Hydrobiology

NORTH STAR EXTENSION POOL IMPACT ASSESSMENT

SEDIMENT DELIVERY MODELLING & FLUSHING IMPACT ASSESSMENT

BRISBANE | PERTH | SINGAPORE | BRAZIL

B24126
FORTESCUE
WORLEY SERVICES
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EXECUTIVE SUMMARY

Background

Fortescue Metals Group (Fortescue) is seeking to expand the current North Star Magnetite Project to the south of the existing mine development envelope (North Star Extension (NSE)). This expansion requires environmental approvals to enable development of the NSE, including new mine pits, a waste rock dump (WRD) extension and associated infrastructure. To support the approval process, Fortescue engaged Worley to complete a pool impact assessment to:

- Identify and map all pools potentially impacted by the NSE development.
- Define the study area.
- Classify the pools in accordance with recognised water presence frameworks.
- Complete hydrological and water quality impact assessments (surface and ground water) for potentially impacted reaches (and associated pools).
- Use the results from the hydrological assessments to assess the inland water impacts.

To assist Worley in quantifying the potential sediment-related surface water quality impacts, Hydrobiology undertook a sediment delivery modelling and flushing assessment. The assessment quantified changes to sediment delivery and transport processes under baseline and developed conditions to evaluate the potential impacts of mine expansion on sediment supply, transport, and deposition within key waterway systems and reaches (and associated pools) identified and classified within the NSE study area.

Justification of Approach

The adopted approach for assessing sediment impacts on reaches (and associated pools) combined both quantitative and qualitative methods based on the water permanence classification of the reaches (and associated pools). This tiered approach ensured that more commonly inundated pools, which are likely to be more susceptible to long-term sediment changes, were assessed with greater detail and certainty. The adopted approach for each pool water permanence classification and the specific reaches (and associated pools) assessed using each approach is provided in the table below.

Pool Water Permanence Classification	Reaches	Method
Permanently Inundated	Mundagoora Pool	**Long-Term Sediment Yield and Transport Model:** A stochastic Monte Carlo framework was used to estimate long-term sediment yield based on catchment sediment supply and transport capacity. This method used probability distributions for input variables to generate a range of potential sediment delivery outcomes over time. The purpose was to understand broad-scale trends in catchment sediment dynamics and cumulative impacts from event-based delivery. **Event-Based Sediment Delivery Model:** This model quantified sediment delivery under selected flow events of different Annual Exceedance Probabilities (AEP). It disaggregated long-term sediment delivery components based on the flow hydrographs and empirically calculated hillslope erosion. The aim was to verify more immediate impacts, identify drivers of long-term trends, and assess how sediment supply changes across different event magnitudes. **Event-Based Flushing Assessment:** The Hjulström Curve, parameterized by Miedema (2013), was used to evaluate sediment scour and transport potential under the same range of AEP events. Event velocity time series data were used to determine the duration of scour and transport for different sediment sizes. The objective was to understand localized sediment dynamics (scour, deposition, transport) within the reaches (and associated pools) to complement the catchment-scale delivery assessments. **Consolidation of Models:** Results from the above assessments were interpreted together using a conceptual sediment storage model. This model considered sediment delivery into the pool and sediment scour and transport out of the pool to infer likely changes in sediment storage. These methods allowed for a detailed understanding of sediment supply, transport, deposition, and scour dynamics under various flow conditions and cumulatively over longer timeframes.
Commonly Wet	Site 12 Pool and Pool Reach	
Seasonally Inundated	NJA19-002 Pool	**Event-Based Sediment Delivery Model:** As per the above method to inform potential changes in the sediment balance (delivery, transport) of the pool. This allowed for an understanding of sediment dynamics during flow events likely to impact the reach (and associated pool).
Periodic Inundation/ Ephemeral	Pool 62; Pool IB-SW-Dry-Reject-DS-002; Pool NJA21-006-US; Pool NJA21-006-DS; Pool-SW; Pool 9; Pool 51; Pool 50; Pool 59; Pool 57	**Qualitative Sediment Impact Assessment:** For periodically inundated and ephemeral pools, the assessment focused on changes in catchment area and hydraulic velocity (derived from catchment-scale hydraulic modelling) due to the NSE development. A matrix combining the mean change in event velocity, the reduction in catchment area, and distance from the NSE development was used to determine the likelihood and potential severity of negative impacts on these pools. The rationale was that changes in these factors are primary drivers of sediment transport in these ephemeral systems.

Reaches (and associated pools) were rated as having Low, Moderate, and High Impact based on their likelihood and severity of change which corresponded to the longevity of, and recoverability from, the changed conditions. For Permanently Inundated, Commonly Wet, and Seasonally Inundated reaches (and associated pools), this encapsulated a semi-quantitative assessment of the sum of all outcomes regarding severity/magnitude, rapidity, and duration. For Periodically Inundated/Ephemeral reaches (and associated pools) this used changes to velocity, catchment area and distance from the development to derive impact levels.

The likelihood and severity ratings are consistent with the understanding that larger reductions in catchment area and flow velocities (leading to reduced flushing capacity relative to sediment supply) are more likely to result in significant and potentially long-lasting impacts on pool sediment dynamics. The severity of sediment impact is considered in terms of potential changes to pool morphology, water quality (turbidity), and substrate composition, aligning with general consequence definitions used in environmental risk assessment.

Technical Outcomes

The key findings of the assessment are summarised in the tables below. The NSE development and associated catchment area reduction / hydraulic changes are expected to have a low impact on most reaches (and associated pools), provided good-practice sediment management forms part of construction and operation within the NSE project area. Those reaches (and associated pools) deemed to be at high or moderate impact are all classified as Seasonally Inundated or Periodic Inundation/Ephemeral pools.

Holistic Consolidation

Overall, the NSE development is expected to have a low likelihood and severity of negative impact on Mundagoora Pool and Site 12 Pool, a moderate likelihood and severity of negative impact on Pool NJA19-002, and variable impacts on the ephemeral pools (as described below) based on the magnitude of catchment reduction, distance downstream, and changes in event velocity, provided best-practice sediment management forms part of construction and operation within the NSE project area. Similar impact likelihood and severity is expected throughout the supplying waterways, although likelihood and severity are both expected to be marginally greater in reaches immediately downstream of the NSE IDF and decrease with distance downstream as flow and sediment inputs from unaffected catchments contribute to overall hydrological and sediment delivery regimes. This spatial variability of impacts to waterways is illustrated by the variability of impacts to the pools across the affected catchments. Over time, these waterways will adapt to the new flow/sediment regimes and reach a new equilibrium that will drive long-term pool maintenance.

Summary of Results

Permanently Inundated – Mundagoora Pool

Long-Term Sediment Yield and Transport

- ↓ 55% less sediment delivery
- ↓ 56% less fine sediment delivery
- ↓ 56% less coarse sediment delivery

Event-Based Sediment Delivery Model

- ↓ 63% mean decrease in delivery of fines material
- ↓ 57% mean decrease in delivery of coarse material

Event-Based Flushing Assessment

- ↓ 44% mean decrease in scour of fines material
- ↓ 18% mean decrease in transport of fine material
- ↓ 33% mean decrease in scour of coarse material
- ↓ 70% mean decrease in transport of coarse material

Key Outcomes

- Overall ***Low*** likelihood and severity of negative impact due to reduced scour/transport potential counteracting the reduced supply and the stabilising effect of underlying bedrock and proximal vegetation. Potential changes may include:
  - Reduction in pool turbidity due to decreased fine sediment supply and retention
  - Reduction in soft sediment substrate, although shallow bedrock will limit scour
  - Continued sediment capture in vegetated margins, supporting the persistence of existing habitat structures
  - Event-driven transition of bed material towards a more erosion resistant (coarser) substrate.

Commonly Wet – Site 12 Pool

Long-Term Sediment Yield and Transport

- ↓ 21% less sediment delivery
- ↓ 31% less fine sediment delivery
- ↓ 13% less coarse sediment delivery

Event-Based Sediment Delivery Model

- ↓ 36% mean decrease in delivery of fines material
- ↓ 36% mean decrease in delivery of coarse material

Event-Based Flushing Assessment

- ↓ 11% mean decrease in scour of fine material
- ↓ 4% mean decrease in transport of fine material
- ↓ 18% mean decrease in scour of coarse material
- ↓ 12% mean decrease in transport of coarse material

Key Outcomes

- Overall ***Low*** likelihood and severity of negative impact due to reduced scour/ transport potential counteracting the reduced supply and the stabilising effect of underlying bedrock. Potential low impact changes may include:
  - Reduction in pool turbidity due to decreased fine sediment supply and retention.
  - Minor reductions in soft sediment substrate but not as pronounced as in Mundagoora Pool.
  - Continued sediment capture in vegetated margins and at bedrock outcrops, supporting the persistence of existing habitat structures.
  - Event-driven scour of both fine and coarse material to bedrock, with currently exposed bedrock limiting impact.

Seasonally Inundated – NJA19-002 Pool

Event-Based Sediment Delivery Model

- ↑ 9% mean increase in delivery of fines material
- ↓ 34% mean decrease in delivery of coarse material

Key Outcomes

- Overall ***Moderate*** likelihood and severity of negative impact due to changes in delivery of coarse sediment material consistent with catchment area reduction, concomitant increases in the delivery of fines, and potential associated increases in turbidity, especially during small, frequent events, with flushing occurring during larger events. These results are a result of impact to the steeper sections of the catchment. Changes will persist for the life of NSE.

Periodic Inundation/Ephemeral Pools

- 10 reaches (and associated pools) impacted, with ratings assigned:
  - 2 with ***High*** potential impacts (Pools 59 & 57) – extreme reductions in catchment area and hydraulics likely to promote aggradation of sediment within the pools.
  - 2 with ***Moderate*** potential impacts (Pool NJA21-006-US & Pool 9) – moderate reduction in erodible catchment area somewhat likely to promote moderate aggradation of sediment within the pools.
  - 3 with ***Low*** potential impacts (Pools IB-SW-Dry-Reject-DS-002, NJA21-006_DS & SW) – minor reductions in catchment area or event flushing velocities likely to have limited impacts of sediment deposition and flushing within the pools.
  - 3 removed (Pools 62, 51 and 50) – located within the NSE IDF.

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1.

INTRODUCTION

1.1 BACKGROUND

Fortescue Metals Group (Fortescue) is seeking to expand the current North Star Magnetite Project to the south of the existing mine development envelope. This expansion requires environmental approvals from the Environmental Protection Authority (EPA) and the Department of Climate Change, Energy, the Environment and Water (DCCEEW) to enable development of new mine pits, a waste rock dump (WRD) extension and associated infrastructure. This new development is called the North Star Extension (NSE).

Several pools have been identified along creek lines within the North Star Stage 2 and NSE development area which are associated with hydrological and hydrogeological (Inland Waters) regimes. The DCCEEW issued PER guidelines in December 2023, which included the need to identify and classify pools, then assess the impact associated with the NSE development.

Infrastructure development and mining within the NSE project area involves the reduction in surface water catchment area reporting to the pools and associated hydraulic changes along waterways and pool reaches. This could have the potential to alter sediment delivery and sediment transport processes for the pools.

This report presents the findings of the sediment delivery modelling and flushing assessment undertaken for the NSE project. The assessment quantifies changes to sediment transport processes under baseline and developed conditions, evaluating the potential impacts of NSE development on sediment supply, transport, and deposition within key waterway systems and their pools. The study applies an approach based on pool water presence, with a combination of quantitative long-term sediment yield modelling and event-based sediment supply and flushing modelling to assess permanent and seasonal pools, and a qualitative impact assessment to characterise sediment dynamics in periodically inundated and ephemeral pools across the project area.

1.2 SCOPE

This assessment is to support the information requested to be provided by the PER Guidelines issued by DCCEEW as part of their assessment of the NSE under the EPBC Act 1999, specifically focussing on potential sediment-related water quality impacts in the identified and classified pools. The scope includes:

- A review of catchment delineation for the identified pools within surface water impact area ((as part of Pools Hydrological and Water Quality Assessment (Worley, 2025)) and characterisation of sediment sources.
- The evaluation of sediment supply and transport mechanisms.
- Rationalisation of the sediment impact assessment methodology based on pool water presence classifications.
- Application of long-term sediment yield modelling using a stochastic Monte Carlo framework for permanently inundated and commonly wet pools.
- Event-based sediment delivery modelling to quantify changes in sediment flux under a range of flow conditions for permanently inundated, commonly wet, and seasonally inundated pools.
- Sediment flushing assessment to determine the magnitude of sediment mobility and deposition for permanently inundated and commonly wet pools.
- Qualitative sediment delivery and transport impact assessment, for ephemeral pools, based on changes to catchment area and hydraulics of waterways reporting to and through pools.
- The analysis of potential impacts to sediment delivery and waterway stability resulting from the NSE.

The results of this assessment inform the sediment impact to pools as a result of catchment area reduction and associated hydraulic changes from NSE development, and potential sediment management controls for NSE development.

1.3 STUDY LOCATION

The Study Area applicable to this project was based on the extent of the estimated surface water impacts associated with the NSE project development. The eastern boundary of the surface water impact area was extended to ensure all named pools were included in the assessment (see full report: 311012-02355-HY-REP-00001-D (Worley 2025); repeated here in Figure 1-1). Groundwater impact areas are not relevant to this study, as they do not affect sediment delivery.

Specifically, this assessment implemented quantitative methods to identify trends in sediment delivery and transport to pools or pool reaches within the surface water impact area identified as permanent and commonly wet pools (e.g., Mundagoora Pool and Site 12 Pool reach – Figure 1-2) and seasonally inundated pools (e.g., NJA19-002 – Figure 1-2). Qualitative methods were used to assess other smaller periodic inundation/ephemeral pools.

For the purposes of impact assessment, Worley (2025) grouped individual pools in the Study Area shown in Figure 1-1 into local reaches along a connecting section of drainage line (reaches (and associated pools)), which formed the basis of this study. The locations of these reaches are shown in Figure 1-1. A list of reach names potentially impacted by changes to sediment delivery, their constituent pool names, and pool classification is provided in Table 1-1.

It is noted that Pool 11 and Pool GE 10 are located within the surface water impact area, but their catchment areas are not impacted by the NSE development (Worley, 2025), so have been excluded from this assessment.

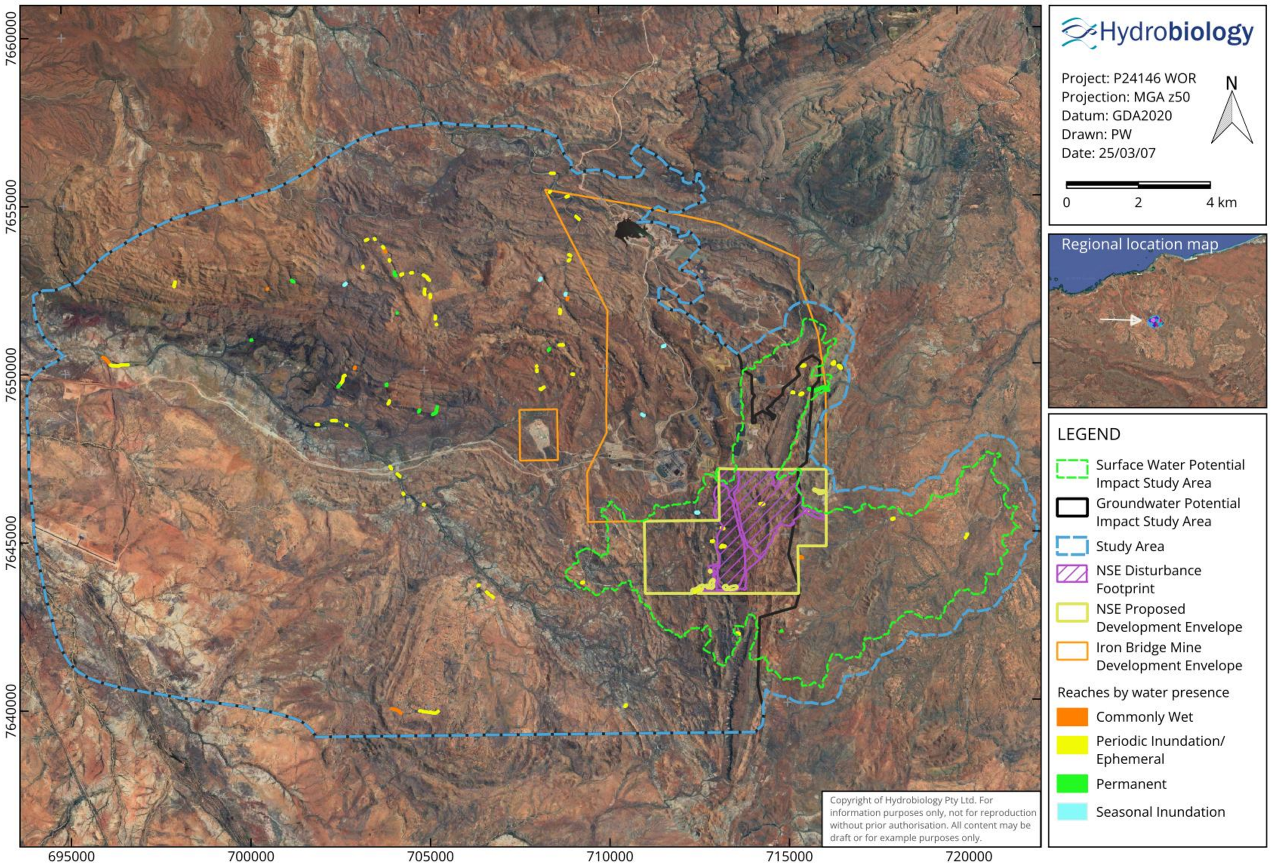

Figure 1-1: NSE pool reaches by water permanence classification (Source: Worley 2025).

