Thunderbird Mineral Sands Project
Baseline Surface Hydrology Study

Prepared for:

Sheffield Resources Limited

October 2016

Prepared by:

Martinick Bosch Sell Pty Ltd
4 Cook Street
West Perth WA 6005
Ph: (08) 9226 3166
Fax: (08) 9226 3177
Email: info@mbsenvironmental.com.au
Web: www.mbsenvironmental.com.au

MBS Environmental

environmental and geoscience consultants

THUNDERBIRD MINERAL SANDS PROJECT BASELINE SURFACE HYDROLOGY STUDY

Distribution List:

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Sheffield Resources	Wayne Groeneveld (Sustainability Manager)	Electronic Only	01/10/2016

Document Control for Job Number: TBSHB

Document Status	Prepared By	Authorised By	Date
Draft Report	Michael Dufty	James Cumming	10/05/2016
Final Report	Michael Dufty	James Cumming	01/10/2016

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1. INTRODUCTION

1.1 BACKGROUND

The Thunderbird Mineral Sands Project (Thunderbird Project) is proposed to be developed by Sheffield Resources Limited (Sheffield Resources, or the Proponent). Sheffield Resources is a mineral sands-focused explorer and developer, headquartered in Perth, Western Australia.

The Thunderbird Project is located on the Dampier Peninsula within the west Kimberley region of Western Australia. It is located approximately 75 km west-southwest of Derby and 95 km northeast of Broome (Figure 1) and is accessed from the Great Northern Highway via a 32 km long site access road. It is situated within the Mt Jowlaenga Pastoral Lease.

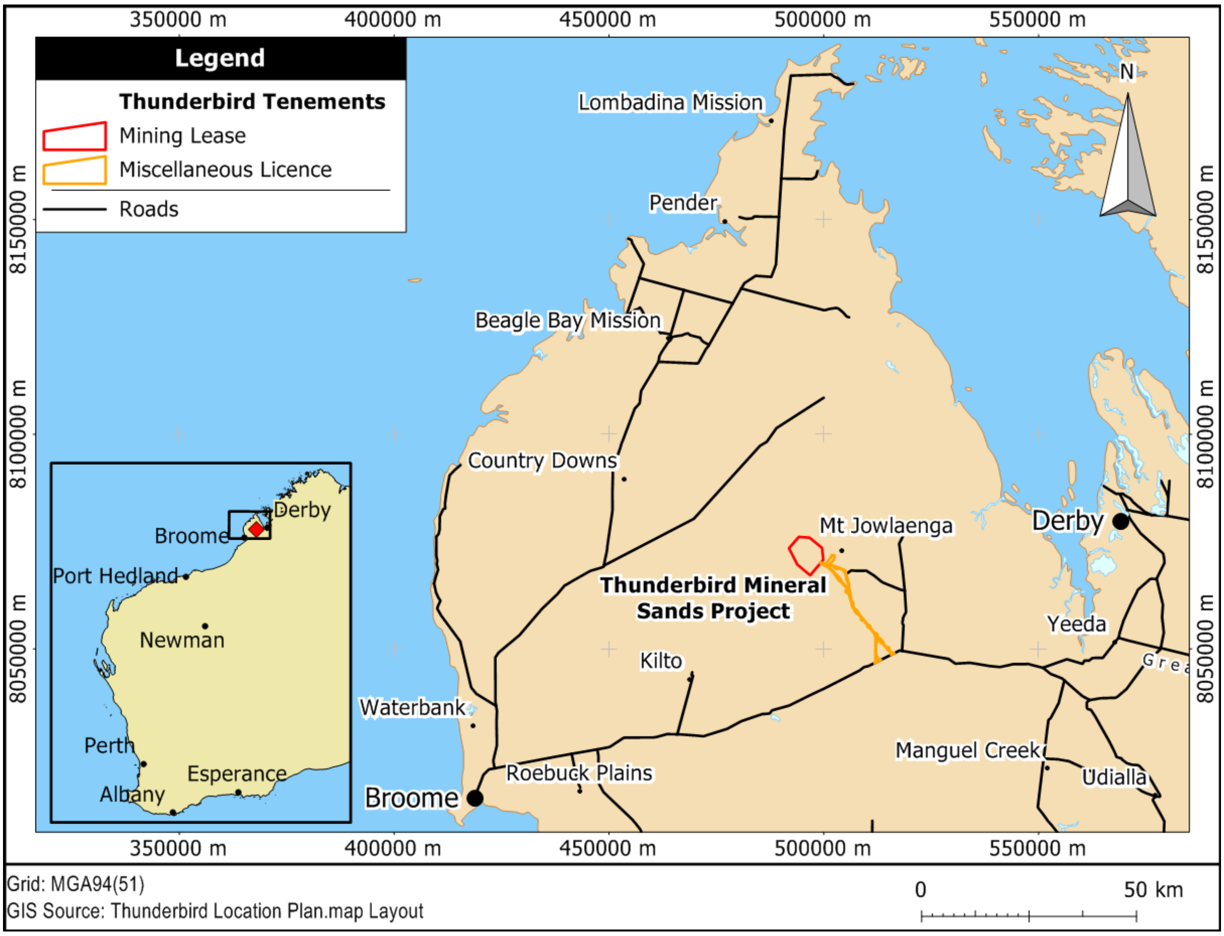

Figure 1: Thunderbird Project Location

1.2 PROJECT DESCRIPTION

The Thunderbird Project will comprise mining of heavy mineral sands over a 47 year life of mine from the Thunderbird deposit and processing onsite before transportation of heavy mineral sand product (ilmenite, zircon, and HyTi88 leucoxene) by road to Derby Port for storage and subsequent export to overseas markets.

The mining method will be progressive, using conventional mineral sand mining and backfill techniques with no blasting required (use of standard earthmoving equipment only). It is proposed that up to 100 ha of pit will be open at any given time, with mined areas undergoing progressive backfilling and rehabilitation. Proposed processing methods and equipment are standard within the mineral sands industry. Mineral sands will initially be screened at the active mine face before being transferred in a slurry form to a primary processing plant located in close proximity to the active mining face. This plant, referred to as a Wet Concentrator Plant (WCP), separates the heavy minerals from the sand by means of water and gravity to produce a heavy mineral concentrate (HMC). No chemicals are added during this process. The WCP will likely be moved a number of times during the project life to minimise slurry piping distances as the active mining face moves over time. Process water will be supplied from local groundwater resources that are hydrogeologically linked to the orebody. All water will be recycled using a nearby dam for storage.

A secondary processing plant will be used to separate the different minerals from the HMC. This plant, referred to as the Mineral Separation Plant (MSP) will be located away from the mining area and will incorporate a combination of gravity, magnetic, chemical, low temperature roasting and electrostatic separation processes.

Uneconomic sands and other waste streams from the MSP will initially be stored within a conventional above ground tailings storage facility (TSF), but once there is sufficient mine void storage capacity, all mine waste material will be returned to mined out areas as backfill material.

A preliminary site layout for the Thunderbird Project is shown in Figure 2. Although aspects of the project will vary as designs are finalised, the major components will be similar. Major components include:

- Mine Pit – to be developed in stages and progressively backfilled.
- Wet Concentrator Plant (to be relocated during operations to remain close to active pit).
- Mineral Separation Plant.
- Tailings Storage Facility.
- Support facilities – power, workshops, borefield, roads.
- Accommodation camp and waste water treatment plant.
- Access road.

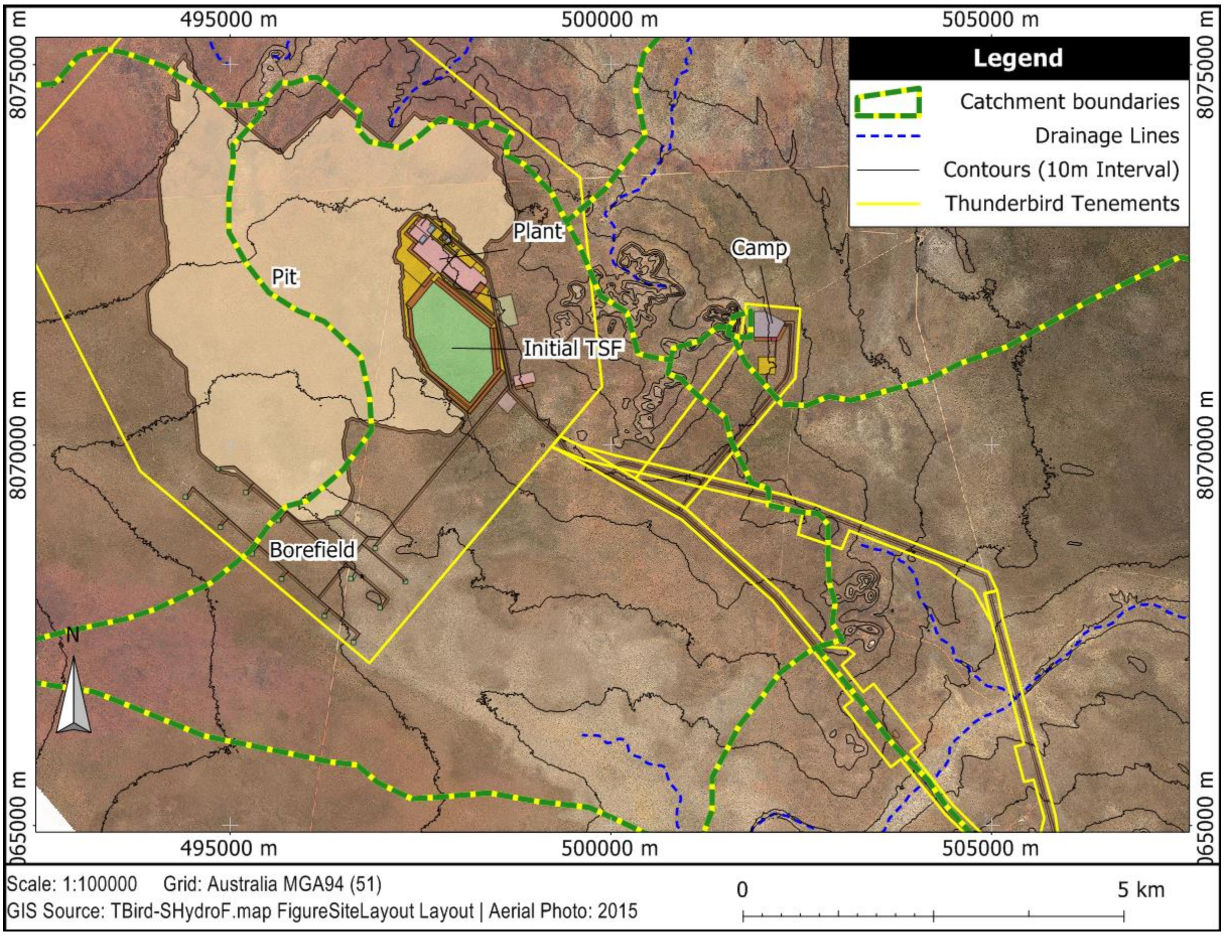

Figure 2: Preliminary Site Layout

1.3 OBJECTIVES

The objective of this report is to provide baseline surface hydrological data to characterise the existing hydrological regime, to aid in identifying potential impacts associated with development of the Thunderbird Project and support environmental approvals for the Thunderbird Project. This includes:

- Identifying catchment boundaries within the project area and upstream.
- Identifying flow paths downstream of the project area to allow assessment of dilution and potential impacts of discharge from the project area.
- Characterising the regional hydrology and potential for flooding as a result of surface runoff.
- Characterising potential runoff volumes from upstream catchments and operational areas.
- Identifying potential risk of flood impacts on operations.
- Identifying the potential impact of project related activities on the surface water environment.

