A and YRD1 (Yule River) during the wet season of the dual phase baseline study (Stantec 2022) (**Figure 4**).

Table 11: Aquatic invertebrate taxa recorded from the Turner and Yule Rivers during the Survey (July 2022).

Aquatic Invertebrate Taxa	Turner River				Yule River	
	TRE2	TRU1	TR1	TRD2	YR1	YRD1
Arachnida						
Trombidiformes						
Arrenuridae spp.					1	
Hydrachinidae spp.					10	
Trombidioidea sp.	1					
Unionicoliidae spp.	1	1				
Branchiopoda						
Diplostraca						
Cyzicidae						
<i>Ozestheria packardi</i>			1			
Chydoridae						
<i>Alona rigidicaudis</i>			1			
<i>Ephemeroporus nr barroisi</i>			20			
Daphniidae						
<i>Ceriodaphnia cornuta</i>			1		17	
<i>Simocephalus heilongjiangensis</i>		7			5	
Moinidae						
<i>Moina micrura</i> s.l.	25	28		27		50
Sididae						
<i>Diaphanosoma</i> spp.	2					
<i>Diaphanosoma excisum</i>	25					1
<i>Latonopsis australis</i>					7	
Clitellata						

Aquatic Invertebrate Taxa	Turner River				Yule River	
	TRE2	TRU1	TR1	TRD2	YR1	YRD1
Oligochaetae						
Oligochaetae spp.				3		
Gastropoda						
Lymnaeidae						
<i>Bullastra vinosa</i>					2	
Planorbidae						
<i>Ferrissia (Pettancyclus) petterdi</i>	1		1			
<i>Gyraulus</i> sp.	1				3	
Hydrozoa						
Hydridae						
Hydra sp.		1				
Insecta						
Coleoptera						
Dytiscidae						
<i>Allodessus bistrigatus</i>				4	1	
<i>Bidessini</i> spp. (L)	1			1		
<i>Hydroglyphus grammopterus</i>					1	20
<i>Hydroglyphus orthogrammus</i>					1	1
<i>Hydrovatus</i> spp. (L)	2					
<i>Hyphydrus</i> spp. (L)	1	1		8		
<i>Hyphydrus lyratus</i>					1	
<i>Neobidessodes denticulatus</i>	8					
<i>Rhantus</i> spp. (L)	2					
<i>Sternopriscus</i> spp. (L)		1	1			

Aquatic Invertebrate Taxa	Turner River				Yule River	
	TRE2	TRU1	TR1	TRD2	YR1	YRD1
Gyrinidae						
<i>Dineutus australis</i> (L)		2				
Hydraenidae						
<i>Hydraena</i> spp.			1			
Hydrochidae						
<i>Hydrochus</i> sp.						1
Hydrophilidae						
<i>Berosus</i> spp. (L)				5		
<i>Berosus pulchellus</i>			1			
<i>Enochrus deserticola</i>	1			1		
<i>Helochaers</i> sp. (L)						1
<i>Helochaers tatei</i>						1
Diptera						
Ceratopogonidae						
Ceratopogonidae sp. (Pupae)		11				
Ceratopogoninae spp.				1	1	1
Chironomidae						
Chironomidae spp. (imm/dam/Pupae)	11		2	5	1	3
<i>Ablabesmyia hilli</i>	4	3	2	6		7
<i>Chironomus</i> spp.	20	4		3	24	5
<i>Cladotanytarsus</i> spp.			6			
<i>Cladopelma curtivalva</i>		2				
<i>Cryptochironomus griseidorsum</i>				1		5
<i>Dicrotendipes</i> spp.	1	7	4	2		5

