Tantabiddi Creek

Hydrology and Geomorphology Study

Department of Transport

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311012-00121

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Executive summary

The Department of Transport (DoT) engaged Advisian to assess the hydrology, hydraulics and geomorphology of Tantabiddi Creek and nearshore coastal area to better understand hydraulic and sediment transport behaviour under a range of flood conditions and between flood events due to prevailing coastal processes.

This report presents results of hydrological, geomorphology and coastal modelling of the Tantabiddi Creek and nearshore coastal area and evaluates the impact fluvial and coastal processes have on the adjacent boat ramp. The modelling results are to be used to evaluate likelihood/frequency of boat ramp deposition as well as the risks and opportunities associated with the existing boat ramp and other potential ramp upgrade and development options.

The key findings from the Tantabiddi Creek Hydrology and Geomorphology study are summarised below:

- The location of the boat ramp, near Exmouth and adjacent to Tantabiddi Creek means it is subject to seasonal flooding, sediment transport and deposition during significant rainfall events. The more extreme flood events are often associated with tropical cyclones between November and April;
- The Tantabiddi Creek catchment area is 27 km^2 extending east into the Cape Range National Park. The catchment has a critical storm duration of between 2 and 6 hours, so responds rapidly to extreme rainfall, resulting in flash flooding. This is typical of catchments in the Cape Range area;
- Rainfall runoff and hydraulic modelling completed for Tantabiddi Creek suggests the peak 1 in 100 AEP flood event is 125 m^3/s. The largest rainfall event recorded since the boat ramp upgrade in 2012-2013, was the 27th April 2014 event, where 237.7mm was recorded at Ningaloo Reef rainfall station, approximately 14km south of the boat ramp. Hydrological modelling of the 2014 rainfall event suggests it resulted in a peak flow of 168 m^3/s. Comparison with the 1 in 100 AEP peak flow suggests the 2014 event was greater than a 1 in 100 AEP event;
- Sediment transport modelling of the 2014 flood event, using MIKE21 software and sedigraphs developed from geomorphological assessment of Tantabiddi Creek, suggests 4,260 m^3 of sediment and alluvial material was transported and deposited at the boat ramp and navigation channel. Dredging activities conducted by the Shire of Exmouth between 12th June 2015 and 22nd September 2015, are reported to have removed between 3,500m^3 and 5,000m^3 of material, which validates the sediment transport model results (URS (2016) and Appendix C).
- Tantabiddi Creek flood flows and sediment transport in the 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP events were simulated in the MIKE21 model and the results used to quantify bed elevations changes and associated volumes of material deposited in the boat ramp area. The results indicate the following:
    - The volume of deposited sediment and the extent of deposition offshore increases with the size of the flood event. The transported sediment is a combination of creek alluvium and beach sand.
    - For the 1 EY event, 1 in 2 and 1 in 5 AEP events, sediment is deposited in proximity to and south of the boat ramp. Although the volumes of material deposited in these

events are lower (up to 250m^3) when compared with larger less frequent events, the accumulation of sediment is expected to impact boat ramp operations and maintenance.

- For events greater than the 1 in 5 AEP, sediment deposition in the channel area and the dredge area can be significant. Modelling suggests deposition in the boat ramp area of between 300 and 1,378 m^3 for the 1 in 10 and 1 in 100 AEP flood events respectively.
- Sediment transport modelling suggests the maximum extent of 1 in 100 AEP deposition impact under current conditions, is approximately 300m from the existing boat ramp. Arcs showing the estimated extent of sediment deposition for the 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP events as well as the 2014 event, are shown in Figure 0-1.
- The extent, volume and frequency of deposition should be considered when evaluating options for boat ramp upgrades and maintenance.

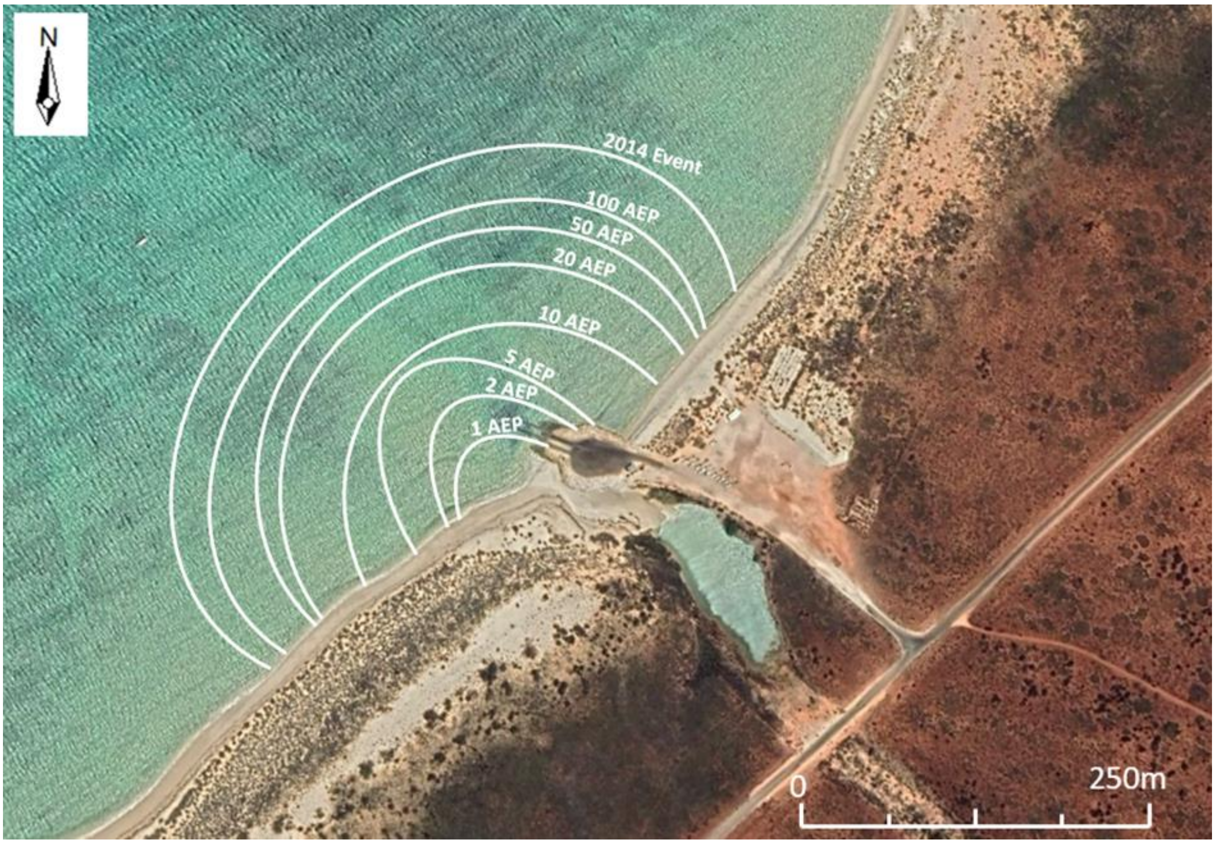


Figure 0-1. Representative arcs defining the potential extent of sediment deposition for the 1 EY to 1 in 100 AEP events

The results of sediment transport modelling presented in this report have been used to present "Pros and Cons" associated with alternative boat ramp facility upgrade options and locations and associated recommendations. For the recommendations, a distinction can be made between 3 areas depicted in Figure 0-2 and described as follows:

- ***Area A:*** Modifications to the existing facility or development of a new facility within the modelled extent of Tantabiddi Creek sediment deposition.
- ***Area B:*** Development of a new facility along the coastline southwest of the creek outlet (outside the modelled area of influence).
- ***Area C:*** Development of a new facility along the coastline northeast of the creek outlet (outside the modelled area of influence).

The Pros and Cons of each area are described below, along with the "do nothing" option.

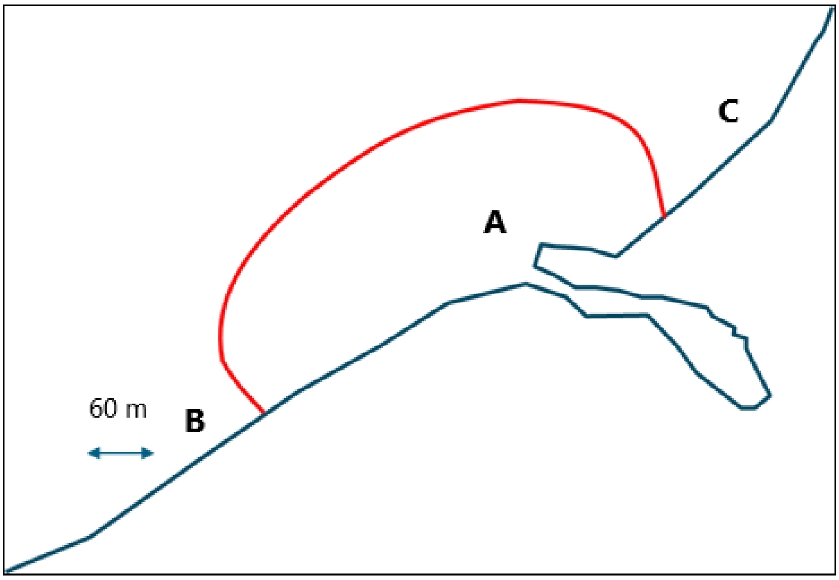


Figure 0-2. Three alternative boat ramp development areas

Do Nothing

Sediment transport modelling of Tantabiddi Creek suggests:

- For the 1 EY event, 1 in 2 and 1 in 5 AEP events, sediment is deposited in proximity to and south of the boat ramp. Although the volumes of material deposited in these events are lower (up to 250m^3) when compared with larger less frequent events, the accumulation of sediment is expected to impact boat ramp operations and maintenance.
- For events greater than the 1 in 5 AEP, sediment deposition in the channel area and the dredge area can be significant. Modelling suggests deposition in the boat ramp area of between 300 and 1,378 m^3 for the 1 in 10 and 1 in 100 AEP flood events respectively.

This sediment transport is in addition to the 5,000 m^3/year of estimated net sediment transport from longshore drift (MP Rogers and Associates, 2018). Therefore, regular routine dredging is expected to be required to remove transported sediment and maintain navigable depths. Besides regular dredging, additional dredging may be required after more extreme events.

Area A: Modifications and upgrade of existing facility

The current facility is located on the northeast side of the creek within the modelled extent of Tantabiddi Creek sediment deposition. As the facility protrudes the coastline, the northeast directed net longshore sediment transport will tend to deposit at the southwest side in front of the creek. When the creek discharges, this accumulated sediment is expected to end up at the boat ramp and dredged navigation areas.

Modifying the existing location, keeping part of the infrastructure can have cost benefits when compared to alternative boat ramp locations. For instance, it will be beneficial if the existing entrance channel can be used, and this may also minimise environmental impacts.

It is however recommended that some of the following boat ramp upgrades are considered:

- Create a barrier between the creek and the facility, to redirect flood flows and minimise sediment transport from the creek ending up in dredged areas. This can be achieved by constructing a training wall to direct creek flows to the northeast away from a new boat ramp constructed on the southwest side of the creek outlet. The training wall could also be used as part of the boat ramp construction. Training walls can have a significant influence on creek and coastal geomorphology, hydraulic and sediment transport behaviour so would require detailed studies. It should also be noted that a curved training wall can result in scouring in the outer bend of the outlet, which should be taken into account in the design of the foundation.
- As with all areas, the net longshore sediment transport directed towards the northeast will need to be taken into account in the development of any options. It could be therefore be considered to remove any obstacles to the natural longshore sediment transport and construct a facility further offshore, which could be achieved by a bridge or a causeway structure with culverts. This is likely to reduce the frequency and volume of sediment deposition in the navigation channel during flood events.

Area B: Development southwest of the creek outlet

Sediment transport modelling suggests the maximum extent of 1 in 100 AEP deposition impact from Tantabiddi Creek under current conditions, is approximately 300m from the existing boat ramp (Figure 0-1).

A new development outside of this area of influence on the southern side of the creek is likely to be unaffected by sediment loads from the creek. Relocation of the boat ramp to this area would require additional dredging to create a navigation channel. It is recommended that the alignment of the navigation channel is optimised using the arcs defining the estimated extent of sediment deposition for the 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP events (Figure 0-1) to assess magnitude and frequency of deposition to determine maintenance costs versus the cost of dredging the channel.

Repositioning of the boat ramp to the south and extending it further west into the ocean (further west than the current boat ramp) is likely to reduce the longshore (north-easterly) transport of deposited creek sediment. This may influence the depth and extent of the alluvial fan long term with potential repercussions for sediment shoaling near the facility, if an unabated alluvial fan grows westward.

If the facility is placed on the south side of the creek, then the northern excavation route may be cut off by flooding in Tantabiddi Creek. However, given the flashy nature of flooding in this region, the duration of impact is expected to be minor. In addition, there are several other similar floodway crossings on Yardie Creek Road which would have similar impacts during flooding conditions.

If a facility south of the creek is preferred, a review of the Yardie Creek Road floodway crossing may be required with possible upgrade of drainage structures to increase serviceability and prevent excessive flooding/debris in the area.

It should be noted that if a new navigational channel will need to be dredged this will have environmental impacts.

Area C: Development northeast of the creek outlet

Given the net longshore sediment transport towards the northeast, sediment deposited by creek flows from will end up further along the coast over time, unless it is captured. Therefore, any development on the northern side of the existing boat ramp will need to take into account the additional sediment load coming from the creek, which may deposit in dredged areas such as entrance channels and impact on boat ramp operations. This frequency and magnitude of impact (volume of sediment) reduces with increasing distance from the creek.

Similar to the other options, if a new navigational channel will need to be dredged this will have environmental impacts.

Acronyms and abbreviations

Acronym/abbreviation	Definition
2D	Two dimensional
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
AIMS	Australian Institute Marine Science
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval
ARR1987	Australian Rainfall and Runoff, 1987 (Institution of Engineers, Australia, 1987)
ARR2019	Australian Rainfall and Runoff, 2019. (Ball *et. al.*, 2019).
BoD	Basis of Design
BoM	Bureau of Meteorology
DBCA	Department of Biodiversity, Conservation and Attractions
DEM	Digital Elevation Model
DoT	Department of Transport (WA)
DSM	Digital Surface Model
EY	Exceedances per Year
HD	Hydrodynamic Module
IFD	Intensity Frequency Duration
MGA	Map Grid of Australia
PO Line	Plot Output Line
PSD	Particle Size Distribution
RFFE	Regional Flood Frequency Estimation Model (ARR Data Hub: http://data.arr-software.org/)
RFFP	Regional Flood Frequency Procedure (Flavell, 2012)
ST	Sand Transport Module
SW	Spectral Wave Module
XRD	X-Ray Diffusion

1 Introduction

1.1 Background

The Tantabiddi Boat Ramp Facility is located on the west side of the North West Cape, about 40 minutes' drive from Exmouth (Figure 1-1) in the Gascoyne region of Western Australia. The boat ramp provides important access for recreational boaters and commercial operators to the regionally significant Ningaloo Reef, making it a key asset to the local tourism industry. It was constructed in the 1990's as a single lane boat ramp and upgraded to two ramp lanes and two finger jetties in 2012 (MP Rogers and Associates, 2018).

The Tantabiddi Boat Ramp is located at the mouth of the Tantabiddi Creek (Figure 1-2). Tantabiddi Creek is ephemeral, so is dry most of the year then floods during significant rainfall events often associated with cyclonic activity. The creek provides a natural channel through the shallow reef which is utilised for boat access.

Fluvial and coastal processes contribute to the deposition of sand in front of, and adjacent to, the boat ramp which reduces the water depths available for safe navigation. Prevailing wind and waves transport nearshore sediment and onshore sediment in a north-easterly direction. The material accumulates on the southern side of the boat ramp, forming a sand bar across the mouth of the creek and a permanent pool immediately upstream. This sand bar is washed out during significant flood events and deposits in front of, and adjacent to the boat ramp, restricting access. The Tantabiddi Creek, boat ramp and sand bar are shown in Figure 1-2. Site photographs showing the creek closed as well as open to the ocean following a flood event are provided in Plate 1.

A long reach excavator has been used to clear small volumes of sediment from the boat ramp over the past 20 years (approx. 4 times per year) while a small dredger is required when the accumulated sand is beyond the reach of the excavator (URS, 2015).

Further upgrades are planned, however, it is recognised that the facility's interaction with the Tantabiddi Creek plays an important role in facility functionality and management/maintenance requirements.

1.2 Objective of Study

The Department of Transport (DoT) engaged Advisian to assess the hydrology, hydraulics and geomorphology of Tantabiddi Creek and nearshore coastal area to better understand hydraulic and sediment transport behaviour under a range of flood conditions and between flood events due to prevailing coastal processes.

This report presents results of hydrological, geomorphology and coastal modelling of the Tantabiddi Creek and nearshore coastal area and evaluates the impact fluvial and coastal processes have on the adjacent boat ramp. The modelling results are to be used to evaluate likelihood/frequency of boat ramp deposition as well as the risks and opportunities associated with the existing boat ramp and other potential ramp upgrade and development options.

The findings from this study will be used to identify and assess future design and management options needed to reduce the likelihood and frequency of sediment transport related impacts to boat ramp operations.

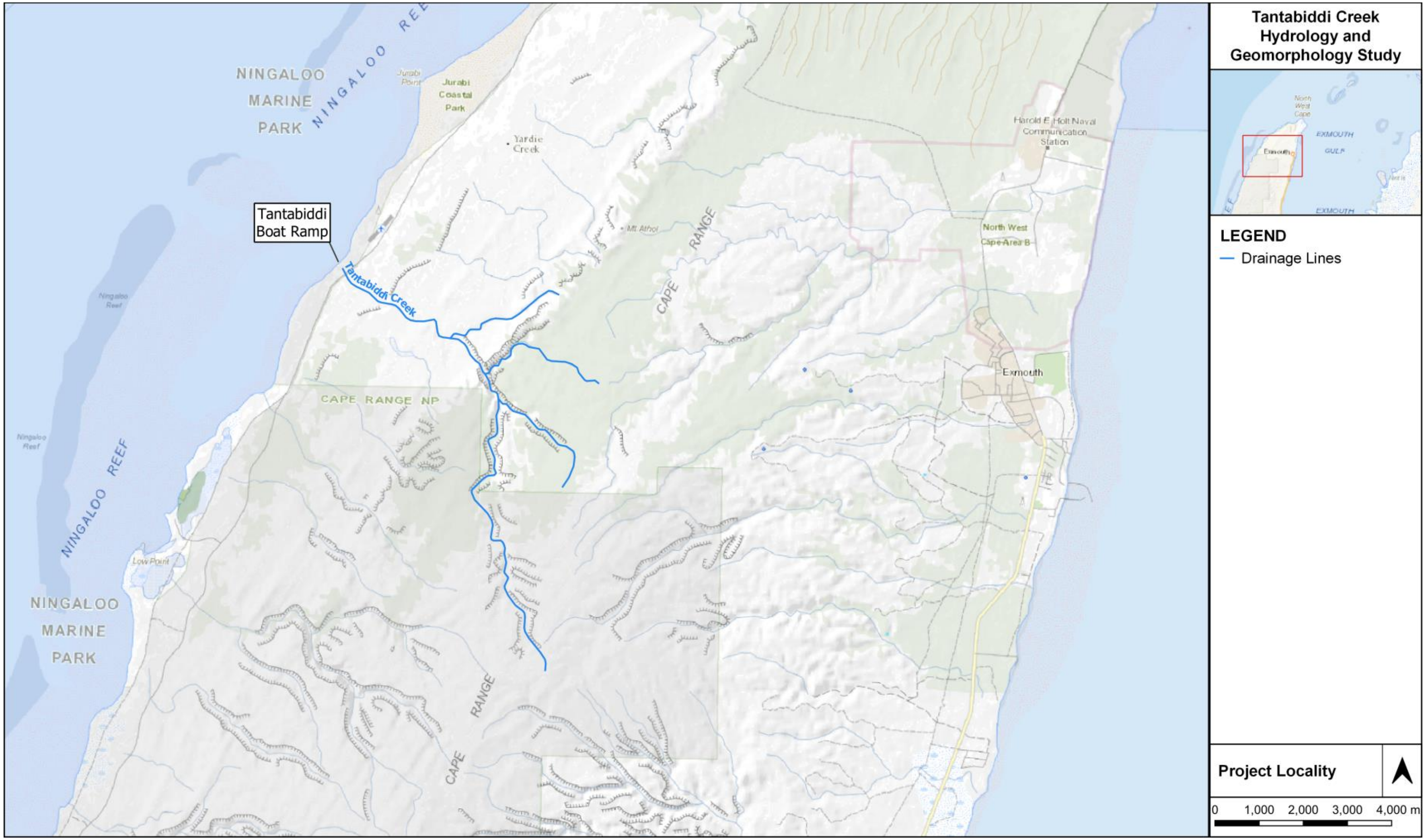


Figure 1-1. Tantabiddi Creek and Boat Ramp location

Figure 1-2. Tantabiddi Creek, Boat Ramp and other features at the site

Plate 1. Photographs showing the creek mouth closed to the ocean (top) and open to the ocean (bottom), with dates.

1.3 Study Team

The study team consists of hydrology and coastal specialists from Advisian and fluvial and coastal geomorphology sub-consultant Hydrobiology. This report was developed by Advisian with contributions from Hydrobiology, who developed a separate Coastal and Geomorphology Report for this study *Tantabiddi Boat Ramp Desktop Review, Fluvial and Coastal Geomorphology Report B20015* (Hydrobiology, 2020).

Relevant sections and figures have been extracted directly from the report where required to develop this single standalone Hydrology and Geomorphology report co-authored by Advisian and Hydrobiology. The standalone Hydrobiology Report (Hydrobiology, 2020) was provided to the DoT.

1.4 Information and Data

1.4.1 Desktop Review

The following data/information was gathered or provided by DoT to complete the study:

- Landgate topographical DSM survey data covering varying extents listed below and depicted in Figure 1-3:
  - November 2018 1-metre; and
  - September 2013 5-metre.
- DoT ocean bathymetric survey data for Tantabiddi Boat Ramp from 2010, 2015 and 2019 (presented in Appendix C);
- Landgate high resolution aerial imagery in ECW format presented in Figure 1-3 (supplemented with google imagery);
  - Point Jurabi November 2018 Mosaic; and
  - Ningaloo Coastal Bundegi Cape Range Lighthouse July 2014 Mosaic.
  - Other coastline specific Landgate imagery from 1969 (October), 2007 (September), 2010 (October), 2013 (September), 2014 (July), 2018 (November).
- Microanalysis Tantabiddi Sediment Sample Analysis Data (2019) summarised in Section 8.2.3 and provided in Appendicies;
- Site photos of the boat ramp captured in 7th June 2019, 18th July 2005, 1st January 2005 and 20th May 2003;
- News article published in the Northern Guardian Carnarvon 4th March 2015 'Shire to clear jetty flood debris'.

Previous studies completed in the region are listed in Table 1-1. These reports were reviewed and relevant information/data extracted to inform the study. A table listing the relevant data/information extracted from each of the reports is provided in Appendix B.

Table 1-1. Relevant studies completed in the Tantabiddi Creek and Exmouth region

Date	Author	Title
2019	Cuttler *et al.*	Source and supply of sediment to a shoreline salient in a fringing reef environment
2018	Drost *et al.*	Predicting the Hydrodynamic Response of a Coastal Reef-lagoon System to a Tropical Cyclone using Phase-averaged and Surfbeat-resolving Wave Models
2018	Cuttler *et al.*	Response of a Fringing Reef Coastline to the Direct impact of a Tropical Cyclone
2018	Pomeroy *et al.*	Spatial Variability of Sediment Transport Processes Over Intratidal and Subtidal Timescales within a Fringing Coral Reef System
2018	MP Rogers	Tantabiddi Boat Launching Facility Investigation
2016	Seashore Engineering	Design Storms for Western Australian Coastal Planning – Tropical
2016	URS	Sand Bypass Dredging & Revetment Repair - Close Out Report
2015	Shire of Exmouth	Fact Sheet – Tantabiddi Boat Ramp Sand Bypassing, Ningaloo WA
2015	URS	Tantabiddi Boat Ramp - Sand Bypassing Environmental Management Plan
2015	URS	Tantabiddi Boat Ramp Sand Bypassing - Environmental Hazard Identification Report
2014	Hyd2o Hydrology	Exmouth Hydrological Study
2012	Eliot I *et al.*	The Coast of the Shires of Shark Bay to Exmouth, Gascoyne, Western Australia: Geology, Geomorphology and Vulnerability
2012	WorleyParsons	Market Street Levee, Exmouth – Flood Mitigation Works Detailed Design Report
2007	SKM	Exmouth Floodplain Management Study – Floodplain Management Strategy
2007	SKM	Exmouth Floodplain Management Study - Flood Modelling Report

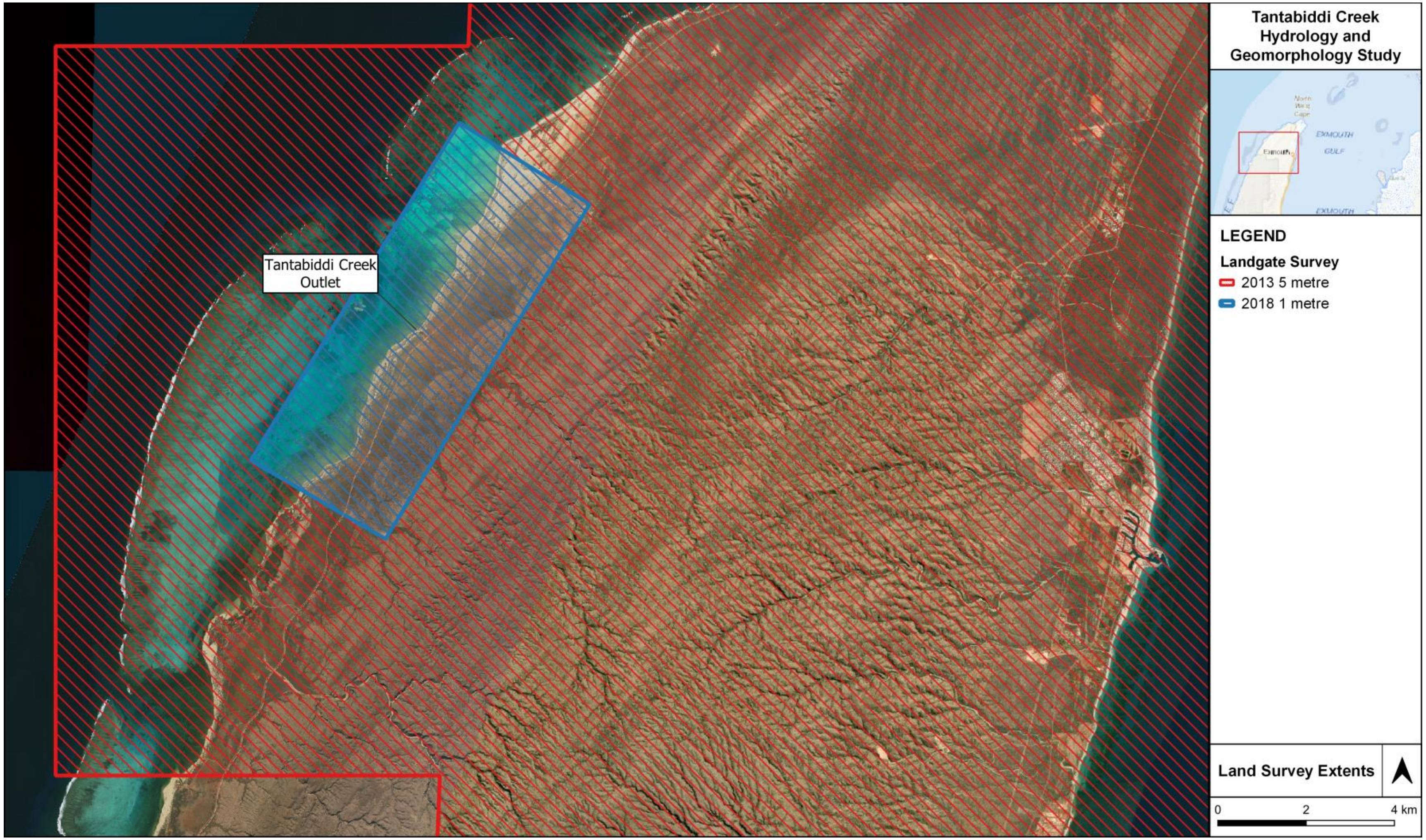


Figure 1-3. Landgate topographic survey data extents

1.4.2 Additional Survey

Platinum Surveys completed a supplementary survey of the site on 31 March 2020 including:

- Bathymetric data of the pool in the creek adjacent to the jetty;
- Topographic survey of the surrounding banks and nearby Yardie Creek Road; and
- Cross sectional survey at a water level logger installed in the pool.

The survey data was captured using a combination of DJI Inspire 2 drone coordinated with RTK GPS Rover and Zodiac for capturing bathymetry. The data was processed using software Drone Deploy.

The Orthomosaic image (2.35cm/px) and DEM (9.39cm/px) were provided to Advisian in Geotiff format (MGA94, AHD) with data accuracy of +-40mm. The combined survey is presented in Figure 1-4 and summary report included in Appendix D.

The survey data was provided to DoT as part of the data package deliverable.

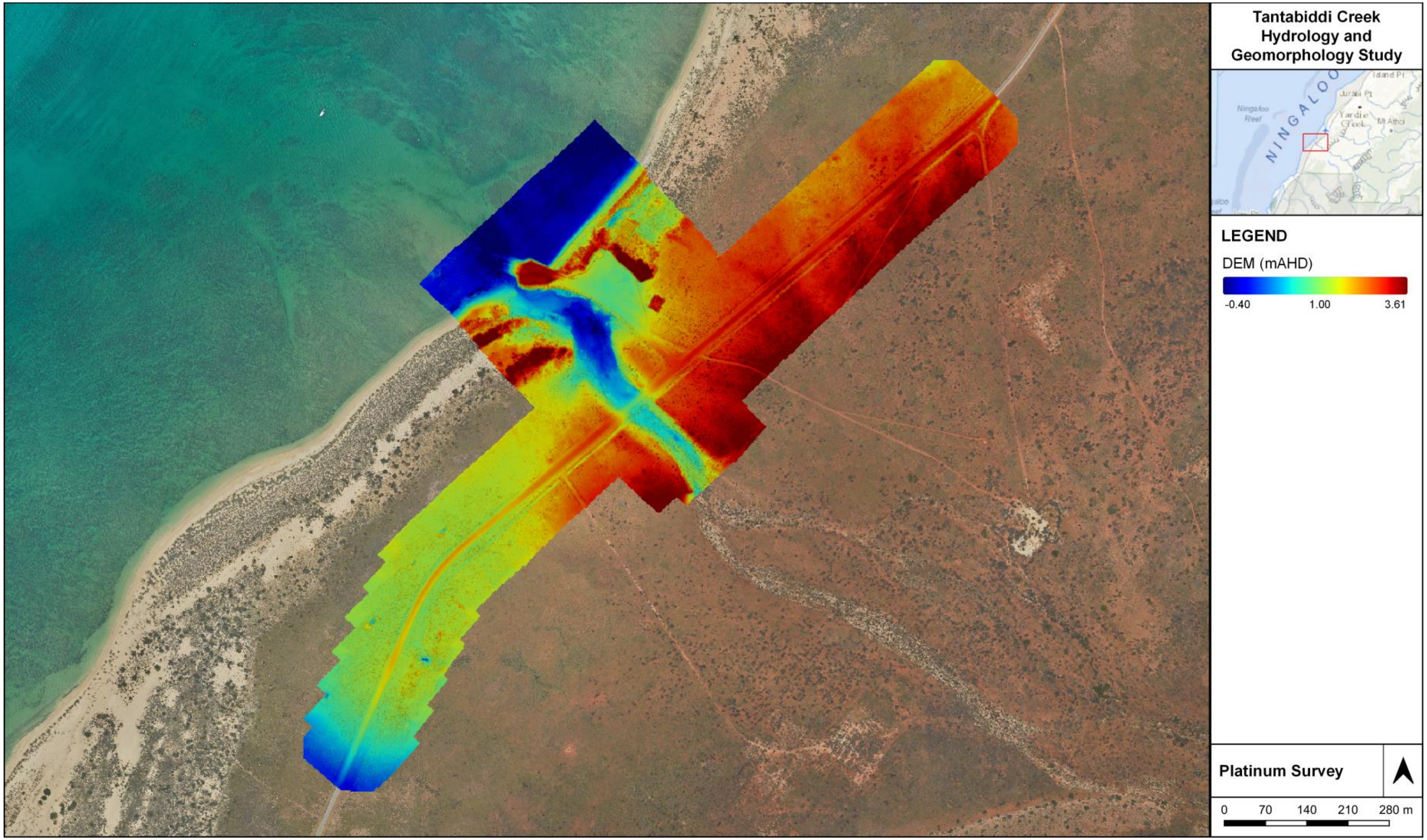


Figure 1-4. Extent of survey data captured by Platinum Surveys on 31 March 2020 and associated DEM

1.5 Terminology

Average Recurrence Interval (ARI) was previously used to define the probability of design flood events as stipulated in Australian Rainfall and Runoff 1987 (ARR87). In the 2019 revision of Australian Rainfall and Runoff (ARR2019), the terminology to define rainfall intensity probabilities was changed to Annual Exceedance Probability. This new terminology meets the requirements of Engineers Australia's National Committee on Water Engineering and provides clarity of meaning, technical correctness and practicality and acceptability.

To present event likelihood consistently and in keeping with non-specialist understanding of event likelihood, a '1-in-x AEP' nomenclature has been adopted. The conversion of event likelihood equivalence across the different nomenclature styles is presented in Table 1-2. For events greater than a 1-in-10 AEP (10% AEP), as is typically discussed in this report, the conversion from ARI to AEP is roughly equivalent to the inverse of the ARI. The 'Exceedance per Year' (EY) terminology has been adopted for the 1 EY (1 in 1.58 AEP) event as preferred by ARR2019.

Table 1-2. Summary of ARI and AEP equivalence

Average Recurrence Interval (ARI) (ARR87)	Annual Exceedance Probability (AEP) equivalent (ARR2019)	Alternate and adopted likelihood nomenclature in this report
1-year	~63.21	**1 EY**
2-year	~50%	**1 in 2 AEP**
5-year	~18%	**1 in 5 AEP**
10-year	~10%	**1 in 10 AEP**
20-year	5%	**1 in 20 AEP**
50-year	2%	**1 in 50 AEP**
100-year	1%	**1 in 100 AEP**

1.6 Spatial Reference System

Model files were set up in projection GDA94/ MGA Zone 49, which was utilised by DoT at the time of writing. The recently updated survey datum, GDA2020, should be considered for use in future project stages.

Fluvial modelling (Section 7) was completed in Australian Height Datum (mAHD) and coastal modelling (Section 9) was completed in Chart Datum (mCD). Results are presented in both mAHD and mCD.

2 Boat Ramp History

2.1 Boat Ramp Construction

The timing of boat ramp construction and improvements are outlined below:

- 1990s – the original single lane boat ramp was constructed and was impacted by extreme coastal processes associated with cyclonic conditions (Plate 2).
- 2004 – the Department of Planning and Infrastructure investigated various options for upgrading the ramp, including offshore wave protection structures.
- 2012 – Upgraded, including two ramp lanes, two finger jetties, a larger turning area, associated scour protection and other infrastructure (Plate 2; Appendix A). The upgrade extended 10 m further seaward.
- 2015 – maintenance of the revetment undertaken due to damage from floods in 2014 (Section 2.2).
- 2018 – an upgrade was investigated and proposed. The proposed design would facilitate increased usage and included additional ramps, finger jetties, commercial loading jetty and breakwater protection (Appendix A; MP Rogers and Associates, 2018).

Plate 2. Tantabiddi Boat Ramp upgrades. Left: the single lane boat ramp pictured in 2005. Right: the ramp was upgraded in 2012 to a dual ramp with two finger jetties (photo captured 2019).

2.2 Dredging

Fluvial and coastal processes contribute to the deposition of sand in front of, and adjacent to, the boat ramp which reduces the water depths available for safe navigation. Over the past 20 years, a long reach excavator has been used to clear small volumes of sediment from the boat ramp approximately 4 times per year on average (URS, 2015). The material removed using the excavator is deposited onshore behind the dunes on the northern side of the car park in the form of stockpiles shown in Figure 1-2 (MP Rogers and Associates, 2018).

A small floating bucket wheel dredger is used to remove sand when it has accumulated beyond the reach of the long reach excavator, to restore safe navigation depths. Dredging has occurred several times, with the most notable dredging campaign completed in 2015 to remove sediment, cobbles and rubble deposited during a major Tantabiddi Creek flood event in April 2014. Photographs showing the deposition are provided in Plate 3.

The Sand Bypass Dredging & Revetment Repair, Close Out Report (URS, 2016) reported the following sediment removal works following the April 2014 flood event:

- Soon after the 2014 flood event, a long reach excavator removed 1,500 m^3 of material from the boat ramp area to make the ramp accessible for boating. The material was deposited in stockpiles north of the parking area.
- Surveys undertaken by the (DoT and the Shire of Exmouth indicated that approximately 3,500 m^3 of accumulated sand spread over an area of approximately 14,000 m^2 still remained, restricting access. This material needed to be removed by the dredger and pumped with seawater as a slurry to the beaches immediately north of the boat ramp and deposited. This bypassing of sediment from the channel to the northern beaches would replenish the sand and sediment.
- Dredging commenced on 12th June 2015 and ceased on 22nd September 2015. There was considerably more rubble present in the dredge area than was anticipated. Site photos taken during the dredging activities show the sand and rubble/cobble deposition on the northern beach (Plate 4).
- The estimated extent of the 2015 dredging is shown in Figure 2-1 (black dashed line), estimated from the survey data provided in Appendix C. Dredging extents from other occurrences were not available, so historic imagery and bathymetric surveys were used to infer possible dredging extents between 2011 and 2019 (Figure 2-1).

The Close Out Report (URS, 2016) report suggests up to 5,000m^3 of material was excavated between the April 2014 flood event and completion of dredging in September 2015. Coastal processes are likely to have been contributing additional deposition of sand at the boat ramp and navigation channel between April 2014 and September 2015, so the actual volume of sediment transported by the creek in the April 2014 flood event is estimated to be between 3,500m^3 and 5,000m^3. Subsequent personal communications with Nello Siragusa (20th May 2020), who was engaged by the Shire of Exmouth to oversee dredging works following the 2014 flood event, confirmed these volume estimates. This volume was adopted when validating the sediment transport model developed for the 2014 flood event, as discussed in Section 9.

Plate 3. Tantabiddi boat ramp showing significant sediment deposition following the 26th April 2014 rainfall and flood event. Images captured 29th April 2020 at low tide (Fishwrecked.com, 2014)

Plate 4. Tantabiddi Boat Ramp dredging, 2015. Top: dredge slurry pumped to the northern beach. Bottom: Rocks deposited on the northern beach on completion of dredging activities (URS, 2016)

Figure 2-1. Dredged or excavated areas at the Tantabiddi Boat Ramp based on bathymetry, reports and aerial imagery from 2011 to 2019. Note: aerial imagery and bathymetric surveys were not conducted at the same time. Aerial imagery provides only an approximate estimate of dredge extent. Base imagery: November 2019.

3 Site Investigation

Advisian and Hydrobiology undertook a site visit to the Tantabiddi creek and boat ramp on the 18th and 19th March 2020. The purpose of the site visit was to collect hydrological and geomorphological data and observations needed to inform the study and install a water level logger to record flood water levels during future rainfall events.

The team initially inspected the permanent pool adjacent the boat ramp as well as the Yardie Creek Road floodway crossing, then walked along Tantabiddi Creek bed approximately 1.5km from the coast. The dredge stockpile material, boat ramp and coastline were then inspected and assessed.

The following were noted during the site inspection:

- The creek bed was dry, with exception to the permanent pool located towards the outlet. The sandbar was present creating a divide to the ocean;
- Asides from the development at the Tantabiddi boat ramp, car park and associated facilities there is no other development in the catchment;
- The catchment is vegetated with shrubs and sparse trees;
- The creek bed contained gravelly and cobble sediments up to around 20cm in diameter, which appear to have been mobilised from upper reaches during flow events;
- Coral noted throughout the walk up the creek bed.

Four sediment samples (TS01, TS02, TS03 and TS05) were collected along the creek bed and an additional sample (TS04) taken from the dredge stockpile located north of the boat ramp. The sediment samples were then sent for laboratory testing (Microanalysis, 2020) to assist with material characterisation and determination of likely sources. This sediment data complimented the existing laboratory testing data (Microanalysis, 2019) for sediment samples collected by the DoT and provided for use in this study. The locations of all sediment samples collected and used in this study are shown in Figure 3-1. A more detailed description and analysis of sediment samples and laboratory data collected by Advisian in 2020 and by the DoT in 2019 is presented in Section 8.2.3. Laboratory test results for all sediment data is provided in Appendix E.

A water level logger (TSW01) was installed on the northern edge of the creek bed to capture any future flooding events. This data may be used in future to validate the hydrological and hydraulic models discussed in Sections 6.3 and 7. Photographs showing the logger installation are presented in Plate 5 and the location shown in Figure 3-1.

The water level logger set up is as described as below:

- A HOBO Water Level Logger (U20L-01) was selected due to capability to record water depths from 0 – 9 metres with 0.1% measurement accuracy in a range of fresh and salt water environments.
- The logger records absolute pressure (kPa) and temperature (°C).
- The logger was encased in PVC piping and secured to a star picket with yellow post safety cap and placed on the northern edge of the permanent pool.
- The logger was set to record at 15-minute increments. This frequency was selected to balance data storage and to adequately capture storm peak and recession.

- The logger will require reading out after approximately 7 months (November 2020) and to be reinstated.
- Mean sea level pressure data recorded at a nearby station such as Learmonth Airport (BoM Station 5007) can be used to convert the absolute pressure recording into water levels.

Table 3-1. Water level logger (TSW01) details

Parameter	Latitude (S)	Longitude (E)	Elevation (mAHD)
Bed Elevation (base of logger)	21.9130492	113.97929	1.1
Top of star picket	21.91304917	113.9792903	1.4
Water level at time of installation	21.91302863	113.979315	1.5

Data from the water level logger was downloaded in August 2020 towards the end of the project. The findings from the logger are presented in Section 12 (Addendum: Surface Water Logger Data).

Some example photos showing the site conditions are provided in Plate 6, Plate 7, Plate 8, Plate 9 and Plate 10.

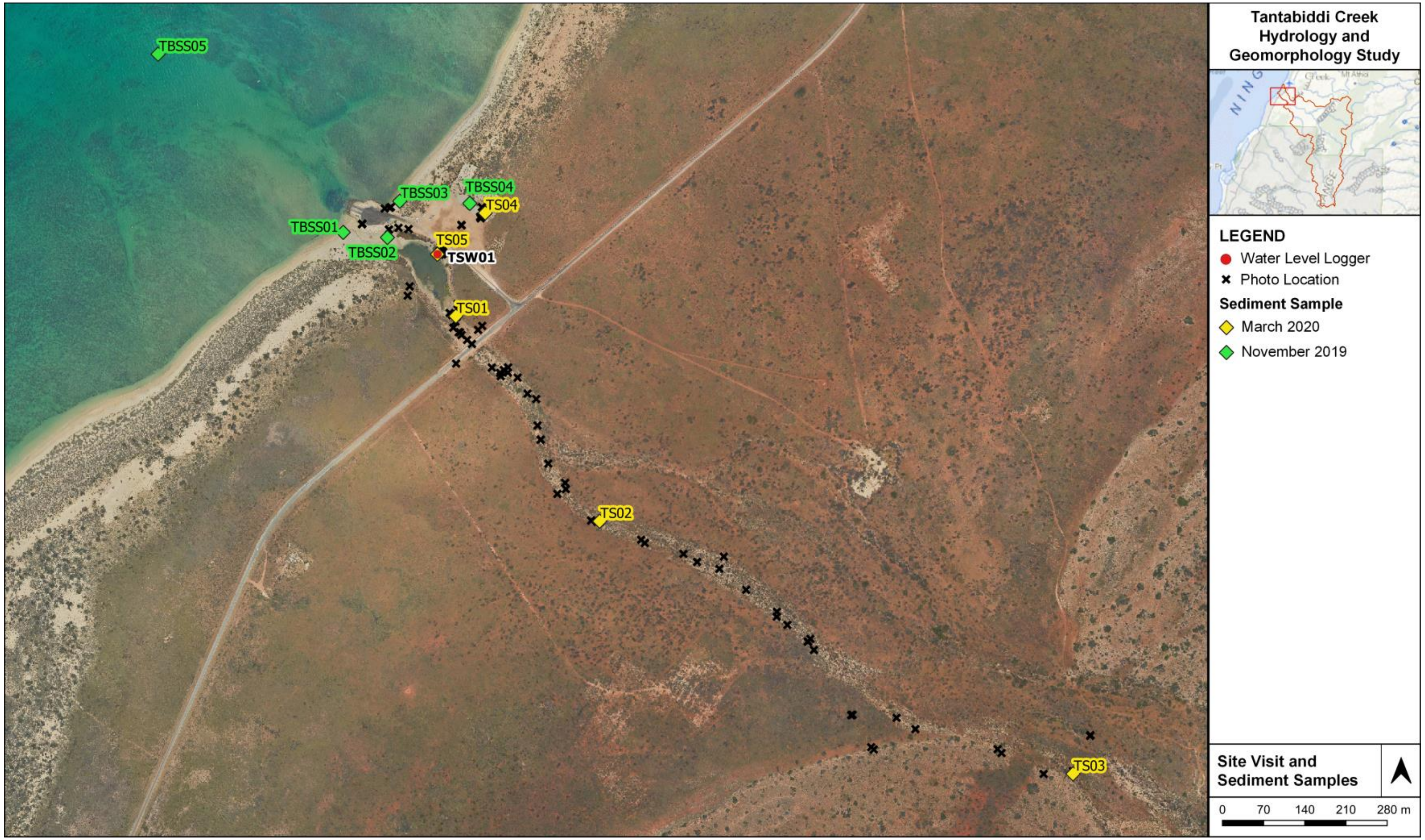


Figure 3-1. Locations of sediment samples collected by DoT (2019) and Advisian (2020), as well as the water level logger location and site photos taken on 18th and 19th March 2020

Plate 5 Water level logger (TSW01) in pool of water near creek mouth. Left: facing south west from creek edge Right: looking north east from creek bed (19th March, 2020)

Plate 6. Sand bar at mouth of Tantabiddi Creek (18th March, 2020)

Plate 7. Estuarine pool adjacent Tantabiddi Creek (18th March, 2020)

Plate 8. Yardi Creek Road floodway crossing of Tantabiddi Creek (18th March, 2020)

Plate 9. Typical Tantabiddi Creek bed material upstream of Yardi Creek Road (18th March, 2020)

Plate 10. Typical vegetation and bed material upstream of Yardie Creek Road (18th March, 2020)

4 Methodology Overview

The methodology adopted to assess the hydrology, hydraulics and geomorphology of Tantabiddi Creek and nearshore coastal area to better understand hydraulic and sediment transport behaviour under a range of flood conditions and between flood events due to prevailing coastal processes, is summarised below.

1. *Rainfall Analysis:* analysis of historical rainfall data to characterise the rainfall-runoff conditions of the Tantabiddi Creek catchment. Detailed analysis of the rainfall data associated with the observed 2014 flood event which caused significant sediment deposition at the boat ramp.
2. *Hydrology Modelling*: development of a rainfall-runoff model for Tantabiddi Creek and simulation of the observed 2014 flood event as well as the 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP design flood events. Extract flow hydrographs at Yardie Creek Road upstream of the boat ramp for development of sedigraphs and input to 2D hydraulic modelling.
3. *Hydraulic Modelling*: development of a 2D TUFLOW hydraulic model for the study area and simulation of the 2014 flood event as well as the 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP flood events to map the depth and extent of flooding, and extract peak water levels, velocities and other relevant hydraulic data.
4. *Geomorphology Assessment*: Particle size distribution analysis of sediment samples, sediment transport modelling and development of design sedigraphs for input in the 2D Hydrodynamic model developed for sediment transport modelling in the study area.
5. *Sediment Transport Modelling:* development of a 2D Mike 21 sediment transport model for the study area and use to simulate sediment transport in the 2014 flood event as well as the 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP design flood events.
6. *Evaluation of Risks and Opportunities:* Use results from modelling to quantify bed level changes and estimate volumes of alluvial material transported and deposited in the boat ramp area in the 2014 flood event as well as the 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP design flood events. Use results to evaluate the extent and likelihood/frequency of deposition as well as the risks and opportunities associated with the existing boat ramp and other potential ramp upgrade and development options.

The 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP were considered to be the suitable range of AEP events required to characterise the hydrological and geomorphological behaviour in the creek. The 1:100 AEP event is most commonly adopted for flood risk assessments and riverine related design. The 1EY event was included in the modelling for an understanding of the sediment transported once a year on average.

The results from the tasks outlined above are presented in the following sections.

5 Rainfall

5.1 Average Statistics

Rainfall data was extracted from several rainfall stations to characterise the rainfall-runoff conditions of the catchment. Locations of the rainfall stations relative to the Tantabiddi boat ramp are presented in Figure 5-3 and details are as follows:

- Exmouth Town (BoM Station 5051) located 15km from the boat ramp, recording rainfall at daily intervals and providing daily totals;
- Learmonth Airport (BoM Station 5007) located 38km from the boat ramp, recording rainfall at 1-minute intervals and providing daily totals;
- Unofficial AIMS station Ningaloo Reef (Milyering) located 14km south of the boat ramp, recording rainfall at daily intervals and providing daily totals.

Other rainfall stations in the region were either inactive and/or do not have available data over the period of interest (2012 to present) and therefore have not been used.

Rainfall data recorded at Exmouth weather station (5051) between 1968 and 2020 was used to generate average monthly rainfall totals shown in Figure 5-1. The monthly data suggests most of the rainfall at Exmouth falls between January and July, often associated with tropical cyclones and storms. The corresponding average annual rainfall recorded over that period is 283.3 mm.

Figure 5-2 shows the daily rainfall and major rainfall events in recent years at the Exmouth Town (5051) weather station. This plot compares the rainfall associated with the major flood event in April 2014 with other historical rainfall events. The April 2014 event was the most significant event recorded in the last 12 years and since the ramp upgrade in 2012-2013. The 2014 event is discussed in more detail below.

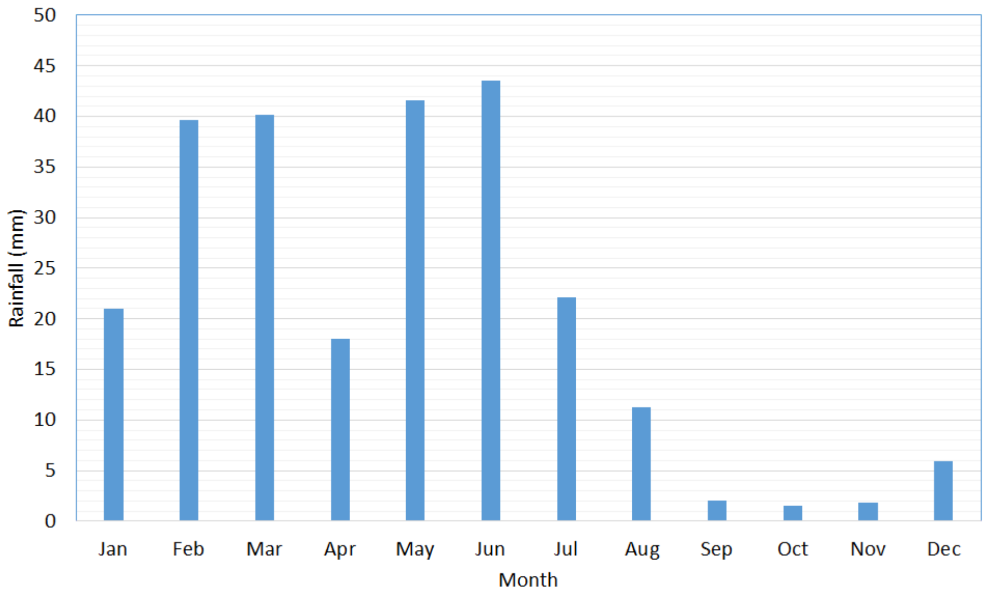


Figure 5-1. Average monthly rainfall recorded at Exmouth (5051)

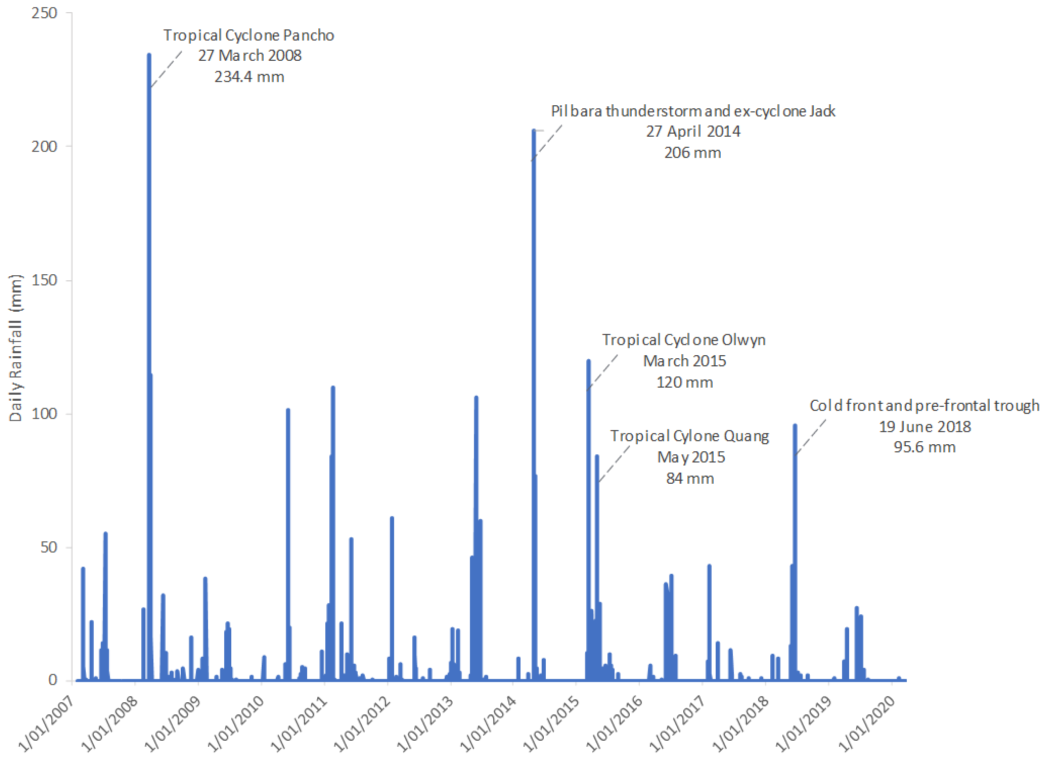


Figure 5-2. Daily rainfall (mm) at Exmouth Town (5051) weather station (BOM, 2020) and key associated weather systems.

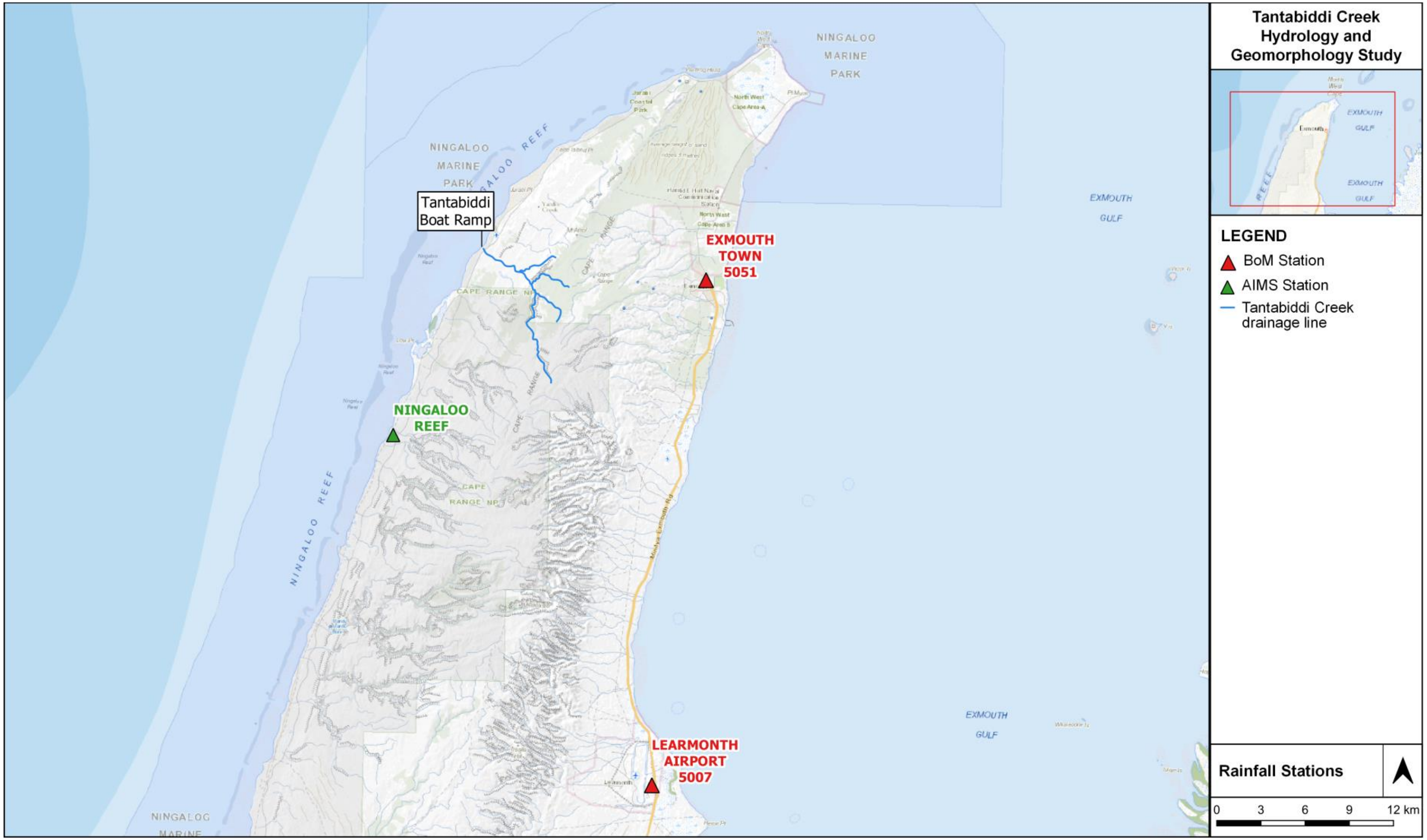


Figure 5-3. Rainfall Stations in proximity to Tantabiddi Creek and boat ramp

5.2 April 2014 Rainfall Event

Since the Tantabiddi boat ramp upgrade in 2012-2013, the highest daily rainfall total recorded at Exmouth station (5051) was 206 mm at 9am on the 27th April 2014 (Figure 5-2). This severe rainfall event was caused by slow moving thunderstorms associated with ex-cyclone Jack in the West Pilbara resulting in flash flooding and extensive damage to the Exmouth region (BoM, 2014).

An AIMS station, Ningaloo Reef (Milyering), located 14km south of the boat ramp in Cape Range National Park (Figure 5-3), recorded 237.7 mm during the event. Anecdotal evidence suggests up to 400mm may have fallen in the Cape Range area to the west of Exmouth (BoM, 2014). The location of this anecdotal recording is unknown but is understood to be in proximity to the Tantabiddi boat ramp.

High frequency rainfall data recorded at Learmonth Airport weather station (5007) was used characterise and assess the likely critical duration of the storm event impacting the Tantabiddi boat ramp. The 15-minute rainfall totals hyetograph for the 26th April 2014 storm is presented in Figure 5-4.

The methodology and findings are summarised below:

- It is evident the storm occurred across a duration of 17-hours (4am to 9pm) on the 26th April. Two separate bursts are observed within this event with peaks occurring around 10am and 6:15pm at Learmonth Airport (Figure 5-4).
- Rainfall radar for the storm available from The Weather Chaser (2020) confirms the storm was largely concentrated north of Learmonth Airport and generally more intense on the western side of the range close to the Ningaloo Reef station. Figure 5-5 presents rainfall intensity radar at early and later stages throughout the storm. The radar data shows the storm passing through Ningaloo Reef station and into the Tantabiddi catchment area shown in Section 6.2.1. The rainfall data recorded at the Ningaloo Reef station is therefore considered most representative of the 2014 event.
- To characterise the storm at the Ningaloo Reef station, the 15-minute rainfall data at Learmonth Airport station were factored up to be representative of likely rainfall at the Ningaloo Reef station. This factor was determined to be 1.5, based on comparison of daily rainfall recorded at Learmonth Airport (154.4mm), and the daily rainfall recorded at the Ningaloo Reef (237.7mm).
- The higher rainfall at Ningaloo Reef is also consistent with the anecdotal observations of significant rainfall in the Cape Range National Park where the Tantabiddi catchment centroid is located (Section 6.2.1).
- The BoM Intensity Frequency Duration (IFD) chart developed for Tantabiddi Creek catchment centroid was used to assign an Annual Exceedance Probability (AEP) to the storm at Ningaloo Reef using the factored rainfall hyetograph. IFD charts presented in Figure 5-6 of the first burst, second burst and total storm shows:
  - The highest intensity rainfall is 100mm in a 2 hour period and is associated with the peak of the second burst in the hyetograph;
  - BoM (2016) IFD chart shows this peak of the second burst is equivalent to 'between a 1 in 100 AEP and 1 in 200 AEP' rainfall event while the peak of the first burst is more representative of a 1 in 50 AEP rainfall event (70mm in 1.5 hours);

- Therefore, when characterising the total storm by the overall peak in rainfall intensity (100mm in a 2 hour period), the 17 hour storm is representative of 'between a 1 in 100 AEP and 1 in 200 AEP' rainfall event.

- Anecotodal photos of the floodwaters at the creek outlet during the April 2014 event are presented in Plate 11 and Plate 12.

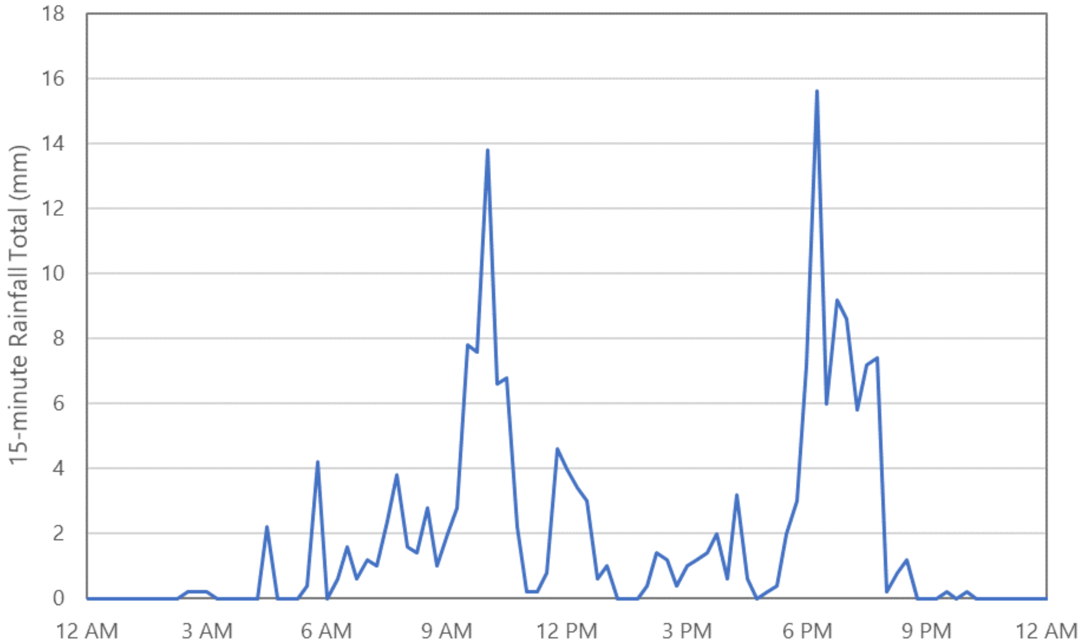


Figure 5-4. 15-minute rainfall totals at nearby Learmonth Airport (5007) during storm on 26th April 2014.

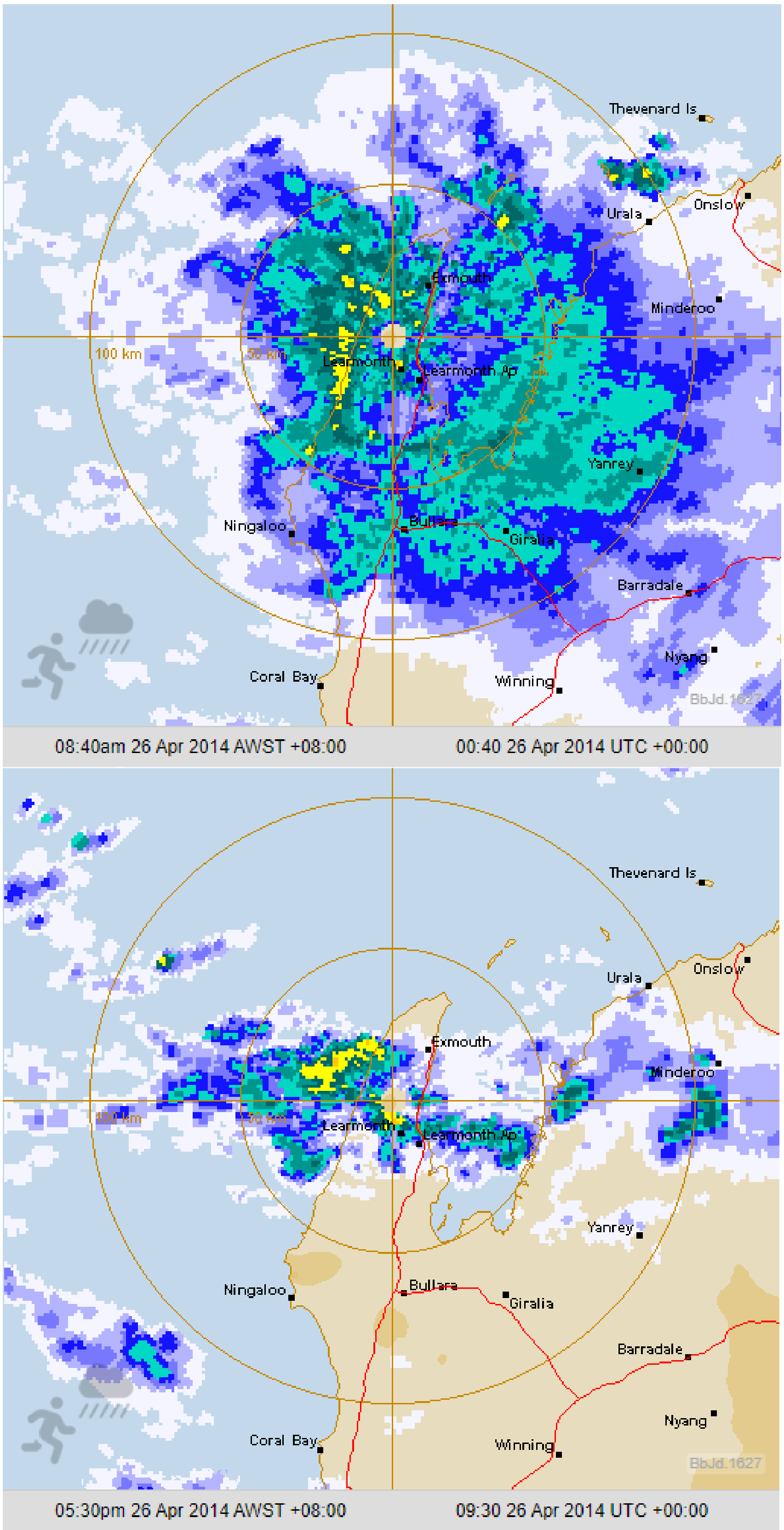


Figure 5-5. Rainfall intensity radar imagery) at 8:40am and 5:30pm during the 26th April 2014 event (The Weather Chaser, 2020.