2. REGIONAL HYDROLOGY AND CATCHMENTS

2.1 REGIONAL SETTING

The Thunderbird Project, located on the Dampier Peninsular, is within the west Kimberley region of Western Australia, approximately 75 km west-southwest of Derby and 95 km northeast of Broome (Figure 1). The Thunderbird Project is located on sandy soils with low runoff generation and there are no defined watercourses within the main mine development areas. The nearest watercourse is the Fraser River South, which has a small visible channel from approximately 4 km downstream of the mineral deposit area. There are no year round surface water bodies within the Thunderbird Project area. The nearest ephemeral pools are approximately 25 km downstream on Fraser River South.

It is within the National Catchments Boundaries (NCB) Level 2 Cape Leveque Coast River Region of the NCB Level 1 Tanami-Timor Sea Coast Division (Stein et al, 2011). The Cape Leveque Coast River Region consists of several river systems draining to the coast and extending up to approximately 100 km inland. All of the catchments of the project area drain east to King Sound (Figure 3). The Thunderbird Project lies within the catchments of Fraser River, Fraser River South and Little Logue River. While the Fraser River enters King Sound from the west, Little Logue River discharges via Logue River to King Sound at Jarrananga Plain immediately adjacent to the Fitzroy River. The adjacent Fitzroy River Basin is a much larger river basin extending approximately 500 km inland and representing the primary surface water inflow to King Sound.

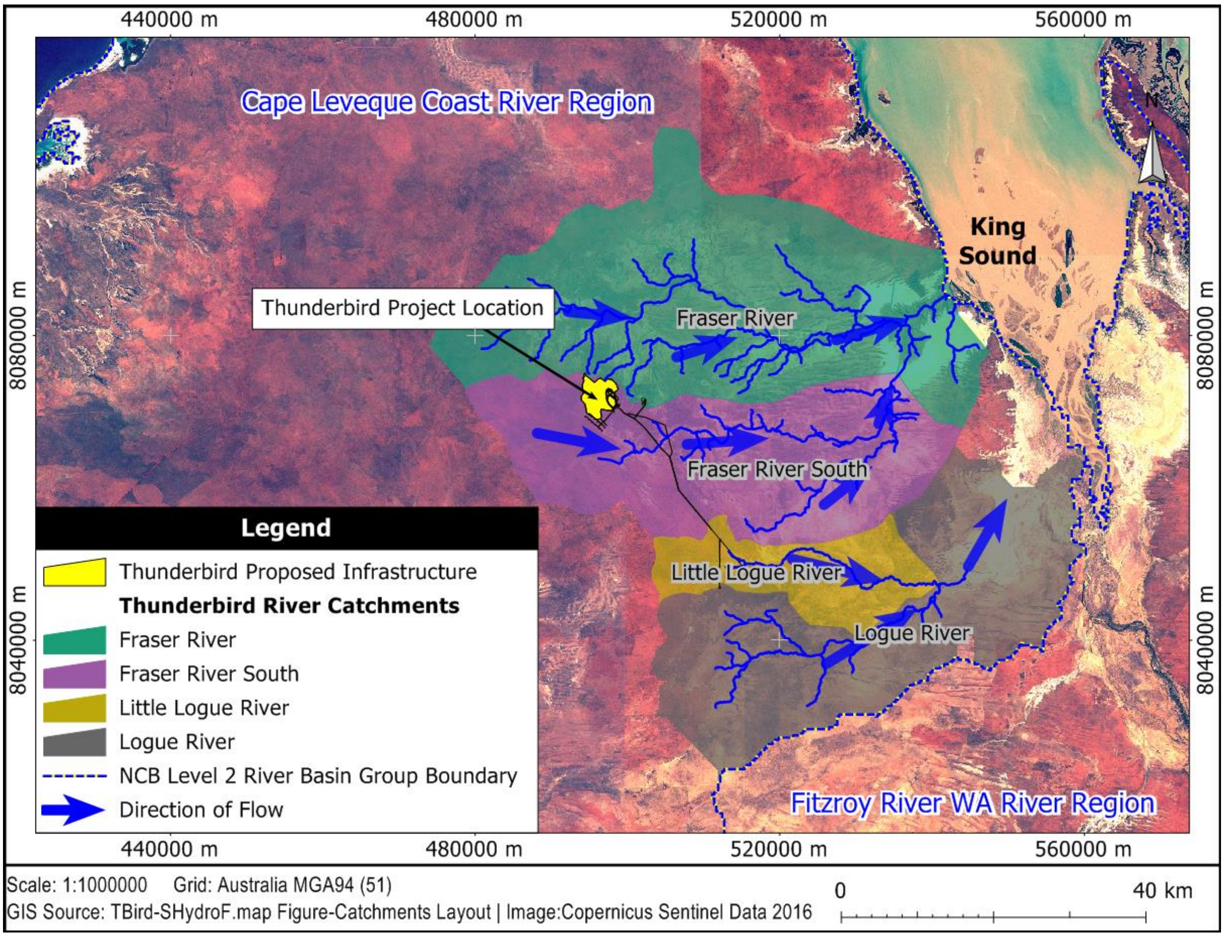

Figure 3: River Catchment Boundaries

The NCB are based on the National Catchment Database and are the foundation for the Bureau of Meteorology's (BoM) Australian Hydrological Geospatial Fabric (Geofabric) framework. These frameworks are an update to previous work of the Australian Water Resources Council and are intended to be used as a standard for hydrological reporting and thus replace the Australian River Basins 1997, which placed the Logue River Catchment in the Fitzroy River Region.

2.2 RIVER CATCHMENTS

The Thunderbird Project area includes catchments of the four named rivers as discussed in Section 2.1 and shown in Figure 3. These comprise:

- Fraser River (total catchment area 1,529 km^2).
- Fraser River South (total catchment area 1,024 km^2).
- Little Logue River (total catchment area 323 km^2).
- Logue River (total catchment area 1,056 km^2).

The majority of the Thunderbird Project is within the Fraser River South catchment. The proposed pit location extends slightly into the Fraser River catchment and the proposed accommodation camp location is entirely within that catchment. The Logue and Little Logue River catchments are crossed by the site access road and do not contain any other project infrastructure.

2.3 TOPOGRAPHY

The topography of the Thunderbird Project catchments is largely comprised of flat sandy plains with some small rocky hills approximately 50 metres high. The rocky hills are confined to an area of approximately 3 km^2 between the proposed operations and accommodation camp areas (Figure 2). The gradient of the plains is flattest at the western side of the project catchments (averaging approximately 0.75%) tending to increase to approximately 1% to the east.

2.4 REGIONAL STREAMFLOW DATA SOURCES

The Department of Water operates a number of streamflow monitoring stations in the Kimberley, however none of these are located on the Dampier Peninsula or within the Thunderbird Project catchments. Ten stations are located within 250 km of the Thunderbird Project, however these are only of limited value in assessing the hydrology of the project area due to distance from site, catchment size and differences in topography and soils giving rise to higher rates of runoff. Table 1 lists the nearest streamflow monitoring sites to the project area and one additional station with relevance to regional stream flows.

The last site listed in Table 1, located 684 km away in the Northern Territory, has been included due to the low yielding characteristics and deep sandy soil that it has in common with the project area. CSIRO used parameters from this site for modelling of the Dampier Peninsula catchments in their review of water resources for the Timor Sea Drainage Division carried out in 2009 as part of the Northern Australia Sustainable Yields (NASY) project (CSIRO, 2009). This was done based on the similarity of catchment characteristics and anecdotal information that runoff on the Dampier Peninsula is very low. Despite the similarities, their level of confidence in modelling of the peninsula was categorised as “low” due to the uncertainties in applying parameters from a catchment so far away.

Table 1: Regional Streamflow Monitoring Sites Summary

Station Number	Station Name	River	Distance (km) from Thunderbird Project	Catchment Area (km²)	Years of Data	Date Closed
802008	Willare	Fitzroy	80	91,902	17	Open
802007	Looma (Kings Bore)	Fitzroy	147	78,372	18	Open
803122	Kimberley Downs	Lennard	176	6,470	9	1967
802003	Camballin Barrage	Fitzroy	183	73,293	35	Open
802004	Ellendale	Mt Wynne Creek	202	722	29	Open
803003	Dromedary	Fletcher	218	66	32	1999
803001	Mt Joseph	Lennard	228	1053	39	2005
802006	Noonkanbah	Fitzroy	232	61,540	18	Open
803002	Mt Herbert	Lennard	242	439	38	2005
804002	Panta Downs	Charnley	252	3,985	26	1999
8100106	Weaber Range	Border Creek	684	1,015	44	Open

2.5 SOILS

The Thunderbird Project and study catchments are located on sand plains including Pindan with some areas of sandstone outcrops and irregular sand dunes. Australian Soils Resource Information System (ASRIS) Level 4 soil mapping (CSIRO, 2016) indicates sandy surface soil and sand or sandy loam subsoil over the project catchments. This is reflected in the high hydraulic conductivity of over 200 mm/hr in the surface layers of the ASRIS Level 4 data. The small hills with sandstone outcrops will have less hydraulic conductivity, but make up a very small proportion of the catchment area.

2.6 RUNOFF COEFFICIENTS AND CATCHMENT YIELD

The CSIRO modelling for the NASY project indicates average annual runoff coefficients of 0.00 to 0.07 for the Dampier Peninsula (Petheram et. al., 2009). This is the lowest value for the entire Northern Australia region covered by the study (Figure 4). Runoff coefficients over the remainder of the Fitzroy region, where better calibration data was available, varied from 0.08 to 0.25.

The majority of rainfall and runoff occurs in the months of December to April.

The CSIRO NASY modelling indicated annual average runoff values for the Dampier Peninsula between 15 and 80 mm per year for long term average rainfall conditions (CSIRO, 2009).

The runoff coefficients discussed above are annual averages useful for estimating long term yield of the catchments. Substantially higher coefficients are possible for short periods during individual rainfall events, but runoff rates will still be low relative to other parts of northern Australia.

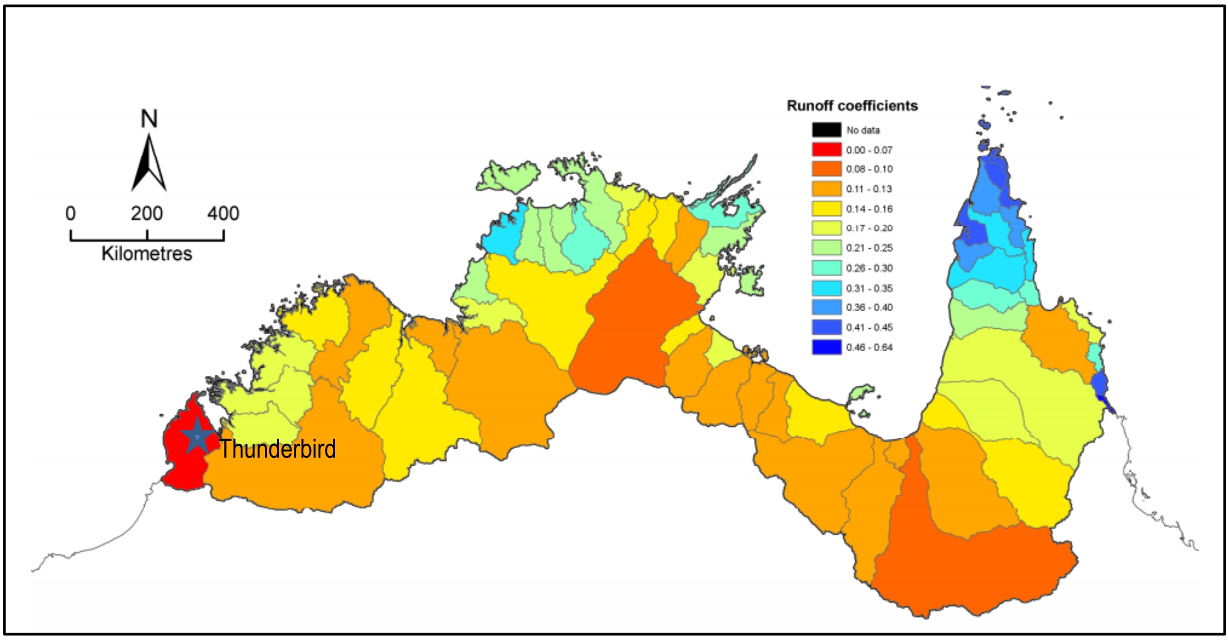

Figure 4: Runoff Coefficients for Northern Australia from Petheram et. al. (2009)

3. WATER QUALITY

No surface water quality monitoring data is available for the Thunderbird Project area or elsewhere on the Dampier Peninsula. Given the lack of industry and other sources of potential contamination, surface runoff is expected to be of good quality suitable for livestock and agricultural use.

