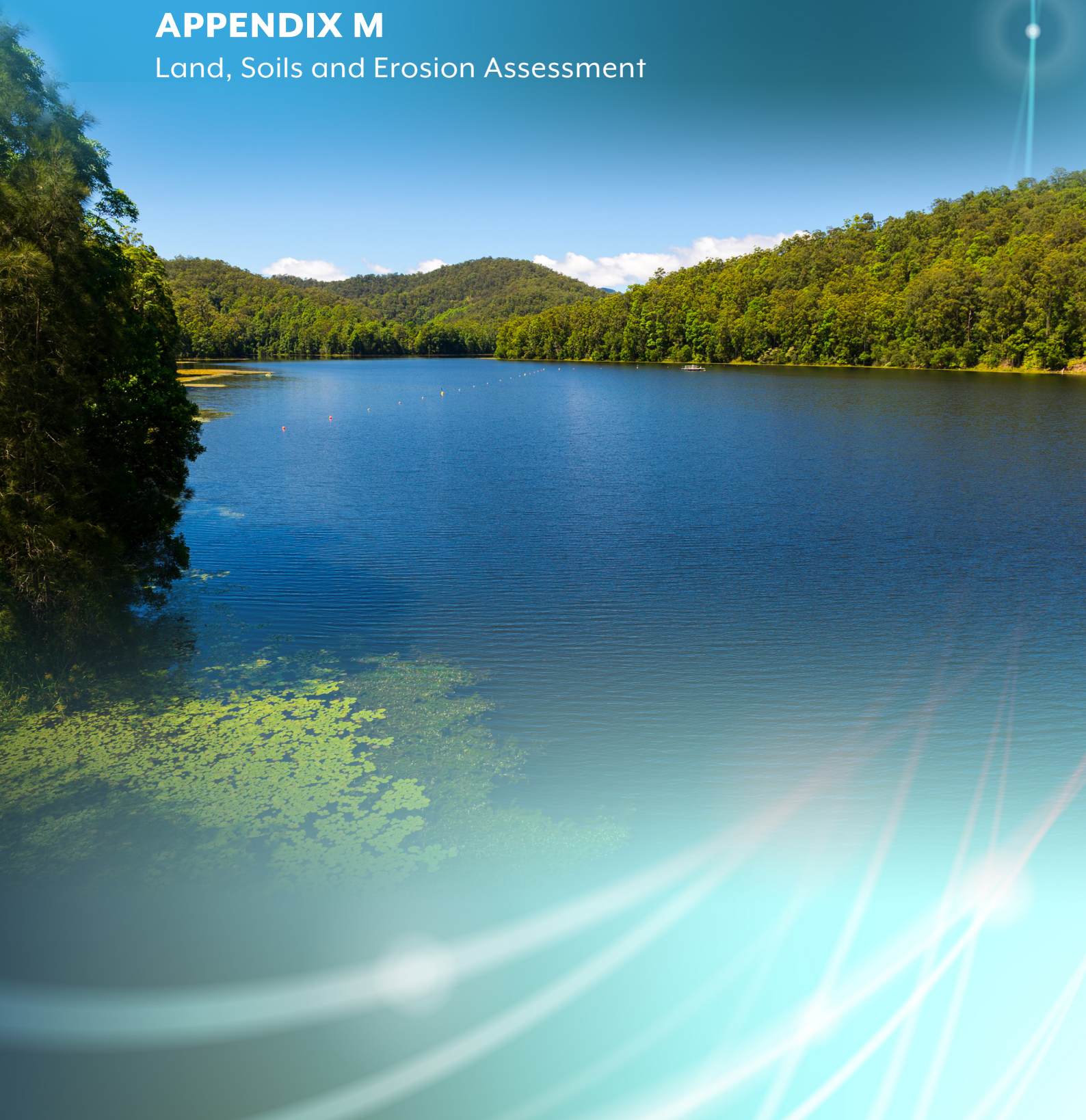


APPENDIX M

Land, Soils and Erosion Assessment



Clarrie Hall Dam - Dam Wall Raising Proposal

Land, Soils and Erosion Assessment

Prepared for Tweed Shire Council

August 2024

Clarrie Hall Dam - Dam Wall Raising Proposal

Land, Soils and Erosion Assessment

Tweed Shire Council

E230040 RP2

August 2024

Version	Date	Prepared by	Reviewed by	Comments
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ABN: 28 141 736 558

Executive Summary

ES1 Overview

A Land, Soils and Erosion Assessment (LSEA) has been prepared for the raising of Clarrie Hall Dam (Proposal) in the far north coast region of NSW. Tweed Shire Council proposes to raise the existing Clarrie Hall Dam by 8.5 metres (m) to achieve a full supply level (FSL) of 70 metres Australian Height Datum (mAHD) including modification of the existing dam inlet tower and construction of a new enlarged concrete spillway on the existing west abutment of the dam. The Proposal also includes a range of ancillary works including re-establishment of an existing quarry, local road realignments and upgrades, removal or modification of impacted infrastructure, realignment of power and telecommunication services, concrete batching and worker accommodation.

The Proposal will increase the dam storage capacity from 16,000 to 42,300 megalitres. The study area for the Proposal is approximately 254 hectares (ha) and covers areas where direct impacts may occur during construction and/or operation and comprising all areas required to construct and operate the raised dam including the inundation area associated with the increased FSL.

Approximately 49.6 ha would be impacted for construction and 209 ha for operation. The area where direct impacts may occur during construction and/or operation of the Proposal is approximately 252.26 ha. During operation, approximately 248 ha could also be impacted in the area between the proposed FSL and the probable maximum flood (PMF) extent.

This LSEA supports the environmental impact statement (EIS) for the Proposal and addresses the relevant Secretary's Environmental Assessment Requirements (SEARs). It documents the assessment methodology, results and the mitigation and management measures proposed to address any unavoidable and significant residual impacts to land and soils arising from the Proposal.

ES2 Characterisation of existing land and soil systems

The dam is positioned within several soil landscapes with the Frogs Hollow and Kunghur landscapes dominant. These landscapes host Dermosol and Kurosol soil orders respectively which provide some agricultural potential. Erosion hazards are expected to range from high to extreme when groundcover is low. The modelled land and soil capability and key soil fertility constraints indicated the most valuable land for agricultural productivity are the areas within the southern end and upper reaches of the dam (Kunghur and Kunghur 'variant a' soil landscapes) and the residual riparian areas within Doon Doon Creek (Terania soil landscape) and the Tweed River (Oxley soil landscape) upstream and downstream of the dam, respectively.

A soil survey was conducted which determined three different soil profile classes as representative across the Proposal footprint. The key outcomes from the soil survey included:

- generally stable soil chemistry with no sodicity and low potential for soil dispersion
- no soil salinity limitations
- minor limitations relevant to rehabilitation activities, with the presence of acidic soils and potential for aluminium toxicity hindering revegetation activities following the completion of construction.

A review of existing agricultural activities adjacent to the dam indicates low viability for productive enterprises due to the topography, and the need for the drinking water quality of the reservoir to be protected.

The geomorphology within the dam catchment area consists largely of headwater systems, flowing into both discontinuous valley fill and single channel systems, with a mixture of meandering and low sinuosity catchment linkages. Upper reaches of the catchment include bedrock materials which transition to sand and gravel bed materials. Doon Doon Creek, downstream of the spillway, is wholly confined by bedrock valley margin with little capacity for channel adjustment. The condition of the riparian corridor is moderate to poor. In-stream vegetation is plentiful but weed infested, and large woody debris offers multiple contraction points to reduce bed and bank shear.

The geological setting of the dam comprises a uniform sequence of hard rhyolite with minor welded tuff for the foundational bedrock. Geotechnical surveys have identified different zones within the subterranean dam embankment profile, ranging from semi-permeable moderately weathered rhyolite to downstream mesh and face zones of unweathered rhyolite. Material required for construction of the dam will come from local sources including the re-establishment of an existing rockfill quarry south west of the existing dam wall. Concrete required for the construction will be sourced from a batching plant proposed to be operated as part of the Proposal.

ES3 Potential impacts

ES3.1 General

Potential land and soils related impacts associated with the Proposal were assessed, including impacts to:

- soil quality and quantity
- erosion hazard
- agriculture
- geomorphology.

The report also describes selected geotechnical considerations raised in the SEARs related to sourcing, importation and management of fill and quarried materials, landform stability, and risks associated with potential landslides.

Key findings are described in the following sections.

ES3.2 Soils

The stripping of top soil is expected to be difficult for the Proposal due to the topographic constraints of the site. The presence of shallow, constrained soils necessitates the implementation of soil management measures to minimise impacts and ensure the preservation of soil quality and quantity suitable for use in rehabilitation.

Recommended mitigation measures to further minimise impacts to soils include:

- development and implementation of a soil and water management plan, including an erosion and sediment control plan with progressive plans, soil stripping and management measures
- development and implementation of a rehabilitation management plan.

ES3.3 Erosion hazard

Erosion hazard for the Proposal is likely to be high to extreme based on projected slopes. In particular for construction on high slope areas, specific staging strategies and mitigation measures will need to be adopted. It will be necessary to implement suitable erosion and sediment control measures, as recommended, to minimise erosion and manage any sedimentation that does occur.

Recommended mitigation measures to address erosion hazard include:

- During construction, site-specific progressive erosion and sediment control plans should be implemented for each major construction area. Plans to be prepared as part of the soil and water management plan and construction environmental management plan.
- Limit flow lengths on disturbed areas with steep gradients.
- Establish systems to implement temporary groundcover measures during periods of significant and/or prolonged rainfall.

ES3.4 Agriculture

Impacts on agricultural productivity associated with the Proposal are negligible as the Proposal footprint is located on areas either unable to be developed, already excluded from agricultural practices due to their location within the drinking water catchment or purchased by Council for drinking water protection.

No mitigation measures are required to further minimise impacts to agriculture.

ES3.5 Geomorphology

A review of potential geomorphology impacts due to the Proposal was completed. The overall risk to the downstream watercourses of Doon Doon Creek and the Tweed River is assessed to be low. Based on the expected changes in the operation of the dam, hydrologic and hydraulic modelling indicates only minor changes in flow regime and associated hydraulic conditions will occur as a result of the Proposal which are not expected to materially influence sediment mobilisation and transport within the existing watercourses.

Bank stability within upstream watercourses is influenced by the degree of cohesiveness of material present and the presence of vegetation and other supporting debris. Topsoils, based on sampling undertaken for the Proposal indicated the presence of cohesive sediments and some localised cobbles and gravels that are likely provide some protection from periodic inundation. However due to the occurrence of mass movement in the catchment, the potential for bank failure, often following periods processes like undercutting is possible. The consequence of this potential bank instability is expected to be minor.

No specific mitigation measures are required to further minimise impacts to geomorphology. However, consideration should be given to activities associated with the rehabilitation of riparian areas that include the removal of weeds, enhancement of native vegetation, and the replacement of natural debris that needs removal during construction.

ES3.6 Geotechnical considerations

The construction of the Proposal will require detailed staging to manage material logistics and optimise the available space. The proposed use of the existing quarry will result in an expansion of the quarry area to the north, west and south. The quarry can be operated with a stable landform assuming similar benching of excavation faces as has been considered in the past in surrounding cut earthworks for the dam's original construction. This will require the development of a quarry extraction plan. The quarry will be backfilled and rehabilitated using excess fill material (including rock and other overburden material) following construction. Any remaining excess material will require offsite disposal. Based on available material balances, the need for offsite disposal is considered possible with utilisation of excess material within other parts of the Proposal to be prioritised such as at the McCabes Bridge construction site. The rehabilitation of the quarry will require a landform consistent with existing slopes to the north and south which can be achieved including a benched configuration, revegetation and drainage specifications, to be documented as part of post approval construction environmental management plans.

Cut and fill material balances have been assessed for the Proposal by KBR (2023). This indicated that the majority of the material for the dam wall will be sourced from the rockfill quarry, with only minor volumes of material being reused from the excavation of the proposed spillway. Material excavated for the proposed spillway is likely used in the rehabilitation of the quarry and/or other parts of the proposal as there is expected to be a high proportion of weathered rock which does not have as high strength as fresh or slightly weathered rock.

Landslides have the potential to occur across the Proposal footprint. There have been several historical landslides occur within the northern portion of the dam's existing FSL. It was determined that the stability of natural slopes is influenced soil depth, moisture, rock type, bedding planes, discontinuities, and weathering. Based on past landslide incidents, identified soil hazards, and length/slope factors, areas of elevated risk were identified for the Proposal in association with the Frogs Hollow soil landscape. However, as it is difficult to predict the occurrence of such events across the Proposal, the identified areas of elevated risk do not preclude events in other areas from occurring. It should be considered that the potential for landslides is across the entire footprint, as regional mapping supports. The consequence of such an event is considered minor due to the absence of receptors (such as people, property and other infrastructure) within and adjacent to the increased FSL. The volume of soil entering the dam due to a landslip occurring is unlikely to significantly influence the total volume of the dam but may result in some localised turbidity within the dam itself around the site of the instability.

Elements of the Proposal will require cut earthworks into rock with steep batters to near vertical. These areas remain subject to detailed design including required geotechnical investigation and engineering to ensure the stability of these slopes.

Dam wall embankment stability analysis is not required for a conventional concrete face rockfill dam. The existing embankment slopes, constructed using fresh to slightly weathered free draining rockfill, were previously selected based on precedent and prior research. For the proposed raised embankment, a similar approach has been considered in the Proposal, utilizing fresh to slightly weathered free draining rockfill and matching the slope ratio of the existing wall.

Construction material logistics will include stockpile areas. These areas will be required nearby the dam wall, the quarry, the concrete batching plant and in association with the McCabes Bridge construction site. Stockpiles if unmanaged can be a major source of sediment runoff. To reduce this risk, the stockpile of materials will require specific control measures to be implemented (in accordance with the guidelines), and their positioning be offset from environmental receptors (such as watercourses and the existing dam water body).

ES4 Summary

Overall, potential land and soils related impacts during construction and operation of the Proposal are considered minor and can be adequately managed through the implementation of recommended mitigation measures. Key issues to be addressed for which mitigation measures have been developed include construction issues associated with landform stability, and erosion and sediment control.

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1 Introduction

1.1 Overview

This Land, Soils and Erosion Assessment (LSEA) has been prepared for the proposed raising of Clarrie Hall Dam (the Proposal), in the far north coast region of NSW.

Due to increasing demand for water due to the projected population growth and the increasing uncertainty of water supply yield associated with climate change, there is a requirement to augment the Tweed Shire district water supply by 2028.

Clarrie Hall Dam was constructed in 1983 by the NSW Department of Public Works and is owned and operated by Tweed Shire Council (Council) for the primary purpose of providing a drinking water supply to the Tweed Shire area. Council proposes to raise the wall of Clarrie Hall Dam by 8.5 metres (m) to a height of 70 m Australian Height Datum (mAHD). This will increase the capacity of the dam from 16,000 megalitres (ML) to approximately 42,300 ML.

The purpose of the Proposal is to ensure water security for the Tweed Shire until at least 2065.

The Department of Planning, Housing and Infrastructure (DPHI), formerly the Department of Planning and Environment (DPE), recently released the Far North Coast Regional Water Strategy (FNCRWS) (DPE, 2023), which provides a 20-year Far North Coast region-specific strategy to improve the security and certainty of water resources. The raising of Clarrie Hall Dam would assist Council to achieve objectives of the FNCRWS.

Clarrie Hall Dam is located on Doon Doon Creek, a third-order stream forming a tributary of the south arm of the Tweed River. The dam, located in Doon Doon, approximately 15 kilometres (km) south-west of Murwillumbah and 4 km south-west of Uki in the Tweed Shire Local Government Area (LGA). The dam has a catchment area of approximately 60 square kilometres and a storage capacity of 16,000 ML. Water is released down Doon Doon Creek via a shuttered intake in the intake tower into a pipe/outlet tunnel that runs under the dam wall to a valve chamber (outlet works). Water passes through the valve chamber before discharging into Doon Doon Creek and ultimately to the Tweed River. The dam features a multi-level offtake (MLO) via an intake tower which can be operated to draw water from various levels within the reservoir water column. Water from the dam, released to the Tweed River, is subsequently harvested at the Bray Park Weir. The regional setting for the dam is shown in Figure 1.1.

Access to the dam wall and spillway area is from Clarrie Hall Dam Road, which runs south from Kyogle Road. The southern extent of Clarrie Hall Dam is accessed from Crams Farm, located off Commissioners Creek Road.

The majority of the Doon Doon sub-catchment of the Tweed River Catchment consists of rural and agricultural land uses (more than 70% of land is zoned Rural).

The Proposal is State significant infrastructure and is subject to approval by the NSW Minister for Planning and Public Spaces under Part 5, Division 5.2 of the *Environmental Planning and Assessment Act 1979* (NSW) (EP&A Act). Further information on the location of the Proposal, a description of the Proposal and statutory context is provided in the environmental impact statement (EIS).

1.2 Purpose and scope of this document

The EIS has been prepared to support an application for approval of the Proposal in accordance with Division 5.2 of the EP&A Act. It addresses the Secretary's Environmental Assessment Requirements (SEARs).

This report has been prepared as part of the EIS to assess the potential land capability, soil erosion, sedimentation, land stability risks, and rehabilitation impacts from constructing and operating the Proposal.

The LSEA documents the assessment methodology, results and the mitigation and management measures proposed to address any unavoidable and significant residual impacts to land and soils arising from the Proposal.

The report:

- addresses the relevant SEARs listed in Table 1.1
- describes and characterises the existing land and soil resources relevant to the Proposal
- identifies and assesses the potential land capability, soil erosion, sedimentation, land stability risks, and rehabilitation impacts of the Proposal's construction and operation
- identifies appropriate mitigation and management measures for the Proposal.

This LSEA has been prepared in accordance with the SEARs for the Proposal as well as the relevant NSW Government guidelines and policies, and in consultation with the relevant government agencies. With respect to specific government agency comments on the Proposal there were no additional requirements identified through consultation than those already outlined within the SEARs.

Table 1.1 lists the SEARs matters relevant to soils (and related matters) and where they are addressed in this report.

Table 1.1 **Relevant matters raised in SEARs (dated 31 May 2024)**

Requirements		Chapter
13. Soils		
1	The Proponent must assess the impacts of sourcing, importation, and emplacement of fill/quarried material for the proposal.	Section 7.2, Section 8.4.1
2	The Proponent must assess potential impacts on landforms (topography), paying particular attention to the long term geotechnical stability of any new landforms (such as embankments etc).	Section 7.3, Section 8.4
3	The Proponent must assess whether the land is likely to be contaminated and identify if remediation of the land is required, having regard to the ecological and human health risks posed by the contamination in the context of past, existing and future land uses. Where assessment and/or remediation is required, the Proponent must document how the assessment and/or remediation would be undertaken in accordance with current guidelines.	Refer to Contamination Preliminary Site Investigation (EMM 2024c)
4	The Proponent must assess whether salinity is likely to be an issue and if so, assess the impacts of the proposal on soil salinity.	Section 3.6.2, Section 8.1
5	The Proponent must assess the impacts on soil and land resources (including erosion risk or hazard). Particular attention must be given to soil erosion and sediment transport consistent with the practices and principles in the current guidelines.	Section 5, Section 8.2
6	Consideration should also be given to areas inundated by the probable maximum flood and how soil and other impacts due to changed hydrological regimes as a result of the proposal would be managed and/or remediated.	Section 8.2.2
7	The Proponent must detail the capacity of the site to support the increased size of the structure.	Section 8.4.3

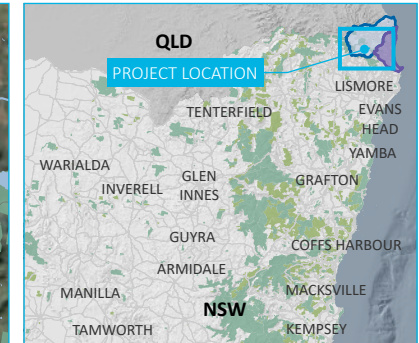
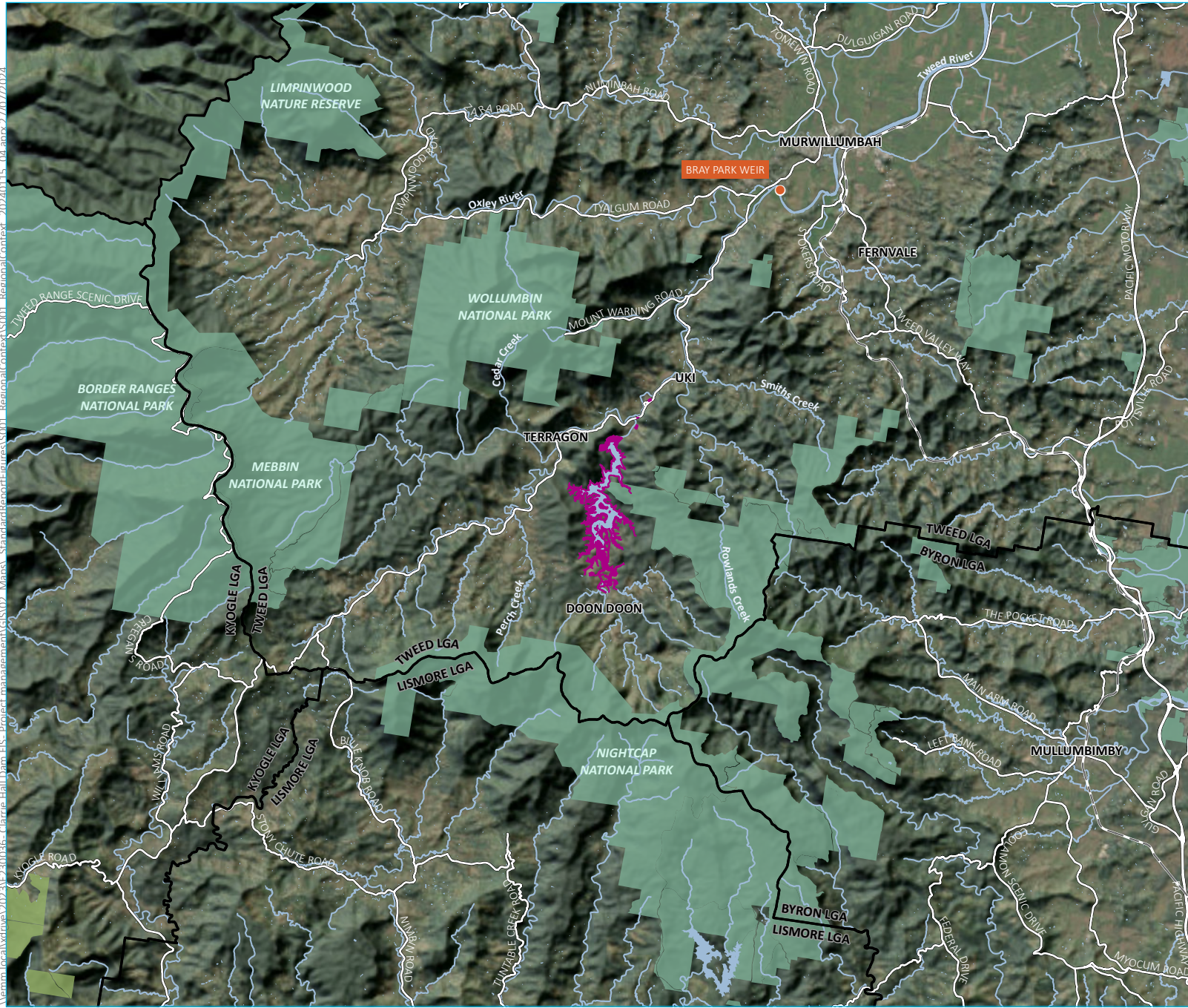
The methodology undertaken for the assessment is detailed within each relevant section of this report.

1.3 Other relevant reports

This LSEA has been prepared with reference to other technical reports that were compiled as part of the EIS. The other relevant reports referenced in this assessment are listed below:

- The Surface Water Assessment (EMM 2024a) (SWA) closely relates to this LSEA in terms of assessment of site geomorphology and expected operation of the dam.
- The Groundwater Impact Assessment (EMM 2024b) (GIA) which provides details on hydrogeology function of the area and the potential influence of the Proposal on the groundwater table.
- A Contamination Preliminary Site Investigation (EMM 2024c) which determines whether the study area includes contaminated areas and identifies if remediation of the land is required. Outcomes from the assessment of the existing environmental conditions for soil is considered through both this investigation and the LSEA.

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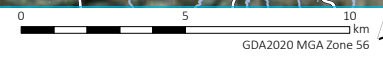
- KEY**
- Construction disturbance footprint
 - Bray Park weir
 - Existing environment
 - Rail line
 - Major road
 - Named watercourse
 - Waterbody
 - NPWS reserve
 - State forest
 - Local government area
- INSET KEY**
- Major road
 - NPWS reserve
 - State forest
 - Brunswick catchment
 - Tweed catchment

Regional setting

Clarrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 1.1



Source: EMM (2024); KBR (2024); ABS (2021); DCSSS (2023); ESRI (2024); GA (2009)



2 Proposal description

This chapter provides a summary of the Proposal. It outlines:

- the permanent infrastructure required to operate the Proposal
- the key construction elements and activities required to construct the Proposal.

Further details of the Proposal are provided in Chapter 3 of the EIS.

2.1 Proposal overview

The existing Clarrie Hall Dam consists of a concrete faced rockfill embankment, a concrete lined spillway, intake tower and outlet works designed by NSW Public Works. The original dam was completed in 1985 with some spillway upgrade works, also designed by NSW Public Works, completed in 2014. Since it was opened, the dam has been operated by Council as a drinking water supply for the Tweed Shire LGA (ELA 2021b).

Council proposes to raise the existing Clarrie Hall Dam by 8.5 m from 61.5 mAHD to 70 mAHD and construct a new enlarged concrete spillway higher on the west abutment. This will increase the FSL inundation area by 209 ha, which is shown in Figure 2.1.

The current Clarrie Hall Dam minimum release volume is 1 to 4 ML/day based on flows observed in the Tweed River at upstream Palmers Road Crossing. Flows in the Tweed River are supplemented with releases from Clarrie Hall Dam when flow in the river is too low to meet the demand for town and domestic water supply and irrigation, and to meet environmental flow requirements. Dam releases are driven by demands and the volume stored in Bray Park Weir, on the Tweed River.

A summary of Proposal elements is provided in Table 2.1, with further details provided in the EIS. The Proposal features are shown in Figure 2.1.

Table 2.1 Overview of the Proposal elements

Proposal elements	Summary of the Proposal
Operation	
Description	Raising the embankment wall of Clarrie Hall Dam by 8.5 m.
Operational footprint	Approximately 209 ha for the proposed FSL. Approximately 248 ha for the area between the proposed FSL and the PMF.
Dam wall infrastructure	• Increasing the base width of the valley-side abutment and raising the crest of the concrete faced rockfill embankment to 70 mAHD. • Constructing a new concrete lined spillway higher on the west abutment. • Extending the upstream concrete face to the new crest height. • Raising the intake tower and access bridge. • Constructing a new section of the Clarrie Hall Dam Road to provide access to the east abutment of the dam wall. • Establishing new recreation and operational facilities including an amenities block, public shelters, viewing areas, interpretation signage, paths, car parks, landscaping, security fences, lighting, monitoring equipment and a boat ramp.

Proposal elements	Summary of the Proposal
Ancillary infrastructure and works	• Upgrading the intersection of Clarrie Hall Dam Road and Kyogle Road. • Replacing McCabes Bridge over Doon Doon Creek. • Realigning an approximately 1,000 m section of Commissioners Creek Road. • Removing or reconstructing impacted infrastructure and facilities at Crams Farm. • Realigning overhead power lines and Telstra assets.
Construction	
Construction impact area	Approximately 49.6 ha, consisting of 26.2 ha at the dam wall, 6.6 ha of construction compound, concrete batching plant and workforce accommodation areas and 16.8 ha of ancillary sites for road realignments and relocating overhead power lines. The removal of the existing overhead power line is not included in the impact area.
Workforce	Estimated peak of 180 persons at the main dam wall site.
Ancillary works	• Constructing access roads to construction areas and establishing the construction site. • Re-establishing the quarry used to construct the existing dam. • Establishing a concrete batching plant and areas for materials stockpiling. • Establishing construction compounds including site offices, compounds and workforce accommodation. • Temporary stockpiles.
Cut / fill	Approximately 100,000 cubic m deficit of fill material will be sourced from the quarry located 300 m from the existing dam.
Dewatering requirements	The dam storage will be lowered by 300 millimetres (mm) below the FSL during construction.
Construction period	The construction duration is approximately 1.5 to 2 years.
Property	Permanent and temporary property adjustments and property access refinements.

2.2 The Proposal footprint and study area

The Proposal footprint and study area includes all areas where direct impacts may be experienced during construction and/or operation. The study area for the Proposal is approximately 254 ha and is comprised of the construction and operational footprints, of which there is some overlap:

- Construction disturbance area (approximately 49.6 ha):
 - the raised dam wall, spillway, road realignments/upgrades, quarry, stockpile sites and construction compounds, workforce accommodation, intake tower and bridge, recreational areas
 - upgrading the Kyogle Road and Clarrie Hall Dam Road intersection
 - replacement of McCabes Bridge and realignment of Commissioners Creek Road
 - removing or reconstructing impacted infrastructure and facilities at Crams Farm
 - utilities relocations
 - new recreation and operational facilities including an amenities block, public shelters, viewing areas, interpretation signage, paths, car parks, landscaping, security fences, lighting, monitoring equipment and boat ramp.

- Operational footprint (approximately 209 ha):
 - raised inundation area, which is the waterline boundary at FSL of 70 mAHD
 - area between FSL and PMF extent
 - downstream areas due to changes in flow.

The activities and disturbance area footprints of the Proposal provide the basis for assessing the extent of direct environmental impacts. Refer to footprint areas which define the study area in Figure 2.1.

2.2.1 Construction disturbance area

The construction disturbance area and associated activities include the dam wall area and ancillary areas. The construction disturbance area is estimated to be approximately 49.6 ha (which includes some areas that overlap with the inundation area of the proposed FSL. The main construction elements are detailed in the following sections.

i Dam wall area

The dam wall construction disturbance areas comprise the following activities:

- increasing the height of the existing concrete faced rockfill dam embankment
- constructing a raised intake tower and reusing existing bridge sections
- constructing a new concrete lined spillway higher up in the west abutment
- excavating the quarry and haul roads
- establishing construction compounds and stockpile sites
- realigning Clarrie Hall Dam Road
- establishing new recreational areas, boat ramp, operational facilities and amenities.