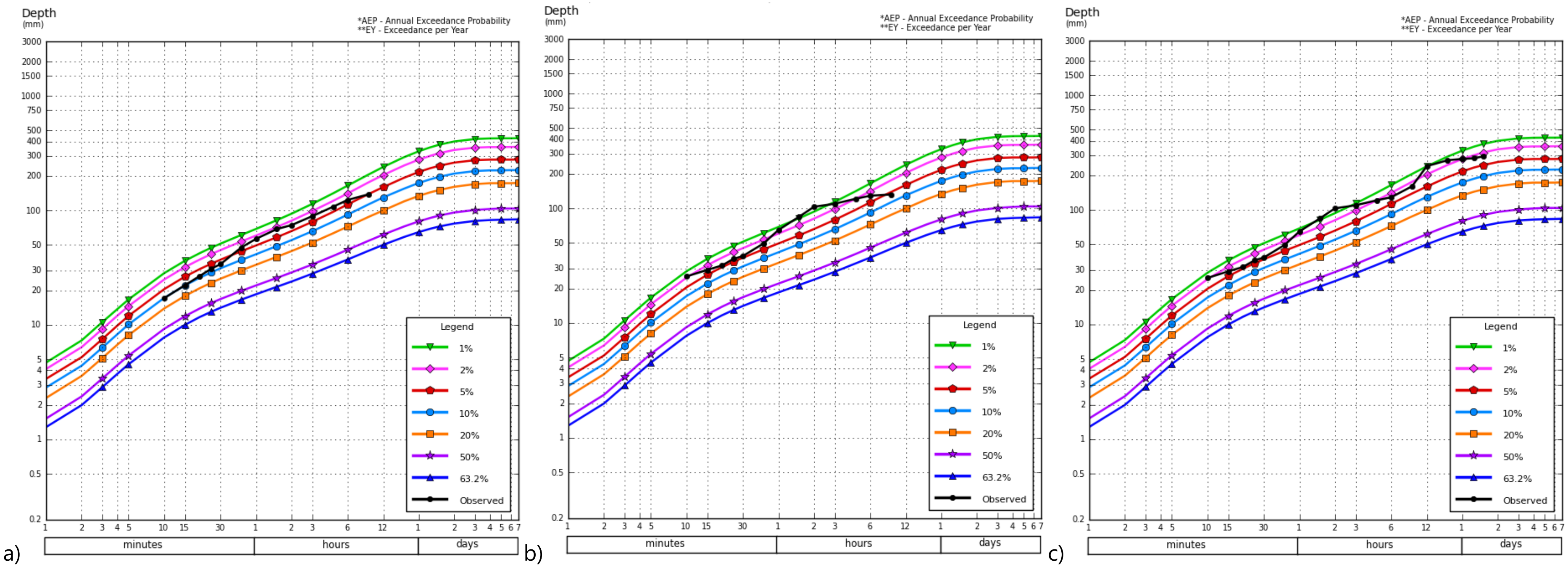


Figure 5-6. 26th April 2014 rainfall event at Ningaloo Reef (factored) against IFD chart (BoM, 2016) a) first peak, b) second peak, and c) full storm.

Plate 11. Floodwater breaking through the sandbar at the Tantabiddi Creek outlet following the April 2014 event, looking east (Fishwrecked.com, 2014)

Plate 12. Floodwater breaking through the sandbar at the Tantabiddi Creek outlet following the April 2014 event, looking north (Fishwrecked.com, 2014)

6 Hydrology

6.1 Regional Hydrology

The hydrology of the Cape Range area is characterised by numerous ephemeral creeks draining west and east of the Cape Range ridgeline during significant rainfall events as shown in Figure 1-1. The topographic elevation of these catchments within the Cape Range area, range between 300 mAHD on the ridgeline to 2 mAHD at the coast.

The upper reaches of creeks in this area are deeply incised and have steeper bed gradients, while the lower reaches exit the Range onto low lying coastal areas with lower bed gradients before flowing into the ocean. There is limited vegetation cover, comprising mainly scrubland and grasses, and the steep terrain and rocky nature of the catchment results in a rapid catchment response to rainfall and flash flooding.

There are no known current water level gauging stations in the Tantabiddi Creek or nearby catchments. Advisian installed a water level depth gauge in Tantabiddi Creek in March 2020 (described in Section 3). Should a significant rainfall-runoff event be observed at Tantabiddi during the project, it is recommended that data from this gauge be used to validate hydrological and hydraulic models.

Data from the water level logger was downloaded in August 2020 towards the end of the project. The findings from the logger are presented in Section 12 (Addendum: Surface Water Logger Data).

6.2 Tantabiddi Creek

6.2.1 Catchment Delineation

The Tantabiddi Creek catchment area is 27km^2 and is shown in Figure 6-1. The watershed boundary was delineated using 5-metre topographic survey data captured by Landgate (2013). The characteristics the Tantabiddi Creek catchment is presented in Table 6-1 below.

Table 6-1. Tantabiddi catchment characteristics

Area (km^2)	27.1
Stream Length (km)	13.7
EA Slope (m/km)	9.6
Catchment Centroid (X,Y)	114.014,-21.947
Catchment Outlet (X,Y)	113.979,-21.914

A smaller 9km^2 catchment to the south-west of the Tantabiddi catchment and other minor northern catchments may contributes flow to the Tantabiddi creek during more extreme events. These catchment areas are shown in Figure 6-1. These catchments are small in comparison to the Tantabiddi Creek catchment and there would be substantial attenuation of flow as this floodwater passes along the eastern side of the coastal dunes to the outlet. Therefore, flow from these catchments is not expected to have a significant influence on the peak flows reporting to the boat ramp (the focus of this study).

Flows from these catchments have been included in the hydraulic modelling presented in Section 7 to capture contributions of flow to Tantabiddi Creek and also characterise the flow paths that may impact on alternative boat ramp options located north and south of Tantabiddi Creek.

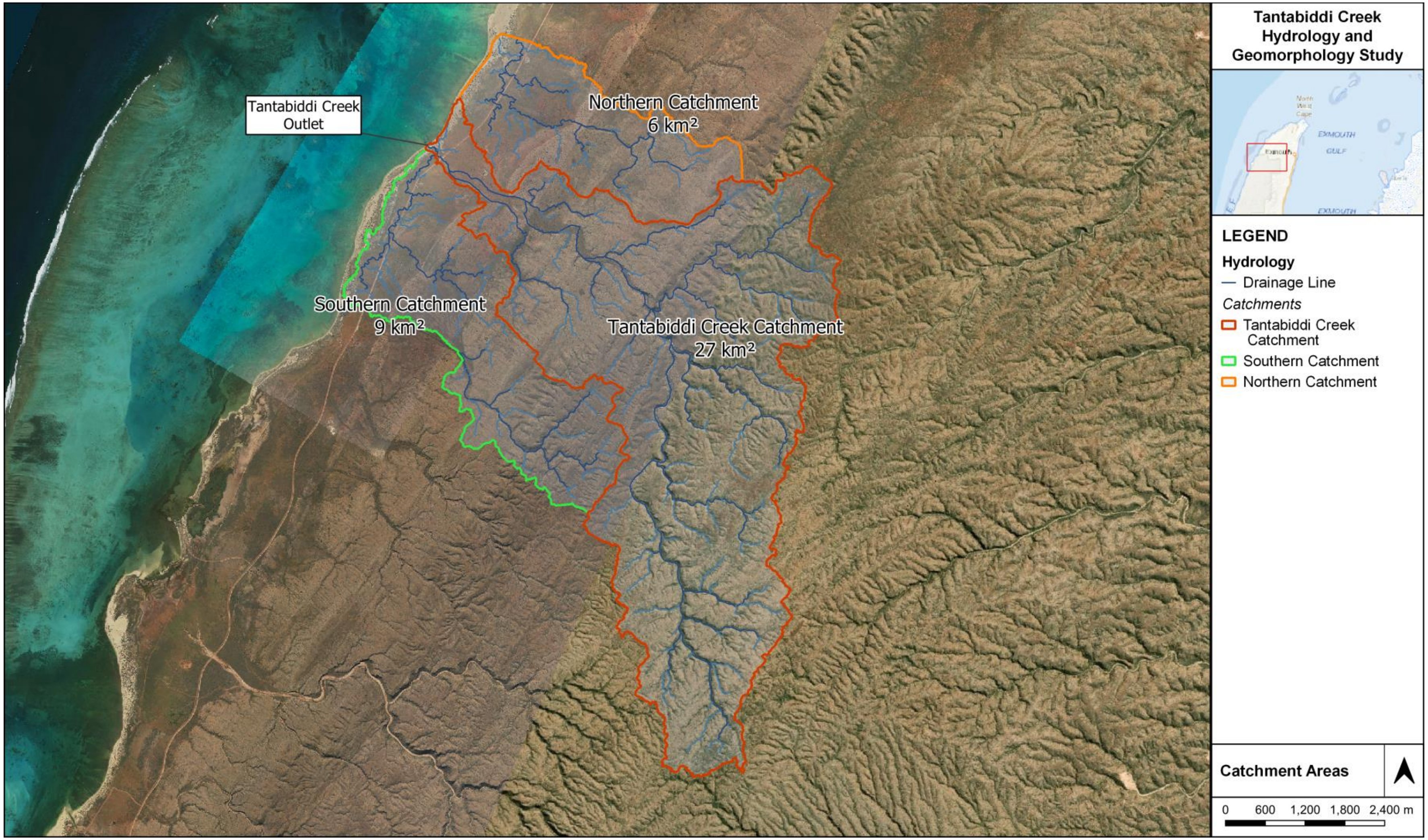


Figure 6-1. Tantabiddi Creek catchment and other minor catchments contributing flow to the study area

6.2.2 Peak Flow Estimation

Peak flow estimation was undertaken for an initial flood magnitude estimate of Tantabiddi Creek and to validate the flows produced in the Rainfall-Runoff Model described in Section 6.3. Peak flow estimation was undertaken based on guidelines outlined in ARR2019.

Due to the lack of observed streamflow and related flood data, site specific Flood Frequency Analysis could not be conducted for estimating the Tantabiddi catchment peak flows. Instead several regional peak flow estimation methods were used. These methods use flood frequency characteristics from other gauged catchments to characterise the catchment of interest (ARR, 2019).

The following methods were considered:

1. Regional Flood Frequency Estimation Model (RFFE) (ARR, 2019)
   - Method developed by ARR (2019) for use across all regions of Australia.
   - The Tantabiddi catchment is located further away than 300 km from the nearest gauged catchment location.
2. Regional Flood Frequency Procedure (RFFP) (Flavell, 2012)
   - Method developed by Flavell (2012) with specific parameters developed for the Pilbara region.
   - Developed from 16 gauged catchments with on average 30 years record.
   - Davies and Yip (2014) found although RFFP was well-suited to discharges in the Pilbara region, it under-estimated the design discharge in the Gascoyne Region.
3. Index Flood Method (IFM) (ARR, 1987)
   - Method outlined in ARR1987 with specific parameters for the Pilbara Region.
   - Developed from 13 catchments in the Pilbara.
   - Davies and Yip (2014) and ARR1987 state IFM overestimates discharges for river basins in the Gascoyne region.
4. Davies and Yip (2014)
   - Specific method developed based on 10 river basins in the coastal part of the Pilbara together with the Gascoyne and part of the Mid-west Region.
   - Based on IFM (ARR,1987) with revised design equations and frequency factors.

The peak flow estimation results from each of the procedures in presented in Table 6-2.

Table 6-2. Regional flood methods and associated peak flow estimates for the Tantabiddi Creek catchment

Peak Flow Estimation Method	Peak Flow Estimation for 1 in X AEP Event (m^3/s)					
	2	5	10	20	50	100
Regional Flood Frequency Estimation Model (RFFE) (ARR, 2019)	8	22	35	52	75	93
Regional Flood Frequency Procedure (RFFP) (Flavell, 2012)	2	7	17	40	72	112
Index Flood Method (IFM) (ARR,1987)	19	37	64	108	199	343
Davies and Yip (2014)	11	34	58	88	141	198

The Davies and Yip (2014) and RFFP (Flavell, 2012) methods are considered most representative of the Tantabiddi catchment conditions. Davies and Yip (2014) was developed based on 10 river basins in the coastal Pilbara area, together with the Gascoyne region. The RFFP (Flavell, 2012) is considered to produce accurate results in the Pilbara (Davies and Yip, 2014).

RFFE (ARR, 2019) estimate was not used as the method was developed for use across all regions of Australia, with the nearest gauged catchment further than 300 km from the Tantabiddi catchment. IFM (ARR,1987) estimate was not used as ARR1987 states IFM overestimates discharges for river basins in the Gascoyne region.

This is supported by the following statement in ARR2019;

> *"Flood engineers have a duty to use other procedures and data that are more appropriate for their design flood problem than those recommended in this Edition of Australian Rainfall and Runoff. This guidance is particularly relevant where approaches have been developed for limited regions of the country without the aim of these approaches being suitable for application across the whole country or being subject to same development testing as the RFFE model proposed herein. An example of this situation is the Pilbara Region of Western Australia where independent studies by Davies and Yip (2014) and Flavell (2012) have developed Regional Flood Frequency Estimation techniques for this region."*

The design flows associated with Davies and Yip (2014) and RFFP (Flavell, 2012) were adopted for developing and validating the Tantabiddi rainfall-runoff model described in Section 6.3 as they are considered the most representative methods of all considered.

6.3 Hydrological Modelling

6.3.1 Model Selection

Runoff routing modelling software RORB (version 6.45) was used to simulate rainfall-runoff in the Tantabiddi Creek catchment for a range of Annual Exceedance Probability (AEP) events. The RORB model was used to develop design hydrographs which were then input to the 2D hydraulic model developed for the boat ramp area as discussed in Section 7.

6.3.2 RORB Model Setup

Sub-catchment extents were delineated using 5-metre topographic survey data captured in 2013 by Landgate (2013). The RORB model set up included sub-catchments, stream routing paths and nodes as shown in Figure 6-2. The minor northern and southern catchments were not included in the RORB model as they have been captured by 2D TUFLOW modelling described in Section 7.

6.3.3 Input Parameters

The model is characterised by a number of input parameters including sub-catchment areas, mainstreams rainfall losses, non-linearity exponent (m) and the routing parameter (K_c) described in the following sections.

6.3.3.1 Rainfall Losses

Losses are applied in RORB using one of the following two methods:

- Initial Loss (IL), Continuing Loss (CL) method; or
- Proportional Loss method.

A literature review was conducted to inform the selection of an appropriate loss model and associated parameters for Tantabiddi Creek. The results are summarised below:

- For arid areas with mean annual rainfalls less than 350 mm, ARR2019 provides no recommendations for design loss information;
- The earlier revision of Australian Rainfall and Runoff (ARR1987) recommended IL values of approximately 40 to 50 mm and a CL of 5 mm/h;
- A previous study of the Exmouth region by SKM (2007) adopted a proportional loss model. The proportional loss and runoff coefficient rates as a percentage of rainfall depth are presented in Table 6-3.

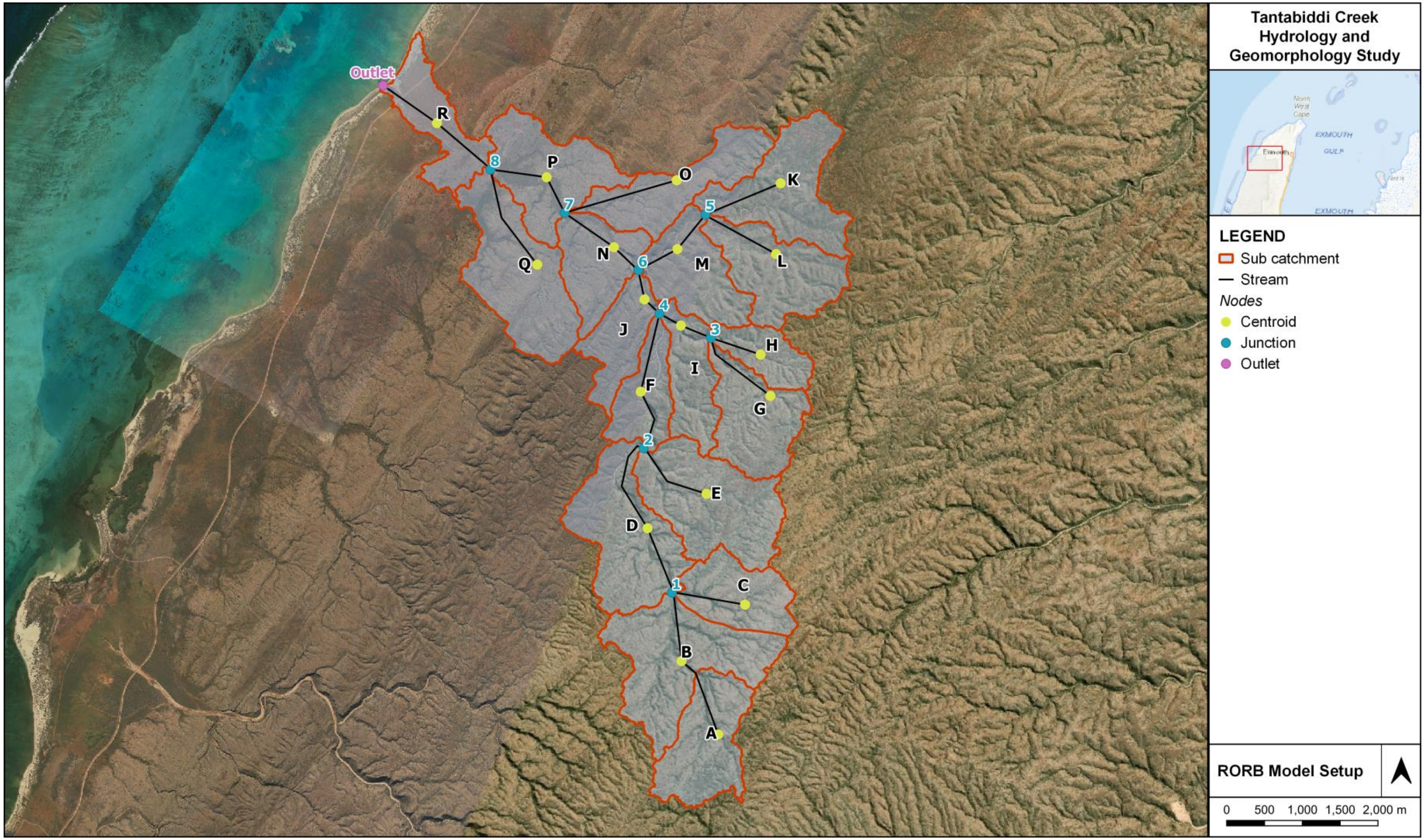


Figure 6-2. RORB Model Setup

Table 6-3. SKM (2007) runoff coefficients

1 in X AEP Event	10	25	100	500
Proportional loss rate (%)	82	68	50	40
Runoff coefficient (%)	18	32	50	60

Flavell (2012) adopted a proportional loss model when calibrating RORB to Pilbara catchments and presented recommended runoff coefficients (RoC) for the Pilbara catchments (Table 6-4). These rates provide suitable estimates of catchment discharge across the full range of AEP events and are based on more recent data in the region.

Table 6-4. Flavell (2012) Proportional Loss Rates for the Pilbara region

1 in X AEP Event	2	5	10	20	50	100
Proportional loss rate (%)	77	75	70	65	56	49
Runoff coefficient (%)	23	25	30	35	44	51

The proportional loss coefficients recommended by Flavell (2012) were considered most appropriate for this study and were adopted for RORB modelling of Tantabiddi Creek. The proportional loss coefficients compare well with the values adopted by SKM (2007).

The Flavell (2012) runoff coefficients were extrapolated to develop a coefficient of 19% for the 1 EY event.

6.3.3.2 Non-Linearity parameter (m)

In the absence of site-specific streamflow data for calibration, the standard and widely adopted non-linearity (m) value of 0.8 was adopted in the RORB model.

6.3.3.3 Routing Lag Parameter (Kc)

The RORB routing lag parameter (K_c) was determined through investigation of two methods presented below:

1. ARR2019 recommends the below equation for the North-West, Wheatbelt, Kimberley and arid interior of Western Australia:

$$K_c = 1.06L^{0.87}S_e^{-0.46} = \mathbf{3.60}$$

Where:

- *L is the mainstream length; and*
- *S_e is the main stream equal area slope (m/km).*

2. Pearcey *et al.* (2014) investigated numerous Pilbara catchments and streamflow to derive the following equation for Kc:

$$K_c = C_{0.8}d_{av}$$

Where:

- d_{av} *is the average flow distance (extracted from the RORB model); and*
- $C_{0.8}$ *= non-linearity parameter.*

Pearcey *et al.* (2014) recommends the use of $C_{0.8}$ = 0.59, for average Pilbara catchments, however many of the catchments considered when developing this $C_{0.8}$ value, were far larger than the Tantabiddi Creek catchment. Pearcey *et al.* (2014) recommends the use of lower $C_{0.8}$ values for steeper catchments, so for this study, we evaluated the range of catchments considered and selected the $C_{0.8}$ value which corresponded to a site with similar catchment size and equal area slope. The Harding River (Marmurrina Pool) was selected and the corresponding $C_{0.8}$ = 0.44 adopted. The resulting equation yielded Kc = 2.78, as follows:

$$K_c = C_{0.8}d_{av} = 0.44 * 6.32 = \mathbf{2.78}$$

The Pearcey *et al.* (2014) method was developed specifically for the Pilbara region and the selected $C_{0.8}$ value is based on a catchment with similar area and slope. Therefore, this method was considered appropriate for use in this study and the corresponding K_c value of 2.78 adopted in the RORB model.

6.3.3.4 Rainfall

Design rainfall was applied in RORB in accordance with the following methods recommended in ARR2019:

- Design rainfall depths were extracted from the BoM (2016) IFD data tool at the Tantabiddi catchment centroid;
- Temporal patterns from the Rangelands West zone were extracted from the ARR Datahub for simulations; and
- The Ensemble Event approach was adopted, where the design peak flow is the weighted average or median of the ensemble.

6.3.4 Results

A range of storm durations for each AEP event were simulated using Ensemble approach and the results assessed to determine the critical storm duration for the catchment. The critical storm duration for each AEP produces the largest peak flow and therefore were adopted for the study. The critical storm duration for the catchment, across the range of AEPs, is between 2 and 6 hours.

Peak flows for the range of AEP events were extracted from the RORB model at Node 6 shown in Figure 7-1, and compared with peak flows estimated using regional methods described in Section 6.2.2. This location (Node 6) was selected for peak flow comparison as the floodplain becomes divergent downstream of this node and RORB is unable to accurately represent the complex floodplain flow behaviour.

The results presented in Table 6-5 suggest RORB produced lower flows than those estimated using the regional equation developed by Davies and Yip (2014) and generally higher than the peak flows estimated using RFFP (Flavell, 2012), with exception to the 1 in 2 AEP event. As the results are within range of these two regional equations the RORB hydrographs (Figure 6-3) were considered to be appropriate for adoption in the TUFLOW model.

The ensemble approach yielded a critical duration of 6 hours for the 1 in 10 and 1 in 20 AEP design events. These hydrographs have two peaks (Figure 6-3) which is typical in Rangelands West design storms with duration greater than 3 or so hours. The other design events with shorter critical duration only have one peak, which is typical of shorter duration storms.

Table 6-5. Ensemble event method patterns, duration and flow results at Node 6 (m^3/s)

Event	1 EY	1 in 2 AEP	1 in 5 AEP	1 in 10 AEP	1 in 20 AEP	1 in 50 AEP	1 in 100 AEP
Duration (hours)	3	3	3	6	6	2	2
Temporal Pattern	8	8	10	13	13	25	25
Peak Flow (m^3/s)	**10**	**15**	**25**	**39**	**57**	**93**	**125**
Davies and Yip (2014) Peak Flow (m^3/s)	-	8	27	46	70	113	159
RFFP (Flavell, 2012) Peak Flow (m^3/s)	-	4	10	20	38	68	106

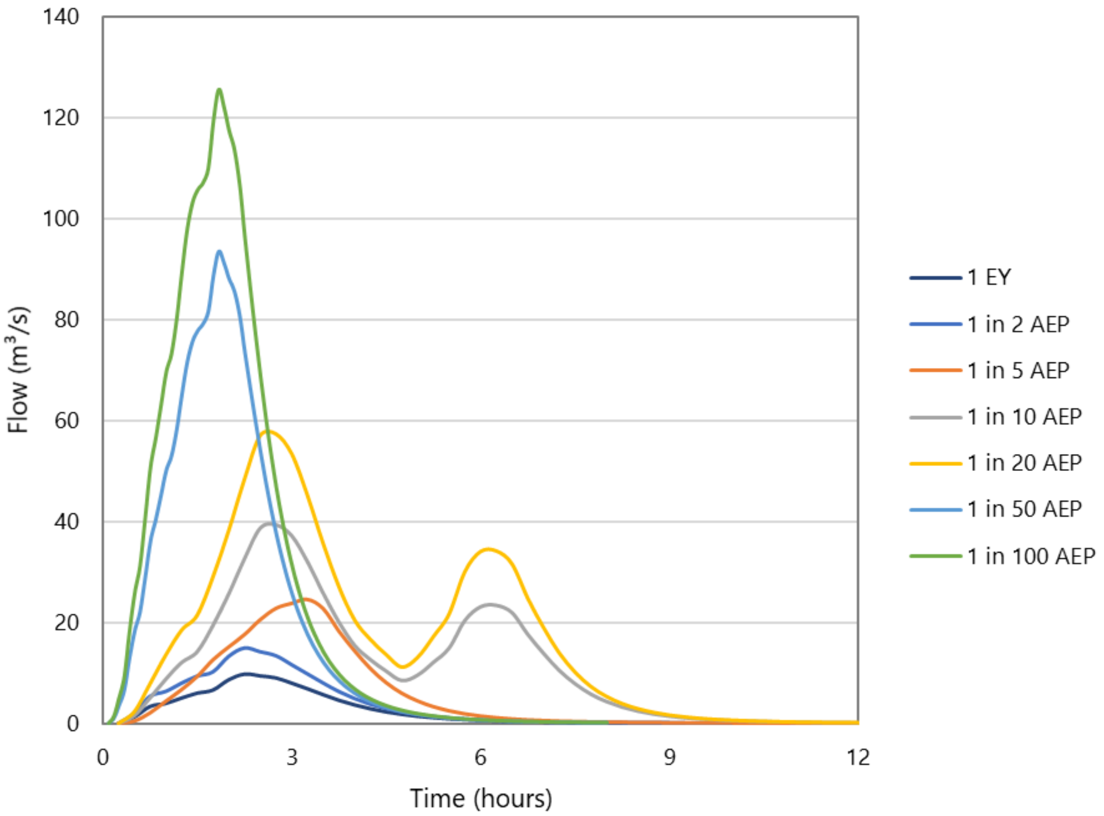


Figure 6-3. RORB design flow hydrographs extracted at Node 6 (TUFLOW inflow)

7 Hydraulic Modelling

7.1 Model Selection

TUFLOW modelling software is widely used to simulate free-surface water flow of rivers, floodplains, estuaries and coastlines. A TUFLOW model (2020 release) was developed to model the distribution of flow and attenuation in the lower gradient areas of Tantabiddi Creek. The resulting flow hydrographs were extracted at the road for input into development of sedigraphs and the 2D coastal hydrodynamic model described in Sections 8.4 and 9 respectively.

7.2 Model Setup

Model files were set up in GIS mapping software QGIS in projection GDA94/ MGA Zone 49, which was utilised by DoT at the time of writing. The recently updated survey datum, GDA2020, should be considered for use in future project stages.

The TUFLOW model set up including the model areas, inflow and outflow boundaries, manning's n layers and the hydrograph PO line location is presented in Figure 7-2 and described in the following sections.

7.2.1 Model Area and Terrain

Two models were developed for modelling the Tantabiddi creek, including a full catchment model and a reduced extent model with an inflow boundary. The full catchment model was developed to validate the flow hydrographs by comparing with the hydrographs produced by the RORB rainfall-runoff (described in Section 7.3). The reduced extent model was developed to focus on the study area and provide higher resolution predictions of flow behaviour.

The details of the model set up are described below:

- The model terrain was developed using a combination of:
  - 5 metre survey data (Landgate, 2013);
  - 1 metre survey data (Landgate, 2018);
  - Bathymetry data of the permanent pool (Platinum Survey, 2020).
- The model domains were delineated to include smaller catchments adjacent to the main Tantabiddi creek catchment to ensure any breakout or other flow interactions in the floodplain were captured; and
- A 5 metre grid size was adopted with sub-grid sampling functionality enabled to capture the higher resolution 1 metre survey.

7.2.1.1 Boundary conditions

The hydraulic model comprised of model edge inflow and outflow boundaries which are described below:

- An outflow boundary was located at the creek outlet to the ocean and set to a fixed mean sea level of 0.06 mAHD based on data recorded at Exmouth (MP Rogers, 2018);

- Outflow boundaries to adjacent catchments with stage-discharge relationship based on terrain slope;
- An inflow boundary was applied to the eastern extent of the model with the flow hydrograph shown in Figure 6-3 extracted from the RORB model.

7.2.2 Rainfall

Design rainfalls from the RORB model were used to simulate rainfall on the model domain. The rainfall losses described in Section 6.3.3.1 were subtracted from the design rainfalls before application on the domain. Pre-burst rainfall was applied to the model domain to fill micro-storage present in the DEM prior to the design storm.

7.2.3 Manning's n Roughness

Manning's n roughness parameters were assigned based on site visit observations, previous studies, aerial imagery, and typical parameters in Chow (1956). The manning's n roughness adopted in the model is presented in Table 7-1.

The creek channel area where manning's n roughness 0.035 was applied in the model is shown in Figure 7-2.

Table 7-1. Manning's n roughness adopted in the model domain

Location	Description	Manning's n
General catchment	Low shrubs, grasses and sparse trees	0.045
Creek channel	Low shrubs, gravelly deposits	0.035

7.2.4 Plot Output (PO) Line

A time-series PO line output, shown in Figure 7-2, was used to extract flow hydrographs at Yardie Creek Road for input in the 2D hydrodynamic and sediment transport model described in Section 9 (at the upstream boundary of that model).

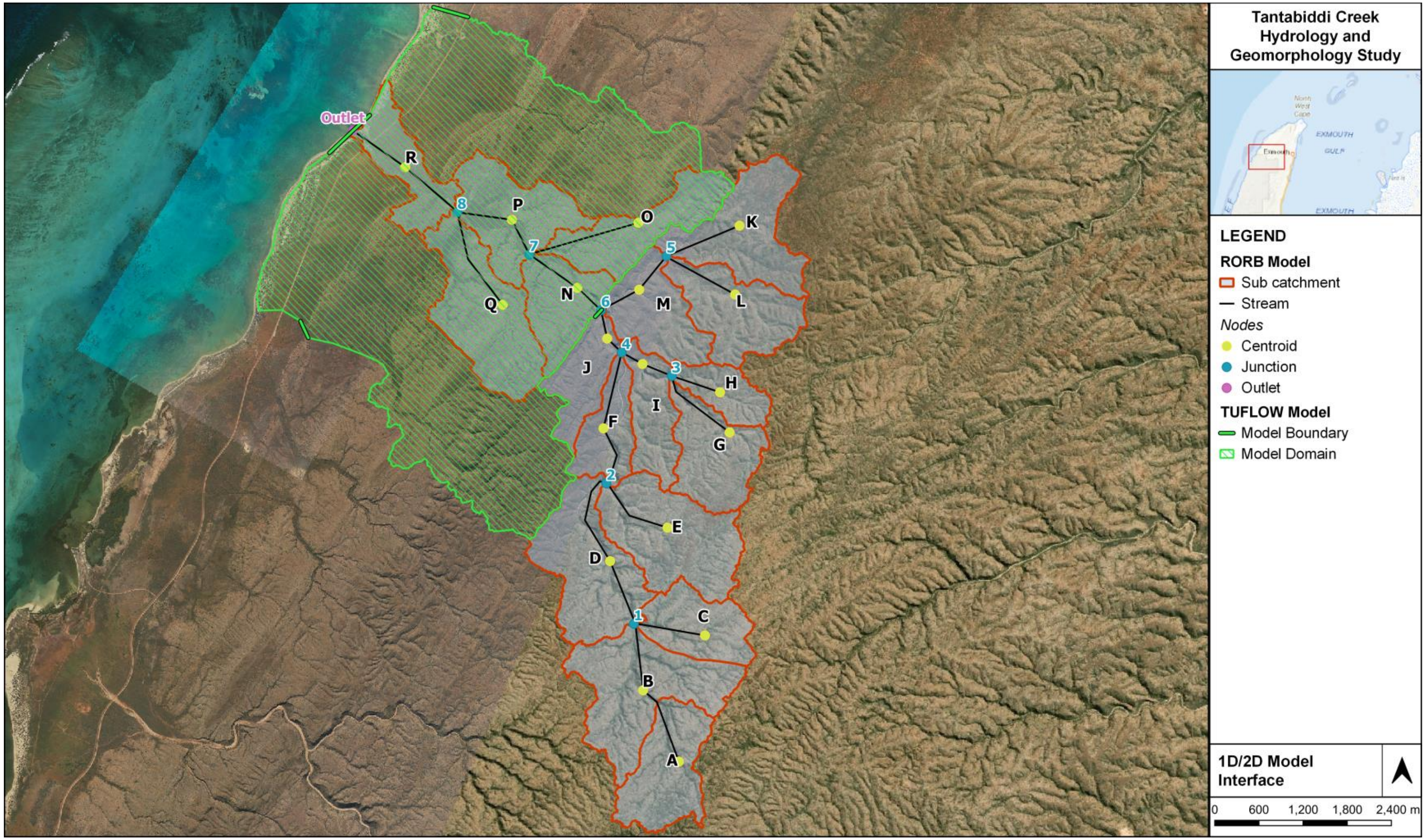


Figure 7-1. RORB and TUFLOW interface

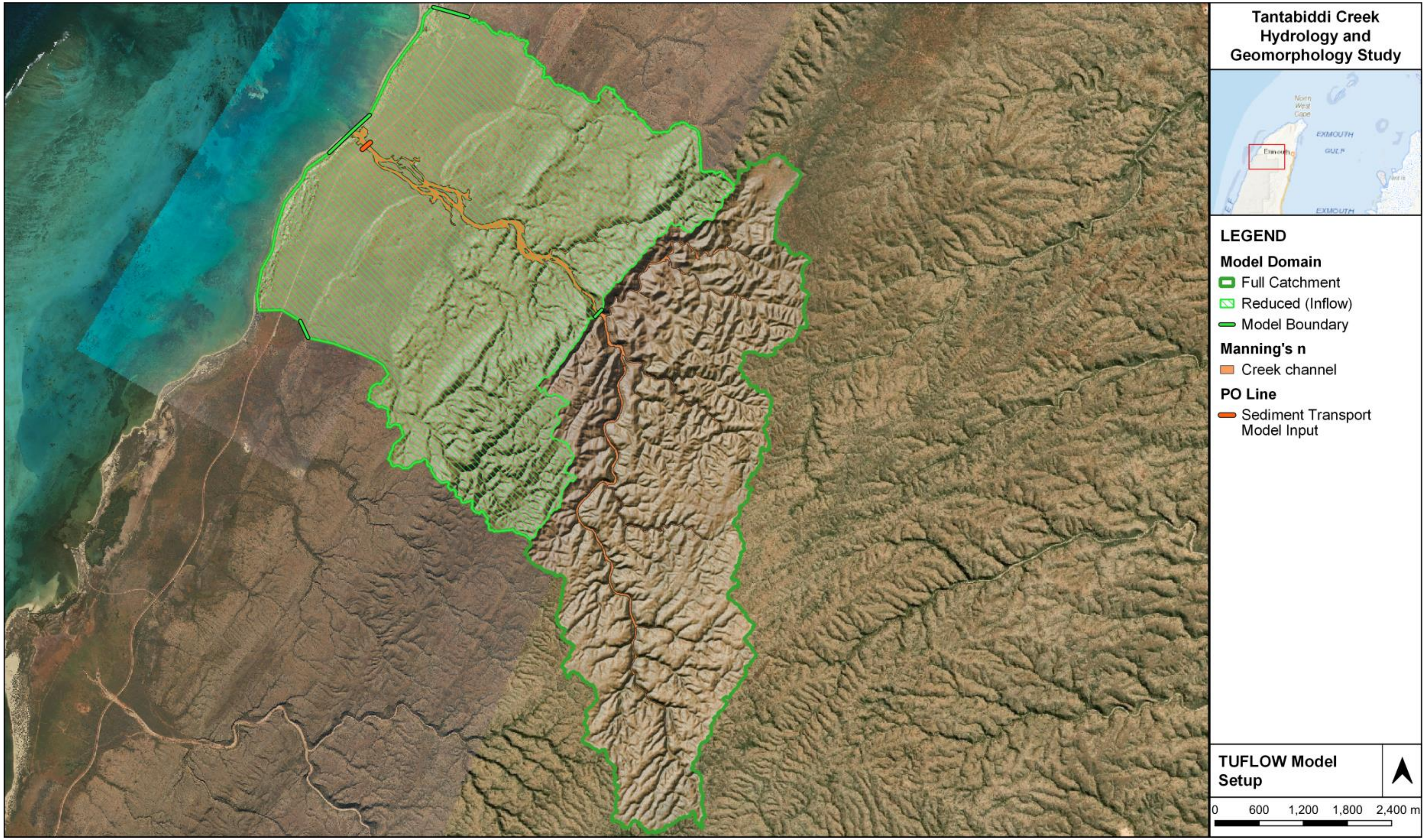


Figure 7-2. TUFLOW modelling domain

7.3 Comparison of RORB and TUFLOW Results

The hydrology produced by the RORB and 2D TUFLOW models was compared and used to corroborate the accuracy of the TUFLOW model and associated model parameters. A rain on grid modelling approach was adopted in TUFLOW for the full catchment using the hyetograph for each AEP design event. Flows were extracted at the RORB Node 6 location shown in Figure 6-2, and compared to confirm the two models produced similar peak flows and hydrographs.

A comparison of the RORB and TUFLOW hydrographs at Node 6 for each design event is presented in Figure 7-3. The results suggest the following:

- The 1D and 2D models produce comparable flows suggesting the parameters adopted in each model are representative of the catchment conditions.
- There is a slight delay and/or reduction in peak flow in the 2D TUFLOW model, which is expected as the 2D rain-on-grid modelling approach is affected by attenuation as floodwater moves through the model domain.

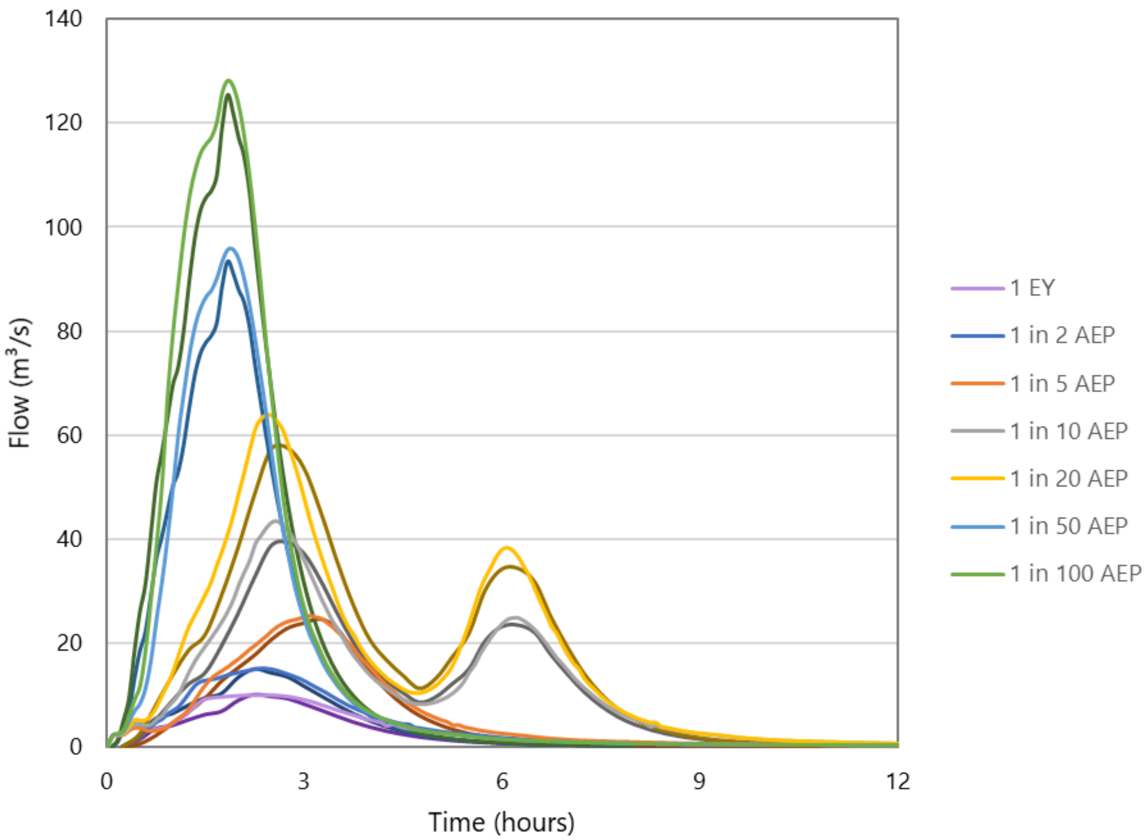


Figure 7-3. RORB (lighter colours) and TUFLOW (darker colours) hydrograph output at Node 6

7.4 Model Calibration

The April 2014 flood event represents a significant flooding event with anecdotal evidence (photos and dredging quantities) of sediment deposition at the boat ramp. The April 2014 storm event was simulated in TUFLOW to produce flow hydrographs needed for calibration of the 2D sediment transport model described in Section 9.

The rainfall hyetograph recorded at Learmonth during the 2014 rainfall event, were scaled up by a factor of 1.5 to represent the rainfall depths at Ningaloo Reef, as described in Section 5.2. The resulting hyetograph for Ningaloo Reef is presented in Figure 7-4 and was used to simulate as rain-on-grid in the full catchment model and the resulting hydrology and hydraulics adopted for calibration of the 2D sediment transport model described in Section 9.

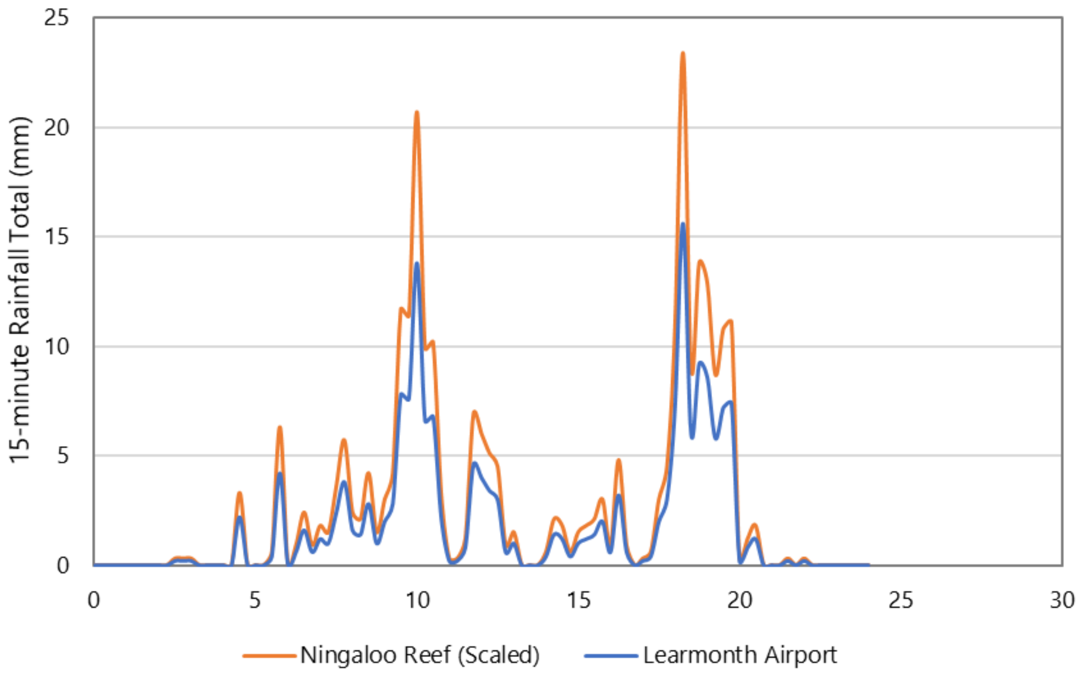


Figure 7-4. Scaled April 2014 event rainfall hyetograph simulated in TUFLOW model

7.5 Results

The resulting hydrographs extracted from the TUFLOW model at the Yardie Creek Road floodway are presented in Figure 7-5 and peak flows from each hydrograph presented in Table 7-2. Analysis of the hydrographs suggest the following:

- There is a period of lag between when the rainfall first started falling during the 2014 event, and the response at the creek outlet. This lag is due to early rainfall being removed as losses in the model before generating rainfall-runoff;
- Comparison with the 1 in 100 AEP peak flow suggests the 2014 event was greater than a 1 in 100 AEP event, which is consistent with IFD chart analysis in Section 5.2;
- The April 2014 rainfall event produces two flood peaks which are both greater than the 1 in 100 AEP design flood peak. The time to peak for the 2014 event (both peaks) and 1 in 100 AEP design event are similar.

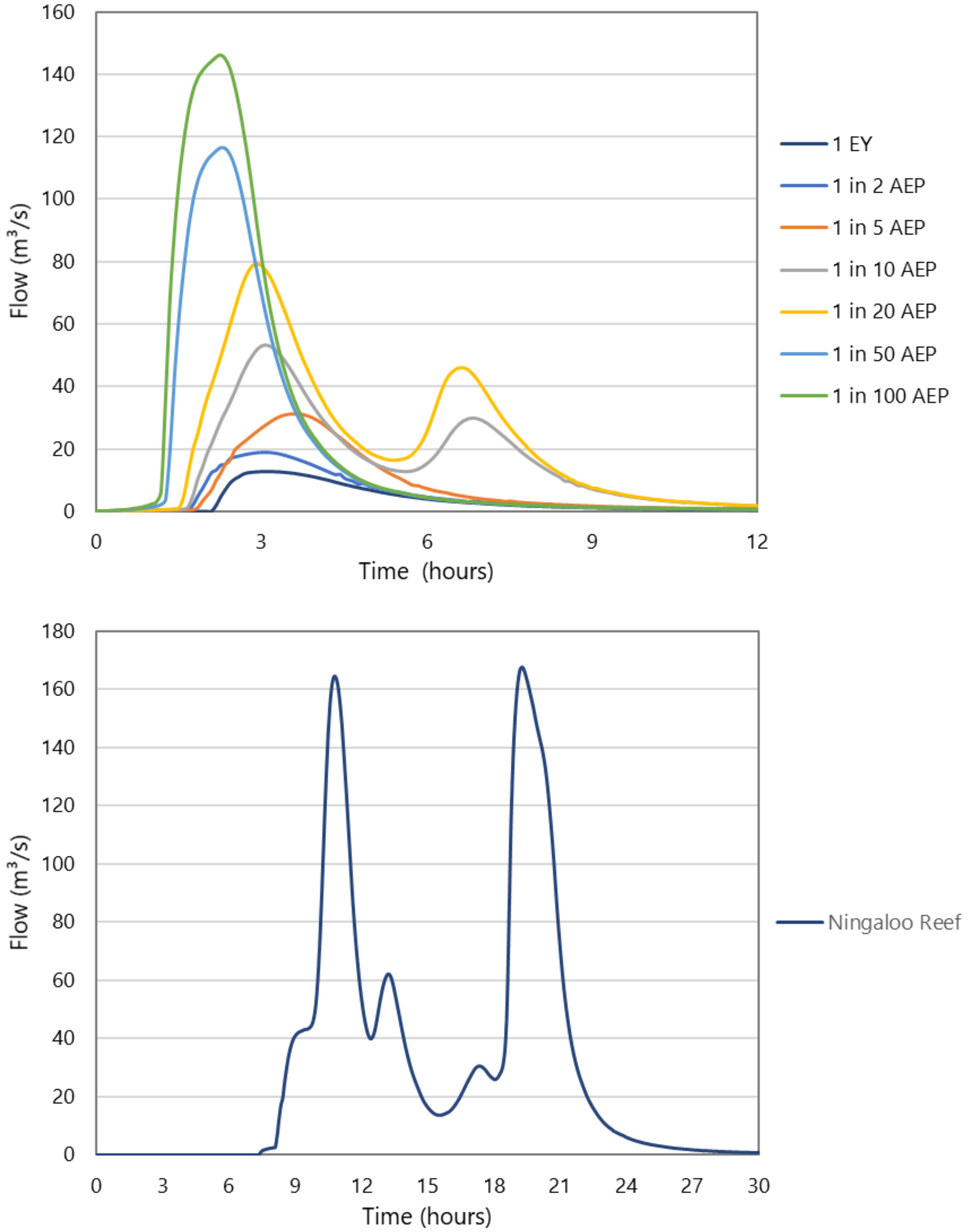


Figure 7-5. Flow hydrographs extracted at Yardie Creek Road for design AEP events (top) and the 2014 flood event (bottom)

Table 7-2. Peak flows at Yardie Creek Road floodway for design events and 2014 calibration event (m^3/s)

Scenario	Peak Flow (m^3/s)
1 EY	13
1 in 2 AEP	19
1 in 5 AEP	31
1 in 10 AEP	53
1 in 20 AEP	79
1 in 50 AEP	117
1 in 100 AEP	146
2014 Event	168

The peak flood depth and velocity results for the 1 in 100 AEP design event are presented in Figure 7-6 and Figure 7-7, respectively. Flood depth and velocity maps for the other events are presented in Appendix F. Analysis of the flood depth and velocity results suggest the following:

- Flood depths within the Tantabiddi Creek channel are up to 2 m in the lower reaches and up to 3.5 m in the higher reaches of the TUFLOW model in the 1 in 100 AEP event;
- In the 1 in 100 AEP event, flood velocities are up to 4 m/s in the upper reaches of the Tantabiddi Creek channel and 3 m/s in the lower reaches;
- The peak flood depth results show ponding up to 0.6 m behind the sand dunes south of the boat ramp. This ponding is likely to be overestimated in the model as it does not take into consideration infiltration of ponded water (rainfall losses extracted before model simulation);
- The flood results suggest up to the 1 in 100 AEP event there is minimal interaction with the adjacent catchments in the floodplain, and therefore minimal contribution from adjacent catchments to the flow crossing Yardie Creek Road;

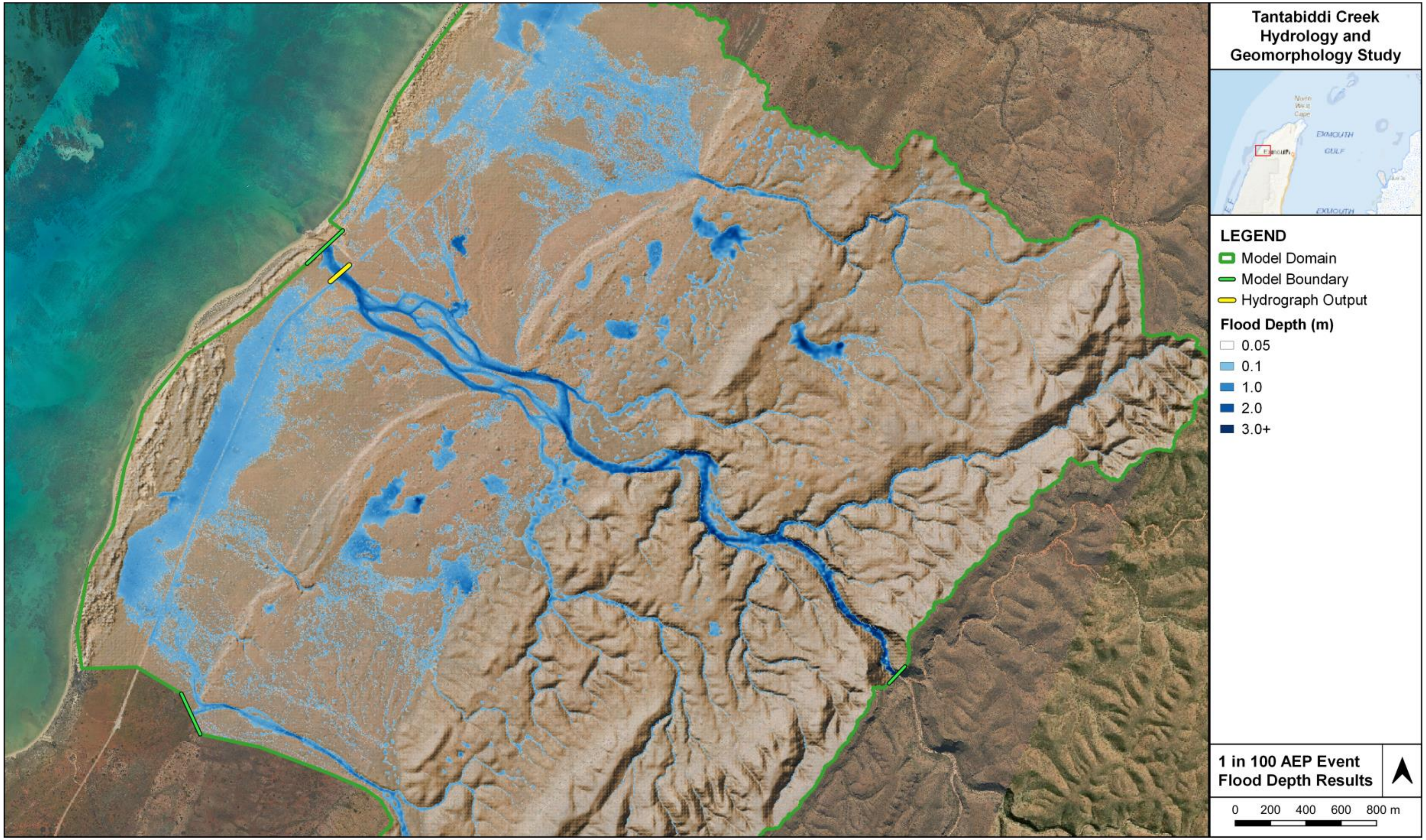


Figure 7-6. Peak flood depth results for the 1 in 100 AEP Event

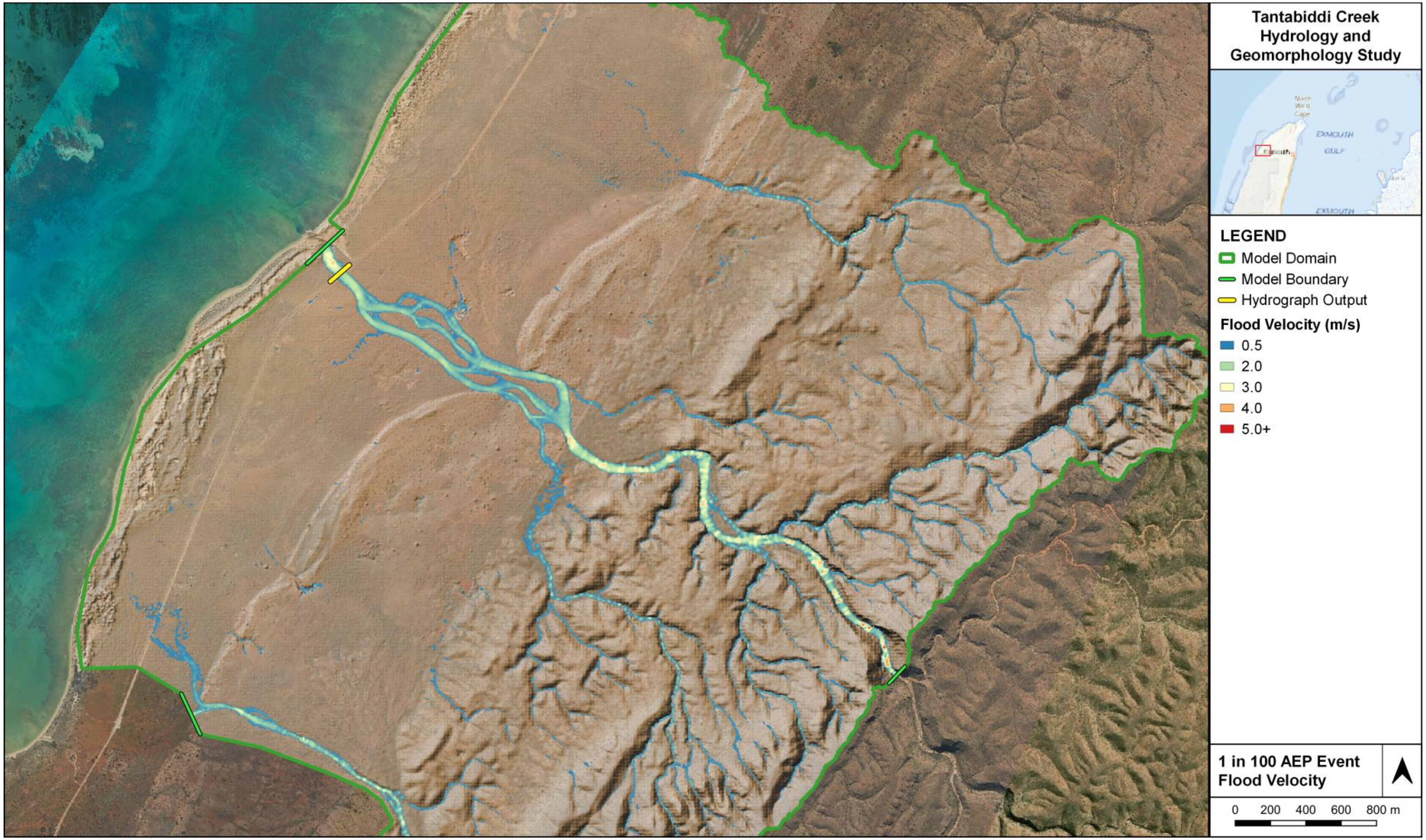


Figure 7-7. Peak flood velocity results for the 1 in 100 AEP Event

8 Geomorphology

8.1 Fluvial Geomorphology

8.1.1 Summary

Tantabiddi Creek contributes sediment from the catchment to the nearshore area of the Tantabiddi Boat Ramp and significantly alters the geomorphic features, such as the estuarine sand bar, during flood events. The creek headwaters flow over steep stony and deeply incised uplifted Tertiary coral reefs and aeolian sandstones in the Cape Ranges. The creek flows downstream to a relatively flat and low-lying terrace of Quaternary coral reef deposits overlain with alluvial fans, before reaching a Holocene dunes system and forming an estuary. The estuary is regularly disconnected from the ocean by a sand bar adjacent to the boat ramp, which is flushed seawards by the creek during high creek flows. Sediment from the upper catchment is visible in the ramp area in aerial imagery following flood events, as are the geomorphic changes resulting from the erosion and deposition of sediment in the ramp area resulting from high creek flows.

Macrofeatures of Tantabiddi Creek are presented in Appendix G.

8.1.2 Background Review

8.1.2.1 Biogeographic Characterisation

The Biogeographic Regionalisation of Australia (IBRA7) divides Australia into bioregions and sub-bioregions based on major biological, geographical and geological attributes. The Tantabiddi Creek catchment area lies within the Carnarvon Bioregion and Cape Range subregion. The Carnarvon bioregion is composed of quaternary alluvial, aeolian and marine sediments overlying Cretaceous strata. A mosaic of saline alluvial plains with samphire and saltbush low shrublands, Bowgada low woodland on sandy ridges and plains, Snakewood scrub on clay flats and tree to shrub steppe over hummock grasslands on and between red sand dune fields. Limestone strata with *Acacia stuartii* or *A. bivenosa* shrubland outcrop in the north, where extensive tidal flats in sheltered embayments support Manga (Kendrick & Mau, 2002).

Cape Range and Giralia dunefields form the northern part of Carnarvon Basin, the Cape Range subregion. The area comprises rugged Tertiary limestone ranges and extensive areas of red aeolian dunefield, Quaternary coastal beach dunes and mud flats. Acacia shrublands over extensive hummock grasslands (*Triodia*) on limestone (*Acacia stuartii or A. bivenosa*) and red dunefields, *Triodia* hummock grasslands with sparse Eucalyptus trees and shrubs on the Cape Range. Dominant land uses in the Carnarvon bioregion are grazing (native pastures), conservation, mining leases, and urban (Kendrick & Mau, 2002).

8.1.2.2 Catchment Geomorphology

Background

The Tantabiddi Creek geomorphological features are summarised in Table 8-1. Tantabiddi catchment is comprised of several different rock units and geomorphic features which influence the sediment transportation and ultimately the deposition of sediment at Tantabiddi Boat Ramp (Figure 8-1 and

Figure 8-2). The following section outlines the geomorphology of Tantabiddi Catchment in further detail, including the major landforms, associated vegetation and Tantabiddi Creek macrofeatures.

Table 8-1. Tantabiddi Creek geomorphological features and geological features summary table.

Feature	Catchment
Reach length (km)	13.7
Catchment area (km2)	27
Slope/gradient (m/m)	0.015 (0.005 in lower reaches; 0.03 in upper reaches)
Channel sinuosity	Low sinuosity 1.2
Bend curvature (radius m)	Upper reaches minimum ~50 average bends ~105 Lower reaches > ~140
Channel margins (m)	Average upper catchment width ~11 m Average lower catchment width ~28 m Average estuary bed width ~16 m
Bank slopes	Deeply incised in upper catchment gorge with steep stony banks Mild banks in lower reaches over vegetated alluvial fans and old reef deposits
Sediment	Tantabiddi Terrace: fine-medium grained clayey sands with interspersed layers of coralline and limestone pebbles and cobbles.
Geology	Upper catchment: Calcareous sedimentary rocks in Cape Range (predominantly Tertiary Tulki limestone) Lower catchment: Quaternary Tantabiddi member (Bundera Calcarenite) coastal plain comprised of coral and coralgal reef deposits, calcarenite and partly overlain by aeolian sediments (some lithified) Coastal system: Holocene quartzose and calcarenite dunes
Vegetation	Shrubland of Eucalyptus xerothermica, Corymbia hamersleyana and Dodonaea viscosa subsp. mucronata over hummock grassland of Triodia epactia
Land Use	Largely unallocated crown lands. Upper catchment in Cape Range National Park.

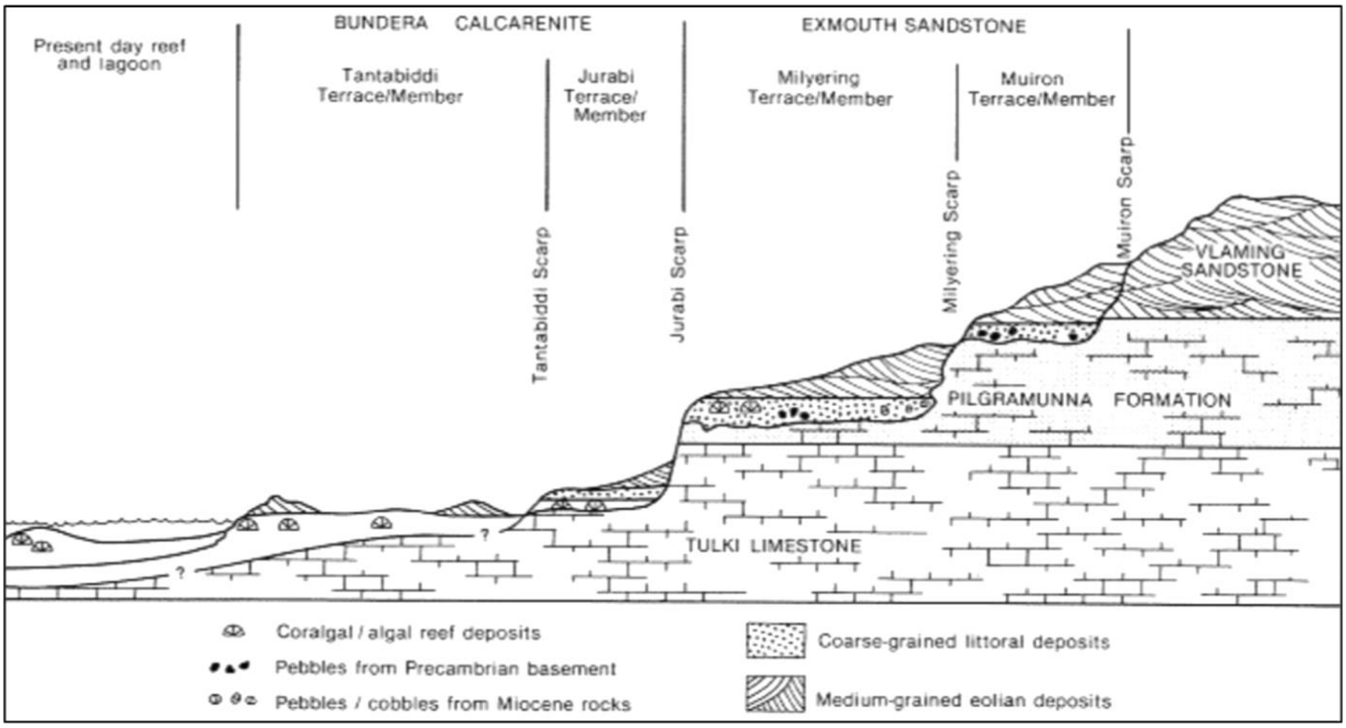


Figure 8-1. The stratigraphic relationships of the main geological units on the west side of Cape Range (Hocking et al., 1987).