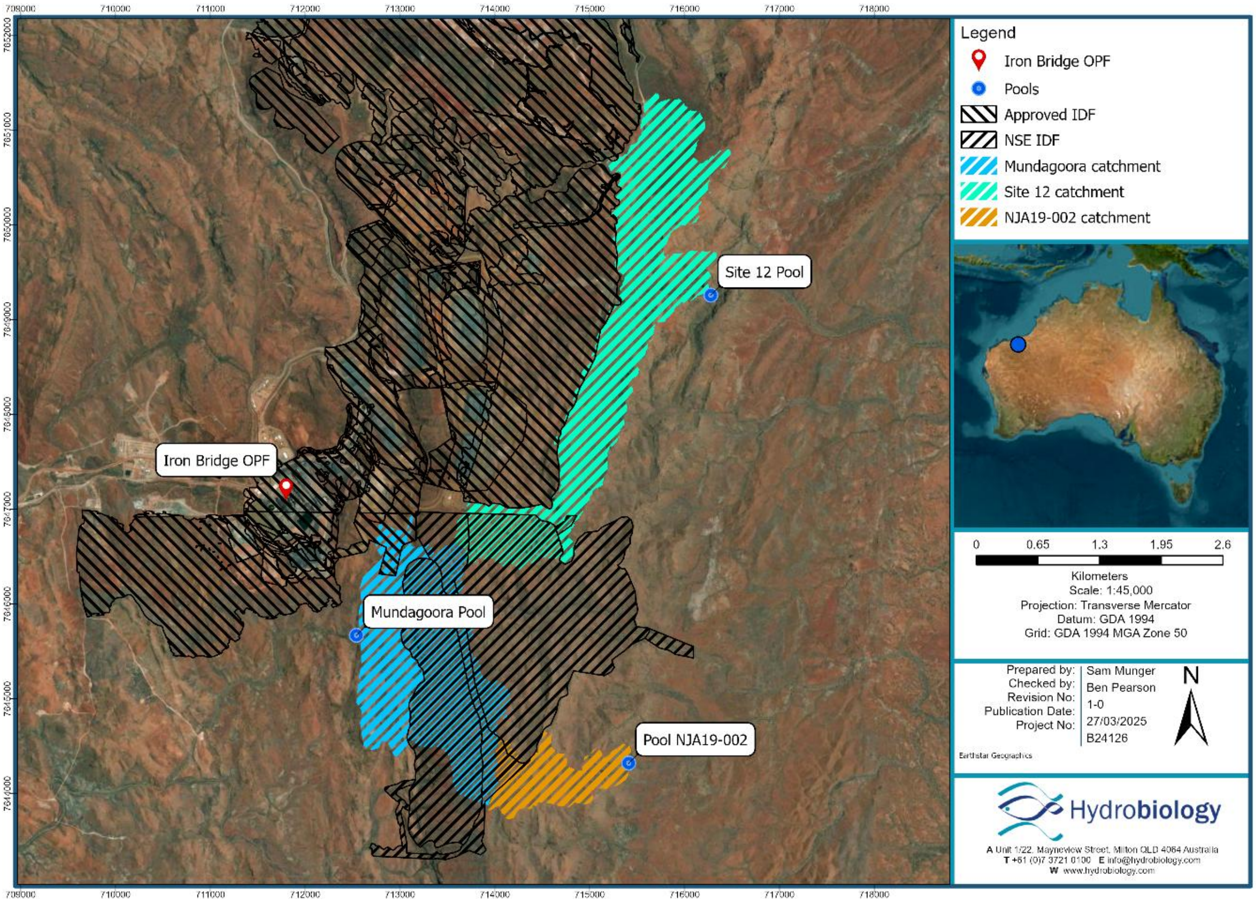

Figure 1-2: Locations of quantitatively assessed catchments relative to the NSE IDF.

Table 1-1: Reaches (and associated pools) within the surface water impact area and requiring sediment impact assessment.

Reach	Pools Included in Pool Reach	Pool Water Permanence Classification
Mundagoora Pool	GV_SW_Pool_ Mundagoora_SS	Permanent
Site 12 Pool	1-IB_SW_Pool12 2-S12string 3-S12string 4-S12string 5-S12string 6-S12string 7-S12string 8 - IB_SW_Pool12_01	Commonly Wet
NJA19-002	61 - GV_SW_Pool_ NJA19-002 52	Seasonal Inundation
Pool 62	78 - GV_SW_Pool _GR 62 65	Periodic Inundation
Pool IB-SW-Dry-Reject-DS-002	IB_SW_DryReject_ DS_02	Periodic Inundation
Pool NJA21-006-US	GV_SW_Pool_NJA21-006-US	Periodic Inundation
Pool NJA21-006-DS	GV_SW_Pool_NJA21-006-DS	Periodic Inundation
Pool-SW	55 - GV_SW_Pool_SW 56 - GV_SW_Pool_SWGV_DS	Periodic Inundation
Pool 9	9	Periodic Inundation
Pool 51	51 - GV_SW_WRD _01	Periodic Inundation
Pool 50	50	Periodic Inundation
Pool 59	59	Periodic Inundation
Pool 57	57 63 64	Periodic Inundation

2.

BACKGROUND

2.1 BACKGROUND TO PILBARA REGION AND WATERWAYS

The Pilbara Region experiences a semi-arid to tropical climate with two distinct seasons: a wet season (November/December to March/April depending on location) characterised by periodic rainfall and a mild dry season (April/May to October/November depending on location) with low rainfall and high evaporation rates. Rainfall is generally low year-round but peaks in the wet season months due to offshore cyclonic activity and local thunderstorms.

Waterways in the region are defined by bedrock and fault-controlled channels or broad, flat, gravel-dominated channels. These channels feature steep to low slopes, narrow rocky gorges in upland areas, and moderate sediment loads that include cobbles (Water and Rivers Commission, 2002). Stream flows are highly seasonal and directly linked to rainfall, resulting in largely ephemeral rivers and creeks that remain dry for most of the year, except for isolated persistent pools. Following significant rainfall, channels can carry large water volumes, with peak flows typically occurring within 24 hours of a rainfall event. These channels then recede to isolated pools, which may persist for weeks or months.

Flatley (2022) identified key features of upper catchment waterways in the Pilbara, including:

- A variety of channel forms ('River Styles') influenced by lithology, slope, degree of confinement, sediment supply, and climatic forces. These include laterally unconfined anabranching channels, bedrock-confined channels, partly confined anabranching channels, and partly confined single channels.
- Coarse, armoured beds and bar formations composed primarily of iron-rich sediments, stabilised by vegetation and large boulders. Headwater channels contain both fine sand (>0.2 mm) and coarser sediment bars (>0.5 mm).
- Common in-channel features such as inset floodplains, meander scrolls, incised pools, bank-attached bars, and mid-channel or longitudinal bars.

- Alternating sections of micro-bars and straight, uniform river reaches, resembling the variability seen in larger Australian ephemeral rivers as seen in Figure 2-1 (Jansen & Nanson, 2004; Nanson & Huang, 2016).
- Vegetation plays a key role in channel roughness by reinforcing banks, increasing floodplain roughness, and stabilising bar formations.

Figure 2-1: Headwater river with distinct alternating bar-non-bar river sections. Bar formation is highly localised (Flatley 2022).

2.2 CATCHMENT GEOMORPHOLOGY AND TOPOGRAPHY

The catchments within the study area feature diverse topography with elevations ranging from 227 m AHD to 434 m (both located within the Mundagoora Pool catchment). Catchment geomorphology is strongly controlled by the imprint of surface geology, with steep hillslopes and plateaus dominating regions within the three main catchments, which comprise a north-south corridor through the centre of the surface water impact area. Channel morphology in each catchment is shaped and controlled by the rugged topography carved by an erosion dominant hydrological regime, where distinctive bedrock outcrops and tight bends, characteristic to the Pilbara region, dominate the landscape. These channels are often characterised by highly confined, steep, entrenched channels which efficiently convey coarse sediment loads generated through hillslope erosion into larger channels located within the ‘transfer’ zone of the broader system.

The landscape flattens downstream, facilitating the development of wider, braid-like, and meandering channels with coarse sediment stored within available accommodation space for subsequent reworking. Channel position has the potential to shift across partly confined valleys during significant rainfall-runoff events as sediment is mobilised and transported downstream resulting in abandonment and reengagement of available braid channels. This transition to a reduction in confinement is particularly noticeable around Site 12 Pool, where a local geological fault has influenced the abrupt change in topography, further reflecting the influence of geological history on the behavioural regime of the system. Figure 2-2 depicts the topography and elevation of the region and provides a general overview of the controls and the downstream pattern of geomorphic variance in channel morphology.

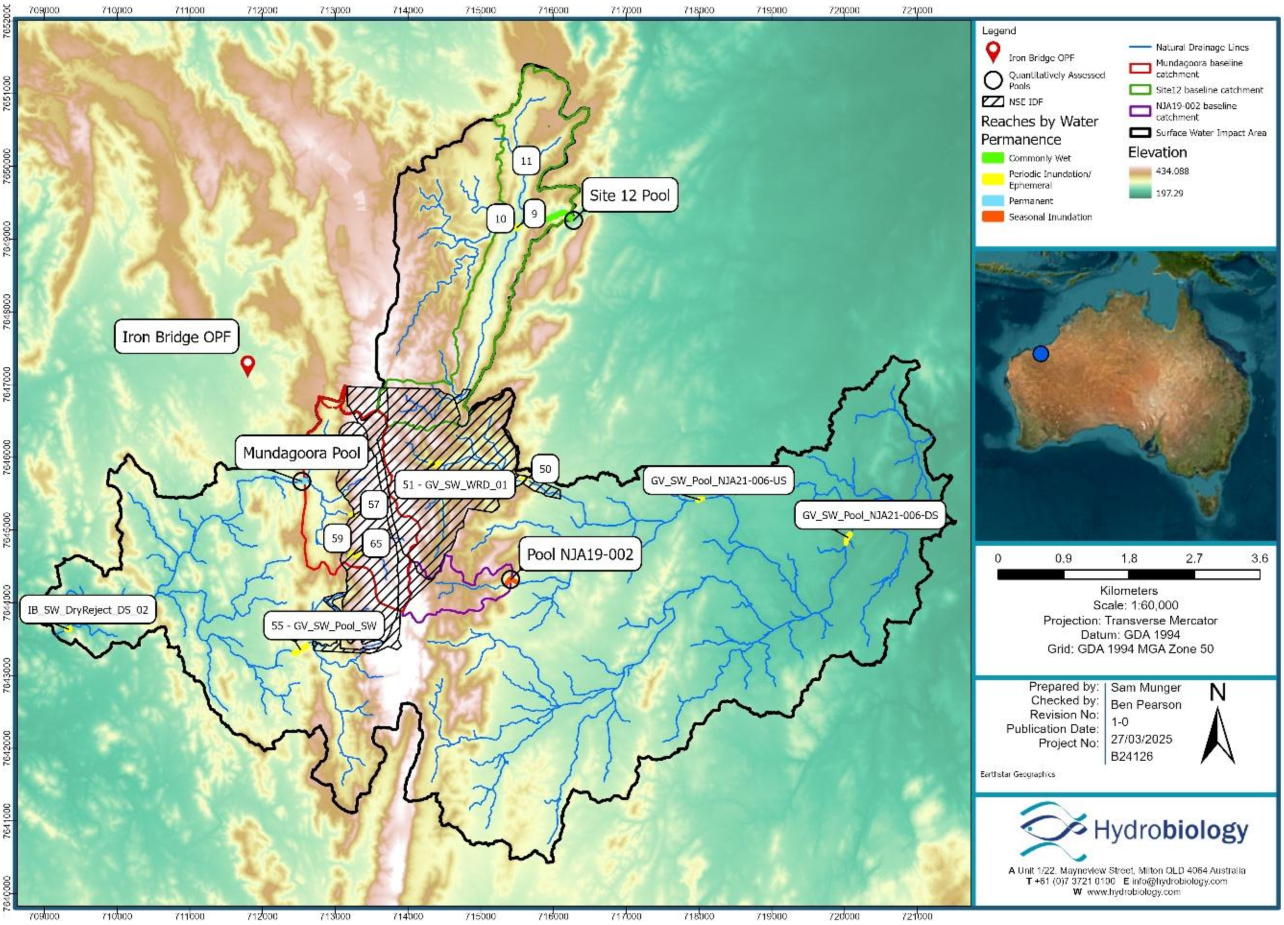

Figure 2-2: Topography of the study area and associated catchments.

2.3 CLIMATE AND HYDROLOGY

Worley (2025) generated a 1,000-year synthetic rainfall dataset for the study. The 1000-year synthetic rainfall data were used in the simulation, but the real observational data were used in this section for description of existing climate. A gridded daily climate surface dataset was developed by splining or kriging observational data (Queensland Government, 2024). The approach used the climate data stations provided in Worley (2025) and allowed for an extended dataset (1900-2024), which allowed for analysis of real long-term climate data. These data were analysed for key statistics relating to certain hydrological drivers and the results are presented herein. Note that these results pertain to rainfall and, while informing the general hydrology of the site, a lack of robust hydrological data limits the hydrological implications that may be drawn from these outcomes.

The climate in the NSE study area is characterised by significant variability in rainfall patterns, which plays a crucial role in shaping the geomorphic processes of the region. The data indicate that the region experiences a wide range of rainfall volumes throughout the year, with notable seasonal variations. Monthly rainfall data reveal that the wettest months are typically January to March, as shown in Figure 2-3, coinciding with the region's monsoon season. During these months, the area receives the highest rainfall, contributing to increased surface runoff and potential flooding events. Conversely, a dry season between April and November (and driest between August and November) leads to reduced flow in streams and rivers.

Furthermore, monthly rainfall in the region is highly variable, achieving a minimum variability index of 3 (measured as: (90th percentile – 10th percentile)/50th percentile). This variability highlights that rainfall patterns may not strictly follow seasonality and may vary randomly from year-to-year. Monthly variability statistics are presented in Table 2-1. Notably, this variability can lead to periods of intense runoff and erosion, followed by drier periods that may reduce vegetation cover and increase susceptibility to erosion. Rainfall volume is positively skewed which may translate to instances of high erosion and sediment transport during larger, less frequent events.

Unlike monthly rainfall volumes, annual rainfall displays only moderate variability, achieving a variability index of less than 1 (10th and 90th percentiles equal to ~200 and ~530 mm respectively). This suggests that seasonal and monthly variation in rainfall is somewhat balanced out annually such that variation in annual rainfall volumes year-to-year is lower than its monthly counterpart. This may suggest some level of interannual stability between sedimentation and deposition in locations throughout the catchment, although this is also dependent on rainfall intensity. Annual rainfall volumes are presented graphically in Figure 2-4.

The study area experiences a mean maximum daily rainfall each year of ~65 mm, with values varying from as little as ~11 mm to the maximum recorded daily rainfall volume of ~230 mm, correlating to a 1 in 123 AEP event. An analysis of the annual exceedance probability of daily rainfall events provides the curve presented in Figure 2-5 and suggests a 1 in 100 AEP 24-hour rainfall volume of ~200 mm.

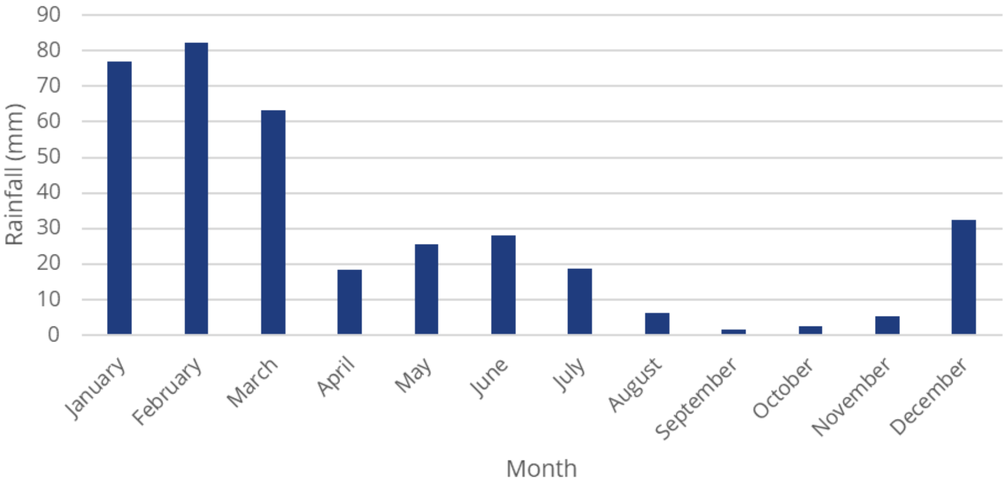

Figure 2-3: Mean monthly rainfall for Iron Bridge Mine from 1900 to 2024.