All watercourses in the Thunderbird Project area remain dry during the dry season. Some salinity records are available from the Fitzroy River where wet season river flows representing surface runoff quality are typically less than 250 mg/L and often less than 100 mg/L (Lindsay and Commander, 2005).

The nearest quality information available on the Statewide River Water Quality Assessment dataset (Department of Water, 2016) is for the Isdell River (Site 804001), 266km east of the Thunderbird Project, which had a median total dissolved solids (TDS) concentration of 106 mg/L and median pH of 7.97 for the period 2005 to 2007.

4. DOWNSTREAM WATER USES

4.1 WATER MANAGEMENT AREAS

There are no declared surface water areas (*Rights in Water and Irrigation Act, 1914*) in either the Thunderbird Project area or the Logue and Fraser River catchments.

The nearest Public Drinking Water reserves are near Broome and Derby, well outside the project catchments. The same is true for the Fitzroy River and Tributaries Irrigation area.

The Thunderbird Project is located within the Canning-Kimberley Groundwater Area.

4.2 LOCAL WATER USE

Local water use is primarily in support of environmental values and some pastoral use. Livestock and domestic water use is not required to be licensed meaning there is no quantitative data available on current water use.

Figure 5 shows the most significant water use locations identified downstream of the project area.

A minor surface expression of groundwater referred to as a 'soak' has been identified approximately 3 km southeast of the proposed pit. As part of their agreement with local indigenous people, Sheffield Resources currently maintains a 2 km buffer around this 'soak' which is left undisturbed. It is located off the main watercourses leading from the project area and will not receive surface runoff from the project area.

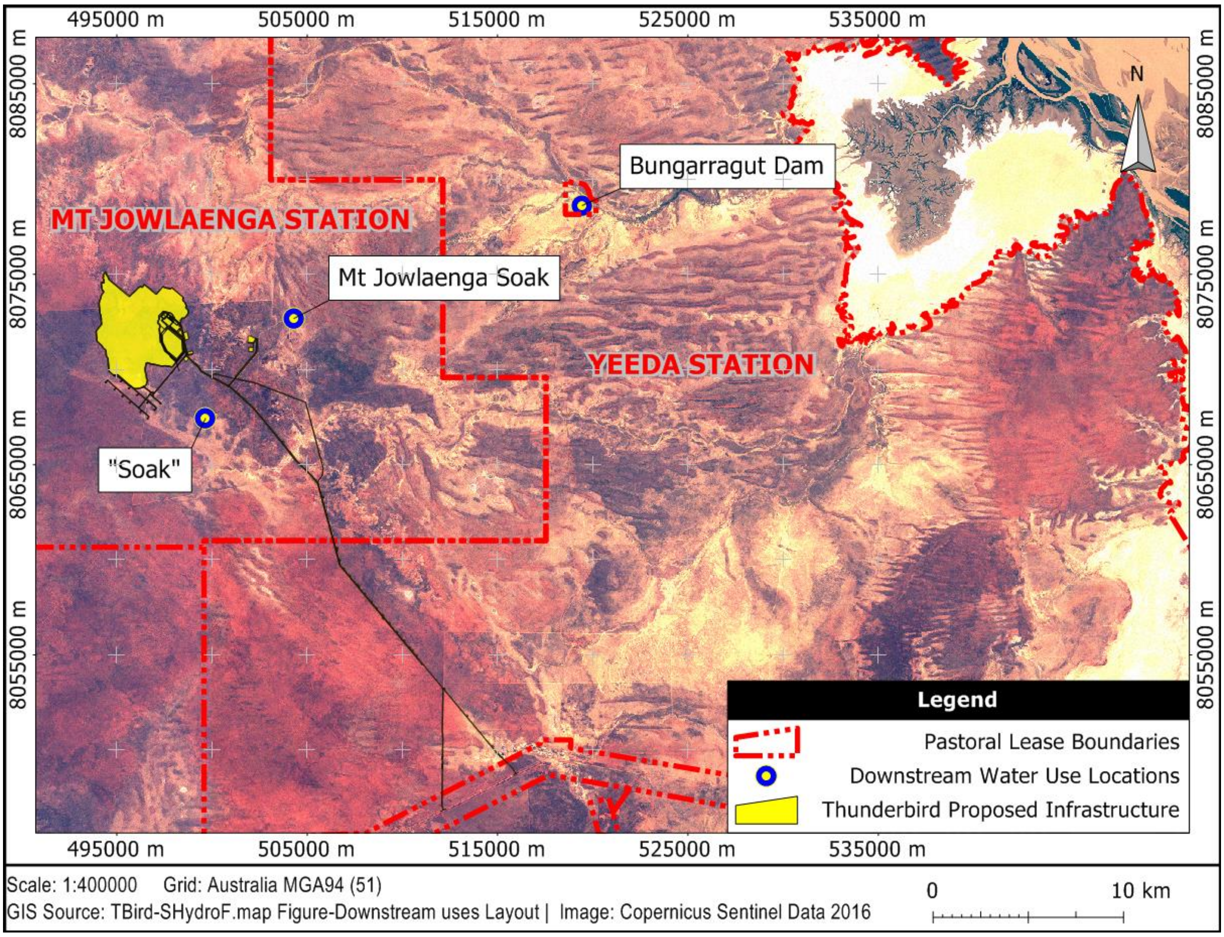

Figure 5: Downstream Water Use Locations

As shown in Figure 5, the Thunderbird Project and locations 15 to 20 km downstream are within Mt Jowlaenga Pastoral Station. Downstream of this is Yeeda Station which extends to the edge of the King Sound mud flats. Livestock on both stations are likely to utilise surface water for drinking when available.

There is little formal extraction of surface water for pastoral use. The natural depression adjacent to the abandoned Mt Jowlaenga Homestead appears to contain an excavated dam or soak for livestock use which is approximately 2 km downstream of the proposed accommodation camp location.

Bungarragut Dam is an off stream water storage facility for livestock water, located near Bungarragut Creek 24 km from the Thunderbird Project area, and not directly affected by runoff from the project area.

5. RAINFALL AND CLIMATE

5.1 CLIMATE

The Dampier Peninsula is in the western part of the Kimberley region. Most rainfall occurs during the wet season between November and April. Areal potential evapotranspiration is very high, averaging 1,980 mm per year and varies moderately across seasons. It generally remains higher than rainfall even in the wet season, resulting in water limited conditions for vegetation (CSIRO, 2009).

Weather data has been collected from an automatic weather station at the Thunderbird Project site since November 2014. Maximum and minimum temperatures and mean humidity are shown in Figure 6. This shows maximum temperatures generally between 35°C and 45°C. The minimum temperature rarely drops below 15°C. Average humidity is around 40% in the dry season and approaches 80% in the wet season. Days with maximum humidity over 90% have been observed in all months.

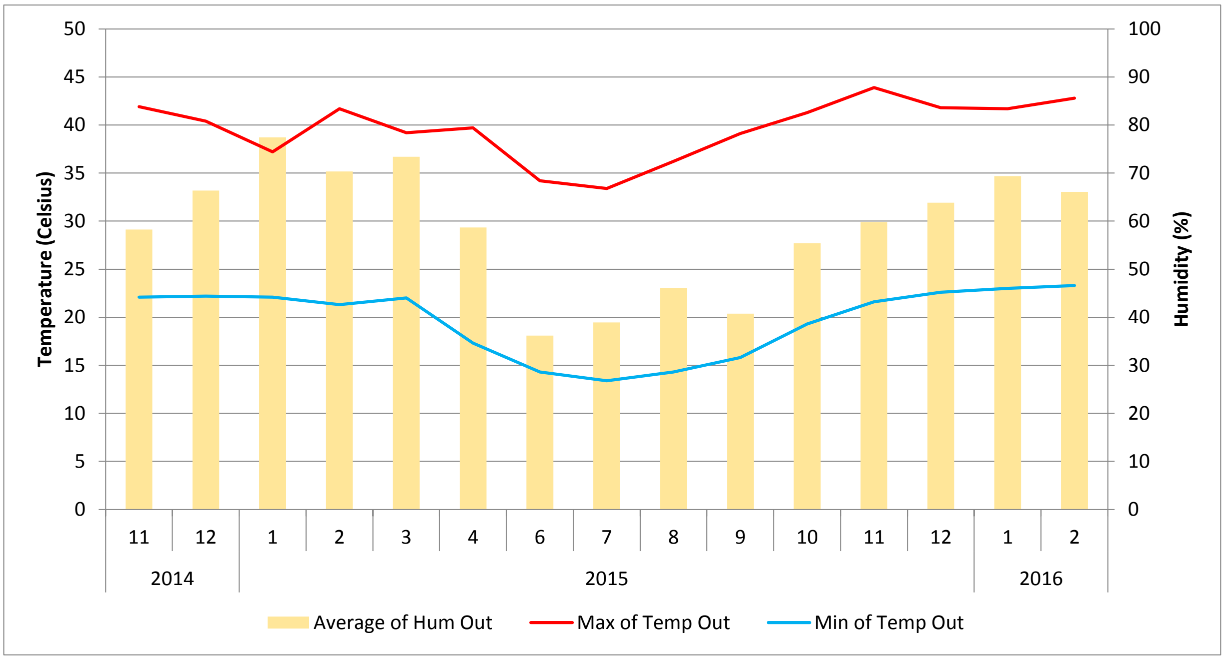

Figure 6: Thunderbird Project Temperature and Humidity

5.2 RAINFALL DATA

Table 2 lists the rainfall stations with useful records near the Thunderbird Project area and the station locations are shown in Figure 7. The current Thunderbird Project weather station is located approximately 4 km southeast of the proposed pit, and the Mount Jowlaenga station (closed in 2002) was a similar distance to the east. These are the best located sites, but have only a short period of record, less than 2 years for the current Thunderbird Project station and less than 10 years at Mt Jowlaenga.

The nearest stations with long term records are Kilto Station, Country Downs, Beagle Bay and Derby (Figure 7). All these stations show similar patterns of average rainfall over the long term, although there can be significant variation between the sites on any day due to local rainfall events. The highest daily and monthly rainfalls were recorded at Country Downs, which is among the closest, located 40 km to the west of the Thunderbird Project.