Aquatic Invertebrate Taxa	Turner River				Yule River	
	TRE2	TRU1	TR1	TRD2	YR1	YRD1
<i>Kiefferulus intertinctus</i>				3		
<i>Larsia albiceps</i>	4	7	6	2		1
<i>Parachironomus</i> spp.	5					8
<i>Parakiefferiella</i> spp.	1					
<i>Paramerina</i> spp.	10		1		3	2
<i>Paratanytarsus</i> spp.			1	3		
<i>Polypedilum leei</i>	3					7
<i>Polypedilum</i> nr <i>watsoni</i>				1	1	2
<i>Procladius</i> spp.	22	32	29	33	7	2
<i>Rheotanytarsus</i> spp.						5
<i>Tanytarsus</i> spp.	11	27	25	29	15	
Culicidae						
Culicidae spp. (Pupae)	2					
<i>Culex</i> spp.	3					
Ephemeroptera						
Baetidae						
Baetidae spp. (imm/dam)	4	2	1	5	3	6
<i>Cloeon</i> sp. Red Stripe	3	13	3	6	9	9
Caenidae						
Caenidae spp. (imm/dam)			5			2
<i>Tasmanocoenis</i> sp. M			5			2
<i>Tasmanocoenis</i> sp. P/ <i>arcuata</i>			12			10
Hemiptera						
Micronectidae						

Aquatic Invertebrate Taxa	Turner River				Yule River	
	TRE2	TRU1	TR1	TRD2	YR1	YRD1
Micronectidae spp. (imm/female)	1	1	1	1	20	
<i>Austronecta</i> spp.		1	1			
<i>Austronecta micra</i>		1				
<i>Micronecta adelaidae</i>				1		
<i>Micronecta annae</i>	1		2			
<i>Micronecta virgata</i>					1	
Notonectidae						
Notonectidae spp. (imm/dam)					1	
Pleidae						
<i>Paraplea brunni</i>		1			11	11
Odonata						
Epiprocta spp. (imm/dam)	2	3			1	
Zygoptera spp. (imm/dam)					2	3
Aeshnidae						
<i>Hemianax papuensis</i>	8				4	1
Coenagrionidae						
<i>Argiocnemis rubescens</i>					2	
<i>Ischnura aurora</i>	1				3	
<i>Ischnura heterosticta</i>	1				1	1
<i>Pseudagrion aureofrons</i>						3
Corduliidae						
<i>Hemicordulia tau</i>					3	
Isostictidae						
<i>Eurysticta coolawanyah</i>	1					

Aquatic Invertebrate Taxa	Turner River				Yule River	
	TRE2	TRU1	TR1	TRD2	YR1	YRD1
Libellulidae						
<i>Diplacodes haematodes</i>			1			
<i>Orthetrum caledonicum</i>	1				2	4
Trichoptera						
Hydroptilidae						
<i>Hellyethira</i> sp.			1			
Maxillopoda						
Calanoida						
Centropagidae						
<i>Boeckella triarticulata</i>				50		12
Calanoid copepodites				2		7
Diaptomidae						
<i>Eodiaptomus lumholtzi</i>	25					2
Cyclopoida						
Cyclopidae						
<i>Mesocyclops notius</i>	25	40	61			50
<i>Thermocyclops</i> spp.				8		
Cyclopoid nauplii				40		
Monogononta						
Flosculariacea						
Filiniidae						
<i>Filinia</i> sp.	1					
Ploima						
Brachionidae						

Aquatic Invertebrate Taxa	Turner River				Yule River	
	TRE2	TRU1	TR1	TRD2	YR1	YRD1
<i>Keratella</i> sp.	1		10			
Euchlanidae						
<i>Euchlanis</i> sp.			1			
Ostracoda						
Podocopida						
Cyprididae						
<i>Cypricercus</i> `BOS1301`			1			
Diversity	40	23	31	27	32	35
Abundance	243	196	208	251	164	251

Fish

A total of 110 individual fish were captured, identified, and released during the Survey, comprising six species. Of these, four are considered obligate freshwater species, including the Western Rainbowfish (*Melanotaenia australis*), Spangled Perch (*Leiopotherapon unicolor*), Hyrtl's Tandan (*Neosilurus hyrtlii*), Bony Bream (*Nematalosa erebi*) and the Indonesian Short-finned Eel (*Anguilla bicolor*) (**Table 12**). The remaining two species, comprising the Milkfish (*Chanos chanos*) and the Common Silverbiddy (*Gerres subfasciatus*) are of estuarine/marine origin (**Table 12**). The juveniles of these species utilise the freshwater reaches of coastal rivers as refugia, before migrating to the ocean to complete their life cycle (Allen *et al.* 2002; Morgan and Gill 2004).