Table 2-1: Monthly rainfall statistics for Iron Bridge Mine based on data from 1900 to 2024.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean rainfall (mm)	77.0	82.4	63.3	18.3	25.5	28.1	18.6	6.1	1.6	2.4	5.3	32.4
Variability Index	3.4	3.0	7.1	15.7	9.0	11.5	52.3	121.2	21.0	55.0	14.6	6.0

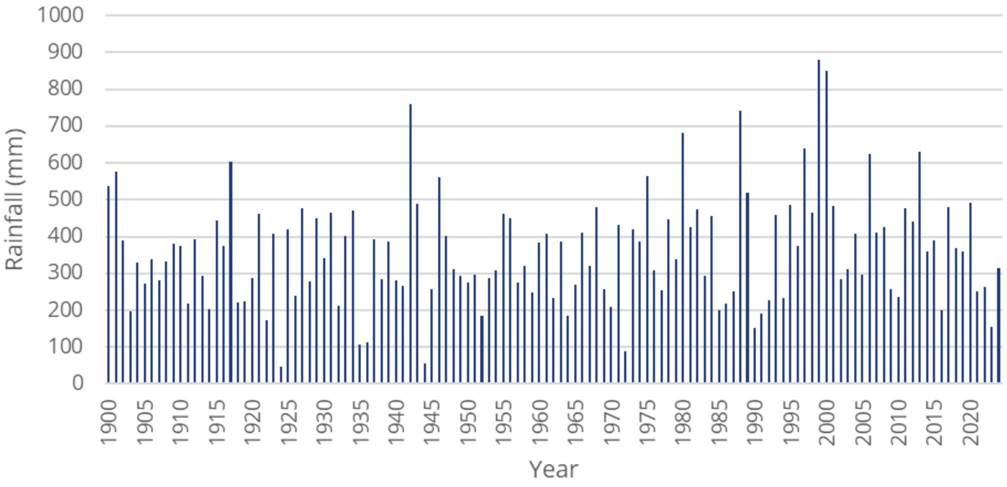

Figure 2-4: Annual rainfall for Iron Bridge Mine from 1900 to 2024.

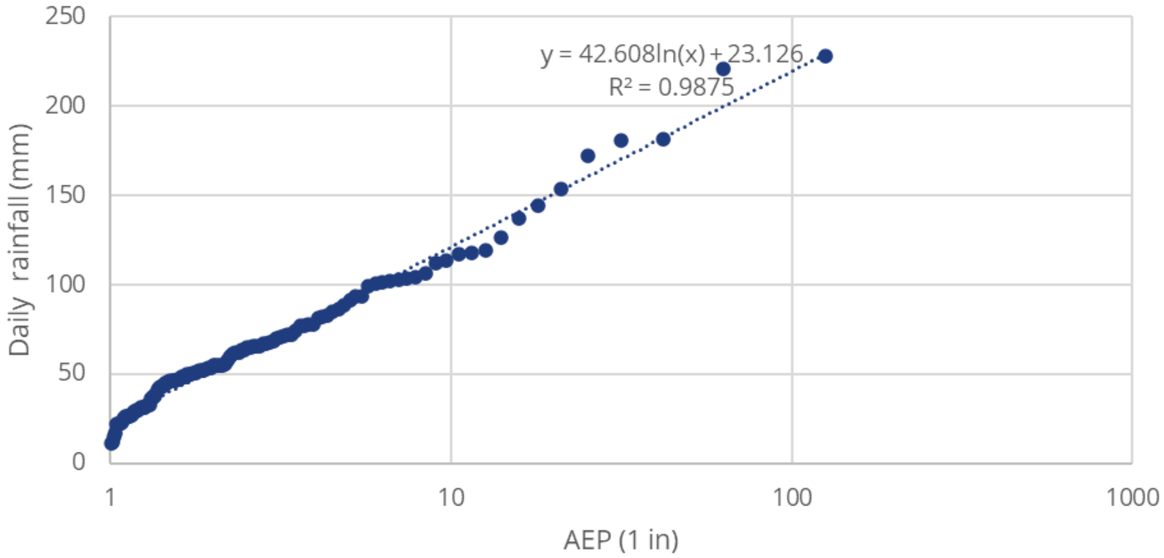

Figure 2-5: AEP curve for daily rainfall at Iron bridge Mine based on data from 1900 to 2024.

Reflective of the climatic variability of the study region, the hydrology of the Pilbara is dominated by extremes, ranging from severe droughts to major floods. The primary mechanism for runoff generation is associated with high intensity cyclonic and monsoonal rainfall which, given its sporadic nature, produces extended periods of low flow or no flow (AECOM, 2012). Combined with a lack of groundwater recharge, this gives rise to largely ephemeral systems with isolated permanent pools. Given interannual variability in monthly rainfall, these ephemeral systems may not always follow seasonal trends.

2.4 GEOLOGY

The arrangement of the geological formations in and around the study area is presented in Figure 2-6.The study area and its catchments primarily overlay two geological formations: the Corboy and Kangaroo Caves formations. These comprise:

- Corboy Formation:
  - Sandstone with polymictic conglomerates, interlayered iron-rich chert, black organic-rich shale, and siltstone. This formation, deposited via underwater landslides or sediment flows, is estimated to be 1-2 km thick (Geoscience Australia, 2024).
- Kangaroo Caves Formation:
  - A chaotic assemblage of large, fragmented rocks, banded iron formations, layered chert, shale, and volcanic units, with a thickness of up to 1,700 m (Geoscience Australia, 2024).

Additional nearby formations include:

- Kunagunarrina Formation:
  - A metamorphosed high-magnesium volcanic rock, shale, conglomerates, quartz-rich sandstone, and chert, reaching up to 3 km in thickness.
- Leilira Formation:
  - Wacke, volcaniclastic sandstone, quartzite, and volcanic deposits, altered by metamorphism, with a maximum thickness of 3,900 m.

The geological composition significantly influences topography and drainage. Resistant rock types like quartzite and chert form ridges, while softer rocks like shale erode into valleys. Differential erosion results in rugged landscapes, natural channel confinement in hard rock areas, and broader valleys in softer regions. Metamorphic processes also affect soil development, with quartzite and schist forming thin, rocky soils, and wacke and shale yielding finer-grained soils.

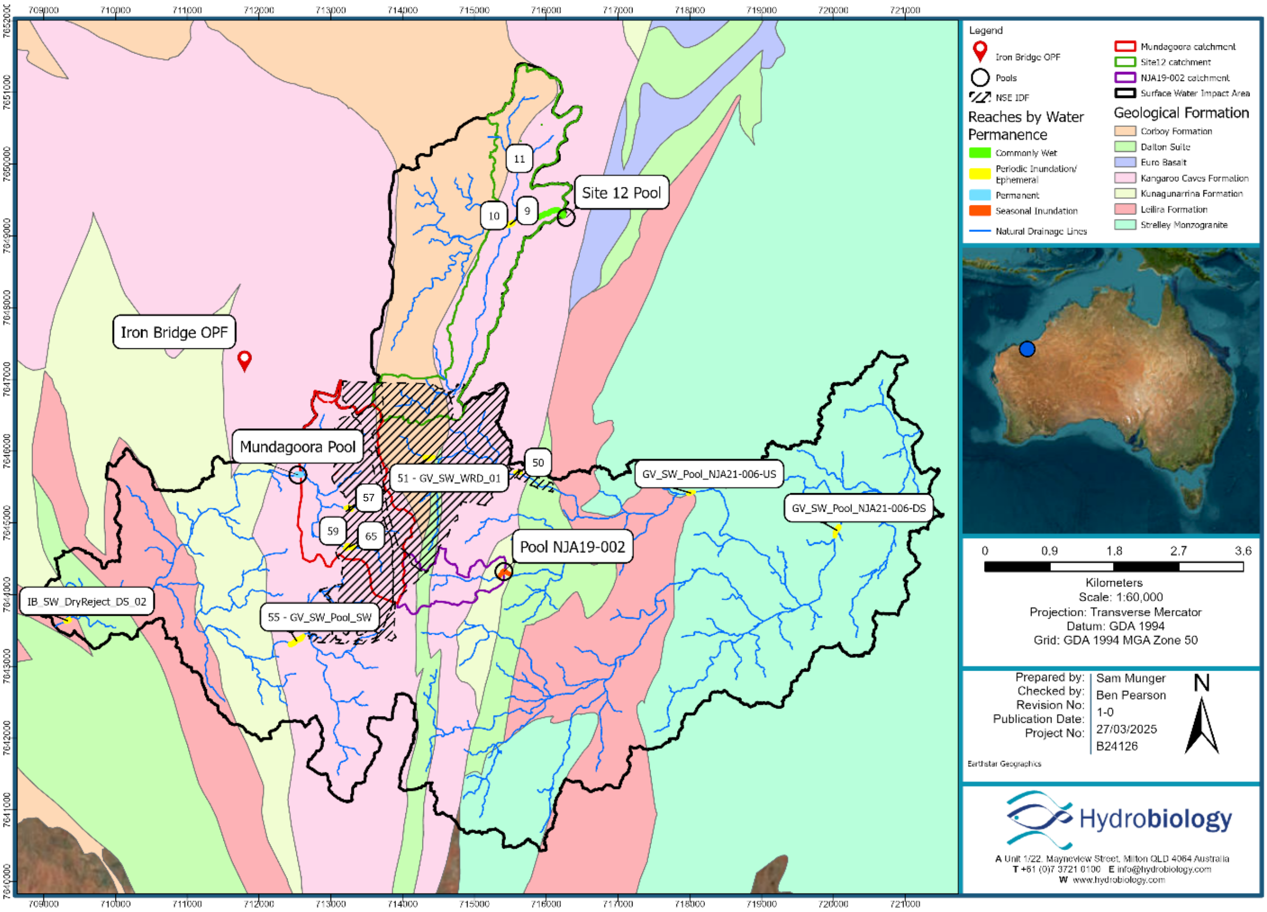

Figure 2-6: Geology of NSE study area and associated catchments.

2.5 SOILS

Soil data from the Western Australia Department of Primary Industries and Regional Development highlight that the study area soils distribution reflects active geomorphic processes, with hydrological forces shaping erosion, sediment transport, and deposition patterns across the landscape. As shown in Figure 2-7, the study area is predominantly covered by the Capricorn System, characterised by rugged hills, ridges, and spinifex vegetation. Soils range from shallow rocky deposits on upper slopes to deeper red loamy soils on lower slopes (Kreeswyk, Leighton, Payne, & Hennig, 2004). Surrounding areas feature the Rocklea and Talga Systems, which include steep, stony upper slopes over restricted lower slopes, with erosional surfaces spanning a relief of approximately 100-110 m.

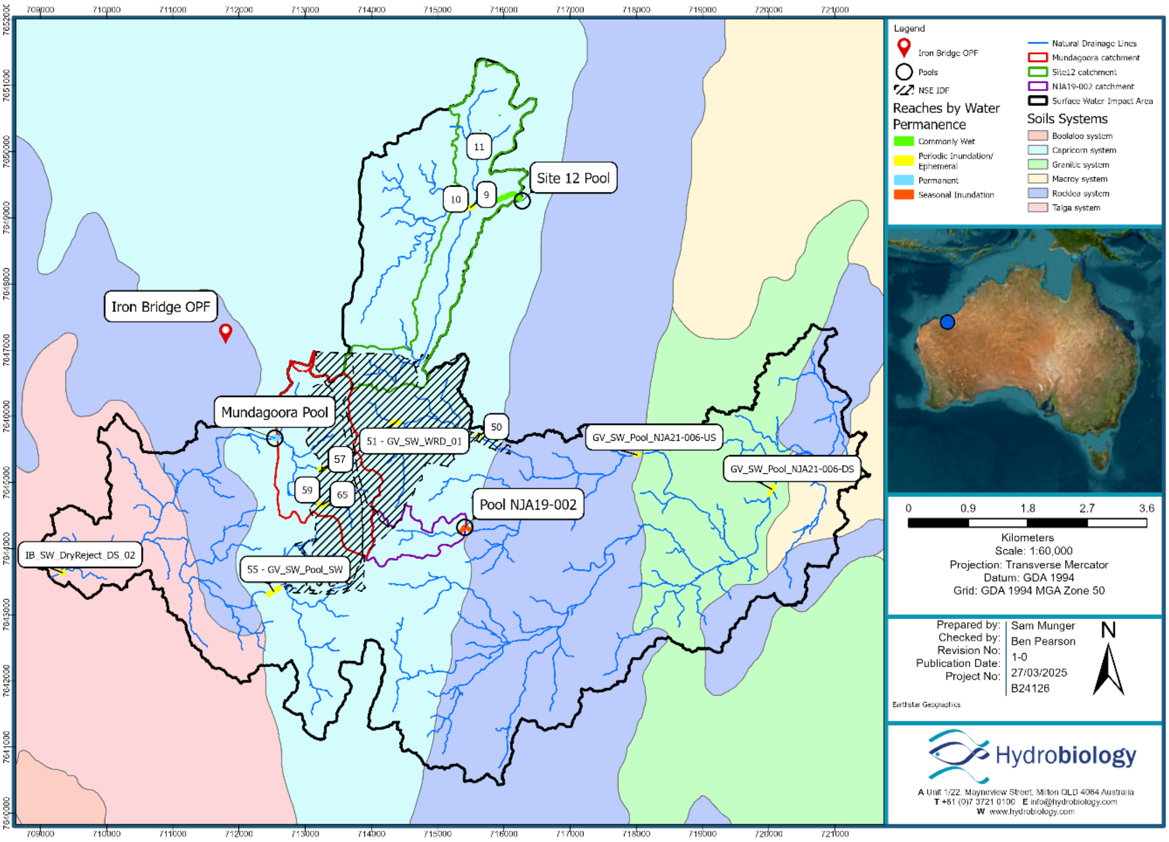

Figure 2-7: Soil systems of the NSE study area and associated catchments.

3.

APPROACH

3.1 POOL IDENTIFICATION AND CLASSIFICATION

As described in Section 1.3, Worley (2025) identified several reaches (and associated pools) within the study area potentially impacted by the NSE (Section 1.3). These reaches (and associated pools) were classified based on the pool persistence or water presence, with classifications adapted from the Australian National Aquatic Ecosystems (ANAE) toolkit (Aquatic Ecosystems Task Group, 2012). The results of this analysis are summarised in Table 3-1, with two reaches (and associated pools) classified as Permanently Inundated/Commonly Wet (Mundagoora Pool, Site 12 Pool), one classified as Seasonally Inundated (NJA19-002 Pool), and the remaining identified as Periodically Inundated/Ephemeral.

As described in Section 1.3, for the purposes of impact assessment, Worley (2025) grouped individual pools into local reaches along a connecting section of drainage line. Where there was only a single pool along a reach, a representative section of drainage line upstream and downstream of the pool "point" feature was included as the pool reach. Table 1-1 presents the water permanence classifications for each reach (and associated pools).

The purpose of generating reaches was to provide a mechanism to group proximal pools (i.e. within several hundred meters along the same drainage line) where the same impact mechanisms and assessment could be applied across the reach. This reduced repetition where groups of pools would be similarly potentially impacted.

Table 3-1: Water permanence classifications and associated reaches.

Water Permanence Classification	Reaches	Description
Permanently Inundated	Mundagoora Pool	Water always present (within the imagery analysed).
Commonly Wet	Site 12 Pool	Water present >70% to 99% of the imagery analysed (may vary depending on the wet season, though the pool is known to dry out occasionally). This category is derived from the ANAE method.
Seasonally Inundated	NJA19-002 Pool	Water present in 50-70% of the imagery analysed. Mostly over the wet season. Relates to pools that routinely dry out over the dry season and are not likely to provide dry season refugia.
Periodic Inundation/ Ephemeral	Remaining Reaches (and associated pools)	Water present <50% of the imagery analysed. Pools that dry out over the wet season, receding after flow events over a period of days to weeks and which do not tend to persist into the dry season.

3.2 ASSESSMENT SCENARIOS

3.2.1 BASELINE

The Baseline Scenario reflects current conditions following all existing and approved North Star Stage 2 developments but prior to implementation of the proposed NSE works. This scenario accounts for modified catchment boundaries and waterway alignments that have resulted from the approved mine development. Key considerations include:

- Current catchment area accounting for existing mine infrastructure.
- Distinction between disturbed and undisturbed sub-catchments.
- Exclusion of flows and sediment from omitted mine areas.
- Implementation of sediment control measures, specifically sediment settling via ponds (removes coarse sediment but has minimal impact on fine particles and flow regimes).

3.2.2 DEVELOPED

The Developed Scenario reflects conditions following the proposed NSE. This includes reductions in catchment areas and modifications to flow and sediment dynamics, analysed using the same method as the baseline scenario. For this study, it is presumed that Fortescue has implemented good-practice sediment runoff management practices that minimise sediment runoff from infrastructure. In addition, Waste Rock Dumps (WRDs) are designed to capture and infiltrate direct rainfall runoff and prevent associated sediment laden runoff from leaving the WRD footprint.