Cape Range

The North West Cape peninsula is dominated by Cape Range, which is an anticline that runs in a north-south direction. The anticline is the result of folding and uplifting of carbonate sediments by the underlying Cape Range fault 15 million years ago. The crest of the range forms a regional drainage divide with drainage systems to the east and west (Figure 8-2). The range consists of steep, highly dissected marginal slopes predominantly composed of Tertiary marine limestones and aeolian sandstones (Plate 13).

Tantabiddi Creek is a significant gully and canyon that intersects the range on the western side with a trellis drainage pattern. The majority of the length of Tantabiddi Creek is located within the Cape Range over Tulki limestone – a Tertiary dissected limestone terrain with karst development and reddish to yellowish shallow marine, partly clayey foraminiferal calcarenitic packstone (Figure 8-2; DMP, 1978). The headwaters of some tributaries of Tantabiddi Creek occur over younger Tertiary Pilgramunna formation – a quartzose cross-bedded calcarenite and shallow marine coralgal limestone, which overlays the Tulki limestone in much of the central region of the Cape Range. The vegetation within the Tantabiddi Creek line within these areas typically consists of a shrubland of *Eucalyptus xerothermica, Corymbia hamersleyana and Dodonaea viscosa subsp. mucronata* over hummock grassland of *Triodia epactia* (Meissner, 2010).

The upper Tantabiddi Creek catchment is characterised by a deeply incised, confined channel with an average width of ~11 m. Tantabiddi Creek flows with a low sinuosity planform (sinuosity=1.2), with main channel bend curvature as sharp as ~50 m radius, although a 105 m radius is more characteristic. The average gradient of Tantabiddi Creek is ~0.0147 m/m, with relatively steep slopes (~0.03 m/m) in the upper catchment. The creek headwaters are located at an elevation of 175 m, dropping to ~8 m at the margin with the Tantabiddi Terrace.

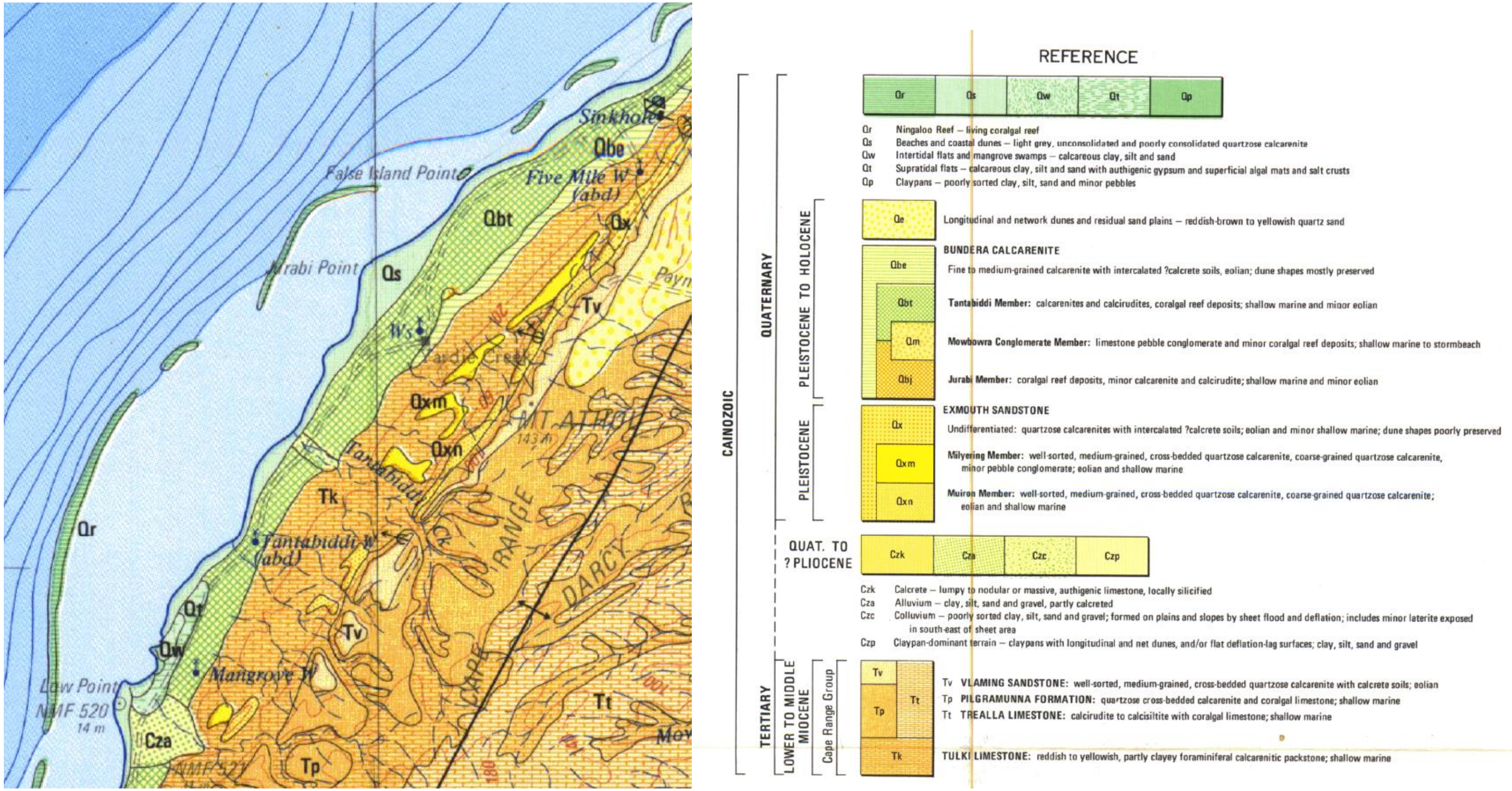


Figure 8-2. The geology of the Tantabiddi Creek catchment as described by The Department of Mines and Petroleum (DMP) geological surveys of Western Australia (DMP 1978). Tantabiddi Creek is denoted as blue lines and the Tantabiddi Creek catchment is outlined in orange


Plate 13. Photographs showing the Tantabiddi upper catchment in Cape Range. Left: canyon incised into Cape Range by Tantabiddi Creek. Right: View from the top of Cape Range looking west towards Tantabiddi Boat Ramp, with Tantabiddi Creek on the right (Meissner, 2010).

Terrace and Coastal Plain

The western margin of the Cape Range peninsula has been eroded by marine processes acting throughout the Pleistocene, resulting in the formation of the Tantabiddi Terrace. The Tantabiddi Terrace is incised into the Tulki limestone and Pilgramunna formation (Plate 14 and Plate 15) and is the lowest (~ 2-5 m above MLWS), youngest (Quaternary) terrace of the Cape Range region. Tantabiddi Terrace is classified as Tantabiddi Member (a geological unit of Bundera Calcarenite) and is comprised of coral and coralgal reef deposits, which grade into calcarenite and is in part overlain by aeolian sediments, some of which are lithified (Hesp and Morrissey, 1984).

Tantabiddi Creek flows in a westerly direction from the Cape Range onto the Tantabiddi Terrace which forms the present coastal plain of variable width (0.2 – 1.5 km wide) (Hesp and Morrissey, 1984). From the western margin of the Cape Ranges to the coastal dune system, Holocene alluvial fans overlay the terrace either side of Tantabiddi Creek with sediments from about 5 m in thickness. The alluvial fans were formed by deposition during stream run-off events and comprise Pliocene to recent littoral, shallow water marine, alluvial and aeolian sediments of variable composition including fine-medium grained clayey sands with interspersed layers of coralline and limestone pebbles and cobbles (Kendrick *et al*. 1991; Allen, 1993). The terrace supports vegetation of mainly soft spinifex hummock grassland and/or open tussock grassland of Buffel grass with scattered acacia shrubs (Plate 14; Meissner, 2010).

The lower (~1.3 km) reaches of the creek, from the Tantabiddi terrace to the estuary, are characterised by a low sinuosity planform (sinuosity=1.1) with all bends of radius greater than ~140 m. The gradient is substantially flatter than the upper reaches (gradient=0.0047 m/m). The previously incised channel widens (average ~28 m) and divides into a multi-threaded channel across the floodplain. The terrace is poorly drained and prone to flooding. The decreased flows due to the mild gradient and denser vegetation contribute to sediment deposition at the eastern margin of the terrace, thinning out seawards as low flows deposit finer sediments towards the estuarine end of the alluvial fans (Hesp and Morrissey, 1984).

Plate 14. The coastal plain on the western side of Cape Range (in background). Buffel grass (Cenchrus ciliaris) is prominent in the foreground (Meissner, 2010).

Estuary and Dune System

The lower 200 – 300 m of Tantabiddi Creek flows through Holocene coastal deposits which overlie the seaward margin of the Tantabiddi terrace. Beaches and dunes consist of low stability, light grey, unconsolidated and poorly consolidated quartzose and calcarenite, with gravel to cobble size deposits observed in the creek bed. The western coastal system generally consists of large dune ridge forms (some unvegetated), restricted parabolic dune development with narrow swales supporting diverse tall and low shrublands (DPIRD 2018).

The estuary sits within relict foredunes and foredunes. The estuary maximum bed width is ~65 m and average bed width is 44 m. The northern banks of the estuary are formed by a revetment that protects boat ramp access, while the southern side has mild low elevation bank slopes that extend onto a wide marshy swale behind the foredune (~100 m) to the south (Plate 15). A tributary creek (bed width ~25 m) flows northeast along this swale and joins the eastern end of the estuary pool.

Plate 15. The Tantabiddi Creek estuary looking eastwards.

8.1.3 Historical Imagery Analysis of Fluvial Processes

8.1.3.1 Flooding Impact to Estuary

The impact of Tantabiddi Creek flooding on the estuary sand bar is shown in Figure 8-4 and Figure 8-5. Figure 8-4 shows aerial imagery over two years (2013 to 2015), which captures the impacts of a torrential rainfall event in 2014 that caused Tantabiddi Creek to flood. At this time the sand bar had been flushed out to form a wider channel between the estuary and ocean and a large amount of suspended sediment was visible in aerial imagery up to about 230 m seawards from the boat ramp. The tidal flushing following the opening of this sand bar would have further acted to transport sediment from the estuary. The accumulation of sediment adjacent to the boat ramp may be exacerbating the impact of the ramp on longshore drift by forming a positive feedback loop and further contributing to accumulation of material on the southern side of the boat ramp. These processes are discussed further in Section 8.2.

Comparatively, a moderate rainfall event in June 2018 with 95 mm falling at Exmouth weather station in 24 hours, is depicted at the ramp at approximately four days prior to the rainfall event (June 2018) and five months after the rainfall event (November 2018; Figure 8-4). IFD data for Tantabiddi Creek (Figure 5-6) suggested that this rainfall event was between a 50% and 20% AEP (1 in 2 and 1 in 5 AEP). The unofficial AIMS station Ningaloo Reef (Milyering) and the Learmonth Airport weather station recorded 22 mm and 72 mm respectively for the same event and the IFD data suggests is equivalent to a < 1 EY event for Ningaloo and a 1 in 2 AEP event at Learmonth. Considering the relative locations to Tantabiddi, the June 2018 was likely to have been a 1 in 2 AEP event and represents a low magnitude and more frequent rainfall event. The accumulation of material on the estuarine sand bar and coastal sand bar adjacent to the southern side of the ramp is visible in aerial imagery after the rainfall event, although this sediment accumulation is likely to be a result of both the rainfall event and longshore drift. It shows that small-moderate rainfall events are capable of mobilising and transporting sediment from Tantabiddi Creek to the coast, but are unlikely to open the estuary and affect the navigable depths of the channel from the boat ramp. However, the larger events described in the preceding paragraph would open the estuary mouth, mobilise previously deposited sediments and deposit these in the nearshore environment, including within the navigable channel.

Flooding in Tantabiddi Creek also impacts the estuarine pool margins due to erosion from high flows and deposition of sediment from the upper catchment (Figure 8-6). While tides are likely to be affecting the water level in the estuarine margins, comparisons of estuarine margins in 2012 (purple line) and 2015 (blue line) clearly show the deepest areas of the pool have migrated seawards by approximately 46 m, potentially as a result of erosion from high flows in 2014 floods. Comparatively, the estuarine water level extent in 2019 (red line) suggests that the accumulation of sand on the estuarine sand bar has caused the estuary to migrate landwards compared to the 2015 extent.

8.1.3.2 Imagery Analysis of Creek Mouth

Analysis of longer-term movement of the creek mouth was undertaken to assess whether it naturally migrated prior to construction of the boat ramp. The analysis was undertaken using recent imagery (i.e. 2014, 2019) and the only imagery datasets pre-dating the current boat ramp development that were available at the time – 1969, 1981, 1985, and 1986. While it was apparent that a smaller boat ramp structure had been constructed between the 1985 and 1986 imagery, there also appeared to be an ad hoc beach ramp in the 1981 and 1985 imagery. As such, any commentary on the creek mouth location is partially affected by the influence of these structures/facilities.

Regardless, the imagery shows that under conditions prior to the development of the current boat ramp structure, the creek mouth is likely to have remained relatively static over time with small variations in the direction of flow. The site geology and underlying old reef platforms both in the estuary and nearshore environment are likely to be dictating the direction/orientation of the mouth (and channel).

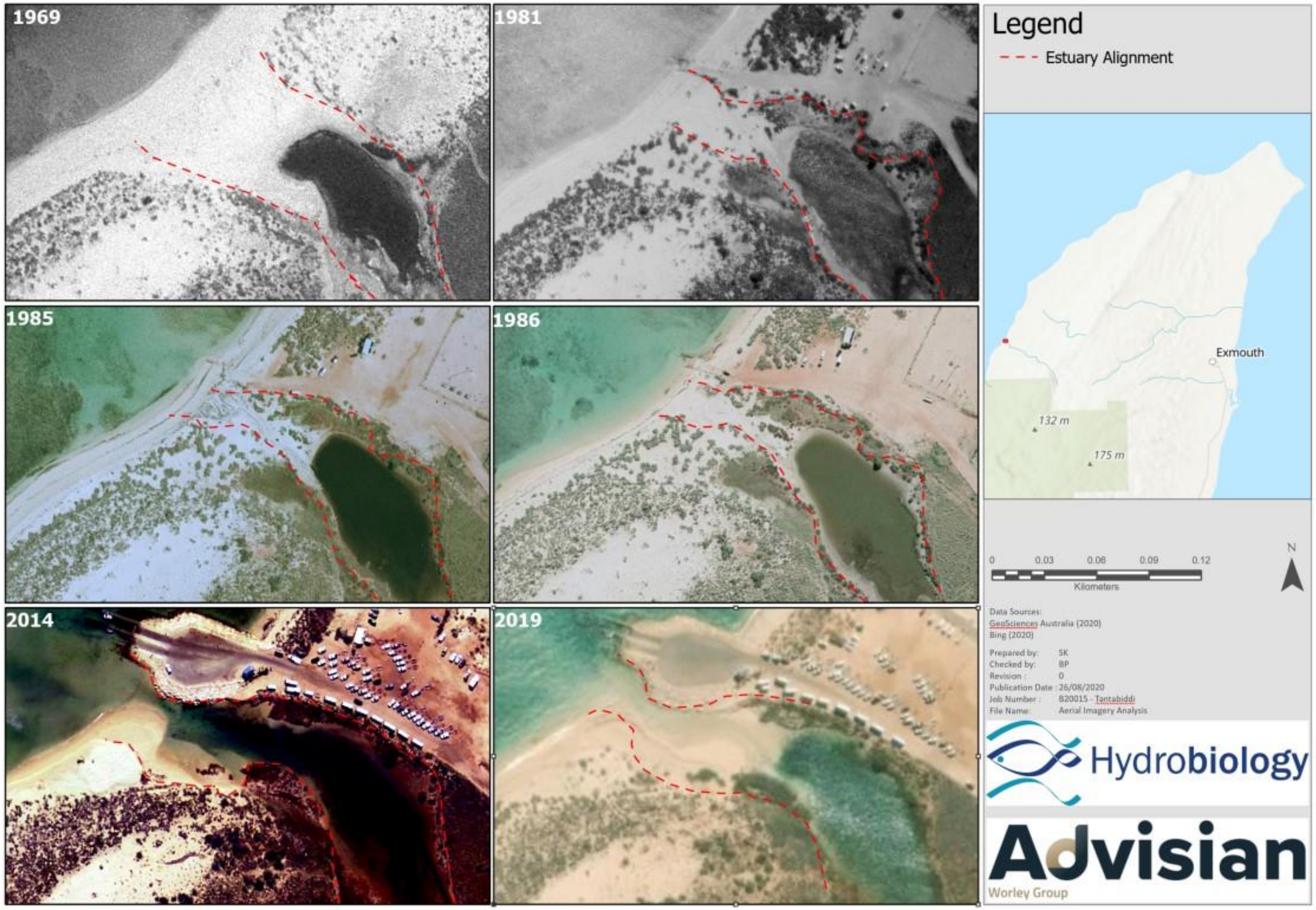


Figure 8-3. Imagery of the creek mouth from 1969 to 2019.

8.1.3.3 Flood Extent (2014)

Analysis of aerial imagery and available literature show heavy rainfall events result in the episodic delivery of sediment from the Tantabiddi catchment to the Tantabiddi Boat Ramp via Tantabiddi Creek. The nearshore area comprises a range of sediment deposits from upstream including fine reddish to yellowish sediments from terrestrial sources, and gravel sized limestone and reef material from ancient marine sources (beach, dune and coral reefs) (MP Rogers and Associates, 2018).

The April 2014 flood resulted in major sediment deposition from the upper catchment of Tantabiddi Creek and other creeks along the west coast of the North West Cape (Plate 16). For example, following the flood event, red sediment was visible lining the beaches near creek mouths (approximately 900 m south of Tantabiddi Creek, indicating a substantial amount of sediment deposition and that much material remained in the nearshore environment. At the Tantabiddi Boat Ramp, the April 2014 flood extent can be inferred from fluvial sediment deposition in the coastal area (Figure 8-7).

Figure 8-4. Aerial images depicting the estuarine and coastal conditions before and after a major flood in April 2014. a) Small channels through the sand bar typical of moderate winter creek flows; b) sand accumulation to the south of ramp associated with low creek flow conditions; c) July 2014, two months after flood shows sediment adjacent to and west (seaward) of the ramp; d) dredge spoil on north beach and dredged channel shows large volumes of material removed from channel to restore navigable depths. Image Credit: Landgate and Google Earth.

Figure 8-5. Aerial imagery showing the estuarine and coastal conditions immediately prior to the heaviest rainfall event of the year (June 2018) and five months after the rainfall event (November 2018). It is evident that the small-moderate rainfall event that occurred resulted in increased deposition of the sand bar but did not affect the navigability of the channel from the boat ramp. The November 2018 imagery suggests dredging may have occurred at the boat ramp as localised depression is evident. Image Credit: Google Earth and Landgate 2020

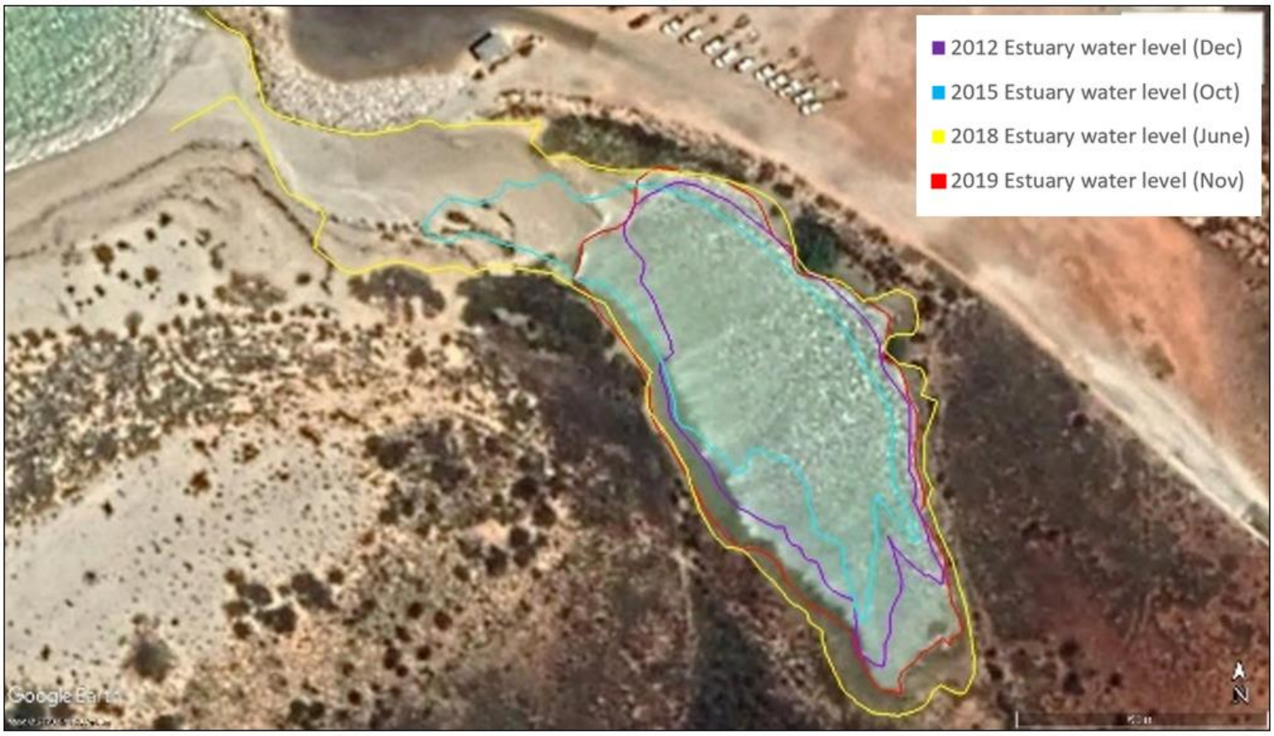


Figure 8-6. Estuarine pool water level extents from 2012 to 2019 shows shifts in the depth and seaward migration of average water extent in response to high flows in Tantabiddi Creek. Image Credit: Landgate and Google Earth 2020.

Plate 16. Flooding creeks on the western side of the North West Cape show sediment deposition into nearshore coastal waters in 2014. Left: creeks to the south of Tantabiddi catchment transporting sediment to the ocean in July 2014 (Landgate aerial imagery). Right: Extensive sediment deposition into the Ningaloo Reef nearshore coastal waters evidenced by the discoloured brown waters in April 2014 (Photo credit: Darrell Herring).

Figure 8-7. Sediment deposition from 2014 flood. Left: September 2013 prior to flood, shows clear sand bar and little evidence of red sediment from the upper catchment. Sand accretion has occurred along the south ramp. Right: July 2014 (after the April 2014 flood) shows red fluvial sediment lines on the sand bar (red line) and revetment (blue line) indicating flood extent. Sand bars and suspended sediment is present in the coastal waters to the south of the ramp and appear to cause waves to break over them.

8.2 Coastal Geomorphology

8.2.1 Summary

At Tantabiddi, the coastal area broadly consists of a Holocene living coralgal reef, interspersed with mobile sands, that encloses a sandy bottom lagoon with nearshore reef platforms. Sediment is transported by wave pumping across the reef into the lagoon area where prevailing wind and waves then transport nearshore sediment and onshore sediment in a northeasterly direction (longshore drift). The boat ramp forms a barrier to the longshore drift, which is the dominant process driving the accumulation of sediment at the boat ramp. Other processes impact the accretion at the ramp, including shoreline progression resulting from shorewards directed cross reef waves, the ramp forming a protective barrier to erosional forces from large north westerly waves during storm events, and fluvial processes previously discussed (sediment deposition from Tantabiddi Creek catchment and high flows transporting the estuarine sand bar seawards).

8.2.2 Background Review

8.2.2.1 Geomorphology

The Ningaloo Reef is the largest fringing coral reef in Australia, extending ~270 km along the coastline of north Western Australia. The reef at Tantabiddi is a Pleistocene reef, overlain by Holocene reef. The reef is orientated in a north westerly direction and is backed by a relatively narrow reef flat (~1 km) that transitions to a lagoon. Gaps regularly intercept the main reef line of Ningaloo Reefs northern extent and a relatively large gap (~1.6 km wide) lies approximately 3 km to the north west of the Tantabiddi boat ramp, known as Tantabiddi Passage. Generally, the Tantabiddi reef has low coral coverage (<10%), with macro-algae (40-60%) and abiotic cover (sand, pavement, rubble) (30-40%) dominating the benthic cover (Kobryn *et al.,* 2013; Cuttler *et al.,* 2019; Table 8-2).

The enclosed lagoon consists of a Pleistocene reef, overlain by Holocene reef, and covered with Holocene sand (Figure 8-8, Figure 8-9). The lagoon is relatively shallow (<5 m deep) and varies in width along the coastline (1-5 km), averaging about 1.2 km in the vicinity of Tantabiddi Creek mouth (Drost *et al.,* 2019). The lagoonal areas behind the reef are interspersed with occasional patch reefs and nearshore platform reefs (Figure 8-10, Figure 8-11) (URS, 2015a). The nearshore consists predominantly of Pleistocene reef outcrops overlain by Holocene sand, in parts, with a mixing of the more recent Holocene reef framework and older Pleistocene reef outcrops occurring in the nearshore area. Subtidal mobile sands are also a common feature at Tantabiddi, predominantly occurring between intertidal coral reef and varying from immediately offshore to approximately 2.5 km from shore.

The immediate Tantabiddi Boat Ramp area comprises predominantly macroalgae with limestone pavement and patches of sand (Figure 8-11). Tantabiddi Creek forms a natural channel approximately 100 m wide through the nearshore reef platforms (Figure 8-12) and dominant to patchy macroalgae. The channel formed by the creek lies directly adjacent to the southern side of the boat ramp and consists of sparse macroalgae interspersed with patchy limestone pavement with sand.

Table 8-2. Constituent assemblages for bulk sediment samples from the subreef environments at Tantabiddi, Ningaloo Reef (table from Cuttler et al., 2017).

Constituent	Reef Crest (%)	Reef Flat (%)	Lagoon (%)	Channel (%)	Beach (%)
Coral	37	38	36	27	33
Coralline algae	21	19	16	17	14
Mollusc	22	20	19	21	24
Foraminifera	8	7	7	5	6
Echinoderm	1	1	1	0	1
Framework	5	3	4	2	4
Quartz	5	5	16	28	18
Other	1	1	1	1	1

The onshore geology consists of Holocene beaches and coastal dunes which are classified as unconsolidated and poorly consolidated quartzose calcarenite (refer to Estuary and Dune System description in Section 8.1.2.2). At the boat ramp, large swell waves propagating through the Tantabiddi Passage from the north east result in typically reflective beaches in the study area. Tantabiddi Passage focuses incoming wave energy in the lee of the gap and results in embayed, slightly coarser, steeper, narrower beaches compared to beaches that are more protected by unbroken stretches of reef (Hesp and Morrissey, 1984). The beach is typically narrower and more reflective on the northern side of the ramp than the southern side, potentially due to the longshore drift processes and/or the boat ramp forming a protective barrier from erosional forces.

The beach is backed by sparsely vegetated foredunes and relic foredunes. Behind the boat ramp is a low-lying car park (~2.6 m elevation) that contains dredge spoil (~70 m (L) x 15 m (W) x 5.6 m(H)) at its eastern end. To the southern side of the boat ramp lies the highly variable sand bar discussed previously (refer to Estuary and Dune System description in Section 8.1.2.2).

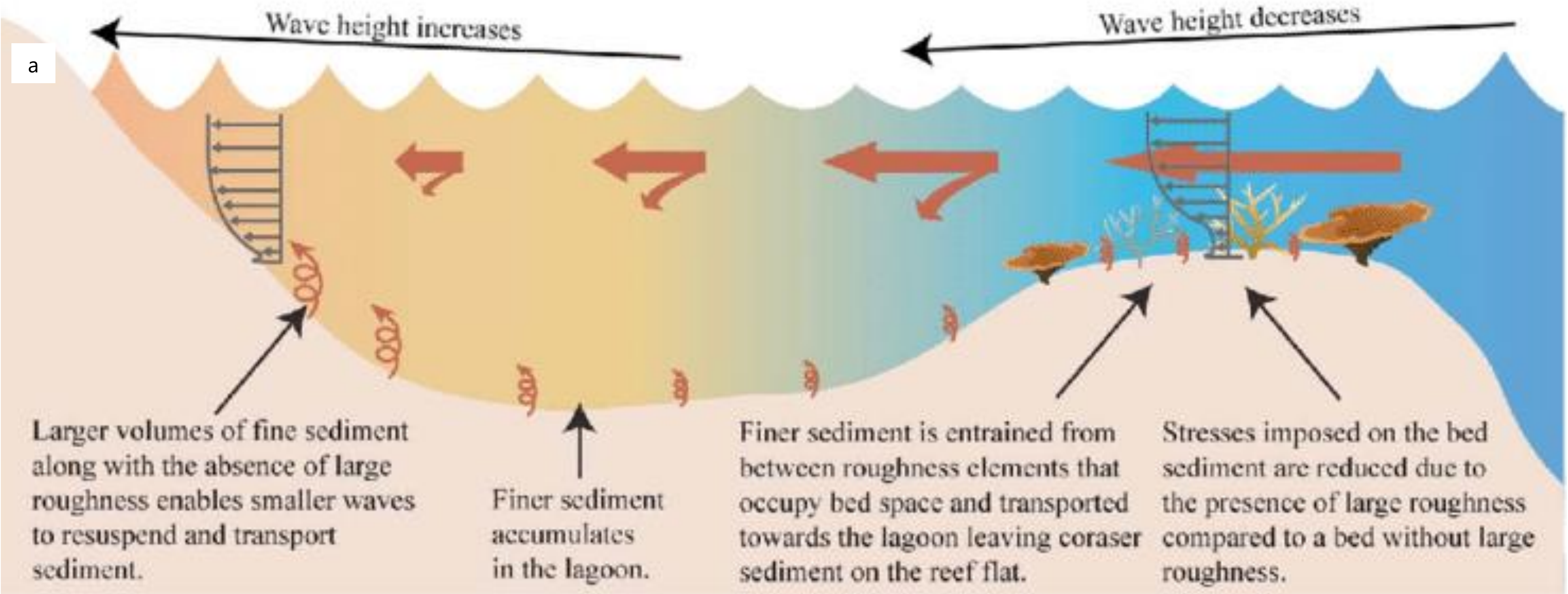


Figure 8-8. Conceptual models proposed for wave driven sediment transport via bedload and suspended sediment across the reef and lagoon at Tantabiddi – Cross section of waves, currents, and sediment processes across a reef and lagoon. Brown arrows indicate the direction of sediment transport by currents, and the upward arrows indicate sediment resuspension. An increase in suspended sediment concentration is indicated by brown shading (Pomeroy et al., 2018)

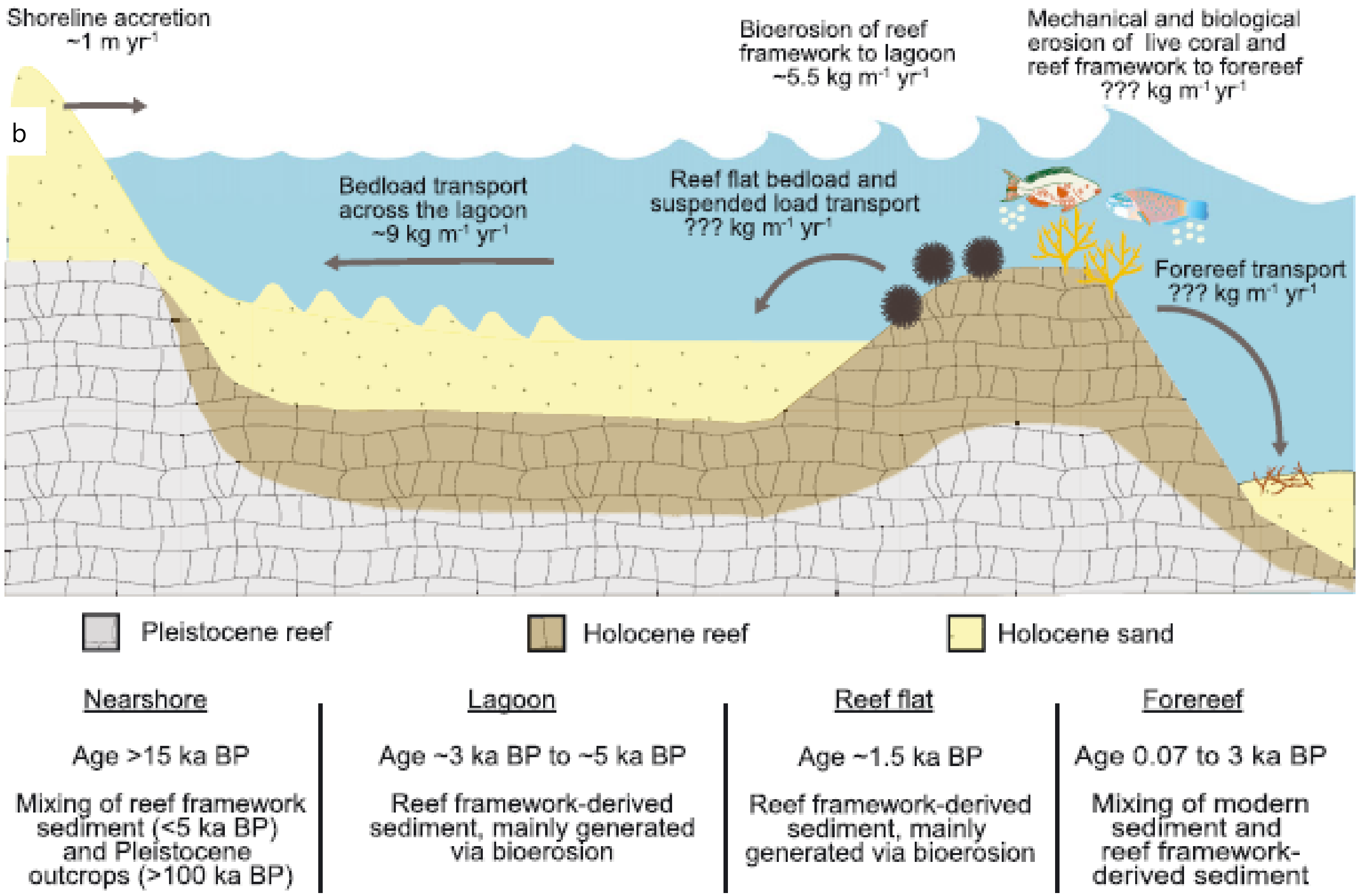


Figure 8-9. Conceptual models proposed for wave driven sediment transport via bedload and suspended sediment across the reef and lagoon at Tantabiddi – a) Cross section of waves, currents, and sediment processes across a reef and lagoon. Brown arrows indicate the direction of sediment transport by currents, and the upward arrows indicate sediment resuspension. An increase in suspended sediment concentration is indicated by brown shading (Pomeroy et al., 2018); b) Bedload transport (migrating ripples) across the lagoon = 9 kg/m/year (Cuttler et al., 2019) and shoreline accretion rates = 1 m/year at the salient to the north of the ramp also linking sediment ages to sediment generation (Cuttler et al., 2019).

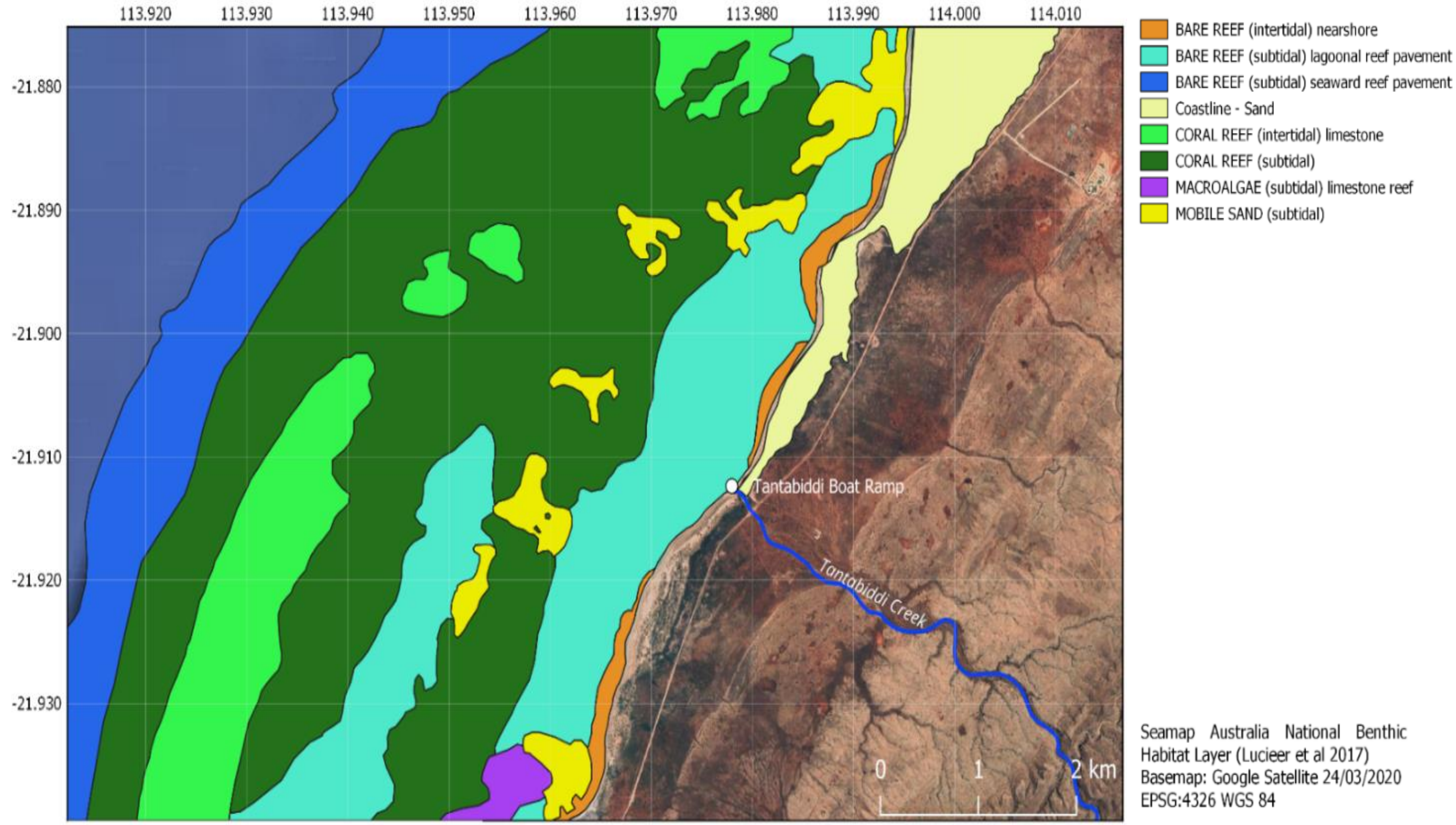


Figure 8-10. Broad scale benthic habitat mapping from Seamap Australia National Benthic Habitat Layer (Lucieer et al., 2017).

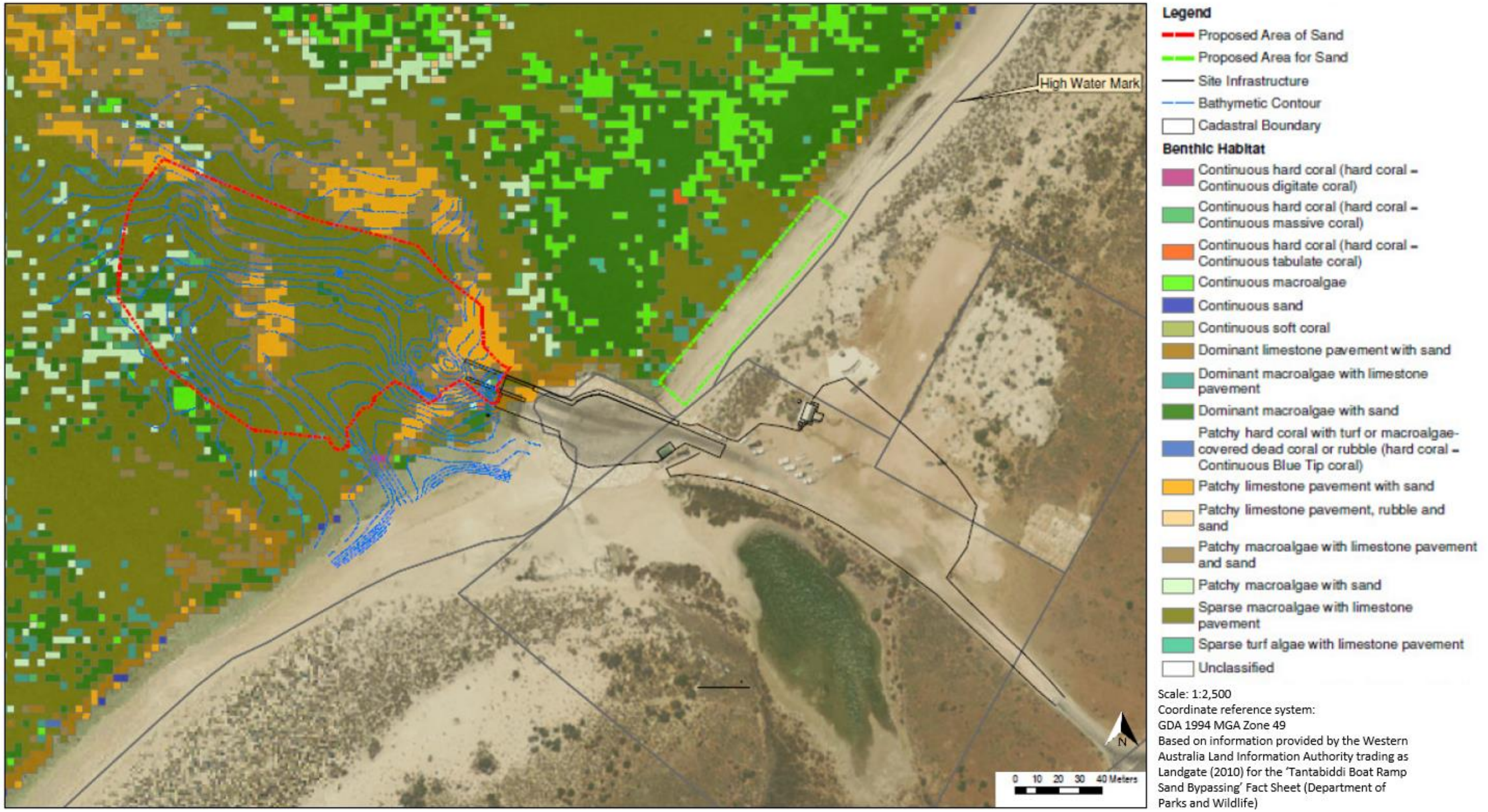


Figure 8-11. Benthic habitat at the Tantabiddi Boat Ramp nearshore area.

Note: proposed areas of dredging do not represent actual areas dredged and storms after mapping may have altered the benthic habitat.

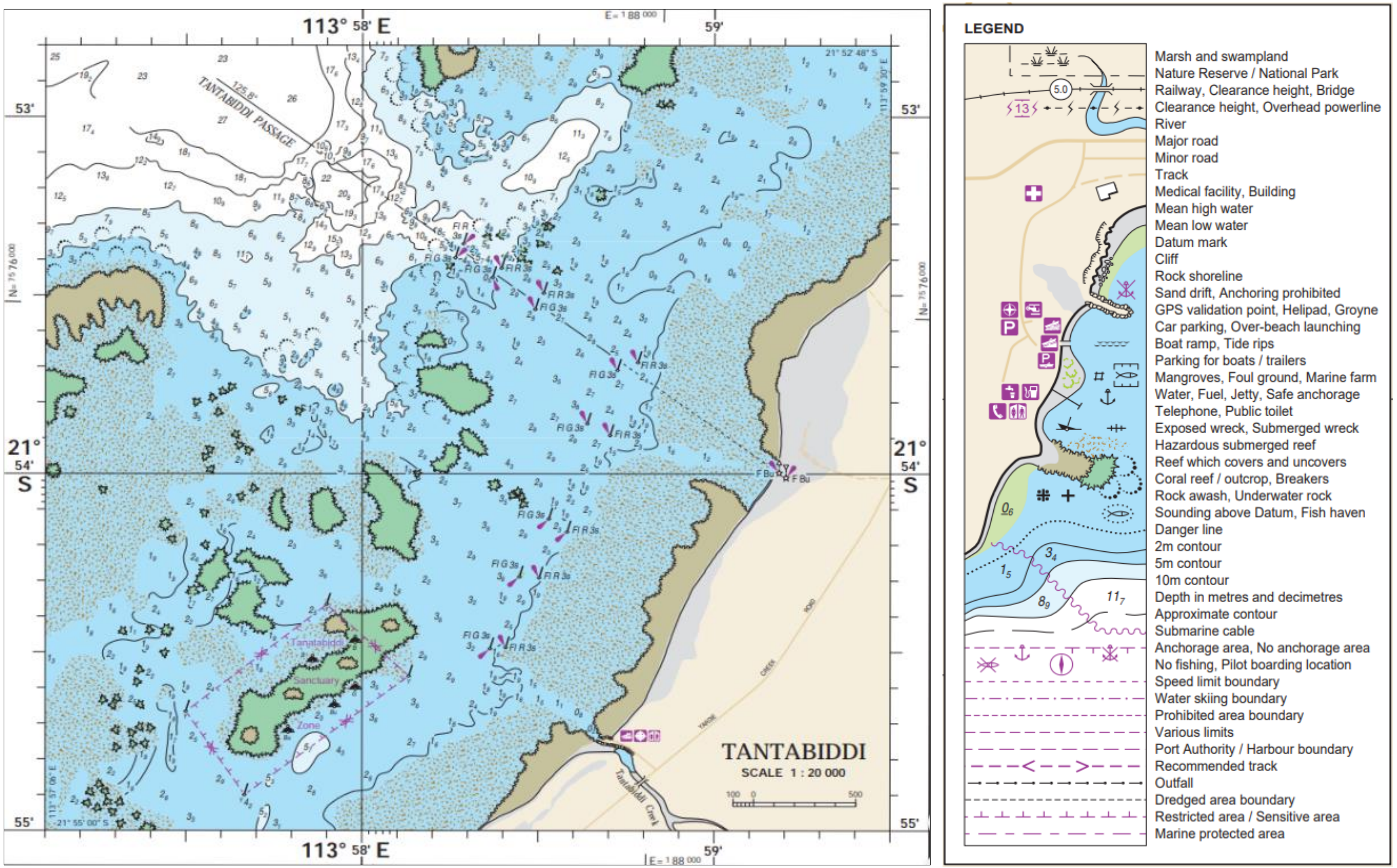


Figure 8-12. Nearshore bathymetry chart extracted from DoT chart WA900. Shows the nearshore reefs surrounding the boat ramp.

8.2.2.2 Waves and Wind

The morphology of the fringing reef influences the hydrodynamic processes (i.e. waves, currents, water levels) and the seabed properties that determine the pathways and magnitude of sediment transport (Pomeroy *et al.*, 2018). Cross reef flows transport sediment as suspended sediment and bedload (as migrating ripples) into the lagoon area (Figure 8-8, Figure 8-9; Cuttler *et al.*, 2019). This sediment has been found to be migrating shorewards at Tantabiddi, accumulating to form a large salient to the north of Tantabiddi Boat Ramp (Pomeroy *et al.*, 2018). Sediment is transported by both shorewards currents (from waves across the reef and channel), and strong northwards directed currents (from prevailing winds from the south west). The south westerly winds create these currents that drive the longshore drift of nearshore sediments northwards, as well as feeding dune systems to the north with wind-blown beach sand (Sanderson, 2000; Sanderson *et al.*, 2000).

The hydrodynamic processes including waves and tides have been investigated and quantified in the Tantabiddi area (MP Rogers and Associates, 2018). The average tidal range at the site is ~0.9 m with a maximum tidal range of 1.5 m and dominated by semi-diurnal constituents (Drost *et al.*, 2019). Locally generated wind waves, predominantly from the south west, were noted by Drost *et al*. (2019) as the dominant waves at the lagoon and shoreline with the reef dissipating large offshore waves. However, during tropical cyclones, locally generated sea swell waves are more dominant and enter at larger magnitudes via Tantabiddi Passage at directions that are highly dependent on the tropical cyclone pathway as shown in Figure 8-13 (Drost *et al.*, 2019). The different directions of wind and wave conditions can cause greater erosion and alongshore sediment transport than the magnitude of the waves suggests (Cuttler *et al.*, 2018; Seashore Engineering, 2018).

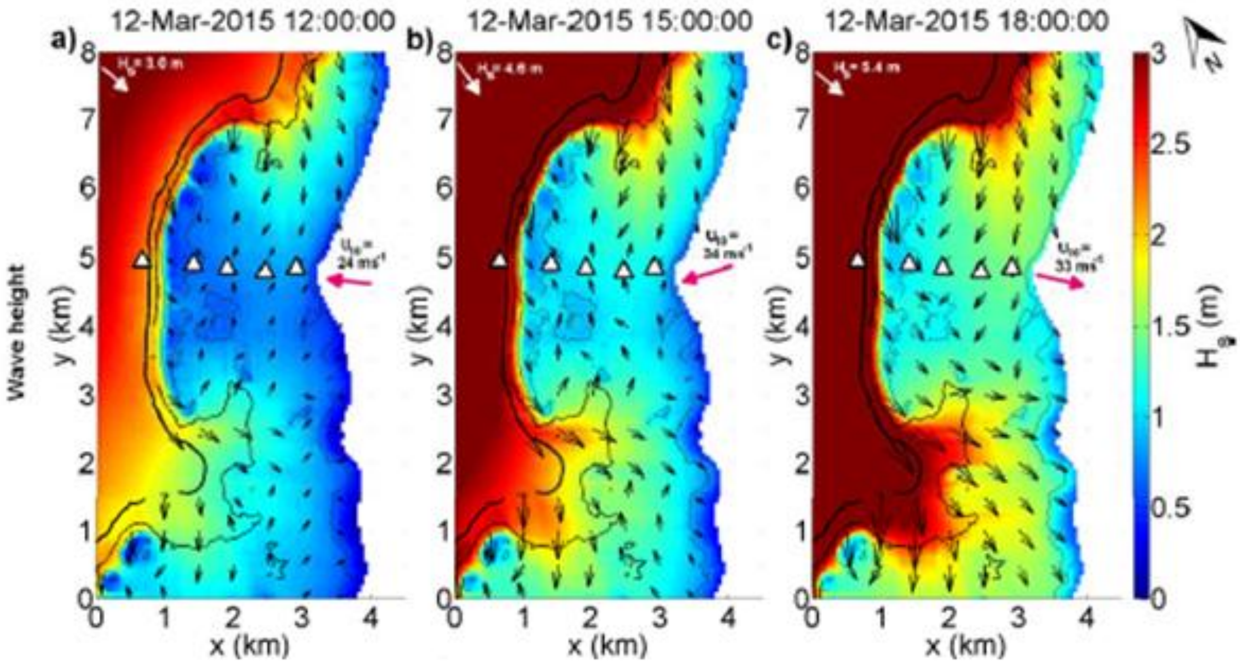


Figure 8-13. Significant wave height from the SWAN model at Tantabiddi during the approach of TC Olwyn (left and centre) and after the passage of the eye (right). Black vector arrows denote the peak wave directions (for depths <10m). The directions of the incoming waves and wind speed are denoted by the white arrows in the upper left corners and magenta arrows on the right. Black contour lines show the isobaths at 10, 5 and 2 m and the measurement locations are denoted by triangles

8.2.3 Data Analysis

The reviews described above identified substantial differences between the geomorphology of the nearshore and beach system to the south of the boat ramp and that to the north of the ramp. This section builds on this review by assessing sediment data provided by the DoT (Section 8.2.3.1) and aerial imagery showing coastal processes (e.g. longshore drift and shoreline accretion) (Section 8.2.3.2) and impacts of Tantabiddi Creek flood events (Section 8.1.3).

8.2.3.1 Sediment (Channel and Beach)

Ten sediment samples were obtained from the Tantabiddi Boat Ramp area including the beach areas, dredge spoil areas, estuary, Tantabiddi Creek and channel locations (Figure 8-14). Five samples were collected by DoT in July 2019 (TBSS01 – TBSS05) and five were collected by Advisian in March 2020 (TS01 – TS05).

Samples were analysed for composition by X-Ray Diffusion (XRD) and for Particle Size Distribution (PSD) to inform the sediment transport conditions and the source of the sediment. The sediment characteristics from the PSD and XRD analyses are summarised in Table 8-4 and Table 8-5, respectively.

Table 8-3. Sediment samples

Sample Date	ID	Description	Longitude (X)	Latitude (Y)
July 2019	TBSS01	South Beach	-21.912741	113.977733
	TBSS02	Estuary	-21.912806	113.978462
	TBSS03	North Beach	-21.912246	113.978654
	TBSS04	Dredge spoil	-21.912260	113.979806
	TBSS05	Offshore Channel	-21.910065	113.974630
March 2020	TS01	Estuary south	-21.9139926	113.979611
	TS02	Creek upstream 1	-21.9170933	113.982043
	TS03	Creek upstream 2	-21.920825	113.989911
	TS04	Dredge spoil	-21.9124016	113.980062
	TS05	Estuary Mid	-21.9130492	113.97929

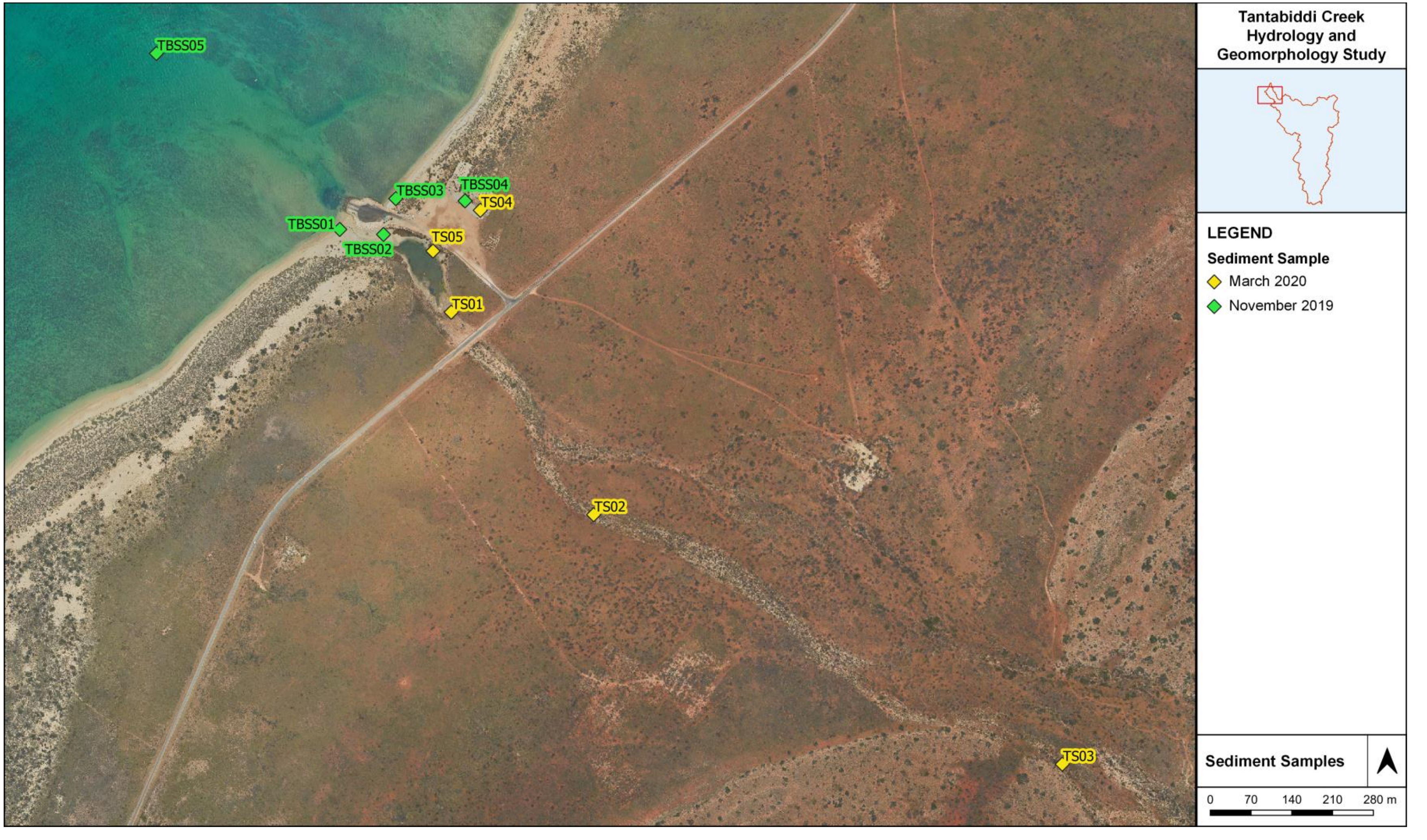


Figure 8-14. Sediment sample locations near Tantabiddi Boat Ramp

Quartz (likely igneous, terrigenous origin) was the highest percentage component in onshore samples, while aragonite (biogenic origin) was the major component of sediment from the marine channel location, indicating reef material contributes a substantial portion to the sediment near Tantabiddi Boat Ramp. This finding was consistent with previous studies in the Tantabiddi area (Cuttler *et al.,* 2019) which found coral was the dominant sediment constituent (~34%) and was primarily relic reef material (aged to be thousands of years old) from the Holocene reef framework. As the uplifted reef framework in the Tantabiddi Creek catchment is older than thousands of years, the sediment samples and previous studies in the Tantabiddi area suggest that the dominant sediment constituent in the lagoon area is not fluvially sourced. This finding is further supported by the composition of recent dredge spoil; this material was dredged from the channel at times that were not associated with major flood events and, consequently, the sediment does not have a composition similar to the Tantabiddi Creek catchment sediment.

Contrastingly, the dredge spoil from the south of the stockpile consists of material dredged following the 2014 flood and is likely to be primarily fluvial sourced sediments. This older dredge material is predominantly quartz (72%), with minor contributions of aragonite (1%), which is consistent with the Tantabiddi Creek upstream sediment (TS03: quartz 61%, aragonite not detected). Similarly, the upstream and estuarine samples from Tantabiddi Creek (TS01-TS03, TS05) contained small (<5%) amounts of ankerite, muscovite, albite, kaolinite and hematite, which were not detected in either the recent channel sediment or recent dredge spoil. These findings suggest that the Tantabiddi Creek contributes minor amounts of sediment to the channel area, although during a flood event may transport substantial quantities of sediment into the channel from the upper catchment.

The PSD data revealed the channel, beach, north estuary and recent dredge sediments were predominantly medium sand sized grains, with slightly varied median particle sizes across the samples (Table 8-4). The channel sediment had larger median grain size (TBSS05, D50=0.46 mm) than the estuary north (TBSS02, D50=0.46 mm) and the beaches to the north (TBSS03, D50=0.40 mm) and south (TBSS01, D50=0.37 mm). A similar trend of varied median grain size has been reported in other studies in the Tantabiddi area, with decreasing median grain size from the reef crest (D50=0.50 mm), shoreward through the lagoon (D50=0.35 mm) to the beach (D50=0.25 mm) (Cuttler *et al.,* 2015, 2018, 2019). The fluvial sediment sizes similarly represent a size gradient down the catchment, as heavier sediments fall through the water column as it reaches the coastal plain (TS03; D50=4.8 mm) and finer sediments are deposited as flows reduce across the low gradient plain (TS02; D50=4.3 mm) and reach the estuary (TS01; D50=2.1 mm).

The median sediment grain size from the lagoon channel location in the current study (TBSS05, D50=0.46 mm) was consistent with previous studies in the Tantabiddi area which classified the majority of deposits from the lagoon as medium sand (D50=0.35 mm) (Cuttler *et al.,* 2019). Comparatively, the PSD showed the creek, south estuary and older dredge spoil were predominantly fine gravel (D50=2.1-4.8 mm). The older dredge spoil PSD (TS04, D50=4.5 mm) similarity to the Tantabiddi Creek upstream sediment (TS03; D50=4.8 mm) further supports the XRD composition findings that older dredge spoil was consistent with fluvial sourced sediment and that flood events result in a substantial contribution of fluvial sediment to the channel. Furthermore, the comparatively finer sediment in the channel and recent dredge spoil compared to the Tantabiddi Creek gravel sized sediment indicates a relatively minor contribution of fluvial sediment when flood events have not occurred.

Table 8-4. Particle Size Distribution (PSD) summary table of sediment samples

Sediment sample	Volume mean (µm)	Surface area mean (µm)	D90 (µm)	D85 (µm)	D50 (µm)	D15 (µm)	D10 (µm)	Span
South Beach (TBSS01)	456	345	839	650	367	240	211	1.7
Estuary north (TBSS02)	592	455	931.49	800	458	317	293	1.4
North Beach (TBSS03)	434	398	605	500	405	316	298	0.8
Dredge spoil recent (TBSS04)	676	395	998	850	436	282	267	1.7
Channel (TBSS05)	687	69	1500	1000	463	126	89	3.1
Dredge spoil older (TS04)	4380	317	8500	8000	4450	2500	2300	1.4
Estuary mid (TS05)	3815	74	8400	7500	4100	1000	178	2.0
Estuary south (TS01)	2538	51	7200	6500	2100	224	100	3.3
Creek upstream 1 (TS02)	4252	78	8500	8000	4300	2500	2200	1.5
Creek upstream 2 (TS03)	4437	551	8700	8000	4750	2500	2400	1.3

Table 8-5. X-Ray Diffraction (XRD) analysis summary table of sediment samples

Sediment sample	Quartz	Aragonite	Calcite, magnesian	Calcite	Microcline	Nosean	Halite	Spinel	Ankerite	Muscovite	Albite	Kaolinite	Hematite
South Beach (TBSS01)	58	17	10	9	6	1	Trace	-	-	-	-	-	-
Estuary north (TBSS02)	39	18	18	12	10	Trace	1	-	-	-	-	-	-
North Beach (TBSS03)	45	19	20	10	5	1	-	-	-	-	-	-	-
Dredge spoil recent (TBSS04)	42	22	17	14	4	Trace	1	Trace	-	-	-	-	-
Channel (TBSS05)	21	52	14	7	3	1	3	-	-	-	-	-	-
Dredge spoil older (TS04)	72	1	-	10	4	-	-	-	8	3	2	1	-
Estuary mid (TS05)	65	7	12	6	3	-	Trace	-	1	-	4	-	1
Estuary south (TS01)	77	1	1	8	6	-	-	-	-	1	4	1	1
Creek upstream 1 (TS02)	44	3	2	36	5	-	-	-	-	3	3	1	2
Creek upstream 2 (TS03)	61	-	-	17	3	-	Trace	-	9	3	5	1	1

8.2.3.2 Historical Imagery Analysis of Coastal Processes

Beach Foreshore Extent

The variability in beach foreshore extent was described based on aerial imagery, to compare the accumulation of material on the southern and northern side of the ramp (referred to as south beach and north beach) as an indication of longshore drift. The percentage difference between south beach and north beach presented in Table 8-6 can be compared over time, although due to tidal variation between the historical images, the beach extents are not directly comparable. The beach extent was measured at a location ~20 m either side of the most southern and most northern extent of boat ramp revetment. The extent was defined as the berm or vegetation line to the shoreline.

Imagery analysis showed the south beach extent was generally greater than the north beach extent, which indicates the ramp is likely to be forming a barrier to northwards longshore drift processes and has resulted in sand accumulation on the south beach. It has been estimated that net northerly transport could be about 5,000 m^3/year (MP Rogers and Associates, 2018). The restriction of the northwards sediment transportation in conjunction with a relative lack of protection from north westerly swell waves has likely caused the erosion of the north beach extent. The variability in historic beach extent has also been impacted by deposition of alluvial sediment (Section 8.1.3). Overall, results suggest that longshore drift is a dominant process, with storm driven erosion, fluvial deposition and dredge spoil deposition also influencing beach extent.

Table 8-6. The variation in beach extent between the southern and northern side of the boat ramp.

Date	Beach Extent		Difference Between North and South (%)
	South of Ramp (m)	North of Ramp (m)	
2019 Nov	13.5	5.8	-57
2018 June	4.4	6.3	43
2015 Oct	15.6	7.6	-51
2013 Sept	19.3	13.7	-29
2012 Dec	12.2	14.7	20
2011 June	12.1	7.3	-39

Nearshore Sand Bar

Mobile sands are a common feature along the North West Cape coastline, and longshore drift processes contribute to their movement along the coast Figure 8-15 shows the high variability in sand bars overlaying or bordering the nearshore reef platforms based on the 0 m contour lines of bathymetric surveys undertaken in April 2005, April 2007, June 2010 and September 2015. The sand bar in 2015 (red line) depicts the result of major dredging which was undertaken in June 2015 to increase the depth of the channel for navigation. The boat ramp is bordered by nearshore intertidal bare reef platforms which are also subject to changes over time and may be captured in the contours. Dredge spoil in 2015 was reported to consist of a large amount of rubble which may indicate dredged reef platform material, that the reef has been broken up and transported into the channel by storm wave action, or fluvial contributions.

Figure 8-15. Coastal sand bar on southern side of the Tantabiddi boat ramp. Bathymetry surveys based on 0 m contours shows the sand bar has moved substantially between 2005 (purple), 2007 (black), 2010 (white) and 2015 (red). Base imagery: October 2015 (~1 month after bathymetry survey was conducted; Google Earth). Other imagery sourced from Landgate and Google Earth

Estuarine Sand Bar

Changes over time were described for the sand bar at the Tantabiddi Creek inlet as an indication of coastal and fluvial processes impacting the Tantabiddi Boat Ramp (Plate 17). Figure 8-16 shows the sand bar is highly mobile and periodically disconnects from the boat ramp when flows from Tantabiddi Boat Ramp are sufficient to create a channel through the sand bar. The sand bar accumulates and closes the estuarine inlet relatively quickly (less than 2 months). The sand bar is likely to be influenced by several sediment transport processes, including:

- The accretion of sand from longshore drift and windblown sand.
- Wave action from storm events eroding the shoreline.
- Tidal flushing, especially when the estuary is open.
- Erosion or deposition of sediments from Tantabiddi Creek during heavy rainfalls. It was noted in Section 8.1.3.1 that different sized events result in varying impacts to the estuary. Small-moderate sized rainfall events (e.g. 2018) appeared to result in an accumulation of sediments at the sand bar without resulting in an opening of the mouth, while larger events (e.g. 2014) mobilised sediments in the estuary, opened the mouth and resulted in deposition of sediments in the nearshore environment.