Diversity was highest at Yule River site YR1 (five species), with no fish recorded from Turner River site TRD2 during the Survey (**Table 12**). Site YR1 is a permanent, deep waterbody with high habitat heterogeneity that includes submerged and emergent macrophytes, large woody debris and overhanging branches and vegetation, supporting both freshwater and marine/estuarine vagrant species. Comparatively, Turner River site TRD2 was a shallow, wide waterbody with limited in-stream habitat complexity. According to the results of the dual phase baseline study (Stantec 2022) and regional Pilbara surveys (Masini 1988; Morgan *et al.* 2009; Morgan and Gill 2004), the Turner River supports fewer fish species (ten species recorded to date), than the Yule River (16 species recorded to date) (**Table 12**).

The fish species recorded during the Survey comprised common, ubiquitous species with broader distributions throughout the Pilbara region (with many extending beyond the region) (Allen *et al.* 2002; Morgan *et al.* 2014a; Morgan and Gill 2004; Morgan *et al.* 2014b). For example, *Melanotaenia australis*, *Leiopotherapon unicolor* and *Nematalosa erebi* are among the most ubiquitous species in the Pilbara region, known from all major river systems (Morgan *et al.* 2014a; Morgan *et al.* 2009; Morgan and Gill 2004). More broadly, *Leiopotherapon unicolor* and *Nematalosa erebi* are two of Australia's most widespread fish species, with distributions spanning drainages of the Kimberley, Northern Territory, Queensland, Murray-Darling basin and Lake Eyre (Morgan *et al.* 2014b). This can be ascribed to their ability to withstand extreme variations in water quality, and high fecundity, with protracted spawning periods extend over many months (Allen *et al.* 2002; Morgan and Gill 2004).

While the dual phase baseline study found Tarpon (*Megalops cyprinoides*) to be the most frequently recorded estuarine species, the marine/estuarine vagrant species Milkfish (*Chanos chanos*) and the Common Silver-Biddy (*Gerres subfasciatus*) were the most dominant species during this Survey (each recorded from one site) (**Table 12**). Although the Common Silver-Biddy has previously been documented in the system (Masini 1988; Morgan *et al.* 2009; Morgan and Gill 2004), Milkfish have only been recorded from the dual phase baseline study (Stantec 2022) and constitute a new record for both the Turner and Yule Rivers (**Table 12**). Milkfish and the Common Silver-Biddy are common and widespread species in the tropical and warm temperate waters of the Indo-Pacific region and occasionally penetrate freshwater systems (Allen *et al.* 2002; Morgan and Gill 2004).

During the Survey, the Turner River generally exhibited low fish diversity, which was likely driven by the increased habitat availability resulting from the high flows prior to sampling dispersing fish more widely throughout the river. There was also a notable decline in diversity between the dry and wet seasons of the dual phase baseline survey, likely due to the prevailing dry conditions and recession of pools, limiting habitat and food availability.

One fish species of conservation significance has been recorded from the Yule River; the Indonesian short-finned eel, *Anguilla bicolor*, which was recorded from site YR1 during the dual phase baseline study and again during this Survey (**Table 12**). This species is the only representative of the family Anguillidae (freshwater eels) known from Western Australia, and is only known from the Fortescue, De Grey and Yule Rivers in the Pilbara, including a single location upstream of MGP tenure near site YRU1-A (Morgan and Gill 2004). The species has a widespread distribution across coastal rivers of the Indo-Pacific region, however, it is listed as Near Threatened on the IUCN Red List of Threatened Species, as it is targeted widely for human consumption and leather products across Asia (Pike *et al.* 2020). Given its broad range, and the limited harvesting of this species locally, *Anguilla bicolor* is considered to be of minor conservation risk in Australia (Shelley *et al.* 2018).