Table 2: Rainfall Records Near Thunderbird Project

Station Name	Distance from Thunderbird Project	Earliest Year of Records	Latest Year of Records	BoM Monitoring Site
Thunderbird	4 km	2014	2016	No
Mount Jowlaenga	4 km	1992	2002	Yes
Kilto Station	38 km	1962	2016	Yes
Country Downs	40 km	1969	2016	Yes
Beagle Bay	55 km	1902	2016	Yes
Yeeda	70 km	1890	2016	Yes
Derby Aero	70 km	1951	2016	Yes

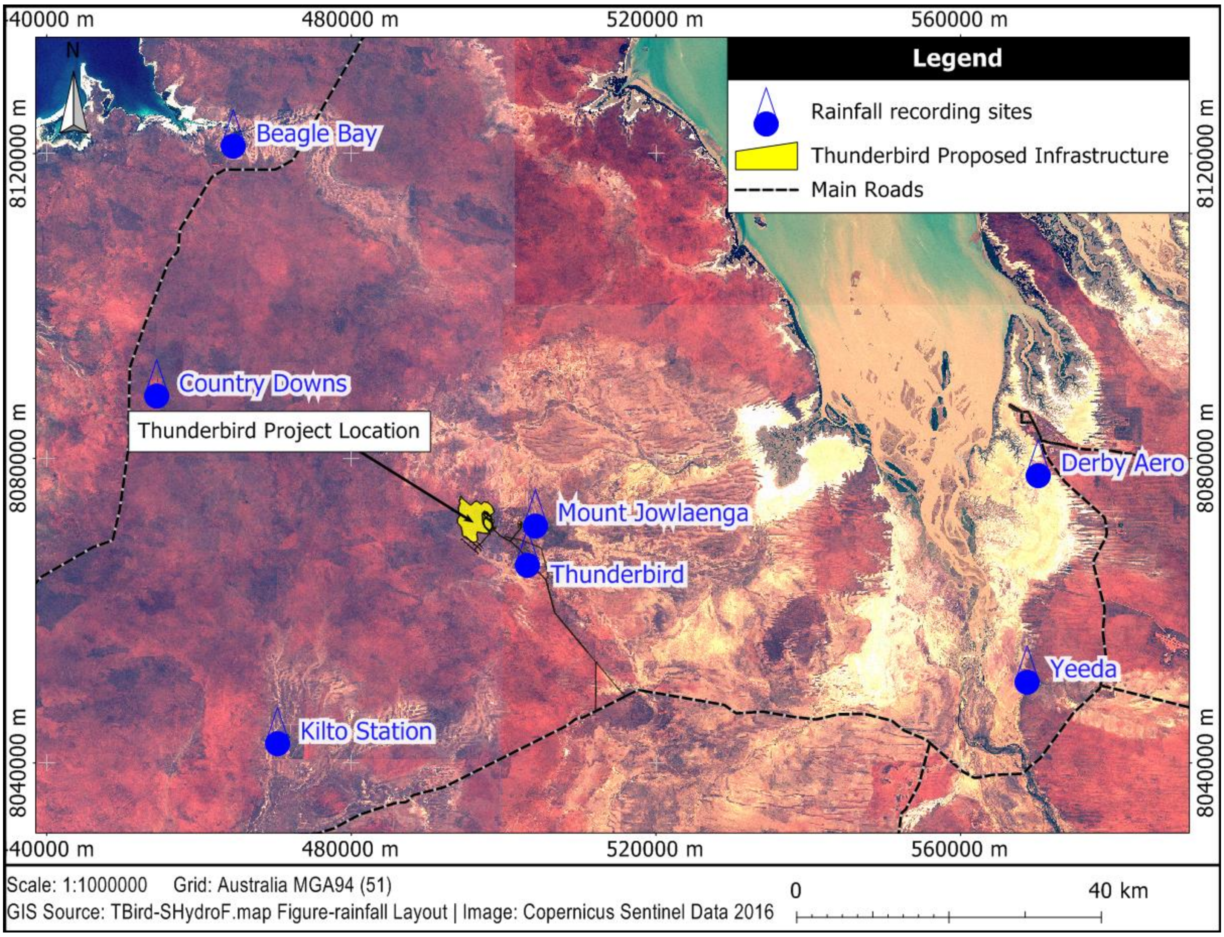

Figure 7: Rainfall Monitoring Station Locations

Spatially extrapolated rainfall and evaporation data is also available for the Thunderbird Project location from the SILO Data Drill data set (Queensland Government, 2016). This is a set of daily data calculated by extrapolation from all available BoM data, including the sites discussed above, to give a continuous estimated record for a specific location. The data in Data Drill are all synthetic; there are no original meteorological station data left in the calculated output. Comparison with local stations shows that, as expected, the Data Drill rainfall closely matches Mount Jowlaenga rainfall records when they were available, and is similar to Country Downs and other nearby stations at other times. In the period since 1997, the Data Drill mean annual rainfall is 839 mm, compared to 937 mm at Country Downs and 790 mm at Derby Aero. It is recommended the Data Drill dataset be used as the reference for long term rainfall patterns for the site.

Monthly rainfall statistics for the Thunderbird Project based on the Data Drill dataset from 1889 to 2015 are shown in Table 3 and Figure 8. The annual figures presented are based on a rainfall year from September to August. Mean annual rainfall is 695 mm. Rainfall is very variable with a lowest annual rainfall of 153 mm and a maximum of 1,503 mm. Median annual rainfall is 675 mm. Median monthly rainfall is 1.2 mm or less during the dry season from May to October. Zero or very low rainfall may occur in any month.

Table 3: SILO Data Drill Rainfall Statistics for Thunderbird Project 1889-2015 (mm)

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Annual
Mean	1.0	3.9	17.8	92.4	193.1	181.0	128.9	29.9	23.4	14.9	6.5	3.5	695.3
Highest	48.5	53.9	229.1	668.5	1,031.8	556.9	535.1	261.7	308.4	159.4	157.6	56.1	1,502.7
Decile 9	1.1	12.0	44.3	181.4	365.3	334.9	288.1	73.5	80.6	53.7	19.8	5.9	1,003.6
Median	0.0	0.3	8.4	66.1	156.6	164.7	96.7	12.4	0.9	0.3	0.0	1.2	675.2
Decile 1	0.0	0.0	0.3	10.8	54.7	47.0	26.0	0.0	0.0	0.0	0.0	0.7	401.2
Lowest	0.0	0.0	0.0	1.1	21.0	12.7	1.8	0.0	0.0	0.0	0.0	0.5	152.6

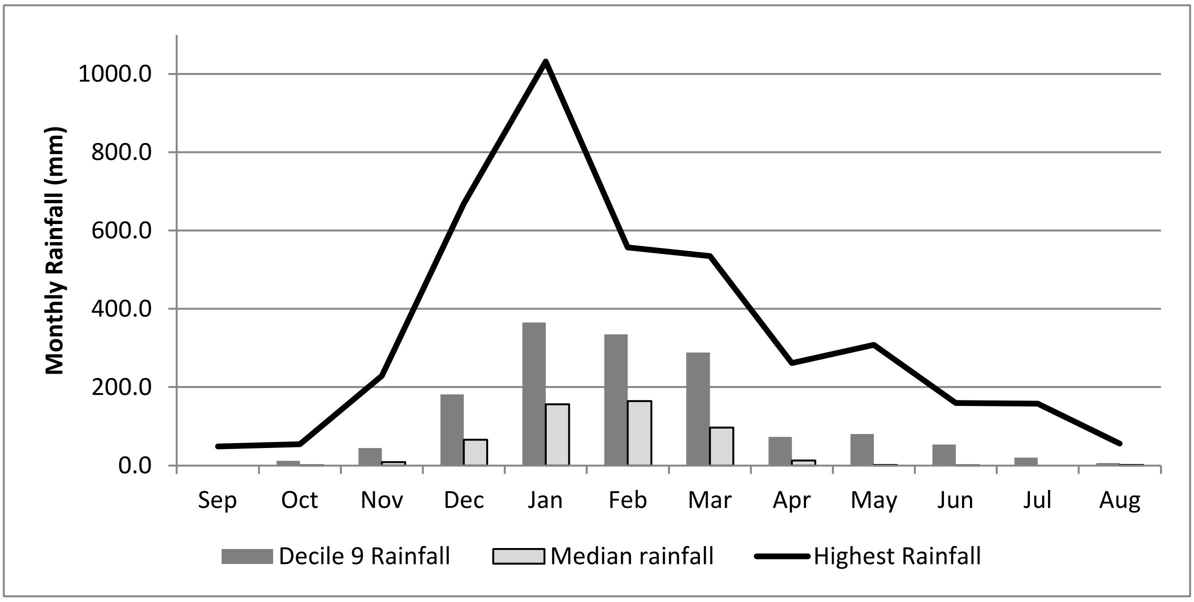

Figure 8: SILO Data Drill Monthly Rainfall Statistics for Thunderbird 1889-2015

As recent rainfall has been higher than the long term average, rainfall statistics for the period since 1997 have also been calculated and are shown in Table 4 and Figure 9. Mean, Median, Decile 1 and Decile 9 rainfalls are all noticeably higher over this period, indicating higher rainfall across wet, average and dryer than average years. The cause of the recent wetter trend is not known and it is not known whether it will persist for the life of the project.

Table 4: SILO Data Drill Rainfall Statistics for Thunderbird Project 1997-2015 (mm)

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Annual
Mean	0.4	11.7	23.4	117.0	226.2	223.0	173.2	27.3	15.8	19.0	12.4	3.1	839.3
Highest	5.0	45.3	53.7	237.7	518.0	466.1	477.8	114.8	96.5	159.4	157.6	26.5	1,230.3
Decile 9	0.3	35.0	41.2	206.0	344.7	382.3	350.4	85.6	82.0	77.3	28.8	6.1	1,148.1

Median	0.0	5.8	21.8	106.3	209.2	211.9	111.2	15.1	0.2	0.0	0.0	0.8	861.9
Decile 1	0.0	0.0	6.0	38.4	116.8	62.7	73.4	2.0	0.0	0.0	0.0	0.6	560.6
Lowest	0.0	0.0	0.4	15.0	65.2	38.3	48.8	0.0	0.0	0.0	0.0	0.6	267.3

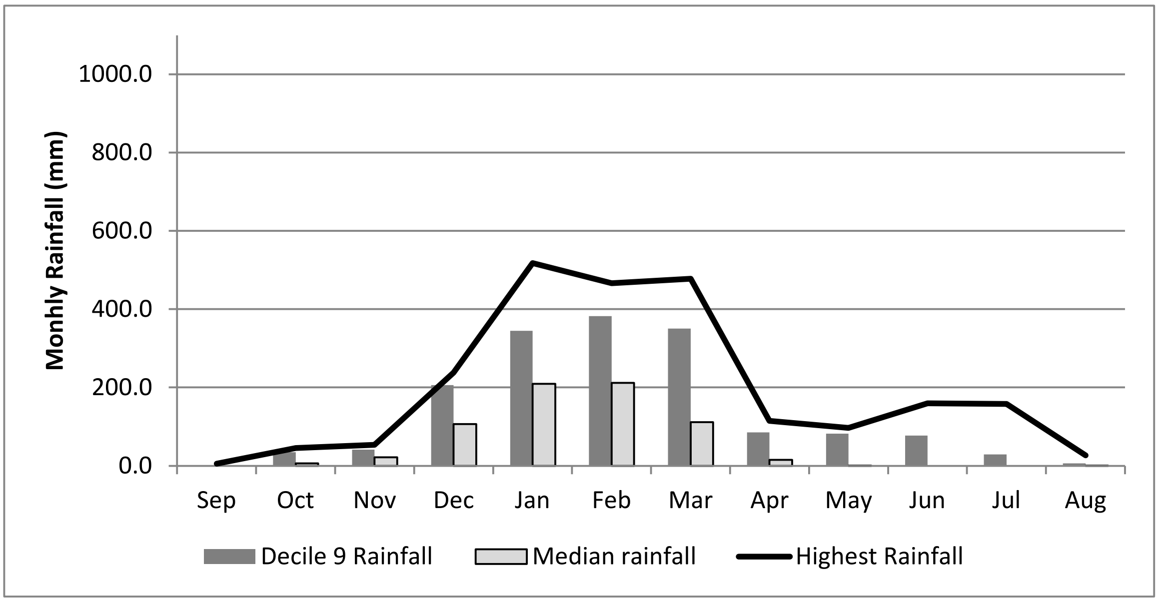

Figure 9: SILO Data Drill Monthly Rainfall Statistics for Thunderbird 1997-2015

5.3 EVAPORATION DATA

The Data Drill dataset includes daily pan evaporation data extrapolated from surrounding monitoring sites. Monthly pan evaporation statistics are shown in Figure 10 and Table 5. Mean monthly evaporation varies from a low of 241 mm in June to a high of around 355 mm from October to December. Mean evaporation is higher than mean rainfall throughout the year.