Plate 17. Top: the estuarine sand bar accumulates on the southern side of the boat ramp and reduces the depths for boat access (Photo: West Regional/Branwen). Bottom: view looking north east shows the relative lack of sand accumulation on the northern side of the ramp (Photo: Ningaloo Ecology Cruises).

Figure 8-16. Estuarine sand bar changes from 2015 to 2019 based on extent of the northern berm of the sand bar. Note the lines do not show the extent of the exposed sand as this is subject to tidal variation (Source: Google Earth and Landgate).

Shoreline Progression and Regression

The Tantabiddi catchment coastline and shoreline was mapped to describe the progression or regression of the shoreline over the long term (50 years) and medium term (7 years), based on historical aerial imagery (Figure 8-17) sourced from Landgate and Google Earth, using the vegetation line as a proxy for the shoreline. The vegetation line visible on aerial imagery defined the coastline, and the water level at the time of image capture defined the shoreline (although this was subject to tidal variation).

In recent years, coastline regression on the northern side of the ramp has occurred between June 2018 to November 2019, suggesting potential erosion resulting from restricted longshore drift following floods in June 2018 (Figure 8-17). However, dredge spoil depositions to the north beach area (e.g. 2015) impacts the ability to assess changes to this area. To the south of the boat ramp, the coastline varied between approximately 0.5 – 2 m per year.

To capture shoreline progression over the long term, the latest imagery (2019 November) (Source: Google Earth) was compared to historical imagery from 1969 (Source: Landgate), before the construction of the Tantabiddi Boat Ramp. This comparison over 50 years revealed that the coastline south of the ramp had progressed seawards by 16-18 m, approximately 0.36 m per year. Similarly, the shoreline south of the ramp had progressed seawards 6-8 m, approximately 0.16 m per year. The average shoreline to the north of the ramp showed minor changes compared to the south shoreline, with the exception of the shoreline immediately north and adjacent to the ramp. The shoreline in this area had regressed by approximately 13.3 m over 50 years. Overall, this long-term comparison of shoreline progression showed sand accumulation south of the ramp and erosion north of the ramp has occurred post construction.

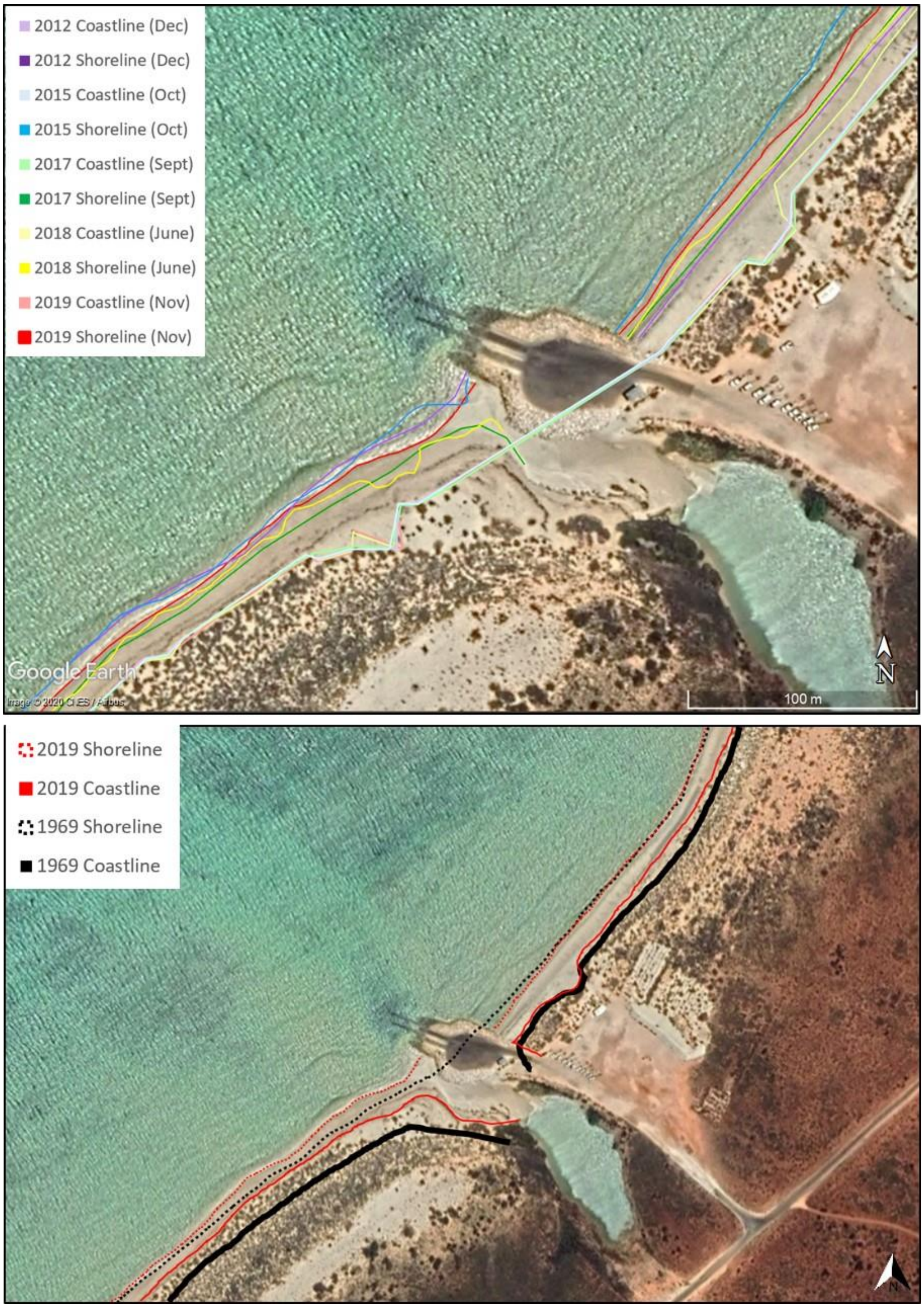


Figure 8-17. Variation in shoreline extent over time. Top: shoreline historical changes at the Tantabiddi Boat Ramp over seven years (2012-2019); Bottom: comparison of 1969 imagery prior to the ramp construction and recent (November 2019) imagery shows long-term (50 years) shoreline progression, sand accumulation south of the ramp and erosion north of the ramp has occurred. Base imagery: November 2019 (Google Earth). Other imagery sourced from Landgate and Google Earth)

These shoreline or coastline accretion rates estimated over the long term (50 years) may underestimate current shoreline progression because changes may have occurred more rapidly following initial construction of the boat ramp. Prior to construction, shoreline accretion may have resulted from deposition of sediments transported by swell waves across the reef and lagoon as suspended sediment and bedload. However, following construction, the accretion may also occur due to the boat ramp interrupting longshore drift processes, from dredge spoil deposits and the increased frequency of floods and storms. In the Tantabiddi area near Jurabi Point (a salient), shoreline accretion rates have been estimated as 1 m/year (Cuttler *et al.,* 2019). The shoreline progression at the study area is expected to be less than the accretion in a salient zone (i.e. less than 1 m/year). Compared to the transport estimated by longshore drift (5,000 m^3/year), the disparity in shoreline accretion on either side of the ramp was considered too extensive to be attributed to only the processes of shoreline accretion (<1 m/year) and high erosion on the north bank. The shoreline accretion on the south of the ramp is more likely to be dominated by longshore drift processes which have been estimated to transport higher amounts of sediment (5,000 m^3/year).

8.3 Sediment Transport Pathways

Based on a review of coastal and fluvial processes using available historical aerial imagery, available literature and elevation data, Figure 8-18 presents the key indicative sediment transport pathways that have been used to inform the assessment of geomorphological processes occurring at Tantabiddi Boat Ramp. The dominant geomorphological coastal and fluvial processes occurring at the Tantabiddi Boat Ramp area are summarised as the following:

- As the wind and waves at the site are predominantly from the south west, net longshore drift transports sediment in a north easterly direction. Sediments are trapped by the protrusion of the boat ramp and accumulate on the southern side leading to the estuarine sand bar and offshore sand bar reducing the navigational safety of the channel. Previous studies have estimated that the net northerly transport could be in the order of 5,000 m3/yr. Analysis of historical aerial imagery supported the occurrence of longshore drift at Tantabiddi Boat Ramp.
- Heavy rainfall events (e.g. April 2014 event) flush fluvial sediment and estuarine sand bar sediments into the nearshore area, opening the estuary to the ocean and further adding to the accumulation present from longshore drift. Evidence of the estuary opening in response to heavy rainfall is clearly depicted in historical aerial imagery and fluvial deposits marking flood extents indicate the transport of substantial quantities of sediment from the Tantabiddi catchment.
- Small-moderate rainfall events (e.g. June 2018 event) appear to result in deposition in the estuarine pool and sand bar resulting in growth of the sand bar adjacent to the boat ramp. These events do not result in an opening of estuarine mouth nor deposition of sediments in the nearshore environment (including the channel from the boat ramp).
- Cross-reef currents transport sediments into the lagoon area which are deposited as fine sediment closer to the shore, leading to shoreline accretion, and largely exit through channels such as the Tantabiddi passage to the north west. Previous studies within the region but outside the study area (and not directly impacted by the boat ramp) have estimated shoreline accretion at 1 m/year, though lower rates are estimated at Tantabiddi Boat Ramp. Sediment analysis at Tantabiddi supports this transport pathway, revealing coral was a dominant sediment constituent in the lagoon. The disparity in shoreline accretion between the southern (progressing) and northern (regressing) sides of the ramp was considered too extensive to be

attributed to only the processes of shoreline accretion on the southern side and high erosion of the northern side of the boat ramp.

- Tidal flushing when the estuary is open transports beach material into the estuary and carries fine sediment from the estuary into the nearshore area.
- Tropical cyclones and other storm events produce a range of wave directions and large swell waves that impact Tantabiddi Boat Ramp. The swell waves are significantly reduced by the fringing reef, although high magnitude waves enter the lagoon through the channels, such as Tantabiddi Passage to the north west. Consequently, sediment transport processes may be highly storm dependent.
- Local sea waves generated behind the reef crest during cyclones, using a small fetch length of the lagoon provide an important role in dictating beach morphology during storms.

Figure 8-18. Sediment transport pathways at Tantabiddi Boat Ramp. a) General influences on sediment movement; b) Example of a small-moderate sized creek flow (e.g. 2018); c) Example of a larger creek flow (e.g. 2014). Imagery sourced from Landgate and Google Earth)

8.4 Sedigraph Development

8.4.1 Background

Sediment delivery to the coast from Tantabiddi Catchment is a major input into the coastal hydrodynamic and sediment transport modelling discussed in Section 9. The coastal model requires sediment delivery rates over the duration of a number of design events. These rates are calculated using sedigraphs, which indicate how sediment delivery changes over the duration of flows.

8.4.2 Data Input

The development of the sedigraphs required a number of data inputs, including:

- Discharge hydrographs (in m^3/s) for the 1 EY to 1 in 100 AEP design events and 2014 rainfall events at Ningaloo Reef. The hydrographs for each of these events are shown in Figure 7-5.
- Water levels at the Yardie Creek road crossing over Tantabiddi Creek.
- Flow velocities across the channel at the Yardie Creek road crossing over Tantabiddi Creek.
- Particle size distribution (PSD) for the creek bed sediment. Samples TS02 and TS03 (discussed earlier) were used for the analysis as they provided the best representation of bed sediment within the creek.

8.4.3 Computation of Sediment Transport Rate/Concentration

Sediment transport rate (N/s/m, q_t) for each point second within the flow hydrograph was calculated using the Engelund-Hansen equation (Engelund, F. & Hansen, E.,1967), as outlined below:

$$q_t = 0.05\gamma_s V^2 \sqrt{\frac{d_{50}}{g\left(\frac{\gamma_s}{\gamma}-1\right)}}\left[\frac{\tau_b}{(\gamma_s-\gamma)d_{50}}\right]^{3/2}$$

The rate was converted into a sediment concentration (mg/l) using the following formula:

$$C = \frac{q_t}{g}\frac{w}{Q} \times 10^3$$

This was then converted into a sediment discharge (kg/s, kg/hour, m^3/hour) using the following formulae:

$$Q_s(kg/s) = C \times Q \times 10^{-3}$$

$$Q_s(kg/hour) = C \times Q \times 10^{-3} \times 3600$$

$$Q_s\ (m_3/hour) = \ Q_s(kg/hour)/p_s$$

The calculation and explanation of the parameters within each of the above equations are provided further below:

- Sediment specific weight $\gamma_s = \rho_s g = 25{,}996\ N/m^3$
- Sediment density ρ_s=2,650 kg/m^3
- Sediment specific gravity $s = \frac{\rho_s}{\rho} = 2.65$

- Gravitational acceleration g=9.81 m/s^2 or N/kg
- Water specific weight $\gamma = \rho g = 9{,}810\ N/m^3$
- Water density ρ=1,000 kg/m^3
- Flow velocities (m/s) V – taken from the flow hydrographs
- Sediment mean diameter (m) d_{50} – taken from PSDs at TS-02 (0.0578505 m)
- Bed shear stress τ_b (in N/m^2) $\tau_b = \rho g h S_b$
- Bed Slope S_b – 0.0045 m/m
- Cross-section geometry – A trapezoid was used to approximate the cross-section geometry at the road crossing, as per Figure 8-19.
- Water depth (m) h – Water level-bed level. Bed level at the crossing is 1.1384 m (Figure 8-19) and water level was derived for for each step in the hydrograph.
- Channel width (m) w – Water level outputs for each step in the hydrograph were used in conjunction with the cross-section geometry (Figure 8-19) to calculate channel width using the following formula:

$$w = 32.9 + h\frac{13.6}{0.9616} + h\frac{31.5}{1.4816}$$

- Discharge (m^3/s) Q – derived for each step of the flow hydrograph
- Flow area (m^2) – Using the cross-section geometry and the following equation:

$$A = 32.9 \times h + 0.5h^2\frac{13.6}{0.9616} + 0.5h^2\frac{31.5}{1.4816} \text{ or } A = 0.5 \times (32.9 + w) \times h$$

- Hydraulic radius (m) R_h as per the equation below:

$$R_h = \frac{A}{32.9 + \frac{h}{cos\left(arctan\frac{13.6}{0.9616}\right)} + \frac{h}{cos\left(arctan\frac{31.5}{1.4816}\right)}}$$

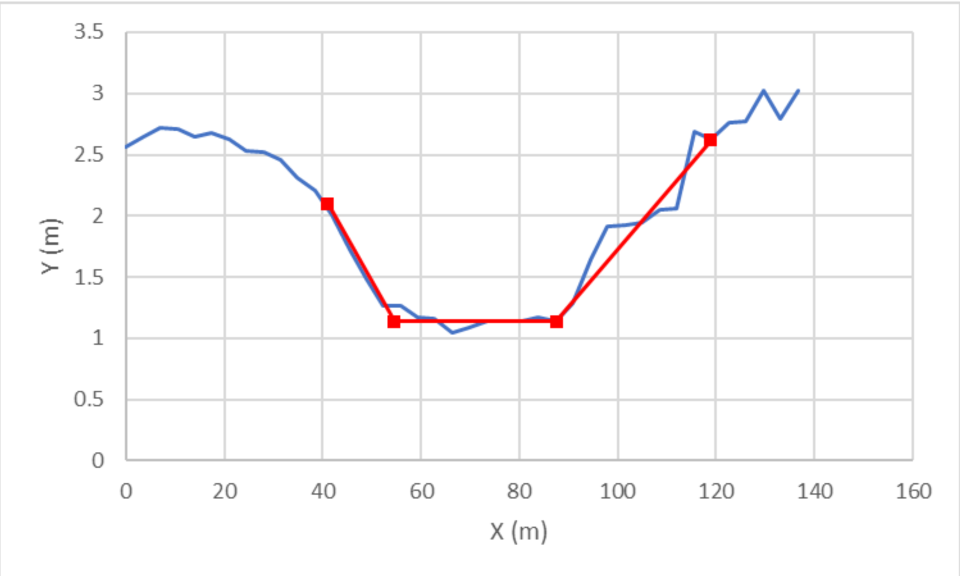


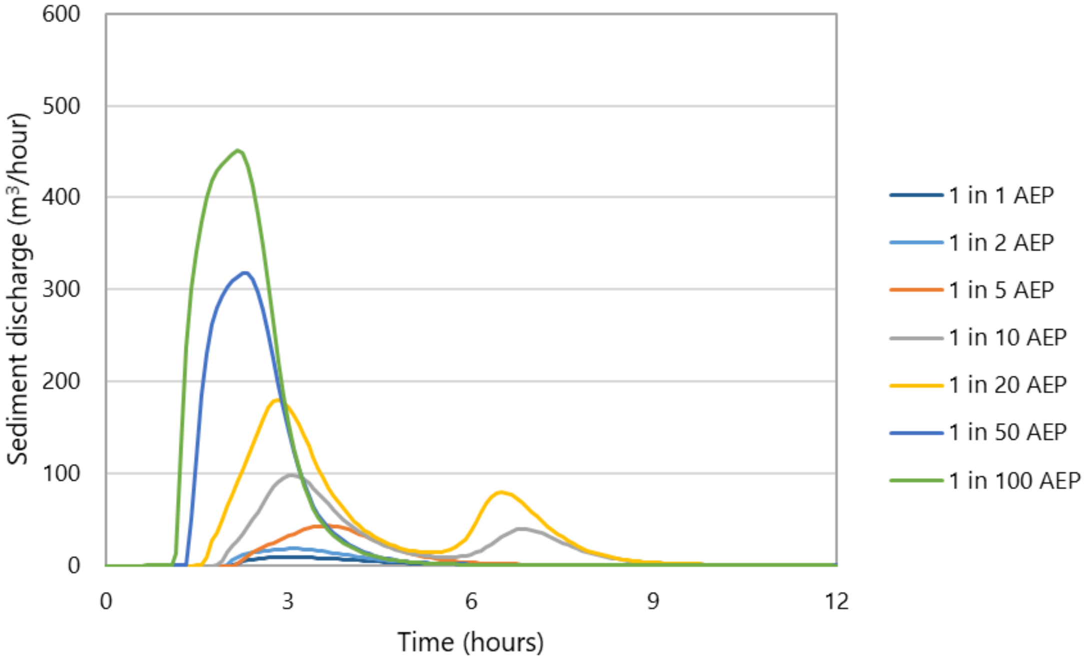
Figure 8-19. Cross section geometry and its trapezoidal approximation at the road crossing

8.4.4 Results

Table 8-7 provides the total volume of sediment delivered to the Tantabiddi estuary in each of the modelled design events. Figure 8-20 shows the hourly sediment delivery rate for the duration of each design flow event. These results were then used as inputs to Section 9.

Table 8-7. Estimated total sediment volume transported throughout the duration of each of the modelled flow events

Scenario	Estimated total sediment volume (m^3)
1 EY	23
1 in 2 AEP	41
1 in 5 AEP	94
1 in 10 AEP	238
1 in 20 AEP	420
1 in 50 AEP	479
1 in 100 AEP	703
2014 event	2,112



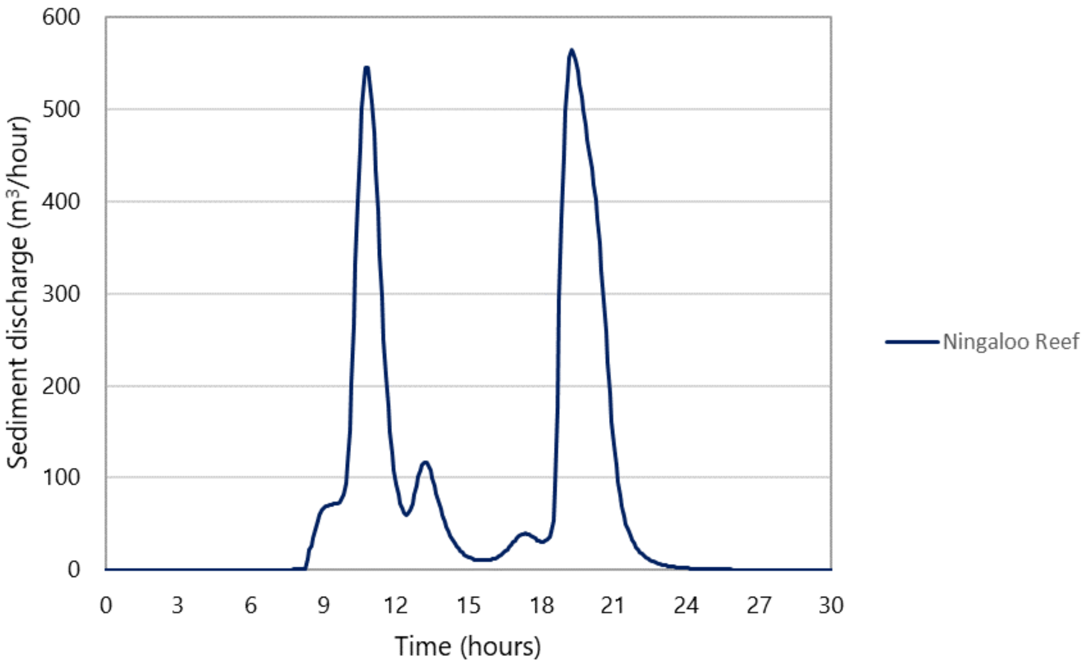


Figure 8-20. Sedigraphs for the modelled design events (top) and 2014 event (bottom)

9 Sediment Transport Modelling

9.1 Available Data used for Modelling

9.1.1 Bathymetry

The bathymetric survey data from 2010, 2015, 2019 and 2020 (listed in Section 1.4.1) was used for sediment transport model study along with MIKE CMAP data (2017). All model results are in Chart Datum (mCD).

9.1.2 Wind

The available wind data includes purchased data from Bureau of Meteorology (BoM) at Learmonth Airport, which is located approximately 37km south southeast from the Tantabiddi boat ramp.

Advisian received wind data recorded at Tantabiddi (Yardie homestead) provided by DoT. This data only recorded wind between 25/07/2019 and 21/04/2020. For this study, wind data is required to cover the period of 2014 event (April 2014) for assessment, therefore the data was not utilised in this assessment.

9.1.3 Tidal Level

Figure 9-1 presents the submergence curve for Tantabiddi (DoT, 2006), in which the tide levels at Tantabiddi are given in Table 9-1. Water depths and levels presented in this section report are referenced to Chart Datum.

Table 9-1. Tantabiddi Tidal Planes (DoT 2006), adapted from Table 3.1 in MP Rogers and Associates, 2018.

Tide	Elevation (m)	
	Chart Datum	AHD
Highest Astronomical Tide (HAT)	2.04	1.03
Mean High Water Spring (MHWS)	1.60	0.59
Mean High Water Neap (MHWN)	1.31	0.30
Mean Sea Level (MSL)	1.07	0.06
Australian Height Datum (AHD)	1.01	0.00
Mean Low Water Neap (MLWN)	0.87	-0.14
Mean Low Water Spring (MLWS)	0.54	-0.47
Lowest Astronomical Tide (LAT)	0.10	-0.91

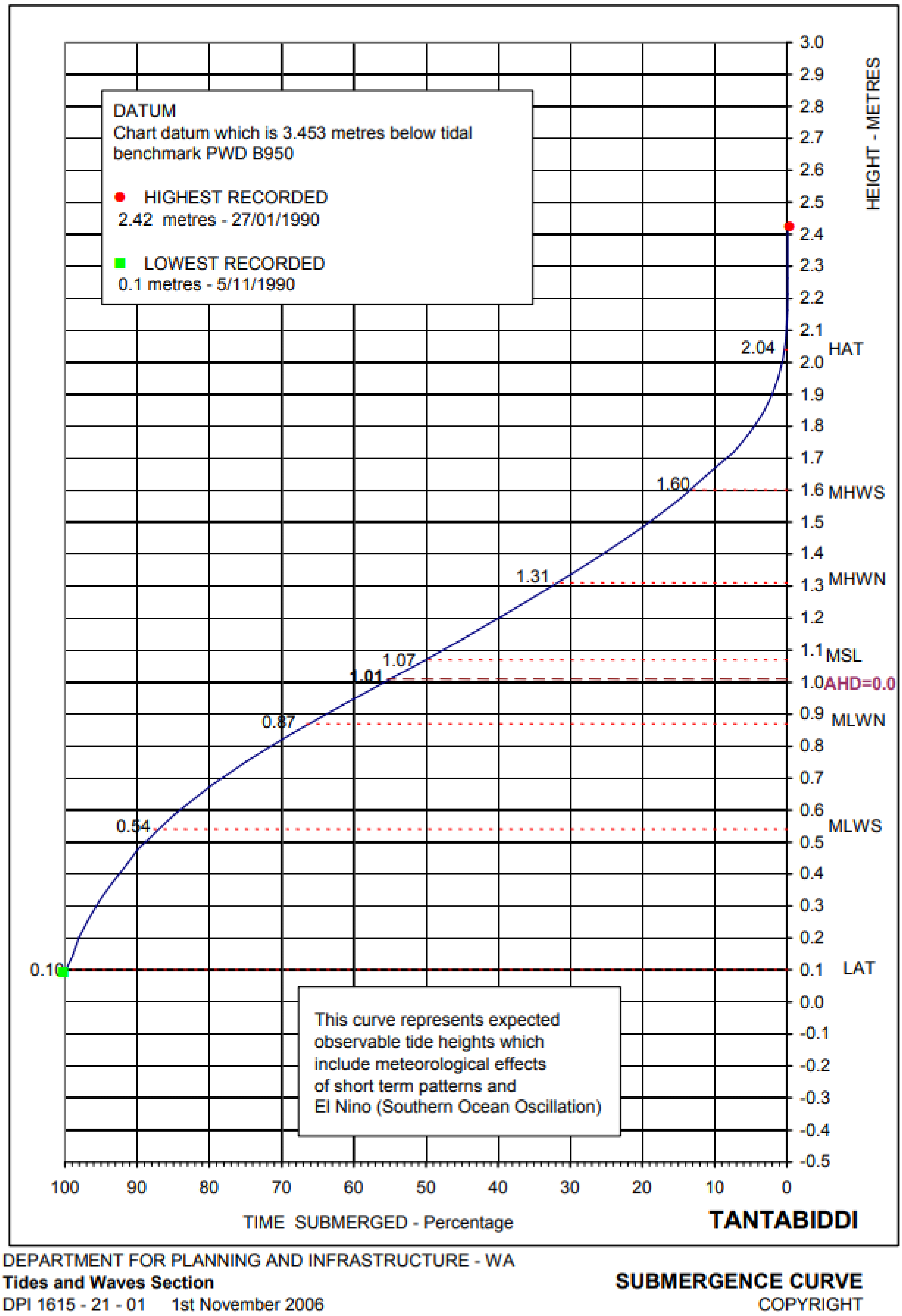


Figure 9-1. Submergence curve for Tantabiddi (DoT, 2006)

9.1.4 Sediment Characteristics

Sediment sampling results at five locations at the creek and the coastline were utilised in the sediment transport model. The sediment sample parameters are presented in Table 9-2 and corresponding locations presented in Figure 3-1 (Section 3).

Table 9-2. Sediment Sampling Results (mm)

Grade	TBSS05	TBSS01	TBSS02	TS02	TS04	TS05
D15	0.12	0.24	0.32	2.5	2.5	1.0
D50	0.46	0.37	0.45	4.3	4.5	4.0
D85	1.0	0.65	0.80	8.0	8.0	7.5
D85/D15	7.9	2.7	2.5	3.2	3.2	7.5

9.2 Model Setup

9.2.1 Model Description

The sediment transport model applies the MIKE21 Coupled Flexible Mesh (FM) Hydrodynamics modelling system to simulate the sediment transport process. The MIKE21 Coupled Model FM is composed of the following modules:

- Hydrodynamic Module (HD);
- Transport Module (TR);
- ECO Lab / Oil Spill Module (ECOLab);
- Mud Transport Module (MT);
- Particle Tracking Module (PT);
- Sand Transport Module (ST); and
- Spectral Wave Module (SW).

The Hydrodynamic Module (HD), Spectral Wave Module (SW) and the Sand Transport Module (ST) are the basic computational components of the sediment transport model. The coupled module allows for full feedback of the bed level changes on the flow calculations, to be included.

In this study, the coupled HD and ST modules were used for the simulations by including wave forcing simulated using SW module when necessary.

The SW model uses the same model domain and bathymetry (Section 9.2.2) as HD and ST model and applies the MIKE21 SW module. MIKE21 SW is a third-generation spectral wind-wave model that simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas and nearshore with a limited fetch. The SW model was previously built and calibrated by Advisian and the model domain and mesh were updated for this study.

The SW model applies fully spectral formulation associated with instationary time formulation. The model is set to accommodate a range of wave period events between 1s to 20s, which allows to simulate for both local wind wave and swells. The directional discretisation was set 15° bins over 360°

rose. The wind forcing input to the wave model was sourced from Bureau of Meteorology (BoM) at Learmonth Airport. The offshore boundary wave conditions were extracted from Advisian's in-house calibrated and validated Indian Ocean Wave model, which has 22 years hindcast wave conditions covering the all Indian Ocean including for West Australia.

The present modified local SW model was not calibrated and validated using the local wave measurements, as it is not critical for the present study purpose.

9.2.2 Domain and Bathymetry

The model domain covers the coastline from Tantabiddi to Mildura and extends offshore to a water depth of approximately 50 metres. The selected domain was considered sufficient for completing the scope of work for this study. Figure 9-2 to Figure 9-4 show the model computational mesh and bathymetry over the full domain and for an enlarged section in the vicinity of the boat ramp, respectively. The mesh incorporated in the model is flexible, which allows for higher resolution around areas of specific interest or areas with complex bathymetry. Computational length scales of the mesh triangles ranged from 300 m at the coarsest scale down to 10 m at the finest scale. These scales were selected to minimise run time, whilst still giving a suitable level of accuracy in the results. For the developed model, it is surrounded by three open boundaries, i.e., northeast, northwest and southwest boundaries.

Local bathymetry in the model is based on hydrographic survey datasets and CMAP digital data. The hydrographic data was used for the boat ramp and the creek areas whereas the CMAP data was used for the areas where hydrographic data was not available. The following datasets were used to define the bathymetry used in the models:

- ***2014 Calibration Event:*** Hydrographic measurements in 2010 and CMAP data was used for the calibration model since model calibration is based on the 2014 rainfall event and the 2010 dataset is the closest hydrographic dataset available before that event. The available 2010 survey data does not include hydrographic data within the creek area, so the available survey data collected in 2019 and 2020 was used for the creek area when generating the bathymetry for the calibration of the model. Figure 9-3 presents the bathymetry zoomed to the boat ramp and creek area for calibration of the model.
- ***Design Events:*** Hydrographic datasets from 2019 and 2020 measurements were combined with CMAP data when generating the bathymetry for sediment transport modelling of the range of design AEP flood events. The combined dataset is assumed to represent the current bed elevations in the boat ramp and creek areas for the sediment transport assessment (Figure 9-4).

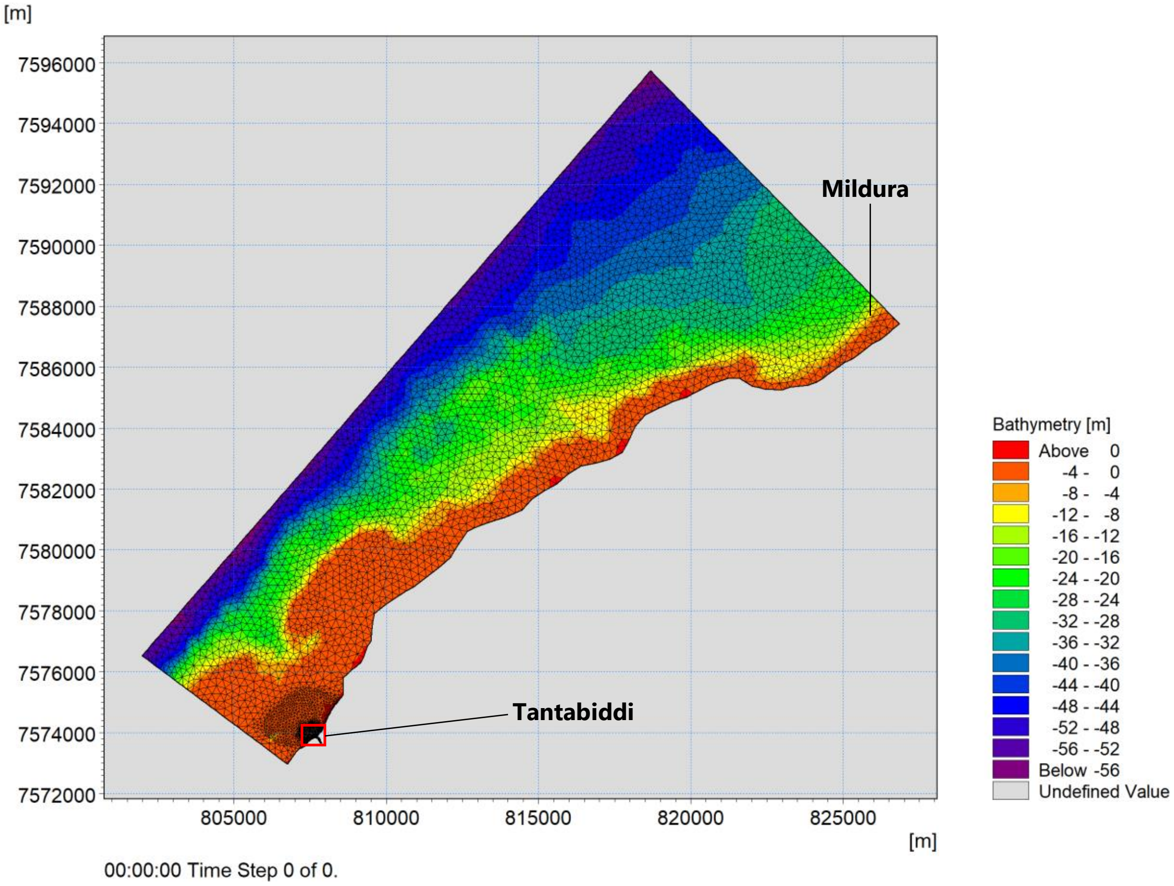


Figure 9-2. Sediment transport model domain and bathymetry (inset depicting location of Figure 9-3 and Figure 9-4)

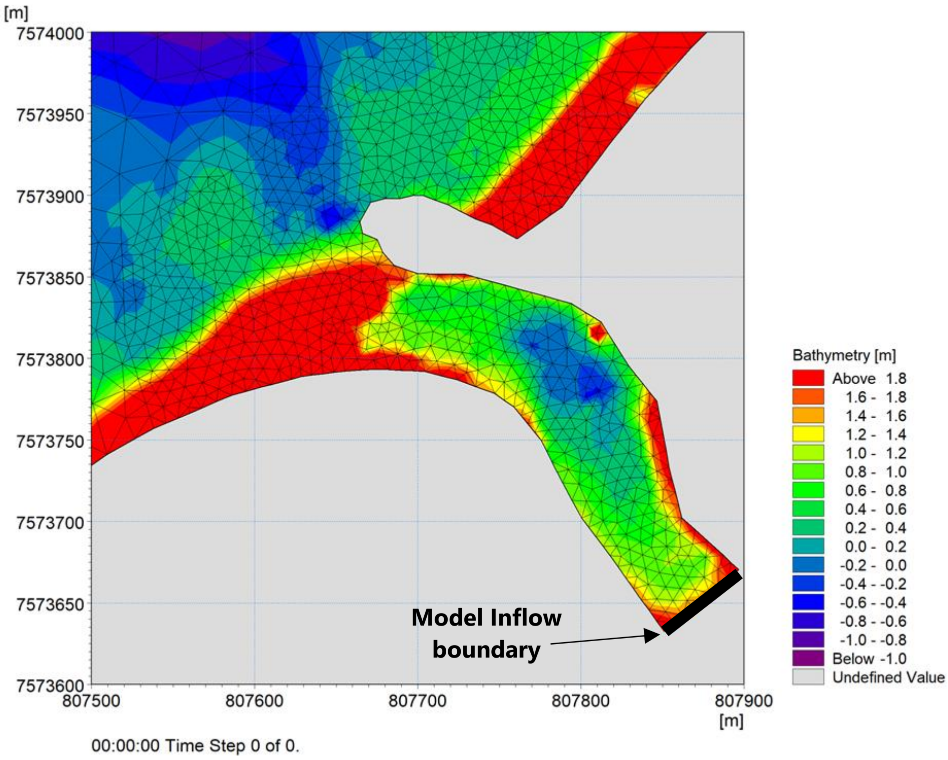


Figure 9-3. Model bathymetry adopted for the 2014 calibration event, zoomed to the boat ramp (2010 hydrographic data combined with 2019/2020 hydrographic data and CMAP data)

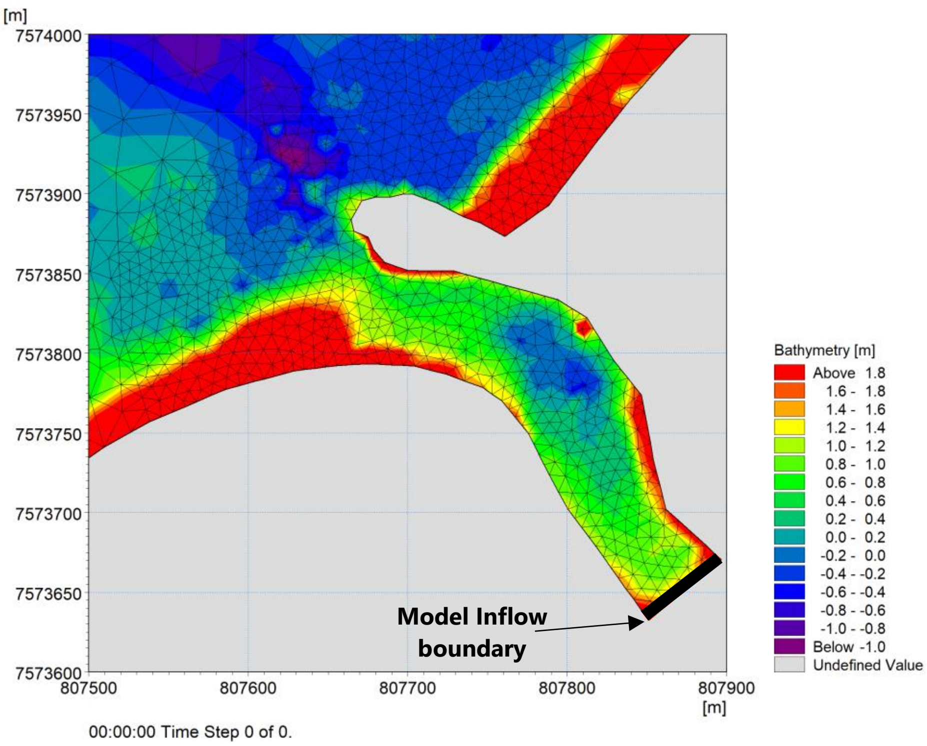


Figure 9-4. Model bathymetry for the design event (AEP) simulations, zoomed to the boat ramp (2019/2020 hydrographic data and CMAP data)

9.2.3 Model Inflows

Flow hydrograph timeseries from the TUFLOW model (Section 7.5) and associated sedigraph timeseries (Section 8.4.4) were input at the upstream boundary of the model at the Yardie Creek Road floodway (presented on Figure 9-3 and Figure 9-4).

9.2.4 Model Forcing

The main hydrodynamic driving forces can be divided into tidal and non-tidal processes:

- ***Non-tidal*** processes include creek discharge and forcing by the local meteorological conditions (e.g. winds and its driven wave).
- ***Tidal*** forcing was included in the model by imposing predicted tidal levels at all open boundaries. The tidal boundary conditions were generated by spatial interpolation of the tidal constituent data (amplitude and phase) from the global TPXO7 tidal model, which is based on Topex/Poseidon tidal altimetry data. The eight dominant semi-diurnal and diurnal tidal constituents were used. The annual (Sa) and semi-annual (Ssa) constituents were also included, based on tidal predictions at Tantabiddi (AHS, 2015), to account for seasonal changes in mean level.

At the model coastal boundaries, this tidal data was supplemented with predictions at local tidal stations available in the Australian Tide tables (AHS, 2015). Tantabiddi tidal station and Point Murat tidal station were used. Along the northwest boundary tidal conditions were generated by interpolation between tidal constituents from the relevant station and the TPXO7 data.

On all the open boundaries, the predicted water levels are site specific and vary in local time and along the boundary line. At points along the boundary, where water is flowing into the model domain, the flow is forced perpendicular to the boundary orientation, while at points where the water is flowing out of the model domain, the flow direction is extrapolated from the nearest points inside the model domain.

The following tailwater conditions were assumed for sediment transport modelling:

- 2014 Calibration Event: the tidal water levels using the method described above have been applied for all the open boundaries; and
- Design Events: a constant water level (mean sea level 1.07 m CD) was adopted, as the effects of tidal level as sensitivity analysis in Section 9.4, found they have limited impact on model results.

9.2.5 Sediment Properties

A sediment map shown in Figure 9-5 was generated based on available sediment information presented in Table 9-2. The generated sediment map contains sediments of D50 with 4mm in the creek area (based on sediment sampling information) and 0.15mm in the offshore area (typical sediment size used for offshore areas in sediment transport models). The model applied the 0.15mm sand size offshore and 4mm onshore based on the PSD data and associated sampling locations then interpolated values in between. Should additional offshore sediment samples be collected, then it is recommended that they are used to update the sediment map and associated model input parameters for future phases of this project.

The porosity and the relative density of sediments are considered as 0.4 and 2.65 T/m^3, respectively, which were default values recommended by model manual. Should additional site measurements be undertaken then this can be used to inform selection of porosity and the relative density values in future project phases.

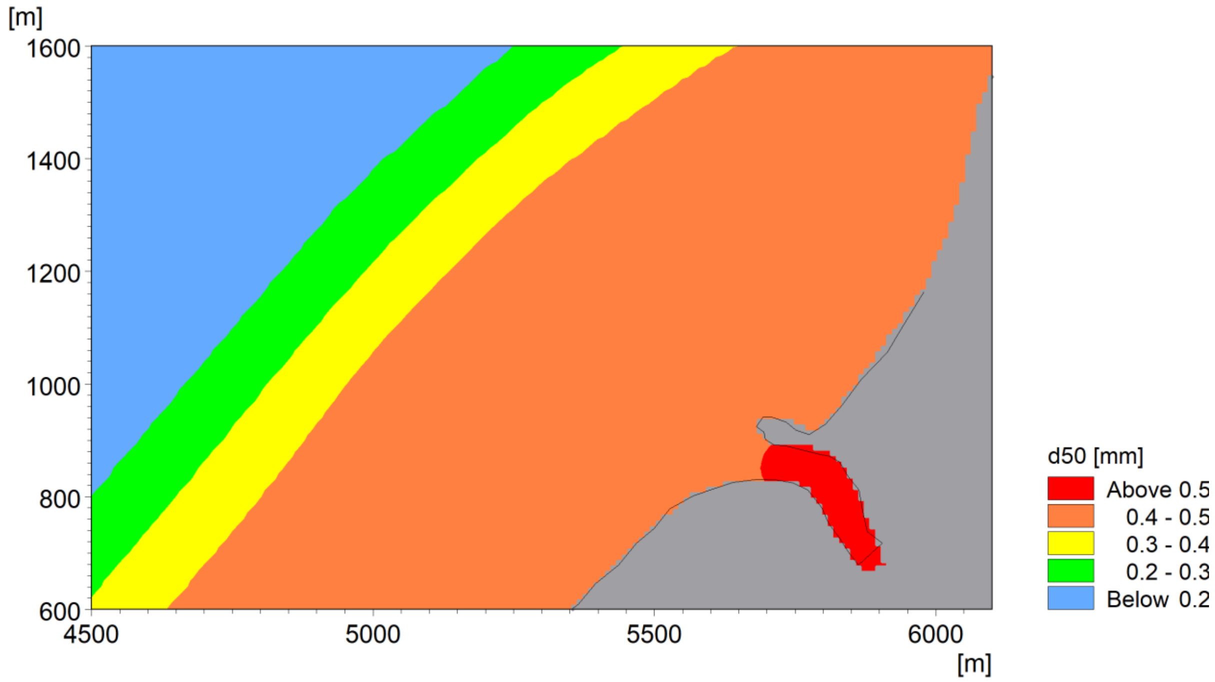


Figure 9-5. Sediment D50 distribution at the ramp area

9.2.6 Simulation Parameters

The key parameters adopted for model runs are presented in Table 9-3.

Table 9-3. Coupled hydrodynamic and sediment transport model key parameters

Parameter	Model set up
Computational timestep	600 seconds (maximum) 0.01 seconds (minimum)
Eddy viscosity	Smagorinsky formulation, constant = 0.4
Bed resistance	Manning number = 32m$^{1/3}$/s
Spatial Resolution (approx): • Open boundaries • Nearshore areas • Near the ramp and the creek	 • 300m • 30 m • 10m
Sediment properties	Spatial D50 shown in Figure 9-5

9.2.7 Model Simulation Scenarios

The following model simulations were carried out:

- The 2014 calibration flood event;
- Sensitivity analysis of:
  - 2014 calibration flood event period without creek discharge to assess the impact ambient wave and tidal conditions have on sediment transport;
  - 2014 calibration flood event with an extended simulation period with ambient wave and tidal conditions.
- Design events: the 1 EY, 1 in 2, 5, 10, 20, 50 and 100 AEP events.

9.3 Results

The results from the sediment transport modelling are presented in the following sections. The following three areas were used to assess net sediment deposition volumes for each of the scenarios, to help understand the distribution of sediment deposition and risks posed to the boat ramp and navigation channel.

- '**Dredged Area'** refers to the fixed area defined the Shire of Exmouth Flood Deposit Survey Drawing 45314TS1-1-0 (Appendix H);
- **'Navigation Channel Area'** refers to the fixed area estimated using the 2015 bathymetric survey data collected on completion of the 2015 dredging, navigation charts and available aerial imagery; and
- '**Total Affected Area'**: refers to the area in the entire model domain which has resulted in a net bed level change. Therefore, the total affected area varies depending on the results from the model simulation scenario.

These areas are plotted (where applicable) as polygons on the figures in purple, orange and black respectively.

9.3.1 2014 Calibration Event

Model calibration was conducted using the hydrograph and sedigraph data developed for the 2014 flood event (Sections 7.5 and 8.4). To calibrate the model, the dredge area was defined using the Shire of Exmouth Flood Deposit Survey Drawing 45314TS1-1-0 (Appendix H) and bed elevation changes predicted by the model used to estimate the volume of material deposited within this dredge area. The volume estimated by the model within the dredge area was then compared with the estimated volume (3,500m^3 to 5,000m^3) of material dredged on site following the 2014 event (Section 2.2).

Figure 9-6 presents the simulated peak current speed during the 2014 event simulation and Figure 9-7 presents the bed level change after simulating the 2014 event.

The bed level change results were used to estimate the net bulk sediment deposition (including volume of water mixing with sediment) within the dredge area, calculated by the average bed level change multiplied by the area (uniform cell size) to get the bulk deposited volume. Net sediment deposition within the total affected area, was also calculated using the bed level change results within the model domain, using the same approach. Figure 9-7 shows the dredge area and the total affected area used to calculate sediment deposition volumes.

The total affected area includes an area of deposition immediately downstream of the Yardie Creek Road boundary. This deposition is due to a reduction in sediment transport capacity immediately downstream of Yardie Creek Road due to the hydraulic conditions predicted by the Mike 21 model. This deposition accounts for approximately 25% of the creek sediment load derived from sedigraphs (Section 8.4) for the 2014 event, and approximately 4% to 20% of the creek sediment load for 1 EY to in 1 in 100 AEP, respectively.

The resulting deposited sediment volumes within the dredge area and the total affected area, are compared in Table 9-4.

Table 9-4. Net deposited sediment volumes for 2014 calibration event

Event	Dredge Area (m^3)	Navigation Channel adjacent the Boat Ramp (m^3)	Total Affected Area (m^3)
2014 Calibration Event	4,260	440	4,150

The model predicts 4,260 m^3 of sediment deposited within the approximate dredge area during the 2014 event. This volume is within the 3,500 m^3 to 5,000 m^3 range of deposited material estimated from the 2014 dredging (Section 2.2). The results suggest the model is producing representative predictions of transported sediment volumes and is therefore considered suitable for modelling the range of design AEP flood events.

The model predicts 4,150 m^3 of sediment deposited within the total affected area. This volume is less than the dredge area volume, due to the large amount of scour that occurs at the mouth of the creek which balances out the offshore deposition near the boat ramp area.

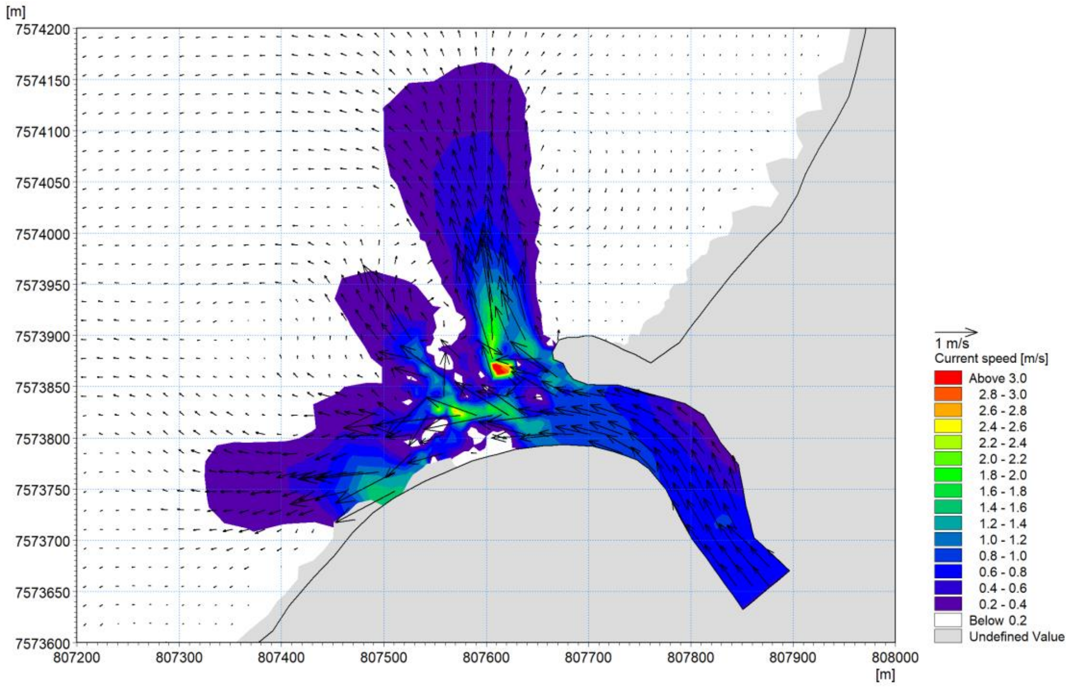


Figure 9-6. Snap shot of peak current speed during 2014 event simulation

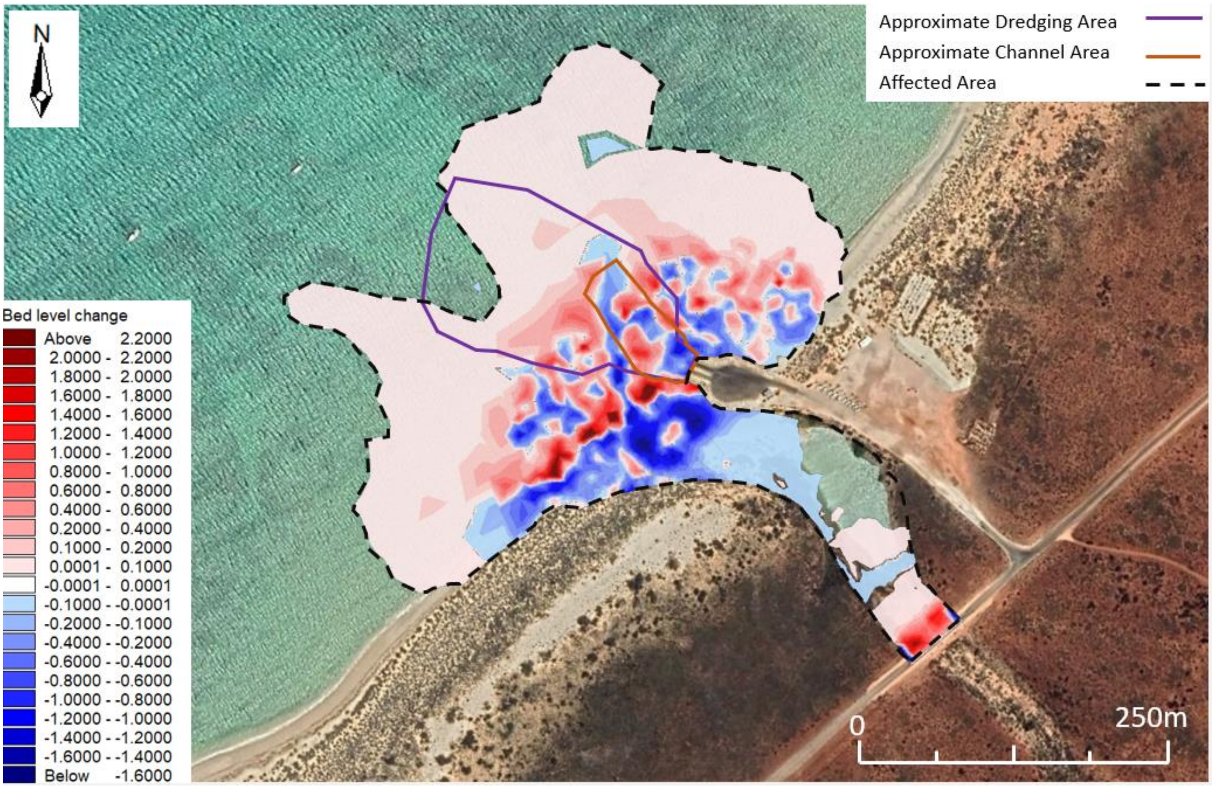


Figure 9-7. Bed level change (m) after 2014 event simulation (dredge area defined using Drawing 45314TS1-1-0 (Appendix H)

9.3.2 Sensitivity Analysis

9.3.2.1 Ambient Conditions (No Creek discharge)

Sensitivity analysis was conducted for the 2014 rainfall event period (36 hours) to assess the effect ambient wave and tidal conditions have on sediment transport. The sediment transport model was used to simulate ambient wave conditions by applying wave boundary conditions from Advisian's existing Indian Ocean Wave model and wind inputs recorded at the BoM weather station at Learmonth Airport (5007). Figure 9-8 presents the bed level change on completion of the same duration as 2014 event (36 hours) simulation period. The results suggest ambient wave and tidal conditions result in minor localised morphological changes and no significant bed level change at the boat ramp when compared to the results of sediment transport modelling with creek inflows (Figure 9-7).

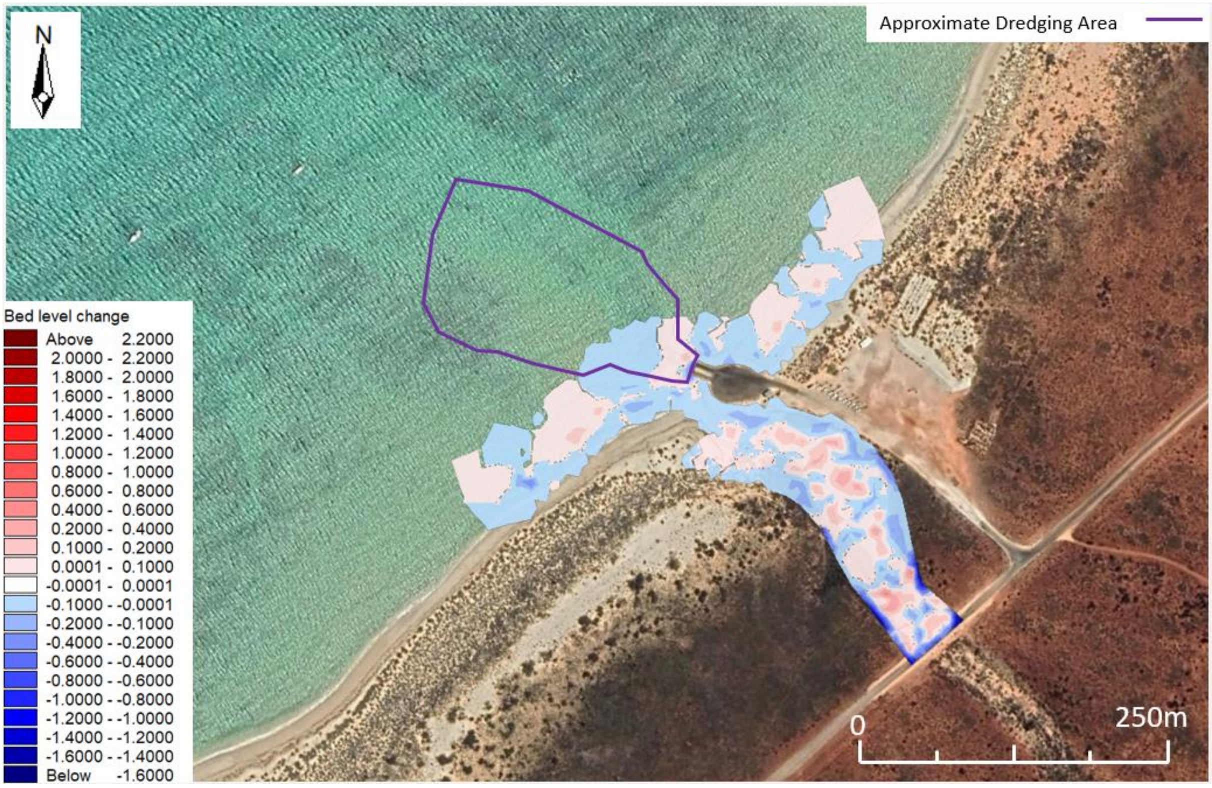


Figure 9-8. Bed level change (m) during 2014 event period without including the creek discharge

During the period of the sensitivity analysis, the peak wind speed is up to 10.8 m/s which is estimated to generate wind-driven currents of around 0.16 m/s. Compared to the ~2.0 m/s peak currents (Figure Figure 9-6) generated by the creek flow, therefore the wind-driven currents are expected to generate relatively less re-suspended sediment compared with the creek flows. If we were to assess long term (eg. 12-month period) sediment transport under the wind-driven current conditions (only), the cumulative volume is expected to be higher even if the current is relatively low. As the focus of this study is on the sediment transport associated with creek flow events (only), which occur over a duration less than 1 day, the sediment transport due to the wind-driven currents is considered negligible and was therefore omitted from simulations.

9.3.2.2 *Extending simulation time*

An additional sensitivity simulation was conducted by extending the simulation period for the 2014 calibration event for an additional 1.5 days, when flow in the creek had ceased. This run tests the effect of ambient wave and tidal condition on sediment transport and deposition immediately after the 2014 flood event. The resulting bed elevations changes are presented Figure 9-9.

Comparison of Figure 9-9 and Figure 9-7 suggests ambient wave and tidal conditions have negligible effect on bed elevations over the one and half day period after the flood event.

Under the ambient tidal current and wave condition, it has been estimated that net northerly transport in the study area could be in the order of 5,000 m^3/year (MP Rogers and Associates, 2018). This estimate equates to approximately 14 m^3/day, so given the short duration of the 2014 calibration simulation, the volume of sediment transport under the ambient tidal current and wave is limited. The offshore and longshore sediment transport under ambient and extreme tidal and wave conditions was not in the scope of this study so has not been considered.

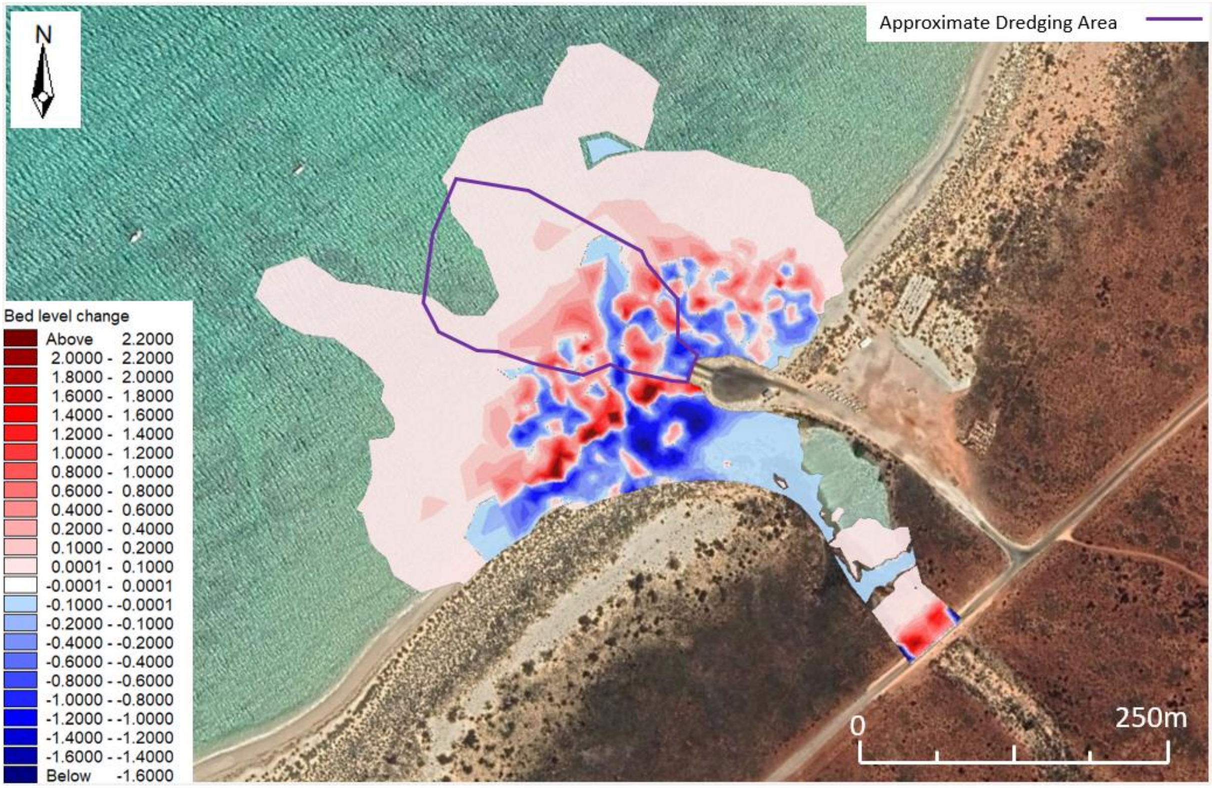


Figure 9-9. Bed level change (m) 1.5days after 2014 event simulation (dredge area indicated)

9.3.3 Design Event Results

The 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP flood events were simulated in the Mike 21 model using the flow hydrographs and sedigraphs presented in Section 6.3.4 and Section 8.4 respectively. Simulations adopted mean seawater level conditions and excluded the effects of wind/wave forcing, as the sensitivity analysis in Section 9.3.2, suggests it has a minor effect on model results.

9.3.3.1 Spatial Peak Currents

Figure 9-10 to Figure 9-16 present the peak currents for the range of design events. Table 9-5 summarises the current conditions for the design AEP events. Analysis of the current conditions results suggest the following:

- The maximum currents are between 2.2 m/s and 6.0 m/s for the 1 EY to 1 in 100 AEP event;
- The 1 in 100 AEP has the highest percentage extent of currents velocity in excess of 1m/s at 17.7%; and
- The 1 in 5 AEP maximum currents are less than the 1 EY and 1 in 2 AEP event maximum currents. This is likely due to spreading of flow over a wider area within the creek vicinity resulting lower current speeds associated with the deeper water in 1 in 5 AEP flows compared to 1 EY and 1 in 2 AEP flows.