3.3 CATCHMENT DELINEATION

3.3.1 BACKGROUND

As part of the pool characterisation, two primary catchments were identified as contributors to the permanent/commonly wet reaches (and associated pools): Mundagoora Pool and Site 12 Pool. These have been designated as Mundagoora Catchment and Site 12 Catchment, respectively. Further, one catchment was identified as a contributor to the seasonally wet reach (and associated pools), NJA19-002, designated as NJA19-002 catchment. The boundaries of these catchments were defined in accordance with the development scenarios outlined in Section 3.2. The catchments for additional affected periodically inundated/ephemeral reaches (and associated pools) within the study area are not referred to by name, but catchment boundaries were also defined based on the same development scenarios.

3.3.2 MUNDAGOORA POOL

Mundagoora Pool is located 1.6 km south-southeast of the Iron Bridge OPF and receives water from a catchment area of approximately 294 ha to its east. The NSE project expands the IDF through much of the eastern catchment area, reducing the catchment area to 124 ha, as shown in Figure 3-1.

3.3.3 SITE 12 POOL

The Site 12 Pool is located 5 km east-northeast of the Iron Bridge OPF and receives water from a catchment area of approximately 366 ha to its west. The proposed NSE adds an additional incursion into the southern-most sub-catchments, reducing the catchment area to 316 ha, as shown in Figure 3-2.

3.3.4 NJA19-002 POOL

Pool NJA19-002 is located 4.5 km southeast of the Iron Bridge OPF and is serviced by a catchment of approximately 75 ha to its west. The NSE extends into the western-most portion of the catchment and reduces its area to approximately 71 ha, as shown in Figure 3-3.

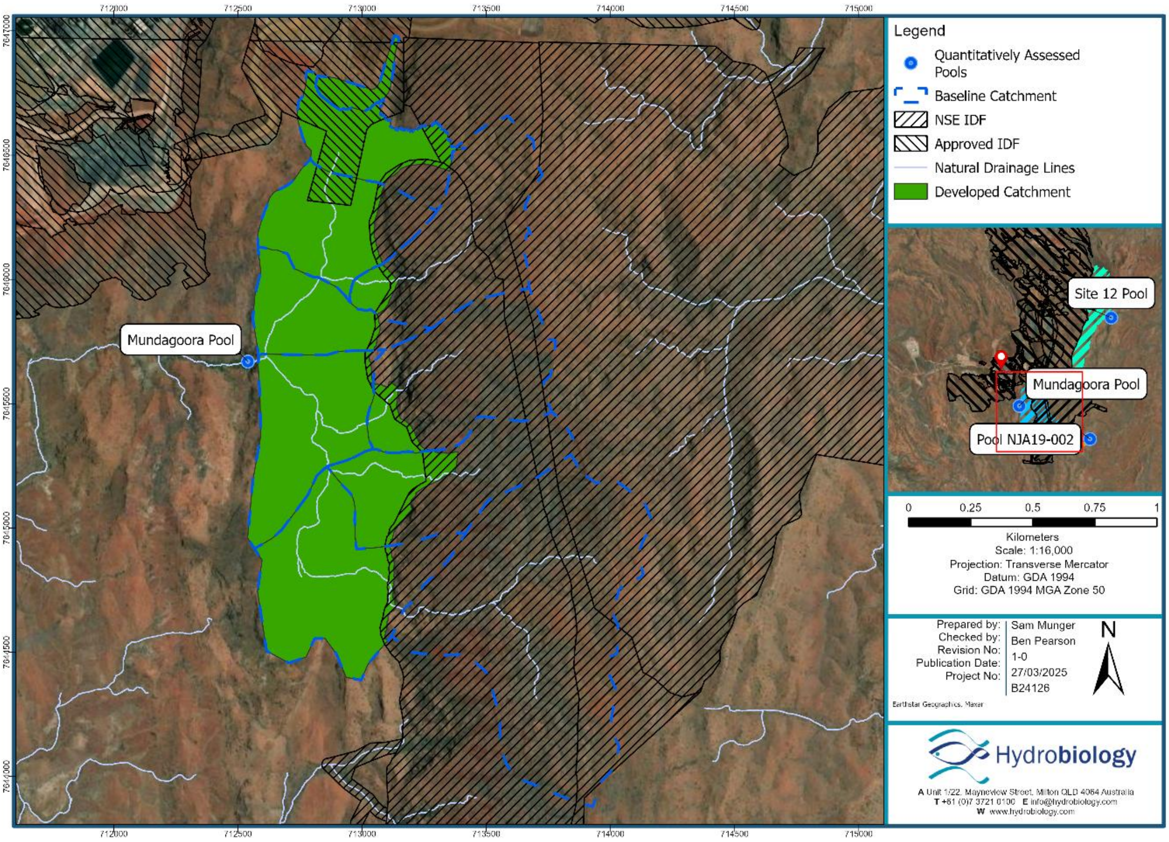

Figure 3-1: Mundagoora Pool developed and baseline catchment area.

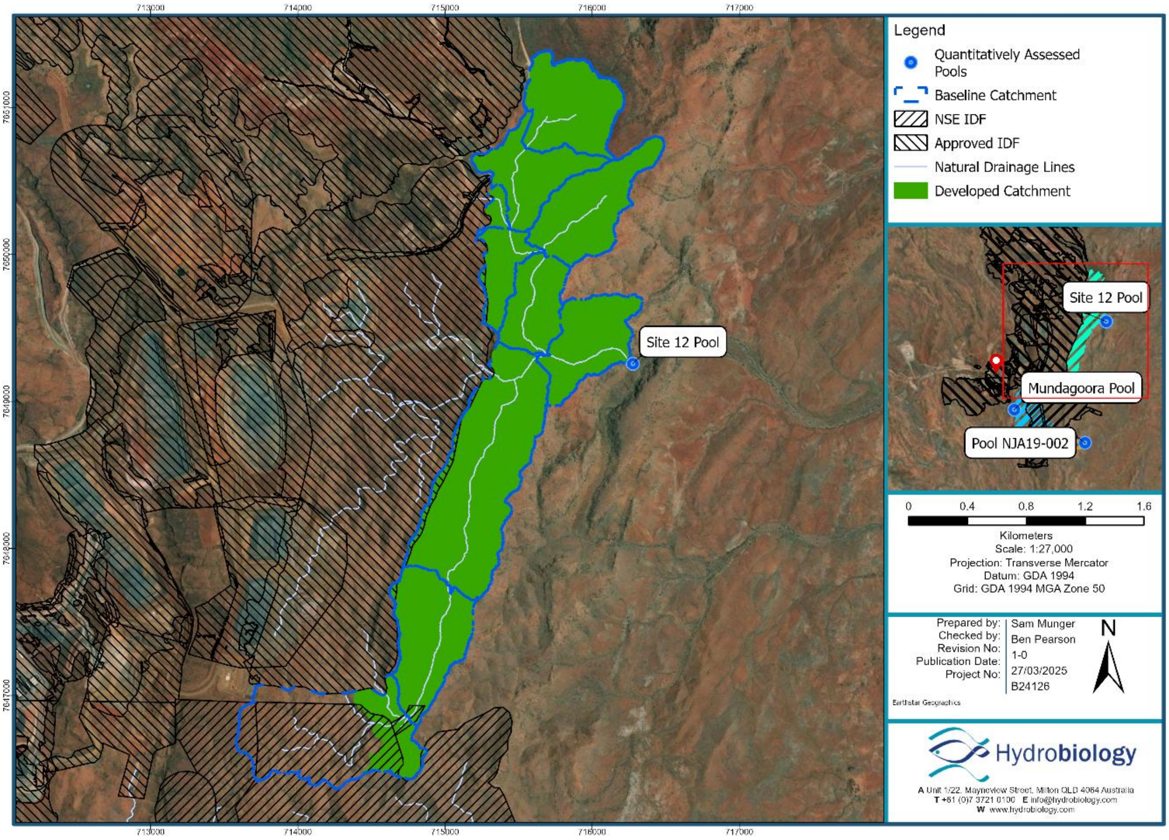

Figure 3-2: Site 12 Pool developed and baseline catchment area.

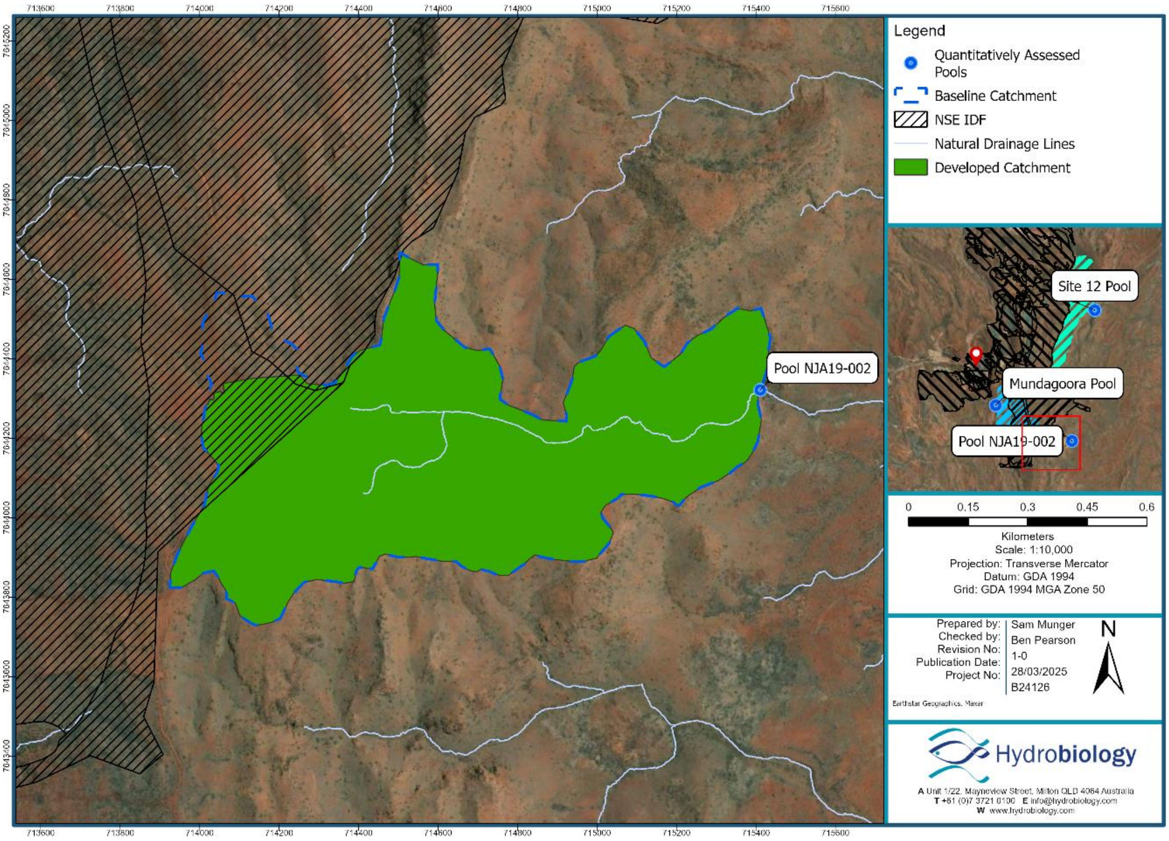

Figure 3-3: Pool NJA19-002 developed catchment area.

3.4 IMPACT ASSESSMENT APPROACH

3.4.1 SUMMARY OF METHODS

The sediment delivery and flushing impact assessment assumed that runoff from disturbed areas within the surface water impact area shall be managed by Fortescue to mitigate risk posed by other water quality parameters during mining operations. Several methods of assessing sediment dynamics within reaches (and associated pools) were implemented, with the approach applied to each reach based on the water permanence classification of the pools within that reach, such that more commonly inundated pools were assessed in greater detail, and therefore to greater certainty, than periodically inundated or ephemeral pools. The methods adopted to assess sediment delivery for varying water permanence classifications are summarised in Table 3-2 and explained below.

Permanently inundated and commonly wet pools adopted several inter-related approaches:

- Long-term modelling of catchment sediment delivery to the reaches was assessed to provide an understanding of the broad-scale trends in catchment sediment dynamics. Longer term modelling provides a cumulative assessment of impacts resulting from event-based sediment delivery.
- This was supplemented with event-based sediment delivery modelling to verify potentially more immediate impacts and identify the drivers of long-term trends.
- An event-based flushing assessment was also conducted to understand localised sediment dynamics (scour, deposition, transport) to supplement the overall reach- and catchment-scale sediment delivery assessments.
- These three methods allow a deduction of both sediment movement through the reaches and changes and trends in sediment storage.
- Potential impacts (likelihood and severity) to the sediment regime were assessed using a semi-quantitative assessment, comparing sediment supply changes and flushing capacity (sediment inflows/outflows) for baseline and developed scenarios.

Reaches containing seasonally inundated pools were assessed using the same event-based sediment delivery method described above, combined with a qualitative analysis of changes in reach hydraulics to assess potential flushing. A similar semi-quantitative impact assessment was adopted as that described above.

A qualitative assessment was also implemented for periodically inundated and ephemeral reaches to understand potential severity and likelihood of impacts. The approach considered changes to catchment area and hydraulics, as well as an understanding of trends in other reaches within the study area to provide an overall likelihood and severity of geomorphic impact.

Table 3-2: Pool classifications and associated sediment delivery impact assessment methods.

Water Permanence Classification	Reaches (& Associated Pools)	Method of Assessment
Permanently Inundated	Mundagoora Pool	Long-term and events-based sediment delivery modelling and pool flushing assessment using local scale 2D hydraulic modelling data to understand potential changes to the sediment balance of the pool (delivery, transport), including an assessment of the influence of bed scour/deposition in the study reach on the sediment balance.
Commonly Wet	Site 12 Pool and Pool Reach	
Seasonally Inundated	NJA19-002 Pool	Events-based sediment delivery modelling and assessment of catchment scale hydraulic modelling data at pools to inform potential changes in the sediment balance (delivery, transport) of the pool.
Periodic Inundation/ Ephemeral	Remaining Reaches	Qualitative sediment delivery and transport impact assessment based on changes in catchment area and the catchment scale hydraulic modelling data at pools to provide a high-level understanding of potential changes to drivers of sediment transport.

3.4.2 LONG-TERM SEDIMENT YIELD AND TRANSPORT MODEL

3.4.2.1 MODEL SETUP

Sediment yield to Mundagoora and Site 12 Pools was estimated using a catchment sediment budget approach and modelled through a stochastic Monte Carlo (MC) framework. This method applies probability distributions to input variables to generate a range of likely sediment delivery outcomes. A total of 100,000 simulations were conducted using the @Risk software. The model accounted for catchment sediment supply (CSS) to the pool reach and sediment transport capacity (STC) within the pool reach, with sediment delivery limited by the lower of these two factors:

- CSS was calculated as the sum of erosion from all mechanisms within the catchment.

$$CSS = HE + BE + BedE + GE \tag{1}$$

- STC was calculated using an extended form of Yang's (1973) equation (Prosser *et al.* 2001):

$$STC = K_1 \frac{12 * Q_m^{\beta} * S_{lr}^{\gamma}}{W_{lr}^{\beta-1}} \tag{2}$$

Where:

HE = Hill Erosion
BE = Bed Erosion
$BedE$ = Bed Erosion
GE = Gully Erosion
K_1 = coefficient of sediment transport capacity (dimensionless).
Q_m = Discharge (ML/month).
S_{lr} = slope of the lower reach channel (m/m).
β = exponent of Q_m.
γ = exponent of S.
W_{lr} = width of the lower reach channel (m).

Further details on the approach are provided in Appendix A.

3.4.2.2 MODEL INPUTS

Input data for sediment modelling were collected through field and desktop assessments. Hydrobiology staff conducted site visits to collect sediment samples and document physical characteristics. Tasks included:

- Ground surveys for geomorphic analysis (e.g., bank stability, channel morphology).
- Collection of bed, bank, and catchment sediment samples for laboratory analysis. Sediment samples used for this analysis are contained within Appendix B, Table 7-1. Figure 7-1 outlines sampling locations. Samples obtained from the Mundagoora catchment were assumed to be representative of the same soil conditions for Site 12 catchment given its proximity and similar underlying surface geology.
- Use of photographs and sediment sizing algorithms for particle distribution analysis.

Furthermore, spatial analysis was conducted using imagery, LiDAR, and datasets from Fortescue and field assessments. Key processes included:

- Catchment characterisation using at least 300 randomly selected points for data extraction.
- Channel segmentation into 10-metre lengths for hydraulic and sediment modelling.
- Utilisation of 1000-year rainfall and hydrology datasets developed by Worley for event-based modelling.

3.4.2.3 SIMULATIONS

The model described above was applied to the catchments feeding each of the Mundagoora and Site 12 pools. Within this, each catchment was modelled separately under each assessment scenario. Thus, a total of four simulations were undertaken, as per Figure 3-4, each incorporating 100,000

Monte Carlo iterations. The result was an estimation of fine, coarse, and total sediment delivery to each reach, under each scenario. These results were then compared between scenarios to define the estimated change in long-term sediment delivery to the reaches.