Table 5: SILO Data Drill Pan Evaporation Statistics for Thunderbird Project 1889 to 2015 (mm)

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Annual
Highest	267	302	300	295	265	222	233	230	221	192	209	230	2,922
Mean	320	356	352	355	323	284	313	295	296	241	253	282	3,413
Lowest	209	224	254	204	185	155	158	166	160	145	168	182	2,474

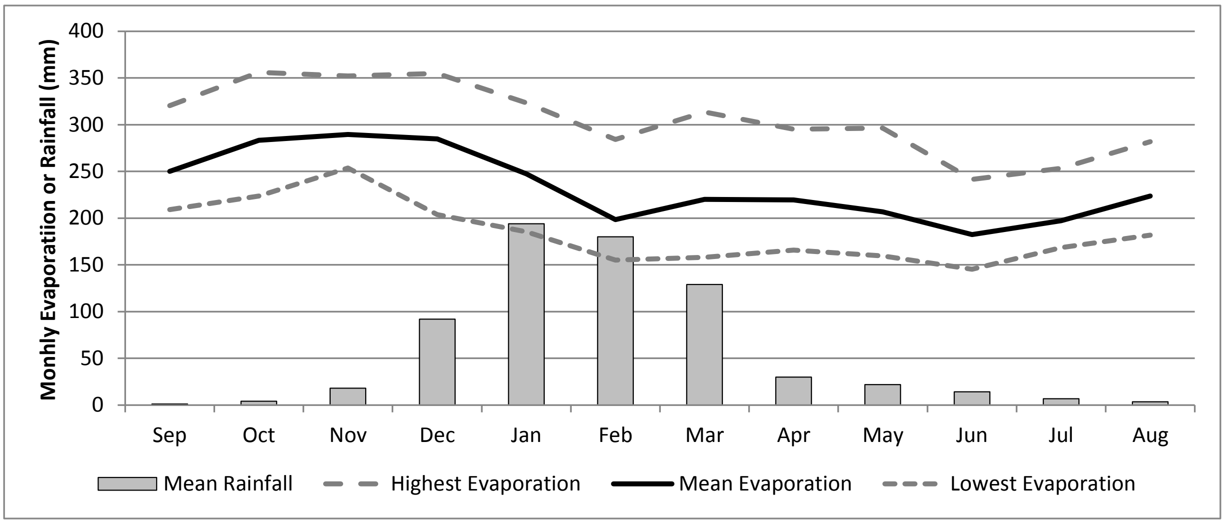

Figure 10: SILO Data Drill Monthly Evaporation Statistics for Thunderbird 1889 to 2015

5.4 POTENTIAL EFFECT OF CLIMATE CHANGE

The NASY Project study (CSIRO, 2009) found that recent rainfall (1996 – 2007) was significantly higher than historical rainfall across the Kimberley Region. Based on the Data Drill records for the Thunderbird Project, mean rainfall for the period from 1997 to 2015 is 20% higher than the long term average (1889-2015).

The NASY study considered possible future change to rainfall patterns based on climate modelling of high medium and low global warming scenarios. The results of 45 variants of models and global warning scenarios varied from a 19% decrease to a 4% increase in annual rainfall. The historical mean rainfall lies well within the range in values of the modelled climate variants. The seasonality of rainfall and areal potential evapotranspiration is not expected to change significantly.

5.5 RAINFALL INTENSITY

Rainfall Intensity Frequency Duration (IFD) data for the Thunderbird Project area is shown in Table 6 (BoM 2013). This data is from the 2013 revision of design rainfalls by BoM. It is the best currently available IFD data, but has the limitation that it cannot be used with the regional Probabilistic Rational Method from Australian Rainfall and Runoff (AR&R) (Pilgrim, 1987), which requires the 1987 Design rainfall to be used.

Table 6: Rainfall Intensity Frequency Duration Data for Thunderbird Project (BoM 2016)

Duration	Annual Exceedance Probability					
	50%	20%	10%	5%	2%	1%
1 hour	46.2	62.8	73.2	82.6	94.0	101.8
3 hour	61.9	88.2	105.1	121.1	141.2	155.8
6 hour	73.0	107.5	131.1	154.3	185.3	209.6
12 hour	87.8	133.4	166.7	201.1	250.1	290.8
24 hour	109.1	169.9	216.7	267.2	342	406.1
48 hour	138.8	219.0	282.2	351.7	455.9	544.7
72 hour	159.6	251.8	324.0	402.9	520.5	619.9
96 hour	175.0	274.8	351.6	434.6	557.1	661.1
120 hour	186.4	290.9	369.8	453.5	576.3	682.4
144 hour	194.9	302.1	381.1	463.6	584.0	691.2
168 hour	201.2	309.5	387.5	467.4	584.0	692.1

5.6 RARE TO EXTREME RAINFALL EVENTS

Two methods have been adopted for estimation of extreme rainfall events, defined as less than 2% Annual Exceedance Probability (AEP) or greater than 50 year Average Recurrence Interval (ARI). The CRC Forge design rainfalls cover longer duration events from 24 to 120 hours. The probable maximum precipitation (PMP) estimate using the Generalised Short Duration Method applies to short duration events up to 6 hours and is more suitable for estimating peak instantaneous flows from small catchments.

Events of this rarity are not typically applicable to operational design criteria, but may be required to be considered in assessment of the long term stability of permanent landforms that will remain after closure.

5.6.1 CRC FORGE Design Rainfalls

Estimated design rainfalls for events of a 50 or greater year ARI were extracted for the Thunderbird Project area from the CRC-FORGE database for Western Australia. This database contains design rainfall estimates calculated by the CRC-FORGE method, which is used to increase reliability of estimates of floods in the rare to extreme range. Specific application of the CRC-FORGE method to Western Australia is described in Durrant and Bowman (2004). The basis of the method and procedures used in preparation of the database are described in Nandakumar et al., (1997).

The WA CRC-FORGE EXTRACT computer program (Department of Environment, 2004) was used to extract the probability of extreme rainfall events for the Thunderbird Project area. Results are given in Table 7 for events between 50 and 2,000 years average recurrence interval (ARI).

The data indicates the highest daily rainfall in the data drill dataset, 322.7 millimetres for 1917, was approximately a 50 year ARI event. The highest daily rainfall of 476mm recorded at Country Downs in 1978 would be approximately a 400 year ARI event if it occurred in the Thunderbird Project area based on the CRC-FORGE output.

Table 7: CRC FORGE Rare to Extreme Rainfalls for Thunderbird Project (mm)

Duration (hours)	Average Recurrence Interval (years)					
	50	100	200	500	1000	2000
24	324.7	377.2	434.5	517.3	585.2	657.6
30	353.5	410.8	472.7	561.9	634.8	712.1
36	378.8	440.4	506.4	601.2	678.5	760.1
48	422.7	491.6	564.6	668.9	753.5	842.4
60	449.1	519.7	595.7	704.1	791.5	883.3
72	471.9	543.9	622.5	734.1	824.0	918.1
96	496.0	571.2	652.2	766.9	859.0	955.2
120	510.1	587.8	670.1	786.4	879.7	976.9

5.6.2 Probable Maximum Precipitation

Probable maximum precipitation (PMP) for the Thunderbird Project location was calculated using the Generalised Short Duration Method (BoM, 2003). Note that, as described in AR&R, design values at these low probabilities are notional values to provide appropriate design levels of safety, rather than being of a precise nature. It is impossible to derive true values for low probabilities. Despite this, the notional values derived from these procedures are appropriate for engineering design.

The values were calculated on the basis of a smooth catchment (more than 20 km from any areas where elevation changes of greater than 50 m within 400 m horizontal distance are common), elevation of less than 1,500m, and Moisture Adjustment Factor of 1.1.

Selected values for the durations and catchment areas relevant to the Thunderbird Project are listed in Table 8. While the estimated PMP is greater for smaller catchments, the probability of the maximum rainfall occurring is lower. Notional Annual Exceedance Probabilities recommended for this method are 10^{-7} for areas of 100 km^2 and below rising to 10^{-6} for areas over 1,000 km^2. This corresponds to an ARI of 10,000,000 to 1,000,000 years.

Table 8: Probable Maximum Precipitation (mm) in Thunderbird Project Catchments

Duration (hrs)	Area (km^2)			
	Point	2	100	400
1	570	550	418	330
3	891	792	605	517
6	1,100	968	781	671

5.7 TROPICAL CYCLONES

Rainfall associated with tropical cyclones is a likely contributor to flooding in the Thunderbird Project area. Cyclone risk with respect to wind is much lower than Broome and coastal Pilbara towns due to fewer cyclones and fewer severe cyclones occurring in this region. On average, approximately five cyclones occur off the north-west coast each year, two of which cross the coast and one is rated as severe (BoM 2016a). These frequencies are for the entire north-west. The risk of a cyclone occurring at any particular location on the coast is much lower.
Figure 11 shows the tracks of some notable cyclones affecting the Dampier Peninsula and Derby areas (BOM,

2016a). Figure 12 shows the tracks of the numerous cyclones that have passed within 100km of the Thunderbird Project between 1906 and 2007.

Widespread rainfall totals in excess of 100 mm across the Kimberley region are common with tropical lows and cyclones. Such rainfalls can occur well to the east of the cyclone due to moisture laden north-westerly monsoon winds. Rainfall is not directly related to the intensity of the cyclone and some of the largest flood events have been associated with tropical lows below cyclone intensity.

The cyclone season officially runs between November and April, although cyclones only rarely occur in November and cyclones have been observed as late as May. The highest risk of category 4 or 5 cyclones is late in the season during March and April. The impact of early cyclones on flooding is also likely to be lower due to dry catchment conditions.

The Bureau of Meteorology tracks cyclone formation and location closely, and is usually able to provide advanced warning well ahead of cyclones crossing the coast. Cyclones that form rapidly near the coast are the most difficult to forecast. The inland location of the Thunderbird Project allows for better warning of cyclones than coastal areas.

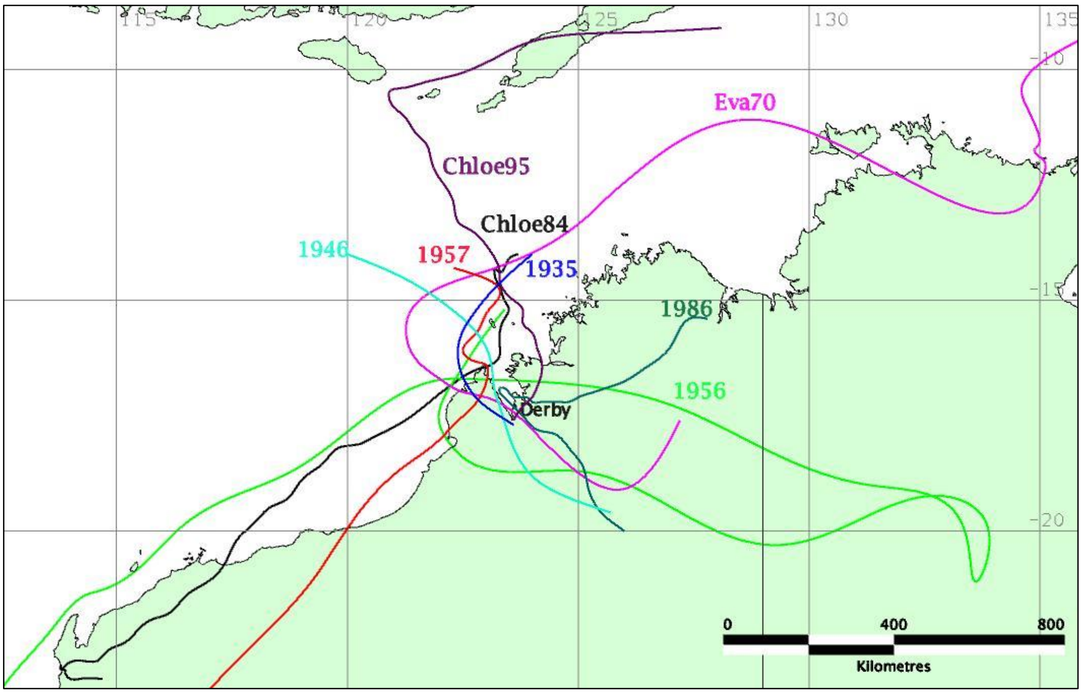

Figure 11: Tracks of Notable Cyclones Affecting the Dampier Peninsula (BoM, 2016a).