Table 9-5. Current conditions for design AEP events

Event	1 EY	1 in 2 AEP	1 in 5 AEP	1 in 10 AEP	1 in 20 AEP	1 in 50 AEP	1 in 100 AEP
Maximum currents (m/s)	3.8	3.1	2.2	5.4	4.9	6.0	3.8
Percentage (%) exceeding 1m/s over Total Affected Area	0.8	1.7	0.9	2.4	10.5	4.9	17.7

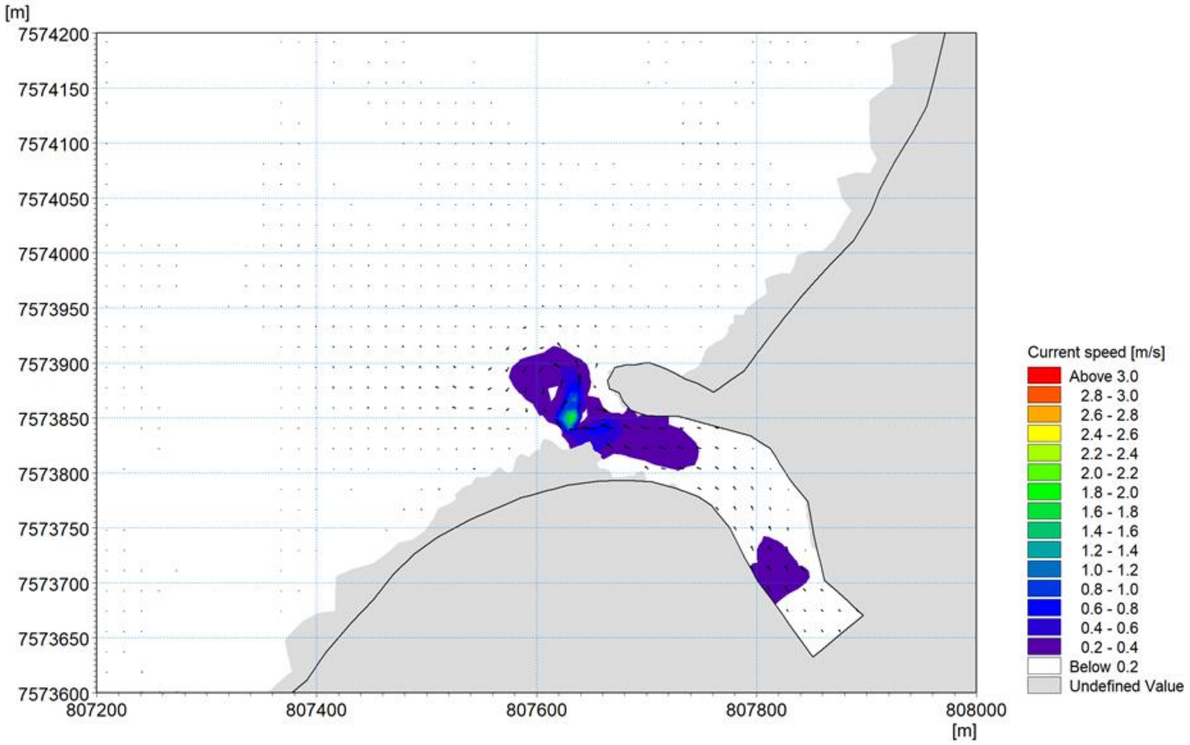


Figure 9-10. 1 EY peak current speed (m/s)

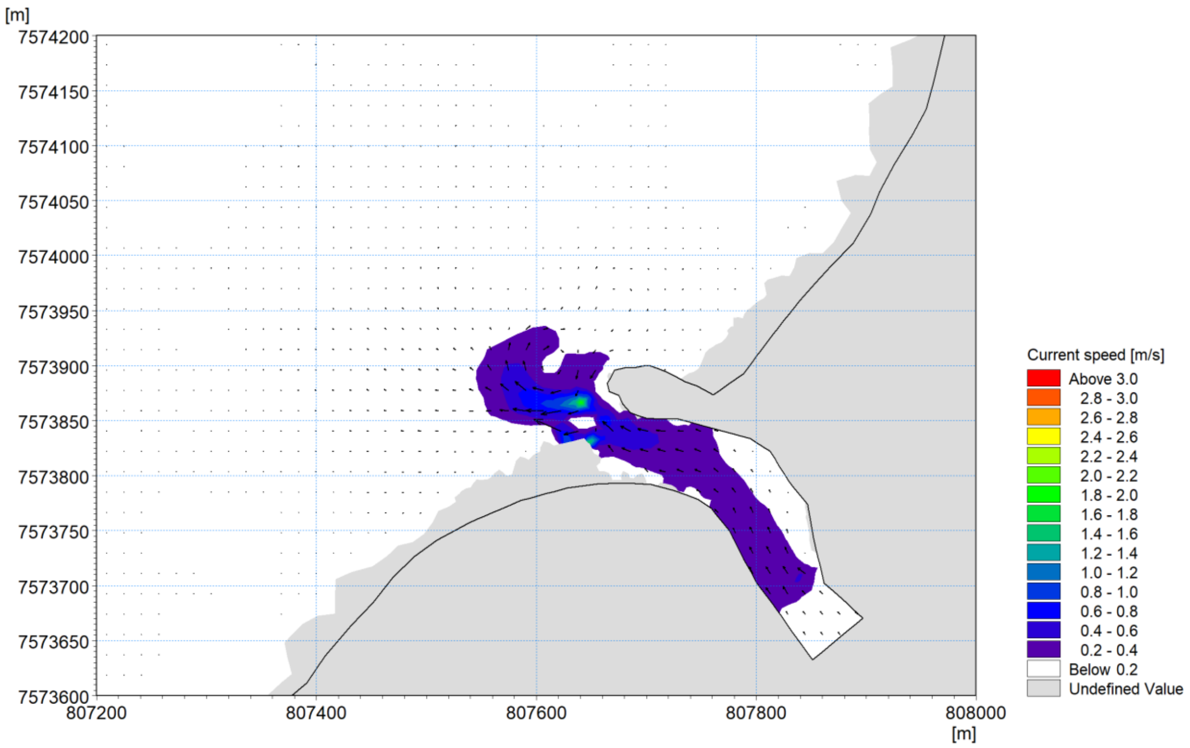


Figure 9-11. 1 in 2 AEP peak current speed (m/s)

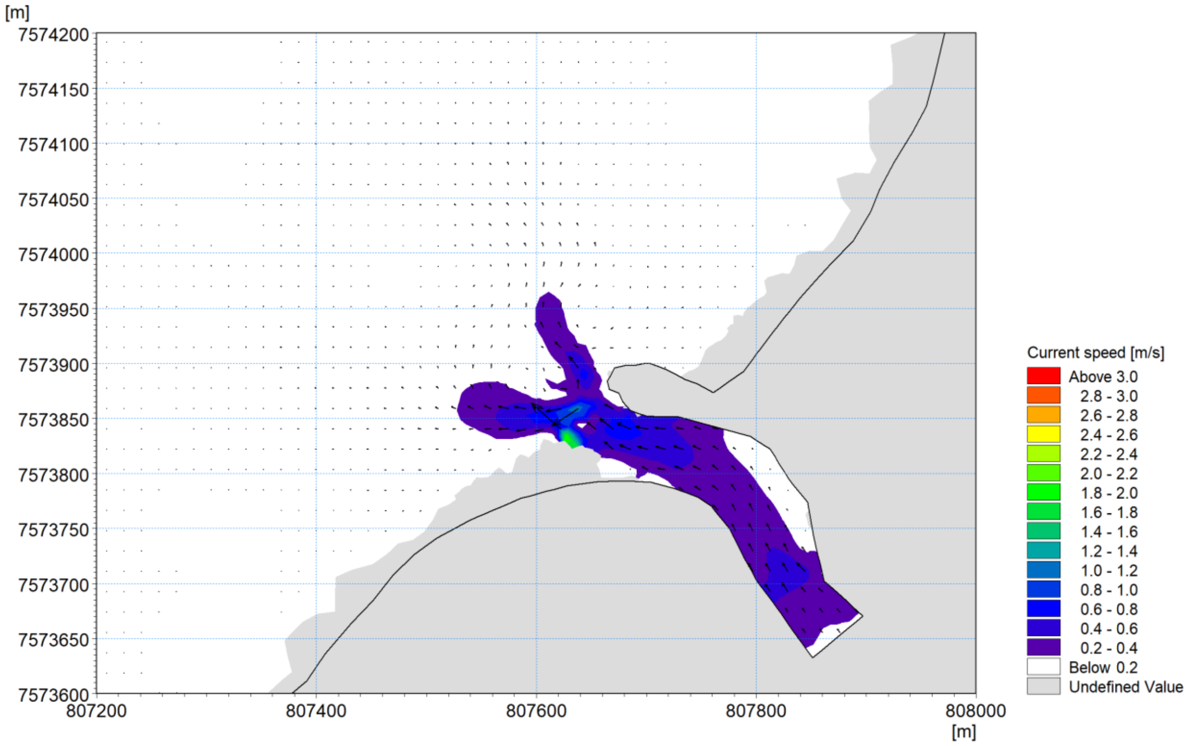


Figure 9-12. 1 in 5 AEP peak current speed (m/s)

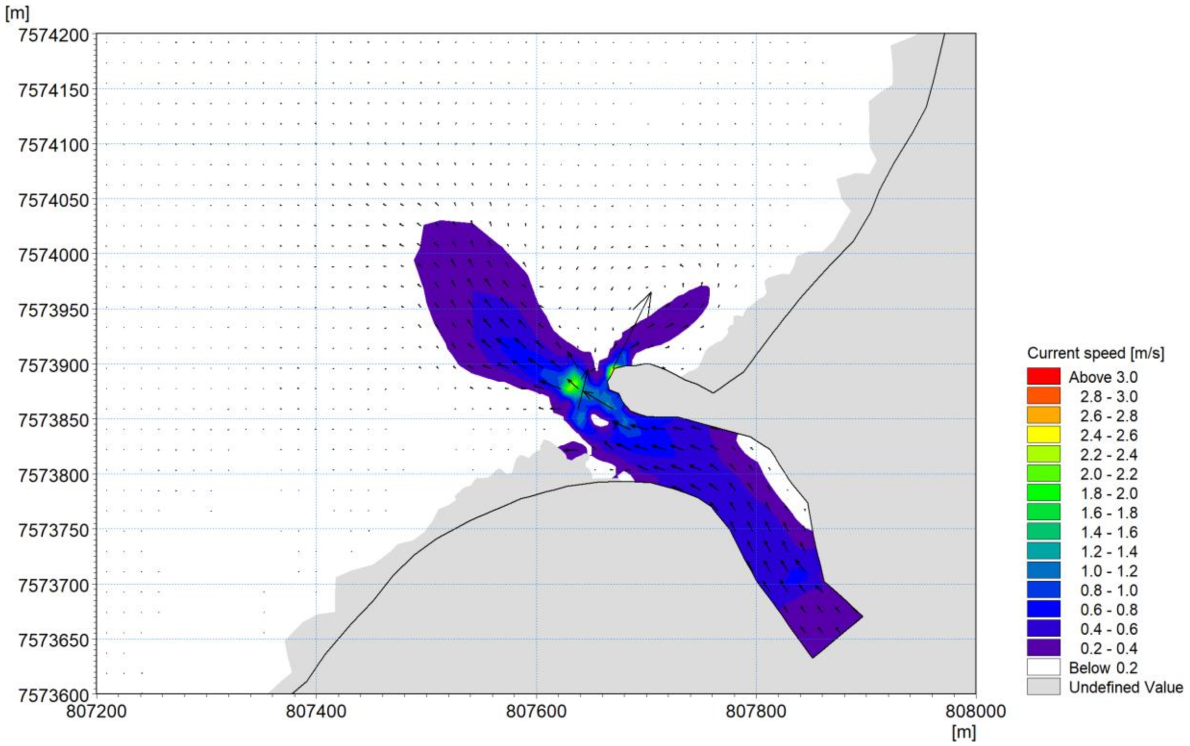


Figure 9-13. 1 in 10 AEP peak current speed (m/s)

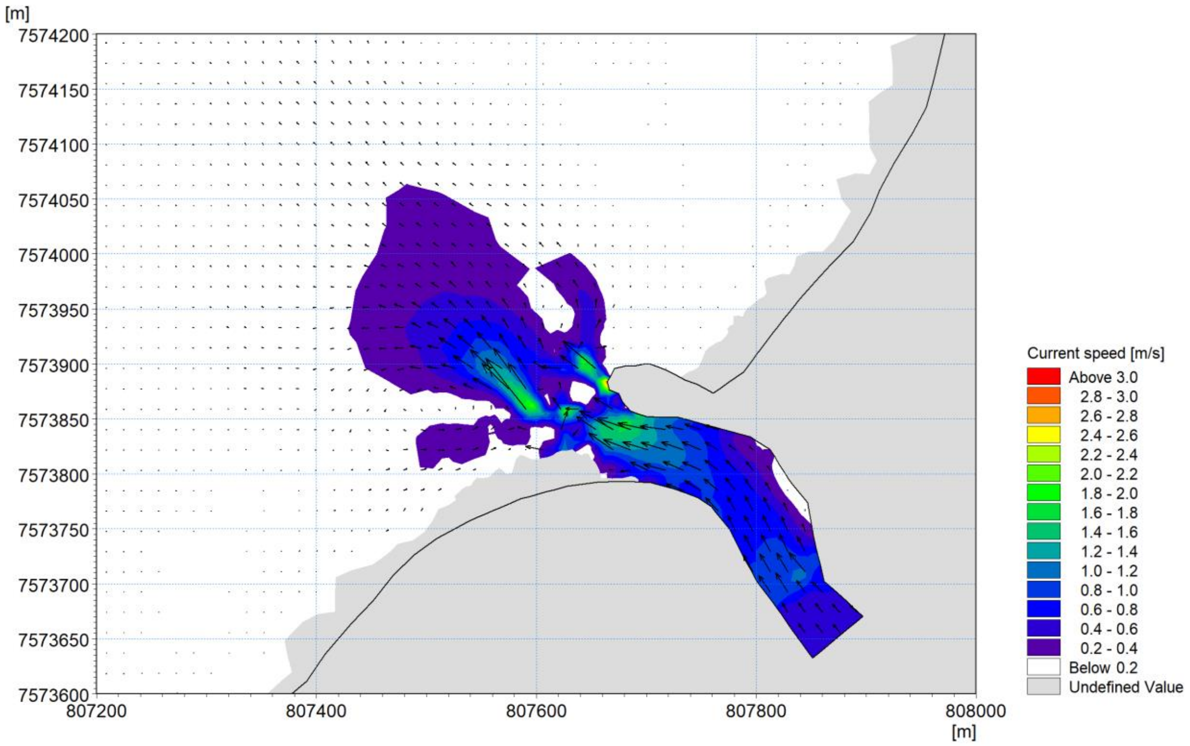


Figure 9-14. 1 in 20 AEP peak current speed (m/s)

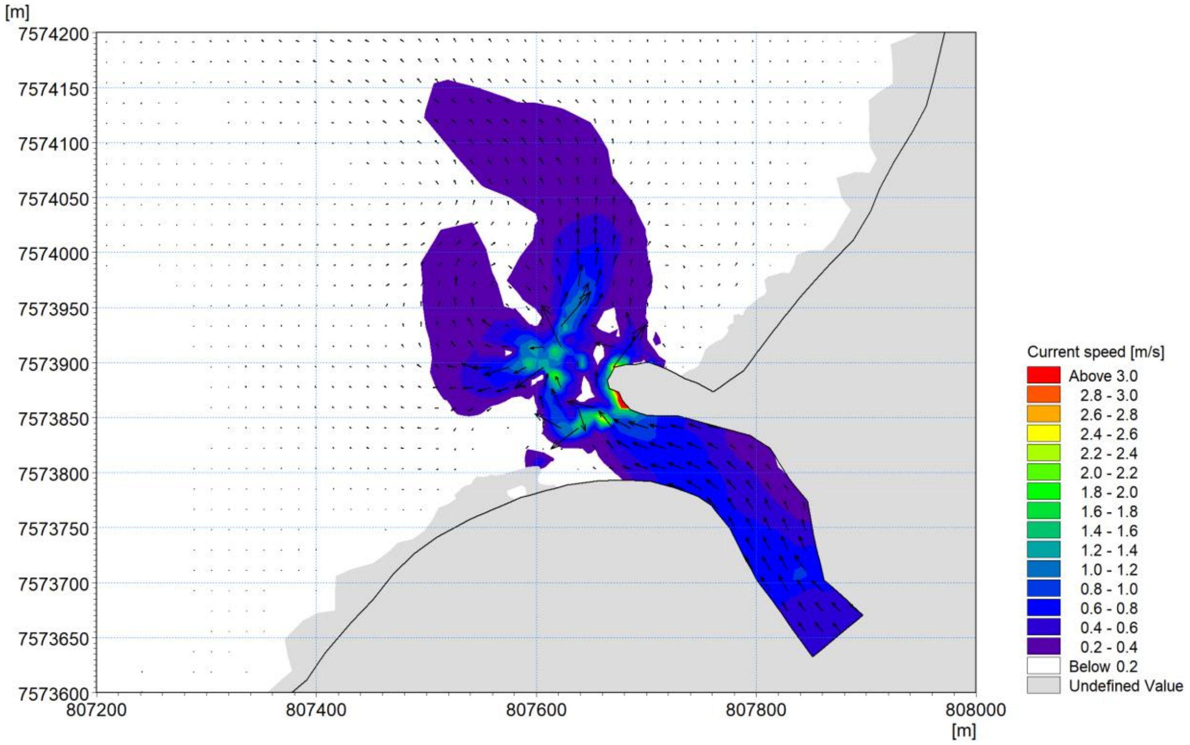


Figure 9-15. 1 in 50 AEP peak current speed (m/s)

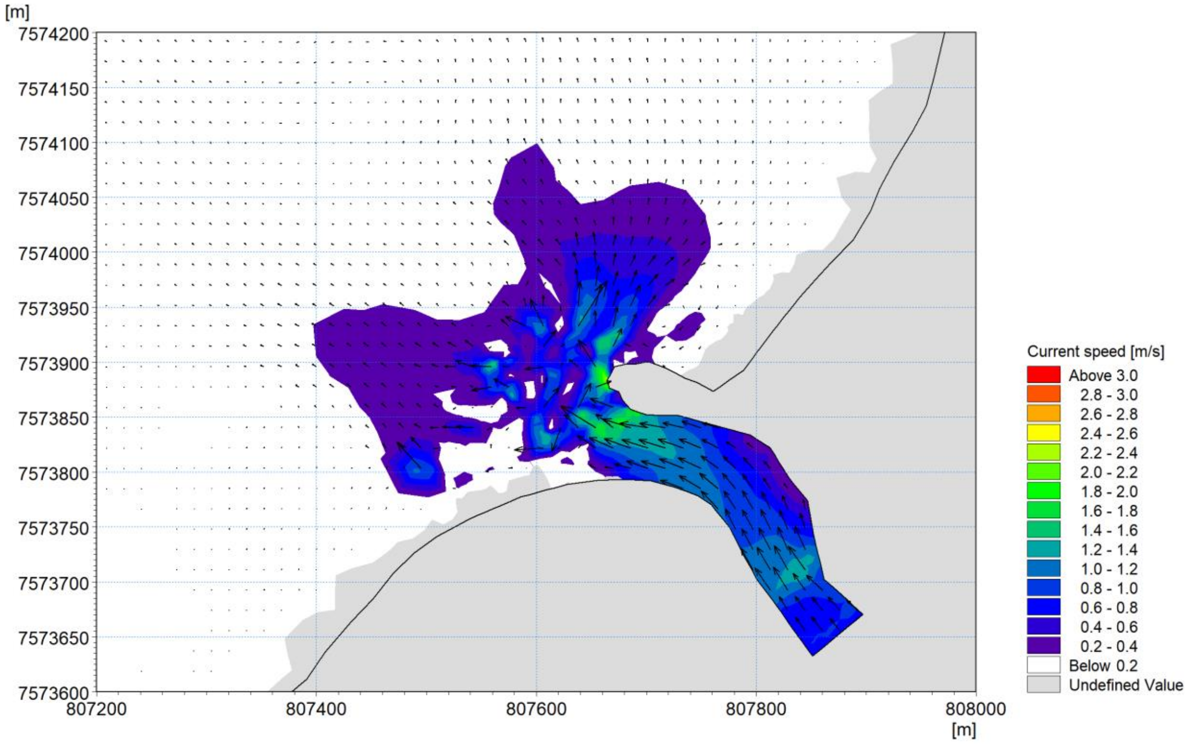


Figure 9-16. 1 in 100 AEP peak current speed (m/s)

9.3.3.2 Bed Level Change

Figure 9-17 to Figure 9-23 present the bed level changes for each of the design events. The results suggest the following:

- ***All design events:*** erosion of sediment is observed south of boat ramp where the sand bar and beach are washed from the mouth of the creek, out into the ocean.
- ***1 EY and 1 in 2 AEP flood events:*** The results presented in Figure 9-17 and Figure 9-18 suggest the extent of scour and erosion is limited to a localised area on the beach, where floodwater breaks out through the sand bar into the ocean. Similarly, the extent of deposition is limited to a small area in proximity to and immediately south of the boat ramp.
- ***1 in 5 to 1 in 100 AEP flood events:*** The results presented in Figure 9-19 to Figure 9-23 suggest the extent of scour and erosion at the mouth of the creek and beach and deposition in the ocean is progressively larger with increasing flow. The deposition extends out across the boat ramp and navigation channel.

Figure 9-17. 1 EY bed level change (m)

Figure 9-18. 1 in 2 AEP bed level change (m)

Figure 9-19. 1 in 5 AEP bed level change (m)

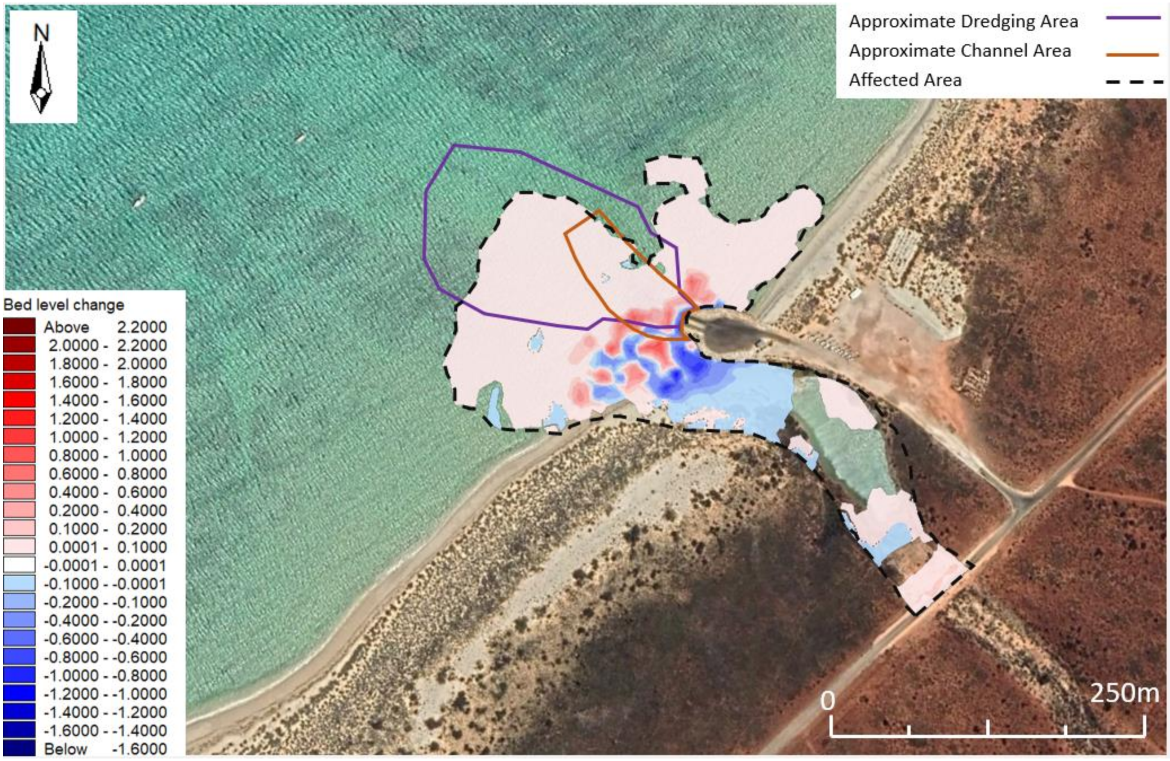


Figure 9-20. 1 in 10 AEP bed level change (m)

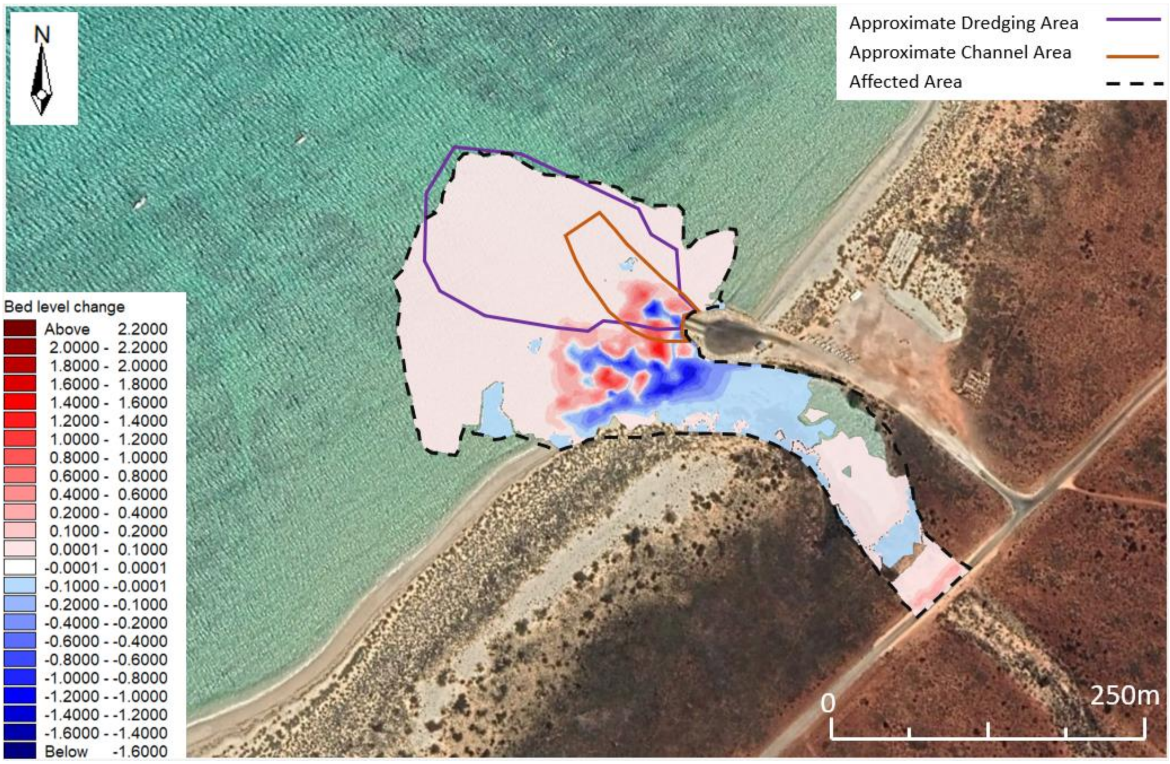


Figure 9-21. 1 in 20 AEP bed level change (m)

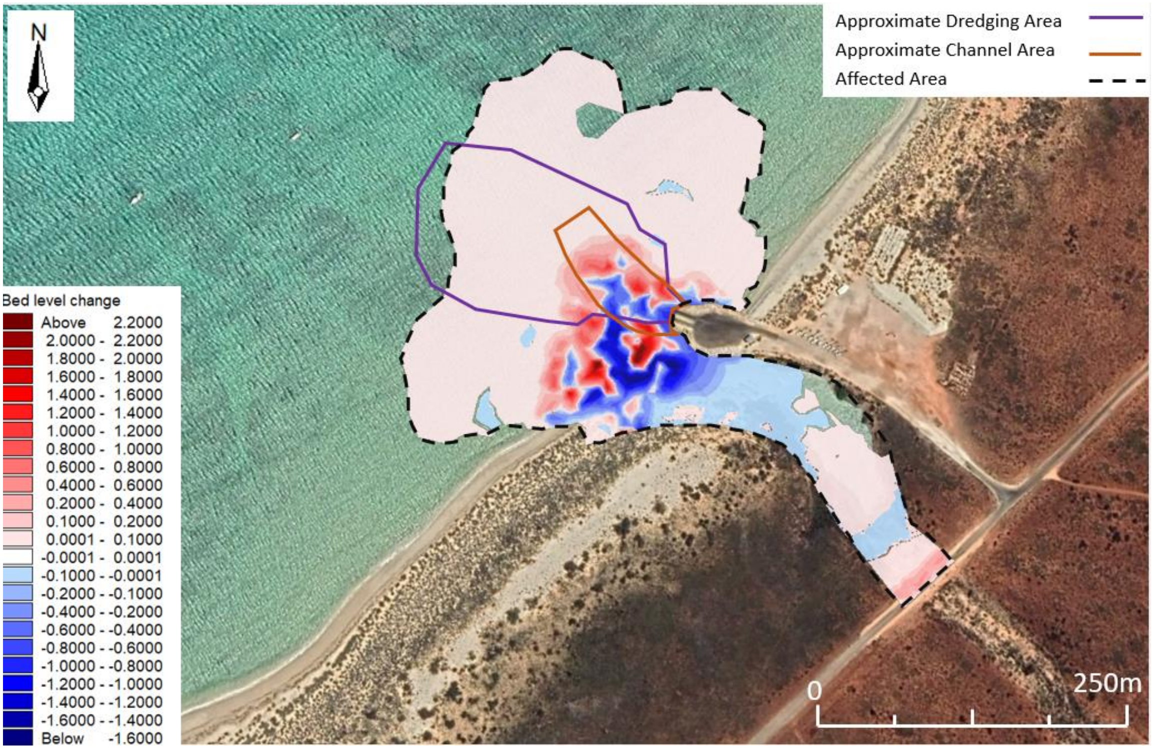


Figure 9-22. 1 in 50 AEP bed level change (m)

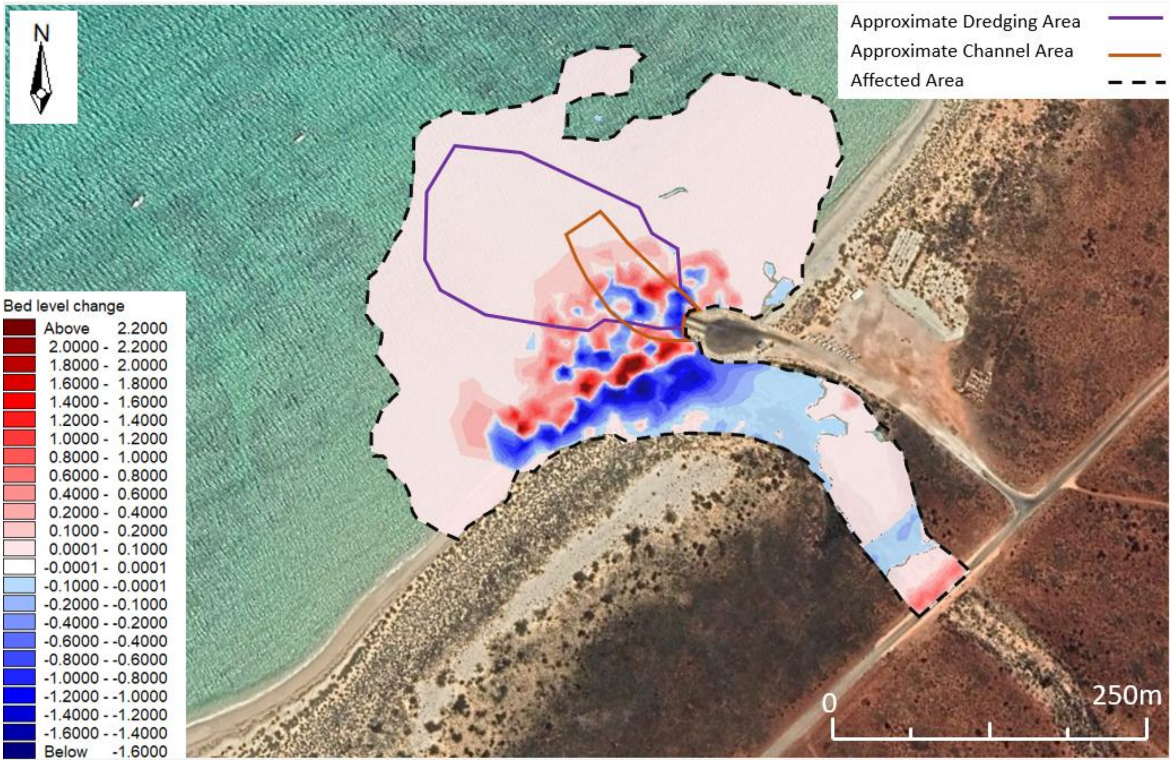


Figure 9-23. 1 in 100 AEP bed level change (m)

The net sediment deposition volumes estimated within the dredge area, navigation channel area and total affected area are compared in Table 9-6. The results suggest:

- The volume of deposited sediment increases with the size of the flood event for all areas. The only exception is the navigation channel area adjacent the boat ramp, where the deposited volume reduces slightly from the 1 in 50 to the 1 in 100 AEP due to offshore propagation of scour and deposition.
- For the 1 EY event, sediments are mostly deposited to the south of the ramp and the sediments deposited within the dredge area and the channel area are lower compared to the total deposited volume.
- For the 1 in 2 AEP to 1 in 50 AEP events, sediment deposition in the channel area and the dredge area are higher than the total deposited volume. This is because of the erosion occurred at the coastline at the creek mouth.
- For the 1 in 100 AEP event, significant erosion is observed at the coastline to the south of the ramp and deposition offshore. The scour propagates further offshore in proximity to the boat ramp.

The results of modelling were used to generate representative arcs defining the potential extent of sediment deposition for the 1 EY to 1 in 100 AEP events. The arcs presented in Figure 9-24, can be used to evaluate potential risks associated with alternative boat ramp upgrade options.

Table 9-6. Deposited bulk sediment volumes for design runs

Event	Dredge Area (m^3)	Navigation Channel adjacent the Boat Ramp (m^3)	Total Affected Area (m^3)
1 EY	8	25	70
1 in 2 AEP	33	78	78
1 in 5 AEP	250	245	145
1 in 10 AEP	308	323	345
1 in 20 AEP	665	735	610
1 in 50 AEP	1283	795	750
1 in 100 AEP	1378	468	1655

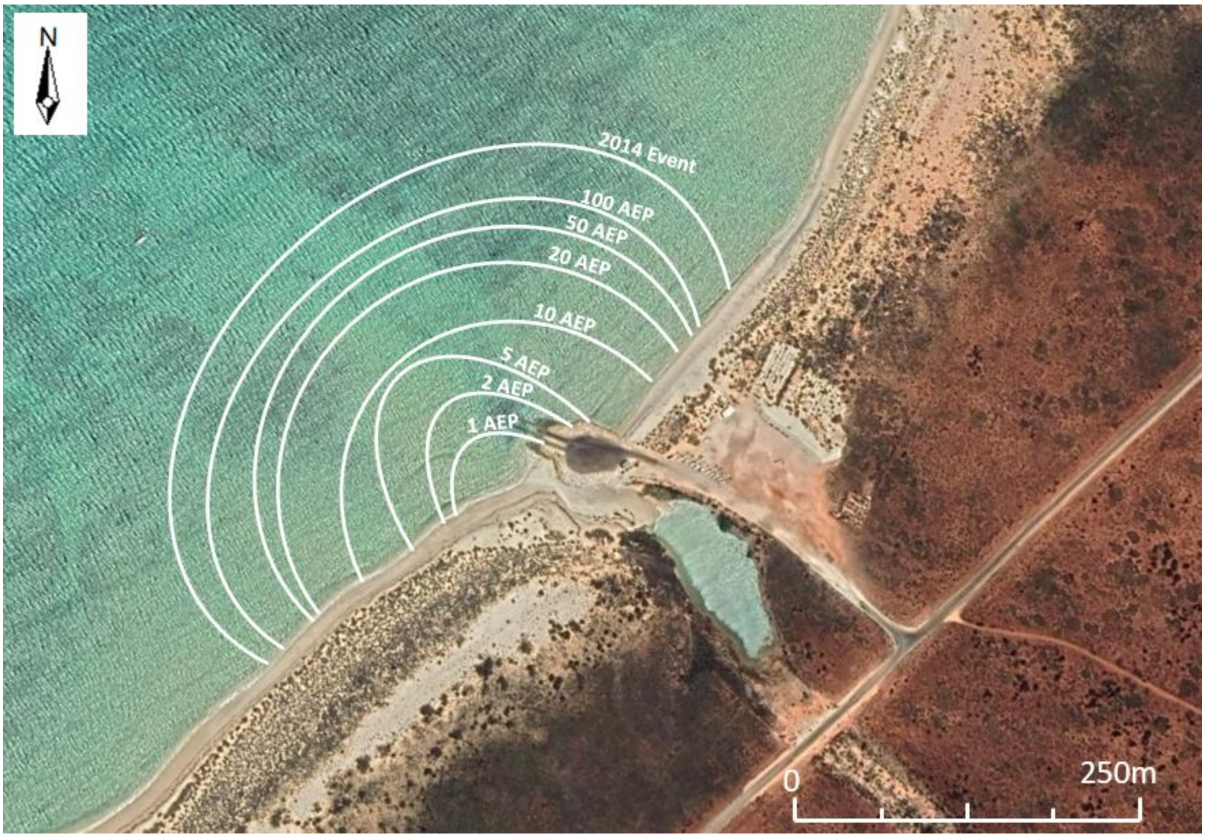


Figure 9-24. Representative arcs defining the potential extent of sediment deposition for the 1 EY to 1 in 100 AEP events and 2014 Calibration Event

9.4 Model Limitations

The following limitations are associated with sediment transport modelling:

- There are uncertainties associated with sediment transport modelling due to the complexity of the processes and various assumptions made when developing sedigraphs and setting up the sediment transport model;
- The sediment map generated for the model are based on few surface sediment samples and is therefore an approximate representation of sediment distribution within the model area;
- The sediment deposition estimates are based on the change in bed level after the model simulation. The bathymetry used in the 2014 calibration model is based on 2010 survey, so may not be an accurate representation of the bathymetry at the time of the 2014 event; and
- The dredging campaign was carried out after approximately one year after the 2014 event, and coastal processes would have also contributed sediment transport over that period. Therefore, the dredged volumes are considered an approximate estimate of the volume of material transported in the 2014 event.

Therefore, the sediment deposition estimates presented in this report should be considered approximate estimates only and the results are best used to make relative comparisons of scenarios.

10 Conclusions

The key findings from the Tantabiddi Creek Hydrology and Geomorphology study are summarised below:

- The location of the boat ramp, near Exmouth and adjacent to Tantabiddi Creek means it is subject to seasonal flooding, sediment transport and deposition during significant rainfall events. The more extreme flood events are often associated with tropical cyclones and ex-tropical cyclones between November and April;
- The Tantabiddi Creek catchment area is 27km^2 extending east into the Cape Range National Park. The catchment has a critical storm duration of between 2 and 6 hours, so responds rapidly to extreme rainfall, resulting in flash flooding. This is typical of catchments in the Cape Range area;
- Rainfall runoff and hydraulic modelling completed for Tantabiddi Creek suggests the peak flow in the 1 in 100 AEP flood event is 146 m^3/s. The largest rainfall event recorded since the boat ramp upgrade in 2012-2013, was the 27th April 2014 event, where 237.7mm was recorded at Ningaloo Reef rainfall station, approximately 14km south of the boat ramp. Hydrological modelling of the 2014 rainfall event suggests it resulted in a peak flow of 168 m^3/s. Comparison with the 1 in 100 AEP peak flow suggests the 2014 event was greater than a 1 in 100 AEP event.
- Sediment transport modelling of the 2014 flood event, using MIKE21 software and sedigraphs developed from geomorphological assessment of Tantabiddi Creek, suggests 4,260 m^3 of sediment and alluvial material was transported and deposited at the boat ramp and navigation channel. Dredging activities conducted by the Shire of Exmouth between 12th June 2015 and 22nd September 2015, are reported to have removed between 3,500m^3 and 5,000m^3 of material, which validates the sediment transport model results (URS (2016) and Appendix C).
- Tantabiddi Creek flood flows and sediment transport in the 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP events were simulated in the MIKE21 model and the results used to quantify bed elevations changes and associated volumes of material deposited in the boat ramp area. The results indicate the following:
  - The volume of deposited sediment and the extent of deposition offshore increases with the size of the flood event. The transported sediment is a combination of creek alluvium and beach sand.
  - For the 1 EY event, 1 in 2 and 1 in 5 AEP events, sediment is deposited in proximity to and south of the boat ramp. Although the volumes of material deposited in these events are lower (up to 250m^3) when compared with larger less frequent events, the accumulation of sediment is expected to impact boat ramp operations and maintenance.
  - For events greater than the 1 in 5 AEP, sediment deposition in the channel area and the dredge area can be significant. Modelling suggests deposition in the boat ramp area of between 300 m^3 and 1,378 m^3 for the 1 in 10 and 1 in 100 AEP flood events respectively.
  - Sediment transport modelling suggests the maximum extent of 1 in 100 AEP deposition impact under current conditions, is approximately 300 m from the existing boat ramp. Arcs showing the estimated extent of sediment deposition for the 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP events as well as the 2014 event, are shown in Figure 9-24.

- The extent, volume and frequency of deposition should be considered when evaluating options for boat ramp upgrades and maintenance.

11 Recommendations

11.1 Alternative Boat Ramp Facility Upgrade Options

It is understood that the DoT is exploring alternative boat ramp upgrade options. The results of sediment transport modelling presented in this report have been used to present "Pros and Cons" associated with alternative boat ramp facility upgrade options and locations and associated recommendations. For the recommendations, a distinction can be made between 3 areas depicted in Figure 11-1 and described as follows:

- ***Area A:*** Modifications to the existing facility or development of a new facility within the modelled extent of Tantabiddi Creek sediment deposition
- ***Area B:*** Development of a new facility along the coastline southwest of the creek outlet (outside the modelled area of influence).
- ***Area C:*** Development of a new facility along the coastline northeast of the creek outlet (outside the modelled area of influence).

The Pros and Cons of each area are described below, along with the "do nothing" option.

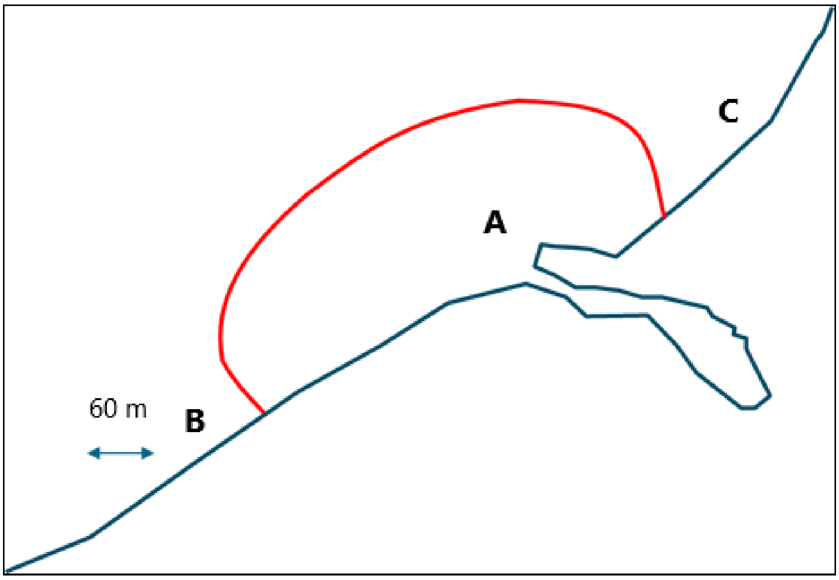


Figure 11-1. Three alternative boat ramp development areas

11.1.1 Do Nothing

Sediment transport modelling of Tantabiddi Creek suggests:

- For the 1 EY event, 1 in 2 and 1 in 5 AEP events, sediment is deposited in proximity to and south of the boat ramp. Although the volumes of material deposited in these events are lower (up to 250m^3) when compared with larger less frequent events, the accumulation of sediment is expected to impact boat ramp operations and maintenance.

- For events greater than the 1 in 5 AEP, sediment deposition in the channel area and the dredge area can be significant. Modelling suggests deposition in the boat ramp area of between 300 and 1,378 m^3 for the 1 in 10 and 1 in 100 AEP flood events respectively.

This sediment transport is in addition to the 5,000 m^3/year of estimated net sediment transport from longshore drift (MP Rogers and Associates, 2018). Therefore, regular routine dredging is expected to be required to remove transported sediment and maintain navigable depths. Besides regular dredging, additional dredging may be required after more extreme events.

11.1.2 Area A: Modifications and upgrade of existing facility

The current facility is located on the northeast side of the creek within the modelled extent of Tantabiddi Creek sediment deposition. As the facility protrudes the coastline, the northeast directed net longshore sediment transport will tend to deposit at the southwest side in front of the creek. When the creek discharges, this accumulated sediment is expected to end up at the boat ramp and dredged navigation areas.

Modifying the existing location, keeping part of the infrastructure can have cost benefits when compared to alternative boat ramp locations. For instance, it will be beneficial if the existing entrance channel can be used, and this may also minimise environmental impacts.

It is however recommended that some of the following boat ramp upgrades are considered:

- Create a barrier between the creek and the facility, to redirect flood flows and minimise sediment transport from the creek ending up in dredged areas. This can be achieved by constructing a training wall to direct creek flows to the northeast away from a new boat ramp constructed on the southwest side of the creek outlet. The training wall could also be used as part of the boat ramp construction. Training walls can have a significant influence on creek and coastal geomorphology, hydraulic and sediment transport behaviour so would require detailed studies. It should also be noted that a curved training wall can result in scouring in the outer bend of the outlet, which should be taken into account in the design of the foundation.
- As with all areas, the net longshore sediment transport directed towards the northeast will need to be taken into account in the development of any options. It could be therefore be considered to remove any obstacles to the natural longshore sediment transport and construct a facility further offshore, which could be achieved by a bridge or a causeway structure with culverts. This is likely to reduce the frequency and volume of sediment deposition in the navigation channel during flood events.

11.1.3 Area B: Development southwest of the creek outlet

Sediment transport modelling suggests the maximum extent of 1 in 100 AEP deposition impact from Tantabiddi Creek under current conditions, is approximately 300 m from the existing boat ramp (Figure 9-24).

A new development outside of this area of influence on the southern side of the creek is likely to be unaffected by sediment loads from the creek. Relocation of the boat ramp to this area would require additional dredging to create a navigation channel. It is recommended that the alignment of the navigation channel is optimised using the arcs defining the estimated extent of sediment deposition for the 1 EY and 1 in 2, 5, 10, 20, 50 and 100 AEP events (Figure 9-24) to assess magnitude and frequency of deposition to determine maintenance costs versus the cost of dredging the channel.

Repositioning of the boat ramp to the south and extending it further west into the ocean (further west than the current boat ramp) is likely to reduce the longshore (north-easterly) transport of deposited creek sediment. This may influence the depth and extent of the alluvial fan long term with potential repercussions for sediment shoaling near the facility, if an unabated alluvial fan grows westward.

If the facility is placed on the south side of the creek, then the northern access to the facility may be cut off by flooding in Tantabiddi Creek. However, given the flashy nature of flooding in this region, the duration of impact is expected to be minor. In addition, there are several other similar floodway crossings on Yardie Creek Road which would have similar impacts during flooding conditions.

If a facility south of the creek is preferred, a review of the Yardie Creek Road floodway crossing may be required with possible upgrade of drainage structures to increase serviceability and prevent excessive flooding/debris in the area.

It should be noted that if a new navigational channel will need to be dredged this will have environmental impacts.

11.1.4 Area C: Development northeast of the creek outlet

Given the net longshore sediment transport towards the northeast, sediment deposited by creek flows from will end up further along the coast over time, unless it is captured. Therefore, any development on the northern side of the existing boat ramp will need to take into account the additional sediment load coming from the creek, which may deposit in dredged areas such as entrance channels and impact on boat ramp operations. This frequency and magnitude of impact (volume of sediment) reduces with increasing distance from the creek.

Similar to the other options, if a new navigational channel will need to be dredged this will have environmental impacts.

11.2 Future Development Works

The following tasks are recommended for future development stages, such as option selection study, engineering concept, detailed design and environmental impact assessments:

- Collect further offshore, nearshore and beach sand samples to provide local spatial sand characteristics.
- Carry out a bathymetric survey to achieve a number of cross shore profiles, ideally before and after a severe cyclone event.
- Sediment transport modelling of the preferred boat ramp option/s. Refine the existing 2D sediment transport model, for instance, to extend the existing model domain further to south to accommodate the potential option site and longshore sediment transport area. Calibration and validation of the local wave and hydrodynamic model, using DoT monitoring data collected at the site.
- Perform a shoreline evolution study to confirm the longshore sediment transport rate under both long-term ambient (say one year) as well as extreme wave, current and wind conditions. The relevant cross profile changes under these conditions should also be assessed. Previous longshore sediment transport estimates by MP Rogers and Associates (2018) suggest

5,000m^3/yr. The recommended shoreline evolution study should be used to confirm the transport rates and predict the longshore sediment transport volumes under extreme conditions.

- Conduct joint probability hydrodynamic modelling assessments for extreme marine events (wave, current, wind) and creek discharge events to test model sensitivity and associated sediment transport impacts for the proposed boat ramp option/s.
- Assess the proposed mitigation options for both creek sand load and marine sediment transport, using the developed coupled 2D sediment transport and 1D longshore sediment transport model. This will provide more detail in sediment transport pattern for both longshore, offshore as well spreading sediment due to the creek/river load, especially to predict such pattern changes for the alternative boat ramp development options under long-term and extreme events for both marine and creek dominated conditions.

If the boat ramp is to be moved and the creek mouth rehabilitated, then it is recommended that the following work is completed to inform the rehabilitation design:

- Sourcing of additional historical aerial imagery at the site, prior to boat ramp development, to quantify historical changes to creek mouth morphology.
- Geological/geotechnical mapping and conceptualization of creek mouth.
- Further geomorphological assessment of mouth to inform rehabilitation design, including an analysis of the potential impacts from altered nearshore hydrodynamics.
- Hydrogeological and aquatic ecological assessments to inform the design to minimise environmental impacts.

For the proposed boat ramp development options:

- Use the existing 2D TUFLOW model to assess flood risk to the boat ramp facility and recommend stormwater drainage management measures to maintain serviceability of the facility up to the 1 in 100 AEP flood event. This includes consideration of floodway access via Yardie Creek Road and potential long-term ponding of floodwater behind sand dunes in more significant flood events.

12 Addendum: Surface Water Logger Data

The water level logger installed in the permanent pool located at the mouth of Tantabiddi Creek in March 2020, was downloaded in August 2020 towards the end of the project.

Analysis of rainfall data collected over the that period suggested that there was one significant rainfall event on the 24th May which had the potential to trigger a streamflow response in Tantabiddi Creek.

Analysis of nearby rainfall stations suggested the following rainfall recorded in the May event:

- Learmonth Airport: 60mm in 6 hours: equating to a 1 in 2 AEP rainfall event;
- Exmouth Town: 52mm in 6 hours: equating to a 1 in 5 AEP rainfall event; and
- Ningaloo Reef: 35mm in 6 hours: equating to a 1 EY rainfall event.

The Ningaloo Reef weather station is the closest to the boat ramp site and associated Tantabiddi Creek catchment and is therefore considered the most representative rainfall for this catchment.

The water level logger data is plotted along with DoT tide levels recorded at Exmouth in Figure 12-1 and show water levels in the pool fluctuating in response to tidal conditions. The logger did not record any significant change in water level in the pool during the 24th May rainfall event. This is evident from the consistent standing water level readings at low tide between peaks. There the results suggest there was no significant catchment response to rainfall in Tantabiddi Creek.

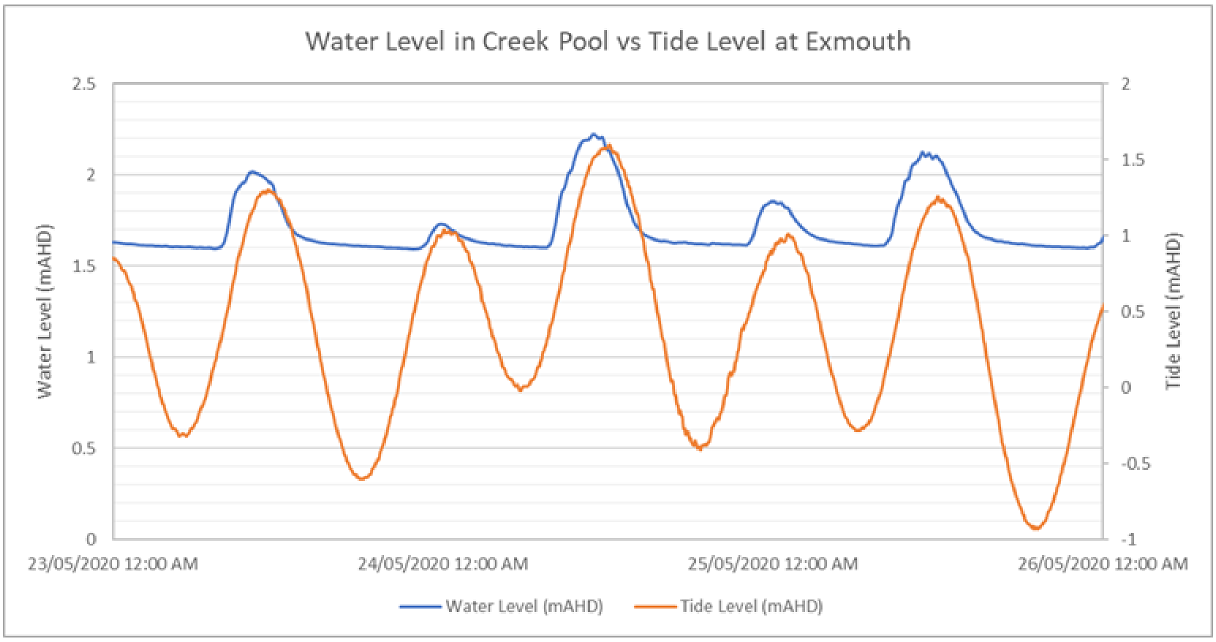


Figure 12-1. Water levels recorded in Tantabiddi Creek (at the pool) and tide levels recorded at Exmouth (DoT, 2020)

Analysis of radar rainfall data (The Weather Chaser, 2020) suggests the actual event exhibited high temporal and spatial variability so was not uniform across the catchment. Therefore, the 1 EY rainfall event recorded at the Ningaloo Reef weather station did not result in a flood event. This is not uncommon in Pilbara catchments, and is likely to be due to dry antecedent catchment conditions and the high associated initial losses. This catchment response is referred to in ARR2019 as AEP non-neutrality. This is more likely to affect the more frequently occurring rainfall events, such as the 1 EY. More significant rainfall events are expected to result in a more significant catchment response to rainfall and corresponding increases in water level recorded by the logger installed in Tantabiddi Creek. It is recommended that monitoring continues to collect sufficient data needed to validate the hydrological and sediment transport models.

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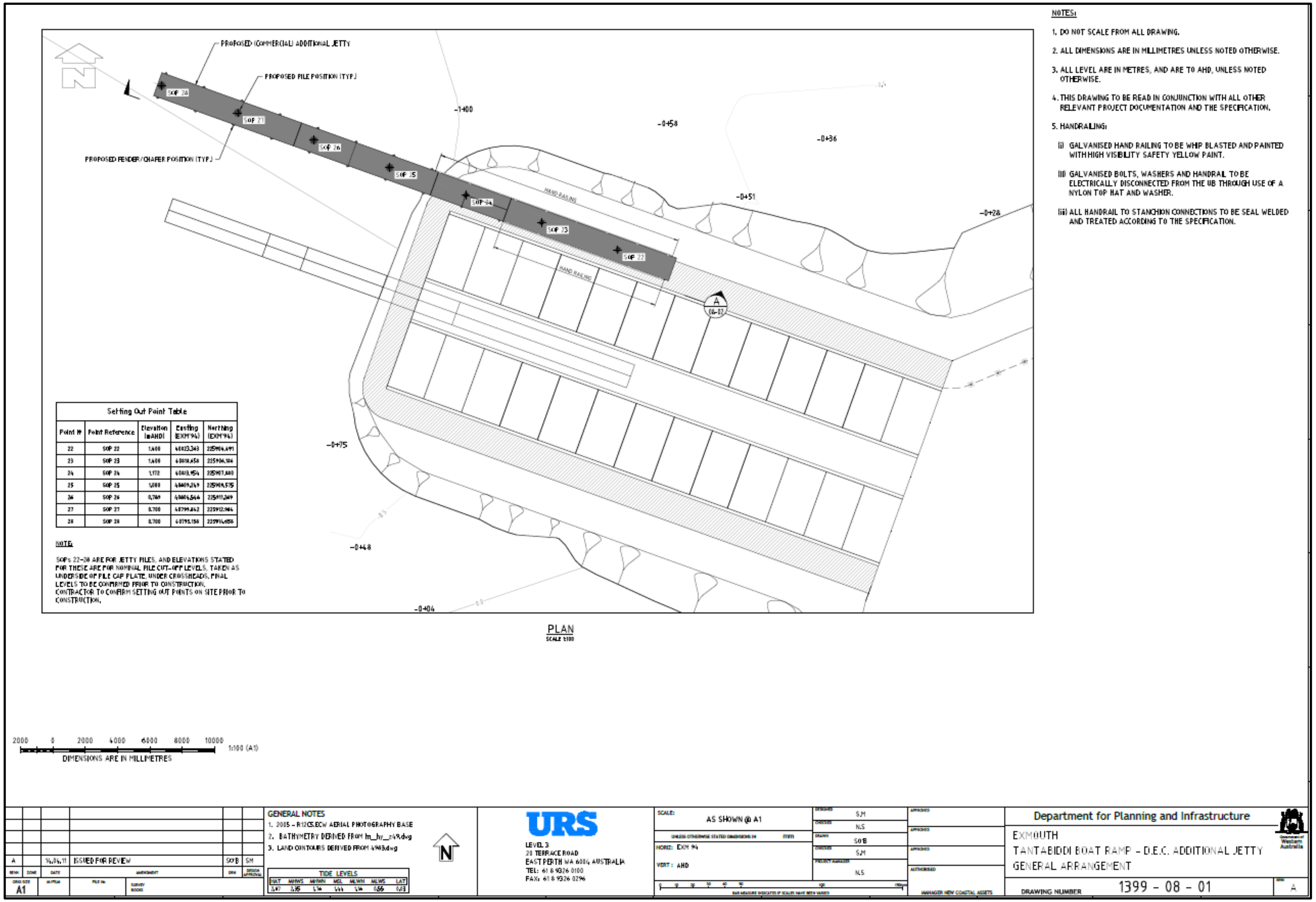
Appendix A Existing Boat Ramp Plan



Setting Out Point Table

Point #	Point Reference	Elevation (mAHD)	Easting (EXM'94)	Northing (EXM'94)
22	SOP 22	1.600	40823.343	225904.691
23	SOP 23	1.600	40818.658	225906.184
24	SOP 24	1.172	40813.954	225907.880
25	SOP 25	1.000	40809.249	225909.575
26	SOP 26	0.749	40804.544	225911.269
27	SOP 27	0.700	40799.842	225912.964
28	SOP 28	0.700	40795.158	225914.658

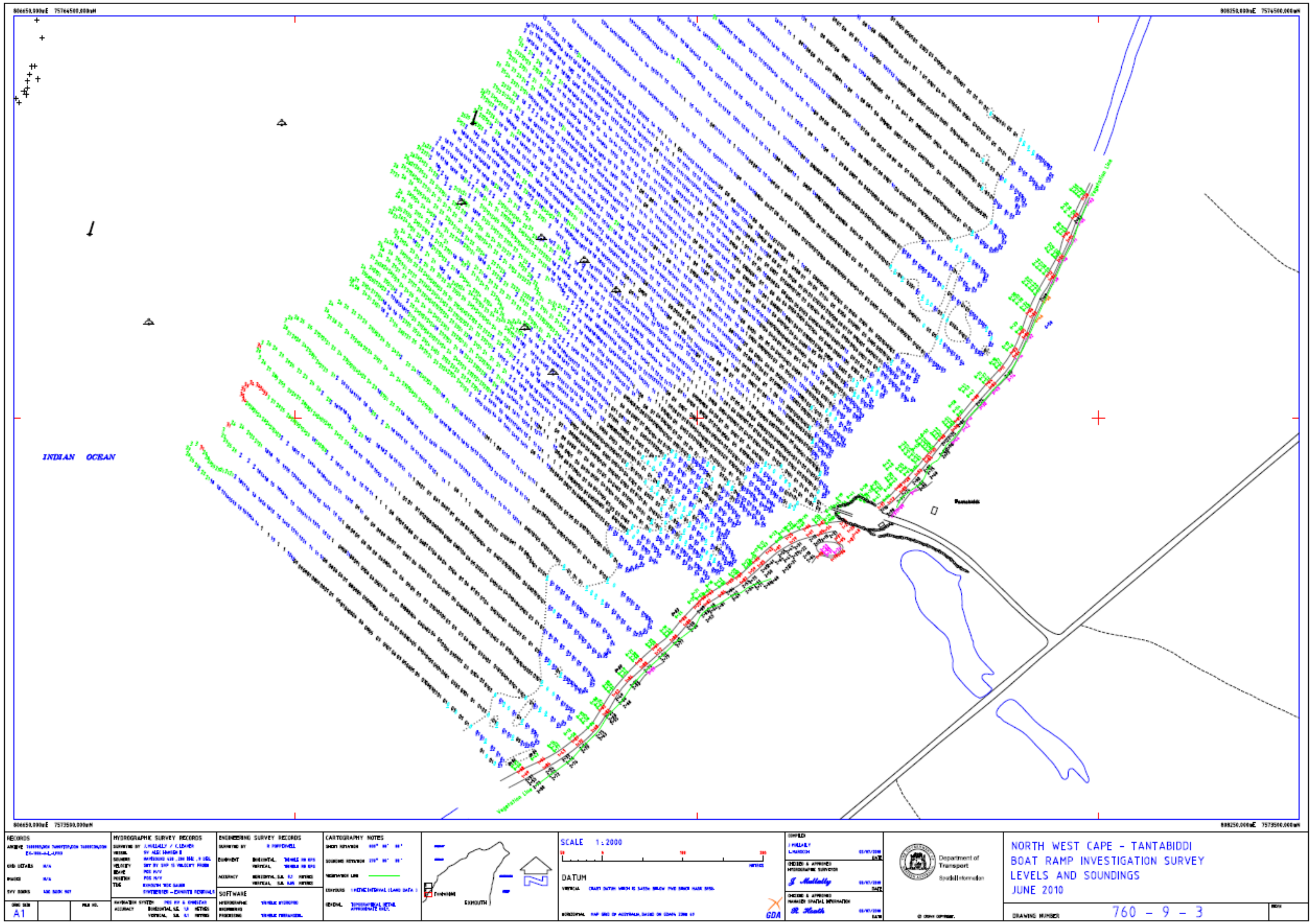
Existing Tantabiddi Boat Ramp plan view sketch

Appendix B Document Review Register

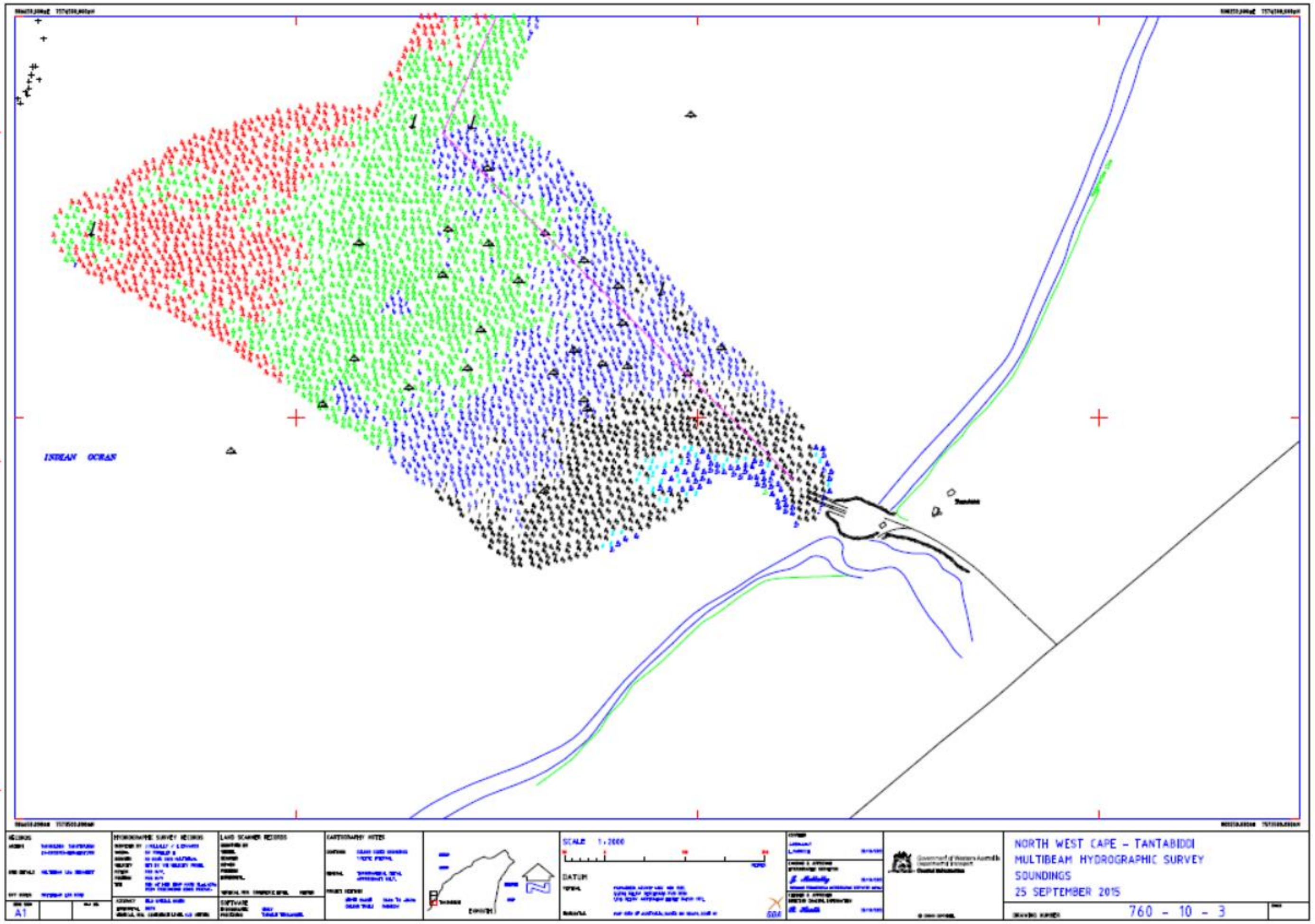
Date	Author	Document Title	Items / information of relevance to this study
2019	Cuttler et al.	Source and supply of sediment to a shoreline salient in a fringing reef environment	Cuttler el. al. (2019) concluded that waves were observed higher during higher tide duration. The site measurement (Cuttler el. al. 2018) during the TC Olwyn indicted the higher waves due the storm surge. The UWA data is not required at this stage for simulation of sediment transport from Tantabiddi Creek. This data could be considered when conducting coastal and sediment transport modelling of boat ramp upgrade options.
2018	Drost et al.	Predicting the Hydrodynamic Response of a Coastal Reef-lagoon System to a Tropical Cyclone using Phase-averaged and Surfbeat-resolving Wave Models	Document content not required for this Tantabiddi Creek study.
2018	Cuttler et al.	Response of a Fringing Reef Coastline to the Direct impact of a Tropical Cyclone	UWA (Cuttler el. al. 2019) recently completed site measurements to provide more information about the wave and currents. The observations of wave height, water level and current velocity were measured at area within fringing reef and one wave measurement by AWAC was deployed in 20 m depth offshore of the reef crest. The incident significant wave heights for wind wave were between 1 m and 3m while the higher swells (Hs>2 m) occurring during the deployment. Compared to the offshore waves, the wave heights at the nearshore instrument arrays were significantly small than the incident waves with the significant wave height at approximately 0.5 m. The mean currents near the salient were weak (mean magnitude 0.04 m/s). under the ambient conditions, the dominate wave and current directions are expected to bring the longshore sediment movement heading to north, but limited volume of sand movement due to the reduced waves and weak tidal currents. The UWA data is not required at this stage for simulation of sediment transport from Tantabiddi Creek. This data could be considered when conducting coastal and sediment transport modelling of boat ramp upgrade options.
2018	Pomeroy et al.	Spatial Variability of Sediment Transport Processes Over Intratidal and Subtidal Timescales within a Fringing Coral Reef System	Document content not required for this Tantabiddi Creek study.
2018	MP Rogers	Tantabiddi Boat Launching Facility Investigation	Recommendations for the upgraded boat ramp design concepts and possible alternate locations. Confirmation of nearby publicly available data stations including wind and wave. Information regarding indicative sediment transport pathways.
2016	Seashore Engineering	Design Storms for Western Australian Coastal Planning - Tropical	Document content not required for this Tantabiddi Creek study.
2016	URS	Sand Bypass Dredging & Revetment Repair - Close Out Report	Close out details of the dredging activity post-2014 event. Report states that: "Soon after the storm event the Shire of Exmouth removed approximately 1,500 m3 of sand using a long reach excavator in order to make the ramp useable. Surveys undertaken by the Department of Transport (DoT) and the Shire of Exmouth indicated that approximately 3,500 m3 of accumulated sand spread over and area of approximately 14,000 m2 still remained to be removed and bypassed on to the beaches immediately north of the boat ramp." "Disposal of the dredged material onto the beach immediately north of the boat ramp. Management of the disposal area such that dredged material is evenly placed over a length of beach totalling approximately 100 m." - so the dredged material was deposited onto the northern beach. "Dredging commenced on 12th June 2015 and ceased on 22nd September 2015. There was considerably more rubble present in the dredge area than was anticipated." Refer to Figures extracted from report below showing sand and rubble/cobble deposition on the northern beach. Report presents conceptual short-term and long-term sediment management options. Details of the post-dredging survey were also provided.
2015	Shire of Exmouth	Fact Sheet - Tantabiddi Boat Ramp Sand Bypassing, Ningaloo WA	Summary of the planned dredging following the April 2014 rainfall event.
2015	URS	Tantabiddi Boat Ramp - Sand Bypassing Environmental Management Plan	Environmental Management Plan (EMP) for initial removal of sand via a dredger and for potential ongoing maintenance dredging. Overview of existing environment including climate, oceanography, sediment quality. Report states: "Severe rainfall events may cause the Tantabiddi Creek adjacent to the Tantabiddi Boat Ramp to burst through the sand dune resulting in the undermining of the rock armour on the southern side of the ramp and the deposition of sand in front of and adjacent to the ramp. One such incident occurred in 2014 where approximately 3,500 m3 of deposited sand remained within the ramp area which reduced the depth available for safe navigation. In order to restore the navigable depths at the Tantabiddi Boat Ramp it is proposed to undertake mechanical sand bypassing to remove accumulated sand. The material will be removed by a small floating dredge and pumped onto a stretch of beach immediately north of the boat ramp." A longreach excavator has been used on several occasions by the Shire of Exmouth to remove sand that has accumulated adjacent to the boat ramp and this excavation program will continue when dredging is not required. The Shire of Exmouth has excavated small volumes of sand from Tantabiddi Boat Ramp for the past 20 years, up to approximately four times per year. A small dredger to remove the sand is required when accumulated sand is beyond the reach of a longreach excavator." "Approximately 3,500 m3 of sand will be bypassed covering an area of approximately 14,000 m2 and the average depth of excavation will be less than one metre (Figure 3-1). Sand will be pumped through a 200 mm polyethylene pipe onto the beach to renourish the beach immediately north of the boat ramp (Figure 3-1). The sand will be deposited into the intertidal zone and will be redistributed through natural coastal processes."
2015	URS	Tantabiddi Boat Ramp Sand Bypassing - Environmental Hazard Identification Report	Information regarding the impacts of the 2014 event and dredging requirements.
2014	Hyd2o Hydrology	Exmouth Hydrological Study	Hydrological study of area extending south of the existing Exmouth town site to Learmonth Airport. Peak flow estimation (Rational Method) for nearby catchments of similar size. Information on manning's n adopted in modelling (0.05). Modelling was completed using 1D HECRAS.
2012	Eliot I et al.	The Coast of the Shires of Shark Bay to Exmouth, Gascoyne, Western Australia: Geology, Geomorphology and Vulnerability	Discussion of data measurements wind, water, waves captured along the Gascoyne Coast. Discussion of the land systems and coastal processes in the Gascoyne region.
2012	WorleyParsons	Market Street Levee, Exmouth – Flood Mitigation Works Detailed Design Report	Details of the Martket street levee detailed design, adopting hydraulic model from SKM (2007). No information of relevance to this study - however geotechnical investigation may be useful for future design stages.
2007	SKM	Exmouth Floodplain Management Study	Hydrological study of eastern side of the cape, near Exmouth town. Characterization of climate and landscape of Exmouth region Discussion around historical rainfall events in 1999 and 2002. Some information surrounding critical durations and peak flow estimates of nearby catchments (request associated flood modelling report from DoT)
2007	SKM	Exmouth Floodplain Management Study - Flood Modelling Report	Flood modelling study of nearby Exmouth catchments. Includes details of modelling parameters used to characterise models including rainfall lossess/runoff coefficients, manning's n roughness, rainfall data etc. Details of rainfall and wave data gauges in the nearby area.