Downstream of the current dam embankment wall and stockpile areas a temporary crossing at Doon Doon Creek is proposed to support the construction activities. The temporary crossing would be developed using rockfill material to enable construction equipment to travel between the dam wall construction site and the quarry.

ii Raised embankment

Raising of the concrete face rockfill embankment is proposed. The concept design indicates the re-use of the existing precast concrete parapet walls. These would be removed and stored onsite for later re-use. Additional wall units may be required and are anticipated to be fabricated offsite. They can be delivered to site as needed, therefore requiring no additional storage.

The new top of the parapet walls on the embankment wave wall crest would be constructed to a height of 77.0 mAHD to match the maximum flood level. The crest pavement level behind the parapet wall would be constructed to a height of 75.5 mAHD, and the crest pavement width would be 5 m.

The embankment upstream and downstream slopes would be 1.3 horizontal (H) to 1 vertical (V), matching the existing embankment slopes.

iii Intake tower, access bridge and hoist house

The intake tower is used to draw water from the reservoir from a selection of heights controlled by stop boards. The flow of water is controlled by valves in the outlet chamber into Doon Doon Creek. The existing intake tower with a vertical reinforced concrete circular shaft is proposed to be raised by 8.5 m, resulting in the total height of the proposed intake tower to be 42.15 m. The raised tower would incorporate three additional water inlet ports, for a new total of 11 water inlet ports, to continue to facilitate selective water withdrawal functionality, which includes a series of trash racks and shutters with a crane over the tower deck.

The access bridge enables safe access to the intake tower. The current intake tower access bridge consists of two unequal spans 16 m and 28 m long, supported by a reinforced concrete pier and abutment block. The existing bridge is to be raised to match the raised height of the intake tower.

A new hoist house similar to the existing hoist house is proposed to be constructed on top of the raised intake tower. The raised intake tower would have the radial beams built into its wall and a peripheral beam running on the outer edge of the radial beams (similar to the existing configuration) to support the floor and super structure. The existing compressed asbestos cement cladding would be replaced with other suitable material in the new hoist house.

iv Spillway

The existing spillway would be covered over by the raised embankment. To ensure the new spillway has suitable discharge capacity, a new spillway channel has been designed to pass the PMF. The new spillway is proposed to be located higher in the left (western) abutment. The new spillway crest is designed with an invert of 70.0 mAHD, which corresponds to the FSL of the raised dam. The new spillway crest design is 40 m wide, and the spillway channel would reduce to 15 m wide at the downstream end, with a flip bucket as the terminal structure.

The new spillway channel concept design is for a fully concrete lined structure.

v Clarrie Hall Dam Road realignment

A section of Clarrie Hall Dam Road would be realigned higher in the landscape, above the new FSL. A vertical cut 8 to 10 m high, adjacent to the existing road, would be required. The boat ramp for operations and maintenance personnel would be relocated as part of the access road upgrade.

vi Quarry and haul road

A quarry was established during construction of the existing Clarrie Hall Dam to supply the required volumes of suitable rockfill material. The quarry is located approximately 300 m upstream of the existing dam wall on the southwest side of the existing dam. The quarry would be re-established and expanded to supply material required for the Proposal.

Material sourced through the quarry expansion would be used in construction of the raised dam wall, new access road and McCabes Bridge works. The expanded quarry footprint would include an area required for the topsoil, overburden and rockfill stockpiles needed during the construction phase. Waste rock material from the new spillway construction area would be used at McCabes Bridge and to backfill the quarry void to develop a stable final landform. Haul roads suitable for heavy vehicles would be required to transport rockfill material between the quarry site and the dam wall embankment.

vii Site offices and general laydown

Construction site offices, construction compounds, laydown areas and other facilities associated with the main construction area are proposed to be located within the construction disturbance area.

The construction compound area downstream of the embankment is a key access point to all the construction work sites. However, it is also the location of critical dam operational assets including the outlet tunnel, outlet control valves and discharge valves.

This location requires most of the area to be cleared and graded to support siting of office accommodation and welfare facilities (toilets, canteens and storerooms).

This location is presently terraced and has a small usable footprint, requiring the majority of the area to be cleared and graded to support siting of office accommodation and welfare facilities (toilets, canteens, storerooms, etc).

viii Power

The key work areas and potential offsite compounds have the potential to be serviced from the existing overhead 11 kilovolt (kV) network. At the southern end of the dam, some existing service provision assets are located within the FSL area and these structures must be realigned to ensure continued power supply to local residents.

Capacity of the existing 11 kV supply and demand needs to be fully investigated by the construction contractor with consultation with Essential Energy. A 20 m buffer for powerline construction requirements has been allowed for in the Proposal construction footprint for services that need to be realigned.

ix Water supply

A packaged filtration plant with abstraction from the dam storage is anticipated.

x Wastewater

Wastewater would be collected via a plumbed storage tank for road tanker collection and exported by a commercial operator to a centralised and licensed wastewater treatment facility for disposal.

Use of the natural terrain in this location would allow gravity drainage to the storage tanks. Tanks would be kept clear of the flow paths and flood inundation levels and tail water effects to ensure no discharges occur to surface water environments.

xi Concrete batching plant

Two options are proposed for the concrete batching plant. The first location is proposed to the north-east of the existing dam, off Clarrie Hall Dam Road. The second location is proposed to the north-east of the existing dam, off Tarcoola Lane. The batching plant requires a minimum area of 5,000 square metres. This includes areas for the batching plant, silos, conveyors, material bins, offices, material stockpiles and yard, delivery and concrete truck movement and circulation. Additional buffer areas for environmental controls would also be required.

Since the concrete materials, sands and other cement components are coming from external sources, there would be truck movements related to external deliveries. Having a location just outside of the main site allows these vehicles to deliver without needing to access the main works site.

Of the concrete produced, 70% would be used for the spillway, 25% for the raised embankment, 2% for the intake tower and 3% for McCabes Bridge.

xii Recreational facilities

The existing recreational infrastructure located in downstream construction areas would be relocated or removed. Upon completion of the dam raising, the rockfill stockpile would no longer be required. Therefore, the area would be developed into a new recreational and operational facilities area including amenities facility, public shelters, viewing areas, interpretation signage, pathways, car parking, landscaping, security fencing and lighting. Dam operations monitoring equipment would be installed, and the boat ramp would be relocated to align with the new access road.

xiii Site-office

The main site-office complex may be located as one complex or as multiple discrete elements.

Each construction work zone would likely have its own satellite offices and facilities in addition to the main office complex.

Several options are proposed for the locations of the main site office within the footprint however, the preferred proposed location for main office complex is downstream of the dam wall located within the existing recreation and carpark areas.

xiv Workforce accommodation

The number of workers per activity based on the concept design construction schedule was assessed, and that information was used to estimate a peak workforce of around 180 persons at the main dam site.

The local town of Murwillumbah, 20 minutes by road from Clarrie Hall Dam, does not have enough hotels or other accommodation that could allow for temporary worker accommodation.

Tweed Heads and other coastal areas would offer suitable accommodation options; however, a minimum of 50 minutes travel time to and from site may be considered excessive and may potentially lead to fatigue and safety issues both onsite and whilst travelling. A shuttle bus service is a potential option. However, the logistics of these services are complex and often not fully utilised by workers.

Therefore, the option for onsite temporary workforce accommodation has been included. It is estimated that an accommodation facility for 100 to 120 personnel would be required during construction.

An area of approximately 12,000 square metres would be required for cabins, facilities and a car parking area.

Two options are proposed for the location of workforce accommodation within the footprint, both north and south of the major Proposal elements.

2.2.2 Ancillary infrastructure

i Upgrade to Kyogle Road and Clarrie Hall Dam Road intersection

The Kyogle Road and Clarrie Hall Dam Road intersection is the primary access road to the Proposal's construction site. An assessment of the intersection to accommodate access for the construction workforce and the transport of rockfill material required for the McCabes Bridge upgrade from the quarry would be conducted as part of the transport and traffic assessment. Allowance for an upgrade to the intersection has been considered as part of the Proposal.

ii Recreational facilities – Crams Farm

The proposed FSL would inundate areas of Crams Farm such as the boat ramp. It is proposed to either remove or relocate various infrastructure, such as the boat ramp, pontoon, signage and access roads. The access road at Crams Farm would be raised above FSL but subject to inundation in a PMF event.

No changes to the amenity facilities or Doon Doon Hall would occur.

iii Existing property fences

Existing property fences located within the proposed FSL would be removed, where possible. New boundary fences will be constructed.

iv McCabes Bridge and Commissioners Creek Road realignment

As part of the proposed dam upgrade, McCabes Bridge, which crosses Doon Doon Creek approximately 5.5 km upstream of the dam's spillway is also proposed to be upgraded. The bridge would be moved approximately 40 m downstream of its current location and the bridge deck level raised to 72.0 mAHD to be above the predicted 1% annual exceedance probability (AEP) flood level. A realignment of Commissioners Creek Road is also required to facilitate the bridge upgrade and approach roads.

The existing McCabes Bridge is approximately 20 m long and 4 m wide. It is of a concrete girder/deck type and consists of 3 spans. The existing bridge would be inundated by the proposed FSL. The proposed replacement bridge and realignment of Commissioners Creek Road would include:

- a 2-lane reinforced concrete bridge raised approximately 5.5 m above the existing bridge level
- three 18 m spans
- a width of 8.4 m
- a length of 50 m.

The entire realignment is approximately 1,000 m long to account for gullies and to reach the design deck level of 72.0 mAHD.

There are two land parcels that could be used for construction compounds, laydown areas and stockpile locations close to the proposed new McCabes Bridge and road realignment. These are:

- Lot 2 DP838936 – this site is located at the southern end of the McCabes Bridge alignment works, with access off Doon Doon Road.
- Crams Farm Reserve – Lot 1 DP716151, which is located approximately 700 m north of the northern end of the McCabes Bridge alignment works, with sealed access from Commissioners Creek Road.

Both of these sites are relatively flat and have open areas of grassland.

Materials for approach embankments would be primarily sourced from won materials from the dam site. McCabes Bridge would likely be an activity with a degree of float. Therefore, the use of either of the two sites above as a material stockpile location may be advantageous to allow movement and storage of these materials ahead of bridge/road construction. This would avoid the need to stockpile this material at the more constrained dam works site.

Concrete is expected to be provided by the dam site batching plant if required, or careful consideration of mix design and transport durations would be required if concrete batching is sourced from existing commercial plants.

The proposed alignment also has some utility aspects (Telstra and Essential Energy) that need to be relocated prior to clear and grade and subsequent site establishment.

Bridge pre-cast beams are expected to be imported from third party suppliers. It is considered that establishing on-site precasting may not be efficient given the small quantity of units required.

Careful consideration of road construction sequencing would be required as the proposed approach roads to the new bridge show raised embankments being constructed on the existing road alignment. This includes approximately 450 m of raised road on the existing alignment north of the new bridge, and 150 m of existing road alignment affected for the tie-ins at the intersection with Doon Doon Road. This has potentially significant implications for local access as no other viable route appears to exist.

Additional land impacts may eventuate from the development of temporary access routes alongside the approach road construction footprint as alternative detour routes do not appear to exist or are likely to be unacceptable due to detour distance.

v Utilities

Utilities for the dam construction area may require upgrading as part of the Proposal. At the southern end of the dam, some existing service provision assets are located within the FSL area. These utilities must be realigned to ensure continued power supply to local residents. New poles and connections would be required along the roadside for sections of Doon Doon Road and Commissioners Creek Road, for sections of the network located within or near the FSL area. Telstra assets would require relocation.

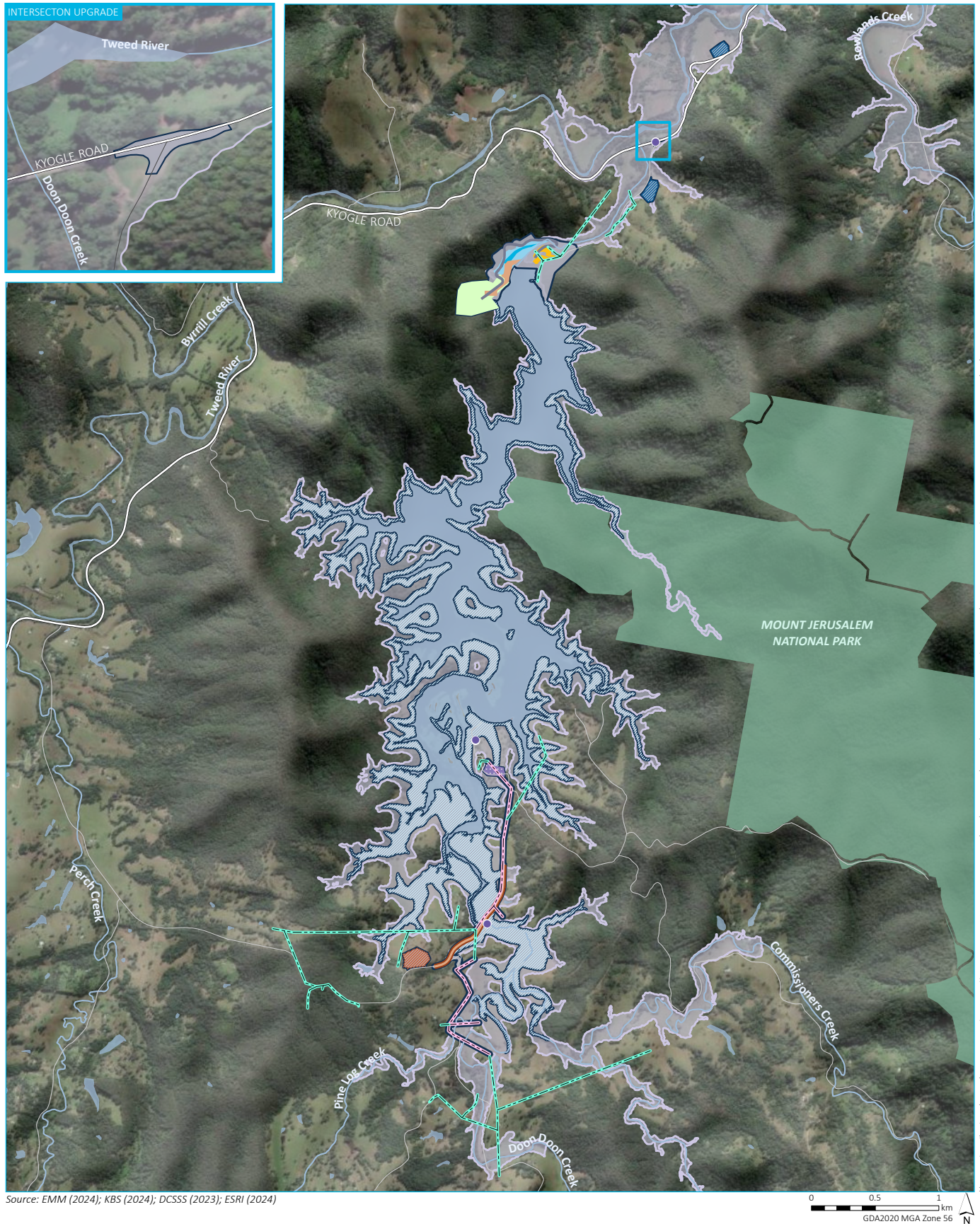
vi Timber harvesting and areas of deeper water around the full supply level

Prior to operations and filling the reservoir the inundation area would be prepared to provide optimal conditions for water storage.

It is proposed that some areas of trees within the inundation area created by the proposed FSL would be cut to stump height and left *in situ*. Some trees, where commercially viable, may be harvested. Confirmation of specific areas will be confirmed as part of detailed design. Erosion protection materials may be placed around the reservoir area shoreline. The requirements and locations for any erosion protection works and areas of high risk (discussed further in Section 8.4.2) that should not be cleared within the proposed FSL are included in this assessment.

vii Decommissioning and rehabilitation

Decommissioning of existing unused assets would be required in the Proposal. These requirements are further discussed in Chapter 9.



- KEY**
- Infrastructure upgrade location
 - Study area
 - Full supply level- proposed
 - Proable maximum flood (PMF) extent
 - Proposed layout
 - Haul Road- option 1
 - Haul Road- option 2
 - Office location
 - Potential McCabes Bridge stockpile and construction office complex
 - Quarry impact area

- Proposed spillway
- Spillway impact area
- Concrete batching plant or workforce accommodation
- Potential McCabes Bridge stockpile and construction office
- McCabes Bridge proposed realignment
- Transmission line
 - Existing
 - New

- Existing environment
- Major road
 - Minor road
 - Named watercourse
 - Waterbody
 - NPWS reserve

Proposal footprint and study area

Clarrrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 2.1



3 Existing environment

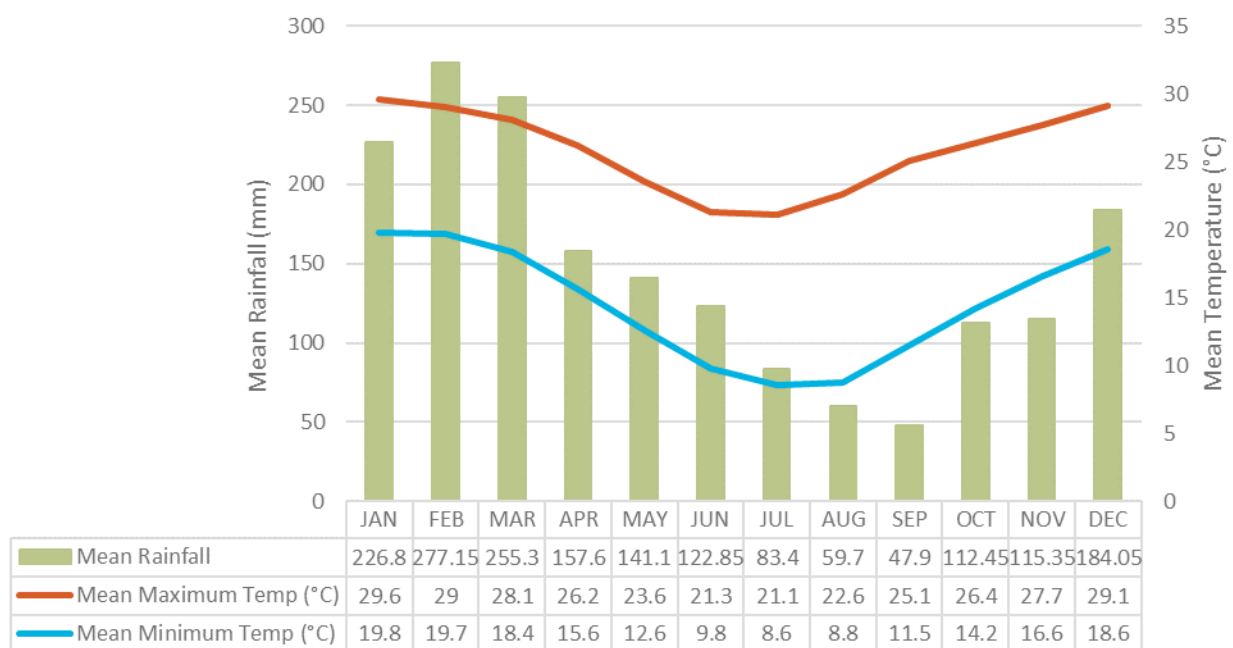
This section provides a description of the existing environment for Clarrie Hall Dam focusing on land and soils related aspects of the study area.

3.1 Locality

Clarrie Hall Dam is located on Doon Doon Creek in the small rural locality of Doon Doon, approximately 15 km south-west of Murwillumbah in the Far North Coast region of NSW. The Doon Doon Creek catchment is predominantly vegetated with native bushland (approximately 54%), with a further approximately 30% of land cleared and typically used for cattle grazing (ELA 2021b). This area also incorporates parts of Nightcap National Park in the south-west and Mount Jerusalem National Park in the east and south.

3.2 Climate

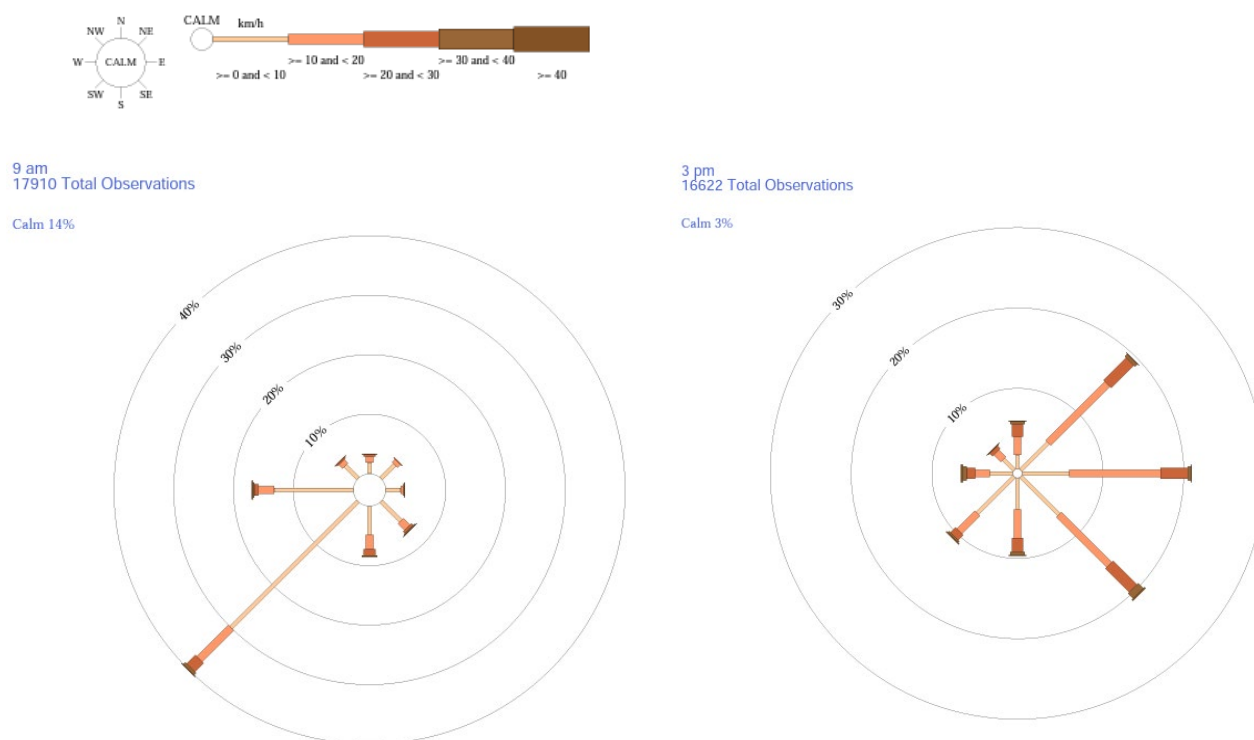
The Proposal site is described by the Bureau of Meteorology (BoM) modified Köppen classification system as subtropical with a distinct dry season, wet summer and low winter rainfall, with warm summer and cold winter (BoM 2016). These descriptions are based on 30-year climatology between 1961 and 1990. Figure 3.1 illustrates the latest rainfall and temperature data retrieved from BoM weather stations 58019 (Doon Doon) and 58005 (Brays Creek). This data is consistent with the Köppen classification where mean rainfall trends below 50 mm per month for late winter and early spring, rising up to 280 mm per month during summer. The mean annual rainfall over the catchment is 1595 mm. On average, 111 days per year rainfall greater than 1 mm occurs.



Source: BoM (2023a)

Figure 3.1 Mean monthly temperature and rainfall for Clarrie Hall Dam

The BoM wind roses for Murwillumbah (Bray Park) (station number 058158) show the daily prevailing wind directions for 9am and 3pm as south-westerly to easterly, respectively (Figure 3.2).



Source: BoM (2023b)

Figure 3.2 Mean 9:00 am and 3:00 pm wind speed and direction for Murwillumbah

3.3 Topography

Clarrie Hall Dam is situated on Doon Doon Creek. The dam has a total catchment area of approximately 60 square kilometres. The volume of the existing dam reservoir is contained within the extended valley margins confined by bedrock and cohesive terraces. Floodplain pockets exist along the margins of the waterline.

Intact native wet-sclerophyll forest is retained on upper slopes and the western boundary. Localised clearing has previously occurred for various land uses including agriculture on the northerly and westerly aspects. The lower slopes of the catchment are extensively cleared for grazing purposes with groundcover restricted to pasture species and some native grasses.

Lateral confinement of Doon Doon Creek is reduced past the bedrock confines downstream of the existing dam spillway. Alluvial floodplains are present with sporadic bedrock and valley margin confinement. The groundcover has been extensively cleared with few intact pockets of narrow riparian corridor. Instream vegetation is common on sedimentary assemblages.

The reservoir is bounded to the east by a ridge, approximately 250 mAHd with 30% gradient across the easterly aspect. Slopes on the opposite (westerly) aspect is 25% and is defined by multiple spur and re-entrance features. Steeper slopes are present proximal to the dam spillway, averaging between 20% and 40%. The southern boundary is characterised by cohesive terraces and floodplain pockets interspersed with dendritic drainage patterns from surrounding ridges. A large crevasse splay feature is present on the westerly aspect, north of the spillway. Parallel drainage paths are tributary to Doon Doon Creek. The western boundary ridge terminates 500 m downstream of the spillway and open to undulating terraced plains and floodplain assemblages. Topography for the existing dam is presented in Figure 3.3.

3.4 Hydrology

3.4.1 Waterways

Doon Doon Creek is a 5th order stream with upstream linkage to lower order streams and downstream linkage to the Tweed River. At and around the junction with Doon Doon Creek, the NSW HydroLines dataset defines the Tweed River as a 6th order waterway. The Tweed River flows in a generally easterly direction towards the coast. In the upper reaches, the river has a stoney bed with sequences of pools and riffles.

Several towns lie along the Tweed River and rely in its flow for water supply. In particular, Bray Park Weir at Murwillumbah has been constructed to create a weir pool to allow extraction of water for town water supply. Downstream from Bray Park Weir the Tweed River is affected by tides, and can contain brackish water. The river meets the ocean at Tweed Heads on the NSW-QLD border. The Oxley River joins the Tweed River 2 km upstream from Bray Park Weir. Downstream from the junction with the Oxley River, the Tweed River is classified as a 7th order waterway.

3.4.2 River styles

The catchment linkages are summarised from the NSW River Styles¹ spatial dataset (DPE Water 2023), accessed via the NSW Sharing and Enabling Environmental Data (SEED) portal (DPIE 2020f), in Table 3.1. Figure 3.3 shows the watercourses present within the catchment of the dam and downstream from the dam wall.

Table 3.1 River Styles of watercourses within and downstream of the Clarrie Hall Dam catchment

Watercourses	River style	Channel bed material	Confinement	Confinement (%)	Highest stream order
Griers Creek	Headwater	Bedrock	Confined, bedrock margin controlled.	>85%	4
Big Creek	Headwater	Bedrock	Confined, bedrock margin controlled.	>85%	3
Blakes Creek	Discontinuous channel, valley fill.	Sand - silt	Laterally unconfined, discontinuous channel, swamp.	10–50%	3
Doughboy Creek	Single channel, low sinuosity.	Gravel	Confined, bedrock margin controlled with floodplain pockets.	50–85%	3
Doon Doon Creek	Single channel, meandering	Gravel	Confined, bedrock valley-margin controlled, occasional floodplain pockets.	>85%	5
Commissioners Creek	Single channel, meandering	Gravel	Confined, bedrock valley-margin controlled, occasional floodplain pockets.	>85%	4
Pine Log Creek	Single channel, low sinuosity	Gravel	Confined, bedrock valley-margin controlled, occasional floodplain pockets.	>85%	4

¹ The River Styles Framework is an approach for the geomorphic analysis of rivers. The framework utilises a staged approach to determine current river character and behaviour, geomorphic condition, and assess the potential recovery of impacted rivers.

Watercourses	River style	Channel bed material	Confinement	Confinement (%)	Highest stream order
Tweed River (Terragon, upstream of Doon Doon Creek confluence)	Single channel, low sinuosity	Mixed	Partly laterally confined, bedrock valley margin controlled, floodplain pockets and bank-attached units.	50–85%	6
Tweed River (Uki, downstream of Doon Doon Creek confluence)	Single channel, low sinuosity	Mixed	Partly laterally confined, planform controlled, broad floodplain units and bank-attached units.	10–50%	6

Further details of catchment geomorphology are presented in Section 3.10.