Table 12: Fish taxa diversity and abundance recorded during the Survey (July 2022), compared to fish species previously recorded from the Turner and Yule Rivers (Masini 1988; Morgan *et al.* 2009; Morgan and Gill 2004; Stantec 2022).

Fish Species		Turner River				Yule River		Previous Surveys (including dual phase baseline study)	
Common Name	Scientific Name	TRE2	TRU1	TR1	TRD2	YR1	YRD1	Turner River	Yule River
Freshwater Species									
Western Rainbowfish	<i>Melanotaenia australis</i>							✓*	✓*
Spangled Perch	<i>Leiopotherapon unicolor</i>	✓	✓	✓		✓	✓	✓*	✓*
Barred Grunter	<i>Amniataba percoides</i>								✓*
Hyrtl's Tandan (Eel-tailed Catfish)	<i>Neosilurus hyrtlii</i>					✓			✓*
Bony Bream	<i>Nematalosa erebi</i>	✓		✓		✓	✓	✓*	✓*
Empire Gudgeon	<i>Hypseleotris compressa</i>							✓	✓*
Indonesian Short-finned Eel	<i>Anguilla bicolor</i>					✓			✓*
Estuarine/Marine Species									
Banded Scat	<i>Selenotoca multifasciata</i>							✓*	✓*
Tarpon	<i>Megalops cyprinoides</i>							✓*	✓*
Milkfish	<i>Chanos chanos</i>	✓						✓*	✓*
Common Silver-Biddy	<i>Gerres subfasciatus</i>					✓		✓*	✓*
Threadfin Silverbiddy	<i>Gerres filamentosus</i>							✓*	
Mangrove Jack	<i>Lutjanus argentimaculatus</i>							✓*	✓*
Sea Mullet	<i>Mugil cephalus</i>							✓*	
Giant Herring	<i>Elops hawaiiensis</i>								✓
Yellow-tail Trumpeter	<i>Amniataba caudavittata</i>								✓
Barramundi	<i>Lates calcarifer</i>								✓
Diversity		3	1	2	0	5	2	6	13

Note: *Collected during the dual phase baseline study.

Other Vertebrate Fauna

A total of four waterbird species were recorded from the Turner and Yule Rivers during the Survey, with the highest diversity (two species) found in Turner River site TRU1 and Yule River site YRD1 (**Table 13**). The most common and widespread species was the black-fronted dotterel (*Charadrius melanops*), recorded from two sites (TRU1 and TRD2; Turner River) (**Table 13**). The black-fronted dotterel is a ubiquitous species in the Pilbara region, known from flowing and standing water bodies, including artificial habitats (Bell et al. 2014). They are usually seen in small numbers (consistent with this Survey), or occasionally as small flocks (Storr 1984). This species was also widespread during the dual phase baseline study. The remaining waterbird species recorded were also common and widespread species that have been previously been recorded from the Turner and Yule Rivers (Masini 1988) and/or the broader Pilbara region (Johnstone et al. 2013).

Compared to the dual baseline study, waterbird diversity during the Survey was notably lower, likely due to the high flows prior to the July sampling. Flooding and high flow conditions are known to influence waterbird abundance and diversity, with waterbirds known to move to other areas as refugia during these periods and only moving back once these flows and conditions have ceased (Wang et al. 2019).

One species of freshwater turtle; the dinner plate turtle (*Chelodina steindachneri*), was recorded from the Turner and Yule Rivers during the dual phase baseline study (Stantec 2022) and is not considered of conservation significance. This is the only freshwater turtle species known from the Pilbara region, where it is widespread, with a distribution that extends to the Gascoyne, and is not listed for (Kuchling 1988). As an arid zone specialist, *C. steindachneri* can survive periods of drought (Kuchling 1988), and are commonly found in ephemeral creeklines, however, they also utilise semi-permanent/permanent pools, where they prey on fish, invertebrates and frogs (Kuchling 1988). However, this species was absent during this Survey, as was the Pilbara olive python (*Liasis olivaceus barroni*), for which anecdotal records exist from the Turner River (Stantec 2022).