Appendix C Bathymetric Survey Data

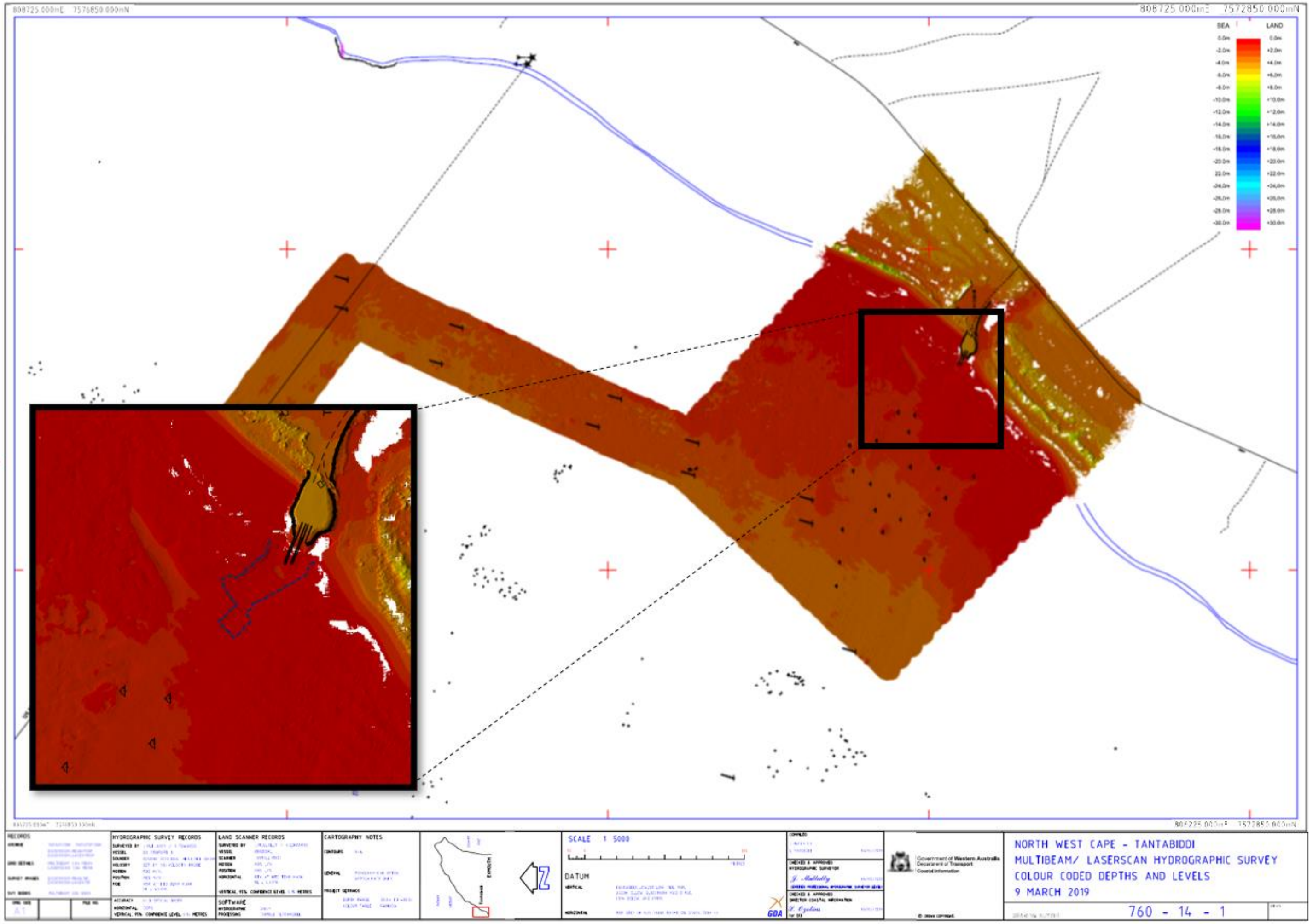
Advisian
Worley Group



Bathymetric survey June 2010 showing extent and finished levels



Bathymetric survey following September 2015 dredging event showing extent and finished levels



Bathymetric survey March 2019. A channel of lower elevation is evident seaward of the ramp and outlined in close-up inset (blue dashed line)

Appendix D Platinum Survey Report

Tantibiddi 01-04-2020 - Tantibiddi 01-04-2020

Captured: Mar 31, 2020, Processed: Apr 01, 2020

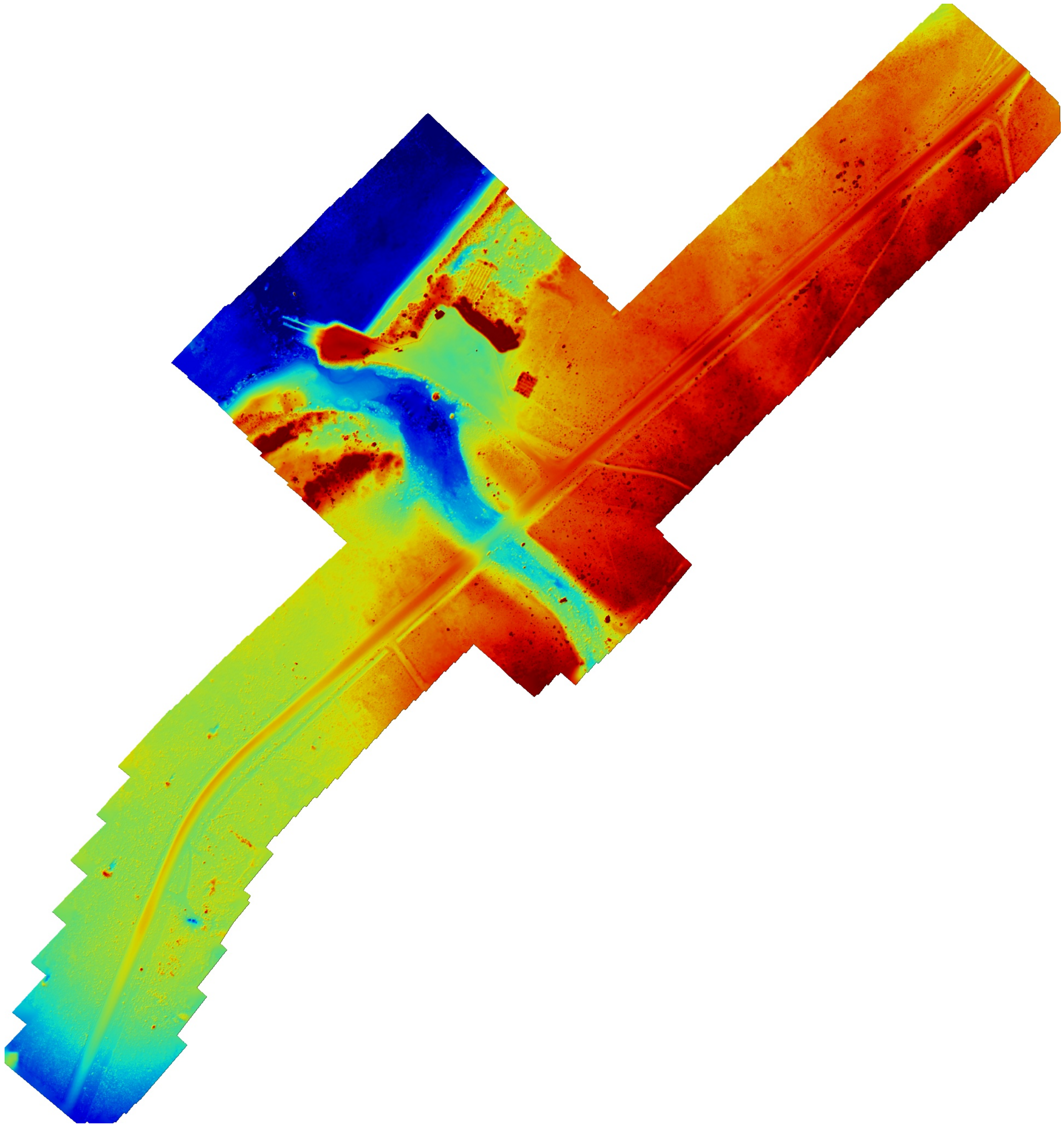
Map Details Summary ⓘ

Project Name	Tantibiddi 01-04-2020 - Tantibiddi 01-04-2020
Photogrammetry Engine	DroneDeploy Proprietary
Date Of Capture	Mar 31, 2020
Date Processed	Apr 01, 2020
Processing Mode	Terrain (2D)
GSD Orthomosaic (GSD DEM)	2.35cm/px (**DEM** 9.39cm/px)
Area Bounds (Coverage)	1617749.03m^2 (28%)
Image Sensors	DJI - FC6510

Quality & Accuracy Summary ⓘ

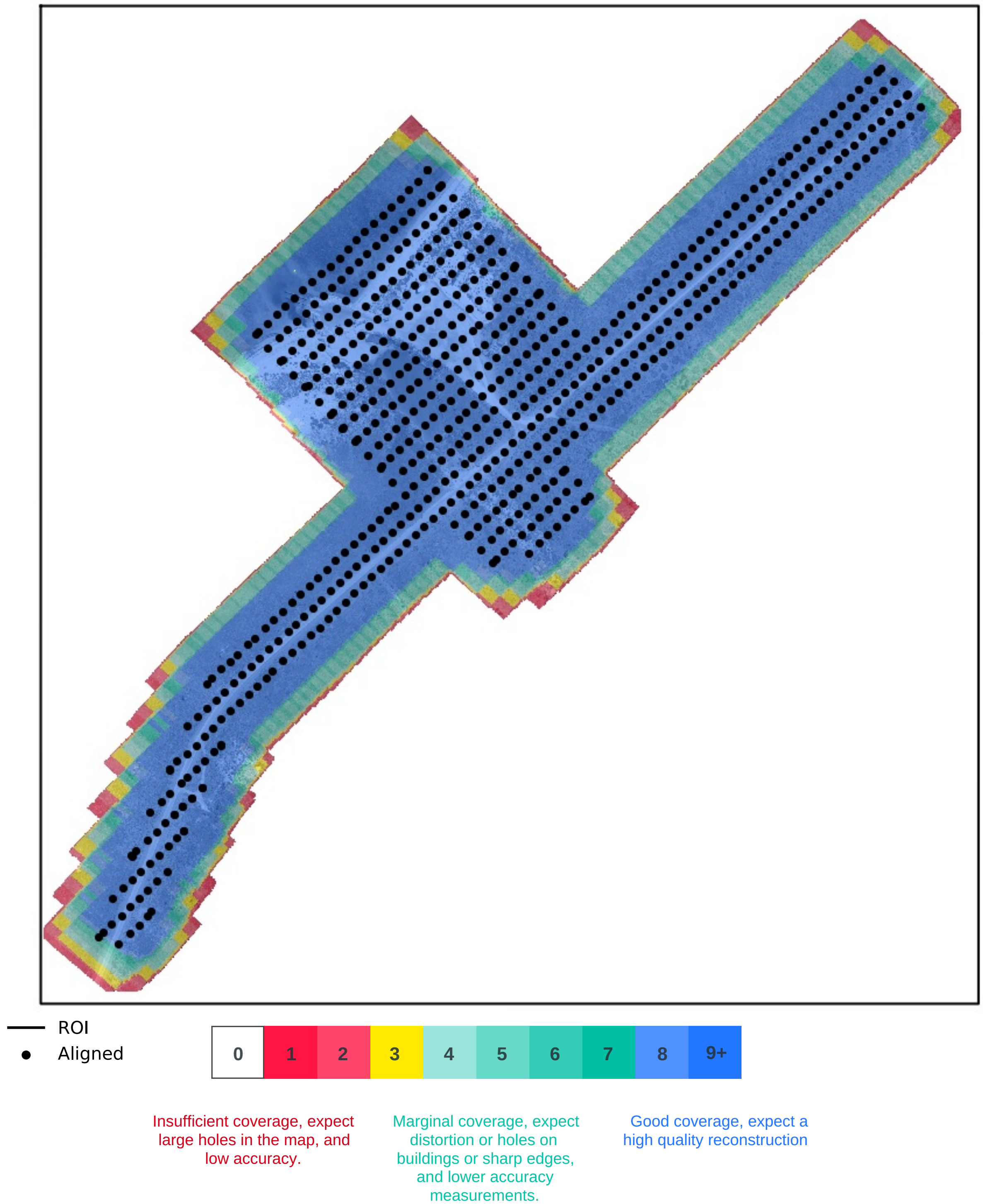
Image Quality		High texture images
Median Shutter Speed		1/100
Processing Mode		**Terrain Mode (2D)** - Optimized for efficiently mapping large fields and crops, natural open terrain, and generating topographical maps. This mode expects Nadir (top down) imagery, and so is not recommended for reconstructing the sides of buildings, overhangs, or complex equipment.
Images Uploaded (Aligned %)		646 (100%)
Camera Optimization		0.00% variation from reference intrinsics
GCP & Checkpoint count		8 GCPs - Mean RMS Error = 0.93cm 0 checkpoints

Preview ⓘ



Dataset Quality Review ⓘ

Orthomosaic Coverage ⓘ



Sensor(s) Used		DJI - FC6510
Image Count (by sensor)		646
Image Resolution		5472x3648 (~20MP)
Orthomosaic coverage (% of area of interest)		28.05
Average Orthomosaic Image Density within Structured Area		15 images/pixel
Median Shutter Speed		1/100

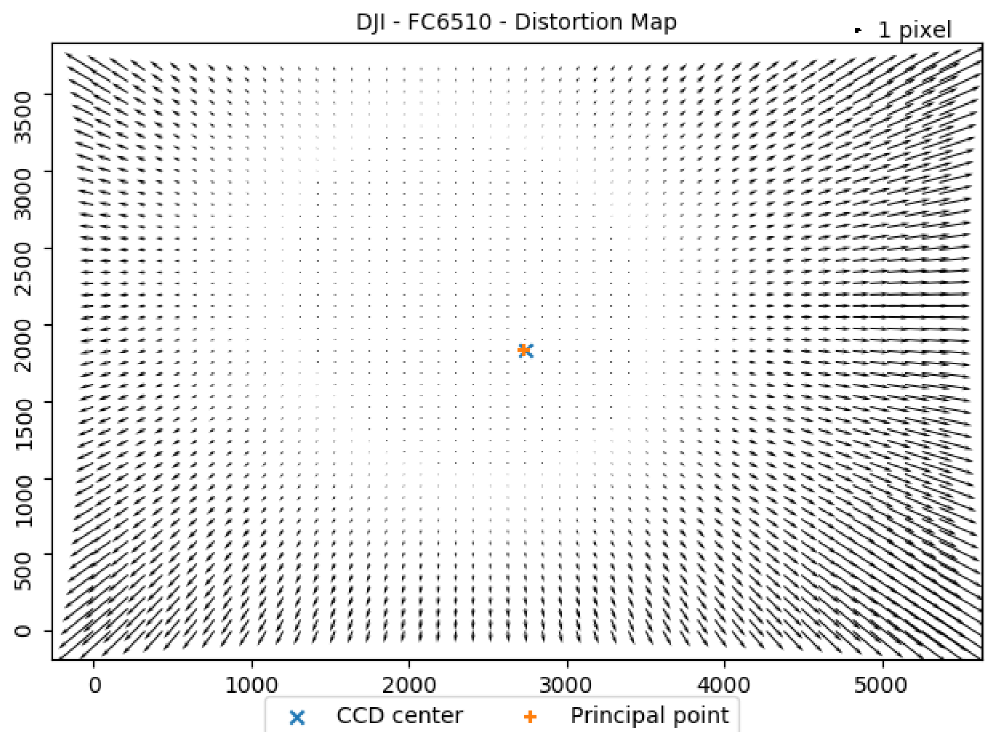
Structure from Motion ⓘ

Aligned Cameras		100% 646/646
RMSE of Camera GPS Location		**X** 3.34m **Y** 3.18m **Z** 0.75m **RMSE** 2.70m

Camera Calibration ⓘ

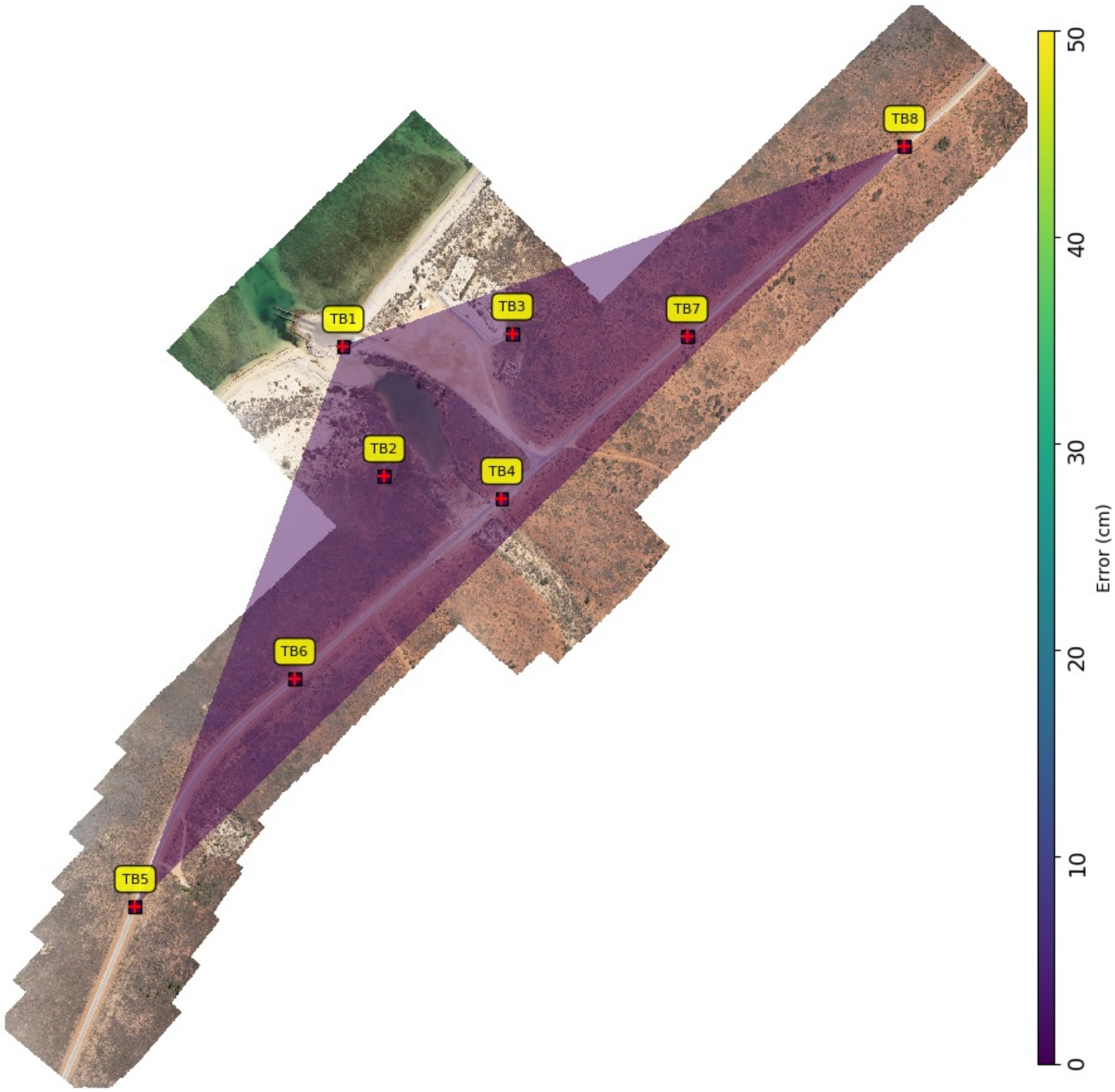
Camera Optimization		0.00% variation from reference intrinsics

DJI - FC6510



GCPs and Checkpoints ⓘ

GCP & Checkpoint count		8 GCPs - Mean RMS Error = 0.93cm 0 checkpoints



Visualisation of the expected absolute position error within the checkpoint area.

GCP Input

EPSG Code	EPSG-28349 - GDA94 / MGA zone 49

GCP Geolocation Error

GCP data is used to constrain the map reconstruction, so real world error between GCPs can ONLY be evaluated using Checkpoints. Error on GCPs is NOT representative of map error, instead it allows you to identify GCPs that have issues - for example incorrect survey locations, or that have been improperly tagged. Typical error should be less than a few centimeters for well tagged GCPs.

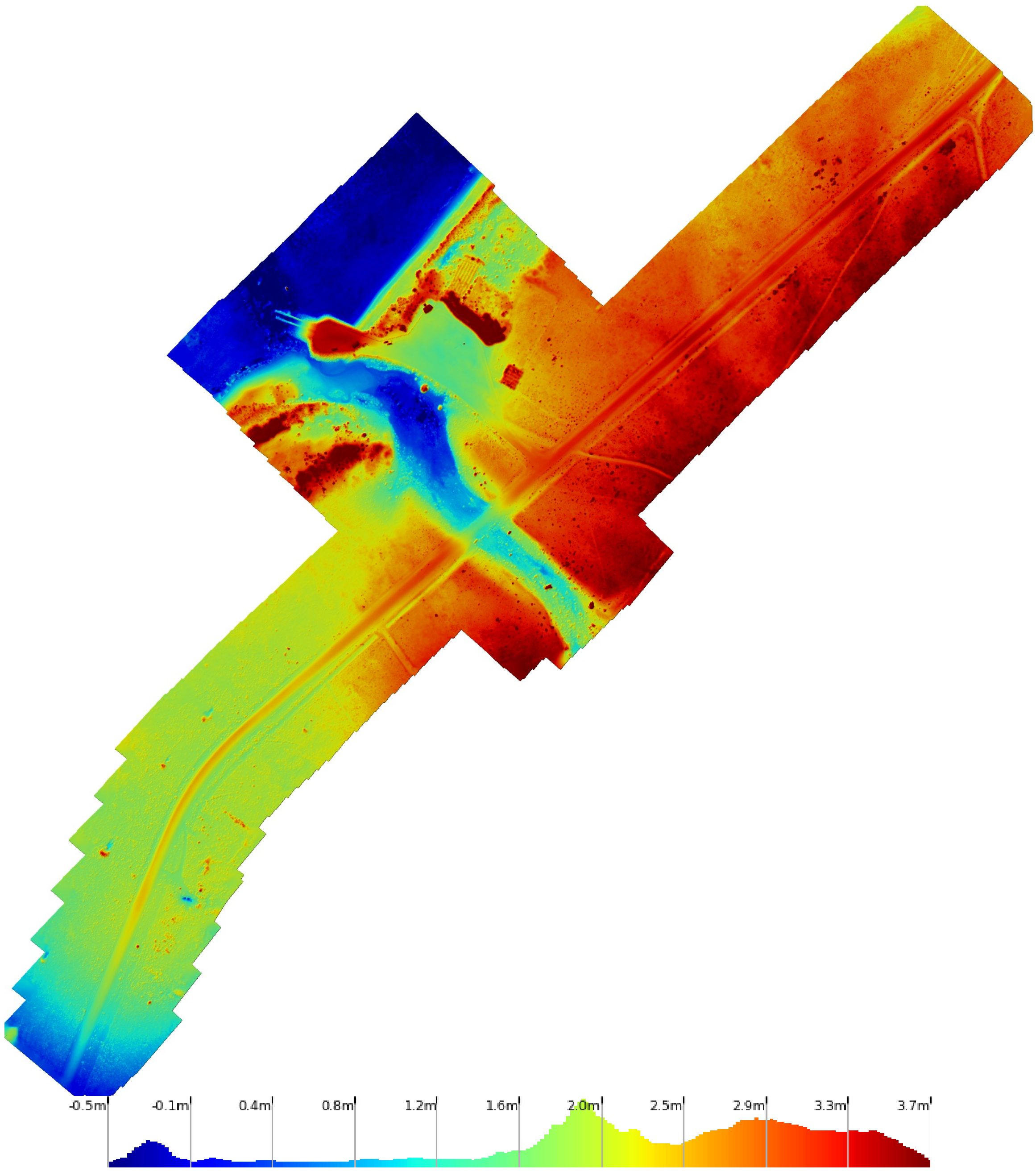
GCP Label		X Error (cm)	Y Error (cm)	Z Error (cm)
TB1		-0.3800	-1.9800	0.0500
TB2		-0.5700	-0.6700	0.3000
TB3		2.2800	0.1500	-0.4200
TB4		-1.8000	2.2600	0.3700
TB5		0.1200	0.1000	-0.1400
TB6		-0.2000	-0.0800	-0.4200
TB7		0.4300	0.2400	0.9200
TB8		0.1300	-0.0300	-0.6500
Total (RMSE) Excludes Outliers		1.0703	1.0940	0.4836

Densification and Meshing ⓘ

Processing Mode		**Terrain Mode (2D)** - Optimized for efficiently mapping large fields and crops, natural open terrain, and generating topographical maps. This mode expects Nadir (top down) imagery, and so is not recommended for reconstructing the sides of buildings, overhangs, or complex equipment.
Processing Mode Quality		High
Nadir Images		100%
Oblique images		0%
Horizontal images		0%
Total Points		15.0 million
Point Cloud Density		33.08 points/m^2
Mesh Triangles		4.0 million

Digital Elevation Model ⓘ

Mode	Generated from Mesh
DEM GSD	**DEM** 9.39cm/px
Relative/Absolute	Absolute Altitude vs GCPs



Appendix E Sediment Analysis Data

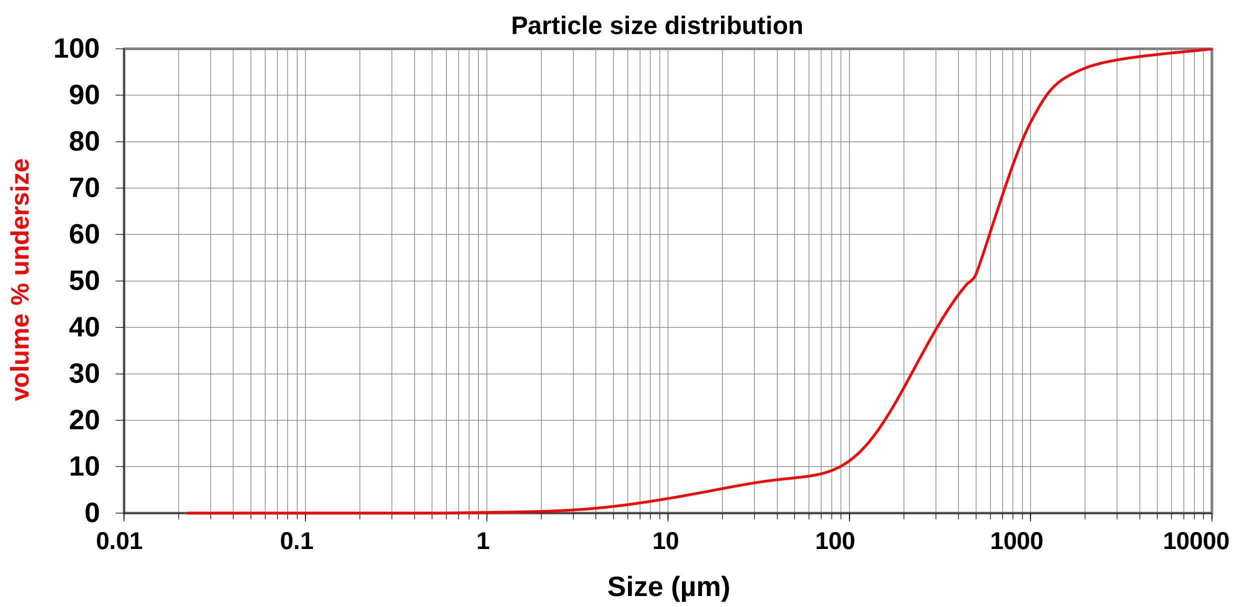
microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Department of Transport
Sample Name : TBSS05 26-7-19
Batch No : 19_1917
Lab ID No : 19_1917_01

Analysis : Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving
Result units: Volume
Dispersant: Water
Analysis model: General purpose
Additives: 10 millilitres sodium hexametaphosphate
Total sample wt (g): 43.218
Sonication: 3 min sonication

Span: 0.99
Vol. Weighted mean D[4,3]: 686.67 µm
Surface weighted mean D[3,2]: 69.44 µm
d(0.1) 112.47 µm
d(0.5) 10000.00 µm
d(0.9) 10000.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.15	7.096	2.22	50.238	7.60	355.66	44.20
0.022	0.00	0.159	0.00	1.125	0.18	7.962	2.52	56.368	7.83	399.05	46.99
0.025	0.00	0.178	0.00	1.262	0.21	8.934	2.83	63.246	8.12	447.74	49.42
0.028	0.00	0.200	0.00	1.416	0.24	10.024	3.15	70.963	8.53	500.00	51.46
0.032	0.00	0.224	0.00	1.589	0.27	11.247	3.49	79.621	9.15	1000.00	84.16
0.036	0.00	0.252	0.00	1.783	0.32	12.619	3.83	89.337	10.04	2000.00	95.85
0.040	0.00	0.283	0.00	2.000	0.37	14.159	4.19	100.237	11.28	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.44	15.887	4.55	112.468	12.91		
0.050	0.00	0.356	0.00	2.518	0.52	17.825	4.92	126.191	14.97		
0.056	0.00	0.399	0.00	2.825	0.62	20.000	5.29	141.589	17.46		
0.063	0.00	0.448	0.00	3.170	0.74	22.440	5.65	158.866	20.35		
0.071	0.00	0.502	0.00	3.557	0.88	25.179	6.01	178.250	23.56		
0.080	0.00	0.564	0.00	3.991	1.05	28.251	6.35	200.000	27.01		
0.089	0.00	0.632	0.03	4.477	1.24	31.698	6.66	224.404	30.60		
0.100	0.00	0.710	0.06	5.024	1.45	35.566	6.94	251.785	34.21		
0.112	0.00	0.796	0.09	5.637	1.69	39.905	7.19	282.508	37.74		
0.126	0.00	0.893	0.12	6.325	1.94	44.774	7.40	316.979	41.10		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Approved: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Department of Transport
Job number: 19_1917
Sample: 19_1917_01
Client ID: TBSS05 26-7-19
Date: 29/11/2019
Revision number: 0
Analysis : Semi-quantitative XRD analysis

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 43774 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

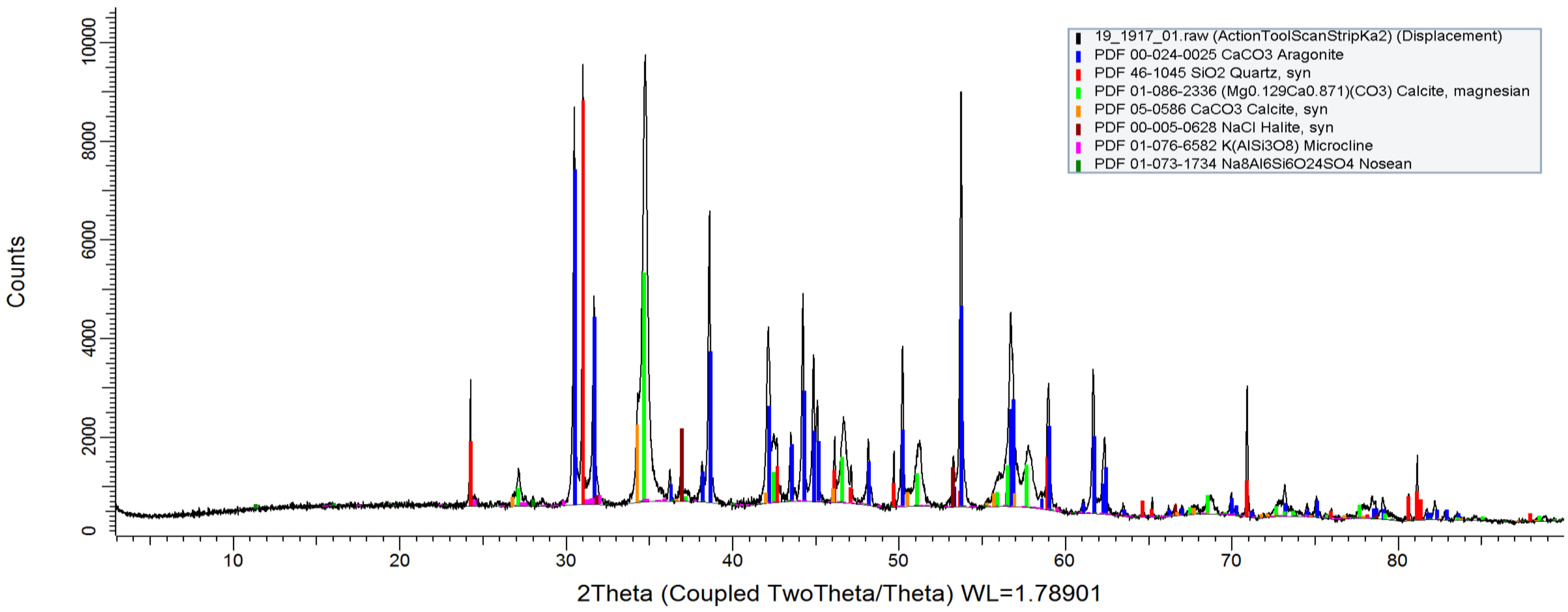
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Mineral phase	Concentration (%)	ICDD match probability
Aragonite (CaCO3)	52	Good
Quartz, syn (SiO2)	21	Good
Calcite, magnesian ((Mg0.129Ca0.871)(CO3))	14	Good
Calcite, syn (CaCO3)	7	Good
Halite, syn (NaCl)	3	Medium
Microcline (K(AlSi3O8))	3	Low
Nosean (Na8Al6Si6O24SO4)	1	Low

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Reported: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Approved: Ian Davies, B.Sc.(Chemistry)

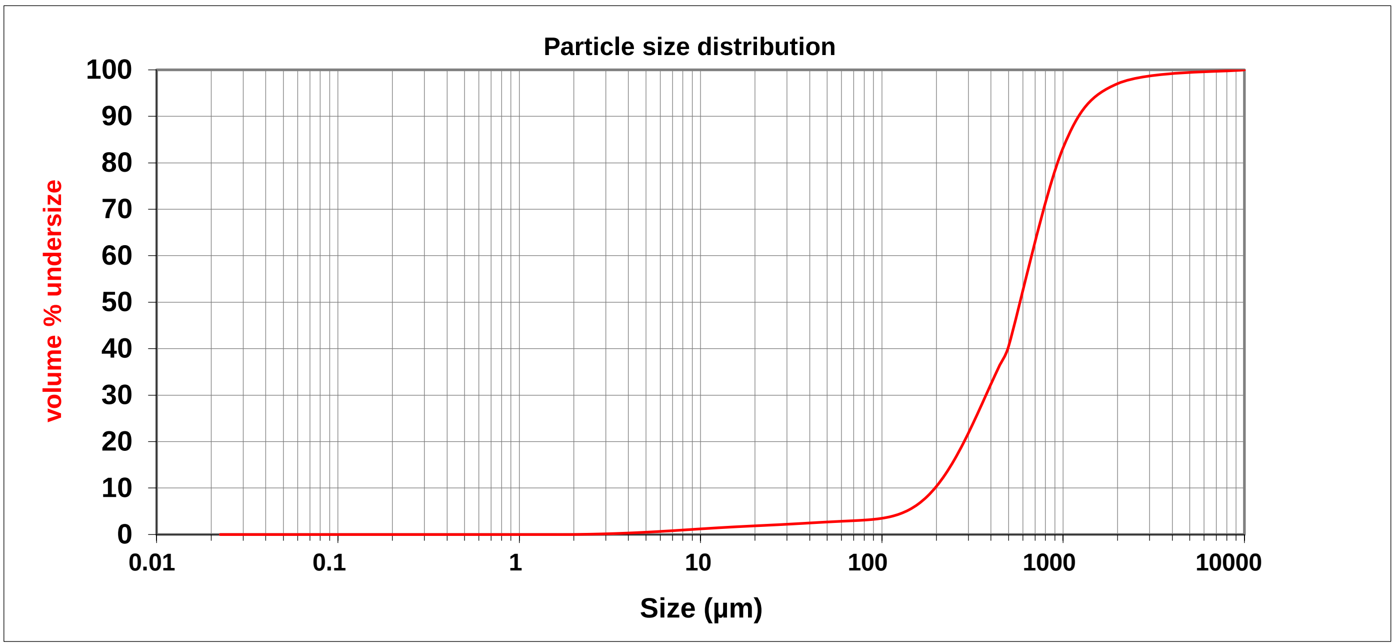
microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Department of Transport
Sample Name : AWAC 26-7-19
Batch No : 19_1917
Lab ID No : 19_1917_02

Analysis : Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving
Result units: Volume
Dispersant: Water
Analysis model: General purpose
Additives: 10 millilitres sodium hexametaphosphate
Total sample wt (g): 39.0618
Sonication: 3 min sonication

Span: 0.98
Vol. Weighted mean D[4,3]: 743.79 µm
Surface weighted mean D[3,2] 181.75 µm
d(0.1) 224.40 µm
d(0.5) 10000.00 µm
d(0.9) 10000.00 µm



Size (µm)	Vol Under %
0.020	0.00
0.022	0.00
0.025	0.00
0.028	0.00
0.032	0.00
0.036	0.00
0.040	0.00
0.045	0.00
0.050	0.00
0.056	0.00
0.063	0.00
0.071	0.00
0.080	0.00
0.089	0.00
0.100	0.00
0.112	0.00
0.126	0.00

Size (µm)	Vol Under %
0.142	0.00
0.159	0.00
0.178	0.00
0.200	0.00
0.224	0.00
0.252	0.00
0.283	0.00
0.317	0.00
0.356	0.00
0.399	0.00
0.448	0.00
0.502	0.00
0.564	0.00
0.632	0.00
0.710	0.00
0.796	0.00
0.893	0.00

Size (µm)	Vol Under %
1.002	0.00
1.125	0.00
1.262	0.00
1.416	0.00
1.589	0.00
1.783	0.00
2.000	0.01
2.244	0.05
2.518	0.08
2.825	0.13
3.170	0.19
3.557	0.25
3.991	0.33
4.477	0.41
5.024	0.51
5.637	0.61
6.325	0.72

Size (µm)	Vol Under %
7.096	0.84
7.962	0.97
8.934	1.09
10.024	1.22
11.247	1.34
12.619	1.46
14.159	1.57
15.887	1.68
17.825	1.78
20.000	1.87
22.440	1.97
25.179	2.06
28.251	2.16
31.698	2.27
35.566	2.37
39.905	2.49
44.774	2.60

Size (µm)	Vol Under %
50.238	2.71
56.368	2.81
63.246	2.90
70.963	2.99
79.621	3.10
89.337	3.26
100.237	3.50
112.468	3.88
126.191	4.47
141.589	5.34
158.866	6.57
178.250	8.22
200.000	10.36
224.404	13.00
251.785	16.15
282.508	19.76
316.979	23.74

Size (µm)	Vol Under %
355.66	27.97
399.05	32.29
447.74	36.51
500.00	40.45
1000.00	83.22
2000.00	97.04
10000.00	100.00

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Approved: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Department of Transport
Job number: 19_1917
Sample: 19_1917_02
Client ID: AWAC 26-7-19
Date: 29/11/2019
Revision number: 0
Analysis : Semi-quantitative XRD analysis

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 43774 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

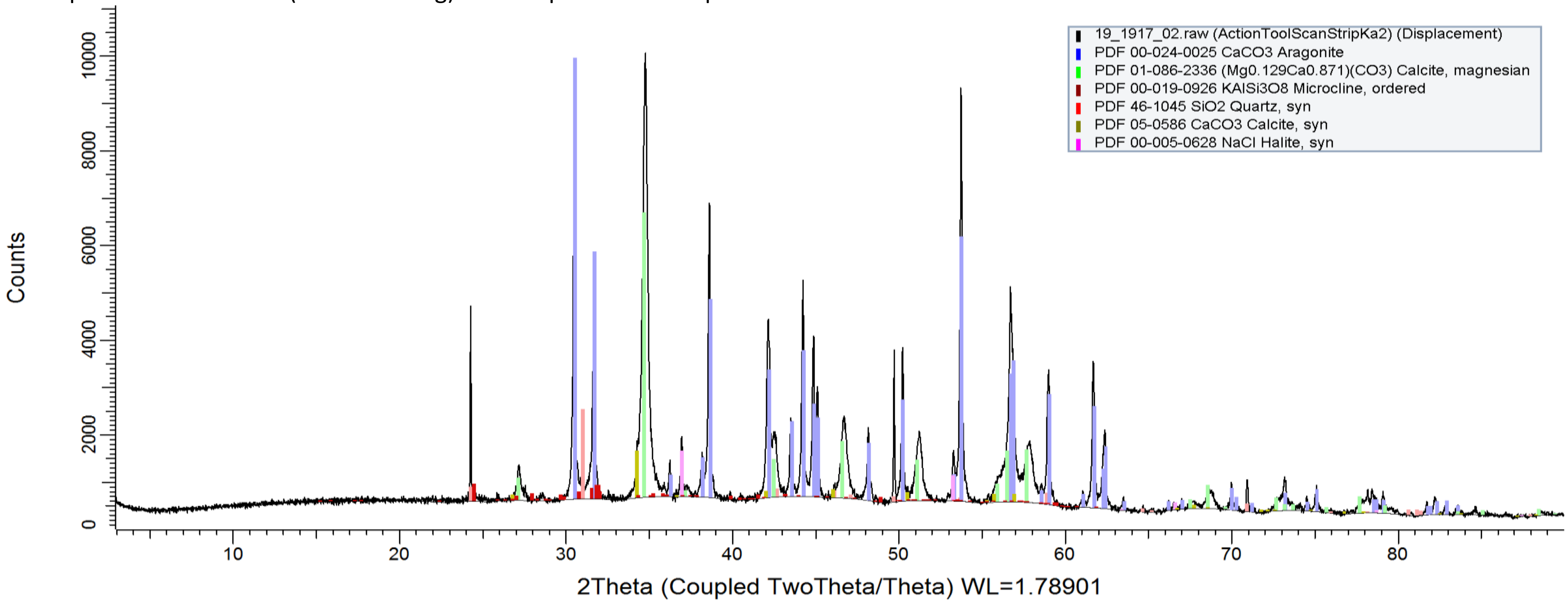
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Mineral phase	Concentration (%)	ICDD match probability
Aragonite (CaCO3)	67	Good
Calcite, magnesian ((Mg0.129Ca0.871)(CO3))	17	Good
Microcline, ordered (KAlSi3O8)	5	Low
Quartz, syn (SiO2)	5	Good
Calcite, syn (CaCO3)	4	Good
Halite, syn (NaCl)	2	Low

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Reported: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Approved: Ian Davies, B.Sc.(Chemistry)

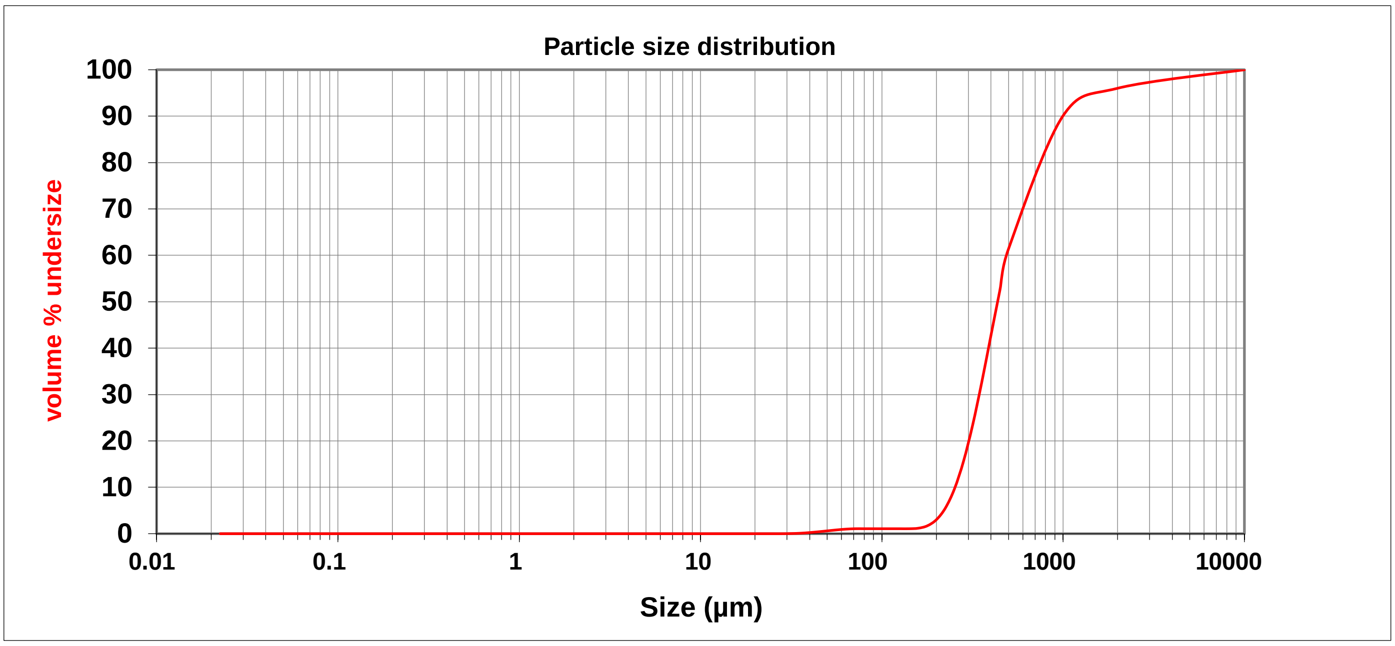
microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client:	Department of Transport
Sample Name :	TBSS04 26-7-19
Batch No :	19_1917
Lab ID No :	19_1917_03

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	66.7038
Sonication:	4 min sonication		

Span:	10.00	**Vol. Weighted mean D[4,3]:**	675.83 µm	**d(0.1)**	0.36 µm
		Surface weighted mean D[3,2]	394.63 µm	**d(0.5)**	1000.00 µm
				d(0.9)	10000.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.00	7.096	0.00	50.238	0.62	355.66	32.60
0.022	0.00	0.159	0.00	1.125	0.00	7.962	0.00	56.368	0.82	399.05	42.53
0.025	0.00	0.178	0.00	1.262	0.00	8.934	0.00	63.246	0.98	447.74	52.40
0.028	0.00	0.200	0.00	1.416	0.00	10.024	0.00	70.963	1.07	500.00	61.39
0.032	0.00	0.224	0.00	1.589	0.00	11.247	0.00	79.621	1.08	1000.00	90.09
0.036	0.00	0.252	0.00	1.783	0.00	12.619	0.00	89.337	1.08	2000.00	96.01
0.040	0.00	0.283	0.00	2.000	0.00	14.159	0.00	100.237	1.08	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.00	15.887	0.00	112.468	1.08		
0.050	0.00	0.356	0.00	2.518	0.00	17.825	0.00	126.191	1.08		
0.056	0.00	0.399	0.00	2.825	0.00	20.000	0.00	141.589	1.08		
0.063	0.00	0.448	0.00	3.170	0.00	22.440	0.00	158.866	1.18		
0.071	0.00	0.502	0.00	3.557	0.00	25.179	0.00	178.250	1.71		
0.080	0.00	0.564	0.00	3.991	0.00	28.251	0.00	200.000	3.02		
0.089	0.00	0.632	0.00	4.477	0.00	31.698	0.03	224.404	5.56		
0.100	0.00	0.710	0.00	5.024	0.00	35.566	0.11	251.785	9.70		
0.112	0.00	0.796	0.00	5.637	0.00	39.905	0.24	282.508	15.67		
0.126	0.00	0.893	0.00	6.325	0.00	44.774	0.42	316.979	23.42		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Approved: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Department of Transport
Job number: 19_1917
Sample: 19_1917_03
Client ID: TBSS04 26-7-19
Date: 29/11/2019
Revision number: 0
Analysis : Semi-quantitative XRD analysis

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 43774 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

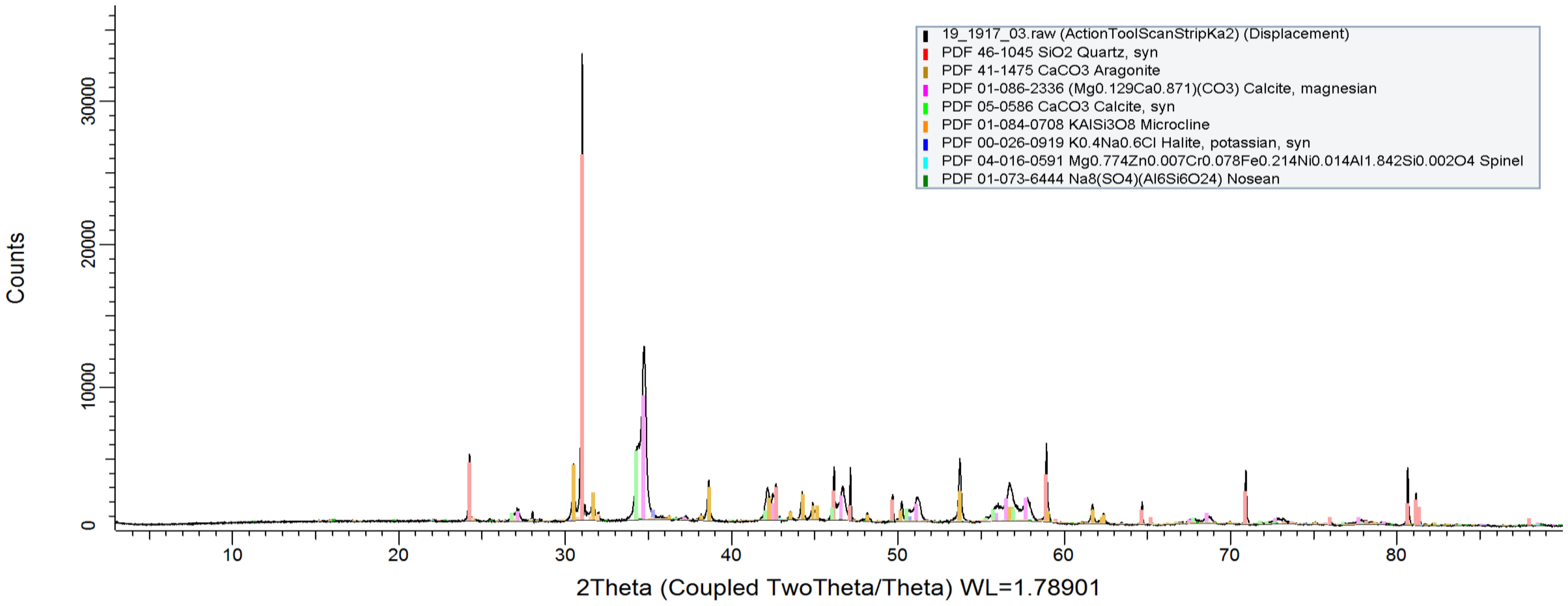
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Mineral phase	Concentration (%)	ICDD match probability
Quartz, syn (SiO2)	42	Good
Aragonite (CaCO3)	22	Good
Calcite, magnesian ((Mg0.129Ca0.871)(CO3))	17	Good
Calcite, syn (CaCO3)	14	Good
Microcline (KAlSi3O8)	4	Low
Halite, potassian, syn (K0.4Na0.6Cl)	1	Low
Spinel (Mg0.774Zn0.007Cr0.078Fe0.214Ni0.014Al1.842Si0.002O4)	Trace	Low
Nosean (Na8(SO4)(Al6Si6O24))	Trace	Low

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Reported: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Approved: Ian Davies, B.Sc.(Chemistry)

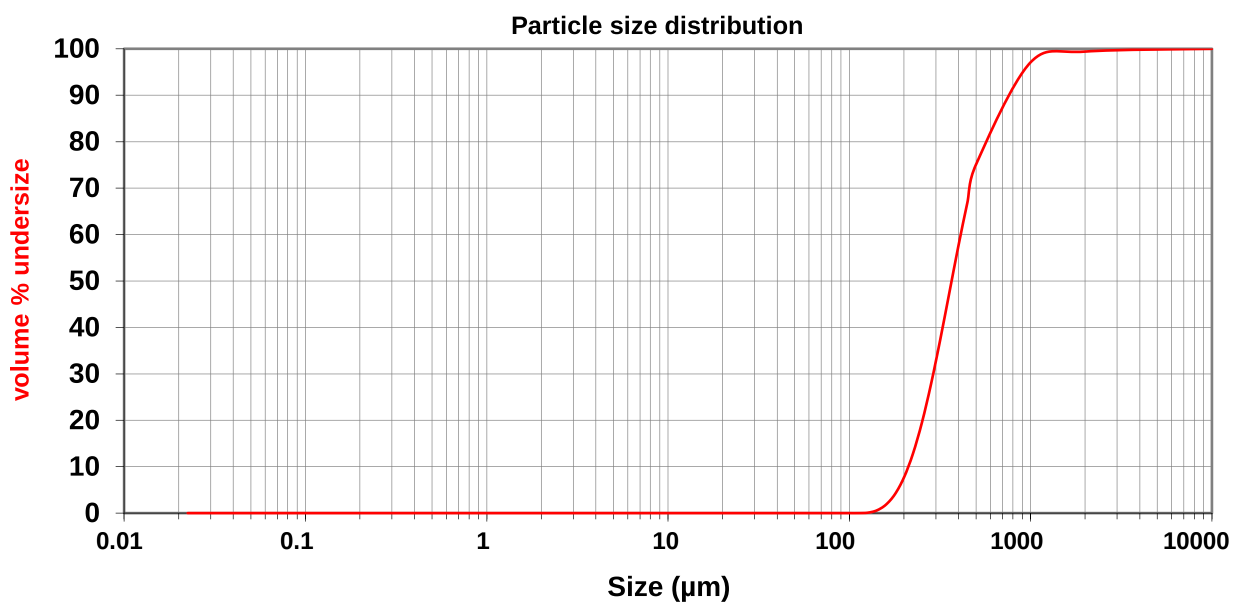
microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client:	Department of Transport
Sample Name :	TBSS01 26-7-19
Batch No :	19_1917
Lab ID No :	19_1917_04

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	90.5692
Sonication:	6 min sonication		

Span:	21.83	**Vol. Weighted mean D[4,3]:**	456.19 µm	**d(0.1)**	224.40 µm
		Surface weighted mean D[3,2]	345.29 µm	**d(0.5)**	447.74 µm
				d(0.9)	10000.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.00	7.096	0.00	50.238	0.00	355.66	47.32
0.022	0.00	0.159	0.00	1.125	0.00	7.962	0.00	56.368	0.00	399.05	57.39
0.025	0.00	0.178	0.00	1.262	0.00	8.934	0.00	63.246	0.00	447.74	66.83
0.028	0.00	0.200	0.00	1.416	0.00	10.024	0.00	70.963	0.00	500.00	75.08
0.032	0.00	0.224	0.00	1.589	0.00	11.247	0.00	79.621	0.00	1000.00	97.09
0.036	0.00	0.252	0.00	1.783	0.00	12.619	0.00	89.337	0.00	2000.00	99.40
0.040	0.00	0.283	0.00	2.000	0.00	14.159	0.00	100.237	0.00	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.00	15.887	0.00	112.468	0.00		
0.050	0.00	0.356	0.00	2.518	0.00	17.825	0.00	126.191	0.09		
0.056	0.00	0.399	0.00	2.825	0.00	20.000	0.00	141.589	0.58		
0.063	0.00	0.448	0.00	3.170	0.00	22.440	0.00	158.866	1.79		
0.071	0.00	0.502	0.00	3.557	0.00	25.179	0.00	178.250	4.04		
0.080	0.00	0.564	0.00	3.991	0.00	28.251	0.00	200.000	7.64		
0.089	0.00	0.632	0.00	4.477	0.00	31.698	0.00	224.404	12.80		
0.100	0.00	0.710	0.00	5.024	0.00	35.566	0.00	251.785	19.57		
0.112	0.00	0.796	0.00	5.637	0.00	39.905	0.00	282.508	27.85		
0.126	0.00	0.893	0.00	6.325	0.00	44.774	0.00	316.979	37.26		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Approved: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Department of Transport
Job number: 19_1917
Sample: 19_1917_04
Client ID: TBSS01 26-7-19
Date: 29/11/2019
Revision number: 0
Analysis : Semi-quantitative XRD analysis

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 43774 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

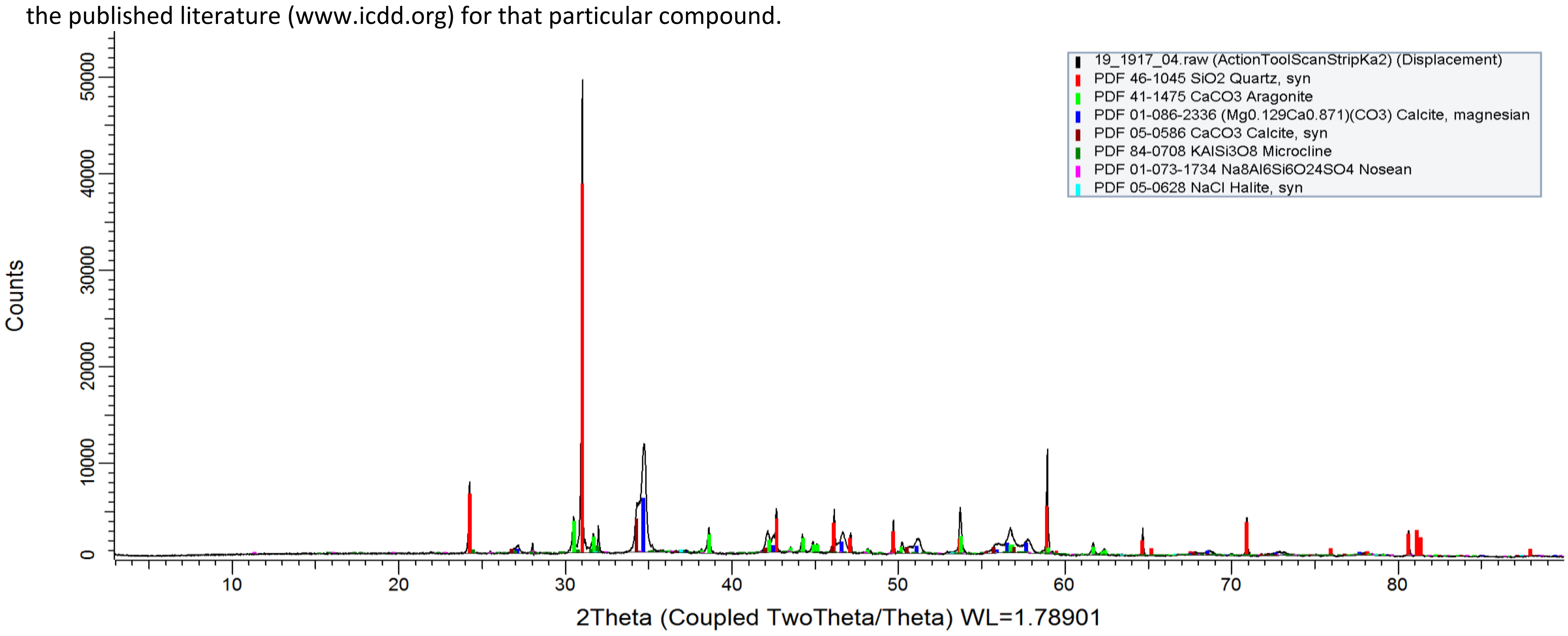
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Mineral phase	Concentration (%)	ICDD match probability
Quartz, syn (SiO2)	58	Good
Aragonite (CaCO3)	17	Good
Calcite, magnesian ((Mg0.129Ca0.871)(CO3))	10	Good
Calcite, syn (CaCO3)	9	Good
Microcline (KAlSi3O8)	6	Low
Nosean (Na8Al6Si6O24SO4)	1	Low
Halite, syn (NaCl)	Trace	Low

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Reported: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Approved: Ian Davies, B.Sc.(Chemistry)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

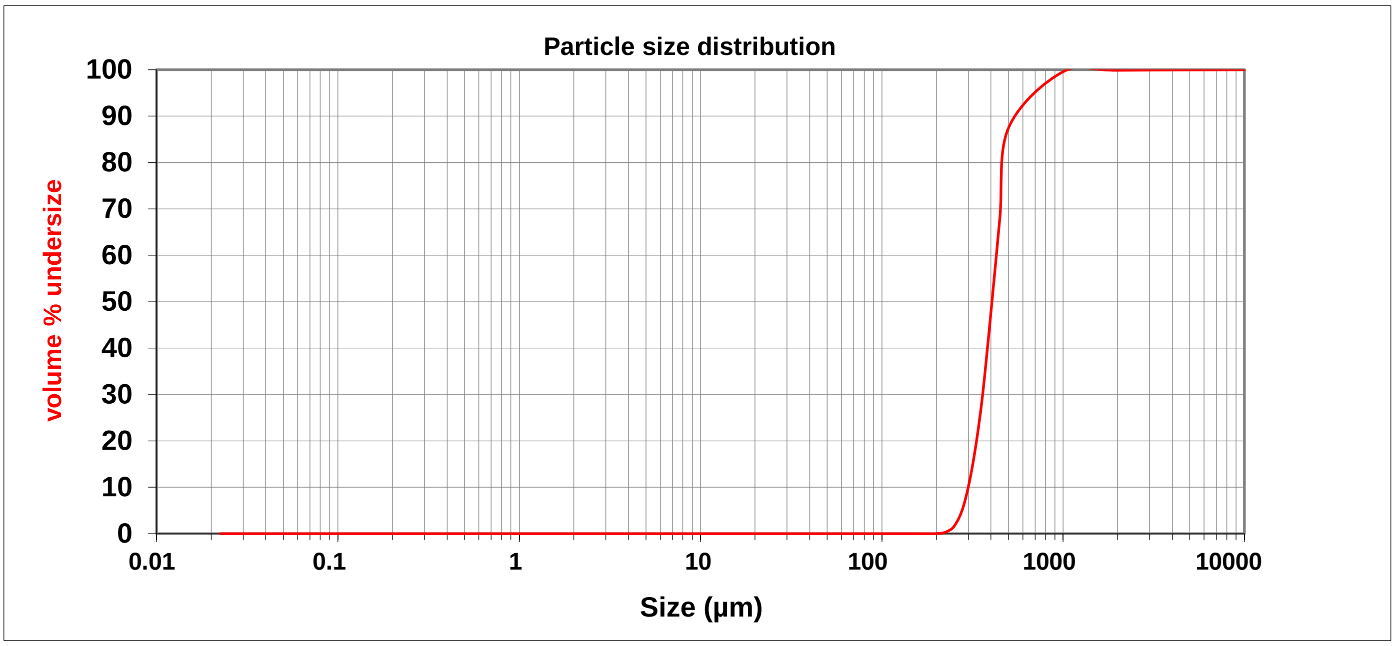
Client: Department of Transport
Sample Name : TBSS03 26-7-19
Batch No : 19_1917
Lab ID No : 19_1917_05