3.4.3 Streamflow regimes

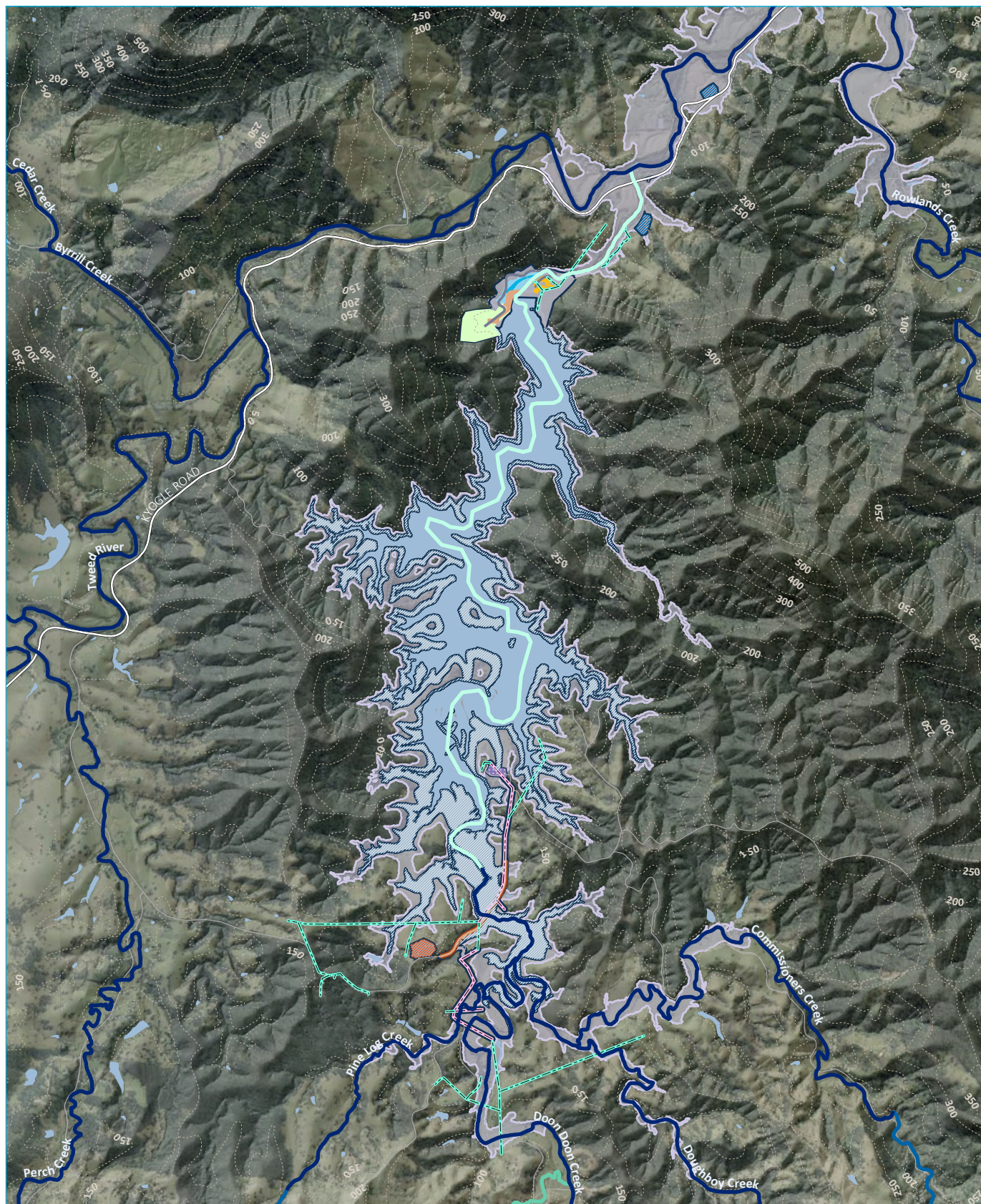
Streamflow has been recorded at the monitoring site, Tweed River D/S Palmers Road Crossing (BoM station number 201015), since 2009 and the site, Tweed River at Uki monitoring station, (BoM station number 201900), since 1967. These streamflow monitoring stations are located upstream and downstream of the Doon Doon Creek confluence with the Tweed River. There is no streamflow gauge located within Doon Doon Creek downstream from Clarrie Hall Dam however the dam operators (Council) have maintained records of manual release volumes.

Flow statistics from these monitoring locations are provided below in Table 3.2.

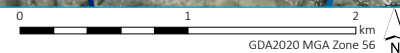
Table 3.2 Flow monitoring statistics

Statistic	Tweed River D/S Palmers Road Crossing - 201015	Tweed River at Uki - 201900
Start	28 Apr 2009	29 Jun 1967
Finish	29 Aug 2023	01 Jan 2024
Years of Record	14.35	56.55
Max Value	1,129.54 cubic metres per second	2,557.49 cubic metres per second
Mean Value	3.07 cubic metres per second	5.01 cubic metres per second
Min Value	0.01 cubic metres per second	0 cubic metres per second

The SWA for the Proposal indicates a strong seasonality to flow conditions within the Tweed River. Both of the gauges demonstrate perennial flow conditions, with summer and autumn typically having higher flow rates than winter or spring.



Source: EMM (2024); KBS (2024); DCSSS (2023); SixMaps (2024)



KEY

- Study area
- Full supply level- proposed Proposed layout
- Haul Road- option 1
- Haul Road- option 2
- Office location
- Potential McCabes Bridge stockpile and construction office complex
- Quarry impact area
- Proposed spillway
- Spillway impact area

- Concrete batching plant or workforce accommodation
- Potential McCabes Bridge stockpile and construction office
- Proable maximum flood (PMF) extent
- McCabes Bridge proposed realignment
- Transmission line
- Existing
- New

River style

- Floodplain pockets, gravel
- Headwater
- Planform controlled, low sinuosity, gravel
- Water storage- dam or weir pool
- Existing environment
- Major road
- Minor road
- Vehicular track
- 50 m contour
- Waterbody

Topography and hydrology

Clarrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 3.3



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Doon Doon Creek is not gauged, however estimates of streamflow have been developed which is described in the SWA. The summary flow characteristics predicted for Doon Doon Creek are:

- perennial flow conditions, supported through releases from the dam
- flow range (20th to 80th percentile) of 4 ML/day to 100 ML/day.

Further detail on the estimates of streamflow, streamflow regimes and flow conditions within Doon Doon Creek and the Tweed River is provided within the SWA.

3.5 Geology

Geology was reviewed utilising the NSW Seamless Geology database, version 2.1 (Colquhoun, GP *et al.* 2021) accessed through the MinView web portal (GSNSW 2023). Parent materials of the study area are described as Triassic igneous rock, silicic to intermediate type. The lithology of these units is not well known with respect to genesis, but are composed of rhyolite, andesite, and basalt. Superpositioned over the lower slopes of these units are sedimentary units of similar age. These sedimentary units are composed of quartz-lithic to quartz-rich sandstones with conglomerate, mudstone and siltstones deposited by high-energy braided palaeochannels.

Holocene sediment deposition has occurred in the existing dam area. Downstream of the spillway, valley boundaries are composed of sedimentary units including feldspar-rich sandstones, siltstones, mudstones and conglomerates.

Floodplain deposits of the Tweed River and in the upgradient reaches of Doon Doon Creek are alluvial mud, silt, sand and gravel. The alluvial deposits are typically narrow, ranging between 50 to 400 m in width, and are thin, i.e. typically less than 10 m in depth. Gravel deposits on the inside bends of Doon Doon Creek bends are mapped in Hawke (1979) and further minor pockets of alluvium are expected based on inspection of aerial imagery.

A summary of the geological units relevant to the Proposal is presented in Figure 3.4 and Table 3.3.

Table 3.3 **Geological units of the study area**

Period	Group	Code	Stratigraphic unit	Description
Quaternary		Qa	Alluvium	Quaternary Alluvium, comprising undifferentiated alluvial deposits of sand, clay and gravel
Tertiary	Lamington Volcanics	NMLal	Nimbin Rhyolite	Rhyolite, obsidian, tuff
		NMLan	Lismore Basalt	Basalt, agglomerate
	Mount Warning Volcanics	NMnm	Mount Warning Complex	Basalt, gabbro, trachyte, rhyolite
Jurassic	Koukandowie Formation	Jinw	Walloon Coal Measures	Claystone, shale, siltstone, coal
		Tbmkh	Heifer Creek Sandstone	Sandstone, quartz rich to quartz lithic sandstone
		Tbmkm	Ma Ma Creek Member	Sandstone, shales, siltstones
		Tbmw	Gatton Sandstone	Sandstone, feldspathic to lithic feldspathic sandstone
Triassic	Woogaroo Subgroup	Tbwi	Ripley Road Sandstone	Sandstone and conglomerates, quartz rich
		Tutc	Chillingham Volcanics	Quartzite, rhyolite, rhyolitic tuff, claystone
Silurian		C_n	Neranleigh-Fernvale beds	Sandstone, greywacke, slate, quartzite, metamorphosed

Source: NSW Mining, Exploration and Geoscience (2023) and Geoscience Australia (2023).

Bold text indicates units underlying the Proposal.



Source: EMM (2024); EnergyCo (2024); DCSSS (2023); DPIE (2021); ESRI (2024)

KEY

- Study area
- Full supply level- proposed
- Infrastructure upgrade location

Geological unit- NSW seamless geology

Quaternary

- Anthropogenic stored water, pondage, reservoirs, canals (Q_hw)
- Alluvial floodplain deposits (QH_af)
- Alluvial valley deposits (Q_av)

Tertiary

- Mount Warning Igneous Complex- dolerite and basalt (NMmw_d)
- Mount Warning Igneous Complex- monzonite (NMmw_m)
- Mount Warning Igneous Complex- basalt (NMmw_b)

- Mount Warning Igneous Complex- trachyte (NMmw_t)

Jurassic

- Walloon Coal Measures (Jinw)
- Heifer Creek Sandstone Member (Tbmkh)
- Ma Ma Creek Member (Tbmkm)
- Gatton Sandstone (Tbmw)

Triassic

- Ripley Road Sandstone (Tbwi)
- Chillingham Volcanics (Tutc)

Silurian

- Neranleigh-Ferrvale beds (C_n)

- Existing environment

- Major road
- Minor road
- Named watercourse
- 50 m contour

0 0.5 1 km
GDA2020 MGA Zone 56

Surface geology

Clarrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 3.4



\\emm.local\drive\2023\E230036-Clarrie Hall Dam EIS-Project management\GIS\02_Maps\LSEA\LSEA002_SurfaceGeology_20240725_03.aprx 10/08/2024

3.6 Soils

Desktop review and characterisation of existing information on soils and soil environments for the study area was sourced from:

- NSW Soil and Land Information System (SALIS) (DPIE 2021b), accessed through eSPADE (DPIE 2020a)
- *Soil Landscapes of Central and Eastern NSW* (DPIE 2020d)
- *Hydrogeological Landscapes of New South Wales and the Australian Capital Territory* (DPE 2022a)
- *Australian Soil Classification system soil type mapping of NSW* (DPIE 2021c)
- *Great Soil Group Soil Type map of NSW* (DPIE 2021d)
- *Inherent soil fertility* (DPIE 2020b)
- *Land and Soil Capability Mapping for NSW* (DPIE 2020c).

3.6.1 Soil landscapes

Soil Landscapes of Central and Eastern NSW mapping (DPIE 2020d) is a compilation of 40 soil landscape maps based on 1:100,000 and 1:250,000 topographic sheets, providing inventory of soil and landscape properties of the areas and identifying major soil and landscape qualities and constraints. Soil and topographic features are integrated into single units with relatively uniform land management requirements. The site is located on the *Soil Landscapes of the Murwillumbah-Tweed Heads 1:100,000 Sheets* (Morand DT, 1996).

The study area is primarily located on the Frogs Hollow and Kunghur (and its variants) soil landscapes. Soil landscapes are described in Table 3.4 and presented in Figure 3.5, with their dominant soil materials and limitations described in Table 3.5.

Table 3.4 **Soil landscapes**

Soil landscape	Topography	Soils (GSG)	Native vegetation	Land use	Existing land degradation
Kunghur (ku) with variants a and b	Undulating and rolling hills. Relief is 100–150 m and slopes are 5–30%. Elevation is 100–300 m. Slopes are long (500–800 m) and waning. Ridges are generally convex and narrow (50–100 m), though in many instances ridge tops form moderately broad (250–300 m), level crests. Rock outcropping is common along ridges and upper slopes. These usually form discontinuous sandstone cliffs, 10–20 m high, flanked by fallen blocks and boulders. Drainage is erosional, tributary and integrated. Streams generally occupy V-shaped valleys.	Shallow to deep (50–150 cm), well-drained Yellow Podzolic Soils (Dy5.61, Dy3.81) on ridges and upper slopes. Deep (>100 cm), moderately well drained Yellow Podzolic Soils (Dy5.21), Red Podzolic Soils (Dr5.21, Gn3.14, Gn2.14) and Red Earths (Uf6.71) on slopes. Moderately deep (100–150 cm), poorly drained Gleyed Podzolic Soils (Dg4.11, Dg4.21) and Yellow Podzolic Soils (Dy5.11, Dy5.21) on lower slopes and poorly drained areas.	Partially, in places extensively, cleared open-forest (wet sclerophyll). Main wet sclerophyll trees include blackbutt (<i>Eucalyptus pilularis</i>), tallowwood (<i>E. microcorys</i>), Sydney blue gum (<i>E. saligna</i>), narrow-leaved white mahogany (<i>E. acmenoides</i>), brush box (<i>Lophostemon confertus</i>) and turpentine (<i>Syncarpia glomulifera</i>). Forest oak (<i>Allocasuarina torulosa</i>) and blackwood (<i>Acacia melanoxylon</i>) are common understory species. In drier areas, particularly near rock outcrops, pink bloodwood (<i>Eucalyptus intermedia</i>), red bloodwood (<i>E. gummifera</i>), grey ironbark (<i>E. paniculata</i>), black ironbark (<i>E. crebra</i>) and scribbly gum (<i>E. signata</i>) are common. Grass trees (<i>Xanthorrhoea</i> spp.) often occur as an understorey species. Common ground species include kangaroo grass (<i>Themeda australis</i>), bracken (<i>Pteridium esculentum</i>) and ferns (<i>Pteris</i> spp.). Pasture species such as couch grass (<i>Cynodon dactylon</i>), kikuyu (<i>Pennisetum clandestinum</i>) and paspalum (<i>Paspalum dilatatum</i>) are common in cleared areas. Common weeds include lantana (<i>Lantana camara</i>), crofton weed (<i>Argemone adenophora</i>) and blady grass (<i>Imperata cylindrical</i>).	Predominantly beef and dairy cattle grazing on improved and voluntary pastures. Includes Nullum State Forest and Clarrie Hall Dam.	There is minor land degradation; however, Manson and Ryan (1979) point out that roadside erosion is severe in places and that minor sheet erosion exists.

Soil landscape	Topography	Soils (GSG)	Native vegetation	Land use	Existing land degradation
Terania (te)	Level to gently undulating, narrow (300–500 m) alluvial plains. The current floodplain is narrow (50–100 m). Relief is extremely low (<5 m) but with considerable areas of very low relief (up to 10 m) at ox-bows and terraces. Slopes are 0–3%, though slopes on isolated terrace scarps are up to 40%. Elevation is 60–80 m. Inset terraces are common and narrow to moderately broad (<100–300 m). They give a distinctive dissected look suggesting frequent channel migration and scouring.	Deep (>300 cm), well-drained soils of no suitable Group and dark Alluvial Clays (Uf6, Uf1, Gn2). Near sandstone areas deep (>300 cm), well drained soils of no suitable Group and brown Alluvial Clays (Db3, Db4). Deep (>200 cm), poorly-drained Weisenboden and Black Earths (Ug5.15, Ug5.17, Uf6) on more recent floodplains. Deep, rapidly drained Earthy Sands (Uc5.21) line channels.	Extensively cleared tall open-forest (wet sclerophyll) with isolated stands of closed-forest (rainforest) and isolated open-forest along stream banks. Common species of the tall open-forest include forest red gum (<i>Eucalyptus tereticornis</i>), cabbage gum (<i>Eucalyptus amplifolia</i>), broad-leaved apple (<i>Angophora subvelutina</i>), rough-barked apple (<i>Angophora floribunda</i>) and brush-box (<i>Lophostemon confertus</i>). Hoop pine (<i>Araucaria cunninghamii</i>) and silky oak (<i>Grevillea robusta</i>) are common remnants of the closedforest. River oak (<i>Casuarina cunninghamiana</i>) forms pockets of open-forest along stream banks. Where cleared, closed sod grassland, dominated by kikuyu (<i>Pennisetum clandestinum</i>) forms a ground cover. Camphor laurel (<i>Cinnamomum camphora</i>) is a common exotic.	Predominantly beef and dairy cattle grazing on improved/voluntary pastures.	Severe stream bank erosion is common. Moderate slumping is common on ox-bow/terrace slopes.

Soil landscape	Topography	Soils (GSG)	Native vegetation	Land use	Existing land degradation
Frogs hollow (fh)	Steep to very steep hills that form a distinct north-south spine, up to 2 km wide, through the centre of the Tweed Volcano Caldera. Mount Warning interrupts the spine and as it emerges from the southern side of the ring dyke system, the trend is north-west-south-east. This soil landscape is also wider (5–6 km) in its southern section. Relief is 250–300 m. Slope angles are 40–50%. Slope shape is generally simple but may often be complex. Slopes are long (up to 1,000 m). Ridges and crests are moderately broad (100–200 m). Isolated high points are a common feature. Elevation is 300–400 m. Streams are erosional, tributary and integrated.	Moderately deep to deep (100–200 cm), moderately well-drained Brown Podzolic Soils and Brown Earths (Db3.51) on ridges and upper slopes. Deep (>200 cm), moderately well-drained Red Podzolic Soils (Dr4.21, Dr2.21, Gn3.14) and Red Clays (Uf6.31, Uf4.41) elsewhere.	Partially cleared open forest (wet sclerophyll). Dominant species include blackbutt (<i>Eucalyptus pilularis</i>), grey gum (<i>E. punctata</i>), white mahogany (<i>E. acmenoides</i>), grey ironbark (<i>E. paniculata</i>), tallowwood (<i>E. microcorys</i>), floodedgum (<i>E. grandis</i>), brush box (<i>Lophostemon confertus</i>) and turpentine (<i>Syncarpia glomulifera</i>). Forest oak (<i>Allocasuarina torulosa</i>), blackwood (<i>Acacia melanoxylon</i>) and sallywattle (<i>Acacia floribunda</i>) are common understorey trees. Tree ferns (<i>Cyathea</i> and <i>Dicksonia</i> spp.) also occur as understorey species. Bracken (<i>Pteridium esculentum</i>) and Pteris sp. are common ferns. Paspalum (<i>Paspalum dilatatum</i>) and kangaroo grass (<i>Themeda australis</i>) are dominant grasses, particularly in previously logged areas. Grass trees (<i>Xanthorrhoea</i> spp.) are also common. Pencil cedar (<i>Polyscias murrayi</i>) occurs in wetter areas.	Generally uncleared bushland or State Forest (Nullum State Forest). Banana plantations are common on steep to very steep slopes which generally have a westerly to northerly aspect. Clarrie Hall Dam, near Frogs Hollow, is a major part of the Tweed Valley's water supply.	There is minor apparent land degradation. Woody weed infestation (camphor laurel) is common in places and severe sheet and rill erosion occur within banana plantations.

Soil landscape	Topography	Soils (GSG)	Native vegetation	Land use	Existing land degradation
Oxley (ox)	Level to gently undulating narrow to broad (250–1,000 m) alluvial plains. Plain width increases with distance downstream. Elevation ranges from 20 m upstream to 5 m in downstream locations. Local relief is generally <9 m and is created by the existence of discontinuous inset terraces and scours. Slopes are <2%, though terrace scarps can be 30–40%. Where the Oxley and Tweed Rivers incise the narrow spine of the Chillingham Volcanics (i.e. Frogs Hollow (fh) soil landscape), the alluvial plain is very narrow or absent. Small bar plains are common within channels in the upper reaches of this soil landscape. Streams are alluvial, tributary and integrated.	Shallow to moderately deep (up to 100 cm), imperfectly drained Alluvial Soils and/or minimal Prairie Soils (Um5.51) on floodplain/bar plain. Deep (>200 cm), moderately well-drained minimal Prairie Soils and dark Alluvial Clays (Uf6.32, Uf6.31, Um6.41) on alluvial plain.	Extensively cleared closed-forest (rainforest). River oaks (<i>Casuarina cunninghamiana</i>), weeping bottlebrush (<i>Callistemon viminalis</i>) and, to a lesser extent, blue quandong (<i>Elaeocarpus grandis</i>) are common along stream banks. Blue lillypilly (<i>Syzygium oleosum</i>) and silky oak (<i>Grevillea robusta</i>) also occur. Otherwise grasses such as kikuyu (<i>Pennisetum clandestinum</i>), carpet grass (<i>Axonopus affinis</i>), rhodes grass (<i>Chloris gayana</i>) and couch (<i>Cynodon dactylon</i>) predominate. Camphor laurel (<i>Cinnamomum camphora</i>) and lantana (<i>Lantana camara</i>) are very common woody weeds.	Generally beef and dairy cattle grazing. Some small rural holdings (i.e. hobby farms).	There is minor land degradation apparent within this soil landscape though stream bank erosion is common and active in many locations.

Soil landscape	Topography	Soils (GSG)	Native vegetation	Land use	Existing land degradation
Burringbar (bu)	High rolling to steep hills. Slopes are steep and slope angles range from 15–>33%, lesser slope angles occurring in lower slopes and very limited footslope areas. Slope length is generally long (400–750 m) and shape is waning or simple. Relief is 100–200 m. Ridges and crests are narrow (<100 m) to moderately broad (200 m). Streams are erosional, tributary and integrated. This soil landscape is occasionally overlain by basalt.	Shallow to moderately deep (<100 cm), moderately well-drained stony Grey Earths (Um2.12, Gn2.54) on crests and some slopes; deep (>100 cm), moderately well-drained Red Podzolic Soils (Dr2.21, Dr2.31, Gn3.24) on slopes of deeply weathered siltstone/mudstone/shale; shallow (50–100 cm), poorly drained Yellow Podzolic Soils (Gn2.34, Dy3.21) on slopes of quartzite/phyllite; deep (>200 cm), moderately well-drained Red Earths (Uf6.31) on footslopes/lower slopes; deep (>150 cm), imperfectly drained stony Yellow Podzolic Soils (K-Gn2.81) on old coastline.	Partially to extensively cleared tall open-forest (wet sclerophyll). Dominant species include blackbutt (<i>Eucalyptus pilularis</i>), narrow-leaved white mahogany (<i>E. acmenoides</i>), tallowwood (<i>E. microcorys</i>), sydney blue gum (<i>E. saligna</i>), grey ironbark (<i>E. paniculata</i>), grey gum (<i>E. punctata</i>) and forest oak (<i>Allocasuarina torulosa</i>). Moister sites, such as sheltered gullies, support brush box (<i>Lophostemon confertus</i>), flooded gum (<i>Eucalyptus grandis</i>) and turpentine (<i>Syncarpia glomulifera</i>). Stands of bangalow palms (<i>Archontophoenix cunninghamiana</i>) also occur in very moist sites. Near-ground level species include wire grass (<i>Aristida spp.</i>), blady grass (<i>Imperata cylindrica</i>), mat-rush (<i>Lomandra longifolia</i>), bracken fern (<i>Pteridium esculentum</i>), kangaroo grass (<i>Themeda australis</i>) and barbwire grass (<i>Cymbopogon refractus</i>). Cleared areas generally have a closed grassland of narrow-leaved carpet grass (<i>Axonopus affinis</i>), couch (<i>Cynodon dactylon</i>), kikuyu (<i>Pennisetum clandestinum</i>) and paspalum (<i>Paspalum dilatatum</i>).	Generally left as bushland and includes Mooball, Nullum and Burringbar State Forests. Less steep slopes have been cleared and grazed by beef and dairy cattle. Banana plantations are common on steep slopes.	Erosion within banana plantations is severe. Road batters within this soil landscape are very prone to slumping.

Table 3.5 Detailed soil descriptions

Soil	Description	Limitations	Hazard				
Kunghur (ku)							
ku1: Dark sandy clay loam – topsoil (A ₁ horizon)	• Colour – brownish black. • Texture – sandy loam to sandy clay loam. • Structure – moderate, polyhedral 5–10 mm parting readily to crumbs <2 mm. • Fabric – smooth-faced polyhedral peds, rough-faced crumbs. • Exposed condition – loose, very weak, labile when dry. • Permeability – moderate to high. • Field pH – 5.5–6.0. • Coarse fragments – few. • Roots – few, 1–5 mm.	• Very strong acidity. • Moderately dispersive. • High erodibility. • High permeability. • Aluminium toxicity potential.	Erodibility				
			K factor	Non-concentrated flows	Concentrated flows	Wind	
			ku1	0.029	mod	mod-high	low
			ku2	0.021	mod	high	low
			ku3	0.021	low-mod	mod-high	low
			ku4	0.069	very high	very high	low
			ku5	0.026	mod	mod-high	low
			ku6	0.031	mod	high	low-mod
			ku7	0.022	mod	mod-high	high
ku8	0.029	mod-high	high	low			
ku2: brownish weakly structures sandy clay – topsoil (A ₂ horizon)	• Colour – dark reddish brown to dull yellowish brown. • Texture – light sandy clay loam to sandy light clay. • Structure – massive to moderate, polyhedral 10–20 mm parting to crumbs <2 mm, commonly massive or weakly structured. • Fabric – earthy, smooth faced. • Exposed condition – hardsetting when dry. • Permeability – low. • Field pH – 4.5–5.5. • Coarse fragments – may be common, weakly to strongly weathered rounded gravels (6–60 mm) of parent material and ironstone. • Roots – generally few, 1–5 mm.	• Extreme acidity. • High erodibility. • Hardsetting. • Aluminium toxicity potential. • Stoniness.					

Soil	Description	Limitations	Hazard			
ku3: reddish brown structured clay - subsoil (B horizon)	• Colour – bright reddish brown, reddish brown, dark reddish brown, faint mottles may occupy 10–20%. • Texture – sandy light clay to light medium clay. • Structure – weak to strong, polyhedral 20–50 mm parting to 10–20 mm and ultimately 5–10 mm and crumbs 2–5 mm. Generally, B₁ horizon has weak structure and B₂ horizon has moderate to strong structure. • Fabric – smooth faced, distinct clay coatings common. • Exposed condition – hardsetting, crumbly when dry, may slake when wet. • Permeability – low. • Field pH – 4.5–5.5. • Coarse fragments – few to common, weakly weathered parent material and strongly weathered ironstone gravels (6–60 mm). • Roots – few, 1–5 mm.	• Very strong acidity. • High erodibility. • Hardsetting. • Aluminium toxicity potential.	Erosion Hazard			
				Non-concentrated flows	Concentrated flows	Wind
			grazing	slight-mod	mod	slight-mod
			cultivation	mod-high	high	mod
			urban	mod-high	mod-high	mod
ku4: red massive clay (deep subsoil – C horizon)	• Colour – bright reddish brown, white kaolinized bands occur sporadically throughout. • Texture – light clay loam to light clay, often sandy. • Structure – massive, often sporadic. • Fabric – earthy. • Exposed condition – firm, may retain ghost-rock structures when dry. • Permeability – low. • Field pH – 4.5. • Coarse fragments – none. • Roots –none.		forestry	mod	high	slight

Soil	Description	Limitations	Hazard
ku5: yellow mottled silty clay (subsoil – B horizons of Gleyed Podzolic Soils)	• Colour – greyish yellow, prominent orange mottles abundant. • Texture – medium to heavy silty clay. • Structure – moderate, sub-angular blocky, 10–20 mm parting readily to sub-angular blocky, 2–5 mm. • Fabric – smooth-faced, prominent clay coatings common (10–50%). • Exposed condition – hardsetting, very wormy when dry; slakes, very plastic, slightly sticky when wet. • Permeability – low. • Field pH – 4.5. • Coarse fragments – none. • Roots –few, 1–5 mm.	• Extreme acidity. • Hardsetting. • High erodibility. • High aluminium toxicity potential.	
ku6: yellowish brown mottled clay (subsoil – B horizon)	• Colour – dull yellowish brown, distinct orange mottles occupy 10–20%. • Texture – fine sandy light medium clay. • Structure – weak, polyhedral 20–50 mm. • Fabric – smooth-faced, few (<10%) faint clay coatings may be present. • Exposed condition – hardsetting when dry. • Permeability – low. • Field pH – 5.5. • Coarse fragments – few. • Roots –few, 2–5 mm.	• Strong acidity. • High erodibility. • Moderately dispersive. • Hardsetting.	
ku7: dark coarse sand (topsoil and deep topsoil – A ₁ and A ₂ horizons)	• Colour – brownish black, brown. • Texture – loamy to clayey coarse sand. • Structure – single-grained/massive. • Fabric – sandy/earthy. • Exposed condition – loose, water repellent when dry. • Permeability – moderate. • Field pH – 6.0. • Coarse fragments – few (2–10%) strongly weathered parent material gravels (6–20 mm). • Roots – common, 1–2 mm; few, >5 mm.	• Strong acidity. • High erodibility. • Moderately dispersive. • High permeability. • Low water-holding capacity.	

Soil	Description	Limitations	Hazard																								
ku8: bright brown sandy clay (subsoil – B horizon)	• Colour – bright brown. • Texture – fine sandy light medium clay. • Structure – massive. • Fabric – earthy. • Exposed condition – hardsetting when dry. • Permeability – low. • Field pH – 5.5. • Coarse fragments – none. • Roots –few 2–5 mm.	• Very strong acidity. • Hardsetting. • High erodibility. • Moderately dispersive. • Aluminium toxicity potential.																									
Terania (te)																											
te1: dark brown clay loam (topsoil – A _p horizon)	• Colour – dark reddish brown to brownish black. • Texture – clay loam, sandy to clay loam or fine sandy clay loam; commonly clay loam, sandy. • Structure – moderate to strong, polyhedral, 10–20 mm, parting to 2–5 mm. • Fabric – smooth-faced, distinct clay coatings common. • Exposed condition – self-mulching, very weak, crumbly when dry. • Permeability – moderate. • Field pH – 6.0. • Coarse fragments – few ferromanganese nodules, 2–6 mm. • Roots – few, 2–5 mm.	• Moderate erodibility. • Low available water-holding capacity.	<table><tr><th colspan="4">Erodibility</th></tr><tr><th></th><th>K factor</th><th>Non-concentrated flows</th><th>Concentrated flows</th><th>Wind</th></tr><tr><td>te1</td><td>0.038</td><td>mod</td><td>mod-high</td><td>mod</td></tr><tr><td>te2</td><td>0.046</td><td>high</td><td>high</td><td>low-mod</td></tr><tr><td>te3</td><td>-</td><td>mod</td><td>high</td><td>high</td></tr></table>	Erodibility					K factor	Non-concentrated flows	Concentrated flows	Wind	te1	0.038	mod	mod-high	mod	te2	0.046	high	high	low-mod	te3	-	mod	high	high
Erodibility																											
	K factor	Non-concentrated flows	Concentrated flows	Wind																							
te1	0.038	mod	mod-high	mod																							
te2	0.046	high	high	low-mod																							
te3	-	mod	high	high																							

Soil	Description	Limitations	Hazard		
te2: brown sandy clay (topsoil and subsoil – A _p and B horizons)	Colour – dark reddish brown in downstream locations to dark brown to brownish grey. Distinct orange mottles, usually 5–20% but occasionally up to 50% Texture – silty to light medium sandy clay, commonly light sandy clay. Sand generally very fine. The siltier components generally found in upstream areas Structure – moderate, polyhedral 5–20 mm parting to 2–5 mm, polyhedral Fabric – smooth-faced, usually faint clay coatings, otherwise distinct, 10–20% Exposed condition – very weak to weak, crumbly/labile (dry) Permeability – slow Field pH – 6.0–7.0 Coarse fragments – common to abundant gravels (6–20 mm) of basalt and/or rhyolite, often form distinct stoniness. In upstream locations boulders (up to 1,000 mm) may be present in stonelines. Charcoal fragments and ferromanganese nodules occasionally present. Roots – few, 2–5 mm ex-ped	- High erodibility. - Stoniness. - Low permeability.	Erosion Hazard		
			Non-concentrated flows	Concentrated flows	Wind
			grazing	slight	slight
			cultivation	slight	sl-mod
			urban	N/A	N/A
te3: brown sandy loam (topsoil A _p horizon)	Colour – dark brown Texture – generally sandy loam, rarely sand or clayey sand Structure – massive Fabric – earthy, at times sandy Exposed condition – loose Permeability – moderate to high Field pH – 6.0 Coarse fragments – few Roots – few to common, 2–10 mm	- High erodibility. - High permeability. - Low fertility.	forestry	slight	sl-mod

Soil	Description	Limitations	Hazard				
Frogs Hollow (fh)							
fh1: dark sandy clay loam (topsoil and deep topsoil – A ₁ and A ₂ horizons)	• Colour – black, brownish black or dark brown • Texture –sandy clay loam • Structure – strong, polyhedral, 2–5 mm • Fabric – rough-faced, but may occasionally be smooth-faced • Exposed condition – moderately weak, crumbly, but may be hardsetting when dry • Permeability – moderate • Field pH – 6.0 • Coarse fragments – few to common (2–20%) weakly weathered gravels and coarse gravels (6–60 mm) of the parent material, sub-rounded. Fine ironstone gravels (2–6 mm) may also be common (10–20%)	• Strong acidity. • High aluminium toxicity potential. • Low fertility (phosphorus fixing).	Erodibility				
			K factor	Non-concentrated flows	Concentrated flows	Wind	
			fh1	0.028	very low	mod	low
			fh2	0.036	mod	high	low
			fh3	0.085	very high	very high	low
			fh4	0.026	mod	high	low
fh2: dark clay loam (topsoil – A ₁ horizon)	• Colour – dark brown to brownish black • Texture –clay loam to light clay • Structure – moderate to strong, polyhedral 2–5 mm parting to crumbs <2 mm • Fabric – rough-faced • Exposed condition – hardsetting when dry • Permeability – low to moderate • Field pH – 5.5–6.0 • Coarse fragments – none	• High erodibility. • Hardsetting. • Low fertility (phosphorous fixing).	fh5	0.024	mod	high	low
fh3: dark reddish brown structured clay (deep topsoil – A ₂ horizon)	• Colour – dull reddish brown to dark reddish brown • Texture – clay loam to light medium clay • Structure – moderate, polyhedral 5–10 mm parting to 2–5 mm and ultimately crumbs <2 mm • Fabric – smooth-faced, few (<10%) distinct clay coatings may be present • Exposed condition – hardsetting when dry • Permeability – low to moderate • Field pH – 5.5–6.0 • Coarse fragments – few weakly weathered, sub-rounded gravels (6–20 mm) of parent material	• High erodibility. • Very strong acidity. • Very high aluminium toxicity potential. • Hardsetting. • Low fertility (phosphorus fixing).					