Previously (during the dry season survey of the baseline study), the desert tree frog *Litoria rubella*, has also been recorded from the Turner River (site TR1) and is a common and widespread species across the arid regions of Australia (Tyler and Doughty 2010). However, no frogs were observed during this Survey. A total of 12 species of frog from two families (Hylidae and Myobatrachidae) are known from the Pilbara region (Tyler and Doughty 2010). However, as the majority are nocturnal, these results may reflect survey timing, and the preference of most species to breed in still freshwaters.

Table 13: Reptile, amphibian and waterbird taxa recorded during the Survey (July 2022).

Species		Turner River				Yule River	
Common Name	Scientific Name	TRE2	TRU1	TR1	TRD2	YR1	YRD1
Reptiles							
Dinner Plate Turtle	<i>Chelodina steindachneri</i>						
Frogs							
Desert Tree Frog	<i>Litoria rubella</i>						
Waterbirds							
Pacific Black Duck	<i>Anas superciliosa</i>		✓				
Black-fronted Dotterel	<i>Charadrius melanops</i>		✓		✓		
Little Pied Cormorant	<i>Phalacrocorax melanoleucos</i>						✓
Australasian Darter	<i>Anhinga novaehollandiae</i>						✓
Diversity		0	2	0	1	0	2

Summary

The Turner and Yule Rivers are ephemeral systems, typically only flowing for short periods following intense, usually seasonal rainfall. While both rivers support permanent/semi-permanent pools, which are surface expressions of groundwater, the Yule River is characterised by larger pools, with greater permanency. These pools provide important refugia for aquatic biota in an otherwise arid landscape. Prior to this Survey, however, high rainfall caused surface water flows, which rapidly ceased, resulting in a series of disconnected yet substantial-sized waterbodies during sampling.

Water and sediment quality during the Survey was consistent with regional Pilbara rivers, characterised by circumneutral to alkaline pH, freshwater conditions, and low nutrient and metal concentrations due to recent flooding. Dissolved metals comprising Cr and Zn were naturally elevated above ANZG (2018) DGVs, and U exceeded the ANZG (2018) freshwater low reliability trigger value (indicative only). There were no exceedances of trigger values for sediment quality during the Survey. Typically, water and sediment quality were more homogenous during the Survey, compared to the dual phase baseline study, reflecting recently flooded conditions.