Analysis : Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving
Result units: Volume
Dispersant: Water
Analysis model: General purpose
Additives: 10 millilitres sodium hexametaphosphate
Total sample wt (g): 82.8812
Sonication: 3 min sonication

Span: 21.63

Vol. Weighted mean D[4,3]: 433.73 µm
Surface weighted mean D[3,2] 398.35 µm

d(0.1) 316.98 µm
d(0.5) 447.74 µm
d(0.9) 10000.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.00	7.096	0.00	50.238	0.00	355.66	28.30
0.022	0.00	0.159	0.00	1.125	0.00	7.962	0.00	56.368	0.00	399.05	47.34
0.025	0.00	0.178	0.00	1.262	0.00	8.934	0.00	63.246	0.00	447.74	68.02
0.028	0.00	0.200	0.00	1.416	0.00	10.024	0.00	70.963	0.00	500.00	87.46
0.032	0.00	0.224	0.00	1.589	0.00	11.247	0.00	79.621	0.00	1000.00	99.57
0.036	0.00	0.252	0.00	1.783	0.00	12.619	0.00	89.337	0.00	2000.00	99.87
0.040	0.00	0.283	0.00	2.000	0.00	14.159	0.00	100.237	0.00	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.00	15.887	0.00	112.468	0.00		
0.050	0.00	0.356	0.00	2.518	0.00	17.825	0.00	126.191	0.00		
0.056	0.00	0.399	0.00	2.825	0.00	20.000	0.00	141.589	0.00		
0.063	0.00	0.448	0.00	3.170	0.00	22.440	0.00	158.866	0.00		
0.071	0.00	0.502	0.00	3.557	0.00	25.179	0.00	178.250	0.00		
0.080	0.00	0.564	0.00	3.991	0.00	28.251	0.00	200.000	0.02		
0.089	0.00	0.632	0.00	4.477	0.00	31.698	0.00	224.404	0.34		
0.100	0.00	0.710	0.00	5.024	0.00	35.566	0.00	251.785	1.72		
0.112	0.00	0.796	0.00	5.637	0.00	39.905	0.00	282.508	6.04		
0.126	0.00	0.893	0.00	6.325	0.00	44.774	0.00	316.979	14.85		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Approved: Rick Hughes, B.Sc.(Hons)Physics, MAIP

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Department of Transport
Job number: 19_1917
Sample: 19_1917_05
Client ID: TBSS03 26-7-19
Date: 29/11/2019
Revision number: 0
Analysis : Semi-quantitative XRD analysis

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 43774 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

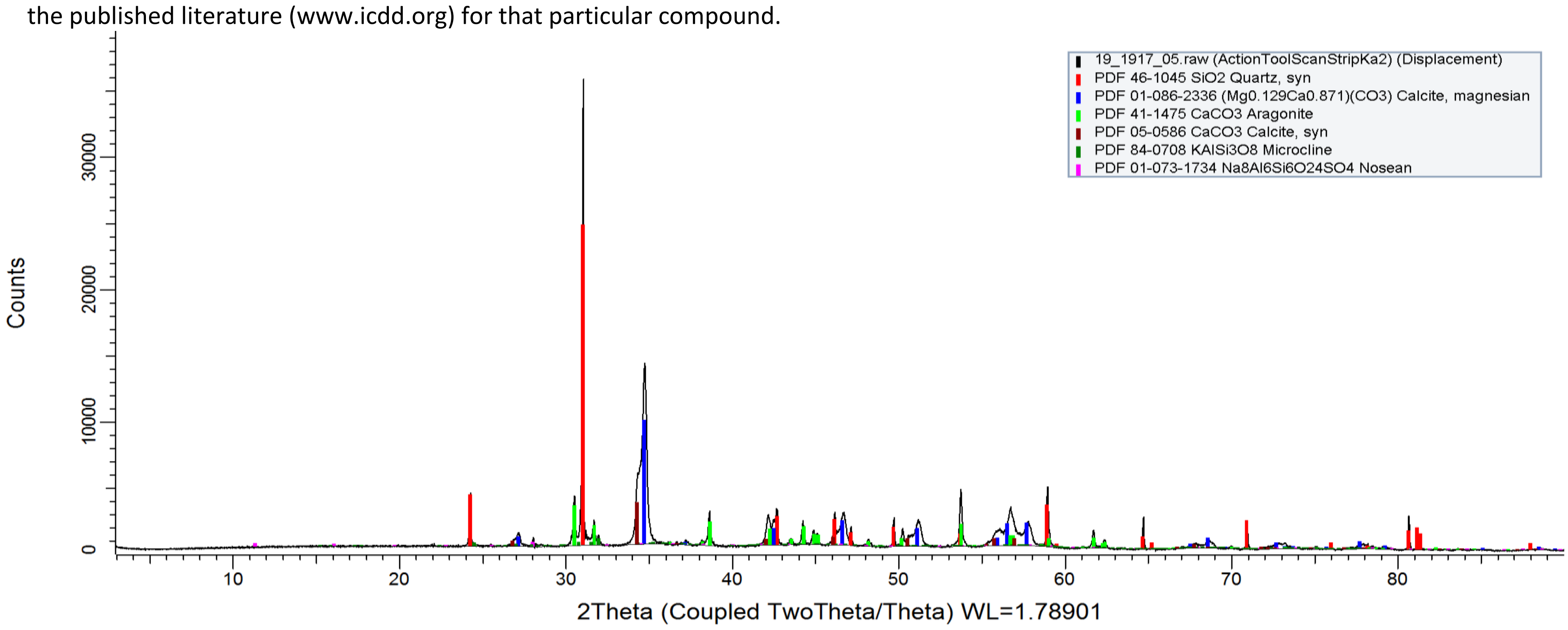
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Mineral phase	Concentration (%)	ICDD match probability
Quartz, syn (SiO2)	45	Good
Calcite, magnesian ((Mg0.129Ca0.871)(CO3))	20	Good
Aragonite (CaCO3)	19	Good
Calcite, syn (CaCO3)	10	Good
Microcline (KAlSi3O8)	5	Low
Nosean (Na8Al6Si6O24SO4)	1	Low

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Reported: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Approved: Ian Davies, B.Sc.(Chemistry)

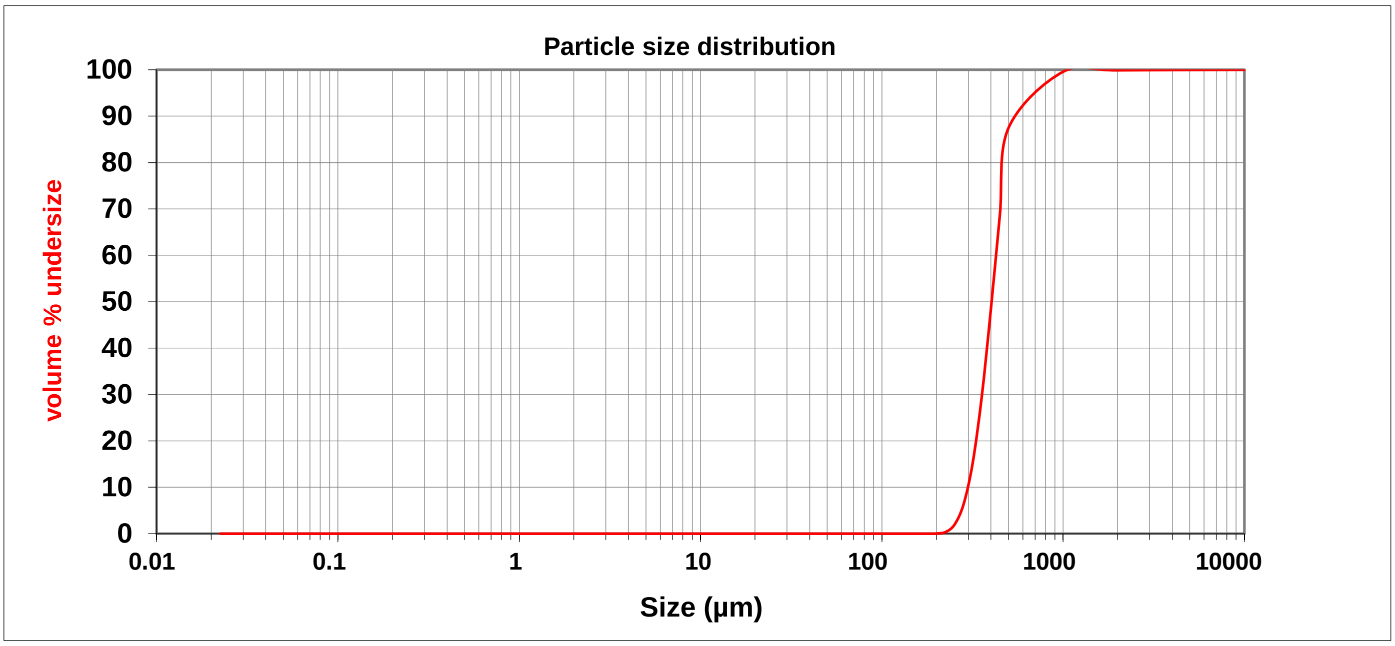
microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client:	Department of Transport
Sample Name :	TBSS03 26-7-19
Batch No :	19_1917
Lab ID No :	19_1917_05Q

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	82.8812
Sonication:	2 min sonication		

Span:	19.37	**Vol. Weighted mean D[4,3]:**	432.27 µm	**d(0.1)**	316.98 µm
		Surface weighted mean D[3,2]	396.55 µm	**d(0.5)**	500.00 µm
				d(0.9)	10000.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.00	7.096	0.00	50.238	0.00	355.66	29.46
0.022	0.00	0.159	0.00	1.125	0.00	7.962	0.00	56.368	0.00	399.05	48.14
0.025	0.00	0.178	0.00	1.262	0.00	8.934	0.00	63.246	0.00	447.74	68.64
0.028	0.00	0.200	0.00	1.416	0.00	10.024	0.00	70.963	0.00	500.00	87.46
0.032	0.00	0.224	0.00	1.589	0.00	11.247	0.00	79.621	0.00	1000.00	99.57
0.036	0.00	0.252	0.00	1.783	0.00	12.619	0.00	89.337	0.00	2000.00	99.87
0.040	0.00	0.283	0.00	2.000	0.00	14.159	0.00	100.237	0.00	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.00	15.887	0.00	112.468	0.00		
0.050	0.00	0.356	0.00	2.518	0.00	17.825	0.00	126.191	0.00		
0.056	0.00	0.399	0.00	2.825	0.00	20.000	0.00	141.589	0.00		
0.063	0.00	0.448	0.00	3.170	0.00	22.440	0.00	158.866	0.00		
0.071	0.00	0.502	0.00	3.557	0.00	25.179	0.00	178.250	0.00		
0.080	0.00	0.564	0.00	3.991	0.00	28.251	0.00	200.000	0.03		
0.089	0.00	0.632	0.00	4.477	0.00	31.698	0.00	224.404	0.36		
0.100	0.00	0.710	0.00	5.024	0.00	35.566	0.00	251.785	1.96		
0.112	0.00	0.796	0.00	5.637	0.00	39.905	0.00	282.508	6.36		
0.126	0.00	0.893	0.00	6.325	0.00	44.774	0.00	316.979	15.19		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed:	Angie Thorpe, B.Sc.(Biological Sciences)
Reported:	Angie Thorpe, B.Sc.(Biological Sciences)
Approved:	Rick Hughes, B.Sc.(Hons)Physics, MAIP

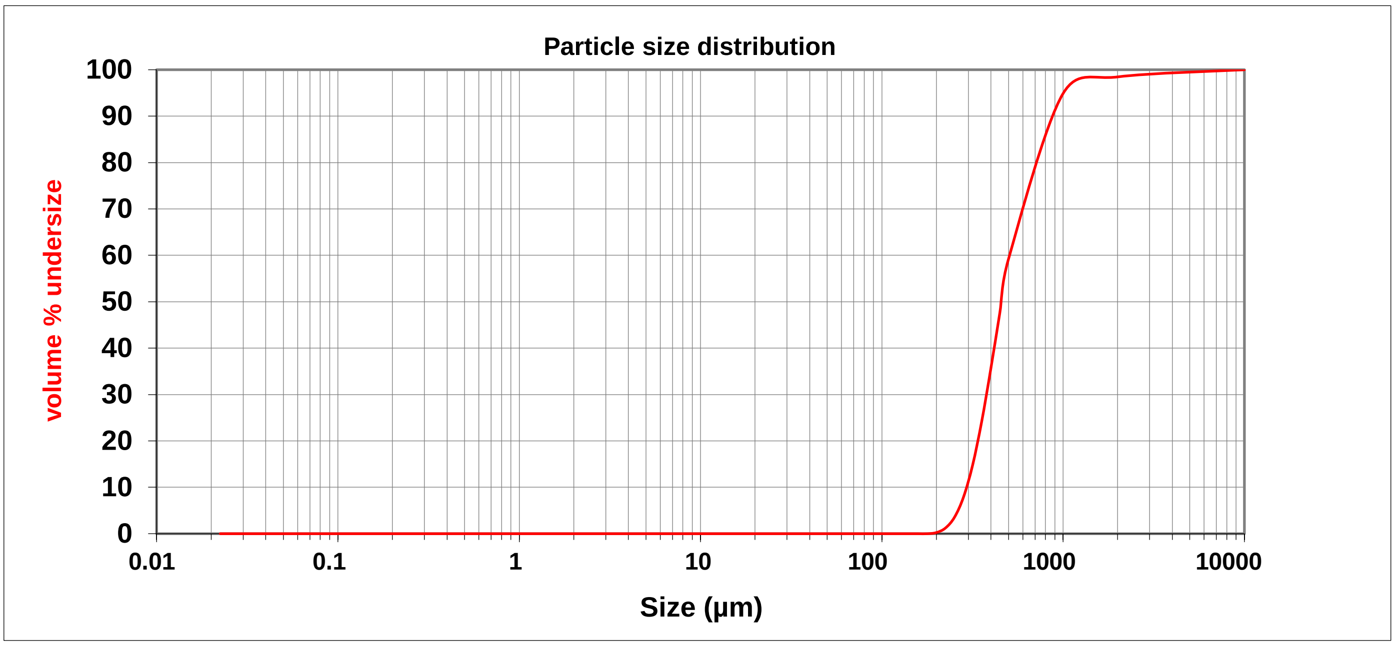
microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client:	Department of Transport
Sample Name :	TBSS02 26-7-19
Batch No :	19_1917
Lab ID No :	19_1917_06

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	103.6357
Sonication:	2 min sonication		

Span:	1.37	**Vol. Weighted mean D[4,3]:**	592.21 µm	**d(0.1)**	316.98 µm
		Surface weighted mean D[3,2]	455.40 µm	**d(0.5)**	500.00 µm
				d(0.9)	1000.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.00	7.096	0.00	50.238	0.00	355.66	24.20
0.022	0.00	0.159	0.00	1.125	0.00	7.962	0.00	56.368	0.00	399.05	35.49
0.025	0.00	0.178	0.00	1.262	0.00	8.934	0.00	63.246	0.00	447.74	47.61
0.028	0.00	0.200	0.00	1.416	0.00	10.024	0.00	70.963	0.00	500.00	59.22
0.032	0.00	0.224	0.00	1.589	0.00	11.247	0.00	79.621	0.00	1000.00	94.89
0.036	0.00	0.252	0.00	1.783	0.00	12.619	0.00	89.337	0.00	2000.00	98.46
0.040	0.00	0.283	0.00	2.000	0.00	14.159	0.00	100.237	0.00	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.00	15.887	0.00	112.468	0.00		
0.050	0.00	0.356	0.00	2.518	0.00	17.825	0.00	126.191	0.00		
0.056	0.00	0.399	0.00	2.825	0.00	20.000	0.00	141.589	0.00		
0.063	0.00	0.448	0.00	3.170	0.00	22.440	0.00	158.866	0.00		
0.071	0.00	0.502	0.00	3.557	0.00	25.179	0.00	178.250	0.00		
0.080	0.00	0.564	0.00	3.991	0.00	28.251	0.00	200.000	0.25		
0.089	0.00	0.632	0.00	4.477	0.00	31.698	0.00	224.404	1.22		
0.100	0.00	0.710	0.00	5.024	0.00	35.566	0.00	251.785	3.56		
0.112	0.00	0.796	0.00	5.637	0.00	39.905	0.00	282.508	7.94		
0.126	0.00	0.893	0.00	6.325	0.00	44.774	0.00	316.979	14.81		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed:	Angie Thorpe, B.Sc.(Biological Sciences)
Reported:	Angie Thorpe, B.Sc.(Biological Sciences)
Approved:	Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Department of Transport
Job number: 19_1917
Sample: 19_1917_06
Client ID: TBSS02 26-7-19
Date: 29/11/2019
Revision number: 0
Analysis : Semi-quantitative XRD analysis

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 43774 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

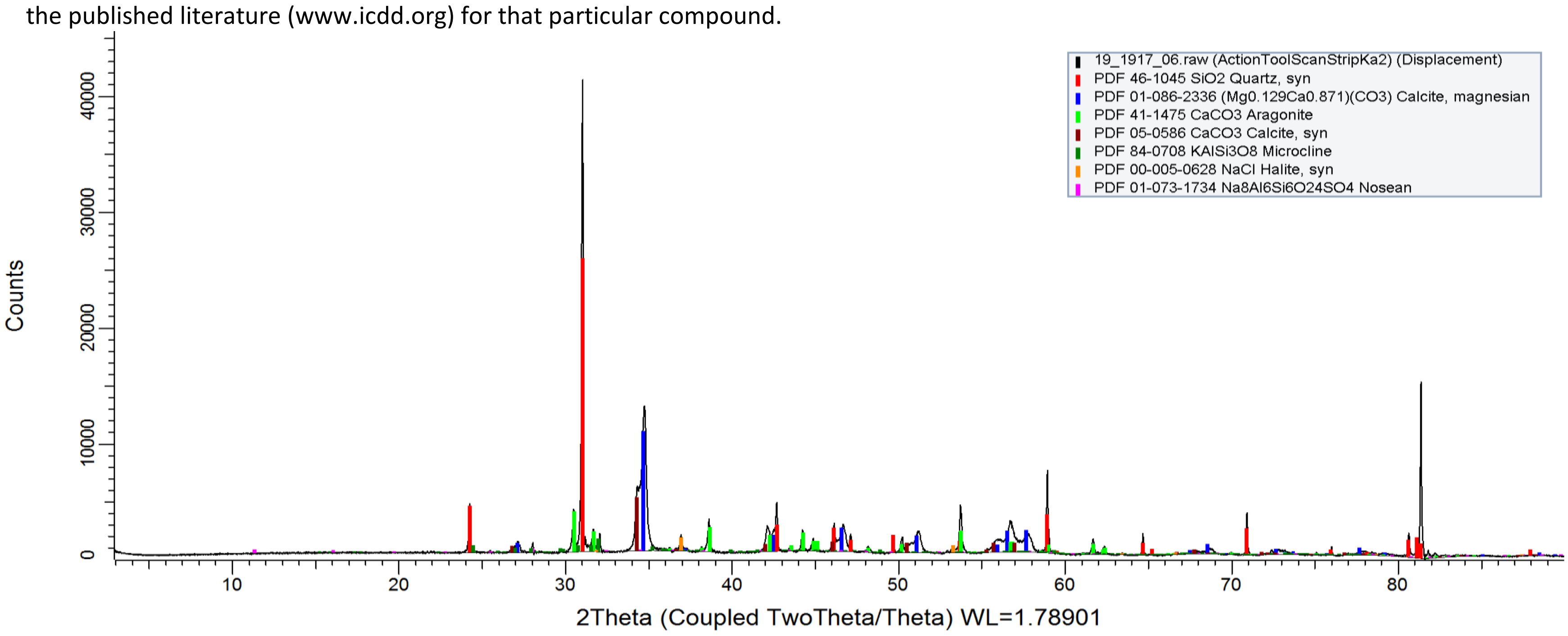
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Mineral phase	Concentration (%)	ICDD match probability
Quartz, syn (SiO2)	39	Good
Calcite, magnesian ((Mg0.129Ca0.871)(CO3))	18	Good
Aragonite (CaCO3)	18	Good
Calcite, syn (CaCO3)	12	Good
Microcline (KAlSi3O8)	10	Low
Halite, syn (NaCl)	1	Low
Nosean (Na8Al6Si6O24SO4)	Trace	Low

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Reported: Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Approved: Ian Davies, B.Sc.(Chemistry)

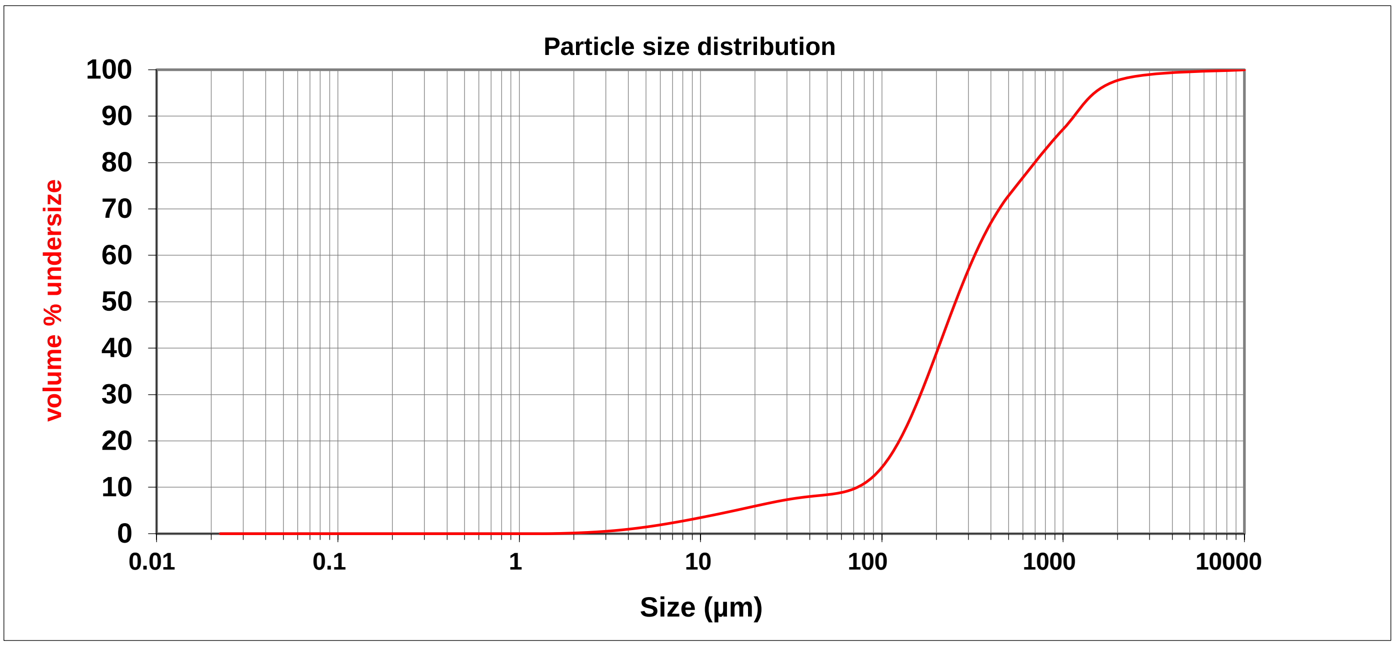
microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Department of Transport
Sample Name : AQUA DOPP 26-7-19
Batch No : 19_1917
Lab ID No : 19_1917_07

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	26.2474
Sonication:	2 min sonication		

Span:	27.84	**Vol. Weighted mean D[4,3]:**	500.47 µm	**d(0.1)**	100.24 µm
		Surface weighted mean D[3,2]	70.79 µm	**d(0.5)**	355.66 µm
				d(0.9)	10000.00 µm



Size (µm)	Vol Under %
0.020	0.00
0.022	0.00
0.025	0.00
0.028	0.00
0.032	0.00
0.036	0.00
0.040	0.00
0.045	0.00
0.050	0.00
0.056	0.00
0.063	0.00
0.071	0.00
0.080	0.00
0.089	0.00
0.100	0.00
0.112	0.00
0.126	0.00

Size (µm)	Vol Under %
0.142	0.00
0.159	0.00
0.178	0.00
0.200	0.00
0.224	0.00
0.252	0.00
0.283	0.00
0.317	0.00
0.356	0.00
0.399	0.00
0.448	0.00
0.502	0.00
0.564	0.00
0.632	0.00
0.710	0.00
0.796	0.00
0.893	0.00

Size (µm)	Vol Under %
1.002	0.00
1.125	0.00
1.262	0.00
1.416	0.00
1.589	0.04
1.783	0.09
2.000	0.15
2.244	0.23
2.518	0.33
2.825	0.45
3.170	0.59
3.557	0.77
3.991	0.97
4.477	1.20
5.024	1.46
5.637	1.74
6.325	2.05

Size (µm)	Vol Under %
7.096	2.38
7.962	2.73
8.934	3.10
10.024	3.47
11.247	3.86
12.619	4.27
14.159	4.68
15.887	5.10
17.825	5.53
20.000	5.96
22.440	6.38
25.179	6.79
28.251	7.16
31.698	7.50
35.566	7.78
39.905	8.02
44.774	8.22

Size (µm)	Vol Under %
50.238	8.42
56.368	8.69
63.246	9.10
70.963	9.76
79.621	10.78
89.337	12.27
100.237	14.33
112.468	17.02
126.191	20.37
141.589	24.33
158.866	28.84
178.250	33.76
200.000	38.94
224.404	44.22
251.785	49.42
282.508	54.40
316.979	59.04

Size (µm)	Vol Under %
355.66	63.25
399.05	66.98
447.74	70.18
500.00	72.85
1000.00	87.18
2000.00	97.72
10000.00	100.00

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Approved: Dan Cukierski, B.Sc.(Geology), M.Sc.(Geoscience)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client:	Department of Transport
Job number:	19_1917
Sample:	19_1917_07
Client ID:	AQUA DOPP 26-7-19
Date:	29/11/2019
Revision number:	0
Analysis :	Semi-quantitative XRD analysis

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 43774 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

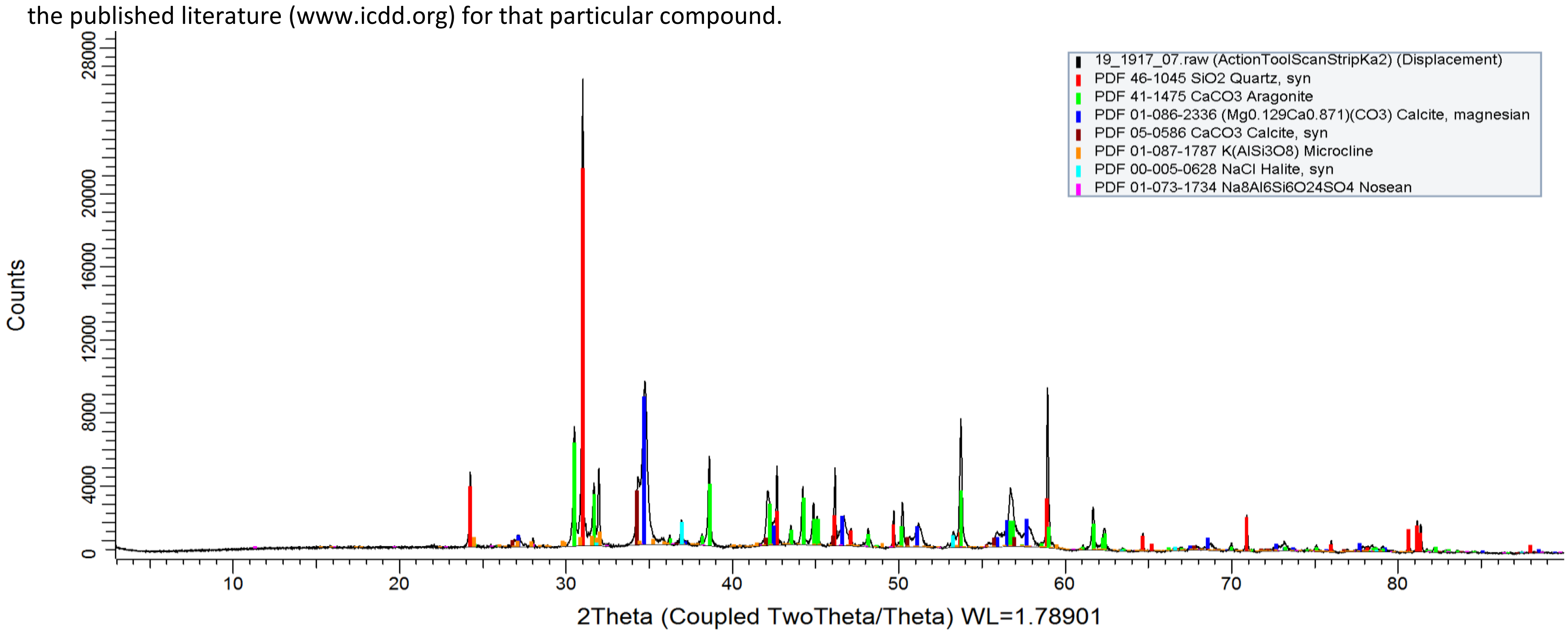
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Mineral phase	Concentration (%)	ICDD match probability
Quartz, syn (SiO2)	34	Good
Aragonite (CaCO3)	32	Good
Calcite, magnesian ((Mg0.129Ca0.871)(CO3))	16	Good
Calcite, syn (CaCO3)	9	Good
Microcline (K(AlSi3O8))	8	Low
Halite, syn (NaCl)	2	Low
Nosean (Na8Al6Si6O24SO4)	Trace	Low

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst:	Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Reported:	Jack van der Pal, B.Sc.(Geology), B.Sc(Geophysics)
Approved:	Ian Davies, B.Sc.(Chemistry)

microanalysis australia

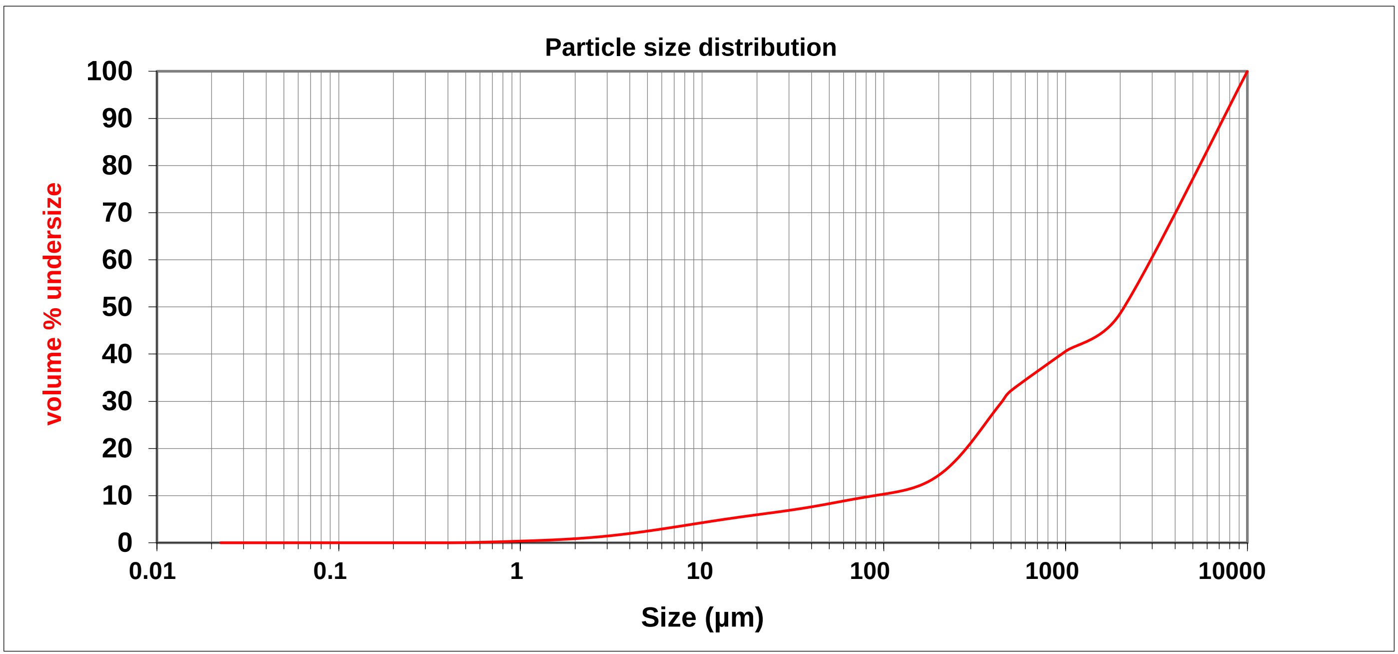
37 Kensington Street
East Perth
WA 6004

Client: Advisian
Sample Name : 18-03-2020 TS-01
Batch No : 20_0489
Lab ID No : 20_0489_01
Revison No : 1
Comment :

This report supersedes "20_0489_01 '18-03-2020 TS-01' PSD by laser diffraction and sieving1 [FINAL].xlsx" to include revised estimates of the D10, D50, D90.

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	5723.77
Sonication:	2 min sonication		

Span:	3.32	**Vol. Weighted mean D[4,3]:**	2537.78 µm	**d(0.1)**	224.40 µm
		Surface weighted mean D[3,2]	51.09 µm	**d(0.5)**	2100.00 µm
				d(0.9)	7200.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.35	7.096	3.35	50.238	8.30	355.66	24.89
0.022	0.00	0.159	0.00	1.125	0.41	7.962	3.65	56.368	8.66	399.05	27.49
0.025	0.00	0.178	0.00	1.262	0.48	8.934	3.95	63.246	9.01	447.74	29.98
0.028	0.00	0.200	0.00	1.416	0.56	10.024	4.25	70.963	9.36	500.00	32.24
0.032	0.00	0.224	0.00	1.589	0.64	11.247	4.55	79.621	9.70	1000.00	40.60
0.036	0.00	0.252	0.00	1.783	0.74	12.619	4.85	89.337	10.01	2000.00	48.68
0.040	0.00	0.283	0.00	2.000	0.86	14.159	5.13	100.237	10.32	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.99	15.887	5.41	112.468	10.64		
0.050	0.00	0.356	0.00	2.518	1.15	17.825	5.67	126.191	11.03		
0.056	0.00	0.399	0.00	2.825	1.32	20.000	5.93	141.589	11.52		
0.063	0.00	0.448	0.01	3.170	1.51	22.440	6.19	158.866	12.19		
0.071	0.00	0.502	0.04	3.557	1.73	25.179	6.45	178.250	13.10		
0.080	0.00	0.564	0.08	3.991	1.96	28.251	6.72	200.000	14.30		
0.089	0.00	0.632	0.12	4.477	2.21	31.698	7.00	224.404	15.83		
0.100	0.00	0.710	0.17	5.024	2.48	35.566	7.29	251.785	17.70		
0.112	0.00	0.796	0.23	5.637	2.76	39.905	7.61	282.508	19.89		
0.126	0.00	0.893	0.28	6.325	3.05	44.774	7.94	316.979	22.32		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Revised: Ian Davies, B.Sc.(Chemistry)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Advisian
Client address: Level 14, 240 St Georges Tce, Perth WA 6000
Job number: 20_0489
Lab ID: 20_0489_01
Client ID: 18-03-2020 TS-01
Revision number: 0
Analysis : Semi-quantitative XRD analysis
Comments: None

Date received: 24th March 2020
Date analysed: 15th April 2020
Date reported: 15th April 2020

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 24th March 2020 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non-crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

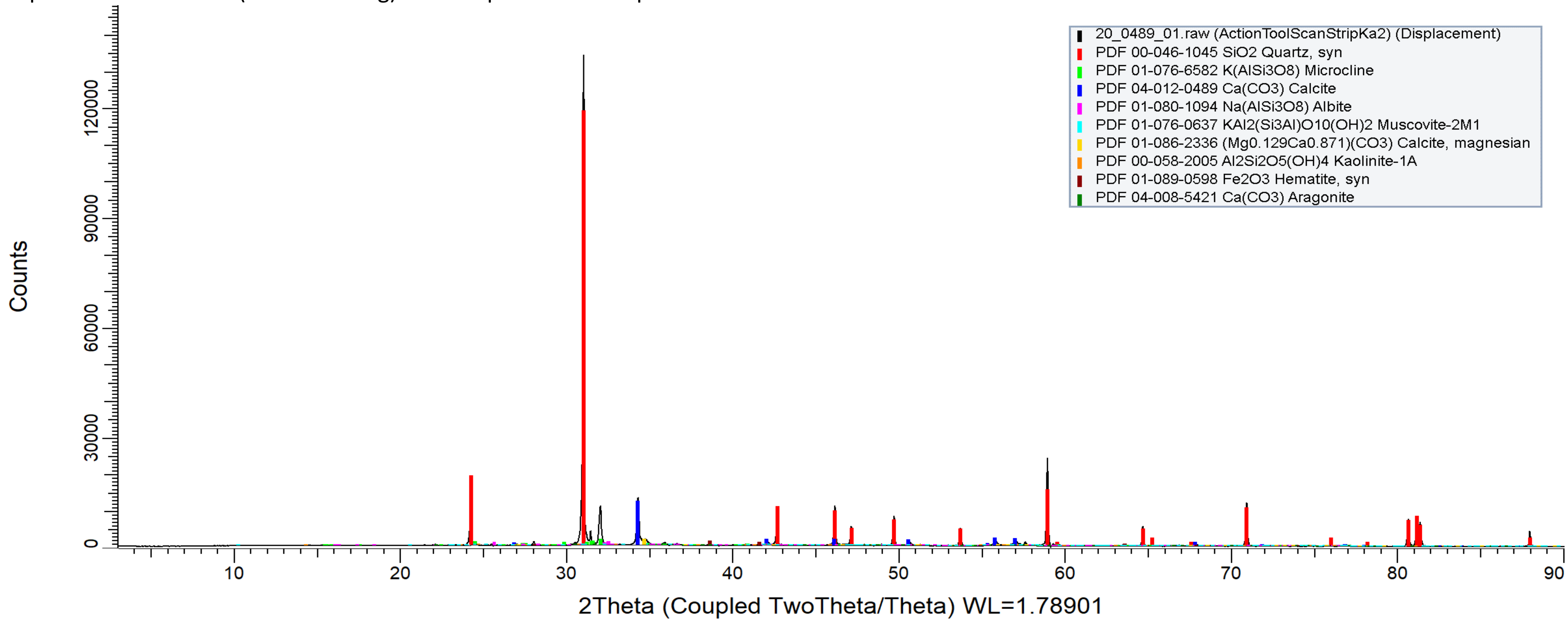
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Crystalline mineral phase	Concentration (%)	ICDD match probability
Quartz, syn (SiO2)	77	Good
Calcite (Ca(CO3))	8	Good
Microcline (K(AlSi3O8))	6	Medium
Albite (Na(AlSi3O8))	4	Medium
Muscovite-2M1 (KAl2(Si3Al)O10(OH)2)	1	Good
Calcite, magnesian ((Mg0.129Ca0.871)(CO3))	1	Good
Hematite, syn (Fe2O3)	1	Medium
Kaolinite-1A (Al2Si2O5(OH)4)	1	Good
Aragonite (Ca(CO3))	1	Medium

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Rhiannan Horton, B.Sc.(Forensic and Analytical Chemistry)(Hons)
Reported: Rhiannan Horton, B.Sc.(Forensic and Analytical Chemistry)(Hons)
Approved: Ian Davies, B.Sc.(Chemistry)

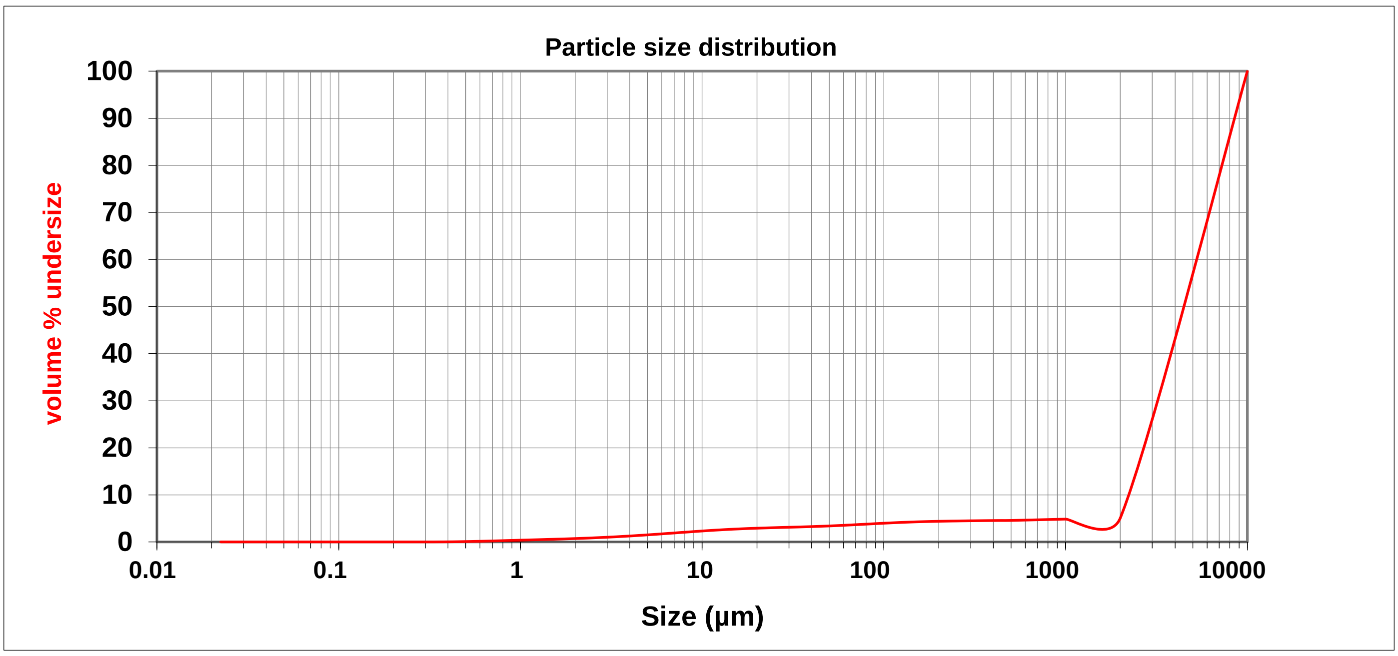
37 Kensington Street
East Perth
WA 6004

Client: Advisian
Sample Name : 18-03-2020 TS-02
Batch No : 20_0489
Lab ID No : 20_0489_02
Revison No : 1
Comment :

This report supersedes "20_0489_02 '18-03-2020 TS-02' PSD by laser diffraction and sieving1 [FINAL].xlsx" to include revised estimates of the D10, D50, D90.

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	2854.742
Sonication:	12 min sonication		

Span:	1.47	**Vol. Weighted mean D[4,3]:**	4251.57 µm	**d(0.1)**	2200.00 µm
		Surface weighted mean D[3,2]	77.58 µm	**d(0.5)**	4300.00 µm
				d(0.9)	8500.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.37	7.096	1.91	50.238	3.39	355.66	4.52
0.022	0.00	0.159	0.00	1.125	0.43	7.962	2.05	56.368	3.48	399.05	4.53
0.025	0.00	0.178	0.00	1.262	0.48	8.934	2.19	63.246	3.57	447.74	4.55
0.028	0.00	0.200	0.00	1.416	0.53	10.024	2.32	70.963	3.67	500.00	4.56
0.032	0.00	0.224	0.00	1.589	0.59	11.247	2.45	79.621	3.77	1000.00	4.84
0.036	0.00	0.252	0.00	1.783	0.65	12.619	2.56	89.337	3.87	2000.00	5.10
0.040	0.00	0.283	0.00	2.000	0.71	14.159	2.67	100.237	3.97	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.78	15.887	2.76	112.468	4.07		
0.050	0.00	0.356	0.00	2.518	0.86	17.825	2.84	126.191	4.15		
0.056	0.00	0.399	0.02	2.825	0.95	20.000	2.91	141.589	4.22		
0.063	0.00	0.448	0.04	3.170	1.04	22.440	2.97	158.866	4.29		
0.071	0.00	0.502	0.07	3.557	1.14	25.179	3.03	178.250	4.34		
0.080	0.00	0.564	0.11	3.991	1.25	28.251	3.08	200.000	4.38		
0.089	0.00	0.632	0.16	4.477	1.37	31.698	3.14	224.404	4.42		
0.100	0.00	0.710	0.21	5.024	1.50	35.566	3.19	251.785	4.45		
0.112	0.00	0.796	0.26	5.637	1.63	39.905	3.25	282.508	4.47		
0.126	0.00	0.893	0.32	6.325	1.77	44.774	3.32	316.979	4.50		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Approved: Ian Davies, B.Sc.(Chemistry)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Advisian
Client address: Level 14, 240 St Georges Tce, Perth WA 6000
Job number: 20_0489
Lab ID: 20_0489_02
Client ID: 18-03-2020 TS-02
Revision number: 0
Analysis : Semi-quantitative XRD analysis
Comments: None

Date received: 24th March 2020
Date analysed: 15th April 2020
Date reported: 15th April 2020

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 24th March 2020 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non-crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

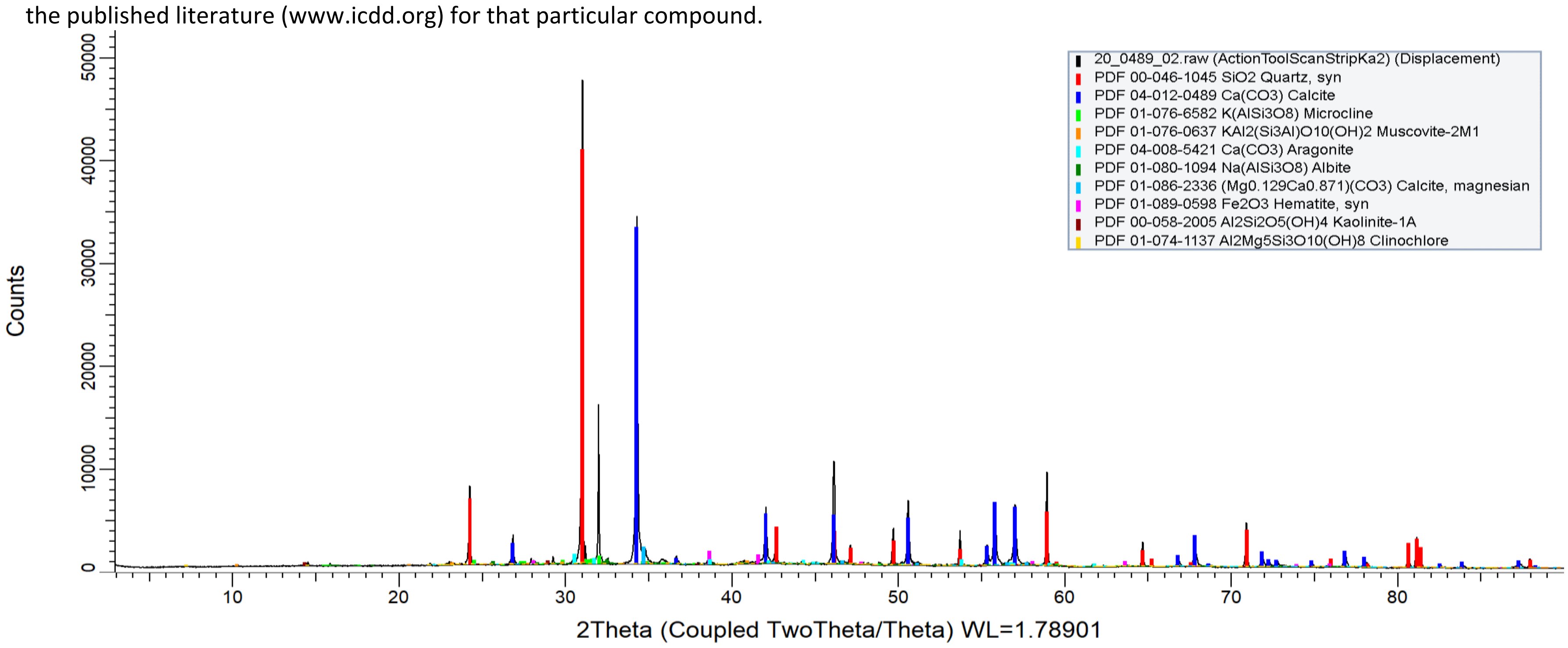
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Crystalline mineral phase	Concentration (%)	ICDD match probability
Quartz, syn (SiO2)	44	Good
Calcite (Ca(CO3))	36	Good
Microcline (K(AlSi3O8))	5	Medium
Muscovite-2M1 (KAl2(Si3Al)O10(OH)2)	3	Medium
Aragonite (Ca(CO3))	3	Medium
Albite (Na(AlSi3O8))	3	Medium
Calcite, magnesian ((Mg0.129Ca0.871)(CO3))	2	Good
Hematite, syn (Fe2O3)	2	Good
Kaolinite-1A (Al2Si2O5(OH)4)	1	Good
Clinochlore (Al2Mg5Si3O10(OH)8)	1	Medium

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Rhiannan Horton, B.Sc.(Forensic and Analytical Chemistry)(Hons)
Reported: Rhiannan Horton, B.Sc.(Forensic and Analytical Chemistry)(Hons)
Approved: Ian Davies, B.Sc.(Chemistry)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Advisian

Sample Name : 18-03-2020 TS-03

Batch No : 20_0489

Lab ID No : 20_0489_03

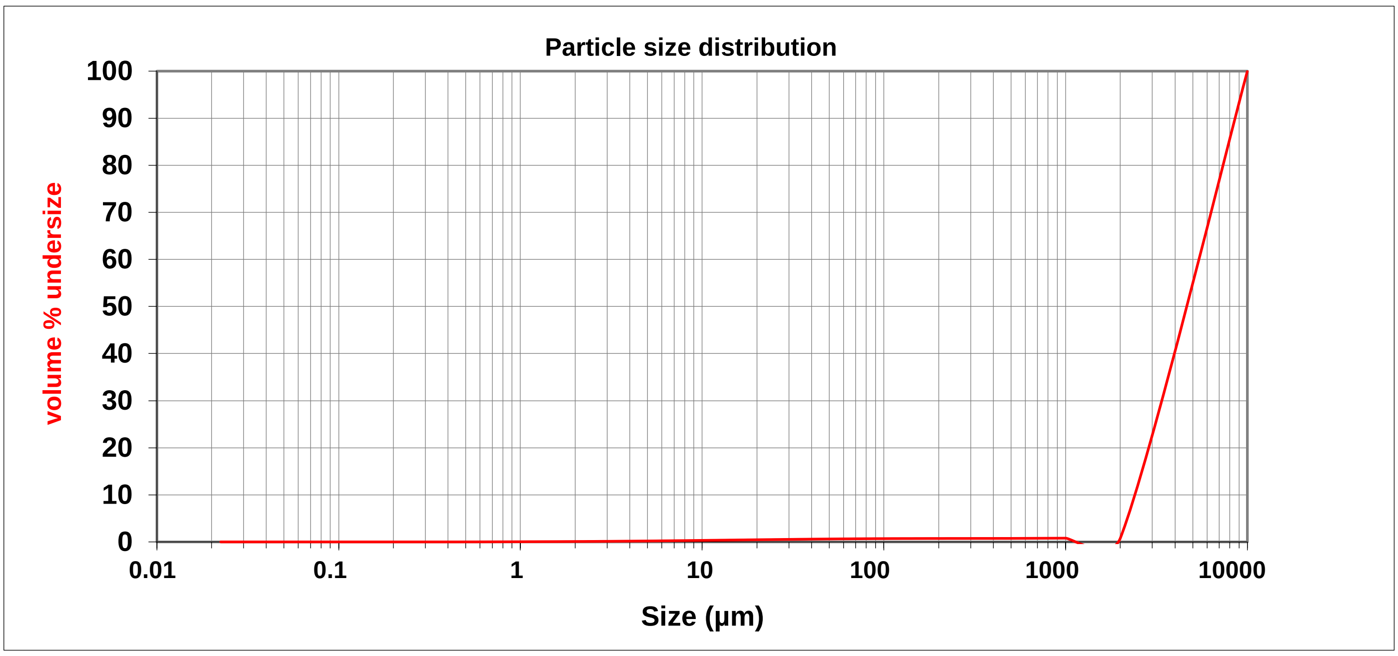
Revison No : 1

Comment :

This report supersedes "220_0489_03 '18-03-2020 TS-03' PSD by laser diffraction and sieving1 [FINAL].xlsx" to include revised estimates of the D10, D50, D90.

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	2125.694
Sonication:	6 min sonication		

Span:	1.33	**Vol. Weighted mean D[4,3]:**	4436.84 µm	**d(0.1)**	2400.00 µm
		Surface weighted mean D[3,2]	551.42 µm	**d(0.5)**	4750.00 µm
				d(0.9)	8700.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.04	7.096	0.26	50.238	0.62	355.66	0.74
0.022	0.00	0.159	0.00	1.125	0.04	7.962	0.28	56.368	0.64	399.05	0.74
0.025	0.00	0.178	0.00	1.262	0.05	8.934	0.30	63.246	0.65	447.74	0.74
0.028	0.00	0.200	0.00	1.416	0.06	10.024	0.32	70.963	0.67	500.00	0.74
0.032	0.00	0.224	0.00	1.589	0.07	11.247	0.34	79.621	0.68	1000.00	0.79
0.036	0.00	0.252	0.00	1.783	0.07	12.619	0.37	89.337	0.69	2000.00	0.81
0.040	0.00	0.283	0.00	2.000	0.08	14.159	0.39	100.237	0.70	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.09	15.887	0.41	112.468	0.71		
0.050	0.00	0.356	0.00	2.518	0.11	17.825	0.44	126.191	0.71		
0.056	0.00	0.399	0.00	2.825	0.12	20.000	0.46	141.589	0.72		
0.063	0.00	0.448	0.00	3.170	0.13	22.440	0.48	158.866	0.72		
0.071	0.00	0.502	0.01	3.557	0.15	25.179	0.50	178.250	0.72		
0.080	0.00	0.564	0.01	3.991	0.16	28.251	0.53	200.000	0.73		
0.089	0.00	0.632	0.01	4.477	0.18	31.698	0.55	224.404	0.73		
0.100	0.00	0.710	0.02	5.024	0.20	35.566	0.57	251.785	0.73		
0.112	0.00	0.796	0.02	5.637	0.22	39.905	0.59	282.508	0.73		
0.126	0.00	0.893	0.03	6.325	0.24	44.774	0.61	316.979	0.73		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Approved: Ian Davies, B.Sc.(Chemistry)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Advisian
Client address: Level 14, 240 St Georges Tce, Perth WA 6000
Job number: 20_0489
Lab ID: 20_0489_03
Client ID: 18-03-2020 TS-03
Revision number: 0
Analysis : Semi-quantitative XRD analysis
Comments: None

Date received: 24th March 2020
Date analysed: 15th April 2020
Date reported: 15th April 2020

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 24th March 2020 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non-crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

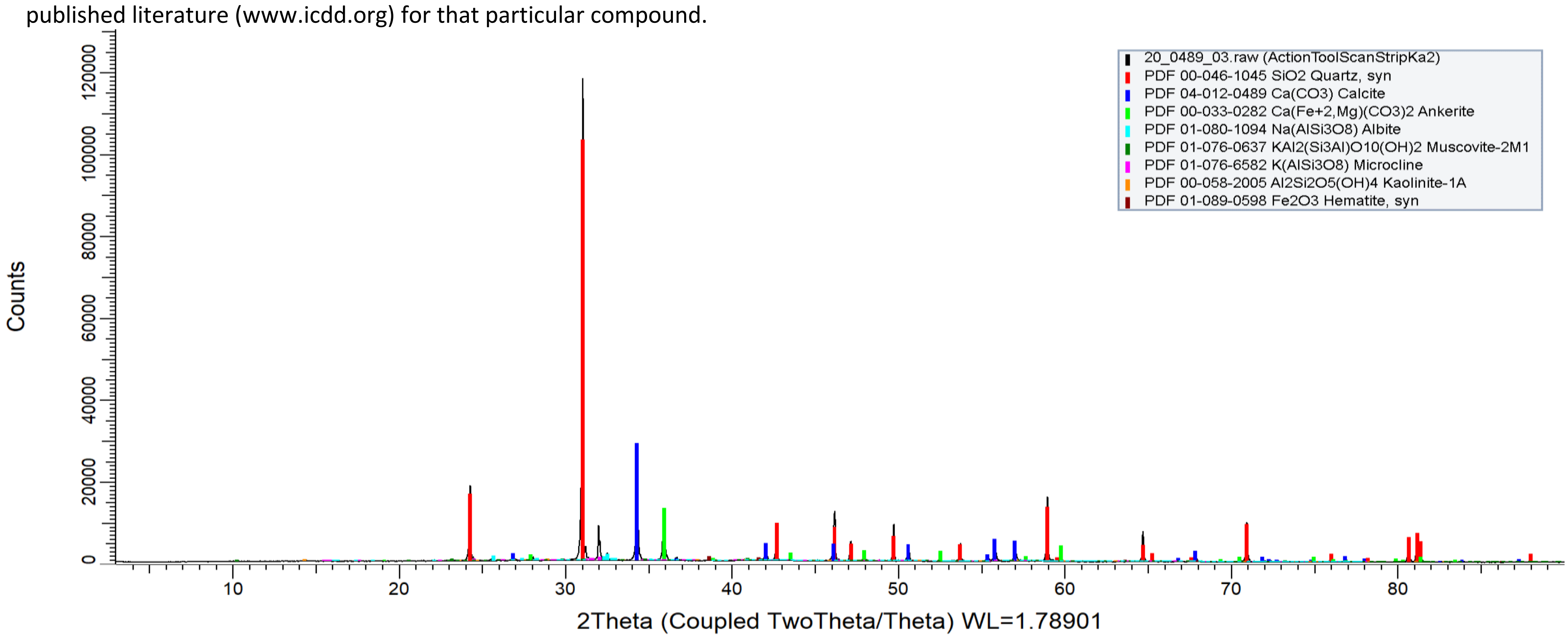
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Crystalline mineral phase	Concentration (%)	ICDD match probability
Quartz, syn (SiO2)	61	Good
Calcite (Ca(CO3))	17	Good
Ankerite (Ca(Fe+2,Mg)(CO3)2)	9	Good
Albite (Na(AlSi3O8))	5	Medium
Muscovite-2M1 (KAl2(Si3Al)O10(OH)2)	3	Medium
Microcline (K(AlSi3O8))	3	Medium
Kaolinite-1A (Al2Si2O5(OH)4)	1	Good
Hematite, syn (Fe2O3)	1	Good

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Rhiannan Horton, B.Sc.(Forensic and Analytical Chemistry)(Hons)
Reported: Rhiannan Horton, B.Sc.(Forensic and Analytical Chemistry)(Hons)
Approved: Ian Davies, B.Sc.(Chemistry)

microanalysis australia

37 Kensington Street
East Perth
WA 6004

Client: Advisian

Sample Name : 18-03-2020 TS-04

Batch No : 20_0489

Lab ID No : 20_0489_04

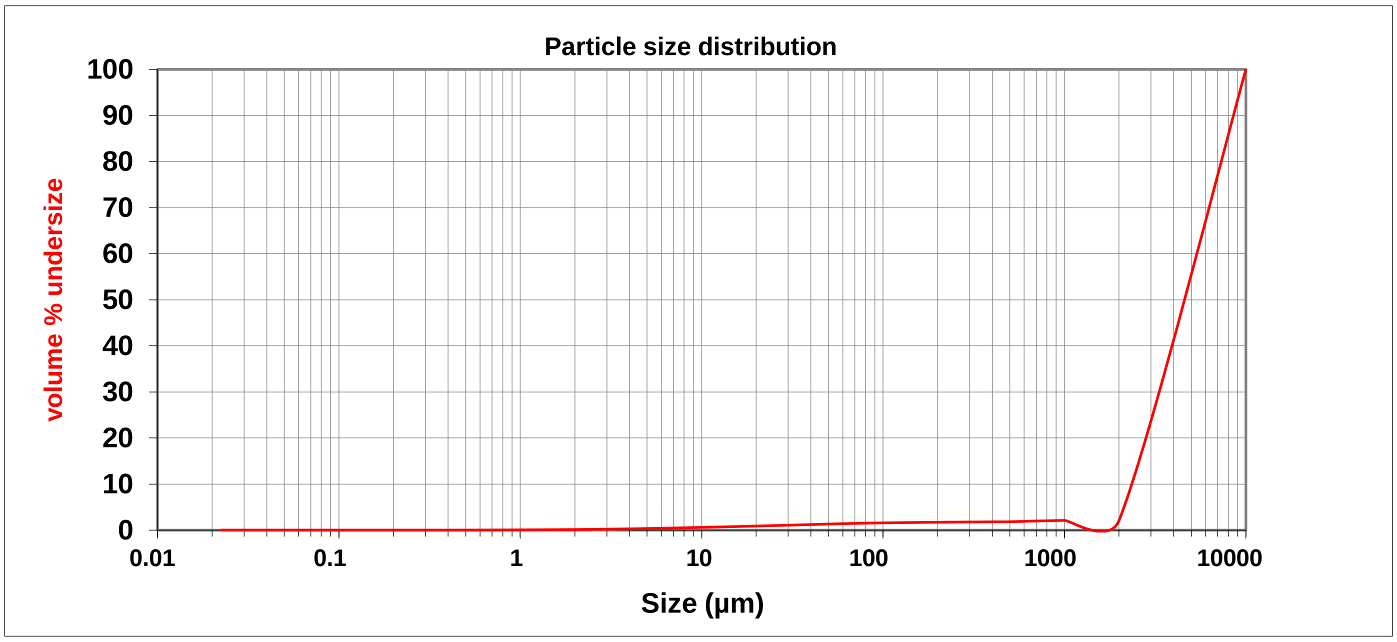
Revison No : 1

Comment :

This report supersedes "20_0489_04 '18-03-2020 TS-04' PSD by laser diffraction and sieving Revised 1 (FINAL).xlsx" to include revised estimates of the D10, D50, D90.