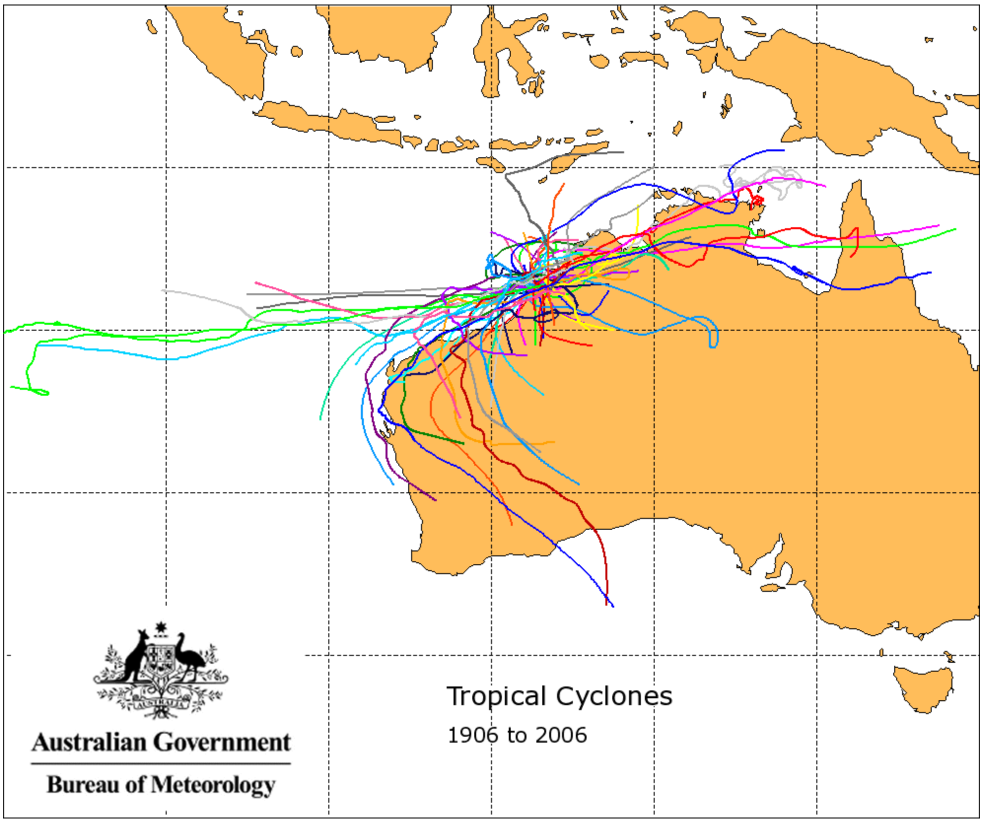

Figure 12: Tropical Cyclones 1906-2007 Passing Within 100km of the Thunderbird Project (BoM 2016b)

5.8 RECOMMENDED SELECTION OF RAINFALL AND CLIMATE DATA

A variety of climate data has been presented in this section. All is potentially useful for different applications. For general design and water balance the Data Drill 1889 – 2015 dataset for rainfall and evaporation is recommended as it makes full use of available local data. In situations where above average rainfall is critical, the more recent subset of this data (1997 – 2015) should also be considered.

The BoM IFD data should be used in analysis relating to rainfall events of less than a week duration and 100 years ARI. The CRC Forge data is likely of less use, but may be required for assessment of post closure permanent landforms, particularly where accumulation of runoff over longer periods is critical, such as freeboard requirements of a residual pit or TSF.

The Probable Maximum Precipitation is not likely to be required unless there are specific design cases where post closure landform suitability depends on estimation of peak flow from short duration rainfalls.

6. POTENTIAL FLOOD IMPACTS ON THE PROJECT

6.1 SUMMARY

Other than the site access road, the proposed location of all mine components is within 5 km of the watershed between the Fraser River South and Fraser River catchments. The catchments upstream of this infrastructure are small so the infrastructure areas are generally not subject to flood risk from large upstream catchments.

The greatest flood risk is to the southernmost extent of the pit location, which encroaches slightly on the ephemeral drainage line of the northwest limit of the Fraser River South catchment. This catchment has an area of 108 km^2 and extends 17 km upstream of the pit. The borefield location has not been finalised, but it may also extend across this drainage line.

6.2 PEAK FLOW ESTIMATE CALCULATIONS

Estimates of peak flood flows at significant locations have been calculated using the Index Flood method of AR&R. This is an accepted method for the area based on statistical analysis of gauged catchments in the region, however it is considered likely that this method will overestimate peak flood flows at the Thunderbird Project for the following reasons:

- The catchments of the Thunderbird Project area are sandy, with runoff rates much lower than the average for the Kimberley region (see Section 2.5). All the gauged catchments from which the regional flood estimation methods were derived have higher runoff characteristics than the Thunderbird Project area.
- The gauging stations used for derivation of the regional estimation methods are located on well defined watercourses suitable for installation of gauging stations. Most of the project catchments have poorly defined drainage lines consisting of broad valleys with no evidence of scoured channels which would be expected if flows of the predicted magnitude were experienced.

Two other methods of flood estimation were considered: The Regional Rational method from AR&R and the draft RFFE method proposed by Engineers Australia to eventually replace the AR&R methods (Rahman et al, 2015). Both these methods produce significantly higher flood estimates than the Index Flood Method. The Index Flood Method has been adopted in preference to the above alternatives since it gives the lowest results of the available methods, making the results closer to those expected based on the observed catchment characteristics.

The absence of suitable local gauging data makes development of more accurate flood estimation methods problematic. Collection of flow records, particularly peak flood levels during operations would be valuable to allow assessment of the accuracy of the available methods and provide potential for improvements to be made in flood estimation methods over the life of the project.

6.3 PIT AND BOREFIELD

The pit location crosses the watershed between Fraser and Fraser River South Catchments and will not receive significant surface runoff from adjacent areas other than at the southern tip. As the pit will be mined progressively with backfilling and rehabilitation, the full proposed pit will never be open at one time, and the upstream catchment requiring diversion around the pit will vary throughout mine operations.

The southern extent of the pit location encroaches slightly on the ephemeral drainage line at the northwestern limit of the Fraser River south catchment (Figure 13), and the borefield may extend across the same drainage line. This drainage line has a catchment area of 108 km^2 and extends 17 km upstream of the pit.

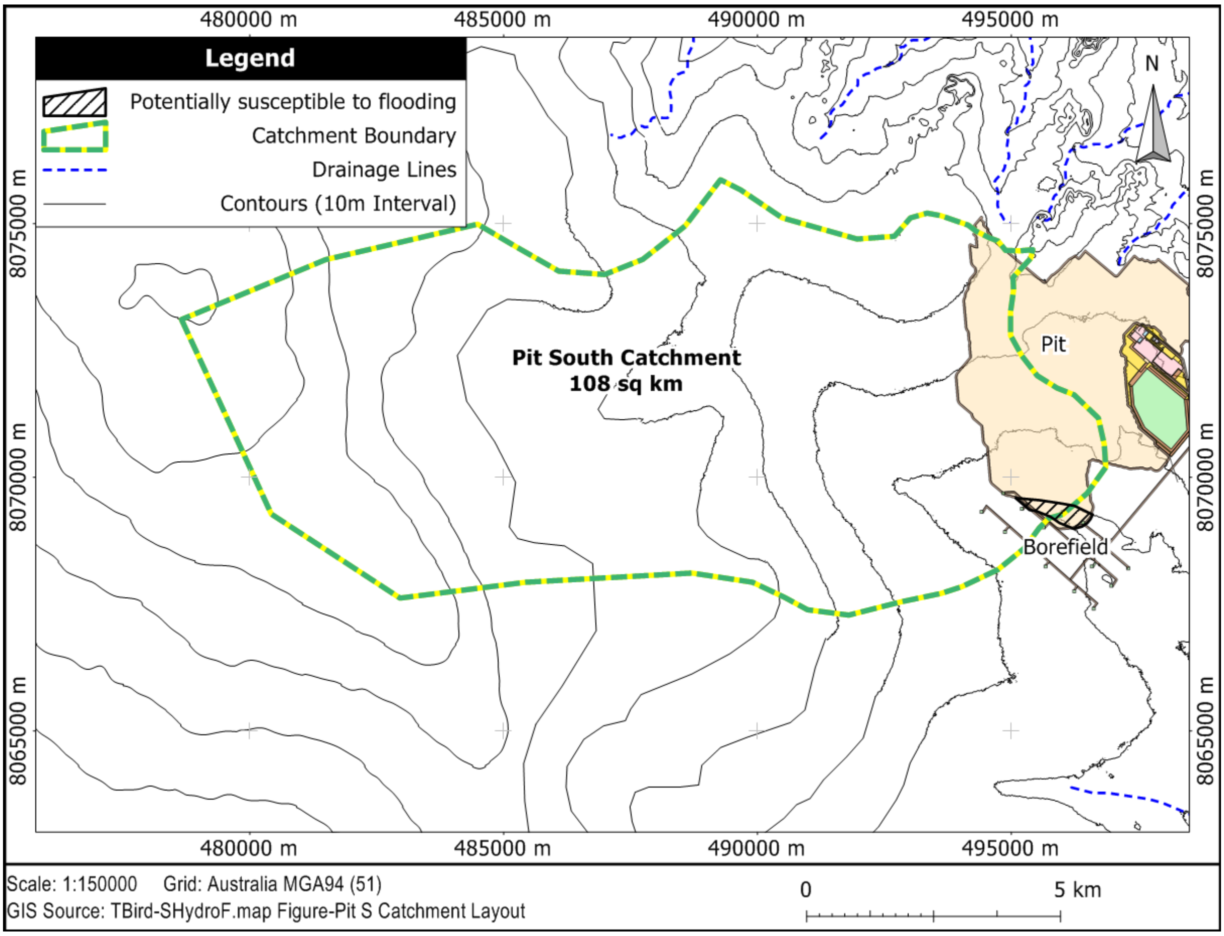

Figure 13: Pit South Catchment

Assessment of 5 cm/pixel resolution aerial imagery indicates there is no distinct watercourse channel associated with the drainage line. There is a broad valley approximately 450 m wide exhibiting variation in vegetation associated with drainage. The pit design extends 350m into the broad valley, potentially affecting surface flows down the valley if they occur.

Peak flows for this catchment have been estimated using the regional Index Flood Method of AR&R. The results for flows between 2 and 100 years ARI are shown in Table 9. A preliminary estimate of potential flood levels in the valley was made using Manning's equation via the HY-8 hydraulic analysis package (US Federal Highway Administration, 2011) to calculate steady flow in a straight channel of similar geometry to the valley. The results, included in Table 9, indicate that water levels up to 1.4 m deep are possible, corresponding to about 400 m width of the valley being inundated with a flow velocity of approximately 1 metre per second. Details of calculations are provided in Appendix 1. This corresponds to water filling the visually differentiated valley/channel. It is likely that these calculations overestimate the actual flood risk given the lack of visible watercourse channels in the area, which would be expected if such high flows were experienced in the past.