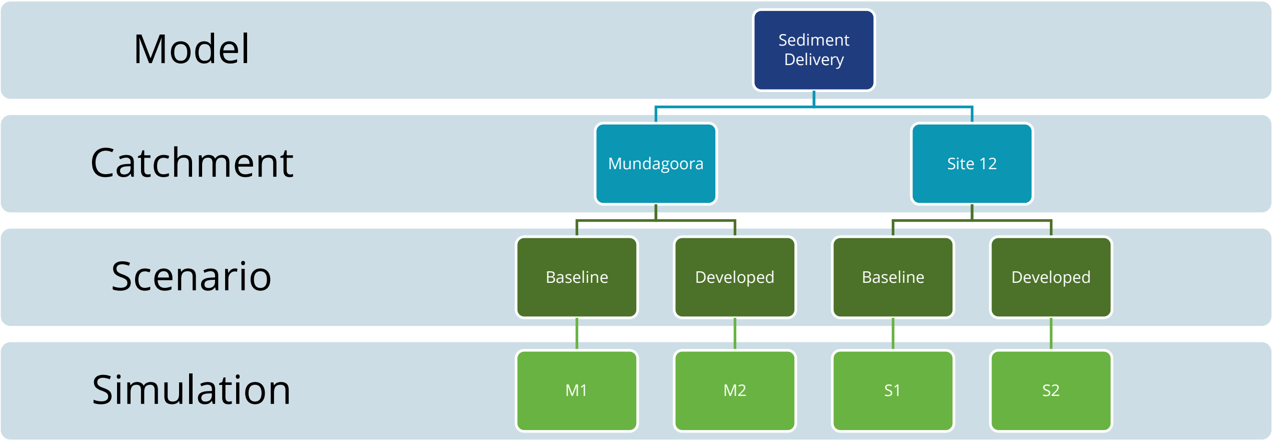

Figure 3-4: Model application structure.

3.4.3 EVENT-BASED SEDIMENT DELIVERY MODEL

An event-based sediment delivery model was developed to inform the volume of sediment delivered to the Mundagoora, Site 12, and NJA19-002 pool reaches under select events. This was achieved by disaggregating long-term sediment delivery results for bank, bed, and gully erosion, as well as sediment transport capacity, as based on the methods in Prosser *et al.* (2001) it was assumed that these parameters all scale linearly with rainfall and flow.

In conjunction with this disaggregation, hillslope erosion was calculated empirically since the assumption that this form of erosion scales linearly with rainfall is less likely. The revised universal soil loss equation (RUSLE) was used to calculate hillslope erosion, in conjunction with a daily rainfall erosivity equation proposed by Yu (1998) in the form:

$$R_j = 0.79\left(1 + 0.29\cos\left(\frac{2\pi}{365}j - \frac{\pi}{6}\right)\right)R_k^{1.49} \qquad (3)$$

Where:

R_j = rainfall erosivity on day, j, of the year (MJ-mm/ha-hour-year).
R_k = rainfall volume for event, k (m).

The RUSLE is described in Appendix A. Rainfall and discharge volumes were obtained from Worley's 1000-year rainfall and hydrology dataset. This dataset was also used to perform the frequency analysis from which event frequency was related to magnitude.

This model was applied in a stochastic framework with 10,000 iterations to estimate sediment supply and its variability for a range of event magnitudes outlined in Table 3-3, and at different times of the year. A smaller number of iterations was used for the daily disaggregation (compared with the long-term model) as this was enough iterations to understand trends and to cover the full range of possible outcomes during a day. The model provided fine and coarse sediment delivery for each scenario and event, such that changes between scenarios could be quantified. It allowed an understanding of which specific events were driving long term trends and whether this changed between scenarios.

Table 3-3: Event AEPs assessed in event-based sediment delivery modelling and flushing assessment.

AEP	24-hour Event Precipitation (mm)	AEP	24-hour Event Precipitation (mm)
1%	297	**10%**	158
2%	265	**20%**	117
5%	199	**50%**	77

3.4.4 EVENT-BASED FLUSHING ASSESSMENT

Sediment flushing was evaluated using the Hjulström Curve, with parameterisation by Miedema (2013). Evaluation was undertaken for both scour (erosion or removal of sediment from the bed) and transport (movement of already mobilised sediment) using the equations:

$$U_T = \frac{77d}{1+24d} \tag{4}$$

Where:

U_T = threshold velocity above which a particle of diameter, d, will be transported (m/s).

Additionally,

$$U_S = 1.5\left(\frac{\nu}{d}\right)^{0.8} + 0.85\left(\frac{\nu}{d}\right)^{0.35} + 9.5\frac{Rgd}{1+2.25Rgd} \tag{5}$$

Where:

U_s = threshold velocity above which a particle of diameter, d, will be scoured (m/s).
ν = kinematic viscosity (m^2/s).
R = relative density of sediment (dimensionless).
g = gravity (m/s^2).

Pools were assessed for sediment sizes from fine silt (0.002mm) to cobbles (200mm) and AEP event conditions outlined in Table 3-3, using event velocity time series data produced by Worley. This assessment provided durations for each scenario and event for which scour and transport occurred. These durations could then be compared between scenarios to determine changes to event scour and transport within each assessed reach. This could then be compared with long-term and event-based sediment delivery to understand the reach-scale sediment regime.

3.4.5 SEDIMENT ASSESSMENT METHODS

The results obtained from the models and assessments pertaining to reaches containing permanent and commonly wet pools (Mundagoora and Site 12) were interpreted in unison to imply the likely outcomes for the two pools. Interpretation was undertaken using the model outlined in Figure 3-5, which considers the fluxes into and out of the pool to determine likely changes to sediment storage within the pool. The terms in the model are:

- Derived from the long-term and event-based sediment delivery modelling:
  - Delivery – Sediment delivery to the pool from the upstream catchment.
- Derived from the event-based flushing assessment:
  - Scour – Likely scour of the pool during events.
  - Transport – Sediment transport to downstream reaches.
- Inferred by comparing delivery and flushing, as outlined below.
  - Deposition – Likely deposition of sediment from the sediment load.

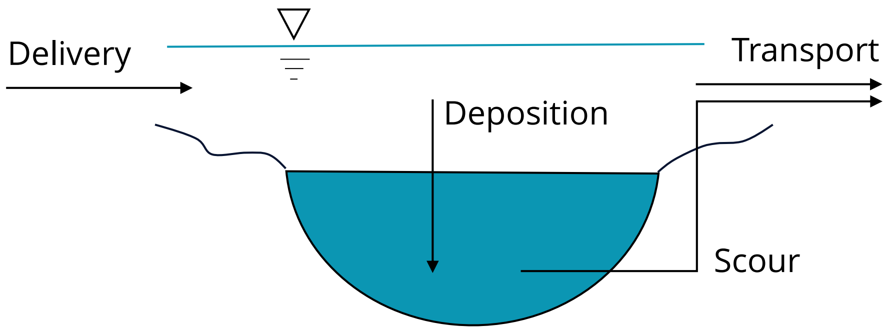

Figure 3-5: Sediment storage model used to interpret results and infer likely outcomes following development.

Considering a node within the pool, the change in storage (ΔS) of the pool is given by:

$$\Delta S = deposition - scour$$

Also, considering a node in the supplying waterway, Delivery is given by:

$$delivery = deposition + transport$$

Rearranging and substituting, the change in sediment storage within the pool as a function of waterway fluxes is given as:

$$\Delta S = delivery - transport - scour$$

This equation may be adapted to provide an indication of likely changes to pool sediment storage by considering the magnitude of changes to each component. This indicative equation takes the form:

$$\delta S = \delta delivery - \frac{(\delta transport + \delta scour)}{2}$$

This equation is used in conjunction with a classified analysis of sediment impact in Mundagoora and Site 12 Pools, based on the classifications outlined in Table 3-4.

Table 3-4: Classification ranges used for classified analysis of likelihood and severity of sediment impact.

Range	Classification
> 80%	Extreme increase
50 - 80%	Large increase
30 - 50%	Moderate increase
10 - 30%	Slight increase
-10 - 10%	Negligible change
-30 - -10%	Slight decrease
-50 - -30%	Moderate decrease
-80 - -50%	Large decrease
< -80%	Extreme decrease

3.4.6 QUALITATIVE SEDIMENT TRANSPORT IMPACT ASSESSMENT

Likelihood and severity of negative impact to the reaches containing periodically inundated/ ephemeral pools (see Table 1-1) was evaluated based on changes in catchment area and hydraulic velocity. As proximity to the proposed NSE was linked to the change in catchment area, the impact assessment used the reduction as a proxy for proximity. Since all identified pools are within erodible systems, sediment supply was assumed equal between removed and retained areas. The assessment used the impact matrix in Table 3-5.

Table 3-5: Matrix used to determine likelihood and potential severity of negative impacts on ephemeral pools.

Mean change in event velocity[1]	Reduction in Catchment Area			
	1 to 20%	**21 to 50%**	**51 to 70%**	**71 to 99%**
1 to 10%	🟢 Low	🟢 Low	🟠 Moderate	🔴 High
11 to 50%	🟢 Low	🟠 Moderate	🔴 High	🔴 High
51 to 70%	🟠 Moderate	🔴 High	🔴 High	🔴 High
71 to 99%	🔴 High	🔴 High	🔴 High	🔴 High

[1] Calculated as the average of the change in the sum of velocities at each step in a time-series across 1%, 2%, 5%, 10%, 20%, and 50% AEP events. Hydrographs were provided by Worley.

4.

RESULTS

4.1 SUMMARY

This section lists the specific results from the modelling, reporting changes in long-term and event-based sediment delivery and event-based flushing between scenarios for Mundagoora Pool and Site 12 Pool, changes in event-based sediment delivery in NJA19-002 Pool, and the qualitative assessment of impacts in the remaining reaches (and associated pools). Implications of these changes to the sediment regime of the pools are then discussed further in Section 5.

4.2 LONG-TERM SEDIMENT DELIVERY MODELLING

4.2.1 SUMMARY

Key Outcomes

Mundagoora Pool

- ↓ **55% less sediment delivery**
- ↓ **56% less fine sediment delivery**
- ↓ **56% less coarse sediment delivery**

Site 12 Pool

- ↓ **21% less sediment delivery**
- ↓ **31% less fine sediment delivery**
- ↓ **13% less coarse sediment delivery**

4.2.2 MUNDAGOORA SIMULATIONS

4.2.2.1 M2 – BASELINE SEDIMENT DELIVERY

Results for baseline simulations are summarised in Table 4-1. It shows a median total sediment delivery to the pool reach of 5,668 t/year (90% Confidence Interval (CI): ± 33 t/year). Coarse sediment delivery accounts for most of this volume at 4,081 t/year (90% CI: ±27 t/year). Fine material subsequently represents a smaller proportion, with a median value of 1,368 t/year (90% CI: ±13 t/year). Variability is very high, with maximum modelled transport reaching 396,577 t/year.

Table 4-1: Simulation results for Mundagoora Pool under baseline conditions.

Delivery Component	Statistic (t / year)				
	Median	90% CI	Minimum	Maximum	Mean
Total sediment delivery	5,668	± 33	130	396,577	6,673
Coarse mass	4,082	± 27	0	305,762	4,832
Fine mass	1,368	± 13	52	302,524	1,841

4.2.2.2 M3 – DEVELOPED SEDIMENT DELIVERY

Developed simulations demonstrate significant reductions in sediment delivery compared to baseline conditions (Table 4-2), achieving a median total sediment delivery of 2,545 t/year (90% CI: ± 13 t/year). This is split between 1797 t/year (90% CI: ± 12 t/year) of coarse sediment and 601 t/year (90% CI: ± 5 t/year) of fine sediment. Variability remains high, and mean values are again above median values.

Table 4-2: Simulation results for Mundagoora Pool under developed conditions.

Delivery component	Statistic (t / year)				
	Median	90% CI	Minimum	Maximum	Mean
Total sediment delivery	2,545	± 13	44	129,497	3,031
Coarse mass	1,797	± 12	0	94,852	2,224
Fine mass	601	± 5	21	123,701	807

4.2.2.3 COMPARISON OF SCENARIOS FOR MUNDAGOORA POOL

Results from simulations for Mundagoora Pool are summarised graphically in Figure 4-1. Note the longer upper whiskers and mean greater than the median across all scenarios, indicating that sediment delivery is positively skewed and thus driven by large events.

Table 4-3 summarises the percentage reductions in median total, coarse, and fine sediment delivery between baseline and developed conditions. Sediment delivery reductions are substantial, with total sediment delivery decreasing by 55%, evenly split between reductions in fine and coarse loads.

4.2.3 SITE 12 SIMULATIONS

4.2.3.1 S2 – BASELINE SEDIMENT DELIVERY

The baseline simulation results for Site 12 Pool are detailed in Table 4-4. Under this scenario the median total sediment delivery is 5,410 t/year (90% CI: ± 40 t/year). Coarse mass accounts for just over half of this volume with a median of 2,728 t/year (90% CI: ± 34 t/year), while median fine mass is 1,817 t/year (90% CI: ± 17 t/year). Variability under this scenario is very high, with maximum modelled sediment delivery reaching over 900,000 t/year.

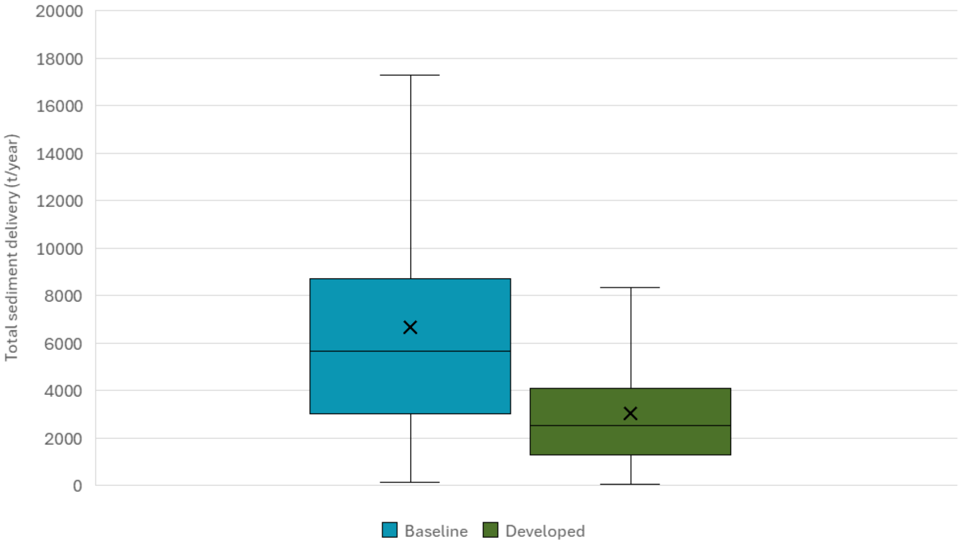

Figure 4-1: Box plots showing distribution of total sediment delivery for baseline and developed scenarios in Mundagoora Pool.

Table 4-3: Change in median total, coarse and fine sediment delivery between baseline and developed scenarios for Mundagoora Pool.

	Total	Coarse	Fine
Change under developed conditions	-55%	-56%	-56%

Table 4-4: Simulation results for Site 12 Pool under baseline conditions.

Delivery Component	Statistic (t / year)				
	Median	90% CI	Minimum	Maximum	Mean
Total sediment delivery	5,410	± 40	29	913,024	7,332
Coarse mass	2,728	± 34	0	834,569	4,792
Fine mass	1,817	± 17	22	215,161	2,540

4.2.3.2 S3 – DEVELOPED SEDIMENT DELIVERY

Developed conditions for Site 12 Pool, as summarised in Table 4-5, indicate reductions in sediment delivery metrics. The total sediment delivery reduces to a median of 4,298 t/year (90% CI: ± 30 t/year). Delivery of coarse mass continues to provide approximately half of this volume with a median of 2,388 t/year (90% CI: ± 27 t/year). Fine mass reduces to a median of 1,252 t/year (90% CI: ± 10 t/year). Despite reductions across all sediment delivery components, the variability remains high, with maximum simulated values of 361,547 t/year for total delivery.

Table 4-5: Simulation results for Site 12 Pool under developed conditions.

Delivery Component	Statistic (t / year)				
	Median	90% CI	Minimum	Maximum	Mean
Total sediment delivery	4,298	± 30	20	361,547	5,860
Coarse mass	2,383	± 27	0	271,292	4,105
Fine mass	1,253	± 10	14	201,779	1,755

4.2.3.3 COMPARISON OF SCENARIOS FOR SITE 12 POOL

Simulation results for Site 12 Pool are summarised in Figure 4-2. As for Mundagoora Pool, the results again portray a positive skew, with mean values consistently greater than the median. A comparison of total, coarse and fine sediment delivery for each scenario provides the reductions presented in

Table 4-6. These results show a developed reduction of 21% in total sediment delivery, with a larger reduction (31%) in fine material than coarse (13%).

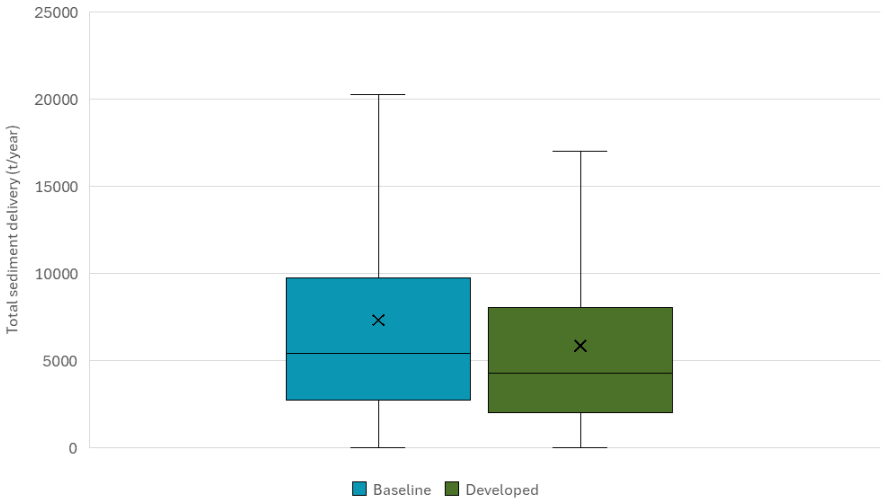

Figure 4-2: Box plots showing distribution of total sediment delivery for baseline and developed scenarios in Site 12 Pool.