Soil	Description	Limitations	Hazard			
fh4: yellow brown massive clay (subsoil – B horizon)	Colour – dull yellowish brown, faint brown mottles may occupy 2–10%. Texture – medium to medium heavy clay. Structure – massive (often wet but may be structured when dry). Fabric – earthy. Exposed condition – rarely exposed. Permeability – low. Field pH – 5.5. Coarse fragments – common (10–20%) weakly weathered parent material, ranging from fine to gravel stones (2–600 mm), generally rounded.	- High erodibility. - Extreme acidity. - Very high aluminium toxicity potential. - Low permeability. - Low fertility (phosphorus fixing). - Stoniness. - Moderate dispersion.	Erosion Hazard			
			Non-concentrated flows	Concentrated flows		Wind
			grazing	mod	mod	slight
			cultivation	very high	extreme	slight
fh5: reddish brown moderately structured clay (subsoil – B horizon)	Colour – reddish brown to dark reddish brown, faint, sometimes distinct, brown mottles can be common. Texture – light medium to medium clay. Structure – moderate, prismatic, 50–200 mm parting readily to dominant angular blocky/polyhedral, 10–50 mm, thence 5–10 mm. Fabric – smooth-faced, many (>50%) clay coatings are present and range from faint to prominent, worm casts may be present. Exposed condition – moderately weak to very firm, labile/plastic, friable when dry. Permeability – low. Field pH – 5.5–6.0. Coarse fragments – none.	- High erodibility. - Very strong acidity. - High aluminium toxicity potential. - Low fertility (phosphorus fixing). - Hardsetting. - Low permeability.	urban	N/A	N/A	N/A
			forestry	high	very high	slight

Soil	Description	Limitations	Hazard				
Oxley (ox)							
ox1 – strongly structured dark clay (topsoil and subsoil, A and B horizons)	• Colour – brownish black, dark brown. • Texture – light to light-medium clay, occasionally clay loam. • Structure – strong, polyhedral 50–100 mm parting to 10–20 mm and hence dominant 2–5 mm polyhedral/crumbs. Peds are tightly packed. • Fabric – smooth-faced large peds, rough-faced crumbs, distinct clay coatings common on the larger sub-dominant peds. • Exposed condition – friable when dry. • Permeability – low to moderate. • Field pH – 6.0. • Coarse fragments – small amounts of charcoal often present.	• Stoniness. • Fertility. • High erodibility. • Moderate plasticity.	Erodibility				
			K factor	Non-concentrated flows	Concentrated flows	Wind	
			ox1	0.049	high	high	low
			Erosion Hazard				
				Non-concentrated flows	Concentrated flows	Wind	
grazing	slight	slight-very high	Slight				
cultivation	slight	slight	Slight				
urban	slight	slight	Slight				

Soil	Description	Limitations	Hazard				
Burringbar (bu)							
bu1 – dark brown crumbly clay loam (topsoil-A horizon)	• Colour – dark brown, brownish black. • Texture – clay loam, occasionally silty clay loam. • Structure – moderate, polyhedral, 10–20 mm parting to dominant 2–5 mm. • Fabric – can be rough- or smooth-faced. • Exposed condition – hardsetting when dry. • Permeability – moderate. • Field pH – 4.5–5.0. • Coarse fragments – few to common (2–20%) angular gravels (6–20 mm) of weathered parent materials.	• Strong acidity. • Moderately dispersive. • Hardsetting. • Stoniness.	Erodibility				
				K factor	Non-concentrated flows	Concentrated flows	Wind
			bu1	0.026	mod	High	low
			bu2	0.030	mod	High	low
			bu3	>0.081	Very high	Very high	low
			bu4	0.048	High	High	low
			bu5	0.054	High	High	low
bu6	0.041	High	High	low			
bu7	>0.087	Very high	Very high	low			
bu2 – Brown hardsetting silty clay loam (deep topsoil – A ₂ horizon)	• Colour – brown. • Texture – silty clay loam, occasionally clay loam. • Structure – weak, polyhedral, 5–10 mm, subdominant prismatic peds, 20–50 mm, may occur. • Fabric – can be rough- or smooth-faced. • Exposed condition – hardsetting when dry. • Permeability – low. • Field pH – 4.5–5.0. • Coarse fragments – few (2–10%) weathered gravels (2–20 mm) of parent material.	• Strong acidity. • Highly dispersive. • Hardsetting. • Low permeability.					

Soil	Description	Limitations	Hazard																				
bu3 – red plastic clay (subsoil -B horizon)	Colour – reddish brown to bright reddish brown. May be brown in upper (AB/B1) segments. Texture – light medium to medium clay. Structure – moderate to strong, polyhedral/subangular blocky 20–50 mm parting readily to 10–20 mm and thence dominant 5–10 mm. Fabric – smooth-faced, distinct clay coatings common in B2 horizons. Exposed condition – crumbly when dry; sticky, plastic when wet. Permeability – low. Field pH – 4.0–4.5. Coarse fragments – strongly weathered, angular gravels and coarse gravels (6–60 mm) of parent material can be common.	- Very strong acidity. - High aluminium toxicity potential. - High erodibility. - High plasticity. - Low permeability.	<table> <tr> <th colspan="4">Erosion Hazard</th></tr> <tr> <th></th><th>Non-concentrated flows</th><th>Concentrated flows</th><th>Wind</th></tr> <tr> <td>grazing</td><td>Mod</td><td>high</td><td>Slight</td></tr> <tr> <td>cultivation</td><td>Very high</td><td>Extreme</td><td>Slight</td></tr> <tr> <td>urban</td><td>high</td><td>Very high</td><td>Slight</td></tr> </table>	Erosion Hazard					Non-concentrated flows	Concentrated flows	Wind	grazing	Mod	high	Slight	cultivation	Very high	Extreme	Slight	urban	high	Very high	Slight
Erosion Hazard																							
	Non-concentrated flows	Concentrated flows	Wind																				
grazing	Mod	high	Slight																				
cultivation	Very high	Extreme	Slight																				
urban	high	Very high	Slight																				
bu4 – stony brown silty clay (deep topsoil – A ₂ horizon)	Colour – olive brown, brown. Texture – silty to sandy clay. Structure – massive to weak, polyhedral 10–20 mm parting to 2–5 mm. Fabric – earthy if massive, otherwise smoothfaced. Distinct clay and topsoil coatings can be common. Exposed condition – hardsetting, very “wormy” when dry. Permeability – low. Field pH – 4.0–4.5. Coarse fragments – many (20–50%) strongly weathered coarse parent material gravels (20–60 mm), generally sub-rounded or subrounded tabular.	- Very strong acidity. - Moderately dispersive. - High erodibility. - Low permeability. - Low fertility. - Stoniness.																					

Soil	Description	Limitations	Hazard
bu5 – yellow mottled clay (subsoil -B horizon)	• Colour – yellowish brown to bright brown, distinct orange and brown mottles occupy 10–50%. • Texture – light medium to medium clay. • Structure – massive to weak, polyhedral, 10–20 mm. • Fabric – earthy if massive, otherwise smooth faced. Many pinholes covered surfaces. • Exposed condition – hardsetting, very “wormy” when dry, very sticky when wet. • Permeability – low. • Field pH – 4.0–4.5. • Coarse fragments – few (2–10%) weakly weathered coarse gravels (20–60 mm) of phyllite and other parent material.	• Very strong acidity. • Highly dispersive. • High erodibility. • Hardsetting.	
bu6 – deep grey gravelly silty clay loam (topsoil and deep topsoil – A ₁ and A ₂ horizons)	• Colour – greyish yellow brown to dull yellowish brown, light grey when dry. • Texture – silty clay loam. • Structure – weak to moderate, polyhedral 2–5 mm parting to crumbs <2 mm. • Fabric – rough-faced, peds often coated with faunal casts. • Exposed condition – hardsetting, very “wormy” when dry, very sticky when wet. • Permeability – moderate. • Field pH – 4.0–4.5. • Coarse fragments – many (20–50%) strongly weathered angular parent material gravels (6–20 mm).	• Very strong acidity. • High aluminium toxicity potential. • Moderately dispersive. • High erodibility. • Low available water-holding capacity. • Hardsetting. • Stoniness.	

Soil	Description	Limitations	Hazard
bu7 – Dark red crumbly clay (topsoil and subsoil – A and B horizons)	• Colour – dark reddish brown, reddish brown . • Texture – light clay. • Structure – moderate, occasionally strong, closely packed polyhedral 10–20 mm parting to 5–10 mm. • Fabric – smooth-faced. • Exposed condition – hardsetting, firm when dry. • Permeability – low. • Field pH – 4.0–5.0. • Coarse fragments – common (10–20%) non-weathered fine to coarse parent material gravels (2–60 mm). Rounded manganese nodules, 2–6 mm, are common (10–20%) in the lower parts.	• Extreme acidity. • High aluminium toxicity potential. • Low available water-holding capacity. • High erodibility. • Hardsetting. • Low fertility.	

3.6.2 Hydrogeological landscapes

Hydrogeological Landscape (HGL) boundaries and descriptions have been derived for a number of areas across NSW based on how salinity manifests itself in the landscape and how differences in salinity are expressed across the landscape. A HGL spatially defines areas of similar salt stores and pathways for salt mobilisation and relies on the integration of a number of factors: geology, soils, slope, regolith depth, and climate; an understanding of the differences in salinity development; and the impacts (land salinity/salt load/water electrical conductivity [EC]) in landscapes. Derivative maps showing overall salinity hazard and individual hazard due to salinity expressed as land salinity, salt export (load) and stream EC are available. Overall salinity hazard uses a five class system (very low, low, moderate, high, very high) whilst hazard due to land salinity, salt export and stream EC uses a three class system (low, moderate, high) (DPE 2022a).

The study area is located outside of detailed mapped areas, but at the State-wide level the area is mapped as low to moderate overall salinity hazard respectively to a north-south divide which roughly correlates to the occurrence of the Frogs Hollow soil landscape. Land salinity is similarly mapped as low in the north and high in the south.

3.6.3 Australian Soil Classification

The Australian Soil Classification (ASC) scheme (Isbell & NCST 2021) is a multi-category scheme with soil orders defined based on diagnostic horizons or materials and their arrangement in vertical sequence as seen in an exposed profile. State-wide mapping (DPIE 2021c) identifies that the site encompasses two soil orders, Dermosols and Kurosols (Figure 3.5), described in Table 3.6.

Of the soil classifications identified:

- Kurosols are often dispersive and subsequently have the highest erosion risk (particularly gully and tunnel erosion) and also the highest risk of generating turbid runoff.
- Dermosols typically have higher agricultural potential and fewer limitations but could exhibit similar constraints to Kurosols under certain conditions and subject to their specific soil chemistry.

The soil chemistry of the site-specific soils is discussed in Section 4.2.

Table 3.6 Summary of regional ASC soil mapping

Soil type	ASC description ¹	Agricultural potential ²
Dermosols (DE)	• Soils with structured B2 horizons and lacking strong texture contrast between A and B horizons. • Soils other than Vertosols, Hydrosols, Calcarosols and Ferrosols which: – have B2 horizons that have grade of pedality greater than weak³ throughout the major part of the horizon – do not have clear or abrupt textural B horizons. • This is a soil order known for its diversity but does bring together a range of soil with important properties in common.	• Generally high agricultural potential. • Good structure, moderate to high chemical fertility and water holding capacity. • Generally few persistent limitations.

Soil type	ASC description ¹	Agricultural potential ²
Kurosols (KU)	• Soils with strong texture contrast between A and <i>strongly acid B horizons</i>. • Soils other than Hydrosols with: – with a <i>clear or abrupt textural B horizon</i> – in which the major part of the upper 0.2 m of the B2t horizon (or the major part of the entire B2t horizon if it is less than 0.2 m thick) is <i>strongly acid</i>. • Many of these soils often have some unusual subsoil chemical features, such as high magnesium, sodium and aluminium.	• Generally low agricultural potential. • High acidity, low chemical fertility, generally low water holding capacity. • Frequent sodic conditions.

1. Per Isbell & NCST (2021).

2. Per Gray and Murphy (1999).

3. It is common experience that pedologists are inclined to use the phrase 'weak to moderate' when they are in doubt as to the grade of structure. If such a designation is used it will result in the soil being classed as a Dermosol (Isbell & NCST 2021).

3.6.4 Great soil groups

Great soil group (GSG) soil classification is a system developed by Stace *et al.* (1968) based on the description of soil properties such as colour, texture, structure, drainage, lime, iron, organic matter and salt accumulation, as well as on theories of soil formation. The great soil groups classification has since been superseded by the ASC and commonly great soil groups soils have been converted to their ASC equivalent in many mapping systems.

Historic soil mapping identified from NSW government mapping (DPIE 2021d) for the study area are displayed in Table 3.7 with their corresponding ASC equivalents and associated soil landscapes and land resource areas.

Table 3.7 Summary of regional GSG soil mapping

Great soil groups	ASC equivalent	Soil landscape
Yellow Podzolic Soils – less fertile	Kurosols	Kunghur (ku) with variants a and b
Alluvial soils – medium to heavy textured	Dermosols	Terania (te) and Oxley (ox)
Red Podzolic Soils – less fertile	Kurosols	Burringbar (bu)
Brown Podzolic Soils (BP)	Dermosols	Frogs hollow (fh)

3.6.5 Inherent soil fertility

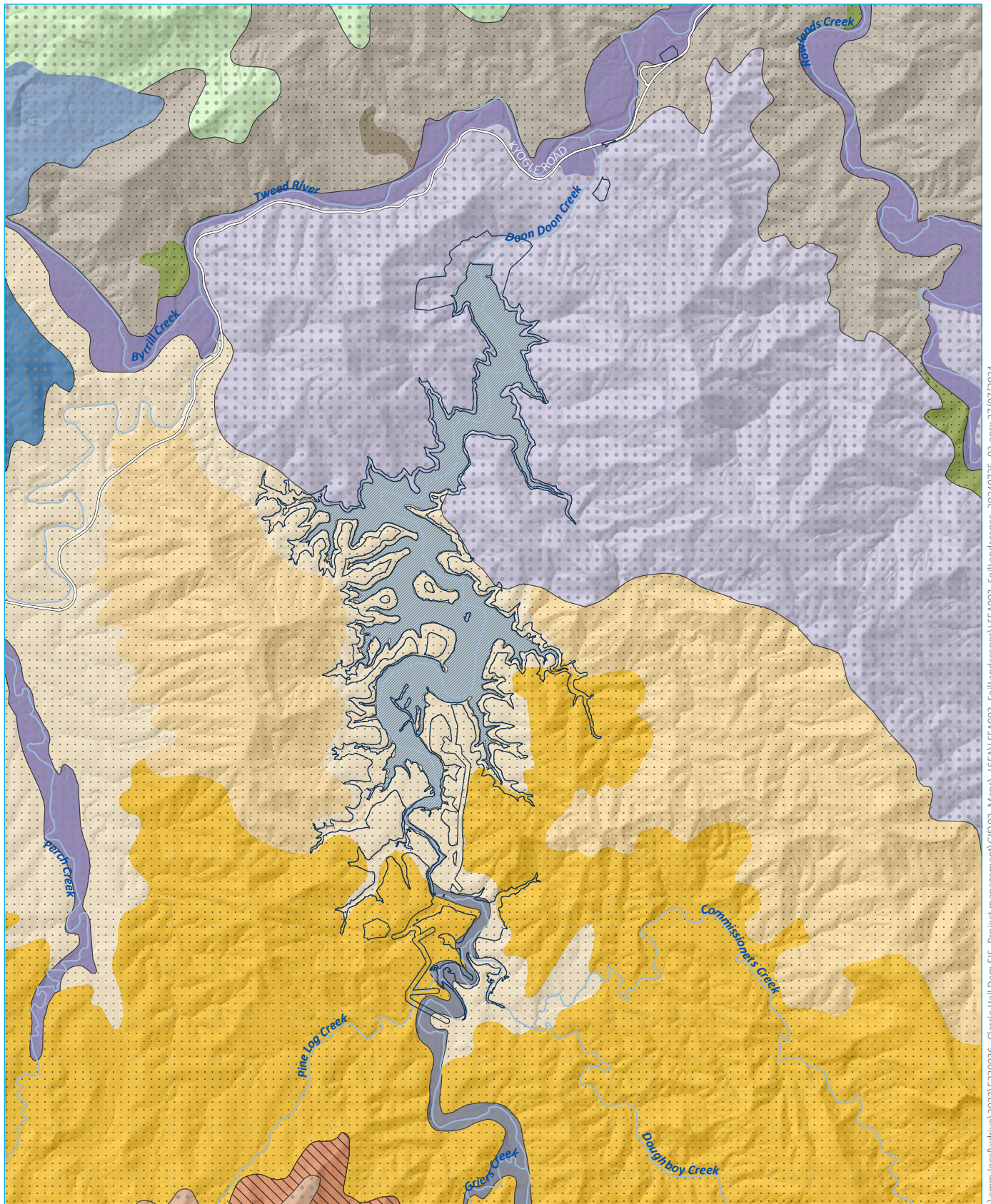
Inherent soil fertility is used as a general indication of a soil's capacity to retain and release nutrients and soil water for use by vegetation and is a function of the interrelationship between physical, chemical and biological components in the soil. The inherent fertility is derived using a relative classification developed by Charman (1978) and based on the regionally mapped soil types.

As per the eSPADE database (DPIE 2020a) the state scale mapping completed for NSW shows that the soils of the study area have variable inherent soil fertility ranging from 'moderate' to 'moderately low' (Table 3.8).

Table 3.8 **Inherent soil fertility**

Inherent soil fertility	ASC	Soil landscape	Description ¹
Moderately high	Dermosols	Terania, Oxley	Soils with high fertility in their virgin state but this fertility is significantly reduced after only a few years of cultivation.
Moderate	Dermosols	Frogs Hollow, Burringbar	Soils with low to moderate fertilities that usually require fertiliser and/or have some physical restrictions for arable use.
Moderately low	Kurosols	Kunghur and variants a and b	Soils with low fertilities that, generally, will only support vegetation suited to grazing with large inputs of fertiliser required to improve the soils and make them suitable for arable purposes.

1. Per Charman (1978).



Source: EMM (2024); KBS (2024), DCSSS (2023); DPIE (2021); DPE (2022)

0 1 2 km
GDA2020 MGA Zone 56

KEY

Study area

Dominant Australian Soil Classification (ASC)- Order

Dermosols (DE)

Ferrosols (FE)

Kurosols (KU)

Water

NSW Soil Landscapes- name

Billinudgel

Billinudgel variant c

Burringbar

Frogs Hollow

Kunghur

Kunghurvariant a

Kunghur variant b

Mount Terragon

Mount Terragon variant a

Mount Warning

Ophir Glen

Oxley

Terania

Water

Existing environment

Major road

Named watercourse

Soil landscapes and regional ASC mapping

Clarrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 3.5

3.6.6 Land and soil capability

The NSW ‘*Land and soil capability assessment scheme, 2nd approximation*’ (OEH 2012) (‘LSC Scheme’) assesses the inherent physical capacity of the land to sustain a range of land uses (and management practices) in the long term without leading to degradation of soil, land, air and water resources. The LSC Scheme considers the inherent biophysical features of the land and soil, and their associated hazards and limitations, to these land uses. Each hazard is given a rating between 1 (best, highest capability land) and 8 (worst, lowest capability land). The overall LSC class of the land is based on the most limiting feature/hazard.

The LSC classes present at a site can be determined at various scales, ranging from state, regional to farm scale, varying in accuracy according to the information and resolution associated with them. With reference to the eSPADE database (DPIE 2020a) and DPIE (2020c) the state scale mapping completed for NSW shows the study area is Classes 3, 4, 6, 7 and 8, representing land with high to extremely-low capability (Table 3.9 and Figure 3.6) with individual LSC hazards from eSPADE shown in Table 3.10.

It should be noted that the regional mapping assigns a singular LSC Class to a soil landscape mapping area, despite the main soil types described within soils landscapes often having variable LSC Classes.

Table 3.9 Land and soil capability classifications mapped for the study area

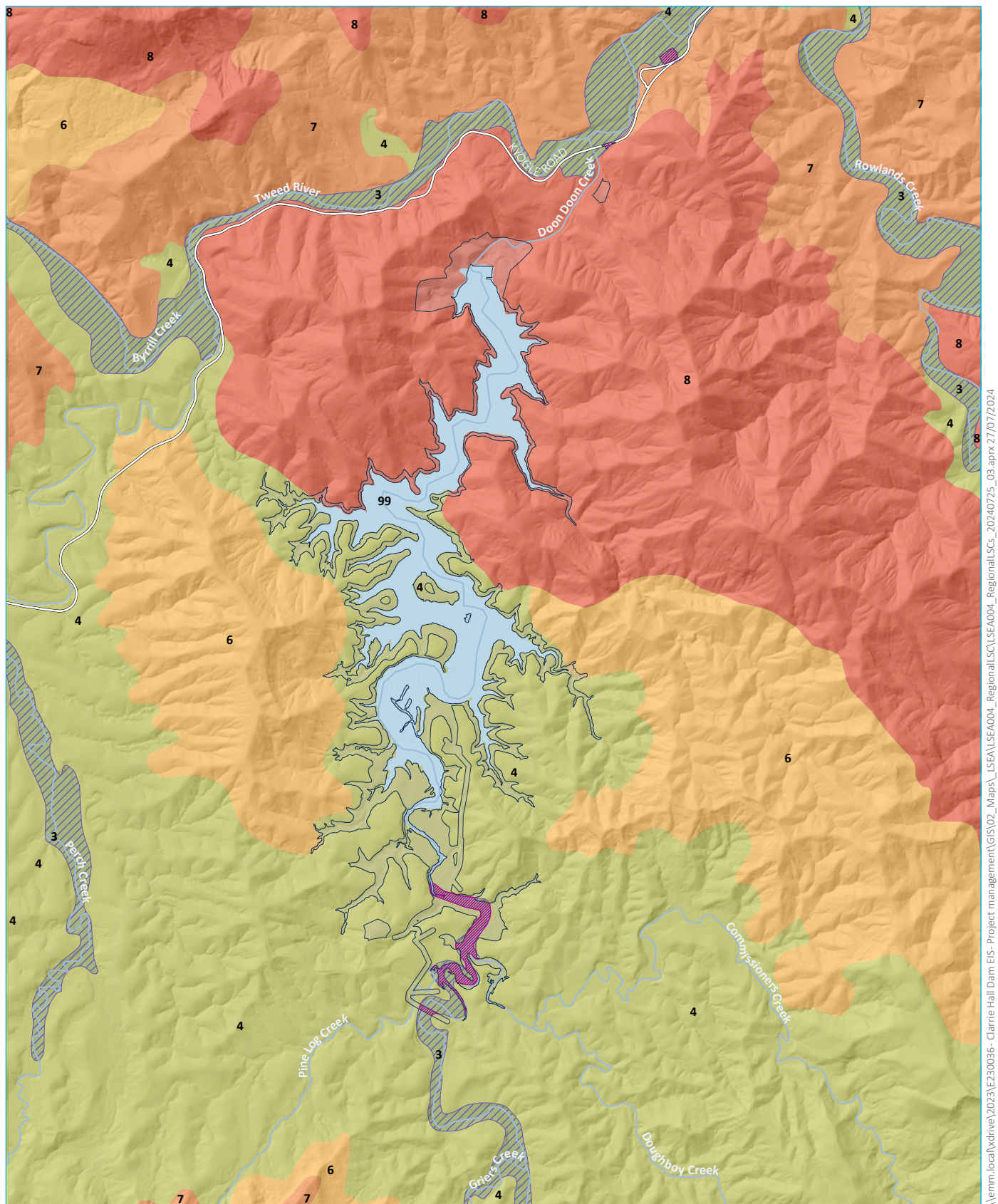
LSC Class ¹	Description	ASC (Soil landscape)
Class 3 – High capability land	- Land has moderate limitations. - Capable of sustaining high-impact land uses, such as cropping with cultivation, using more intensive, readily available and widely accepted management practices. - However, careful management of limitations is required for cropping and intensive grazing to avoid land and environmental degradation.	Dermosols (Terania and Oxley)
Class 4 – Moderate capability land	- Land has moderate to high limitations for high-impact land uses. - Will restrict land management options for regular high-impact land uses such as cropping, high-intensity grazing and horticulture. - These limitations can only be managed by specialised management practices with a high level of knowledge, expertise, inputs, investment and technology.	Kurosol (Kunghur and ‘variant b’)
Class 6 – Low capability land	- Land has very high limitations for high-impact land uses. - Land use restricted to low-impact land uses such as grazing, forestry and nature conservation. - Careful management of limitations is required to prevent severe land and environmental degradation.	Kurosol (Kunghur ‘variant a’)
Class 7 – Very low capability land	- Land has severe limitations that restrict most land uses and generally cannot be overcome. - On-site and off-site impacts of land management practices can be extremely severe if limitations not managed. - There should be minimal disturbance of native vegetation.	Kurosols (Burringbar)
Class 8 – Extremely low capability land	- Limitations are so severe that the land is incapable of sustaining any land use apart from nature conservation. - There should be no disturbance of native vegetation.	Dermosol (Frogs Hollow)

1. Per OEH 2012

Table 3.10 **LSC classes mapped for the study area**

ASC (soil landscape)	LSC hazard							
	Water	Wind	Structure	Acidification	Salinity	Waterlogging	Shallow soils	Mass movement
Dermosols (Terania)	2	2	3	3	NR	2	1	1
Dermosols (Oxley)	2	1	2	3	NR	2	3	1
Kurosols (Kunghur)	4	2	4	4	NR	2	2	1
Kurosols (Kunghur 'variant b')	3	2	4	4	NR	3	1	1
Kurosols (Kunghur 'variant a')	6	2	4	4	NR	2	3	1
Kurosols (Burringbar)	7	2	4	4	NR	1	3	7
Dermosol (Frogs Hollow)	8	2	4	4	NR	1	2	8

NR. not recorded in dataset.



KEY

- Study area
- Biophysical Strategic Agricultural Land (BSAL)
- BSAL within study area

Land and soil capability (LSC) class

- 3- Moderate limitations
- 4- Moderate to severe limitations
- 6- Very severe limitations
- 7- Extremely severe limitations
- 8- Extreme limitations

- Water
- Existing environment
- Major road
- Named watercourse

Regional LSC and BSAL mapping

Clarrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 3.6



3.6.7 Acid sulfate soils

Acid sulfate soils (ASS) probability mapping has been completed along the NSW coast over 128 map sheets at 1:25,000 scale (Naylor *et al.* 1998). The desktop assessment identified that there are no ASS or potential ASS in the study area, in accordance with the *Guidelines for the Use of Acid Sulfate Soil Risk Maps* (Naylor *et al.* 1998). The NSW OEH Acids Sulfate Risk Map (OEH 2018) indicates that the risk mapping extends to 10.5 km of the study area while the nearest site with a high probability of ASS is approximately 10.5 km northeast of the study area.

The Australian Soil Resource Information System (ASRIS) Atlas of Australian ASS mapping (Fitzpatrick *et al.* 2011) has mapped the study area at the highest risk level as Bn(p4), Low Probability of Occurrence with moderate confidence.

Sulfate soils are typically found in coastal areas which does not apply to the study area. However, inland ASS theoretically has the potential to occur in association with any waterway where suitable conditions prevail (such as sulfate salinised areas with anoxic conditions and abundant organic matter). Such conditions could occur within the Proposal area albeit with a low probability. Where the Proposal can mitigate additional salinity and carbon sources (such as algae, riparian litter, and municipal wastewater) the potential for ASS remains a low probability.