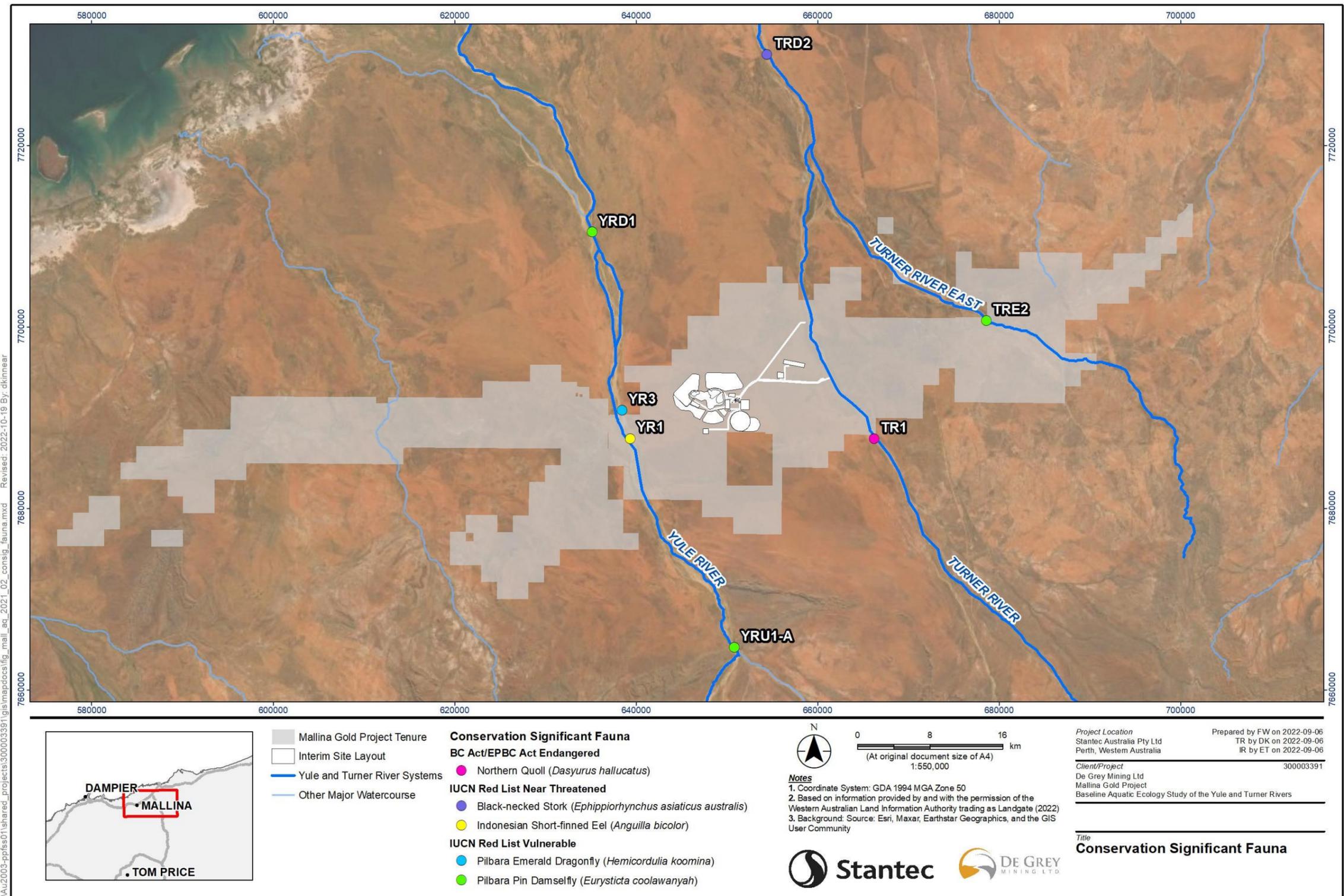
The flooded conditions also resulted in reduced diversity of aquatic biota (macrophytes, algae, invertebrates, and vertebrate taxa) recorded during the Survey compared to the dual phase baseline study, although the assemblage was relatively consistent across sites. This was driven by the preceding high flows creating homogenous conditions. It is likely that the diversity and abundance of aquatic biota would have continued to increase as conditions in the pools stabilised over time, with increased colonisation by a variety of biological groups.

The majority of macrophyte, algal, invertebrate, and vertebrate taxa recorded during the Survey have broader distributions throughout the Pilbara, northern-Australia, or Australia, with few listed for conservation significance. Exceptions included the following species recorded during the Survey (**Figure 4**):

- damselfly *Eurysticta coolawanyah*, recorded from Turner River East site TRE2, and is considered endemic to the Pilbara and listed as Near Threatened on the IUCN Red List; and
- Indonesian short-finned eel, *Anguilla bicolor*, which was recorded from Yule River site YR1, and is listed as Near Threatened on the IUCN Red List.

Both species have also previously been identified from these sites during the dual baseline study. No other species of conservation significance were either collected or observed during the Survey, although additional listed and endemic aquatic invertebrate taxa have been recorded from the Yule River during the dual phase baseline study.

Sites sampled on the Turner River during the Survey were characterised by large, surface water pools, in contrast to small, remnant pools during the dual phase baseline study. The waterbodies of the Yule River were more substantial in size across all surveys and support higher ecological values, providing an important refugia in prolonged dry conditions. In addition, there have been no state or federally listed conservation significant aquatic biota taxa that have been recorded from the Turner River during any of the surveys. The results of this Survey support the dual phase baseline study, with the **preliminary risk** to aquatic biota from proposed MGP discharge to the Turner River considered to be **low**, due to the resilient, widespread biological assemblage recorded and the expected temporary nature of the discharge.



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Figure 4: Distribution of conservation significant species recorded during the Mallina Gold Project (November 2021, May 2022 and July 2022).

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