Table 4-6: Change in median total, coarse and fine sediment delivery between baseline and developed scenarios for Site 12 Pool.

	Total	Coarse	Fine
Change under developed conditions	-21%	-13%	-31%

4.3 EVENT-BASED DELIVERY MODELLING

4.3.1 SUMMARY

Key Outcomes

Mundagoora Pool
- ↓ **63% mean decrease in delivery of fines material**
- ↓ **57% mean decrease in delivery of coarse material**

Site 12 Pool
- ↓ **36% mean decrease in delivery of fines material**
- ↓ **36% mean decrease in delivery of coarse material**

NJA19-002 Pool
- ↓ **9% mean increase in delivery of fines material**
- ↓ **34% mean decrease in delivery of coarse material**

4.3.2 MUNDAGOORA POOL

In alignment with the results of long-term modelling, event-based modelling depicts a reduction in sediment delivery to Mundagoora Pool for the developed scenario. Fine sediment experiences a mean reduction of 63% across all flow events. Coarse material experiences a similar decrease in delivery, with a mean reduction of 57%. Notably, these results experience very little variation between events with a range of only 3-4%, as presented in Table 4-7 and Figure 4-3.

Table 4-7: Change in sediment delivery to Mundagoora Pool between baseline and developed scenarios.

AEP	1%	2%	5%	10%	20%	50%	Mean
Fine change	-65%	-64%	-63%	-63%	-62%	-63%	-63%
Coarse change	-59%	-58%	-56%	-56%	-55%	-56%	-57%

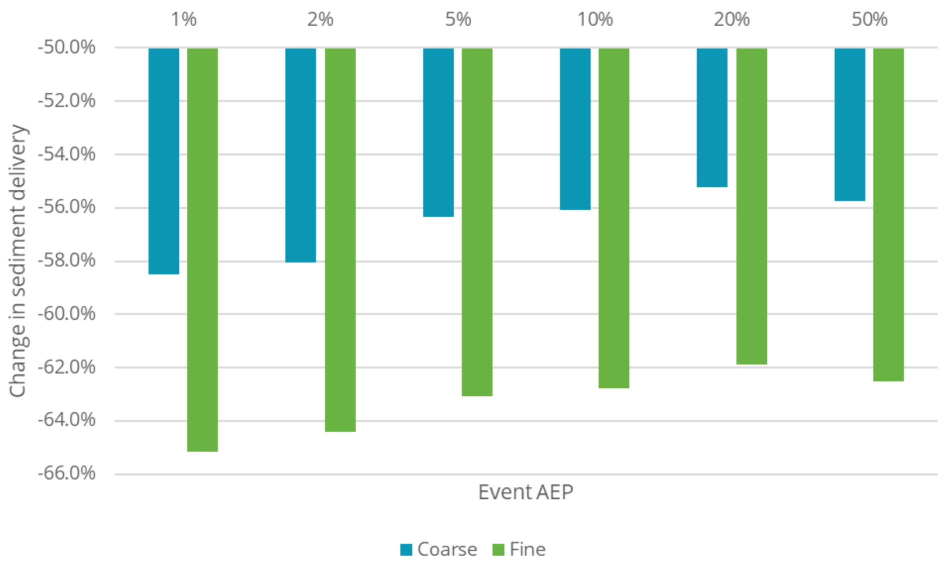

Figure 4-3: Changes in fine and coarse sediment delivery to Mundagoora Pool.

4.3.3 SITE 12 POOL

Like Mundagoora Pool and the long-term modelling results, event-based delivery to Site 12 Pool decreases baseline to developed scenarios. As shown in Table 4-8 and Figure 4-4, both fine and coarse sediment experience a mean reduction in event delivery of ~36%. Notably, results are not as consistent across events, as for Mundagoora Pool, with a range of up to ~23% (-25% – -48%). Unusually, results for 1%, 5%, and 20% AEP events align closely while differing substantially from the also closely aligned results for 2%, 10% and 50% AEP events.

Table 4-8: Change in sediment delivery to Site 12 Pool between baseline and developed scenarios.

AEP	1%	2%	5%	10%	20%	50%	Mean
Fine change	-26%	-46%	-27%	-48%	-25%	-43%	-36%
Coarse change	-26%	-47%	-26%	-48%	-25%	-43%	-36%

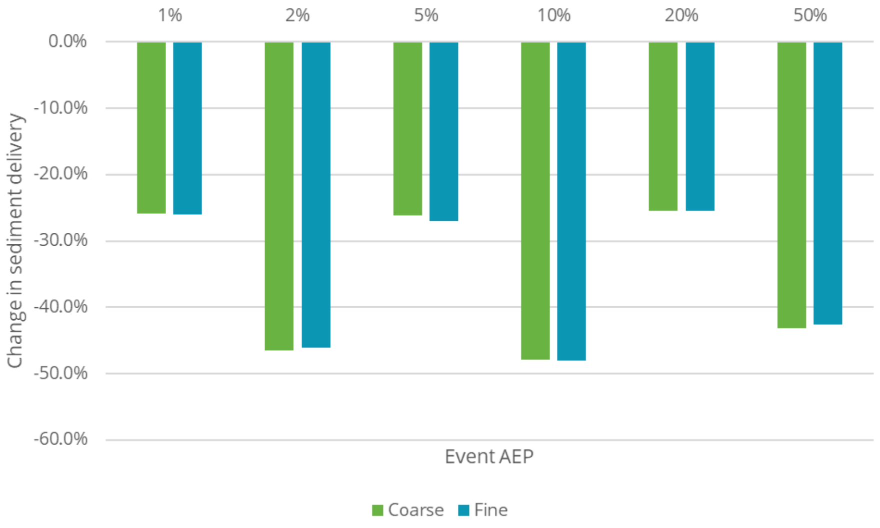

Figure 4-4: Changes in fine and coarse sediment delivery to Site 12 Pool.

Note that the mean decrease in event-based coarse sediment delivery is much greater than that seen for long-term delivery. This suggests that changes to coarse sediment delivery are likely to be greater for less frequent, larger events (that is, those captured within the event-based model) than for more frequent, smaller events (which undergird the long-term model).

4.3.4 POOL NJA19-002

Changes in sediment supply to Pool NJA19-002 differ in pattern to those for Mundagoora and Site 12 Pool. Pool NJA19-002 experiences a moderate decrease in supply of coarse material of approximately 34% with little variation in this change between events (~3%). Fine sediment, however, shows negligible change for extreme events (1 to 5% AEP), but presents a slight increase for more frequent events (10 to 50% AEP), with increases ranging from ~9% to 19%. These changes are shown in Table 4-9 and Figure 4-5, with the figure highlighting the consistency in changes to coarse sediment supply across events, and the gradual increase in fine sediment supply with increasing event frequency. These results differ considerably from those of Mundagoora and Site 12 pools due to the size of the Pool NJA19-002 catchment (compared to Site 12 and Mundagoora), the fact that the area removed from the catchment is an area of much higher relief (and greater producer of coarse sediment) than the remaining catchment areas, and the altered flow and sediment dynamics following the removal of the higher relief area.

Table 4-9: Change in sediment delivery to Pool NJA19-002 between baseline and developed scenarios.

AEP	**1%**	**2%**	**5%**	**10%**	**20%**	**50%**	**Mean**
Fine change	+1%	+3%	+5%	+9%	+13%	+19%	+9%
Coarse change	-35%	-35%	-34%	-34%	-34%	-32%	-34%

Figure 4-5: Changes in fine and coarse sediment delivery to Pool NJA19-002.

4.4 EVENT-BASED FLUSHING ASSESSMENT

4.4.1 SUMMARY

Key Outcomes

Mundagoora Pool

- ↓ **44% mean decrease in scour of fines material**
- ↓ **18% mean decrease in transport of fine material**
- ↓ **33% mean decrease in scour of coarse material**
- ↓ **70% mean decrease in transport of coarse material**

Site 12 Pool

- ↓ **11% mean decrease in scour of fine material**
- ↓ **4% mean decrease in transport of fine material**
- ↓ **18% mean decrease in scour of coarse material**
- ↓ **12% mean decrease in transport of coarse material**

4.4.2 MUNDAGOORA POOL

Table 4-10 compares baseline and developed flushing in Mundagoora Pool. Fine sediment scour and transport both declined significantly (means: -44% and -18%, respectively). Coarse sediment scour was eliminated for high-frequency events (1% and 2% AEP, -100%), with an overall mean reduction of -33%. Coarse sediment transport was severely impacted (mean: -70%), showing complete loss at higher AEP events (≥ 5%), and significant reduction for lower AEP events.

Table 4-10: Change in fine and coarse sediment flushing in Mundagoora Pool.

AEP	1%	2%	5%	10%	20%	50%	Mean
Fine / Scour	-57%	-56%	-65%	-40%	-43%	0%	-44%
Fine / Transport	-21%	-21%	-24%	-20%	-18%	0%	-18%
Coarse / Scour	-100%	-100%	0%	0%	0%	0%	-33%
Coarse / Transport	-58%	-60%	-100%	-100%	-100%	0%	-70%

4.4.3 SITE 12 POOL

Table 4-11 presents the comparison between baseline and developed flushing in Site 12 Pool. Fine sediment scour decreased across all events (mean: -11%), with the most notable reductions occurring at the 5% and 10% AEP events (-16% and -17%, respectively). Fine sediment transport also declined slightly overall (-4% mean), with reductions concentrated at moderate AEP events. Coarse sediment scour and transport both exhibited overall decreases (-18% and -12% mean, respectively), with particularly strong reductions in scour at the 5% AEP event (-47%). These results indicate a general decline in sediment mobility following development, particularly for coarse material.

Table 4-11: Change in fine and coarse sediment flushing in Mundagoora Pool between baseline and developed scenarios.

AEP	1%	2%	5%	10%	20%	50%	Mean
Fine / Scour	-2%	-2%	-16%	-17%	-7%	-21%	-11%
Fine / Transport	0%	0%	-13%	-13%	<+1%	0%	-4%
Coarse / Scour	-11%	-12%	-47%	-24%	-7%	-9%	-18%
Coarse / Transport	-8%	-7%	-21%	-23%	-8%	-6%	-12%

4.5 QUALITATIVE SEDIMENT TRANSPORT ASSESSMENT

The results from the temporary pools assessment are presented in Table 4-12. Of the 10 pools identified as potentially having sediment delivery impacts, two pools (Pools 59 & 57) were noted to have extreme changes in catchment area and hydraulics as a result of the NSE IDF, which is likely to result in persistent change to sediment storage. A further two pools (NJA21-006_US and Pool 9) are likely to experience a moderate reduction in erodible catchment area. The modelling results from these pools within the study area suggest that sediment transport capacity is likely to decrease faster than sediment supply, thereby limiting the free movement of sediment. In combination with a reduction in flushing frequency, stored sediment within the reaches containing these pools is likely to increase over time, albeit at varying rates. Additionally, three pools had small reductions in catchment area or event flushing velocities, while three pools lie within the NSE IDF and will be removed by mining.

Table 4-12: Results of qualitative sediment transport impact assessment for reaches (and their catchments) containing ephemeral pools.

Catchment	Change in area	Mean change in event velocity	Proximity to NSE (m)
Pool 62	Eliminated	N/A	0
Pool IB-SW-Dry-Reject_DS-002	< 5%	6%	3,353
Pool NJA21-006_US	32%	13%	1,907
Pool NJA21-006_DS	11%	9%	4,015
Pool SW	23%	7%	130
Pool 9	27%	24%	160
Pool 51	Eliminated	N/A	0
Pool 50	Eliminated	N/A	0
Pool 59	>95%	94%	157
Pool 57	>95%	83%	18

5.

IMPACT ASSESSMENT

5.1 PERMANENT AND COMMONLY WET POOLS

5.1.1 SUMMARY

Key Outcomes

Mundagoora Pool

- **Reduction in pool turbidity due to decreased fine sediment supply and retention**
- **Reduction in soft sediment substrate, although shallow bedrock will limit scour**
- **Continued fine sediment capture in vegetated margins, supporting the persistence of existing habitat structures**
- **Likely event-driven transition of bed material towards a more erosion resistant, coarser substrate.**
- **Overall Low impact is expected within Mundagoora Pool**

Site 12 Pool

- **Reduction in pool turbidity due to decreased fine sediment supply and retention**
- **Minor reductions in soft sediment substrate, though not as pronounced as in Mundagoora Pool**
- **Continued fine sediment capture in vegetated margins and at bedrock outcrops, supporting the persistence of existing habitat structures**
- **Event-driven scour of both fine and coarse material to bedrock, with currently exposed bedrock limiting impact**
- **Overall Low impact is expected within Site 12 Pool**

5.1.2 MUNDAGOORA POOL

When considered independently, modelled results comparing baseline to developed scenarios in Mundagoora Pool suggest significant impacts to pool water quality. A 56% reduction in long-term delivery of fine sediment is mirrored by a 63% reduction in event-based delivery. Similarly, the flushing assessment suggests reductions in transport and scour of fine materials of 18% and 44%, respectively. Classifying these reductions based on the classification ranges defined in Table 3-4 indicates a large decrease in fine delivery, a slight decrease in transport of fines, and a moderate decrease in scour of fines. When considered holistically, it is expected that, because the decreases in scour and transport are smaller than the decrease in sediment delivery, the system will be removed of its fine sediment. Considering the magnitude of the changes, it is estimated that this reduction in fine sediment within the pool will be moderate.

Similarly, long-term modelling presented a 56% reduction in coarse sediment delivery. This was closely matched by a 57% reduction in event-based delivery of coarse material. Furthermore, the flushing assessment provided values of transport and scour of coarse material equal to 70% and 33%, respectively. These values are classified as a large decrease in delivery, large decrease in transport, and a moderate decrease in scour of coarse material. Subsequently, due to the undersized reduction in scour, it is expected that sediment storage will experience a slight increase.

These results are summarised in Table 5-1.

Table 5-1: Sediment assessment results and impact classification for changes following development in Mundagoora Pool.

Parameter	Scour	Transport	Delivery	Sediment storage[1]
Fines				
Event mean	-43.5%	-17.5%	-63.3%	-32.8%
Long-term			-56.0%	-25.5%
Impact	Moderate decrease	Slight decrease	Large decrease	Moderate decrease
Coarse				
Event mean	-33.3%	-69.6%	-56.7%	-5.3%
Long-term			-56.0%	-4.6%
Impact	Moderate decrease	Large decrease	Large decrease	Slight decrease

[1] *Calculated using indicative equation for δS, values are purely indicative and should not be used to closely estimate magnitudes of possible changes.*

When considered collaboratively, the outsized decrease in fine sediment storage within the pool compared to coarse sediment implies a shift in pool sediment composition towards a coarser substrate. That is, large decreases in delivery of fine sediments combined with persistence of much of the transport and scour of fines is likely to lead to less deposition of fine sediment. In contrast, the reductions in coarse sediment transport and scour, which more closely match reductions in coarse sediment delivery, suggest continued deposition of this material.

Likely consequences include:

- Reductions in pool turbidity due to decreased supply and retention of fine sediment.
- Reductions in soft sediment substrate.
- Persistence of fine-grained sediment capture in vegetated margins.
- Event driven transition of bed material towards a more erosion resistant, coarser substrate.

Overall, these consequences are likely to have minimal negative geomorphic impact on Mundagoora Pool. Decreases in sediment recharge are expected to be countered by the ability of the substrate to resist bed erosion as it trends towards a coarser material. Similarly, the persistence of fine sediment capture in vegetated margins is likely to provide resistance against lateral expansion of the pool. These impacts are portrayed in Figure 5-1.

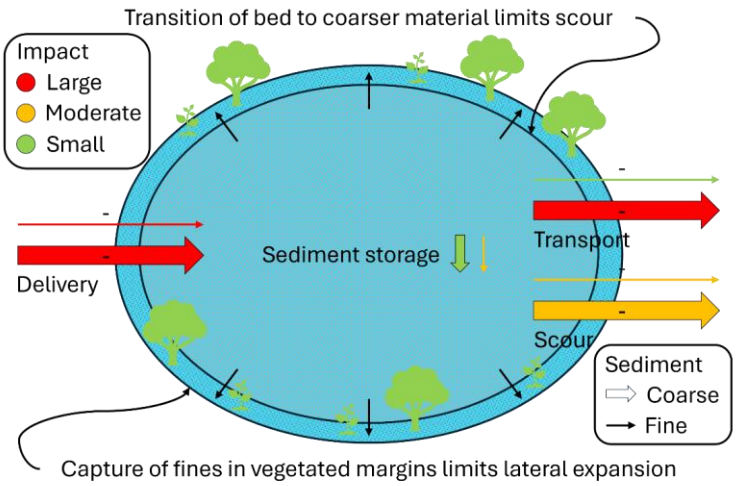

Figure 5-1: Impacts to Mundagoora Pool resulting from NSE.