3.6.8 Desktop review summary

A summary of the available land and soil mapping available from eSPADE (DPIE 2020a) characteristics and their associations relevant to the Proposal footprint is presented in Table 3.11.

Table 3.11 Regional soil mapping summary

Soil landscapes	Great soil groups	ASC	Inherent soil fertility	LSC class	Area (ha)
Terania (te)	Alluvial soils – medium to heavy textured (Am)	Dermosols (DE)	Moderately high	3	12.5
Kunghur (ku)	Yellow Podzolic Soils – less fertile (YPI)	Kurosols (KU)	Moderately low	4	27.9
Kunghur ‘variant b’ (kub)	Yellow Podzolic Soils – less fertile (YPI)	Kurosols (KU)	Moderately low	4	154.8
Kunghur ‘variant a’ (kua)	Yellow Podzolic Soils – less fertile (YPI)	Kurosols (KU)	Moderately low	6	1.2
Frogs Hollow (fh)	Brown Podzolic Soils (BP)	Dermosols (DE)	Moderate	8	51.4
Oxley (ox)	Alluvial Soils – medium to heavy textured (Amh)	Dermosols (DE)	Moderately high	3	1.4
Burringbar (bu)	Red Podzolic Soils – less fertile	Kurosols (KU)	Moderate	7	<0.1
Not mapped					4.8

The Frogs Hollow (fh) and Kunghur (ku) soil landscapes are the dominant in the study area. They are modelled as host to Dermosol and Kurosol soil orders, respectively. The erosion hazards discussed for the soil landscapes is commonly high to extreme when surface cover is low (including cultivation) or flows are concentrated.

The modelled LSC and inherent soil fertility indicate the more valuable land for agricultural productivity will be associated with the Kurosols of the Kunghur and Kunghur ‘variant b’ soil landscape (LSC Class 4) and Dermosols of the Terania and Oxley soil landscape (LSC Class 3). Confirmation of the soil orders of the study area via field investigation is discussed in Chapter 4.

3.7 Hydrogeology

The groundwater systems within the study area comprise:

- minor local, shallow groundwater associated with alluvial deposits
- local, groundwater systems associated with the Tertiary volcanic rocks
- local to regional groundwater systems associated with the porous and fractured rock units within the Clarence-Moreton Basin
- local to regional groundwater systems associated with the fractured rock units of the New England Fold Belt.

These groundwater systems have different hydrogeological properties due to their depositional environment. Generally, this is a low yielding region with no highly productive aquifer systems. The groundwater systems are discussed in detail within the GIA.

Alluvial groundwater systems are in locations where alluvial sediments have been mapped and include Doon Doon Creek, Tweed River and other perennial watercourses. The alluvial groundwater system is in direct hydraulic connection with the surface watercourses.

Tertiary volcanics groundwater systems are associated with water stored within basalt volcanics rocks, where water moves through fractures, joints and other secondary rock openings. These systems tend to be localised with relatively low yields compared to other groundwater sources.

Two regional groundwater systems are present within the study area which includes the porous and fractured rock within the Clarence-Moreton Basin, and the fractured rock system of the New England Fold Belt. The Clarence-Moreton Basin includes sedimentary porous rock units such as the Walloon Coal Measures and Ripley Road Sandstone and volcanic units such as the Chillingham Volcanics. A low to moderate connectivity exists between surface water features and Clarence-Moreton Basin. Within the New England Fold Belt, groundwater systems are of a similar character to the localised tertiary volcanic rocks. Yield within the groundwater source is highest in areas of increased fracturing.

3.8 Land use and zoning

3.8.1 Land use

Land use within the study area was assessed utilising *Catchment scale land use of Australia* (ABARES 2021), a national compilation of catchment scale land use data for Australia compiled at a resolution of 50 m by 50 m.

The 2021 mapping utilises the standards of the Australian Collaborative Land Use and Management Program (ACLUMP) and the Australian Land Use and Management (ALUM) Classification Version 8. The ALUM classification is a three-tiered hierarchical structure featuring primary, secondary and tertiary classes which are broadly structured by the potential degree of modification and the impact to the 'natural state', essentially native land cover. In this system the primary and secondary classes relate to land use, the main use of the land defined by the management objectives of the land manager. The tertiary classes can include other information such as commodity groups, specific commodities, land management practices and vegetation information.

Six primary land use classes are described in Table 3.12.

Table 3.12 ALUM classification

ALUM primary class	Overview	Description
1	Conservation and natural environments	Land used primarily for conservation purposes, based on maintaining the essentially natural ecosystems present.
2	Production from relatively natural environments	Land used mainly for primary production with limited change to the native vegetation.
3	Production from dryland agriculture and plantations	Land used mainly for primary production based on dryland farming systems.
4	Production from irrigated agriculture and plantations	Land used mostly for primary production based on irrigated farming.
5	Intensive uses	Land subject to extensive modification, generally in association with closer residential settlement, commercial or industrial uses.
6	Water	Water features (water is regarded as an essential aspect of the classification, but it is primarily a cover type).

Under the ALUM classification and mapping, the study area is predominantly mapped as ALUM 6.1.0 Lake and secondarily as ALUM 1.3.3, Residual native cover. ALUM 2.1.0, grazing native vegetation and 3.2.0, grazing modified pastures are the other more significant land uses. A detailed breakdown of the ALUM classification of the study area is contained in Table 3.13.

Table 3.13 Study area ALUM classification

ALUM primary class	ALUM secondary class	ALUM tertiary class	Study area (hectares)
1	1.1.0 Nature conservation	1.1.3 Nature park	0.4
1	1.3.0 Other minimal use	1.3.0 Other minimal use	0.5
1	1.3.0 Other minimal use	1.3.3 Residual native cover	62.1
1	2.1.0 Grazing native vegetation	2.1.0 Grazing native vegetation	33.7
3	3.1.0 Plantation forests	3.1.1 Hardwood plantation forestry	0.2
3	3.2.0 Grazing modified pastures	3.2.0 Grazing modified pastures	39.9
3	3.4.0 Perennial horticulture	3.4.0 Perennial horticulture	< 0.1
3	3.4.0 Perennial horticulture	3.4.3 Tree nuts	2.0
3	3.5.0 Seasonal horticulture	3.5.3 Seasonal vegetables and herbs	0.8
3	3.6.0 Land in transition	3.6.5 Abandoned perennial horticulture	3.1
5	5.4.0 Residential and farm infrastructure	5.4.3 Rural residential without agriculture	2.3
5	5.4.0 Residential and farm infrastructure	5.4.5 Farm buildings/infrastructure	12.3
5	5.7.0 Transport and communication	5.7.2 Roads	3.3
6	6.1.0 Lake	6.1.0 Lake	91.2
6	6.2.0 Reservoir/dam	6.2.1 Reservoir	2.3

1. ABARES 2021a, Catchment scale land use of Australia—update December 2020.

3.8.2 Land zoning

The Tweed Shire Local Environmental Plan (LEP) 2014 identifies land use zones and the type of land uses that are permitted (with or without consent) or prohibited in each zone on any given land identified within the Tweed Shire LGA. Land within the study area is zoned RU2 (69.9 ha), Rural Landscape, with SP2, Water Supply System Infrastructure associated with Clarrie Hall Dam (173.9 ha) and minor areas (0.7 ha) of C1, National Parks and Nature Reserves, associated with Mount Jerusalem National Park to the east.

3.9 Agriculture

The Proposal is located within the Tweed Shire LGA within the North Coast Natural Resource Management (NRM) Region of NSW.

The assessment of Proposal impacts to agricultural land has been based on desktop assessment of available agricultural land use and productivity at a regional level.

3.9.1 Strategic agricultural land

Strategic agricultural land in NSW is safeguarded through two primary measures, classification as Biophysical Strategic Agricultural Land (BSAL) or the implementation of Critical Industry Clusters (CICs). The Stage Significant Agricultural Land (SSAL) map is currently in draft format on public exhibition for comment and feedback and is not yet approved or implemented for any purpose but has been considered in addition to BSAL and CICs.

The presence of BSAL, SSAL and CICs within the study area is described below.

i Biophysical Strategic Agricultural Land

Biophysical Strategic Agricultural Land is defined in the Interim Protocol for Site Verification and Mapping of Biophysical Strategic Agricultural Land ('BSAL') (OEH 2013), the 'Interim Protocol', as land with a rare combination of natural resources highly suitable for agriculture. A total of 2.8 million ha of BSAL has been identified and mapped at a regional scale across the State.

The *State Environmental Planning Policy (Resources and Energy) 2021*, also known as the Resources and Energy SEPP, requires certain types of developments to verify whether the proposed site is located on BSAL. The Interim Protocol assists proponents and landholders to understand what is required to identify the existence of BSAL and outlines the technical requirements for the on-site identification and mapping of BSAL. Given the Proposal is not classified as a mining proposal under the *Mining Act 1992*, the Resources and Energy SEPP is not applicable. However, a BSAL review provided in this assessment provides context on the agricultural significance of any present BSAL in the study area.

The NSW Government has mapped BSAL across the whole of NSW, based on a desktop study. The BSAL shown on the maps comprises land which meets criteria described in the interim Protocol. The criteria used to measure BSAL under the original Strategic Regional Land Use Plans were based on three regional scale parameters:

1. Soil Fertility – based on the regional scale Draft Inherent General Fertility of NSW (Section 3.6.5, DPIE 2020b).
2. Land and Soil Capability – based on the regional scale Land and Soil Capability Mapping of NSW (Section 3.6.6, DPIE 2020c).
3. Access to reliable water supply, defined as:
 - a) rainfall of 350 mm or more per annum (9 out of 10 years)
 - b) a regulated river (maps show those within 150 m)

- c) a 5th order or higher unregulated river (maps show those within 150 m)
- d) an unregulated river which flows at least 95% of the time (maps show those within 150 m)
- e) highly productive groundwater sources, as declared by the NSW Office of Water. These are characterised by bores having yield rates greater than 5 litres per second (L/s) and total dissolved solids (TDS) of less than 1,500 milligrams per litre (mg/L) and exclude miscellaneous alluvial aquifers, also known as small storage aquifers.

There is a small area of mapped BSAL present that overlaps the southern portion of the Proposal footprint, associated with the Terania soil landscape, and Class 3 LSC mapping (Figure 3.6).

ii State Significant Agricultural Land (SSAL)

NSW Department of Primary Industries (DPI) is undertaking a mapping program across NSW to assist state and local government, along with other organisations and industries to recognise and value SSAL. Loss of access to agricultural resources and increased incidents of agricultural land use conflict in the rural landscape have the potential to create inefficient land use shifts. This can result in a net loss of value to the State through:

- direct and indirect economic loss of produce and markets
- loss of primary industries, associated businesses and services and related employment
- social decline and loss of community connectivity.

Knowing where SSAL is situated and understanding its location, value and contribution will assist in making decisions about current and future allocation of land.

The draft SSAL mapping prepared by DPI was on public exhibition for comment and feedback until 31 January 2022 and is currently in early draft stage.

The biophysical criteria used to map SSAL include:

- land and soil capability (refer to Section 3.6.6) based on:
 - soil type
 - slope
 - landform position
 - acidity
 - salinity
 - drainage
 - rockiness
 - climate
- inherent soil fertility (refer to Section 3.6.5)
- a soil pH of 5 to 8

- water availability – either more than 500 mm of rainfall per annum or land on highly productive groundwater sources.

The data utilised for the development of the SSAL mapping is predominantly regional-scale mapping or modelling and subject to associated data limitations.

There is a small area of mapped BSAL present to the south of the study area, associated with the Terania soil landscape, as well as to the north, associated with the Tweed River.

iii Critical Industry Clusters

Critical Industry Clusters (CICs) are concentrations of highly productive industries within a region that are related to each other, contribute to the identity of that region and provide significant employment opportunities. The creation of these industry clusters aims to protect this high-quality agricultural land from the impacts of coal seam gas and mining activities.

No CICs are present within the study area.

3.9.2 Agricultural water resources

i Drainage and surface water

The existing use of surface water resources in agricultural activities is discussed within the SWA. The assessment summarised that agricultural land use within the Tweed Shire LGA consists of around 75% of RU1, RU2, R5, 7(d), 7(f), and 7(l) zoned land, comprising of grazing lands, broadacre sugarcane cropping, horticulture, forestry and rural living activities. Water use through irrigation is typically highest with cattle production and dairying. Within the surface water source associated with Clarrie Hall Dam, five irrigation and one stock and domestic water access licences exist, totalling 56 shares (equivalent to 56 ML/year when water availability is 100%).

ii Groundwater

Groundwater is also a relevant water resource component when considering agricultural purposes. The Proposal is located within the Clarence Moreton Basin Groundwater Source under the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016*. Within a 5 km radius of Clarrie Hall Dam, 32 registered groundwater bore installations exist. Of these registered groundwater bores, approximately two have an irrigation purpose and three have a stock and domestic purpose, indicating some level of water access for agriculture. Further information about groundwater access and interactions with the Proposal can be found within the GIA completed for the EIS.

3.9.3 Agricultural land uses

i Regional agricultural land use

As per Section 3.8, data on land use was collected based on the *Catchment scale land use of Australia* (ABARES 2021), a national compilation of catchment scale land use data for Australia compiled at a resolution of 50 m by 50 m.

The land use for the Tweed Shire LGA utilised for agriculture is shown in Table 3.14.

Table 3.14 **Agricultural land use**

Land use	Tweed Shire LGA ¹	
	Area (ha)	Area of LGA (%)
Cropping–dryland	9,755	7.47
Horticulture–dryland	2,050	1.57
Horticulture–intensive plant production	112	0.09
Horticulture–irrigated horticulture	18	0.01
Livestock–grazing modified pastures	24,763	18.97
Livestock–grazing native vegetation	19,593	15.01
Livestock–intensive animal production	154	0.12
Livestock–irrigated pastures	410	0.31
Livestock–land in transition	2,757	2.11
Agriculture–total	59,612	45.67
Land area–total	130,512	

1. ABARES 2021a, Catchment scale land use profile dashboard–Local government areas.

The LGA has agricultural land use dominated by livestock production, with 33.98% of the LGA land use being grazing of native or modified pasture, making up 74.4% of the agricultural land use. Much of the LGA outside of agriculture is utilised for nature conservation (34.82%) (ABARES 2021a).

ii Local agricultural land use

Land use at the Proposal level was developed using information obtained in discussion with David Hannah (pers comms.). Much of the study area is too steep and isolated for viable agricultural production.

Given the utilisation of the dam for local drinking water supply, the Council has endeavoured to remove all agricultural practices, such as grazing, from proximity of the dam to protect the dam catchment from degradation and minimise water quality impacts associated with sedimentation and agricultural runoff.

Productivity associated with the agricultural activities on site is described in Section 3.9.5.

3.9.4 Agricultural production

i Regional production

Agricultural productivity for selected commodities for the Tweed Shire LGA are presented in Table 3.15 from the Australian Bureau of Statistics' (ABS) *2020-21 Value of Agricultural Commodities Produced (VACP)* collection which measures agriculture's contribution to the Australian economy (ABS 2022).

In 2020–21 the most important commodities in the Tweed Shire LGA (based on the gross value of agricultural production) were cropping (\$81.07 million (m)), dominated by broadacre cropping (\$35.82 m) and nurseries, cut flowers or cultivated turf (\$22.26 m), followed by livestock disposals (\$9.91 m) and products (\$6.35 m) (ABS 2022).

Table 3.15 Value of agricultural commodities–2020-2021

Agricultural commodity	Tweed Shire LGA ¹	
	Gross value (\$m) ²	Local value (\$m) ³
Crops–broadacre–total	35.82	29.72
Hay–total	0.06	0.06
Nurseries, cut flowers or cultivated turf – total	22.26	20.20
Fruit and nuts (excluding grapes) – total	11.25	10.44
Vegetables – total	11.67	10.00
Crops–total⁴	81.07	70.43
Livestock products–wool	0.01	0.01
Livestock products–milk	6.20	6.20
Livestock products–eggs	0.14	0.13
Livestock products–total	6.35	6.34
Livestock slaughtered and other disposals – Sheep and lambs	0.02	0.01
Livestock slaughtered and other disposals – Cattle and calves	9.65	8.92
Livestock slaughtered and other disposals – Pigs	0.19	0.17
Livestock slaughtered and other disposals – Poultry	0.05	0.05
Livestock slaughtered and other disposals – other n.e.c.	0.01	0.01
Livestock slaughtered and other disposals – total	9.91	9.16
Total agriculture–all commodities	97.33	85.92

1. ABS 2022, Value of Agricultural Commodities Produced by Local Government Area - 2020-21.

2. Gross values are those realised at the point(s) of valuation where ownership of the commodity is relinquished by the agricultural industry.

3. Local values are derived using survey and administrative sources to remove marketing and transport costs. They are the value placed on recorded production at the place of production, including indirect taxes.

4. All crops includes broadacre, hay, silage and horticultural (fruit and nuts, grapes, vegetables and nurseries, cut flowers or cultivated turf) produce.

3.9.5 Productivity values

i Regional

Indicative dollar per hectare (\$/ha) values for selected commodities are given in Table 3.16 based on the available land use and productivity data described in Sections 3.9.3 and 3.9.4. These provide a broad indication of potential land productivity for agricultural land use categories and the relative impacts on agricultural productivity associated with the Proposal. These values do not have sufficient resolution to account for variation in productivity associated with site-specific land capability, management practices or other ‘farm-scale’ factors.

These figures are limited by the inability to derive the specific land uses to suitable levels to associate to specific commodity production. This limiting factor results in a grouping of land use and commodity into:

- Productivity values (refer to Table 3.15):
 - livestock including slaughtered, disposals and products.
- Land use (refer to Table 3.14):
 - livestock land use of grazing modified pastures and native vegetation, intensive animal production, irrigated pastures and land in transition.

Table 3.16 Indicative annual commodity values per hectare

Area	Commodity sector	Land use (ha)	Production value (\$m) ¹		Value (\$/ha)	
			Gross	Local	Gross	Local
Tweed Shire LGA	Livestock	47,677	16.26	15.49	341.1	325.0

1. ABS 2022, Value of Agricultural Commodities Produced by Local Government Area - 2020-21

Extrapolating from the indicative annual commodity values (refer to Table 3.16), the proposed extension to the FSL area, if fully developed, would encompass some 73.6 ha of grazing land, as per Section 3.8. Were this 73.6 ha to be developed (change of use to livestock production) it would be valued at approximately \$25,097 in annual productivity based on calculated agricultural values for the Tweed Shire LGA (refer to Table 3.17).

Table 3.17 Estimated Proposal land value

Area	Commodity sector	Estimated land value (Gross \$/ha)	Area (ha)	Proposal land value (\$)¹
Study area				
Tweed Shire LGA	Livestock	341.1	73.6	\$25,097
	Total			\$25,097

1. Rounded to nearest dollar.

It is noted that due to the function of Clarrie Hall Dam as a domestic water supply, that much of the agricultural land adjacent to the dam, subject to potential impact by the Proposal, has been purchased by the Council. With these purchases, much of the agricultural activities have ceased in order to prevent future impacts to drinking water. As such, the estimated agricultural impacts are likely to be much reduced compared to those values calculated in Table 3.17.

3.10 Catchment geomorphology

3.10.1 Existing watercourse condition

Of the watercourses present within the dam catchment, identified in Table 3.1, further review of the River Styles dataset was undertaken to understand the existing condition of each system. Table 3.18 summarises the outcomes from the desktop review.

Table 3.18 Watercourse condition mapping within the Clarrie Hall Dam catchment

Watercourses	River Style	Fragility	Geomorphic stream condition	Potential to recover	Priority for river management
Griers Creek	Headwater	Low to moderate.	- Good – upper sections. - Poor – lower sections.	- Intact within the upper sections. - Moderate within lower sections.	- Upper sections should be conserved. - Medium priority for rehab in the lower sections.
Big Creek	Headwater	Moderate.	Moderate.	Moderate.	Medium priority for rehab.
Blakes Creek	Discontinuous channel, valley fill.	Moderate.	Poor.	Moderate.	Medium priority for rehab.
Doughboy Creek	Single channel, low sinuosity.	Low to moderate.	- Good – upper sections. - Moderate – lower sections.	- Intact within the upper sections. - Moderate within lower sections.	- Upper sections should be conserved. - Medium priority for rehab in the lower sections.
Doon Doon Creek	Single channel, meandering	Moderate.	Poor.	Moderate.	Medium priority for rehab.
Commissioners Creek	Single channel, meandering	Moderate.	Moderate.	Moderate.	Medium priority for rehab.
Pine Log Creek	Single channel, low sinuosity	Low to moderate.	- Good – upper sections. - Poor – lower sections.	- Intact within the upper sections. - Moderate within lower sections.	- Upper sections should be conserved. - Medium priority for rehab in the lower sections.

Pine Log, Griers and Doughboy creeks had good condition upper sections with poorer condition lower sections. All other watercourses had moderate conditions with Doon Doon Creek generally mapped as being in a poor condition. This classification is likely due to the degree of artificial control placed on the flow paths.

3.10.2 Morphology

To characterise the hydrological response of the catchment in which the dam is located and better understand the existing geomorphology present, a series of standard catchment morphometrics have been determined for the Doon Doon Creek catchment.

The elongation ratio (E_r) along with the form factor (R_f) can be used to understand how catchment shape influences hydrological response. The elongation ratio was estimated at 0.717 which indicates a typically slower rainfall and runoff response from the catchment due to its shape being elongated. The form factor was estimated at 0.432 which is indicative of an elongated catchment with a low flood intensity.

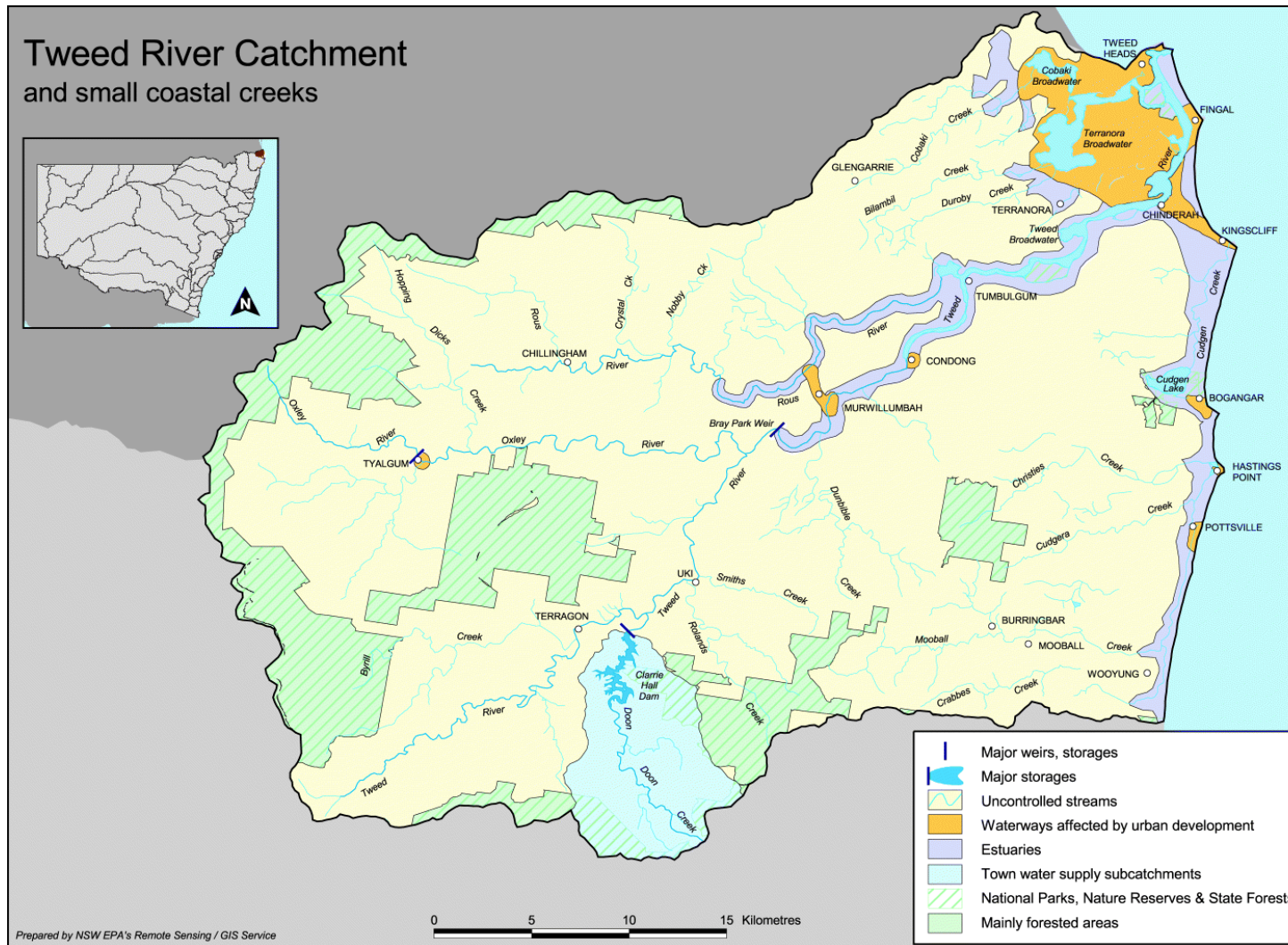
The overall relief of the catchment is 520 m. The relief can be used to inform the relief ratio (R_h) and which was equal to 0.0624. The hypsometric interval is a topographic measure of the relative proportion of catchment area with respect to elevation. The proportion of total catchment area under a 250 m elevation accounts for approximately 96.4%. Therefore, the catchment is mainly composed of low foothills and would suggest a more stable sediment transfer from the headwater regions.

The drainage density ratio (i.e. the unit length of watercourse channels per unit area) approaches one and parallel drainage pattern is observed where tributaries join the trunk at acute angles. This configuration commonly occurs when there is a lack of structural impediment and produces a smooth downstream conveyance of sediment.

A summary of catchment morphometrics is listed in Table 3.19. An overview of the Doon Doon Creek catchment is provided in Figure 3.7 in the context of the Tweed River catchment system by DPE (2006).

Table 3.19 Summary of Doon Doon Creek catchment morphology

Metric	Value
Elongation ratio	0.717 – slower runoff response
Form factor	0.432 – low flood intensity
Relief ratio	0.0624
Drainage density	3.9
Maximum stream order	5



Source: DPE (2006)

Figure 3.7 Dam catchment extent in the context of regional Tweed River system

3.10.3 Planform adjustments

The volume of the existing dam is contained within extended valley margins and is confined by bedrock and cohesive terraces. This bedrock laterally and vertically confines watercourses upstream of the dam; however, small floodplain pockets exist which is a regime that is typical within upper catchment morphology.

The landscape of the upper elevations within Doon Doon Creek is relatively uncleared with intact native vegetation typically comprising wet sclerophyll forest and areas cleared and planted for agriculture. Localised sheet and rill erosion exists in these areas where banana plantations are present, generally restricted to northerly to westerly aspects.

Lower slopes of the Tweed River catchment are more disturbed where land clearing has occurred for grazing purposes where groundcover is restricted to pasture species and some native grasses. Pockets of wet sclerophyll forest exists on steeper slopes and proximal to rocky outcrops. Erosion has been observed as minor sheet erosion, and erosion hazard is moderate-high to high for non-concentrated to concentrated flows. There is minor erosion hazard in response to wind.

There is less lateral confinement across the floodplains of the Tweed River. Native vegetation has been widely cleared with pockets of intact riparian corridors. Ground cover is restricted to native and exotic grasses in many cases where cattle grazing occurs. Cattle grazing in combination with land clearing produces significant erosion hazard to channel banks. Active erosion has been observed along the Tweed River downstream of the spillway.

A longitudinal profile of Clarrie Hall Dam and Doon Doon Creek is provided Figure 3.8.

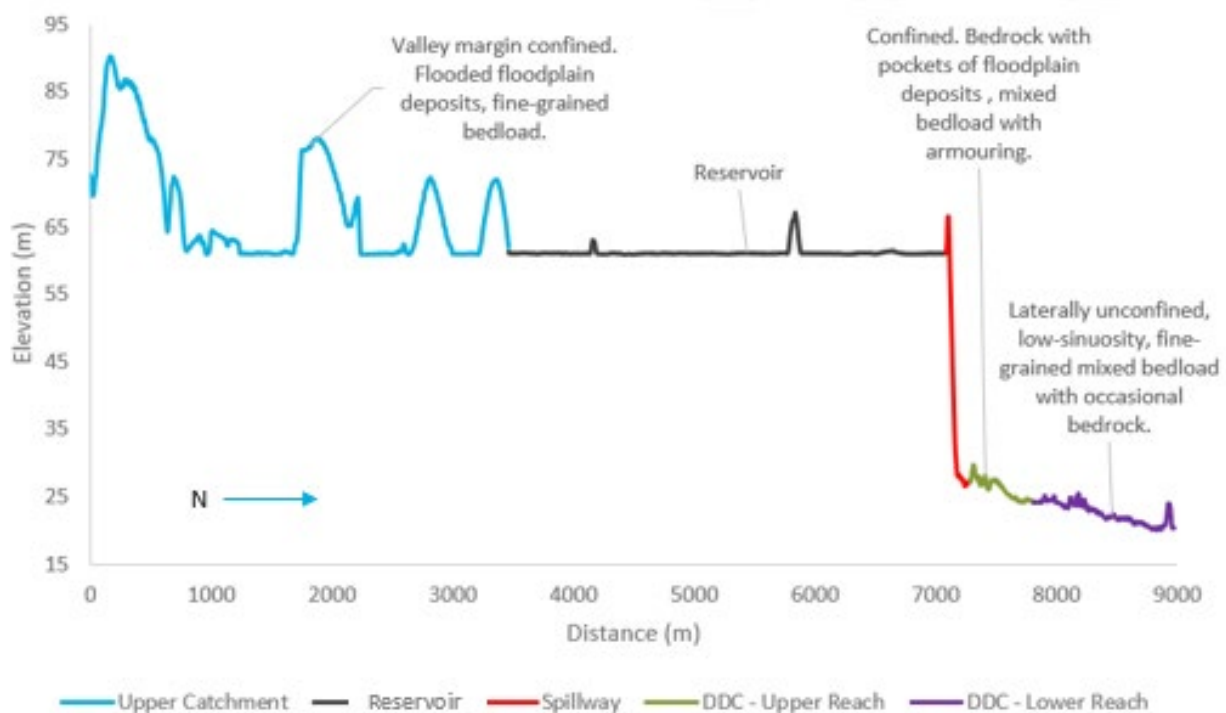


Figure 3.8 Longitudinal profile of Clarrie Hall Dam and Doon Doon Creek

The dam has been constructed across Doon Doon Creek such that this watercourse is now functioning as an altered system with adjusted flow rates and sedimentary regime.