If the southern portion of the pit is to be mined during the wet season, then potential flood flows will need to be considered and appropriate design measures included to manage potential flood impacts on the pit. The pit is to be mined progressively and the affected portion would only be open for a few years towards the end of the mine life, approximately 30 years after commencement of mining. Observation and monitoring of surface flows over the mine life will allow a better estimate of likely flows to be made by the time final design of drainage measures for this portion of the pit are required. The borefield will be constructed early in project development, but would be less sensitive to potential flood impacts.

Table 9: Peak Flow and Flood Level Calculations for Pit South Catchment

ARI (Years)	Peak Flow (m3/s)	Flow depth (m)
2	128	0.8
5	189	0.9
10	240	1.0
20	297	1.1
50	379	1.3
100	462	1.4

6.4 CAMP AND PLANT

Other than the pit and borefield, all proposed major site components are located close to the Fraser River watershed and will only receive surface runoff from local catchments less than 2 km^2 in area. There are no visually discernible drainage lines requiring diversion, but some of the infrastructure lies over broad depressions which may be subject to waterlogging and shallow surface water in wet conditions (Figure 14).

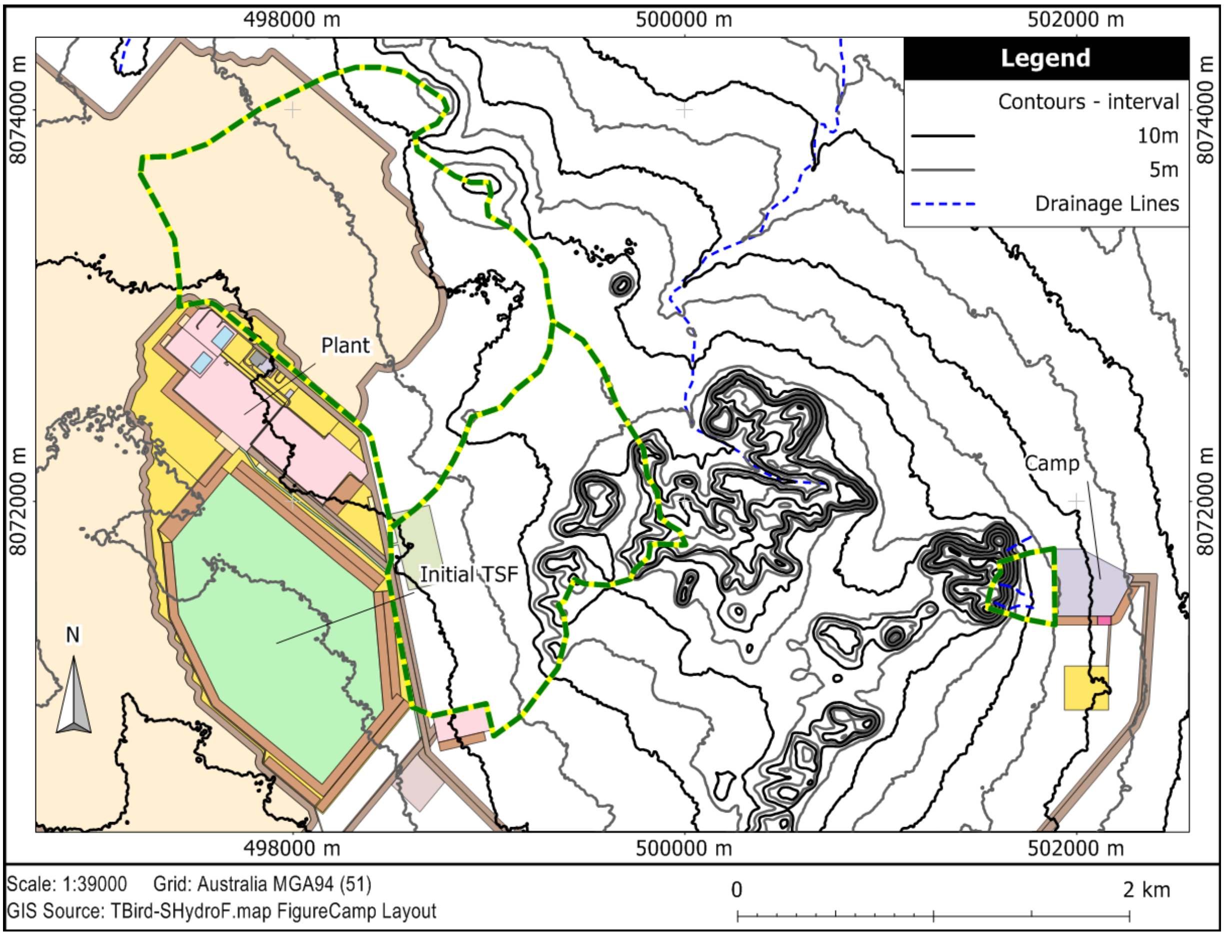

Figure 14: Camp and Plant Catchments

The proposed camp and plant locations are 250 to 500 m downslope of small rocky hills which will generate local surface flows during intense rainfall events. Drainage lines visible in the hills peter out before reaching the infrastructure areas, but runoff from the hills has been observed to create wet ground conditions in these areas.

The infrastructure locations are approximate and may change, but overall catchment size and characteristics are likely to be similar for the final locations.

Estimated peak flows using the Index Flood method for events up to 100 years ARI are shown in Table 10. Results are given for the camp catchment and for the TSF catchment. Runoff for the plant locations will be similar to that of the TSF as the catchments are very similar. Details of calculations are provided in Appendix 1.

Table 10: Peak Flow Estimates for Camp and Plant Catchments (m^3/s)

Catchment	Area (km^2)	Average Recurrence Interval (years)					
		2	5	10	20	50	100
Camp	0.1	2.6	3.8	4.8	5.9	7.6	9.3
Initial TSF	1.7	12.6	18.5	23.5	29.0	37.1	45.3
Plant	2.6	15.9	23.4	29.8	36.8	47.0	57.4

6.5 ACCESS ROAD

The proposed access road crosses four main drainage lines. The catchments corresponding to each of these drainage lines (referred to as R1 to R4) are shown in Figure 15. The Northernmost catchment, R1, is by far the largest and includes the catchment passing the southwest corner of the pit. A small defined watercourse channel is visible within a broader flood plain at the road crossing point (Plate 1).

Plate 1: Fraser River South – Catchment R1

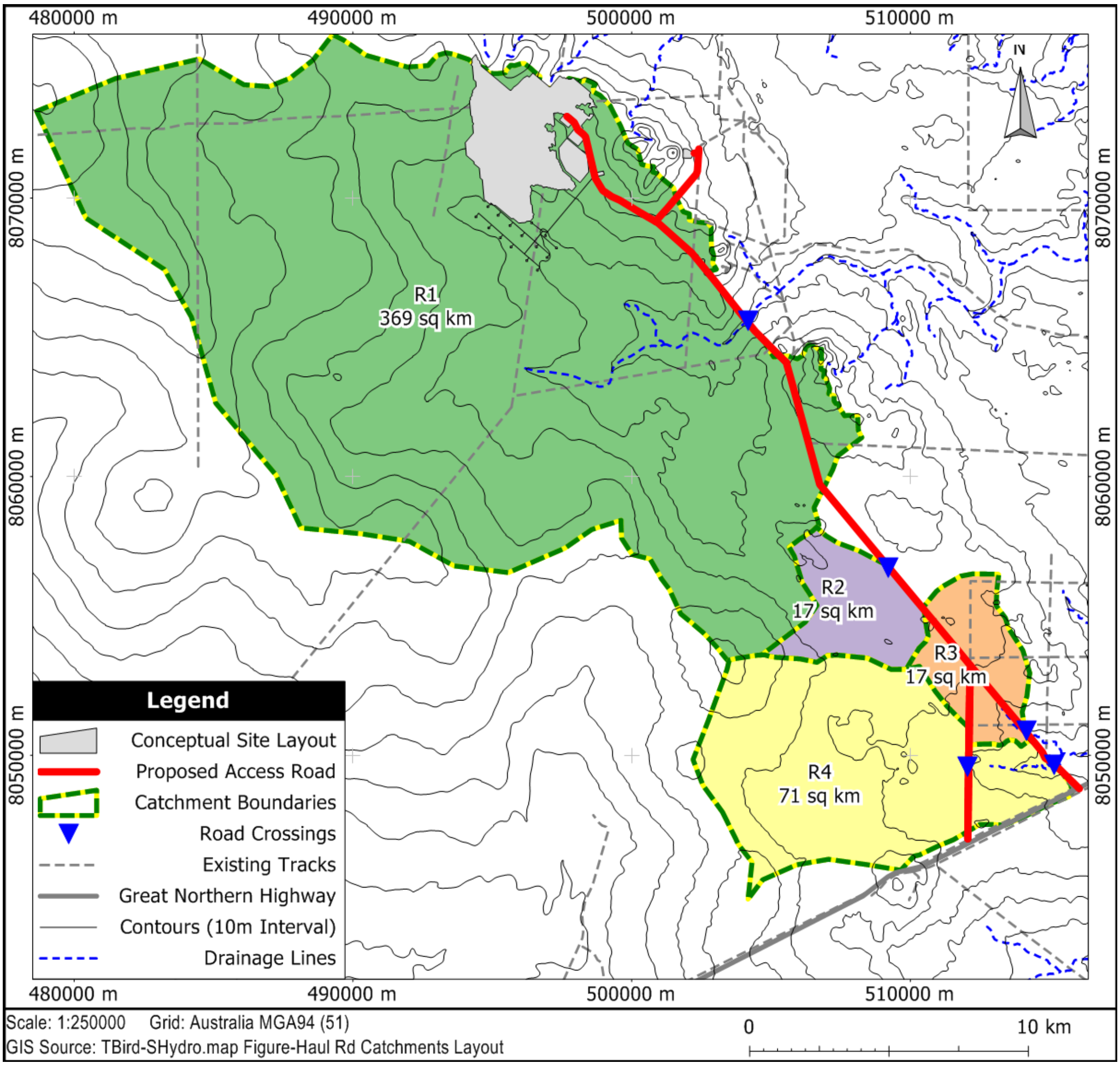

Figure 15: Access Road Catchments and Crossing Points

Catchments R2 and R3 are much smaller. R2 is very flat with no visible watercourse at the road crossing, while R3 is steeper and has a distinct water course channel.

The branch at the southern end of the site access road allows for two alternative routes at the Little Logue River crossing. Catchment R4 on the Little Logue River crosses both alternatives. The eastern alternative crosses visible sandy drainage channels (Plate 2). The western branch crosses three broad valleys with no visible watercourse. Estimated total flood flows are provided for the eastern option (see Table 11). Flows for the western option would be slightly lower, but spread over the three valleys.

Existing tracks on the proposed access road alignment have no engineered floodways or bridges/culverts at the crossing points, with any surface flow able to pass over the track. The existing track is not passable during wet conditions due to wet ground and occasional surface flows across the road. Potential flows at the crossings will need to be considered during access road design. The road will need to be appropriately designed to allow access road use during the wet season while minimising interference with natural flow patterns by appropriate placement of culverts and floodways.

Plate 2: Little Logue River – Catchment R4

Preliminary flood flow calculations for the Access Road catchments using the regional Index Flood method are given in Table 11. Details of calculations are provided in Appendix 1.

Table 11: Peak Flow Estimates for Access Road Catchments (m^3/s)

Catchment	Area (km^2)	Average Recurrence Interval (years)					
		2	5	10	20	50	100
R1 Access North	369	255.7	375.8	478.1	590.6	754.2	920.4
R2 Access Central	17	45.6	67.1	85.4	105.4	134.7	164.3
R3 Access East	17	45.6	67.1	85.4	105.4	134.7	164.3
R4 Access South	71	101.6	149.4	190.1	234.8	299.8	365.9

7. POTENTIAL PROJECT IMPACTS ON THE SURFACE WATER ENVIRONMENT

7.1 POTENTIAL IMPACTS

Potential impacts of the Thunderbird Project on the surface water environment are:

- Increased sediment load in runoff from areas of disturbed ground.
- Potential spills of hydrocarbons or other substances from operational areas.
- Localised changes to surface flow patterns due to restriction of natural flow paths by infrastructure.