5.1.3 SITE 12 POOL

When considered independently, modelled results comparing baseline to developed scenarios in Site 12 Pool present more moderate impacts to pool water quality and sediment composition compared to Mundagoora Pool. The changes in fine sediment fluxes indicate a 31% reduction in long-term delivery of fine sediment, accompanied by a 36% reduction in event-based delivery. The flushing assessment suggests reductions in transport and scour of fine materials by 4% and 11%, respectively.

Classifying these changes using the classification ranges defined in Table 3-4 indicates a moderate decrease in fine sediment delivery, a negligible change in fine sediment transport, and a slight decrease in scour of fines. When evaluated holistically, the more substantial decrease in sediment delivery compared to the minor changes in transport and scour implies an overall reduction in fine sediment within the pool. Considering the magnitude of changes, it is estimated that this reduction in fine sediment storage will be small.

Similarly, long-term modelling presented a 13% reduction in coarse sediment delivery. This is increased under event modelling outcomes to represent a 36% reduction in event-based delivery. Additionally, the flushing assessment provided values of transport and scour of coarse material equal to 12% and 18%, respectively. These values correspond to a moderate decrease in delivery, a slight decrease in transport, and a slight decrease in scour of coarse material.

Given the relatively small decreases in scour and transport, and the not-much-larger decrease in delivery, coarse sediment storage in Site 12 Pool is likely to experience only slight changes. Specifically, since the reductions in coarse sediment delivery exceed the reductions in scour and transport, the pool is expected to see a minor decrease in stored coarse sediment.

These results are summarised in Table 5-2.

Table 5-2: Sediment assessment results and impact rating for changes between baseline and developed scenarios in Site 12 Pool.

Parameter	Scour	Transport	Delivery	Sediment storage[1]
Fines				
Event mean	-10.7%	-4.2%	-35.8%	-28.4%
Long-term			-31.0%	-23.6%
Impact	Slight decrease	Negligible change	Moderate decrease	Slight decrease
Coarse				
Event mean	-18.2%	-12.1%	-35.9%	-20.8%
Long-term			-13.0%	+2.2%
Impact	Slight decrease	Slight decrease	Moderate decrease	Slight decrease

[1] *Calculated using indicative equation for δS, values are purely indicative and should not be used to closely estimate magnitudes of possible changes.*

When considered collaboratively, the results indicate that Site 12 Pool is likely to experience a smaller shift in sediment composition compared to Mundagoora Pool. The key implications of these changes include:

- Reduction in pool turbidity due to decreased fine sediment supply and retention.
- Minor reductions in soft sediment substrate, though not as pronounced as in Mundagoora Pool. Given the exposed bedrock and minimal soft sediment in this pool, this is unlikely to be observed.
- Continued fine-grained sediment capture in vegetated margins, supporting the persistence of existing habitat structures.
- Event-driven scour of both fine and coarse material to bedrock.

Overall, Site 12 Pool is projected to experience a slight decrease in stored fine and coarse sediment, suggesting that the fundamental characteristics of the pool's sediment composition will remain relatively stable under developed conditions. The pool’s bedrock confinement and vegetated margins are also expected to limit bed and bank erosion These impacts are presented in Figure 5-2.

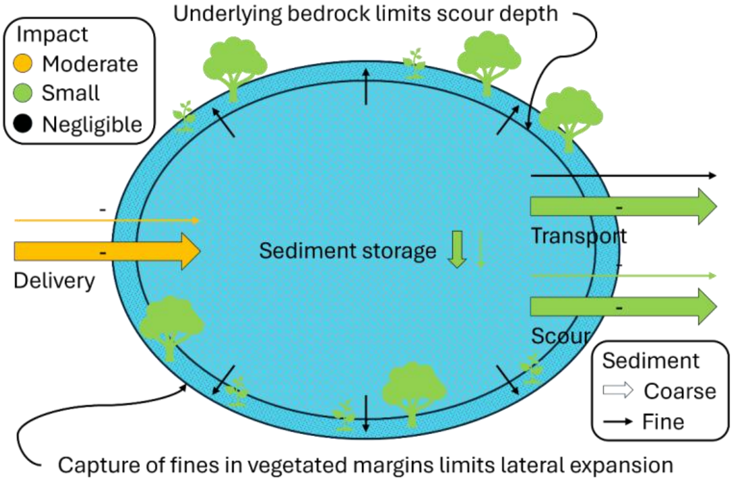

Figure 5-2: Impacts to Site 12 Pool resulting from NSE.

5.2 SEASONALLY INUNDATED POOLS

As per Section 4.3.4, analysis of NJA19-002 data suggests a moderate decrease in supply of coarse material (approximately 34%). Additionally, it is expected that supply of fine sediment to the pool will experience a slight increase (average of 9%), with greater increases expected for smaller, more frequent events.

These changes to coarse sediment supply are consistent with changes to catchment area, especially given that the area removed comprises more coarse soils in the upper catchment. Given the increase in supply of fine sediment, it is likely that pool turbidity will increase in kind, especially under small frequent events, with flushing occurring during larger events.

Furthermore, the disbalance between fine and coarse sediment supply is likely to enforce a shift in bed material towards a finer substrate. This may make the pool susceptible to bed erosion of deposited fines during larger events, however, in the absence of a flushing assessment for Pool NJA19-002, it is unclear to what extent net scour relative to baseline conditions might occur. Results from other pools within the study area suggest that a faster rate of decrease in transport capacity than sediment supply may counter any susceptibility to flushing as a greater proportion of the delivered sediment is deposited within the pool. This has the potential to cause increased aggradation during smaller events, with scour of these deposited fines occurring during larger events.

Ultimately, the expected increase in pool turbidity, and uncertainty regarding erosion dynamics place this pool at a moderate likelihood of experiencing negative impacts.

5.3 PERIODIC INUNDATION/EPHEMERAL POOLS

Key Outcomes

- **10 pool reaches (and associated pools) impacted, with ratings assigned:**
  - **2 identified as high impact (Pool 59 & 57) – extreme reductions in catchment area and hydraulics.**
  - **2 identified as moderate impact (Pool NJA21-006-US & Pool 9) – moderate reduction in erodible catchment area.**
  - **3 low impact – minor reductions in catchment area or event flushing velocities.**
  - **3 eliminated – located within the NSE IDF.**

The results of the qualitative sediment transport impact assessment for ephemeral pool reaches is shown in Table 5-3. Of the 10 ephemeral pools assessed within the surface water impact zone of NSE, the NSE IDF completely removed three pools (Pools 62, 51, 50), high negative impacts were expected at 2 pool reaches (Pools 59 & 57), moderate negative impacts were expected at 2 additional pool reaches (Pool 9 & NJA21-006-US), while low negative impacts were expected 3 pool reaches. Pools 59 and 57 displayed extreme reductions in event velocities, meaning that scour and transport of material through the pools is unlikely. Although it is likely that these pools will experience a concurrent decrease in sediment supply, the remaining supply is likely to fill the pool in the absence of the required flushing. Pool 9 and Pool NJA21-006 US were deemed as moderate impact due to a similar, although more moderate, dynamic between sediment supply and flushing. Notably, given the qualitative nature of this assessment, opportunities for supply-flushing balancing have not been considered, and thus impact has been scaled with magnitude of change.

Table 5-3: Results of qualitative sediment transport impact assessment for reaches containing ephemeral pools.

Catchment	Likelihood and Severity of Change
Pool 62	🔴 Removed
Pool IB-SW-Dry-Reject-DS-002	🟢 Low
Pool NJA21-006_US	🟠 Moderate
Pool NJA21-006_DS	🟢 Low
Pool SW	🟢 Low
Pool 9	🟠 Moderate
Pool 51	🔴 Removed
Pool 50	🔴 Removed
Pool 59	🔴 High
Pool 57	🔴 High

5.4 IMPACT ASSESSMENT SUMMARY

Table 5-4 summarises the outcomes of the analysis undertaken throughout this report and presents the likelihood of change to each of the pools within the NSE surface water impact zone. In summary, those high or moderate impact pools, of which there are five, are all classed as Seasonally Inundated or Periodic Inundation/Ephemeral pools. A further five pools are deemed to have a low impact – including ephemeral pools through to the permanent and commonly wet pools of Mundagoora and Site 12. Three pools are removed by the NSE development.

Table 5-4: Summary of likely impacts to pools within the NSE surface water impact zone.

Pool Reaches (Associated Pools)	Classification	Likelihood and Severity of Impact	Description
Mundagoora Pool: (GV_SW_Pool_ Mundagoora_SS)	Permanent	🟢 Low	In relation to sediment transport / pool turbidity, the following minor impacts are expected which are unlikely to result in a significant geomorphological change to Mundagoora Pool: • Reductions in pool turbidity due to decreased supply and retention of fine sediment. • Reductions in soft sediment substrate. • Persistence of sediment capture in vegetated margins. • Armouring of pool bed with coarse sediment.
Site 12 Pool: (1-IB_SW_Pool12; 2-S12string; 3-S12string; 4-S12string; 5-S12string; 6-S12string; 7-S12string; 8 - IB_SW_Pool12_01)	Commonly wet	🟢 Low	In relation to sediment transport / pool turbidity, the following minor impacts are expected which are unlikely to result in a significant geomorphological change to Site 12 Pool: • Reduction in pool turbidity due to decreased fine sediment supply and retention. • Minor reductions in soft sediment substrate, but not as pronounced as Mundagoora Pool. • Continued sediment capture in vegetated margins or at bedrock outcrops. • Event-driven scour of both fine and coarse material to bedrock.
NJA19-002: (61 - GV_SW_Pool_ NJA19-002)	Seasonal	🟠 Moderate	The development is expected to result in a moderate reduction in sediment supply and flow due to a moderate reduction in catchment area. This is likely to result in some aggradation/accumulation of sediment in pool reach as transport capacity decreases, with flushing of sediment occurring during larger events. Therefore, geomorphological changes to pool area and depth are expected to be episodic but limited over the longer term.
Pool 62: (78 - GV_SW_Pool _GR; 62; 65)	Ephemeral	🔴 Removed	Entire catchment within NSE IDF.
Pool IB-SW-Dry-Reject_DS-002: (IB_SW_DryReject_ DS_02)	Ephemeral	🟢 Low	Small reductions in catchment area and event velocity, combined with significant distance between the reach and the NSE development footprint suggest limited impacts to sediment dynamics.
Pool NJA21-006-US: (GV_SW_Pool_NJA21-006-US)	Ephemeral	🟠 Moderate	The development is expected to result in a moderate reduction in sediment supply and flow due to moderate reduction in catchment area. This is likely to result in some sediment aggradation/accumulation in pool reach as transport capacity decreases, although this is expected to be minor and gradual given that the decrease to catchment area (a proxy for sediment supply) is greater than the decrease in event velocity. The significant distance between the pool and the NSE development footprint also buffers against impacts. Therefore, geomorphological changes to pool area and depth are expected to be limited.
Pool NJA21-006-DS: (GV_SW_Pool_NJA21-006-DS)	Ephemeral	🟢 Low	Small reductions in catchment area and event velocity, combined with significant distance between the reach and the NSE development footprint suggest limited impacts to sediment dynamics.

Pool Reaches (Associated Pools)	Classification	Likelihood and Severity of Impact	Description
Pool SW: (55 - GV_SW_Pool_SW; 56 - GV_SW_Pool_SWGV_DS)	Ephemeral	🟢 Low	Moderate reduction in catchment area (and thus sediment supply) is offset by a small reduction in event velocity which will maintain flushing capability. Pool is, however, susceptible to impacts posed by its proximity to the NSE development footprint, such as increased turbidity, although these impacts are likely to be remediated during flushing events.
Pool 9 **(9)**	Ephemeral	🟠 Moderate	The development is expected to result in a moderate reduction in headwater region of catchment area compounded by proximity to mining operations and moderate reduction in flushing velocity, so there is potential for increased sediment aggradation/accumulation. Therefore, the reach may experience minor to moderate changes in pool morphology as it re-establishes a new state of sediment transport equilibrium.
Pool 51: (51 - GV_SW_WRD_01)	Ephemeral	🔴 Removed	Entire catchment within NSE IDF.
Pool 50	Ephemeral	🔴 Removed	Entire catchment within NSE IDF.
Pool 59: (59)	Ephemeral	🔴 High	Extreme reductions in both catchment area and event velocities are likely to lead to high impacts to pool morphology. Persistent sediment delivery from background processes (hillslope erosion) and proximity to NSE development footprint, combined with reduced flushing is likely to lead to deposition within pool reach – may incur a moderate to major increase in pool turbidity, as well as a large, although gradual reduction in pool area and depth over time.
Pool 57: 57; 63; 64	Ephemeral	🔴 High	

6.

SUMMARY

This assessment for the NSE project evaluated the potential impacts of mine expansion on sediment delivery and transport processes within key waterway systems and pools. The assessment focused on the pools identified by Worley (2025) as Permanent/Commonly Wet (Mundagoora Pool, Site 12 Pool), Seasonal Inundation (NJA19-002 Pool) and several other Periodic Inundation/Ephemeral pools within the project area. Key findings and implications for specific pools included:

- Mundagoora Pool:
  - A reduction in sediment delivery developed, including a decrease in fine sediment delivery by 63% and coarse sediment delivery by 57%.
  - A reduction of scour within, and downstream transport from, the pool.
  - An overall impact of ***Low*** due to the reduced scour counteracting the reduction in sediment delivery. Some changes that may be observed in the pool include:
    - A reduction in pool turbidity due to decreased fine sediment supply and retention.
    - A reduction in soft sediment substrate, although shallow bedrock will limit scour.
    - Continued fine grained sediment capture in vegetated margins, supporting the persistence of existing habitat structures.
    - Likely event-driven transition of bed material towards a more erosion resistant, coarser substrate.
- Site 12 Pool:
  - A moderate reduction in sediment delivery developed, including an expected reduction in fine and coarse sediment delivery by 36%.

  - An overall impact of ***Low*** due to the reduced scour and bedrock confinement counteracting the lower sediment delivery. Some changes may include:
    - Reduction in pool turbidity due to decreased fine sediment supply and retention.
    - Minor reductions in soft sediment substrate but not as pronounced as in Mundagoora Pool.
    - Continued sediment retention within vegetated margins and near bedrock outcrops.
    - Event-driven scour of both fine and coarse material to bedrock, with currently exposed bedrock limiting impact.
- NJA19-002 Pool:
  - A moderate decrease in the supply of coarse material.
  - A slight increase in the supply of fine sediment to the pool, particularly during smaller, more frequent events.
  - An overall impact of ***Moderate*** partly due to its proximity to the mine but also due to the potential for an increase in pool turbidity, especially during small, frequent events, with flushing occurring during larger events.
- Ephemeral Pool Reaches:
  - Two high geomorphic impact pool reaches (Pool 59 & 57).
  - Two moderate impact pool reaches (Pool NJA21-006-US & Pool 9).
  - Three low impact pool reaches.
  - Three pool reaches removed due to the NSE.

Overall, the NSE development is expected to have a ***Low*** likelihood and severity of impact on most pools, provided best-practice sediment management forms part of construction and operation within the NSE project area. Similar impact likelihood and severity is expected throughout the supplying waterways, although likelihood and severity are both expected to be marginally greater in reaches immediately downstream of the NSE IDF and decrease with distance downstream as flow and sediment inputs from unaffected catchments contribute to overall hydrological and sediment delivery regimes. This spatial variability of impacts to waterways is illustrated by the variability of impacts to the pools across the affected catchments. Over time, these waterways will adapt to the new flow/sediment regimes and reach a new equilibrium that will drive long-term pool maintenance.

7.

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APPENDIX A. LONG-TERM SEDIMENT DELIVERY MODEL

A.1 HILLSLOPE EROSION (HE)

Sediment yield from the hillslopes was estimated by using a modified plot-scale Revised Universal Soil Loss Equation (RUSLE) model (Wischmeier and Smith, 1978) (Equation A.1). It was then scaled up to catchment scale by utilising hill sediment delivery ratio (Equation A.4) and the Monte Carlo simulation (MCS) method. The plot scale RUSLE model is defined by:

$$A = RKL_1S_1CP \qquad (1)$$

Where:

A = average annual soil loss (t/ha-year).

R = rainfall/runoff erosivity factor (MJ-mm/ha-hour-year).

K = soil erodibility factor – resistance of the soil to erosion (t-ha-hour/MJ-mm-ha).

L_1 = hillslope length factor (dimensionless).

S_1 = hillslope gradient factor (dimensionless).

C = cover and management factor (dimensionless).

P = support practice factor (dimensionless).

P was set to one to reflect the assumption that there are limited soil conservation measures adopted in the sub-catchments. Consequently Equation 1.4 was reduced to:

$$A' = RKL_1S_1C \qquad (2)$$

The delivery of eroded material (sediment yield) from the hillslopes into channels and streams within each catchment was estimated as:

$$HE = C_a * SDR_h * A' \qquad (3)$$

Where:

HE = sediment yield due to hillslope erosion (t/year).

C_a = catchment area (ha).