As spillway discharges flow from Doon Doon Creek into the Tweed River, they are likely to have greater degrees of freedom for lateral and vertical adjustment. This is because bedrock confining the channel of Doon Doon Creek is only present for between 10 to 50% of the downstream reach from the dam.

3.10.4 Downstream longitudinal channel slope

It is common practice to derive a catchment slope value in metres over metres (m/m) to simplify the potential energy generated at a control volume under steady state conditions. An average channel slope constant was derived of 0.0034 m/m using the Murwillumbah 5 m digital elevation model (DEM). Figure 3.9 shows the longitudinal gradient for 5 km downstream of the dam wall. The average channel slope is similar to that of the Tweed River downstream of the confluence with Doon Doon Creek.

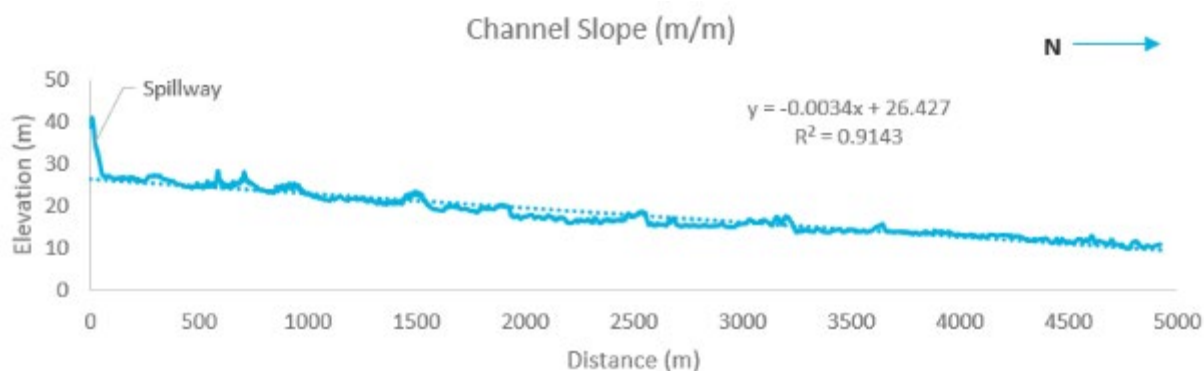


Figure 3.9 Catchment point-slope function from Clarrie Hall Dam

3.10.5 Downstream channel flood level

Available flood frequency data (BoM 2023) were used to estimate the expected flood levels with respect to the channel geometry on the Tweed River at Uki, downstream of the spillway. Although the data is representative of the downstream effects at the Tweed River, this simplified one-dimensional hydraulic estimation is useful to assessing the natural range of water level depth variability of the floodplain in response to flood events. Indicative river levels for a range of return periods within the Tweed River channel at Uki is illustrated in Figure 3.10, with overbank flows estimated in events equal to or greater than about a 1 in 5 year (1:5) return period.

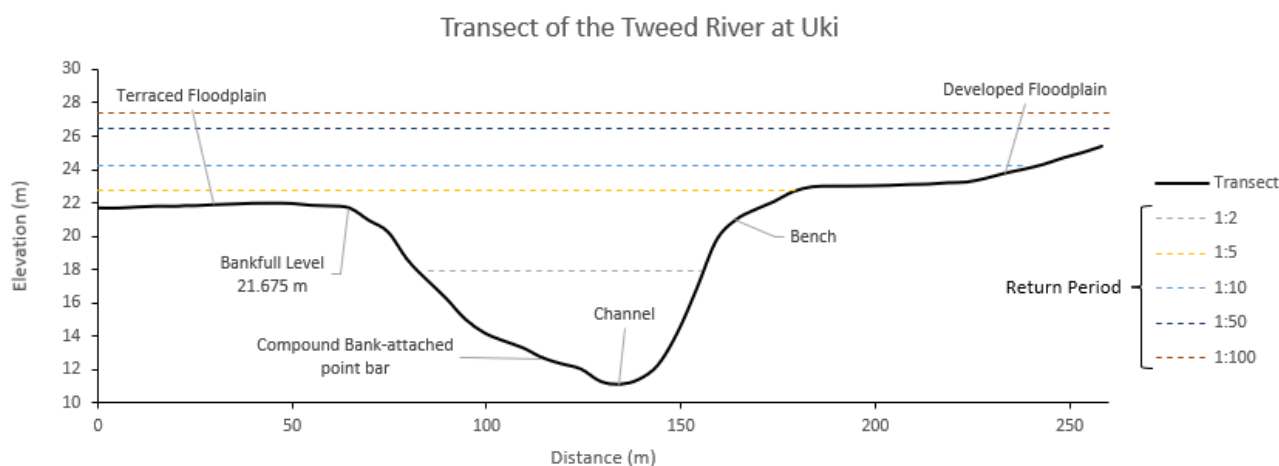


Figure 3.10 Indicative flood levels and relationship with channel and floodplain at Tweed River, Uki

4 Soil field investigation

The overall soil characterisation undertaken for the LSEA comprised the following:

- a desktop review of existing information and the current state of the environment within the study area (Chapter 3)
- a field soil survey methodology to validate and inform the soils present within the study area (Section 4.1)
- determination of the soil profile classes (SPCs) present in the study area and their key physical and chemical characteristics (Section 4.2).

The soil characterisation provides key information used in the erosion hazard assessment (Section 5) and some considerations to catchment geomorphology and stability.

4.1 Soil survey methodology

A field soil survey was completed from 27 to 29 March 2023, to examine the soil and landform properties of the study area, with samples obtained for laboratory analysis.

The sampling program (site selection and intensity) and field and laboratory analyses undertaken are described in Section 4.1.1.

4.1.1 Sample site selection and density

Site investigations focused on surveying the proposed inundation and construction areas around the dam wall, with a site density of one site per 20 to 100 ha, achieving a 1:50,000 scale survey of 'medium (semi-detailed)' survey intensity as per McKenzie *et al.* (2008), suitable for objectives of moderately intensive uses at farm level, semi-detailed project planning, and district level planning.

The field program was designed as an integrated free survey, designed on the premise that many land characteristics are interdependent and tend to occur in correlated sets (NSCT 2009). Investigation sites are irregularly located according to the survey teams' judgement to enable the delineation of soil boundaries. Soil boundaries can be abrupt or gradual, and catena and toposequences are used to aid the description of gradual variation.

The rationale for the location of the soil investigation sites was based on the desktop assessment detailed in Section 3.6. The investigation sites were distributed according to variations in the available land characteristics, including desktop soil mapping, elevation, landform and geology. The aim was to provide at least one detailed site description for each combination of these factors to assess their influence on soil distribution across the site area.

The surveyed area encompasses approximately 232 ha of the 254 ha study area. A total of five soil profile sites were investigated within the study area, achieving an approximate site intensity of one site per 51 ha, closely matching the requirements per McKenzie *et al.* (2008). An additional four soil investigation sites were completed where profile assessment was not possible to collect discrete soil samples for laboratory analysis.

The soil investigation site locations are detailed below in Table 4.1, and shown on Figure 4.1.

Table 4.1 **Soil investigation sites**

Site	Coordinates		Sampling method
	Latitude	Longitude	
CH01	-28.439934	153.301601	Brief mapping observation with some soil morphological data recorded.
CH02	-28.450117	153.308880	Brief mapping observation with some soil morphological data recorded.
CH03	-28.448712	153.302697	Brief mapping observation with some soil morphological data recorded.
CH04	-28.457886	153.299597	Detailed profile description.
CH05	-28.466453	153.300126	Detailed profile description.
CH06	-28.476081	153.298491	Detailed profile description.
CH07	-28.470310	153.301658	Detailed profile description.
CH08	-28.492697	153.301171	Detailed profile description.
CH09	-28.437388	153.306142	Brief mapping observation with some soil morphological data recorded.

4.1.2 Field methodology

i Profile description

Soil site descriptions were undertaken in accordance with the *Australian Soil Survey and Land Survey Field Handbook, 3rd Edition* (NCST 2009) and classified using *The Australian Soil Classification* (Isbell & NCST 2021). Soil site descriptions include a soil profile description, site observations and photographs taken of the soil profile and landscape at each location. These profile descriptions are included in Appendix A.

Site observations include descriptions of:

- location (GPS)
- landform (including slope and morphology)
- geology
- surface characteristics (e.g. gilgai and rockiness)
- vegetation.

Soil profile descriptions include (where applicable) details of:

- horizon depths and designation
- soil surface condition (crusting, cracking, self-mulching)
- boundary distinctness
- field texture (ribboning technique as per NCST 2009)
- colour (hue and chroma using the Munsell colour chart)

- mottles
- coarse fragments (visual assessment of shape, size and distribution)
- structure and pedality
- segregations
- hydrology (profile drainage and permeability)
- field tests (e.g. pH).

ii Photographs

Photographs of the excavated soil profiles were taken, along with photos of the surrounding landscape of the site. Select photographs are included in Section 4.2 and Appendix B.

4.1.3 Soil samples

Table 4.2 summarised the soil sampling activities undertaken.

Table 4.2 Soil sampling activities

Activity	Description
Soil core locations (sites)	Sampling locations were recorded with ArcGIS Field Maps GPS location software used on a mobile phone. Where the above was not possible the estimated position coordinates are retrieved from online mapping georeferencing.
Soil coring	Where pre-excavated pits or exposures were not available, hand auguring was undertaken with the use of a 75 mm Jarret auger or a shovel and crowbar where required. Soil cores were extended to a maximum of 1.2 m below ground level (BGL).
Abandonment	Where hand augured, soil cores were backfilled to the existing natural ground level using soil retrieved during soil coring.
Decontamination	Prior to commencing each soil core, bulk soil material was removed from the auger head.
Soil logging	Soil characteristics were described and profiles classified in accordance with the <i>Australian Soil and Land Survey Field Handbook</i> (NCST 2009) and the <i>Australian Soil Classification</i> (Isbell & NCST 2021) respectively. In addition to soil descriptions, the associated landscape features, including terrain, land use, areas of degradation, slopes and vegetation were recorded and photographed.
Soil sampling	Soil samples, approximately 500 g in volume, were obtained at nominal depths of 0–0.1 m, 0.2–0.3 m, 0.5–0.6 m, 0.8–0.9 m and 1.1–1.2 m, depending on sample site depth. These depths sometimes varied to accommodate horizon boundaries. Discrete soil samples were collected and placed into resealable plastic bags for dispatch to the laboratory.
Labelling	Sample bags were labelled with the survey acronym (Clarrie Hall Dam – CH), sample site number and depth. For instance, a sample collected at site CH01 at a depth of 0–10 cm BGL was labelled as follows: CH01, 0–10 cm.
Dispatch	Samples were stored out of direct sunlight and transported by road for analysis at East West EnviroAg Pty Ltd (Tamworth, NSW).

4.1.4 Laboratory analysis

A National Association of Testing Authorities (NATA) and Australasian Soil and Plant Analysis Council (ASPAC) accredited laboratory, East West Enviro Ag Pty Ltd (NATA accreditation 12360 and 15708), was used to ensure that laboratory testing was undertaken using scientifically correct methods. The analyses undertaken on sampled soils is given in Table 4.3.

Table 4.3 Soil chemical analysis

Horizons	Indicative sampled depths ¹	Analysis performed
Topsoil	0.0–0.1 m	pH; EC; Cl ⁻ (1:5); exchangeable cations (Ca, Mg, Na, K, Al) and CEC (NH ₄ Cl or Ammonium Acetate); OC and OM (Walkley and Black); Colwell P; Sulfate Sulfur; Total P, Total N, nitrate N, Ammonium N, micro nutrients (Boron (B), Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn)); ESP: Emerson Aggregate Test (EAT); PSA (Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 micrometres; μ m), Clay (<2 μ m)).
Subsoil	0.2–0.3 m 0.5–0.6 m 0.9–1.0 m	pH, EC, Cl ⁻ (1:5); exchangeable cations (Ca, Mg, Na, K, Al) and CEC (NH ₄ Cl or Ammonium Acetate); ESP, Emerson Aggregate Test (EAT), PSA (Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 μ m), Clay (<2 μ m)).

1. These depths will vary to accommodate horizon boundaries.

Detailed laboratory result tables for soil investigation sites are provided in Appendix B with the laboratory report contained in Appendix C. Soil ‘fertility’ is utilised to describe the assessment of topsoil nitrogen (total), potassium (exchangeable), phosphorous (Colwell) and organic carbon. Interpretation of the laboratory analysis results is based predominantly on guidelines provided in:

- *Soil Chemical Methods–Australasia* (Rayment & Lyons 2011)
- *Analytical methods and interpretations used by the Agricultural Chemistry Branch for soil and land surveys* (Bruce & Rayment 1982)
- *Soil testing and some soil test interpretations used by the Queensland Department of Primary Industries* (Rayment & Bruce 1984)
- *Interpreting soil test results–what do all the numbers mean?* (Hazelton & Murphy 2016).

4.2 Soil profile classes

Soil profiles were described at five locations, with single soil samples taken at a further four locations. The soil profile at each detailed site was classified using the Australian Soil Classification system (Isbell & NCST 2021). Soils with comparable profiles determined by similar morphological properties, physico-chemical properties, parent material, representative landforms and geomorphological position in the landscape were grouped into SPCs (McKenzie *et al.* 2008).

Soil profiles across the study area were grouped into three SPCs (Table 4.4), based primarily on classification under the ASC, with the site consisting predominantly of non-cracking clay Dermosols and acidic, texture contrast Kurosols with minor areas of poorly developed alluvial Rudosols, generally consistent with regional soil mapping described in Section 3.6. Investigation sites and correlation with SPCs are shown on Figure 4.1.

Table 4.4 Soil profile classes

SPC	Concept	Typical ASC	Landform	Sites
SPC01	Deep, acidic profiles with sandy clay loam topsoils over strong to moderately structured red to brown clay subsoils.	Kurosols (KU)	Lower sections of rise slopes and saddle/ridge features.	CH04, CH05, CH06
SPC02	SPC02: Buried, weakly structured, non-cracking clays with light clay topsoils over brown, acidic clay subsoils.	Dermosols (DE)	Floodplain deposits proximal to reservoir embankment and bank attached assemblages.	CH07
SPC03	SPC03: Shallow sandy clay loams with little pedologic organisation.	Tenosols (TE)	Active depositional assemblages in the floodplain.	CH08

4.2.1 SPC01: Deep, acidic profiles with sandy clay loam topsoils over strong to moderately structured red to brown clay subsoils

SPC01 soils typically present as massive to weakly structured, sandy loam to clay loam topsoils, commonly thin (<0.10 m) but occasionally thick (0.3–0.6 m) in association with A2 horizons. A1 topsoils range from black to very dark greyish brown and with A2 horizons of dark greyish brown. There are no conspicuous coarse fragments or segregations. A clear or abrupt texture contrast between topsoil and subsoils is commonly present.

Subsoils are moderate to strong, subangular blocky structured. Dominant colour class in the upper subsoils is brown trending to brownish yellow into the lower subsoils, with occasional dark reddish brown trending to red. Distinct brown, red and grey mottles are present through upper and lower subsoils in few to common abundance (2–20%). No conspicuous segregations are present through the subsoils.

Sites CH04 and CH06 are representative of SPC02, classified as an Acidic-Mottled Eutrophic Brown Dermosol and Mottled Eutrophic Brown Kurosol respectively. Typical landform of SPC02 and profile descriptions of CH04 and CH06 is detailed in Table 4.5.

Table 4.5 SPC01 typical landform and representative profile descriptions

Landform			
Slope	0–2% (level to very gently inclined)	Runoff	Slow
Morphological type	Hillocks, mid-and upper slopes	Permeability	Slowly
Landform element	Rise slope	Drainage	Poorly drained
Landform pattern	Low hills	Surface condition	Firm to hardsetting
Relief modal class	Gently undulating rises	Disturbance	Extensive to complete clearing
Surface coarse fragments	None	Rock outcrop	None
Associations	Kunghur and <i>variants</i> (kub) – deep (>100 cm), Yellow Podzolic Soils, Red Podzolic Soils on slopes. Moderately deep (100–150 cm), Gleyed Podzolic Soils and Yellow Podzolic Soils (Dy5.11, Dy5.21) on lower slopes and poorly drained areas.		



CH04 – Soil profile (surface top left, 0.3 m increments)



CH04 – Landscape

Profile description: CH04

Easting	-28.470310	Northing	153.301658
ASC soil order	Acidic-Mottled Eutrophic Brown Dermosol	ASC family criteria	BEMOV
Horizon	Depths (m)	Description	
A1 – topsoil	0.00–0.10	Very dark greyish brown (10YR 3/2); clay loam; massive to weak 2–5 mm structure; pH 6.0; clear boundary to –	
B21 – subsoil	0.10–0.50	Brown (7.5YR 4/4); light medium clay; weak to moderate 5–10 mm subangular blocky structure; 2–10% faint red mottles <5 mm in size; pH 5.5; gradual boundary to –	
B22 –subsoil	0.50–0.75	Brown (10YR 4/3); medium clay; weak to moderate 2–5 mm subangular blocky structure; 2–10% faint brown and <2% distinct orange mottles 5–15 mm in size; pH 5.5; gradual boundary to –	
B23 –subsoil	0.75–0.90	Brown (10YR 4/3); medium clay; moderate 2–5 mm subangular blocky structure; 10–20% distinct grey and <2% distinct red mottles 5–15 mm in size; pH 5.5.	



CH06 – Soil profile (surface top left, 0.3 m increments)



CH06 – Landscape

Profile description: CH06

Easting	-28.476081	Easting	153.298491
ASC soil order	Mottled Eutrophic Brown Kurosol	ASC family criteria	CELOW

Horizon	Depths (m)	Description
A1 – topsoil	0.00–0.30	Black (10YR2/1); sandy loam; massive structure; pH 6.0; gradual boundary to –
A2 – topsoil	0.30–0.50	Dark greyish brown (10YR 4/2); sandy loam; massive structure; pH 6.0; clear boundary to –
B2 – subsoil	0.50–1.00	Strong brown (7.5 YR 5/8); light medium clay; moderate subangular blocky of 5–10 mm; 2–10% distinct red and <2% distinct grey mottles of 2–5 mm; pH 5.5; gradual boundary to –
B3 – subsoil	1.00–1.20	Brownish yellow (10YR 6/6); fine sandy light medium clay; moderate subangular blocky of 2–10 mm; 20–50% distinct red and 10–20% distinct dark mottles of 5–15 mm; pH 5.5.

i SPC01: Soil chemistry

SCP01 topsoils are highly fertile with high levels of total nitrogen, exchangeable potassium and organic carbon with variable levels of phosphorus, ranging from low to high. Soil pH is consistently acidic, being moderately to very strongly acid in the topsoils and very strongly to extremely acid in the subsoils. The major part of the profile is strongly acid (pH 4.0–5.0) such that phosphorus may be precipitating with aluminium through the profile, resulting in low exchangeable phosphorus levels (phosphorus fixation).

Aluminium levels are elevated through the depth of the profile, increasing with depth, ranging from between 2–48% exchangeable Al in the topsoils to 39–78% in the subsoils. These levels are extreme and sufficient to impact on even very tolerant plant species.

Topsoils are otherwise non-sodic (exchangeable sodium percentage (ESP) <5%) with very low salinity (<0.09 | 20–40% clay). Subsoils are consistently non-sodic with very low salinity through to depth.

Effective cation exchange capacity (CEC) is predominantly high (>15 cmol(+)/kg) throughout the depth of the profile but is often moderate (5–15 cmol(+)/kg) in the topsoils, occasionally low (<5 cmol(+)/kg) where A2 horizons are present. CEC balance is typically poor with calcium (Ca) deficiency observed throughout all profiles except some deep topsoils, though calcium/magnesium (Mg) ratio (Ca:Mg) is commonly balanced to Mg deficient. This is due to the high levels of aluminium resulting in generally deficient levels of other cations. Acceptable magnesium and sodium levels are otherwise observed, whilst potassium decreases with depth, being typically sufficient in topsoils and deficient in subsoils. Base saturation is eutrophic (>15 cmol(+)/kg clay) through to depth with weak to moderate leaching common, becoming often mesotrophic (5–15 cmol(+)/kg clay) in deeper subsoils which can be strongly leached.

The topsoil Emerson Class is 7 (swelling but no slaking or dispersion of submerged aggregates). The major part of the upper subsoils are Emerson Class 5 (slaking but no dispersion of submerged aggregates, remoulded at equivalent to field capacity, carbonate and gypsum absent, dispersion after further agitation) and Emerson Class 6 (slaking but no dispersion of submerged aggregates, remoulded at equivalent to field capacity, carbonate and gypsum absent, no dispersion after further agitation) through the lower subsoils. A summary of SPC01 soil chemistry is shown in Table 4.6.

Table 4.6 SPC01 soil chemistry summary

Depths (m)	pH	Texture	Cation balance and Ca:Mg	Salinity	Sodicity
0.00–0.10	Strongly acid	Sandy clay loam	Poor – Balanced	Very low	Non-sodic, low dispersion risk
0.20–0.30	Very strongly acid	Light to medium clay	Poor – Mg low	Very low	Non-sodic, low dispersion risk
0.50–0.60	Very strongly acid	Medium clay	Poor – Mg low	Very low	Non-sodic, low dispersion risk
0.80–1.20	Extremely acid	Medium clay	Poor – Mg deficient	Very low	Non-sodic, no dispersion

ii SPC01: Key features

The key features of SPC01 include:

- loam topsoils over red to brown clay subsoils
- common clear or abrupt texture contrast between topsoils and subsoils
- pH is strongly acid and exchangeable aluminium levels are elevated through the depth of the profile
- the major part of the lower subsoil is mottled.

4.2.2 SPC02: Buried, weakly structured, non-cracking clays with light clay topsoils over brown, acidic clay subsoils

Thick (0.02–0.40 m BGL), very dark brown, light clay topsoils are overlain by a thin (0.02 m BGL), brown light clay lithological discontinuity horizon. Topsoils are massive to weakly structured with no conspicuous coarse fragments or segregations.

Upper subsoils (0.40–0.80 m BGL) are weakly structured to massive, brown light clays with few (2–10%), distinct, fine (<5 mm) mottles of both red and grey. Lower subsoils (> 0.80 m BGL) presents as red, medium clays with moderate subangular blocky structure and common (10–20%), faint, medium (5–15 mm) brown mottles.

CH07 is representative of SCP02 soils and is classified under the ASC as a Eutrophic Mottled Brown Dermosol. A profile description and typical landform summary of SPC02 is shown in Table 4.7.

Table 4.7 SPC02 typical landform and representative profile description

Landform			
Slope	0–1% (level)	Runoff	Very slow
Morphological type	Flat	Permeability	Moderate
Landform element	Floodplain	Drainage	Poorly drained
Landform pattern	Plain	Surface condition	Firm
Relief modal class	Level plain	Disturbance	Complete clearing
Surface coarse fragments	None	Rock outcrop	None
Associations	Kunghur <i>var.</i> (kub) – Yellow Podzolic Soils on ridges and upper slopes. Yellow Podzolic Soils, Red Podzolic Soils and Red Earths on slopes. Yellow Podzolic Soils and Gleyed Podzolic Soils on lower slopes and poorly drained areas.		



CH07 – Soil profile (surface top left, 0.3 m increments)

CH07 – Landscape

Profile description: CH07

Easting	-28.457031	Easting	153.301658
ASC soil order	Eutrophic Mottled Brown Dermosol	ASC family criteria	BEMOW
Horizon	Depths (m)	Description	
A1 – topsoil (depositional)	0.00–0.02	Brown (10 YR 4/3); light clay; weak apedal to massive structure; pH 6.5; abrupt boundary to –	
2A1b – topsoil	0.02–0.40	Very dark brown (10YR 2/2); light clay; weak apedal to massive structure; pH 6.0; gradual boundary to –	
2B21b – subsoil	0.40–0.80	Brown (7.5YR 4/4); light clay; weak to moderate structure of 2–5 mm; 2–10% distinct red and grey mottles of <5 mm; pH 6.0; distinct boundary to –	
2B22b – subsoil	0.80–1.20	Red (2.5YR 4/6); medium clay; moderate subangular blocky structure of 5–10 mm; 10–20% faint brown mottles of 5–15 mm; pH 6.0.	

i SPC02: Soil chemistry

SPC02 soils have moderate to high fertility presenting in moderate phosphorus and exchangeable potassium with high total nitrogen and organic carbon. Soil pH is very strongly to strongly acid throughout.

ECEC is moderate (5–15 cmol(+)/kg) throughout with fair to poor ECEC balance that decreases with depth due to elevated magnesium and subsequent calcium deficiency, with Ca:Mg consistently decreasing from balanced to Ca low with depth. Sufficient potassium is present throughout the profile with elevated exchangeable sodium levels being slightly sodic (3–6% ESP). Salinity is consistently very low with slightly sodic subsoils. Base saturation is eutrophic to mesotrophic at depth, and profiles are very weakly leached throughout.

Topsoil Emerson Class is 7 through topsoils with the subsoils Class 6, suggesting low dispersion risk throughout the profile. A summary of SPC02 soil chemistry is shown in Table 4.8.

Table 4.8 SPC02 soil chemistry summary

Depths (m)	pH	Texture	Cation balance and Ca:Mg	Salinity	Sodicity
0.02–0.10	Strongly acid	Light clay	Poor – Ca low	Very low	Non-sodic, low dispersion risk
0.20–0.30	Strongly acid	Light clay	Poor – Balanced	Very low	Slightly sodic, low dispersion risk
0.50–0.60	Moderately acid	Light clay	Poor – Balanced	Very low	Non-sodic, low dispersion risk
0.80–0.90	Strongly acid	Medium clay	Poor – Ca low	Very low	Slightly sodic, low dispersion risk
1.10–1.20	Moderately acid	Medium clay	Poor – Ca low	Very low	Slightly sodic, low dispersion risk

ii SPC02: Key features

The key features of SPC02 include:

- buried soils from flood deposits
- subsoil horizons lacking clear or abrupt texture contrast
- the dominant class colour of the major part of the upper subsoil is brown
- the major part of the lower subsoil is mottled.

4.2.3 SPC03: Shallow sandy clay loams with little pedologic organisation

Soils categorised under SPC03 are alluvial depositional soils with weak pedological organisation or structure. Surface conditions are firm and thick (0–0.60 m BGL) topsoils generally present as sandy loams. The dominant colour class is dark brown with massive structure. There are no conspicuous coarse fragments or segregations.

CH08 is representative profile of SCP03, classified as a Stratic Rudosol. The landform and profile of CH08 is contained in Table 4.9.

Table 4.9 SPC03 typical landform and representative profile description

Landform			
Slope	0–1% (level)	Runoff	Very slow
Morphological type	Flat	Permeability	High
Landform element	Terrace flat	Drainage	Imperfectly drained
Landform pattern	Meander plain	Surface condition	Firm
Relief modal class	Level plain	Disturbance	Complete clearing
Surface coarse fragments	None	Rock outcrop	None
Associations	Terania (te) – dark Alluvial Clays, brown Alluvial Clays near sandstone, Weisenboden and Black Earths on recent floodplains. Earthy Sands in channels.		



CH08 – Soil profile (surface top left, 0.3 m increments)

CH08 – Landscape

Profile description: CH08

Easting	-28.492697	Easting	153.301171
ASC soil order	Stratic Rudosol	ASC family criteria	ELV
Horizon	Depths (m)	Description	
A11 – topsoil	0.00–0.25	Dark brown (7.5YR 3/2); sandy loam; massive structure; pH 6.5; gradual boundary to –	
A12 – topsoil	0.25–0.60	Dark brown (7.5YR 3/3); sandy clay loam; massive structure; pH 6.5. Refusal.	

i [SPC03: Soil chemistry](#)

SPC03 are very highly fertile with high total nitrogen, high organic carbon and very high exchangeable phosphorus and potassium. The soils are non-sodic with very low salinity throughout.

ECEC is consistently high with fair cation balance with generally sufficient calcium and elevated magnesium, as evidenced by calcium low Ca:Mg ratios. Potassium is within acceptable levels through the depth of the profile.

There is low dispersion risk through the depth of the profile as indicated by Emmerson Class 5. A summary of SPC03 soil chemistry is shown in Table 4.10.