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	1029.22
Sonication:	8 min sonication		

Span:	1.39	**Vol. Weighted mean D[4,3]:**	4379.64 µm	**d(0.1)**	2300.00 µm
		Surface weighted mean D[3,2]	317.09 µm	**d(0.5)**	4450.00 µm
				d(0.9)	8500.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.06	7.096	0.47	50.238	1.32	355.66	1.79
0.022	0.00	0.159	0.00	1.125	0.07	7.962	0.52	56.368	1.38	399.05	1.81
0.025	0.00	0.178	0.00	1.262	0.09	8.934	0.56	63.246	1.43	447.74	1.82
0.028	0.00	0.200	0.00	1.416	0.10	10.024	0.61	70.963	1.47	500.00	1.82
0.032	0.00	0.224	0.00	1.589	0.11	11.247	0.65	79.621	1.51	1000.00	2.12
0.036	0.00	0.252	0.00	1.783	0.13	12.619	0.70	89.337	1.55	2000.00	2.14
0.040	0.00	0.283	0.00	2.000	0.14	14.159	0.75	100.237	1.58	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.16	15.887	0.79	112.468	1.61		
0.050	0.00	0.356	0.00	2.518	0.18	17.825	0.84	126.191	1.64		
0.056	0.00	0.399	0.00	2.825	0.20	20.000	0.89	141.589	1.66		
0.063	0.00	0.448	0.00	3.170	0.23	22.440	0.94	158.866	1.68		
0.071	0.00	0.502	0.01	3.557	0.26	25.179	1.00	178.250	1.70		
0.080	0.00	0.564	0.02	3.991	0.29	28.251	1.05	200.000	1.71		
0.089	0.00	0.632	0.02	4.477	0.32	31.698	1.10	224.404	1.73		
0.100	0.00	0.710	0.03	5.024	0.36	35.566	1.16	251.785	1.75		
0.112	0.00	0.796	0.04	5.637	0.39	39.905	1.21	282.508	1.76		
0.126	0.00	0.893	0.05	6.325	0.43	44.774	1.27	316.979	1.78		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Approved: Ian Davies, B.Sc.(Chemistry)

37 Kensington Street
East Perth
WA 6004

Client: Advisian
Client address: Level 14, 240 St Georges Tce, Perth WA 6000
Job number: 20_0489
Lab ID: 20_0489_04
Client ID: 18-03-2020 TS-04
Revision number: 0
Analysis : Semi-quantitative XRD analysis
Comments: None

Date received: 24th March 2020
Date analysed: 15th April 2020
Date reported: 15th April 2020

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 24th March 2020 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non-crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

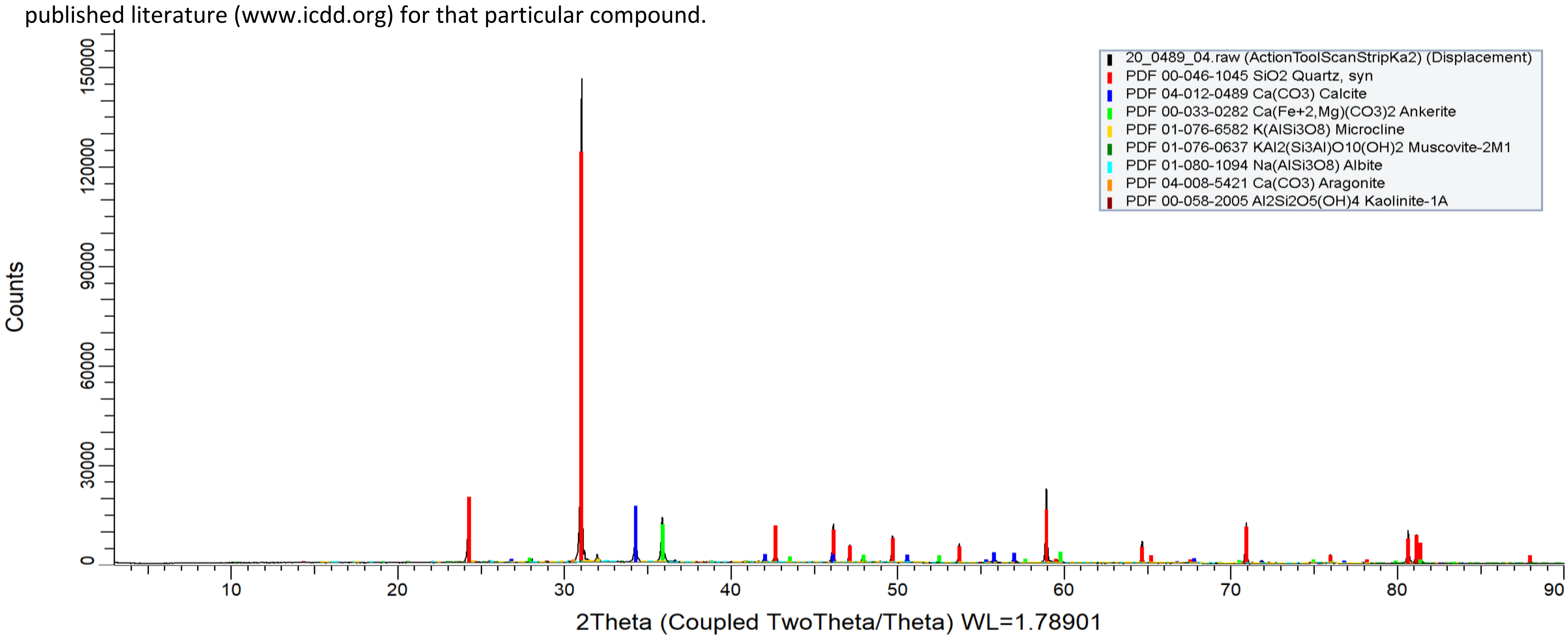
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Crystalline mineral phase	Concentration (%)	ICDD match probability
Quartz, syn (SiO2)	72	Good
Calcite (Ca(CO3))	10	Good
Ankerite (Ca(Fe+2,Mg)(CO3)2)	8	Good
Microcline (K(AlSi3O8))	4	Medium
Muscovite-2M1 (KAl2(Si3Al)O10(OH)2)	3	Medium
Albite (Na(AlSi3O8))	2	Medium
Aragonite (Ca(CO3))	1	Good
Kaolinite-1A (Al2Si2O5(OH)4)	1	Good

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Rhiannan Horton, B.Sc.(Forensic and Analytical Chemistry)(Hons)
Reported: Rhiannan Horton, B.Sc.(Forensic and Analytical Chemistry)(Hons)
Approved: Ian Davies, B.Sc.(Chemistry)

37 Kensington Street
East Perth
WA 6004

Client: Advisian

Sample Name : 18-03-2020 TS-05

Batch No : 20_0489

Lab ID No : 20_0489_05

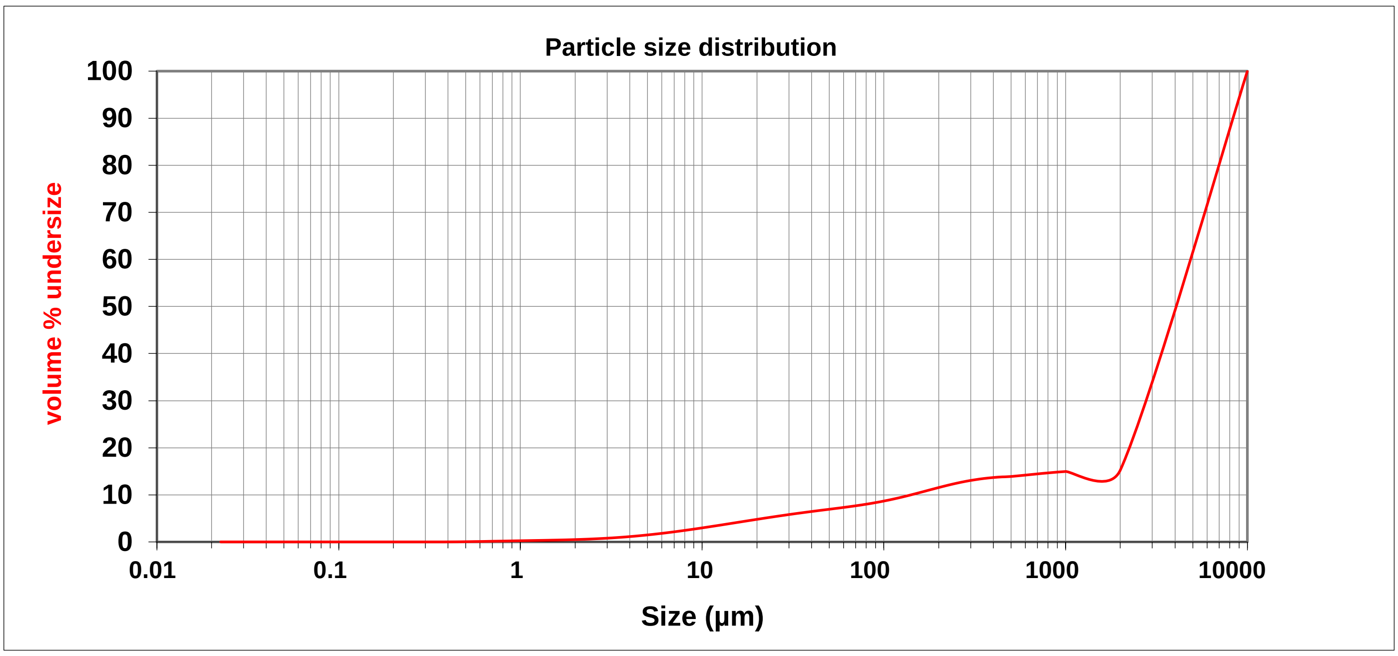
Revison No : 1

Comment :

This report supersedes "20_0489_05 '18-03-2020 TS-05' PSD by laser diffraction and sieving1 [FINAL].xlsx" to include revised estimates of the D10, D50, D90.

Analysis :	Size distribution by laser diffraction following ISO13320-1:2009 and wet sieving	**Result units:**	Volume
Dispersant:	Water	**Analysis model:**	General purpose
Additives:	10 millilitres sodium hexametaphosphate	**Total sample wt (g):**	1643.61
Sonication:	2 min sonication		

Span:	2.01	**Vol. Weighted mean D[4,3]:**	3814.50 µm	**d(0.1)**	178.25 µm
		Surface weighted mean D[3,2]	74.44 µm	**d(0.5)**	4100.00 µm
				d(0.9)	8400.00 µm



Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %	Size (µm)	Vol Under %
0.020	0.00	0.142	0.00	1.002	0.25	7.096	2.17	50.238	6.94	355.66	13.47
0.022	0.00	0.159	0.00	1.125	0.28	7.962	2.43	56.368	7.19	399.05	13.67
0.025	0.00	0.178	0.00	1.262	0.32	8.934	2.70	63.246	7.44	447.74	13.81
0.028	0.00	0.200	0.00	1.416	0.35	10.024	2.98	70.963	7.71	500.00	13.89
0.032	0.00	0.224	0.00	1.589	0.39	11.247	3.28	79.621	8.00	1000.00	14.95
0.036	0.00	0.252	0.00	1.783	0.44	12.619	3.57	89.337	8.33	2000.00	15.27
0.040	0.00	0.283	0.00	2.000	0.49	14.159	3.88	100.237	8.69	10000.00	100.00
0.045	0.00	0.317	0.00	2.244	0.56	15.887	4.18	112.468	9.09		
0.050	0.00	0.356	0.00	2.518	0.64	17.825	4.49	126.191	9.54		
0.056	0.00	0.399	0.01	2.825	0.73	20.000	4.79	141.589	10.01		
0.063	0.00	0.448	0.02	3.170	0.85	22.440	5.09	158.866	10.52		
0.071	0.00	0.502	0.04	3.557	0.98	25.179	5.38	178.250	11.03		
0.080	0.00	0.564	0.07	3.991	1.13	28.251	5.66	200.000	11.54		
0.089	0.00	0.632	0.10	4.477	1.30	31.698	5.94	224.404	12.03		
0.100	0.00	0.710	0.14	5.024	1.49	35.566	6.20	251.785	12.48		
0.112	0.00	0.796	0.18	5.637	1.70	39.905	6.45	282.508	12.87		
0.126	0.00	0.893	0.21	6.325	1.92	44.774	6.70	316.979	13.20		

Note: Data from 500µm to 10000µm by wet screening, from 0.02µm to 500µm by laser diffraction.

Analysed: Angie Thorpe, B.Sc.(Biological Sciences)
Reported: Angie Thorpe, B.Sc.(Biological Sciences)
Approved: Ian Davies, B.Sc.(Chemistry)

37 Kensington Street
East Perth
WA 6004

Client: Advisian
Client address: Level 14, 240 St Georges Tce, Perth WA 6000
Job number: 20_0489
Lab ID: 20_0489_05
Client ID: 18-03-2020 TS-05
Revision number: 0
Analysis : Semi-quantitative XRD analysis
Comments: None

Date received: 24th March 2020
Date analysed: 15th April 2020
Date reported: 15th April 2020

Sample preparation

The sample was supplied by the client to Microanalysis Australia on 24th March 2020 for the above mentioned analyses. A representative sub-sample was removed and lightly ground such that 90% was passing 20 µm. Grinding to this size helps eliminate preferred orientation.

Analysis

Only crystalline material present in the sample will give peaks in the XRD scan. Amorphous (non-crystalline) material will add to the background. The search match software used was Eva 4.3. An up-to-date ICDD card set was used. The X-ray source was cobalt radiation.

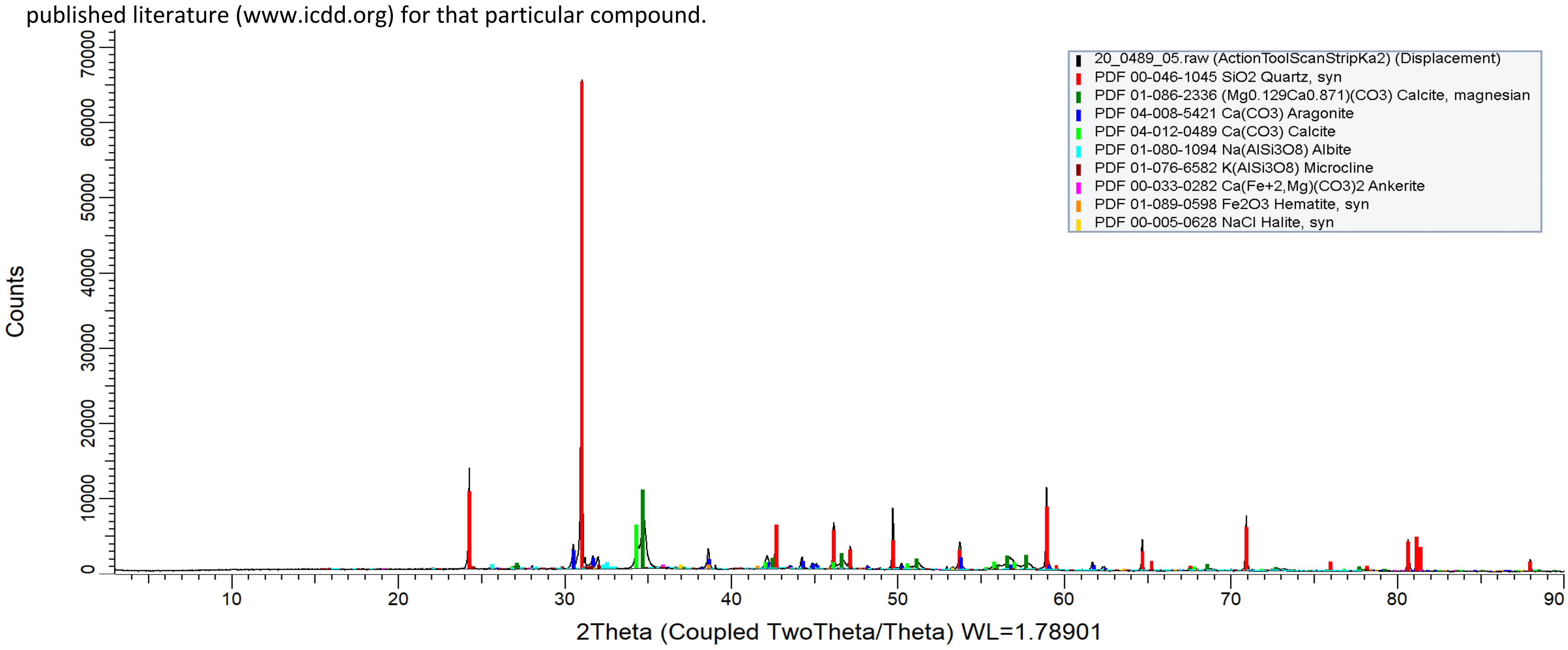
No standards were used in the quantification process. The concentrations were calculated using the normalized reference intensity ratio method where the intensity of the 100% peak divided by the published I/Ic value for each mineral phase is summed and the relative percentages of each phase calculated based on the relative contribution to the sum. This method allows for slight attention to be paid to preferred orientation but is limited in considering other factors including but not limited to; variable crystallinity, alteration, fluorescence, substitution and lattice strain.

Summary

The phases are listed in order of interpreted concentration:

Crystalline mineral phase	Concentration (%)	ICDD match probability
Quartz, syn (SiO2)	65	Good
Calcite, magnesian ((Mg0.129Ca0.871)(CO3))	12	Good
Aragonite (Ca(CO3))	7	Good
Calcite (Ca(CO3))	6	Good
Albite (Na(AlSi3O8))	4	Medium
Microcline (K(AlSi3O8))	3	Medium
Ankerite (Ca(Fe+2,Mg)(CO3)2)	1	Good
Hematite, syn (Fe2O3)	1	Good
Halite, syn (NaCl)	trace	Medium

The ICDD match probability is reported as an indication as to how well the peak positions and relative intensities for the sample matched those in the published literature (www.icdd.org) for that particular compound.



Analyst: Rhiannan Horton, B.Sc.(Forensic and Analytical Chemistry)(Hons)
Reported: Rhiannan Horton, B.Sc.(Forensic and Analytical Chemistry)(Hons)
Approved: Ian Davies, B.Sc.(Chemistry)

Appendix F Flood Modelling Results

Tantabiddi Creek Hydrology and Geomorphology Study

LEGEND

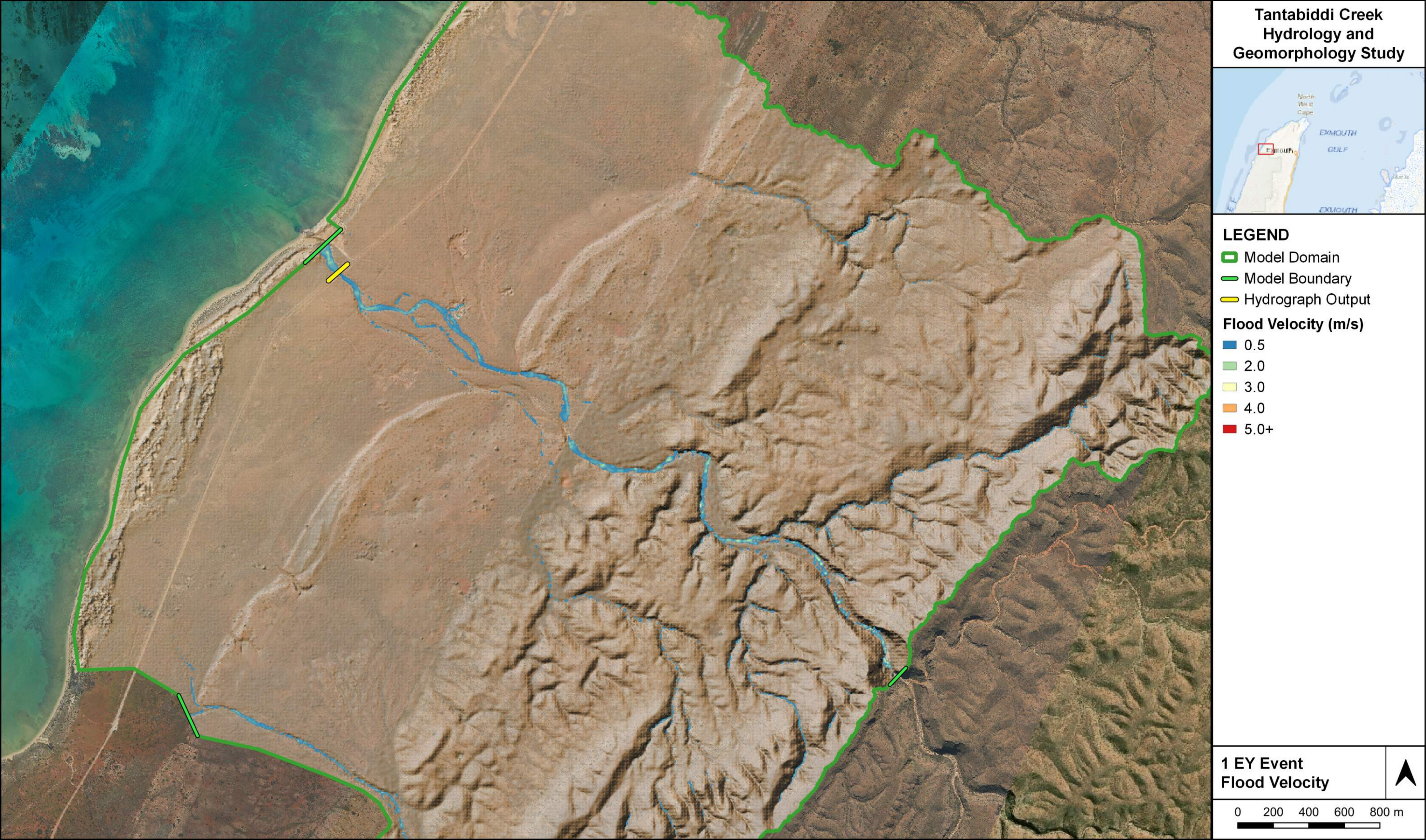
- Model Domain
- Model Boundary
- Hydrograph Output

Flood Depth (m)

- 0.05
- 0.1
- 1.0
- 2.0
- 3.0+

1 EY Event Flood Depth

0 200 400 600 800 m



Tantabiddi Creek Hydrology and Geomorphology Study
North West Cape
EXMOUTH GULF
Exmouth
LEGEND
Model Domain
Model Boundary
Hydrograph Output
Flood Velocity (m/s)
0.5
2.0
3.0
4.0
5.0+
1 EY Event Flood Velocity
0 200 400 600 800 m


Tantabiddi Creek Hydrology and Geomorphology Study
North West Cape
EXMOUTH GULF
Exmouth
EXMOUTH
LEGEND
Model Domain
Model Boundary
Hydrograph Output
Flood Depth (m)
0.05
0.1
1.0
2.0
3.0+
1 in 2 AEP Event Flood Depth
0 200 400 600 800 m

Tantabiddi Creek Hydrology and Geomorphology Study

LEGEND

- Model Domain
- Model Boundary
- Hydrograph Output

Flood Velocity (m/s)

- 0.5
- 2.0
- 3.0
- 4.0
- 5.0+

1 in 2 AEP Event Flood Velocity

0 200 400 600 800 m


Tantabiddi Creek Hydrology and Geomorphology Study
North West Cape
EXMOUTH
GULF
LEGEND
Model Domain
Model Boundary
Hydrograph Output
Flood Depth (m)
0.05
0.1
1.0
2.0
3.0+
1 in 5 AEP Event Flood Depth
0
200
400
600
800 m

Tantabiddi Creek Hydrology and Geomorphology Study

LEGEND

- Model Domain
- Model Boundary
- Hydrograph Output

Flood Velocity (m/s)

- 0.5
- 2.0
- 3.0
- 4.0
- 5.0+

1 in 5 AEP Event Flood Velocity

0 200 400 600 800 m

Tantabiddi Creek Hydrology and Geomorphology Study

LEGEND

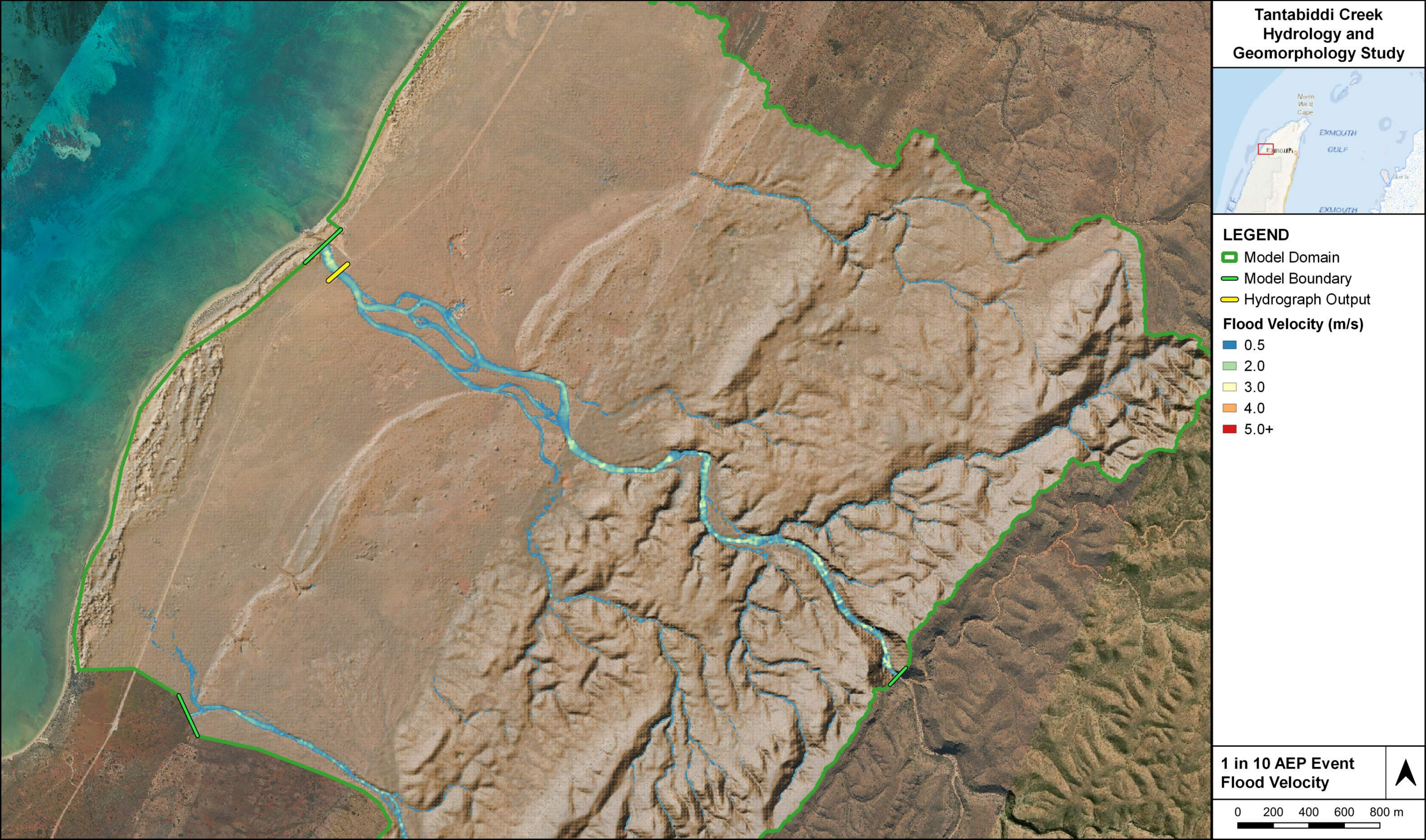
- Model Domain
- Model Boundary
- Hydrograph Output

Flood Depth (m)

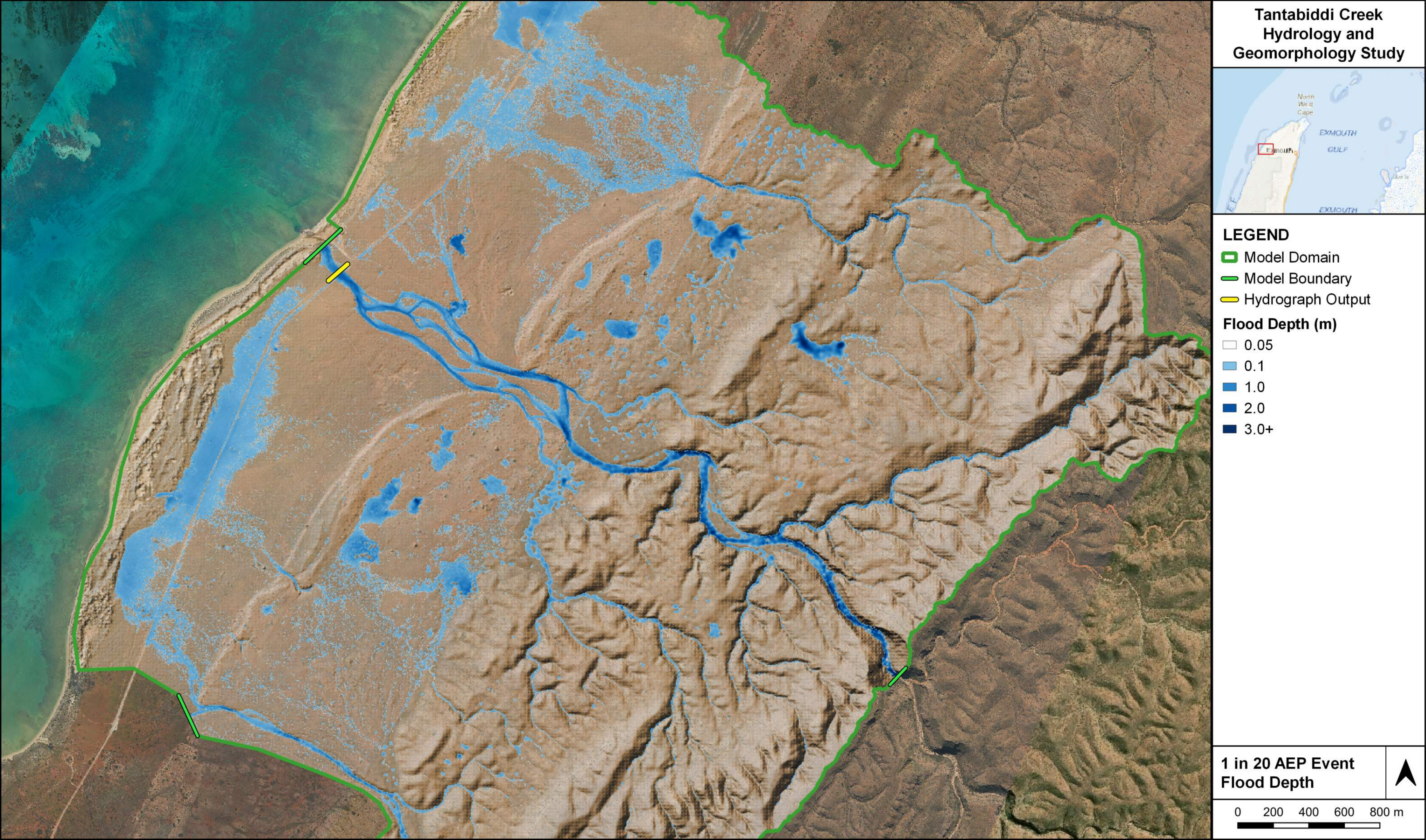
- 0.05
- 0.1
- 1.0
- 2.0
- 3.0+

1 in 10 AEP Event Flood Depth

0 200 400 600 800 m



Tantabiddi Creek Hydrology and Geomorphology Study
North West Cape
EXMOUTH GULF
Exmouth
LEGEND
Model Domain
Model Boundary
Hydrograph Output
Flood Velocity (m/s)
0.5
2.0
3.0
4.0
5.0+
1 in 10 AEP Event Flood Velocity
0
200
400
600
800 m


Tantabiddi Creek
Hydrology and
Geomorphology Study
North West Cape
EXMOUTH
GULF
Exmouth
LEGEND
Model Domain
Model Boundary
Hydrograph Output
Flood Depth (m)
0.05
0.1
1.0
2.0
3.0+
1 in 20 AEP Event
Flood Depth
0 200 400 600 800 m

Tantabiddi Creek Hydrology and Geomorphology Study

LEGEND

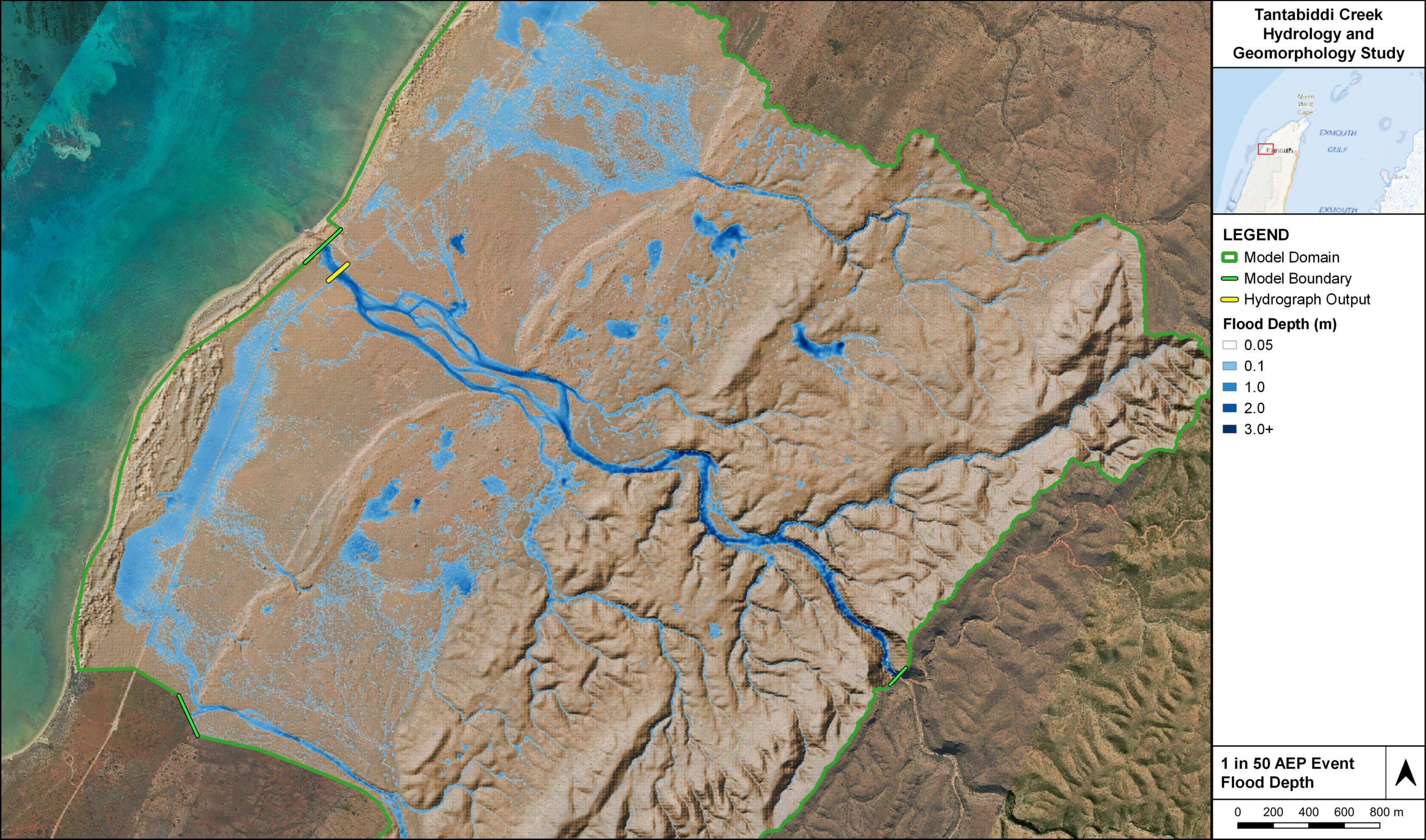
- Model Domain
- Model Boundary
- Hydrograph Output

Flood Velocity (m/s)

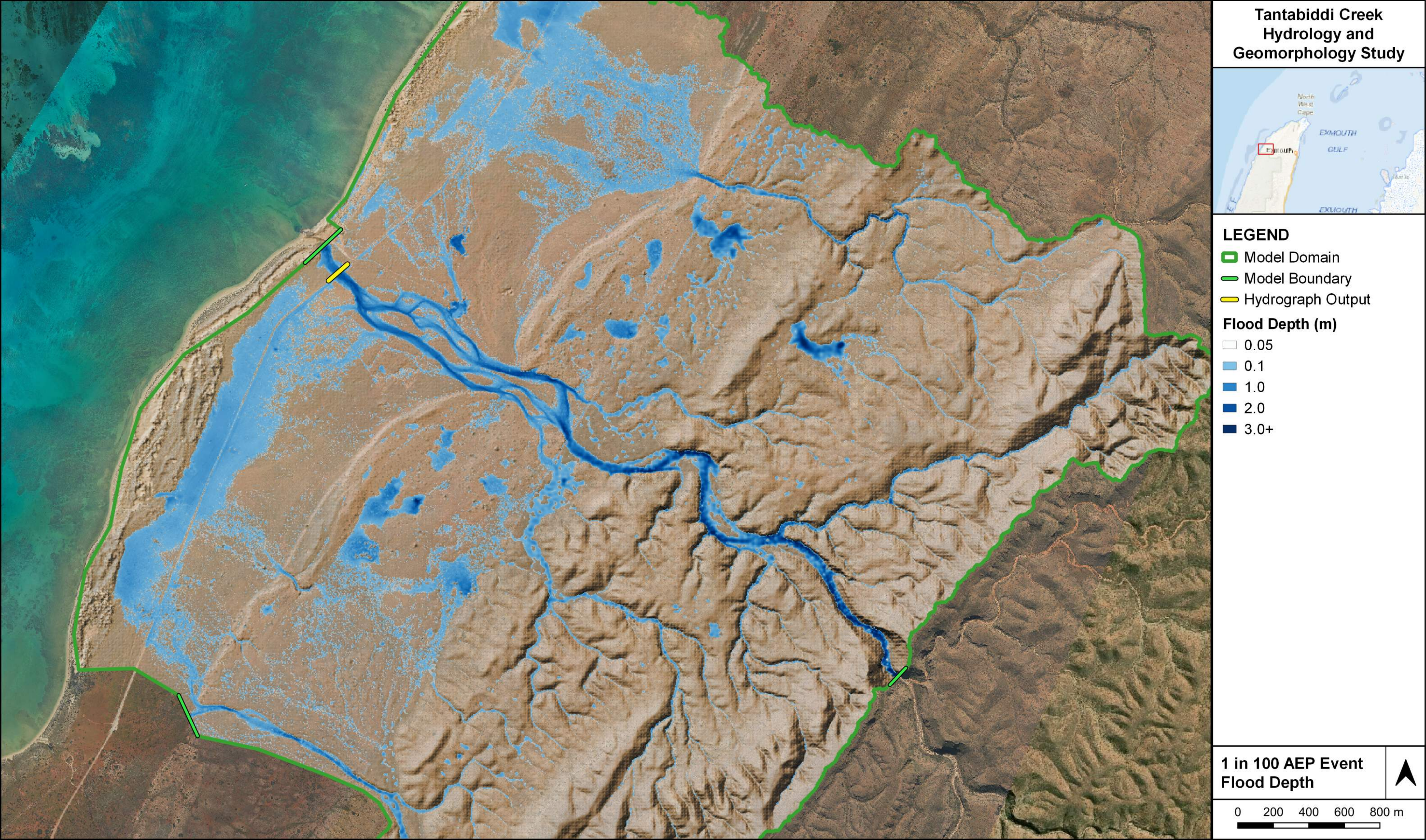
- 0.5
- 2.0
- 3.0
- 4.0
- 5.0+

1 in 20 AEP Event Flood Velocity

0 200 400 600 800 m


Tantabiddi Creek
Hydrology and
Geomorphology Study
North West Cape
EXMOUTH GULF
Exmouth
LEGEND
Model Domain
Model Boundary
Hydrograph Output
Flood Depth (m)
0.05
0.1
1.0
2.0
3.0+
1 in 50 AEP Event
Flood Depth
0 200 400 600 800 m

Tantabiddi Creek Hydrology and Geomorphology Study
North West Cape
EXMOUTH GULF
LEGEND
Model Domain
Model Boundary
Hydrograph Output
Flood Velocity (m/s)
0.5
2.0
3.0
4.0
5.0+
1 in 50 AEP Event Flood Velocity
0 200 400 600 800 m


Tantabiddi Creek Hydrology and Geomorphology Study
North West Cape
EXMOUTH GULF
Exmouth
LEGEND
Model Domain
Model Boundary
Hydrograph Output
Flood Depth (m)
0.05
0.1
1.0
2.0
3.0+
1 in 100 AEP Event Flood Depth
0 200 400 600 800 m

Tantabiddi Creek Hydrology and Geomorphology Study

LEGEND

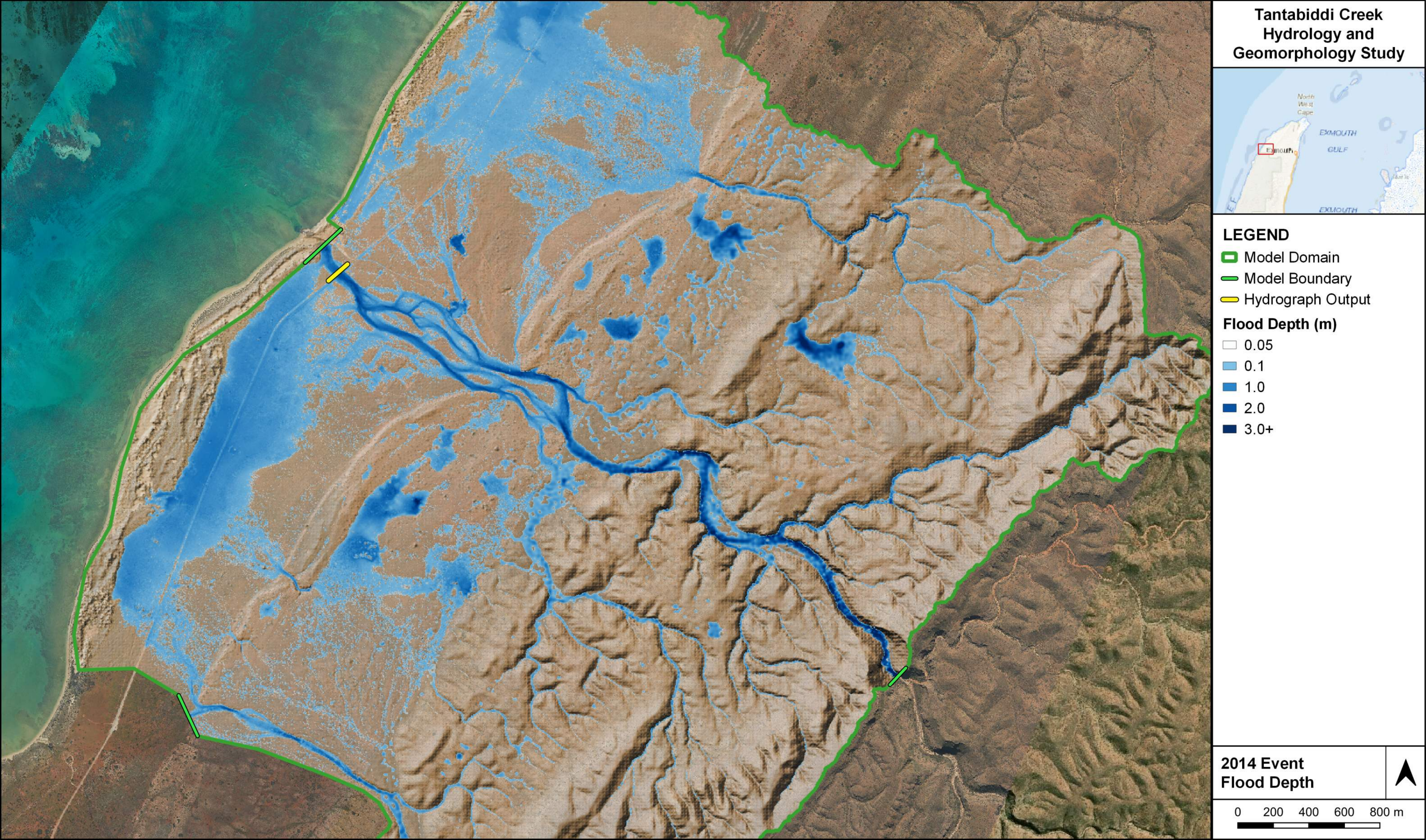
- Model Domain
- Model Boundary
- Hydrograph Output

Flood Velocity (m/s)

- 0.5
- 2.0
- 3.0
- 4.0
- 5.0+

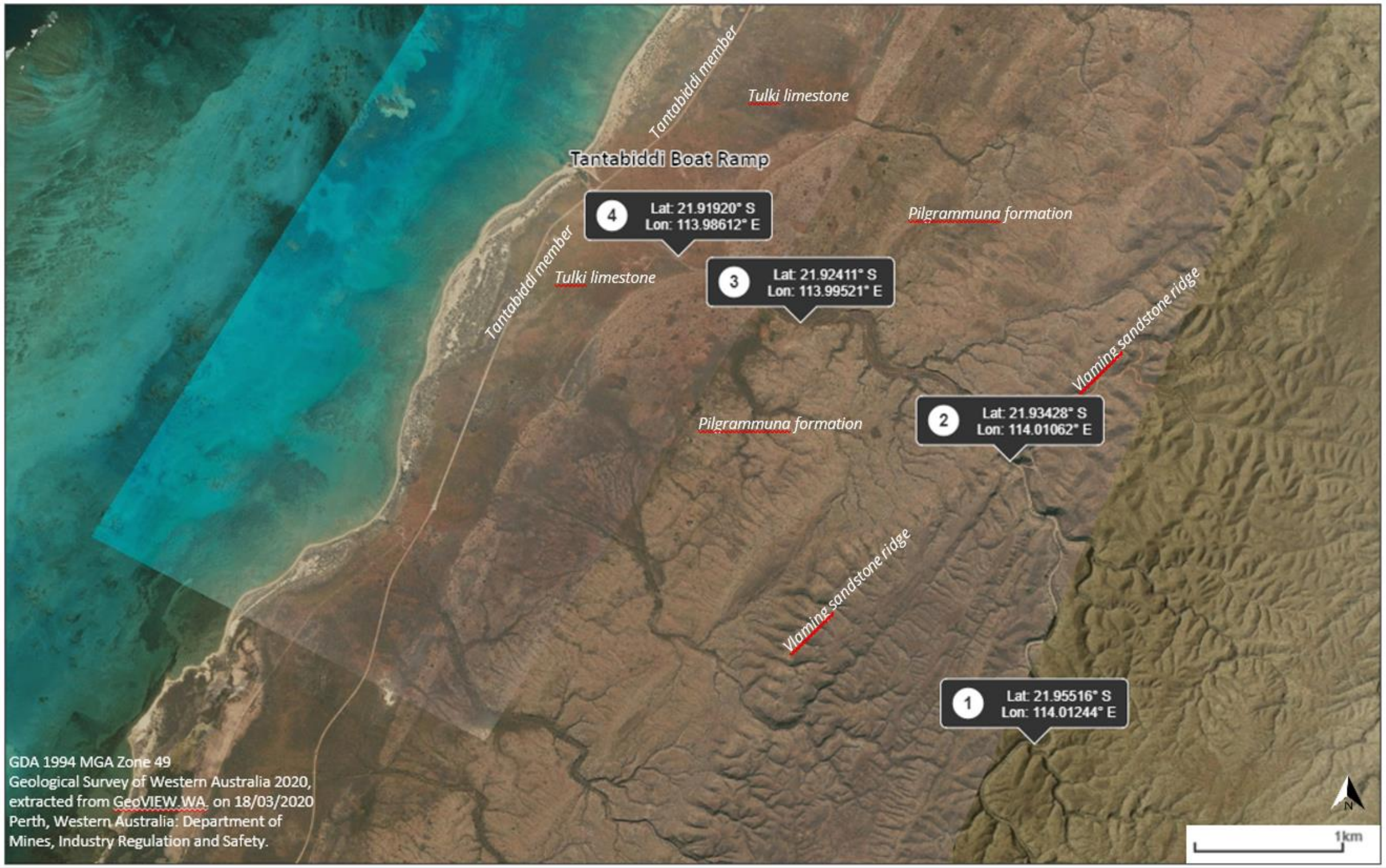
1 in 100 AEP Event Flood Velocity

0 200 400 600 800 m


Tantabiddi Creek Hydrology and Geomorphology Study
EXMOUTH
GULF
LEGEND
Model Domain
Model Boundary
Hydrograph Output
Flood Depth (m)
0.05
0.1
1.0
2.0
3.0+
2014 Event
Flood Depth
0 200 400 600 800 m

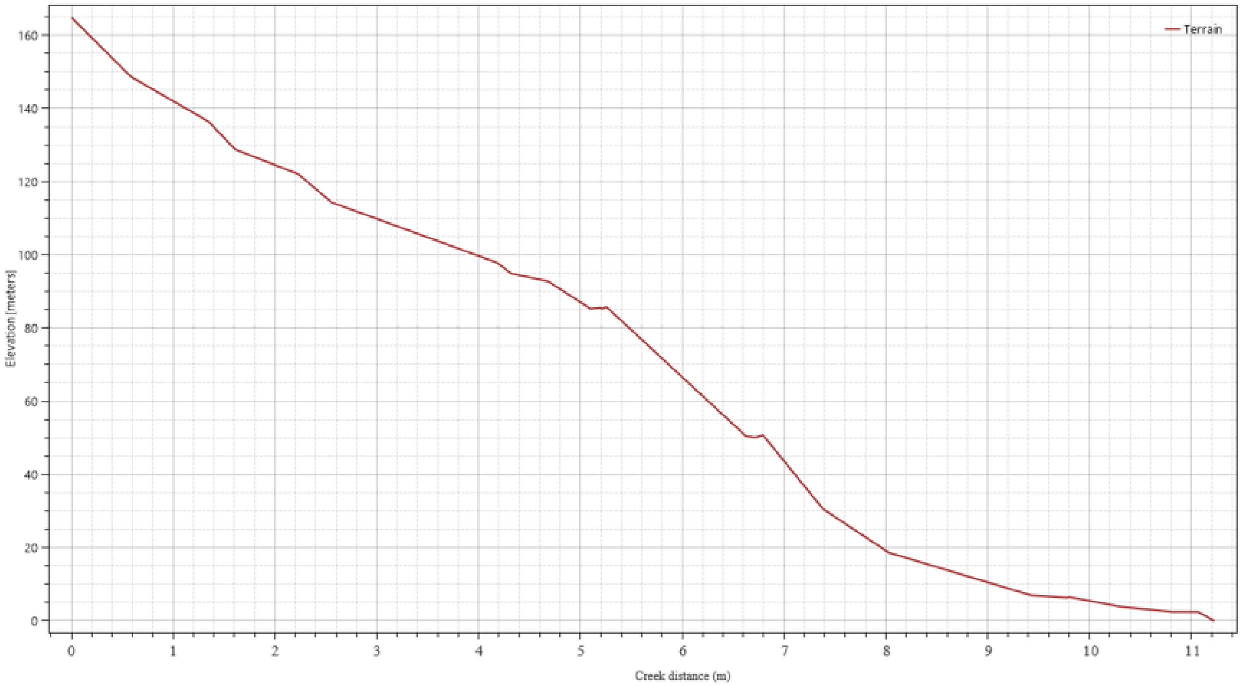

Tantabiddi Creek Hydrology and Geomorphology Study
North West Cape
EXMOUTH GULF
Exmouth
LEGEND
Model Domain
Model Boundary
Hydrograph Output
Flood Velocity (m/s)
0.5
2.0
3.0
4.0
5.0+
2014 Event Flood Velocity
0 200 400 600 800 m

Appendix G Macrofeatures



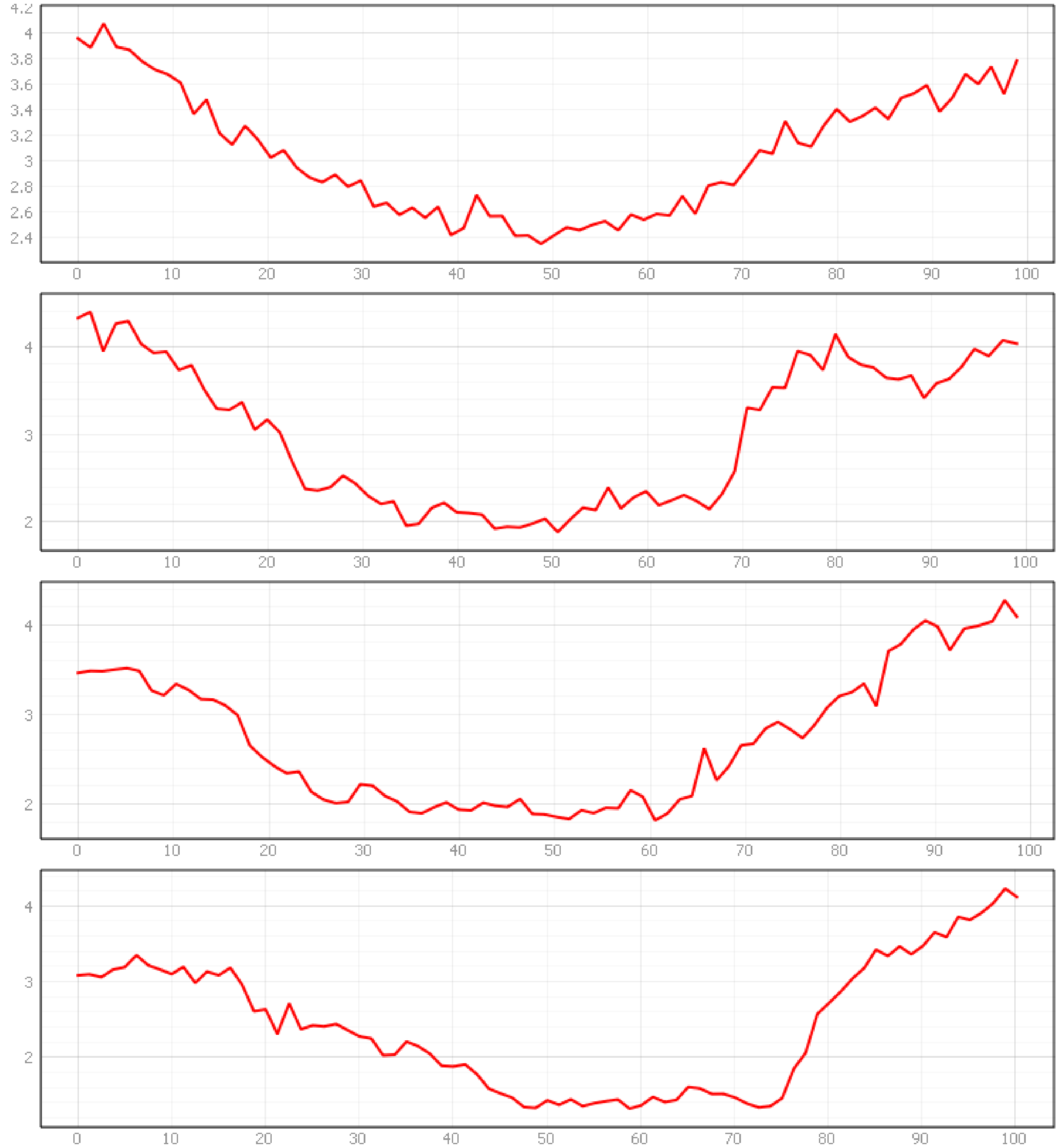
(1) Upper catchment traverses Tulki limestone and cuts through Pilgramunna formation in a steep and deeply incised confined channel.
(2) Mid reaches pass through a ridge of limestone and sandstone and widens
(3) Wider channel joined by major tributaries and evidence of red soils, relatively dense shrubs
(4) Lower reaches comprise low gradient, wide creek channel on Tantabiddi Terrace.

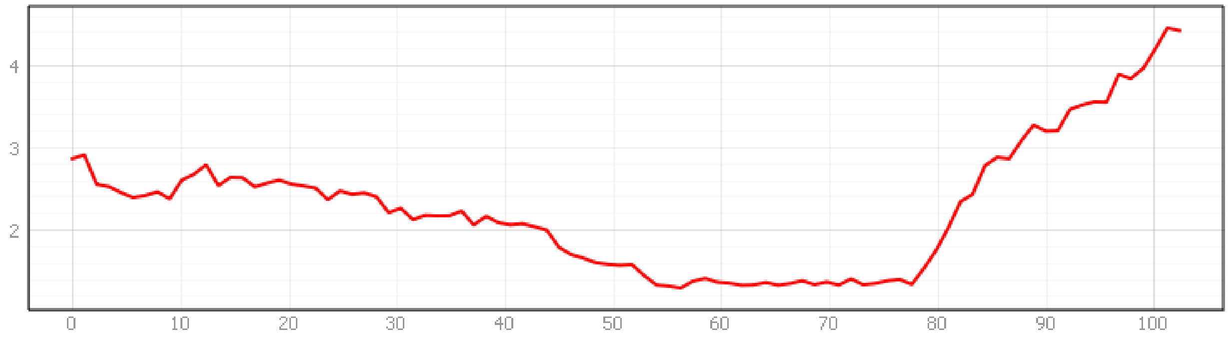
Tantabiddi Creek reaches. Clockwise from top right: The upper catchment traverses Tulki limestone and cuts through Pilgramunna formation in steeper narrow confined channel lined with trees and sparse shrubland; the mid reaches passes through a ridge of Cape Range limestone and sandstone, and is joined by tributaries transporting red sediment from terrestrial sources with tributary flows widening the channel; the creek meets Tantabiddi terrace and widens onto a mild gradient alluvial fans over aeolian and fluvial sourced sediment deposits; the lower reaches comprise low gradient, wide creek channel with denser shrubland over hummock grasslands (DMIRS, 2020). Base imagery: ESRI Satellite.



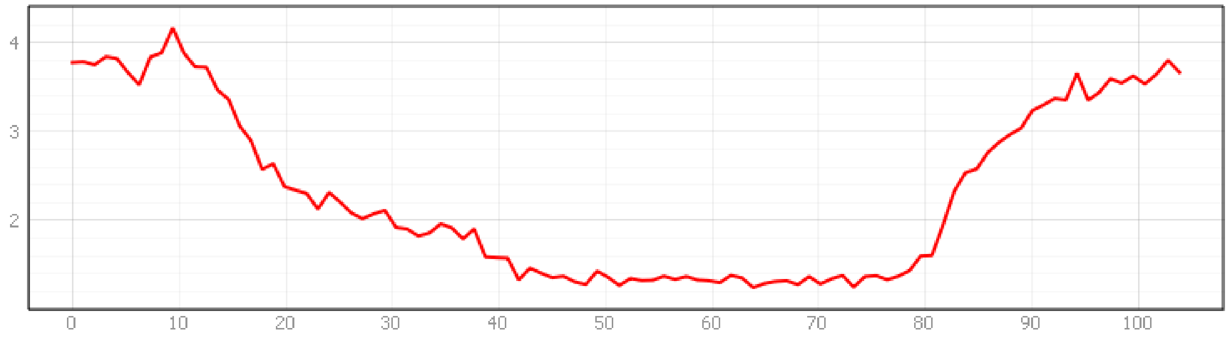
Longitudinal gradient of Tantabiddi Creek. Steeper slopes in the Cape Range upper catchment graduate into mild slopes in lower reaches as the creek traverses the Tantabiddi terrace.

Tantabiddi Creek Estuary Cross Sectional Elevation Profiles: Cross sections of the Tantabiddi Creek estuary. Cross sections taken from upstream to downstream (top to bottom plots) from left bank (0 m) to right bank over at least 100 m. Based on 1 m resolution DEM.

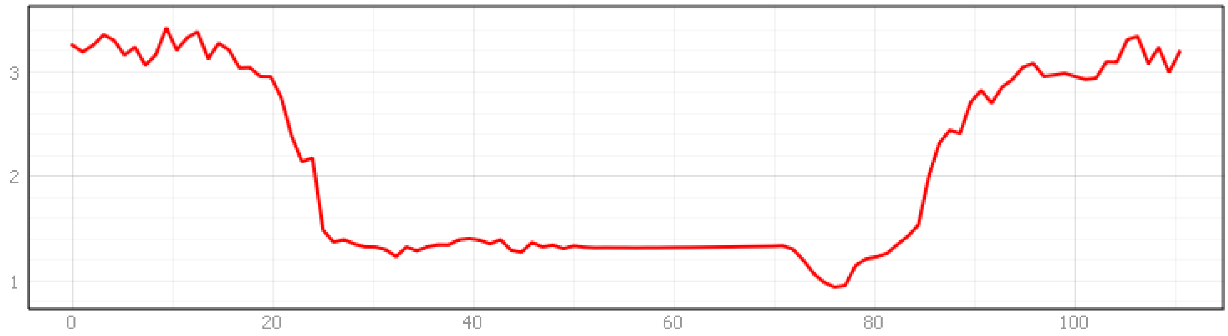




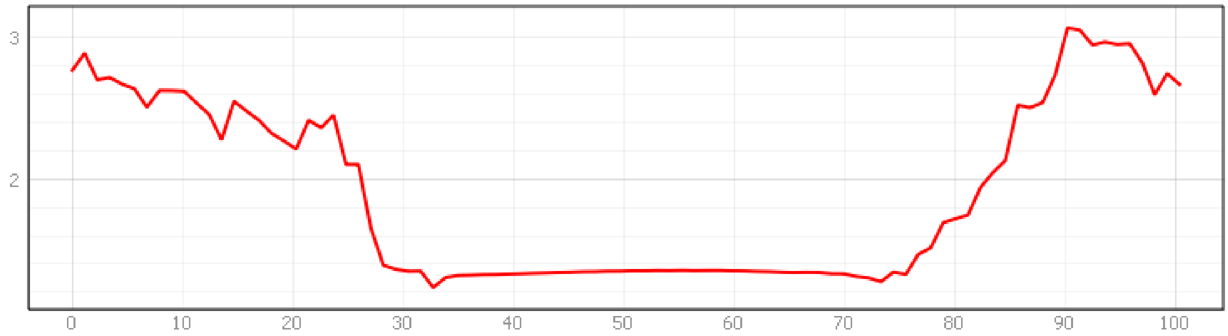
4
3
2
0 10 20 30 40 50 60 70 80 90 100



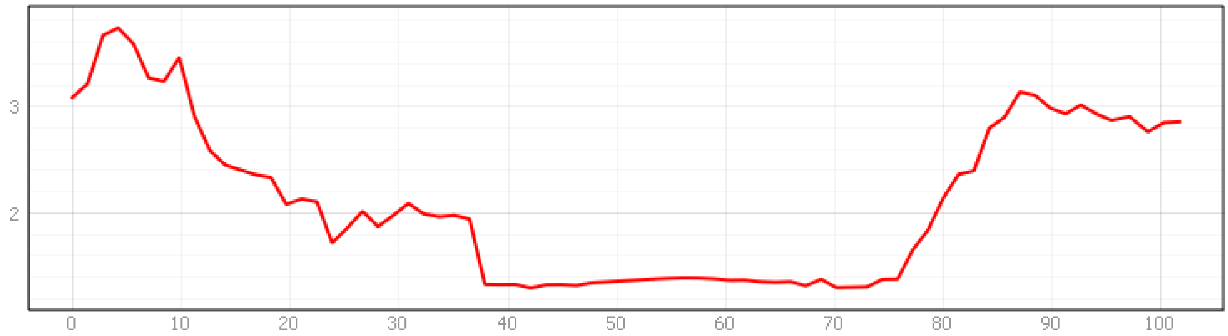
4
3
2
0 10 20 30 40 50 60 70 80 90 100

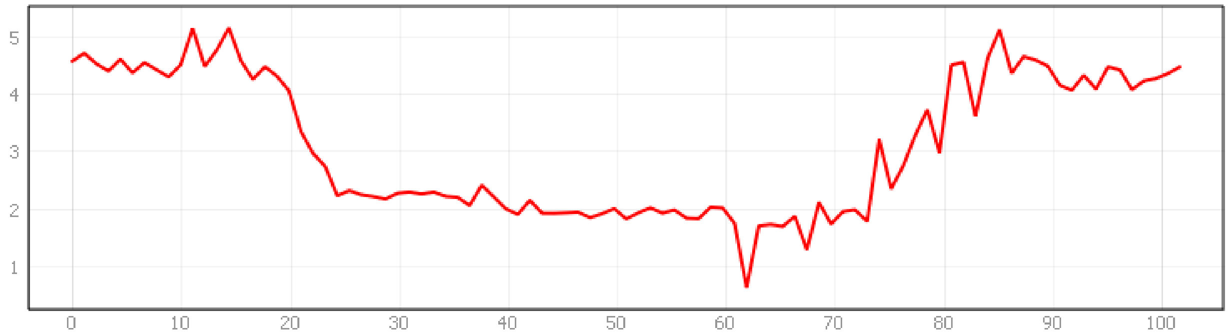


3
2
1
0 20 40 60 80 100

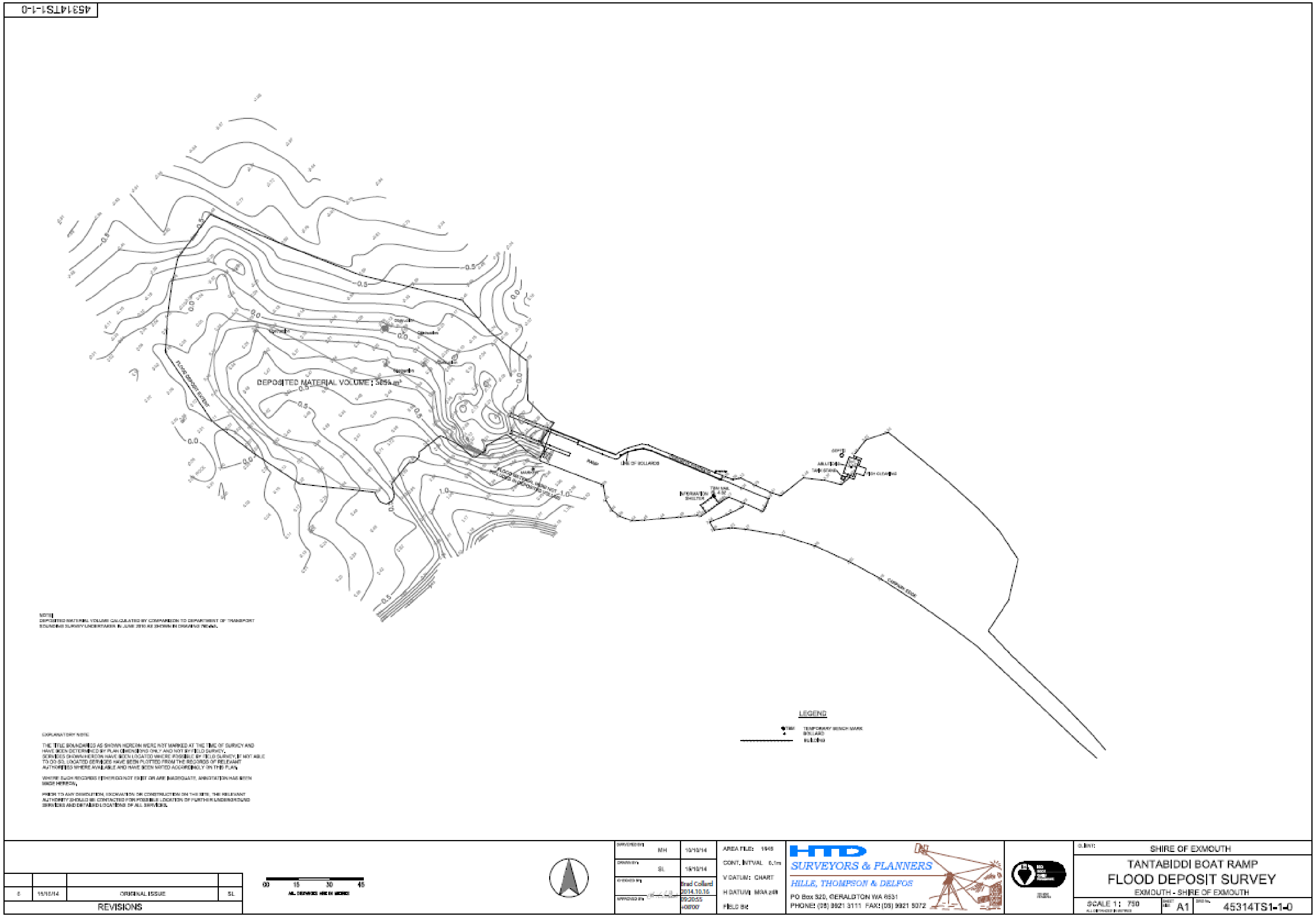


3
2
0 10 20 30 40 50 60 70 80 90 100


3
2
0
10
20
30
40
50
60
70
80
90
100


5
4
3
2
1
0
10
20
30
40
50
60
70
80
90
100

Appendix H Flood Deposit Survey


45314TS1-1-0
DEPOSITED MATERIAL VOLUME : 3855 m³
LEGEND
REVISIONS
0 15/10/14 ORIGINAL ISSUE SL
SURVEYED BY MH 10/10/14
DRAWN BY SL 15/10/14
CHECKED BY Brad Collard 2014.10.16 09:20:55 +08'00'
AREA FILE: 1645
CONT. INTVAL 0.1m
V DATUM: CHART
H DATUM: MGA z49
FIELD BK
HTD
SURVEYORS & PLANNERS
HILLE, THOMPSON & DELFOS
PO Box 320, GERALDTON WA 6531
PHONE: (08) 9921 3111 FAX: (08) 9921 5072
CLIENT: SHIRE OF EXMOUTH
TANTABIDDI BOAT RAMP
FLOOD DEPOSIT SURVEY
EXMOUTH - SHIRE OF EXMOUTH
SCALE 1 : 750
A1
45314TS1-1-0