SDR_h = sediment delivery ratio from hillslopes, reflecting the ratio of erosion on the hillslopes in question to that at the plot scale (dimensionless).

A.1.1 RAINFALL EROSIVITY FACTOR (R)

The rainfall erosivity factor (R, MJ-mm/ha-hour-year) reflects the ability of rainfall and resulting surface runoff (overland flow) to cause soil erosion at a particular location. It was estimated using Arnoldus' modified Fournier index (Renard and Freimund, 1994), defined as:

$$MFI = \sum_{i=1}^{12} \frac{p_i^2}{P} \qquad (4)$$

Where:

p_i = average monthly precipitation (mm).

P = average annual precipitation (mm).

Using this value, the R-factor was defined using the Renard and Freimund's equation (1994), as follows:

$$R = 0.07397 \times MFI^{1.847} \qquad (5)$$

R was calculated using the above formulae for each year of record and analysed using @Risk to produce a PDF of possible R-factor values. Note also that the R-factor does not change under a developed scenario.

A.1.2 RAINFALL ERODIBILITY FACTOR (K)

The soil erodibility factor (K, t-ha-hour/Mj-mm-ha) reflects the inherent properties of soil and, for a particular soil, it is defined as the rate of soil loss per erosion index unit measured on a unit plot of 21.1 m length with a uniform 9% slope maintained under continuous bare fallow, tilled up and down the slope over an extended period of at least 10 years (Toy and Foster, 1998). K measures:

1. The susceptibility of soil or surface material to erosion.
2. The transportability of the sediment.
3. The amount and rate of runoff on a unit plot.

The value of K is always > 0 and normally < 1 (Rosewell, 1993). A K value less than 0.02 indicates low erodibility, a K value between 0.02 and 0.04 indicates moderate erodibility and a K value greater than 0.04 indicates highly erodible soils (Rosewell, 1993).

K was calculated using the following equation:

$$K = 2.8 \times 10^{-7} \times M^{1.14} \times (12 - O_c) \qquad (6)$$

Where:

K = soil erodibility factor (K, t-ha-hour/Mj-mm-ha)

M = (%silt + %very fine sand) x (100 – %clay).

O_c = % organic content

To account for spatial variability and uncertainty in K, several K values were calculated from soil samples throughout the catchment and used to form a PDF from which the model produced possible values. This involved interpolating PSD samples in ArcGIS Pro using Thiessen Polygons to determine spatial patterns and distributions of soil parameters, such that random samples could be taken from the greater catchment. These samples represented values of:

- % silt
- % very fine sand
- % clay

Values of organic content (O_c) were sampled from a triangular distribution based on typical values of organic soil content in the Pilbara region (www.agric.wa.gov.au). Due to spatial variability on soil parameters, K was defined differently for the impacted and unimpacted areas under each scenario.

A.1.3 HILLSLOPE LENGTH AND GRADIENT FACTORS (L_1, S_1)

The hillslope length and gradient factors (L_1, S_1, dimensionless) address the effect of hillslope length and gradient on soil loss. L_1 is defined as the ratio of soil loss from a given hillslope length to that from a 21.1 m length under otherwise identical conditions. Similarly, S_1 is defined as the ratio of soil loss from a hillslope gradient to that from a 9% slope under identical conditions. Of course, as length or gradient increase, it is expected that soil loss will also increase due to increased runoff accumulation and shear stress.

Both L_1 and S_1 were calculated using the methods outlined by Wilkinson *et al.* (2008), as follows:

$$L_1 = \left(\frac{x_h}{22.13}\right)^m \qquad (7)$$

Where:

X_h = horizontal slope length (m).

m = variable slope length exponent.

m is calculated as:

$$m = \frac{\varepsilon}{1+\varepsilon} \tag{8}$$

Where ε is defined as:

$$\varepsilon = \frac{sin\,\theta}{0.0896*[3.0*(sin\,\theta)^{0.8}+0.56]} \tag{9}$$

And:

θ = slope angle.

Similarly, S1 was calculated as:

$$S_1 = 10.8\,sin\,\theta + 0.03 \quad \sigma \leq 9\% \tag{10}$$

$$S_1 = 16.8\sin\theta - 0.50 \quad \sigma > 9\%$$

Where:

θ = slope angle (rad/degrees).

σ = slope gradient (%).

Both L_1 and S_1 were calculated for several points within the catchments of interest and analysed using @Risk to form PDFs for each. The model then sampled values of L_1 and S_1 from these PDFs. Note that different subsets of L_1 and S_1 were used to represent impacted and unimpacted conditions under each scenario.

A.1.4 SURFACE COVER FACTOR (C)

The cover and management factor (C, dimensionless) reflects the effect of any vegetation and land use on soil loss. It estimates the combined effect of prior land use, canopy cover, surface cover, surface roughness, soil biomass and soil disturbing activities on soil loss. It is defined as the ratio of soil loss from a specified condition to soil loss from continuous bare fallow. C varies mostly between 0 and 1 (0 ≤ C ≤ 1). C = 0 suggests there is no soil loss, whereas C = 1 indicates there is no reduction in soil loss rates.

There is little published information about the typical distribution of the C factor for these or other regional sub-catchments. As such, potential C Values were calculated from NDVI datasets for the study area using the methods of van der Knijff *et al.* (1999) and Durigon *et al.* (2014). Two NDVI datasets were downloaded from the Sentinel Hub website, with the first dataset (February 2021) reflecting wet season conditions and the second reflecting dry season conditions (October 2021). Specific acquisition dates were selected to ensure minimal cloud cover and to be representative of wetter and drier ground, respectively. Each cell in each NDVI image produced a discrete C value.

Different values of C were used to represent impacted and unimpacted areas under each scenario.

A.1.5 SEDIMENT DELIVERY RATIO (SDR_h)

As a plot-based method of estimating soil loss, the RUSLE requires scaling to account for differences between plot and catchment scales, such as accounting for soil deposition on hillslopes. Since this ratio cannot be easily determined, it was modelled stochastically from a triangular distribution.

A.2 BANK EROSION (BE)

The rate of sediment supply from stream bank erosion was predicted by extending the method outlined by Wilkinson *et al.* (2008). This method determines bank erosion as:

$$BE_x = K_3 * Power * (1 - PR) * FP \tag{11}$$

Where:

BE_x = rate of erosion into the stream banks (m/year).

K_3 = coefficient of bank erosion (dimensionless).

$Power$ = bankfull stream power (W).

PR = proportion of riparian trees along banks (dimensionless).

FP = floodplain factor (dimensionless).

This one-dimensional erosion rate was converted to a mass rate by multiplying by the length and height of the stream banks, as well as the bulk density of the sediment:

$$BE = BE_x * H * L * BD \tag{12}$$

Where:

BE = sediment yield due to bank erosion (t/year)

H = height of bank (m).

L = length of river (m)

BD = bulk density of soil in catchment (t/m^3)

A.2.1 COEFFICIENT OF BANK EROSION (K_3)

Due to limitations around understanding spatial variation in bank erosion, K_3 was modelled stochastically from a uniform distribution representing a typical range of possible values.

A.2.2 STREAM POWER

Stream power is a common concept by which the flow in a stream is equated to the work done by that flow. This value is defined as:

$$Power = \rho g Q_{bf} S_c \tag{13}$$

Where:

ρ = water density, taken as 1000 kg/m^3.

g = acceleration due to gravity, taken as 9.81 m/s^2.

Q_{bf} = bankfull flow rate (m^3/s).

S_c = unit slope of catchment channels (m).

Notably, the bankfull flow rate was calculated from the mean annual flow (MAF) using the equation:

$$Q_{bf} = e * MAF^f \tag{14}$$

Where:

e = discharge multiplier.

f = discharge exponent.

Since e and f are unknown, they were modelled stochastically using a uniform distribution representing their respective ranges of possible values. MAF was also modelled stochastically by sampling from a PDF based on monthly flow rates for various nodes throughout the catchment and upscaling by 12 months.

A.2.3 VEGETATION PROPORTION (PR)

Vegetation proportion was modelled stochastically using a triangular distribution based upon observations from the catchment. This involved assessing vegetation presence at several river locations to determine the proportion of sites with vegetation. This proportion was then taken as the most likely value in the triangular distribution and set between the minimum and maximum range of 0 to 1.

A.2.4 FLOODPLAIN FACTOR (FP)

Floodplain factor (FP) was estimated using the equation by Derose *et al.* (2002), as follows:

$$FP = 1 - e^{(-0.0008W_{FP})} \tag{15}$$

Where:

W_{FP} = width of floodplain along (m).

To account for spatial variation and uncertainty, the width of the floodplain was determined at several locations and analysed using @Risk to generate a PDF. The model then sampled widths from this PDF and calculated the corresponding value of FP.

A.2.5 BANK HEIGHT (H)

Riverbank height was modelled stochastically from a triangular distribution based on observations of minimum, maximum and median values.

A.2.6 RIVER LENGTH (L)

River length was modelled deterministically for unimpacted areas under each scenario. This was achieved using flow accumulation and clip features in ArcGIS Pro.

A.2.7 SOIL BULK DENSITY (BD)

The bulk density of soil within the catchment was modelled stochastically based on a range of possible densities. This took the form of a triangular distribution from which the model randomly sampled.

A.3 BED EROSION ($BedE$)

The rate of sediment supply from riverbed erosion was determined by multiplying scour depth by the dimensions of the river:

$$BedE = Scour * W_c * L * BD \tag{16}$$

Where:

$BedE$ = sediment yield due to bed erosion (t/year).

$Scour$ = depth of bed scour (m).

W_c = width of channels within the catchment (m).

L = length of river (m).

BD = bulk density of soil in catchment (t/m^3).

The scour depth was predicted stochastically using a triangular distribution, whose bounds were defined based on field observation and professional experience.

A.3.1 RIVERBED SCOUR DEPTH

Due to limitations and uncertainties around the depth to which the riverbed will erode at an annual rate, scour was defined stochastically using a triangular distribution, whose bounds were defined based on field observation and professional experience.

A.3.2 CATCHMENT CHANNEL WIDTH (W_c)

The width of channels within the catchment was modelled stochastically from a PDF based upon observations and calculations from ArcGIS Pro. Using Lidar data, a relative elevation model (REM) was produced and a threshold elevation above the channel bed was set which defined channel extents. Transect widths were then taken from several points throughout the channel network and used to inform the PDF.

A.4 GULLY EROSION (GE)

The rate of sediment supply from gully erosion was calculated using the method defined by Wilkinson *et al.* (2008). This method determines gully erosion as:

$$GE = \frac{BD * A * L_g}{\tau} \tag{17}$$

Where:

GE = sediment yield due to gully erosion (t/year).

BD = bulk density of soil in catchment (t/m^3).

A = cross-sectional area of gullies (m^2).

L_g = length of gullies (m).

τ = average age of gullies (years).

For this analysis, the average age of gullies was assumed equal to 100 years, in alignment with Wilkinson *et al.* (2008).

A.4.1 CROSS-SECTIONAL AREA OF GULLIES (A)

Gully cross-sectional area was modelled using a uniform distribution with minimum and maximum values based on field observations and expert knowledge.

A.4.2 LENGTH OF GULLIES (L_g)

The lengths of gullies within the unimpacted areas for each scenario were modelled deterministically using ArcGIS Pro. This was achieved in a similar manner to river length (L) but using different thresholds of flow accumulation.

A.5 SEDIMENT TRANSPORT CAPACITY (STC)

Calculation of the sediment transport capacity requires the definition of six additional parameters. The following sections outline the methods used to obtain these values.

A.5.1 COEFFICIENT OF SEDIMENT TRANSPORT CAPACITY (K_1)

The coefficient of sediment transport capacity (K_1) depends upon the particle size, and hydraulic roughness within the channel. To account for variability and uncertainty in hydraulic roughness and particle size, both parameters were modelled stochastically. Particle size was modelled from a PDF based on sampled PSD data. Hydraulic roughness was modelled discretely for values of Mannings n between 0.025 and 0.04. The resultant values were then used to find K_1 from a lookup table (Wilkinson *et al.* 2008).

A.5.2 MONTHLY FLOW RATE (Q_m)

The monthly flow rate was modelled stochastically based on monthly flow rates for the outlets of the catchments in question. As with other parameters, this involves generating a PDF for Q_m from which the model could sample.

A.5.3 SLOPE OF CHANNELS IN LOWER REACH (S_{lr})

The slope of the channels at the outlet of the catchments in question was modelled in the same was as slopes for channels in the greater catchment, whilst considering only the reach containing the pools in question. This was done to inform likely sedimentation in these critical reaches.

A.5.4 EXPONENTS OF FLOW AND SLOPE (β, γ)

Due to a lack of information regarding the determination of β and γ, these values were modelled stochastically using a triangular distribution. Data from Prosser and Rustomji (2000) was utilised to set the bounds for these distributions.

A.5.5 WIDTH OF CHANNEL IN LOWER REACH (W_{lr})

The width of channels at the outlets of the catchments in question were modelled in a similar way to channel widths within the greater catchment, however, like S_{lr}, modelling of this parameter focussed solely on the reaches containing the relevant pools. In this way, sampled widths from ArcGIS Pro were used to develop a PDF from which a range of values could be modelled.

APPENDIX B. CATCHMENT SEDIMENT DATA

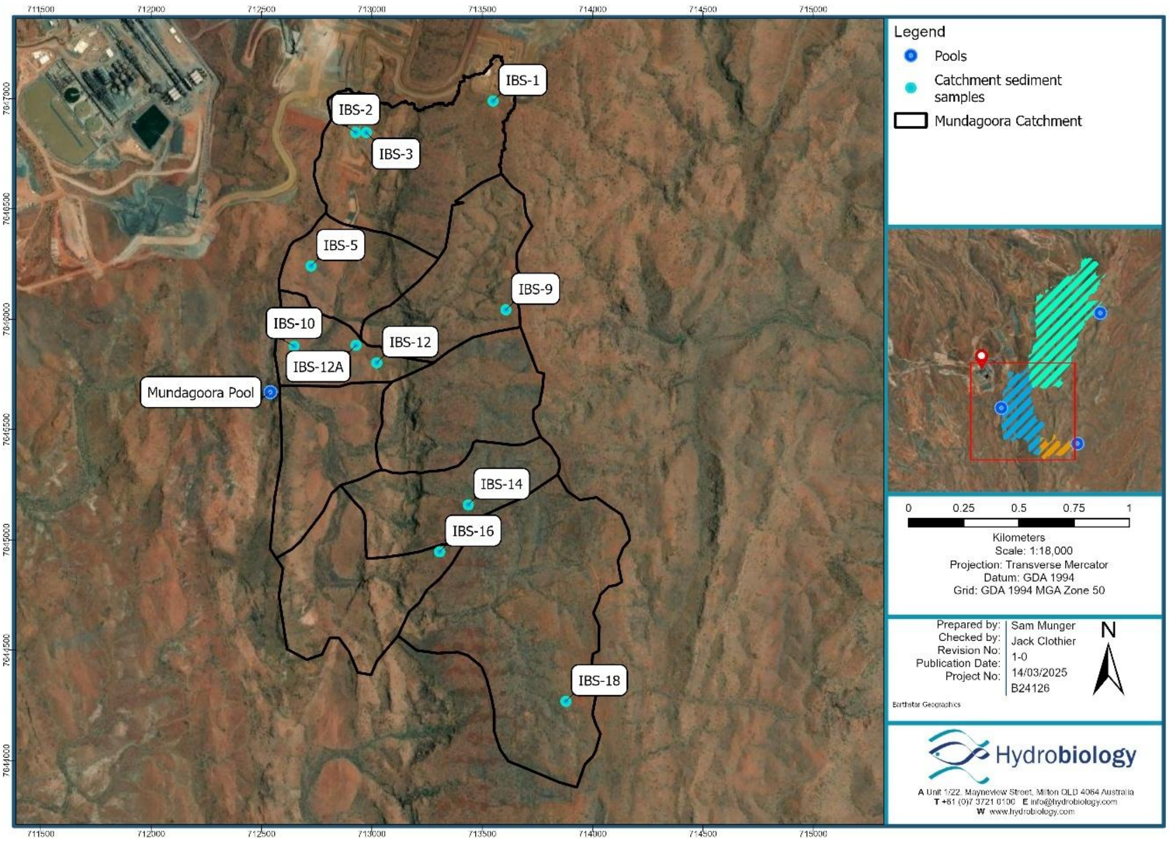

Figure 7-1: Locations of catchment sediment samples used to inform modelling.

Table 7-1: Catchment sediment details used for modelling.

Site	Coarse Fraction	% Silt	% Very Fine Sand	% Clay	D50
IBS-1	0.77	10.4242424	5.909090909	10.66666667	4.431333333
IBS-10	0.83	10.34375	2.65625	6	7.125
IBS-12	0.8	9.34375	2.65625	10	3.6984
IBS-12A	0.88	5	1	7	3.953333333
IBS-14	0.71	13.3958333	10.9375	11.66666667	1.9175
IBS-16	0.96	0		4	17.8125
IBS-18	0.82	8.09090909	4.909090909	8	6.333333333
IBS-2	0.72	12.3	5.7	15	6.147058824
IBS-3	0.41	18	2	41	0.00525
IBS-5	0.81	9.33333333	1	9.666666667	12.21428571
IBS-9	0.79	10.6	3.4	9	7.464285714

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