Table 4.10 [SPC03 soil chemistry summary](#)

Depths (m)	pH	Texture	Cation balance and Ca:Mg	Salinity	Sodicity
0.00–0.10	Moderately acid	Sandy loam	Poor – Ca low	Very low	Non-sodic, low dispersion risk.
0.50–0.60	Slightly acid	Sandy clay loam	Poor – Ca low	Very low	Non-sodic, low dispersion risk.

ii [SPC03: Key features](#)

The key features of SPC03 include:

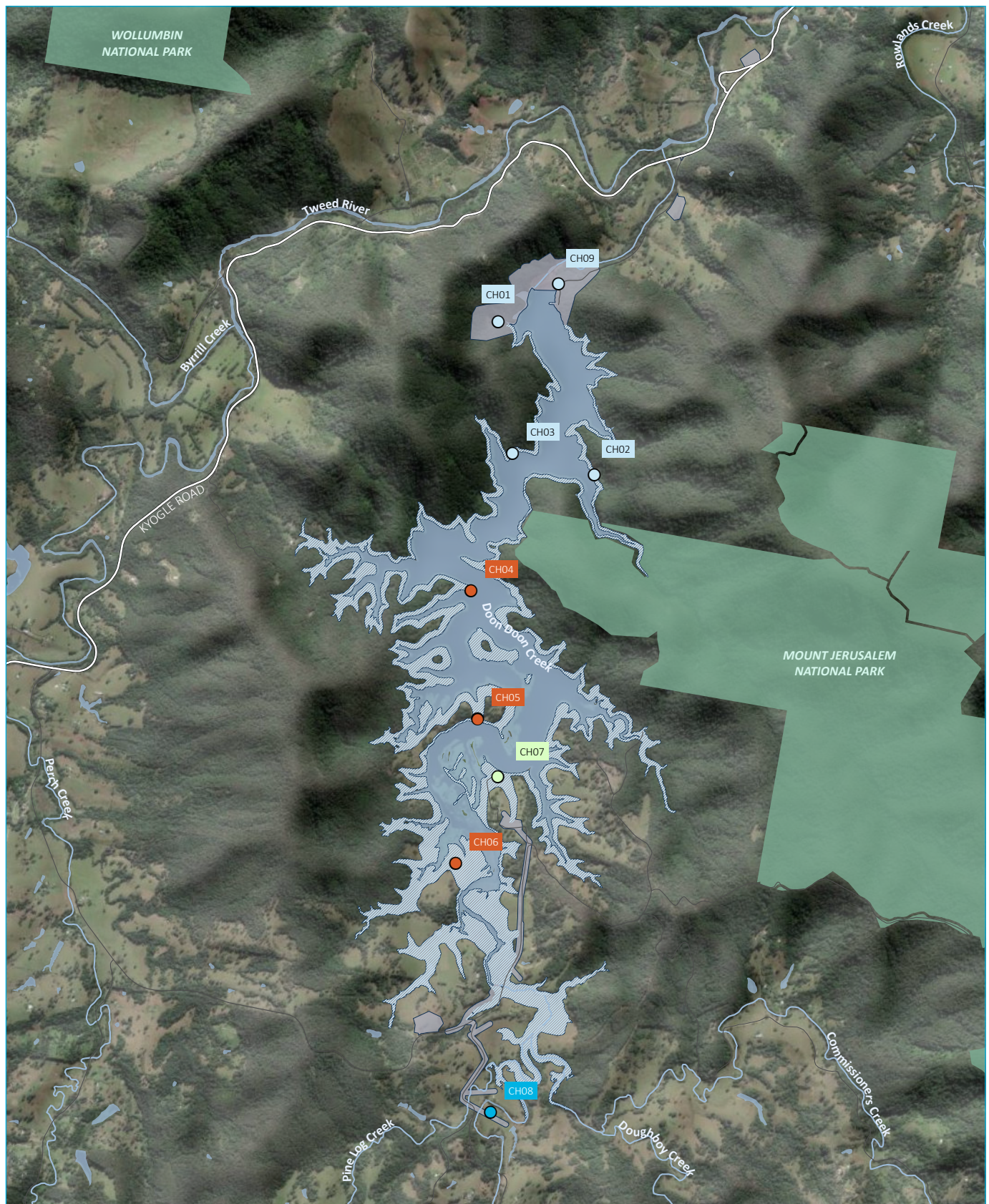
- weak pedologic organisation
- massive structure
- the dominant colour class of the major part of the profile is brown.

4.3 Proposal soil hazards

The study area soils are relatively stable from an assessment of soil chemistry, with no sodicity and typically balanced Ca:Mg ratios, indicating the potential for soil dispersion is low. This is inconsistent with the potential for erosion and dispersion identified in the soil landscape soil materials, which should be considered. Erosion risk is increased in the sandier, less developed profiles (SPC03) as their reduced cohesion means they are likely to be susceptible to erosion.

There are no apparent soil salinity limitations in any of the soil samples submitted for laboratory analysis.

The primary chemical limitation identified, consistent with some of the soil landscape soil materials, is the acidic soil pH and potential for aluminium toxicity which could be a constraint to revegetation and should be considered in selection of species utilised in rehabilitation.



Source: EMM (2024); KBS (2024); DCSSS (2023); ESRI (2024)

KEY

 Study area	Existing environment
 Full supply level - proposed	 Rail line
Soil investigation site	 Major road
 Discrete sampling site	 Minor road
 SPC01	 Named watercourse
 SPC02	 Waterbody
 SPC03	 NPWS reserve
	 State forest

Soil investigation sites and SPC's

Clarrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 4.1

5 Erosion hazard analysis

To understand the potential loss of soil due to the construction and operation of the Proposal, an assessment of erosion hazard was undertaken and is described in the following sections.

5.1 Methodology

The methodology for assessing erosion hazard in NSW is detailed in Section 4.4.1 of Landcom (2004). It is a two-part process that firstly considers the overall Proposal erosion hazard in considering slope and rainfall erosivity (R-factor). This is followed by a more detailed assessment where land soil loss classes (SLC) are determined using annual soil loss if a high initial erosion hazard is triggered, calculated using the Revised Universal Soil Loss Equation (RUSLE) with site specific slopes considering a known or nominal slope length of 80 m. The SLC dictates the recommended erosion management and mitigation strategies as detailed in Landcom (2004).

5.2 Revised Universal Soil Loss Equation (RUSLE)

The RUSLE is designed to predict the long term, average, annual soil loss (in tonnes per hectare per year (t/ha/yr)) from sheet and rill flow at nominated sites under specified management conditions. The equation is represented by:

$$A = R K L S P C (1)$$

where:

A = computed soil loss (tonnes per hectare per year (t/ha/yr))

R = rainfall erosivity factor ('R-factor')

K = soil erodibility factor ('K-factor')

LS = slope length/gradient factor ('LS-factor')

P = erosion control practice factor ('P-factor')

C = ground cover and management factor ('C-factor').

The main limitations of the RUSLE are that:

- it only predicts sediment entrained in the erosion process and does not predict sediment yields into particular sediment basins
- it predicts average annual soil loss and not that for a particular storm event
- it is effective for erosion through sheet and rill flow only on short slopes (<300 m) and not for concentrated flow or long slopes
- it does not adequately take into account soil dispersibility in assessment of the K-factor.

5.2.1 Rainfall erosivity (R-factor)

Rainfall erosivity is the kinetic energy of raindrop impact and the rate of associated runoff, a measure of the ability of rainfall to cause erosion. The R-factor is a multi-annual average index that measures rainfall kinetic energy and intensity to describe the effect of rainfall on sheet and rill erosion and is used in the RUSLE to predict annual average rill and inter-rill (sheet erosion). Among the factors used within RUSLE, rainfall erosivity is of high importance as precipitation is the driving force of erosion and has a direct impact on the detachment of soil particles, the breakdown of aggregates and the transport of eroded particles via runoff. A precise assessment of rainfall erosivity requires recordings of precipitation at short time intervals (1–60 minutes) for a period of at least several years. The rainfall erosivity is calculated by multiplying the kinetic energy by the maximum rainfall intensity during a period of 30 minutes for each rainstorm. The R-factor accumulates the rainfall erosivity of individual rainstorm events and averages this value over multiple years.

The R-factor is calculated using the formula:

$$R = 164.74 (1.1177)^S S^{0.6444}$$

Where, S is the 0.5EY, 6-hour event in mm/h (Rosewell & Turner 1992). For the Proposal S equals 15.4 mm/h (BoM 2020). The calculated R-factor for the Proposal is 5,324 Mjmmha⁻¹h⁻¹.

Rainfall erosion hazard for the study area ranges from moderate to extreme and is typically high to extreme through the summer and moderate through the winter. Table 5.1 provides an indication of the erosion hazard associated with monthly annual rainfall averages based on Tables 4.4.1 and 4.4.2 of IECA (2008).

Table 5.1 Monthly rainfall erosion hazard

Rainfall (monthly mm)	Erosion potential	Relevant months ¹
0–30	Very low	NA
31–45	Low	NA
46–100	Moderate	Jul, Aug, Sep
101–225	High	Oct, Nov, Dec, Apr, May, Jun
>225	Extreme	Jan, Feb, Mar

1. As per BoM 2021a mean monthly rainfall.

5.2.2 Soil erodibility (K-factor)

The erosion potential of a soil is determined by its physical and chemical properties and is expressed as its K-factor (t.ha.hr)/(ha.MJ.mm). K-factor is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. For a particular soil, the soil erodibility factor is the rate of erosion per unit erosion index from a standard plot. The K-factor reflects the fact that different soils erode at different rates when the other factors that affect erosion (e.g. infiltration rate, permeability, total water capacity, dispersion, rain splash, and abrasion) are the same. Texture is the principal factor affecting the K-factor, but electrochemical stability, structure, organic matter, and permeability also contribute.

An assessment of the erodibility of the soil itself is important as the presence or absence of a highly erodible dispersive soil will significantly influence drainage, erosion and sediment control requirements.

When a sodic soil (ESP >6%), or a magnesian soil (calcium:magnesium ratio <0.1) is exposed to non-saline water, water molecules are drawn in-between the clay platelets causing the clay to swell to such an extent that individual clay platelets are separated from the aggregate. This process is known as dispersion. Dispersive soils have an extreme rill, gully and tunnel erosion risk and can erode irrespective of surface treatments (e.g. rock lining) applied to the soil surface.

Table 5.2 provides a soil erodibility ranking for K-factor from Table F5 of IECA (2008).

Table 5.2 Soil erosion K-factor erosion ranking

K-factor (t.ha.hr / ha ⁻¹ .MJ ⁻¹ .mm ⁻¹)	Erosion potential
<0.02	Low
>0.02 but ≤0.04	Moderate
>0.04 but ≤0.06	High
>0.06	Extreme

The modelled K-factors for the study area, determined from the eSPADE database (DPIE 2020a), range from 0.04 to 0.07 t ha h ha⁻¹MJ⁻¹mm⁻¹, which indicate that the study area soils have a moderate to high erosion potential. The modelled K-factors apply to a maximum depth of 100 mm (Yang *et al.* 2017). Yang *et al.* (2017) used digital soil maps and NSW Soil and Land Information System to map and validate soil erodibility for soil depths up to 100 cm. They assessed eight empirical methods or existing maps on erodibility estimation and produced a harmonised high-resolution soil erodibility map for the entire state of NSW with improvements based on studies in NSW. The modelled erodibility values were compared with those from field measurements at soil plots for NSW soils and revealed good agreement.

K-factors have been adopted for determined SPCs based on calculations as per Landcom (2004) and McKenzie, Coughlan and Cresswell (2002) to determine the erosion hazard of study area soils (Table 5.3) which are classified as having a moderate erosion potential.

Table 5.3 Soil unit K-factor

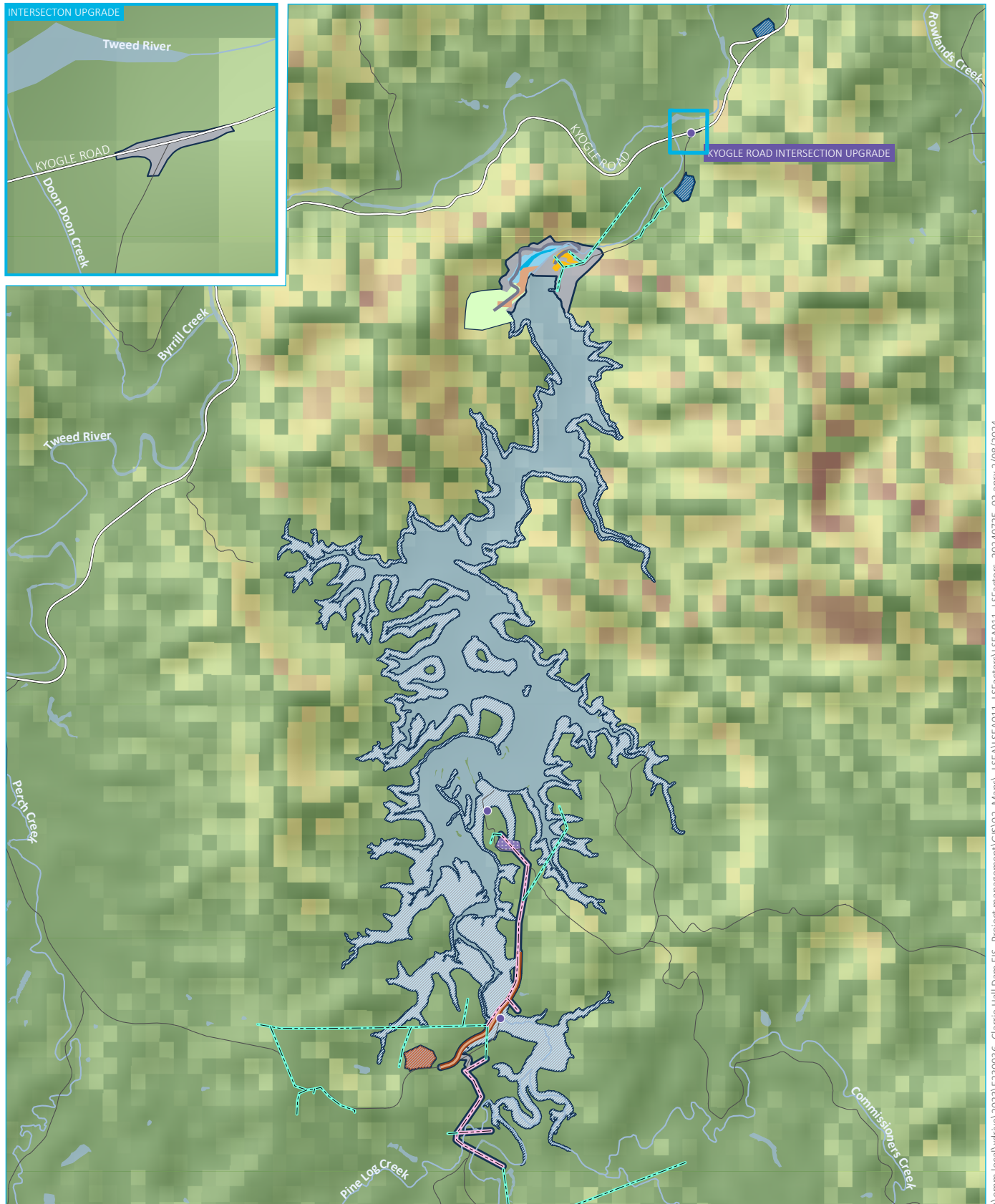
SPC	ASC	Sodicity	Salinity	Topsoil soil texture	Subsoil soil texture	K-factor (t.ha.hr/ha ⁻¹ .MJ ⁻¹ .mm ⁻¹)	Erosion potential
1	Kurosol and Dermosols	Non-sodic	Very low	Sandy loam to clay loam	Light medium clay	0.027	Moderate
2	Dermosol	Non- to slightly sodic	Very low	Light clay	Light to medium clay	0.028	Moderate
3	Rudosols	Non-sodic	Very low	Sandy clay loam	NA	0.035	Moderate

Virgin excavated natural material (VENM) and excavated natural material (ENM) sourced from various external construction projects will potentially be imported to provide material for rehabilitation and landform construction. The VENM/ENM may have chemical and physical properties that render it more erodible than site soils, particularly if the VENM/ENM is sodic or dispersive. Testing or characterisation of imported VENM/ENM should be undertaken so that its erosion potential can be determined. At the time of the assessment information on the external source of material required in construction was not available.

5.2.3 Slope and gradient (LS-factor)

The LS-factor describes the combined effect of slope length and slope gradient on soil loss. It is the ratio of soil loss per unit area at any particular site to the corresponding loss from a specific experimental plot of known length and gradient and are derived from Table E3 of IECA (2008) or Table A1 of Landcom (2004). Slope length should be kept as low as practicable (less than 80 m at least) across disturbed areas where possible during construction.

LS-factors for the study area, as mapped in eSPADE and developed by Yang (2023), are shown in Figure 5.1.



Source: EMM (2024); KBS (2024); DCSSS (2023); DPE (2018)

KEY

- Infrastructure upgrade location
- Study area
- ▨ Full supply level- proposed
- ▨ Proposed layout
- ▨ Haul Road- option 1
- ▨ Haul Road- option 2
- ▨ Office location
- ▨ Potential McCabe's Bridge stockpile and construction office complex
- ▨ Quarry impact area

- ▨ Proposed spillway
- ▨ Spillway impact area
- ▨ Concrete batching plant or workforce accommodation
- ▨ Potential McCabe's Bridge stockpile and construction office
- ▨ McCabe's Bridge proposed realignment
- ▨ Transmission line
- ▨ Existing
- ▨ New

- ▨ Existing environment
- ▨ Rail line
- ▨ Major road
- ▨ Minor road
- ▨ Named watercourse
- ▨ Waterbody
- Slope length and steepness (LS) factor
- 52
- 30
- 20
- 10
- 0.05

LS-factors across the study area

Clarrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 5.1



\\emm.local\drive\2023\E230036-Clarrie Hall Dam EIS-Project management\GIS\02_Maps\LSFA\SEA011_LSFactors_20240725_02.aprx 2/08/2024

5.2.4 Erosion control factor (P-factor)

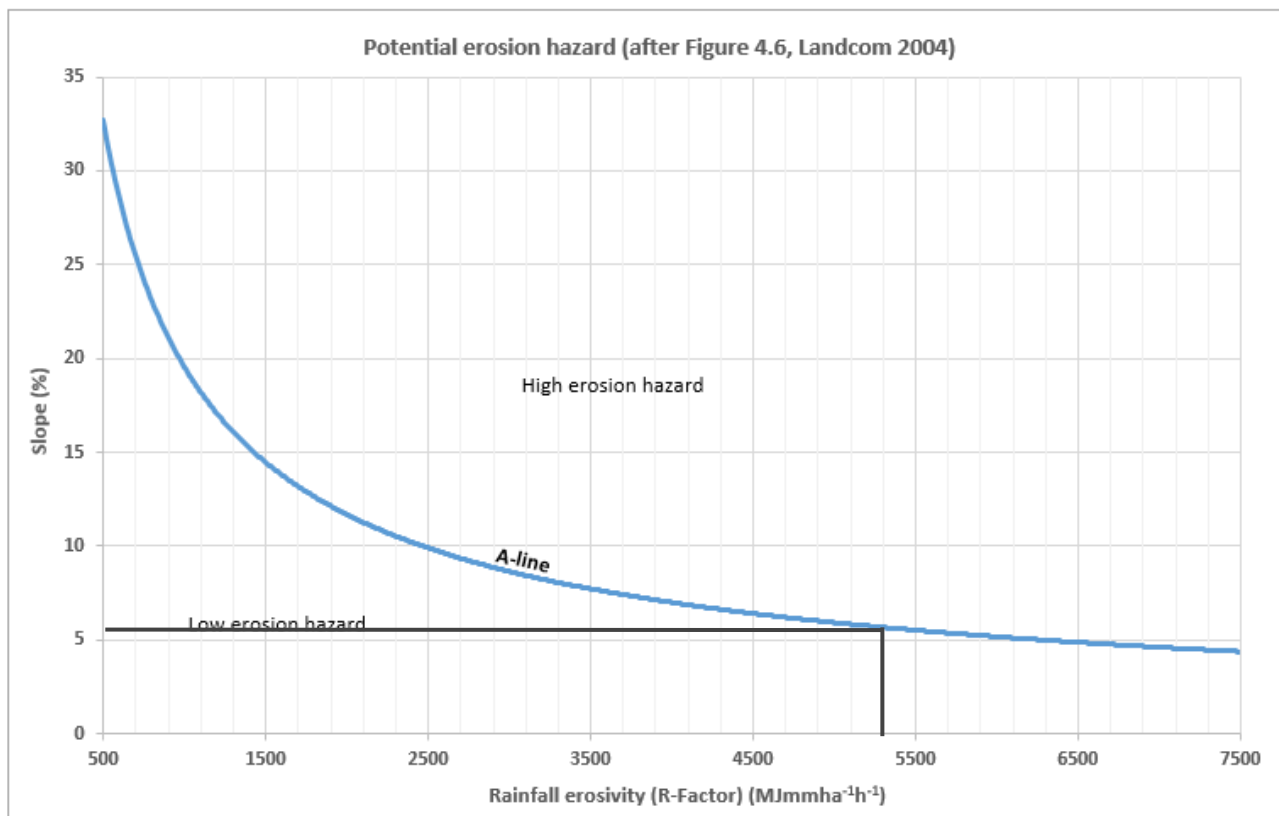
The P-factor is the ratio of soil loss with a nominated surface condition ploughed up and down the slope. It is reduced by practices that reduce both the velocity of runoff and the tendency of runoff to flow directly downhill. At construction sites, it reflects the roughening or smoothing of the soil surface by machinery, with a compacted and smooth surface condition being assigned a P-factor of 1.3 (IECA 2008).

5.2.5 Ground cover (C-factor)

The C-factor is the ratio of soil loss from land under specified crop or mulch conditions to the corresponding loss from continuously tilled, bare soil. In construction conditions, where surfaces are stripped of all soil cover and are effectively bare, C-factor is 1.

5.3 Proposal erosion hazard analysis

The first step in the hazard assessment uses a nomograph from Figure 4.6 of Landcom (2004) (reproduced as Figure 5.2) that considers slope of the land and rainfall erosivity to provide an indication of low or high erosion hazard.



Source: Landcom (2004)

Figure 5.2 Assessment of potential erosion hazard against rainfall erosivity

Based on the application of the R-factor relevant to the Proposal (5,324 MJmmha⁻¹h⁻¹), on the Landcom (2004) nomograph, the potential erosion hazard is expected to be high for areas of the Proposal where slopes exceed approximately 5%. Proposal slopes are considered further below.

5.3.1 Proposal slopes

Slope ranges and associated erosion hazard for the key Proposal elements are provided in Table 5.4.

Table 5.4 is based on the proposed layout and inundation area.

Table 5.4 Slope ranges and erosion hazard for key Proposal elements

Proposal element	Slope (min %)	Slope (max %)	Slope (mean %)	Standard deviation	Potential erosion hazard
Study area overall	<0.1	297.9	22.8	18.1	Low to high
Construction workforce accommodation areas	0.8	82.5	20.6	10.3	Low to high
Raised Dam Embankment Wall, Spillway and Clarrie Hall Dam Road Realignment	0.1	220.7	59.7	32.7	Low to high
Quarry area	0.2	297.9	51.3	39.3	Low to high
Quarry haul road options	<0.1	168.3	31.6	21.9	Low to high
McCabes Bridge construction site and stockpile location	0.3	18.4	9.8	2.9	Low to high
McCabes Bridge and Realignment	0.1	88.8	23.7	17.1	Low to high
Office buildings/Recreation areas	0.3	225.6	41.9	31.4	Low to high
Intersection upgrade	0.1	15.8	2.7	2.1	Low to high
Concrete batching site	0.2	91.3	30.8	16.7	Low to high
Powerline easement	0.1	175.1	18.4	15.8	Low to high
Increase in FSL area	<0.1	157.0	20.6	15.3	Low to high
Increased PMF area	<0.1	150.0	24.5	15.3	Low to high

The Proposal generally has a high erosion hazard based on mean slope, with the exception of the intersection upgrade as per Figure 5.2 and Table 5.4. As such, further assessment of erosion hazard is necessary in accordance with Section 4.4.2 of Landcom (2004) to determine soil loss classes (Table 5.5). Additionally, construction activities, such as cut and fill, will result in areas of steep slopes that will present a high erosion hazard. As per Section 4.4.2 of Landcom (2004), areas of high erosion hazard require additional management strategies and consideration.

5.3.2 Soil loss class (SLC)

SLCs are determined calculating the annual average soil loss using the RUSLE with a nominal 80 m slope length, soil surface cover factor (C-factor) of 1 (areas with 100% bare soil) and a soil conservation factor (P-factor) of 1.3 (representative of a compacted and smooth soil surface).

Table 5.5 **Soil loss classes**

Soil Loss Class	Calculated soil loss (t/ha/yr)	Erosion hazard
1	0–150	Very low
2	151–225	Low
3	226–350	Low-moderate
4	351–500	Moderate
5	501–750	High
6	751–1,500	Very high
7	>1,500	Extremely high

Adapted from Table 4.2 Landcom (2004)

Calculated indicative soil loss (in t/ha/yr) for slopes ranges from 1 to 40% for the Proposal are provided in Table 5.6.

Table 5.6 **Annual average soil loss (t/ha/yr) during construction**

Slope	1%	5%	10%	15%	20%	25%	30%	40%	100%
R-factor (calculated)	5324	5324	5324	5324	5324	5324	5324	5324	5324
LS (Table A1 Landcom 2004 and USDA 1997)	0.19	1.19	2.81	4.61	7.32	9.51	11.6	15.67	25.22
P (Table A2 Landcom 2004)	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
C (Figure A5 Landcom 2004)	1	1	1	1	1	1	1	1	1
SPC 1									
K-factor (Landcom 2004)	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
Soil loss (t/ha/y)	35.5	222.4	525.1	861.5	1367.9	1777.2	2167.8	2928.3	4713.0
SLC	1	2	5	6	6	7	7	7	7
SPC 2									
K-factor (Landcom 2004)	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
Soil loss (t/ha/y)	36.8	230.6	544.6	893.4	1418.6	1843.0	2248.0	3036.8	4887.6
SLC	1	3	5	6	6	7	7	7	7

Slope	1%	5%	10%	15%	20%	25%	30%	40%	100%
SPC 3									
K-factor (Landcom 2004)	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Soil loss (t/ha/y)	46.0	288.3	680.7	1116.8	1773.2	2303.8	2810.1	3796.0	6109.5
SLC	1	3	5	6	7	7	7	7	7

Applying the calculated annual average soil loss to Table 5.5 results in SLCs ranging from 1 (very low) to 7 (extremely high). Assessing changes in the SLCs with associated change in slope gives an indication of potential erosion hazard across different SPCs, which is shown in Table 5.7. Generalising across the SPCs, high erosion hazard was predicted for slopes at and exceeding 8%. Slope length has been assumed as a constant 80 m length. Where this is can be reduced, LS factors also reduce which can also result in lower predicted soil loss rates.

Table 5.7 **Proposal SLC estimated slope and area**

SPC	SLC	Erosion hazard	Estimated slope range
SPC01	1–3	Very low to low-moderate	0–7%
	4	Moderate	>7–9.5%
	5 and 6	High and very high	>9.5%–22%
	7	Extreme	>22%
SPC02	1–3	Very low to low-moderate	0–7%
	4	Moderate	>7–9.5%
	5 and 6	High and very high	>9.5%–21%
	7	Extreme	>21%
SPC03	1–3	Very low to low-moderate	0–6%
	4	Moderate	>6–8%
	5 and 6	High and very high	>8–17.5%
	7	Extreme	>17.5%

i **Construction timing considerations for erosion and sediment control**

Lands with SLCs ≥ 4 trigger increased erosion and sediment control management requirements as stipulated in Section 4.4.2 of Landcom (2004). Additionally, disturbance of highly sensitive land should be scheduled for periods when rainfall erosivity is low. Landcom (2004) defines highly sensitive land as:

- always on SLC 7 lands
- at certain times of the year:
 - on SLC 5 or 6 lands in all rainfall zones
 - on SLC 4 lands in rainfall zones 5 and 11.

The Proposal is located in rainfall Zone 1 (Figure 5.3). Low and high rainfall erosivity periods for Zone 1 are provided in Table 5.8 below and indicate times of year where land disturbance activities should be undertaken only with the application of special measures ('H') and where special measures are not required ('L').

Table 5.8 Zone 1 high and low rainfall erosivity periods

SLC	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1-4	L	L	L	L	L	L	L	L	L	L	L	L
5	L	L	H	H	L	L	L	L	L	L	L	L
6	H	H	H	H	H	L	L	L	L	L	L	H
7	H	H	H	H	H	H	H	H	H	H	H	H

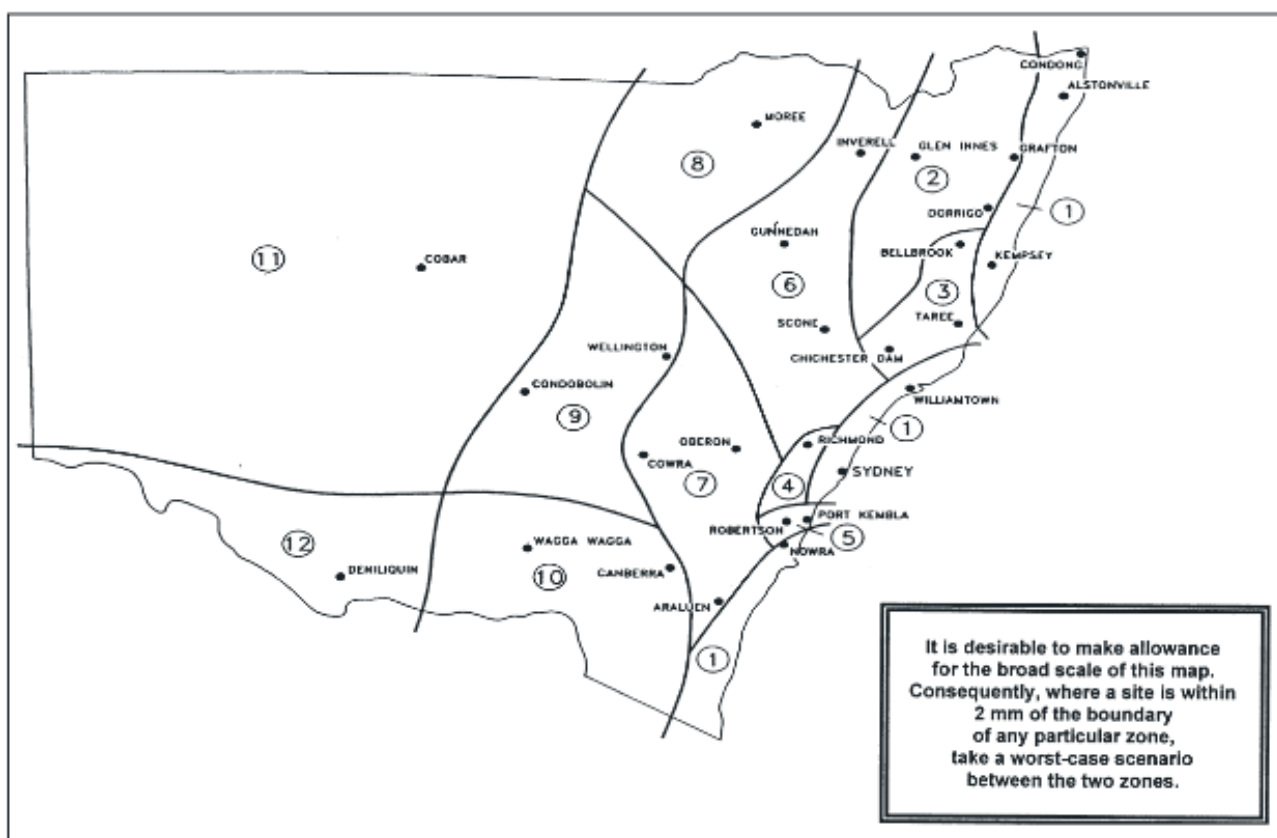
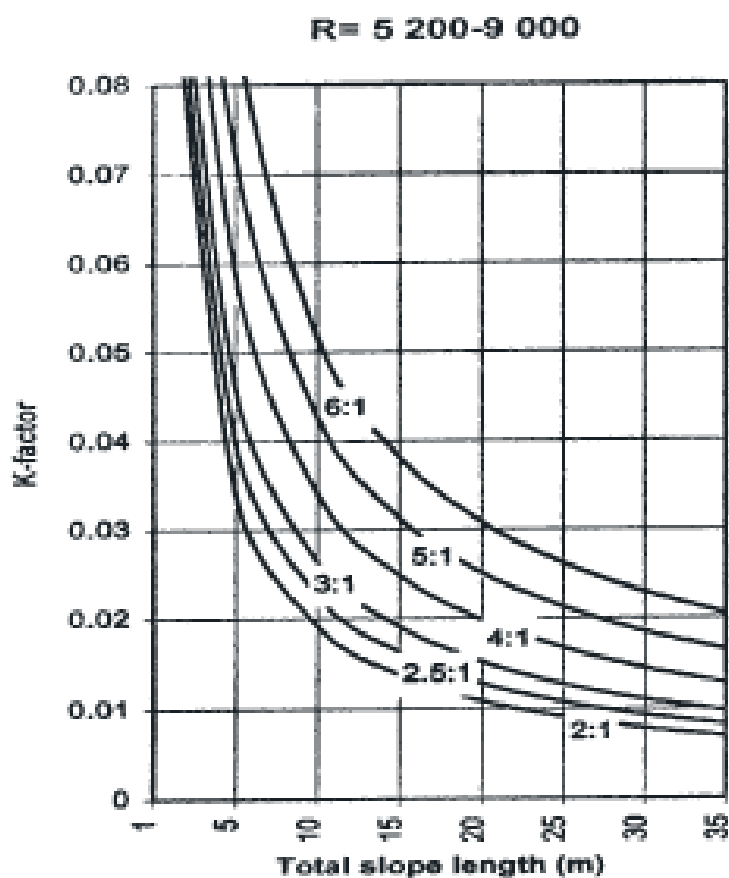


Figure 5.3 Rainfall zones (Landcom 2004)

If scheduling of activities on highly sensitive land to occur during periods when rainfall erosivity is low (Table 5.1) is not possible or impractical, ideally ensure that any disturbed lands have C-factors lower than 0.1 when the 3 day rainfall forecast predicts that rain is likely.

ii Design slope lengths

Additionally, Figure 4.7 in Landcom (2004) (reproduced as Figure 5.4) nominates maximum slope design lengths based on gradient, K-factor (0.027 to 0.035) and R-factor. Table 5.9 details application of Figure 5.4 to site constraints. Based on these results, slope lengths should be limited to 5 m for 1V:2H (50%) slopes, and 18 m for 6H:1V (16.7%) slopes. No recommendations are provided for slopes at or greater than 1V:1H (100%) which are likely to occur in the study area. Flow length on these slopes should be kept to a minimum to avoid erosion.