The likely impact is very low due to the following factors:

- There is little catchment area upstream of proposed operations due to the project's location adjacent to the major drainage divide between the Fraser River and Fraser River South Catchments.
- The catchments of the Thunderbird Project area naturally produce low levels of surface runoff due to high infiltration rates into the sandy soils. This is evident in the absence of any well defined drainage channels within the project area (excluding the access road).
- There are no specific sensitive uses downstream of the project area. The 'soak' identified by traditional owners 3 km southeast of the pit will not be directly affected by surface runoff from operational areas.

7.2 DOWNSTREAM DILUTION

Impacts on some water quality parameters such as sediment load and salinity can be effectively ameliorated by dilution. Any streamflow leaving the project area will be rapidly diluted by inflow from other catchments. Table 12 details the degree of dilution expected as surface flow progresses from the catchment to King Sound, notably from the main operational areas in the Fraser River South Catchment.

Table 12: Downstream Dilution of Runoff from Thunderbird Project

Distance Downstream of Thunderbird Project	Total Catchment Area	Proportion of Surface Flow from Catchments Affected by Project	Description
0 km	126 km^2	100 %	Immediately downstream of Thunderbird Project operational areas.
8 km	369 km^2	34 %	Fraser River South access road crossing.
48 km	1,024 km^2	12 %	Both major branches of Fraser River South join.
54 km	2,363 km^2	5 %	Fraser River South joins Fraser River.
62 km	>100,000 km^2	0.1%	Discharge to King Sound, along with discharge from Fitzroy and other Rivers.

Runoff from the camp, located in the adjacent Fraser River catchment, will be more rapidly diluted due to the very small upstream catchment of approximately 0.1 km^2. If any surface runoff from the camp flowed as far as the first identifiable watercourse 6 km downslope, the camp catchment would make up less than 0.5% of the watercourse catchment at that point.

7.3 MANAGEMENT MEASURES

The likely impacts will be manageable by implementation of standard surface water management measures such as:

- Separation of clean water flows and potentially contaminated water.
- Sediment management measures downstream of all areas of ground disturbance.
- Building up infrastructure above ground level in areas prone to water accumulation.
- Suitable floodways, drains and culverts being constructed to transfer flow past operational areas and across roads and return it to its natural flow path.
- Use of suitable discharge structures to redistribute sheet flow downstream of culverts, diversions and bunds where no suitable natural channels are present.
- Storage of potentially hazardous materials in bunded areas.
- Spill management procedures.

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APPENDICES

APPENDIX 1: HYDROLOGICAL CALCULATIONS

Regional Index and Rational Method Peak Flow Calculations
Thunderbird Project
Latitude -17.475 Longitude 122.95

Methods

Calculation methods from AR&R 1997 5.4.7a
For Kimberley Region Annual Rainfall 450-850mm

Kimberley Region i: Catchments with average rainfall 450-850mm
The Rational and Index Methods are based upon data from 17 catchments with the following characteristics.

Area (A) =	29.6 - 44,600	km^2
Length (L) =	11.9 - 410	km
Equal Area Slope(S_e) =	0.98 - 4.30	m/km
Mean Annual Rainfall (P)=	450 - 850	mm

The Probabilistic Rational Method design equations are:

$Q_Y=0.278*C_y*I_{tc,Y}*A$

$t_c = 0.56A^{0.38}$ ARR Eqn 5.32

$C_{10} =0.77 L^{-0.23}$ ARR Eqn 5.33

Rational Method Frequency Factors (C_Y /C_{10}):

Mainstream Length L (km)	ARI (years)	2	5	10	20	50	100
	1	0.85	0.92	1	1.09	1.2	1.3
	10	0.72	0.86	1	1.14	1.31	1.49
	100	0.61	0.8	1	1.22	1.48	1.75
	250	0.57	0.78	1	1.25	1.63	2

* 100 Year ARI factor extrapolated from lower ARI on Log-Log Plot

Index Flood Method design equations is:

$Q_2 = 9.34 A^{0.56}$ ARR Eqn 5.25

Index Flood Frequency Factors (Q_Y /Q_2) — log-log interpolation:

Area (km2)	ARI (years)	2	5	10	20	50	100*
	1	1	1.37	1.63	1.9	2.25	2.55
	10	1	1.47	1.87	2.31	2.95	3.6
	100	1	1.58	2.15	2.85	3.88	4.9
	1000	1	1.69	2.47	3.5	5.2	7
	10000	1	1.81	2.84	4.27	6.85	10

* 100 Year ARI factor extrapolated from lower ARI on Log-Log Plot

Calculations and Results

1. A - Pit South

A	107.810 km^2	P	600	mm (from ARR V2 Fig 5.8)
L	17.5 km			
Rational Method Factors		Index Flood Factors		
t_c	3.32 hr	Q_2	128.421	
C_{10}	0.399			

Average Recurrence Interval (years)		2	5	10	20	50	100
Coefficient	C_Y	0.29	0.34	0.40	0.45	0.52	0.59
Time of Conc rainfall intensity	Itc	20.01	27.33	31.93	37.85	45.93	52.31
Peak Discharge (Rational)	Q_Y (m^3/s)	172.1	280.8	381.5	515.6	718.9	931.2
Peak Discharge (Index)	Q_Y (m^3/s)	128.4	188.8	240.1	296.7	378.8	462.3
Peak Discharge (Average)	Q_Y (m^3/s)	150.3	234.8	310.8	406.1	548.9	696.7

2. Camp

A	0.100	km^2	P	600	mm (from ARR V2 Fig 5.8)
L	0.26	km			
Rational Method Factors			Index Flood Factors		
t_c	0.23	hr	Q_2	2.572	
C_{10}	1.050				

Average Recurrence Interval (years)		2	5	10	20	50	100
Coefficient	C_Y	0.89	0.97	1.05	1.14	1.26	1.36
Time of Conc rainfall intensity	Itc	96.35	127.74	146.98	172.02	205.63	231.81
Peak Discharge (Rational)	Q_Y (m^3/s)	2.4	3.4	4.3	5.5	7.2	8.8
Peak Discharge (Index)	Q_Y (m^3/s)	2.6	3.8	4.8	5.9	7.6	9.3
Peak Discharge (Average)	Q_Y (m^3/s)	2.5	3.6	4.5	5.7	7.4	9.0

3. Access R1

A	368.700	km^2	P	600	mm (from ARR V2 Fig 5.8)
L	29	km			
Rational Method Factors			Index Flood Factors		
t_c	5.29	hr	Q_2	255.672	
C_{10}	0.355				

Average Recurrence Interval (years)		2	5	10	20	50	100
Coefficient	C_Y	0.26	0.31	0.35	0.40	0.46	0.53
Time of Conc rainfall intensity	Itc	14.14	19.59	23.07	27.53	33.65	38.50
Peak Discharge (Rational)	Q_Y (m^3/s)	370.4	613.0	839.4	1141.8	1603.5	2086.8
Peak Discharge (Index)	Q_Y (m^3/s)	255.7	375.8	478.1	590.6	754.2	920.4
Peak Discharge (Average)	Q_Y (m^3/s)	313.1	494.4	658.7	866.2	1178.9	1503.6

4. Access R2 and R3

A	17.000	km^2	P	600	mm (from ARR V2 Fig 5.8)
L	6	km			
Rational Method Factors			Index Flood Factors		
t_c	1.64	hr	Q_2	45.646	
C_{10}	0.510				

Average Recurrence Interval (years)		2	5	10	20	50	100
Coefficient	C_Y	0.37	0.44	0.51	0.58	0.67	0.76
Time of Conc rainfall intensity	Itc	33.15	44.44	51.41	60.45	72.66	82.24
Peak Discharge (Rational)	Q_Y (m^3/s)	57.5	92.1	123.9	166.1	229.4	295.3
Peak Discharge (Index)	Q_Y (m^3/s)	45.6	67.1	85.4	105.4	134.7	164.3
Peak Discharge (Average)	Q_Y (m^3/s)	51.6	79.6	104.6	135.8	182.0	229.8

5. Access R4

A	71.000	km^2	P	600	mm (from ARR V2 Fig 5.8)
L	12	km			
Rational Method Factors			Index Flood Factors		
t_c	2.83	hr	Q_2	101.637	
C_{10}	0.435				

Average Recurrence Interval (years)		2	5	10	20	50	100
Coefficient	C_Y	0.31	0.37	0.43	0.50	0.57	0.65
Time of Conc rainfall intensity	Itc	22.49	30.58	35.64	42.16	51.04	58.04
Peak Discharge (Rational)	Q_Y (m^3/s)	139.0	225.7	305.9	412.5	573.8	742.1
Peak Discharge (Index)	Q_Y (m^3/s)	101.6	149.4	190.1	234.8	299.8	365.9
Peak Discharge (Average)	Q_Y (m^3/s)	120.3	187.5	248.0	323.6	436.8	554.0

6. Initial TSF

A	1.700	km^2	P	600	mm (from ARR V2 Fig 5.8)
L	1.6	km			
Rational Method Factors			Index Flood Factors		
t_c	0.69	hr	Q_2	12.572	
C_{10}	0.691				

Average Recurrence Interval (years)		2	5	10	20	50	100
Coefficient	C_Y	0.59	0.64	0.69	0.75	0.83	0.90
Time of Conc rainfall intensity	Itc	57.50	76.03	87.38	102.16	121.95	137.41
Peak Discharge (Rational)	Q_Y (m^3/s)	16.0	22.8	28.5	36.4	47.8	58.3
Peak Discharge (Index)	Q_Y (m^3/s)	12.6	18.5	23.5	29.0	37.1	45.3
Peak Discharge (Average)	Q_Y (m^3/s)	14.3	20.7	26.0	32.7	42.4	51.8

7. Plant

A	2.600	km2	P	600	mm (from ARR V2 Fig 5.8)
L	1.4	km			
Rational Method Factors			Index Flood Factors		
tc	0.81	hr	Q2	15.949	
C10	0.713				

Average Recurrence Interval (years)		2	5	10	20	50	100
Coefficient	CY	0.61	0.66	0.71	0.78	0.86	0.93
Time of Conc rainfall intensity	Itc	52.40	69.38	79.79	93.34	111.51	125.71
Peak Discharge (Rational)	QY (m3/s)	22.9	32.9	41.1	52.4	68.9	84.2
Peak Discharge (Index)	QY (m3/s)	15.9	23.4	29.8	36.8	47.0	57.4
Peak Discharge (Average)	QY (m3/s)	19.4	28.2	35.5	44.6	58.0	70.8

Hy-8 Flow Curve for Pit South Catchment Channel

Channel profile - from contour data

Distance (m)	Elevation (m)
0	2
50	1.5
120	1
190	0.5
320	0
450	0.5
520	1
590	1.5
640	2

Estimated Peak Flows for Catchment

Based on Index Flood Method (Australian Rainfall and Runoff, 1997).

ARI	Peak Flow	Flow depth	Velocity
(Years)	(m3/s)	(m)	(m/s)
2	128	0.8	0.81
5	189	0.9	0.91
10	240	1.0	0.97
20	297	1.1	1.03
50	379	1.3	1.10
100	462	1.4	1.17

Flood Levels for Peak Flows were estimated using Manning's Equation for an irregular channel.
Mannings n of 0.04 was used for the channel (long pasture grass/moderate brush and trees).
Calculations were done with the HY-8 hydraulic analysis package version 7.2 (US Federal Highway Administration, 2011).