Source: Figure 4.7, Landcom (2004)

Figure 5.4 Maximum batter gradients for R-factors 5,200-9,000

Table 5.9 Maximum recommended slope lengths

Slope gradient (Horizontal:Vertical)	SPC01	SPC02	SPC03
2:1	6 m	6 m	5 m
2.5:1	8 m	8 m	6 m
3:1	10 m	9 m	7 m
4:1	15 m	14 m	10 m
5:1	20 m	19 m	13 m
6:1	26 m	25 m	18 m

5.4 Erosion hazard summary

An assessment of erosion hazard has been completed as per Landcom (2004) which considers the overall erosion hazard based on slope and rainfall erosivity (R-factor) and subsequent determination of SLC.

The erosion potential of soils of the study area, expressed as K-factor, is moderate. Assessment of rainfall erosivity indicates erosion hazard will be high for areas of the Proposal where slopes exceed 5%, which aligns with the assessment of SLCs, indicating a moderate erosion hazard (SLC 4) at 6–7% and high erosion hazard (SLC 5) at slopes between 8–9.5% (Table 5.7). Beyond approximately 17% slopes and lengths of 18 m, erosion hazard during construction disturbance activities should be considered extreme and appropriate strategies and mitigations be adopted.

The average gradients within the quarry, dam office buildings and recreation area footprint and the raised dam wall and spillway embankments were identified as the highest in the Proposal area and therefore are likely to be the areas with the greatest susceptibility to erosion and sediment loss.

6 Geomorphology assessment

6.1 Methodology

To support an understanding of the potential for change due to the Proposal on downstream geomorphology, a desktop review, informed as well by site inspections by EMM and others, was undertaken. Outcomes from modelling completed as part of the SWA was also considered in this LSEA.

The key mechanisms for geomorphic change as a result of the Proposal are:

- changes in sediment mobilisation downstream of the dam
- increased scour due to changes in the frequency, duration and volume of the raised dam spillway releases.

To understand the potential for the above impact mechanism to occur or be significant, the geomorphology assessment comprised of a condition analysis and review of hydraulic modelling outcomes described within the SWA.

6.2 Condition analysis

6.2.1 Overview

On review of the available 5 m DEM channel, features can be identified that are otherwise hidden by vegetation. Downstream of the existing dam spillway, evidence exists of a lateral shift in the channels of Doon Doon Creek and the Tweed River in the form of palaeochannels and terraced benches. This has occurred in a region of partial lateral confinement in alluvial floodplain. Lateral shifts in channel shape in this setting occur through incision of established bank-attached units in response to changes in sediment flux (i.e. excessive sediment deposition will often trigger such events). It is not possible to establish a date for such a sequence of events with the available data, however, a reduction in stream flow and/or increase in sedimentation rates during construction of the original dam could have influenced some lateral shift. Multiple features suggest periodic aggradation of the Tweed River channel bed. Given the proximity to Doon Doon Creek, it is likely that similar conditions would have been observed. Therefore, despite significant influence on the hydrology of the channel through the original construction of the dam, it is reasonable to assume a degree of lateral translation is within the range of natural variability for Doon Doon Creek.

The downstream reach of Doon Doon Creek is partially bedrock confined; leaving little degree of freedom for wholesale channel adjustment except for the bed aggregation in response to increased bedload. Conversely, as the channel moves further downstream toward the Tweed River, floodplain sediment storage is much greater and thus the potential degree of freedom for channel adjustment is significantly greater. Historical lateral migration is evident and is often associated with bed incision or aggregation in response to changes in sedimentological and hydrological regime.

There is little potential of channel adjustment within the bedrock confines, downstream of the spillway. However, upstream changes to hydrology and/or sediment load are expected to have a greater influence on floodplain planform-controlled upstream watercourses. Similarly change in sedimentological and hydrological regimes are not likely to affect bedrock confined reaches (local to the spillway) but are likely to have a greater potential impact to the lower reaches of Doon Doon Creek and the Tweed River.

6.2.2 Analysis

A condition analysis was conducted of Doon Doon Creek downstream of the dam in accordance with the River Styles framework. Doon Doon Creek, downstream of the spillway, was split into three transects to study the key features along the reach. The locations of transects and other geomorphic features are shown in Figure 6.1.

i Channel geometry

Channel geometry refers to channel size and shape, which are influenced by flow and sediment load conditions. Erosional and depositional processes along the bed and bank produce channel size and shape as indicated by the Lane balance (Lane 1954) incision and aggregation processes. Bank erosion processes are differentiated into entrainment and mass movement mechanisms.

Material size and cohesion are key variables for the morphology of channel features such that channels with cohesive banks tend to have low width/depth ratios. The defining geometry features are presented in Table 6.1.

Table 6.1 Channel geometry descriptions taken from Fryirs & Brierley (2013)

Transect	Width/ depth ratio	Channel shape	Bank process	Bed process	Energy distribution
A	11.28	Irregular: bedrock imposed by woody debris	Imposed Condition, such as bedrock or coarse boulder stream. Influenced by erosion (e.g. slumping) or deposition (e.g. bank-attached bar formation).	Erosion (e.g. sculpted pools of cascades) or deposition (e.g. mid-channel bars and island formation).	Unevenly distributed around alluvial materials or bedrock outcrops. Rough surfaces generate turbulent flows.
B	24.93	Compound (macrochannel): depositional benches	Depositional (e.g. bench formation) or erosion (e.g. ledge formation).	Deposition (e.g. sand sheet formation) or erosion (e.g. headcut formation that creates and incised (slot) channel).	Evenly distributed across channel but varies with flow stage and differing surfaces are inundated.
C	12.21	Asymmetrical: meander bend	Deposition along convex bank (point bar); erosion along concave bank (often undercut).	Deposition (point bar formation along convex bank), and erosion (pool scour along concave bank).	Thalweg along concave bank. Secondary circulation cells are common.

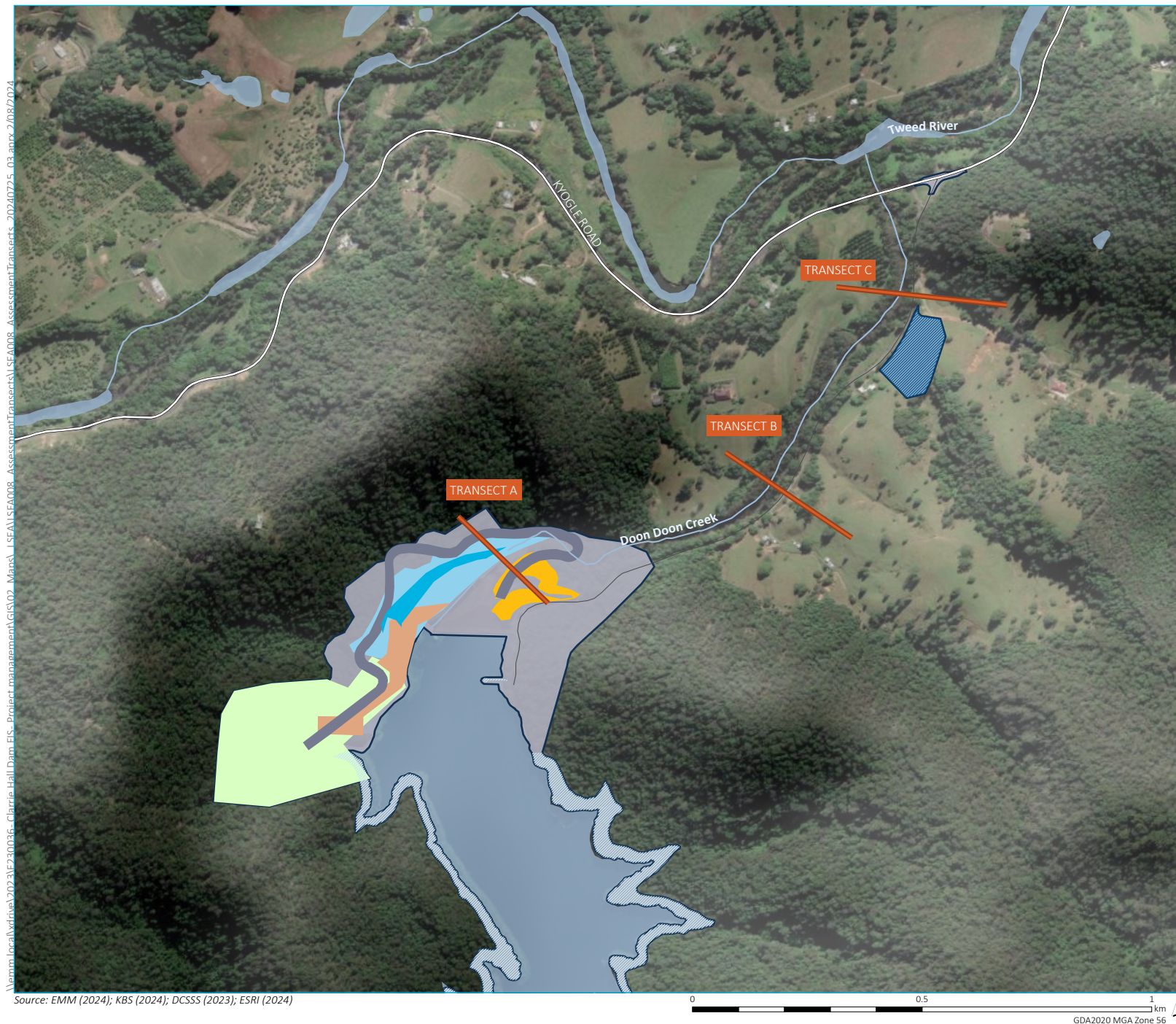
It is noted that channel geometry typically adjusts with progression downstream, and contributing catchment area, however this is not the case with Transect C with a channel contraction evident.

ii Bank geometry

Bank geometry can reflect a range of differing conditions that have occurred over time such as the way sediment is composed due to hydraulic conditions. Bank overflow mechanisms also influence bank geometry where surface roughness's are variable. Table 6.2 summarises the bank geometry found along the assessed downstream reach from the dam.

Table 6.2 **Summary of bank geometry**

Transect	Mean bank slope (%)	Geometry	Sedimentation process
A	37.6	Irregular bedrock with woody debris and riparian vegetation.	Irregular bank morphologies occur when resisting/impelling forces (i.e. riparian and woody debris) induce local turbidity, scour and deposition. Bedrock exposure provides localised deposition.
B	37.1	Compound erosion/selective removal.	Channel expansion may result in the selective erosion of less cohesive materials, producing stepped bank morphology.
C	29.5	Compounded with toe sediment deposition.	Banks with multiple sedimentation layers of varying texture as coarse materials are selectively reworked. Hydraulic action (i.e. fluvial entrainment and undercutting) against the concave bend often a precursor to mass failure by slab failure or fall.



- KEY**
- Study area
 - Full supply level- proposed
 - Condition assessment transect
 - Proposed layout
 - Haul Road- option 1
 - Haul Road- option 2
 - Office location
 - Potential McCabes Bridge stockpile and construction office complex
 - Quarry impact area
 - Proposed spillway
 - Spillway impact area
 - Concrete batching plant or workforce accommodation
 - Potential McCabes Bridge stockpile and construction office
 - Existing environment
 - Major road
 - Minor road
 - Named watercourse
 - Waterbody

Condition assessment transects and geomorphic elements

Clarrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 6.1

Riparian vegetation and wood resistance elements reduce flow and shear stress against the bank sediments, resulting in reduced rates of erosion and channel migration.

In-channel vegetation such as macrophytes, water reeds, shrubs and trees increase surface roughness, reducing flow velocity at the boundary layer that results in greater rates of settling. Once established, vegetation induced flow resistance affects the geomorphic effectiveness of flow events upon differing geomorphic surfaces.

The riparian condition was assessed using *Rapid Appraisal of Riparian Condition, version 2* (RARC) (Jansen *et al.* (2005). The assessment criteria provide a framework to assess the ecological condition of riparian habitats using indicators that reflect functional aspects of landscape features. The RARC was applied in this context because it provides a rapid method of assessing the extent of vegetation (trees, groundcover, deadwood) that affects the channel roughness and consequently the critical bed shear stress threshold under variable flow conditions. It is well established that features such as deadwood and roots (large woody debris) have significant resisting effects on the effects of flow paths on channel bed and bank stability (Curran 2010).

The RARC process has been developed for generalised fluvial environment in south-eastern Australia and may need to be adjusted on a situational basis. Ideally, several pristine systems should be assessed to verify the benchmark for the scoring system, however, the application to this LSEA pertains more to the general channel roughness and not necessarily the broader native freshwater ecosystem health. Appropriate scoring for these systems is relative to anthropogenic adjustment to the flow dynamics and the greater catchment surface.

Table 6.3 and Figure 6.2 summarise results of the RARC and comparison to benchmarks.

Table 6.3 RARC totals compared to benchmark value

	Habitat	Cover	Natives	Debris	Features	TOTAL
Benchmark	11	12	9	10	8	50
Actual	6	7	2.7	6	1.3	23

Note: Benchmark based on a site in excellent condition on the Edward River part of the Murray

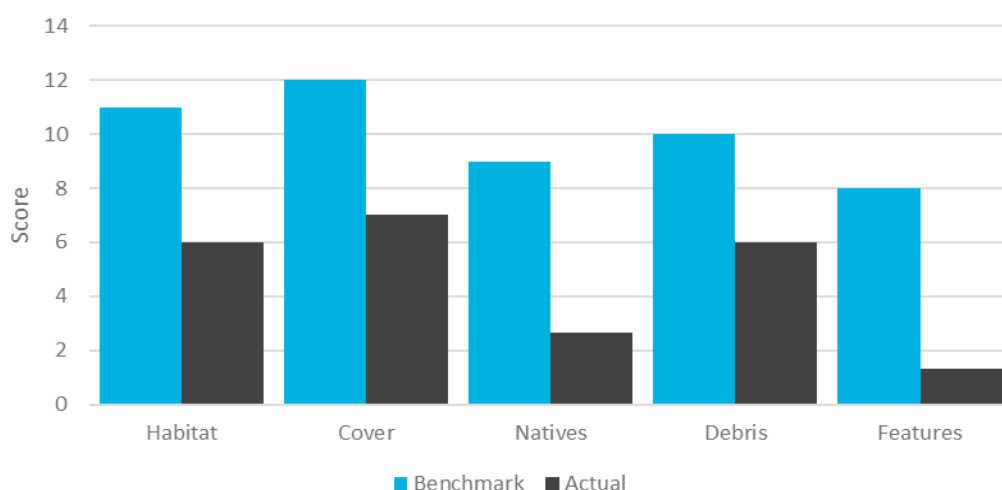


Figure 6.2 Comparison between actual and benchmark values obtained from RARC assessment

The results of the RARC comparison provided in Table 6.3 and Figure 6.2 indicates a relatively modified system, with reduced biodiversity value due to generally poorer riparian characteristics, compared to benchmark levels.

iv Channel sinuosity and stability

The channel was assessed to be a partially confined, irregular, low sinuosity, single channel. There were observed markers to suggest flood level features such as chute channels in the DEM that reveal historical lateral migration toward the Tweed River, suggesting confinement is significantly reduced as a function of distance from the spillway. Table 6.4 summarises relevant channel sinuosity metrics.

Table 6.4 Summary of channel sinuosity metrics

Straight channel length (m)	Channel length (m)	Sinuosity (λ)	Degree	Range	Type
1384.51	1691.88	1.222	low sinuosity	1.06–1.30	Irregular

v Instream geomorphic units

Downstream from the dam wall, Doon Doon Creek is incised into the landscape with wooded banks and a rocky bed featuring sequences of pools and riffles. Pools and riffles were identified through detailed bathometric survey of Doon Doon Creek and are shown in Photograph 6.1.



Photograph 6.1 Pool and riffle in the Doon Doon Creek downstream from Clarrie Hall Dam

Table 6.5 describes the relevant pool and riffle form and processes typical for this in-stream geomorphic unit.

Table 6.5 Pool and riffle geomorphic unit description (Fryirs & Brierley 2013)

Unit	Form	Process interpretation
Pool and Riffle Sequence	<i>Riffle</i> – topographic highs along an undulating reach. Typically occur along inflection points and sinuous alluvial channels. Alluvial riffles alternate shallow step-like forms that span the channel bed. Tend to comprise of tightly imbricated bed materials, suggesting localised sorting. Induce local steepening of channel bed.	<i>Riffle</i> – zones of temporary sediment accumulation which increases roughness during high stage flow, inducing deposition. Concentration of coarser fractions at higher discharges produces incipient riffles, while lower discharges may be sufficient to amplify initial undulations. Riffles commonly dissected at waning flood phases. Riffles are generally stable but may be mobile at bankfull phase and above. May be reworked during extreme floods.
	<i>Pool</i> – may span the channel, hosting laminar flow regimes. Alluvial pools are alternating deep areas of channel and tend to store sediments. Typically occur along concave banks of sinuous alluvial channels.	<i>Pool</i> – at high flow phases, bed scour may be induced, and sediments are flushed. Conversely, subcritical flows induce pool infilling in deep sections. Genetically linked to alluvial rivers. Velocity reversal maintains structures.

vi Morphostratigraphy

Sediment size and sorting, also referred to as sediment calibre, influences what geomorphological features and behaviour a watercourse will exhibit. The grain size will affect particle entrainment, mode of sediment transport, distance of transportation and patterns of deposition. The process of analysing the facies assemblage of geomorphic units, known as morphostratigraphy, is used to discern the dominant sedimentary regime at the reach scale.

A field analysis of soils proximal to Clarrie Hall Dam (refer to Chapter 4) was conducted to discern the dominant grain size and sorting, and by proxy, the dominant sedimentation regime. Focus was put on the median grain size (D_{50}), field texture, and associated depths. Most soils observed within the channel and associated floodplains were classified under the ASC as Tenosols, Dermosols, or Kurosols.

Table 6.6 summarises the data obtained from field analysis of soils. Topsoils were found to be loamy in field texture, ranging from clayey to sandy clay with weak apedal to massive structure. Light clay topsoils were occasionally observed. Local armouring of the upper topsoils is observed with cobbles and gravels, likely sourced from local bedrock exposures. The degree of rounding indicates these sediments were transported some distance; therefore, it is difficult to ascertain the origin of these sediments to be pre or post dam construction.

Subsoils were homogeneous light-medium to medium clays with moderate to strong subangular blocky structure. The presence of pedogenic organisation through the major part of subsoils indicates a degree of permanency to these horizons. Therefore, without further lab analysis, it could be assumed that these facies are uniform and normally distributed in grain size distribution within a geometric standard deviation (σ_g).

Cohesive sediments ($0.002 \text{ mm} < D_{50} < 0.063 \text{ mm}$), such as clays and silts, exhibit complex particle bonds that effect their erosion, deposition, and resuspension. The content of organic carbon matter increases the interparticle bonding and subsequent risk of erosion in combination with the valance in response to pore and eroding fluid field variable gradients.

Lithogenic discontinuities in the form of buried soils were observed at site CH07, with light clay topsoils remaining intact. The permanence of light clay topsoils, however, could suggest limited hydrological capacity to rework floodplain deposits likely due to flow modulation at the spillway.

The facies structure are variable, but generally trends to massive or weakly apedal structures super positioned over moderate to strong structured clay subsoils. The lack of pedogenic structure within the fluvial zone is likely due to historical stripping of non-cohesive or exposed materials and subsequent deposition of alluvial materials.

Channel bedload is highly variable and subject to bedrock confinement, with many exposures and large woody debris providing cores for sedimentation at low flow phase. Channel armouring is present as subangular cobbles, possibly from local sources such that the degree of rounding is predictive of the distance travelled by sediments. The armouring suggested localised resistance to rework potential in bankfull and overbank flow phases.

Table 6.6 Summary of key sediment profile characteristics

Site	Dominant field texture	Clay content	Median grain size (D_{50})	Facies structure
CH04 – topsoil	clay loam	30–35%	$0.0625 \text{ mm} < D_{50} < 0.125 \text{ mm}$	Weak to massive
CH04 – subsoil	medium clay	45–55%	$D_{50} < 0.0625 \text{ mm}$	Moderate to weak
CH05 – topsoil	sandy clay loam	20–30%	$0.250 \text{ mm} < D_{50} < 0.50 \text{ mm}$	Massive, apedal
CH05 – subsoil	medium clay	45–55%	$D_{50} < 0.0625 \text{ mm}$	Strong, subangular blocky
CH06 – topsoil	sandy loam	10–20%	$0.50 \text{ mm} < D_{50} < 1.00 \text{ mm}$	Massive, apedal
CH06 – subsoil	light-medium clay	40–45%	$D_{50} < 0.0625 \text{ mm}$	Moderate, subangular blocky
CH07 – topsoil	light clay (lithological discontinuity)	35–40%	$D_{50} < 0.0625 \text{ mm}$	Weak to massive, apedal
CH07 – subsoil	medium clay	45–55%	$D_{50} < 0.0625 \text{ mm}$	Moderate, subangular blocky
CH08 – topsoil	sandy loam	10–20%	$0.50 \text{ mm} < D_{50} < 1.00 \text{ mm}$	Massive, apedal

vii Bank stability

Bed stability throughout the Proposal is influenced by the degree of cohesiveness of bank materials and supporting structures such as vegetation (roots) and debris. These features are key to reducing surface shear forces in response to wholesale flow regime and secondary scouring. The sediments predominantly consist of cohesive clay particles, potentially deposited through secondary flow cells or waning flood phases.

There is evidence to suggest, despite material cohesiveness and channel roughness features, that mass movements have been, or are currently, occurring adjacent to channel banks. These events are likely to result in channel widening with subsequent downstream aggradation. These examples are observed in Table 6.7.

There are various likely causes for such events, such as localised anthropogenic disturbance (i.e. road building). However, bank failure is often following a period of channel bed vertical incision or undercutting. The sporadic exposure of bedrock units provided limited confinement of channel expansion and adjustment.

Table 6.7 **Mass movement features adjacent to channel bank**

Location	Feature	Comments
Doon Doon Creek (upstream of dam)		• Rotational slip and slump. • Partially confined by bedrock exposure. • Non-cohesive sediment bank-attached bar opposite. • Suggests localised scouring and reworking at concave meander during extreme floods. • Vulnerable to further flood events • Low flood phase likely to deposit sediments proximally downstream.
Access road above Doon Doon Creek		• Localised fall/sloughing. • Proximal to road surface, possibly externally forced. • Origin of cobbles possible artificially placed for road construction. • Thinning of vegetation suggests recent event – lack of pioneer species. • Possible sediment source into channel.
Doon Doon Creek, transect A		• Fluvial entrainment and localised bank armouring. • Historical stripping/reworking phases super positioned by unconsolidated cobbles and boulders of nearby origin. • Possible parallel sliding occurring, diagnosed by discontinuity on form at upper bank.
Doon Doon Road		• Rotational slip and slump. • Confined by bedrock exposures. • Exposed roots and lack of pioneer species suggest recent mass movement. • Cohesive bank materials. • Possibly due to lack of in-stream vegetation and geomorphic assemblage.

The hydraulic diversity of a watercourse is linked to the geomorphological assemblage of in-stream units such that it is an important determinate variable in the range of variability at the reach scale. The variation in planform confinement of Doon Doon Creek induces a variation in flow regimes across the longitudinal and lateral profile of the channel. Flood phase descriptions are shown in Table 6.8.

Table 6.8 Flood phase descriptions

Flood phase	Hydraulic diversity
Low flow	Partially constrained by bedrock, restricting adjustments to local reworking of transient bedload flux. Flow paths are representative of coarse substrate and scour patterns in bedrock exposures and large boulders. Secondary flows deposit finer sediments in wakes or local pools. Localised secondary flow paths and turbulence occurs about large woody debris and depositional assemblages, contributing to deposition and in-stream sediment storage capacity and provides localised sorting of sediments.
Bankfull	Upper reaches are heavily confined by valley margin and bedrock exposure – limiting channel adjustment except in the most extreme flood events. Large boulders may be saltated and bedrock may become vulnerable to corrosion along jointing, forming potholes and pools. Sediment stores are flushed from pools and other storage features. Average pressure and velocity fields may become locally constrained by forced features. In-stream units may be reworked, redistributed, and adjust to variation in flow paths but are largely imposed. Lateral adjustment is restricted to channel expansion (erosion) or contraction (deposition) adjacent to floodplain pockets. Riffle and pool sequences become inundated and localised turbulence is reduced through the water column.
Overbank	Floodplain features may be reworked in alignment with flow path distribution outside the confines of the channel boundaries. Average velocity is reduced as flow is laterally unconfined. Pressure fields are evenly distributed. Secondary and tertiary flow paths may be generated by inundated features and under-currents. Potential for floodplain reworking/stripping is dependent on flood intensity. Vertical accretion of suspended load materials occur with waning flood levels, local turbidity and reduction in velocity preferentially settles coarser particles, resulting in vertical fining of sedimentary assemblages.

6.2.3 Summary

A summary of the condition analysis conducted in accordance with the River Styles framework is provided in Table 6.9.

Table 6.9 Geomorphic analysis summary

Element	Comment
Channel geometry	Non-cohesive boulder type – irregular channel morphology as flow moves around coarse boundary materials that are only mobilised during major floods. Surface armouring is common. Bed material may be ‘locked in place’, many attributes of boulder systems are essentially ‘forced’.
Bank geometry	Irregular morphology results from localised imposition and/or resisting forcers. Evidence of channel expansion and consequential stepped bank morphology as bank materials are selectively reworked at higher flood phases.
Riparian vegetation	Weedy understory with moderate levels of riparian shrubs. Riparian corridor generally between 20–50 m wide on the western bank. Road on the eastern bank significantly reduces width of riparian corridor suggesting low bank-full stage resistance to flow. Floodplain forest is localised within pockets, occasionally complete clearing. Overall poor to moderate condition.
Woody debris	Woody debris is plentiful at the reach-scale. Jams are associated with in-stream and bank-attached geomorphological units. Position with respect to deposition of sediments suggests relationship is not causal but does contribute to channel roughness. Possibly resulting to recent flood events.

Element	Comment
Number of channels	Single channel with occasional chute channels associated with compound bars and channel expansion.
Channel sinuosity	Irregular, low sinuosity.
Lateral stability	Partially bedrock confined grading to laterally unconfined. Upstream imposed by confinement, downstream evidence of wholesale channel adjustment and lateral migration.
Geomorphic unit assemblage	Floodplain, bank-attached and in-stream units with armoured sediment assemblages and sustained riparian vegetation suggests localised resistance to erosion.
Grain Size/Sorting	Cohesive, largely homogeneous, facies are present as subsoils. Topsoils are comprised for larger grains, suggesting historical stripping and re-deposition of surface materials. Bedload is mixed ranging from exposed bedrock units to sandy loams. Many sections through the reaches downstream of the dam are armoured by subangular cobbles, suggesting localised sediment source providing resistance to turbid extremes.
Bank Stability	Localised mass movement are observed upstream and downstream of the dam. Some examples may be resultant of road building efforts and localised vegetation loss. Cohesive sediments within laterally unconfined reaches suggest localised channel contraction. Other sections are largely confined by bedrock exposure. Localised armouring and instream large woody debris provide resistance to erosive regimes.
Hydraulic Diversity	Flow phases are largely constrained by bedrock and valley confinement subject to localised projection of boulders and bedrock irregularities. Pool and riffle sequences become homogenised in higher flow phases with subsequent flushing of temporarily stored sediments. Floodplain reworking and stripping is restricted to lower reaches where floodplain sediment stores are non-cohesive.

6.3 Downstream hydraulic modelling outcomes

As part of the SWA, the modelling of potential hydraulic impacts downstream of the dam was completed. The focus of the modelling was on the potential hydraulic changes to Doon Doon Creek and the Tweed River due to the dam wall raising. The Proposal will likely result in a decreased frequency of spillway discharge in each season with the larger reservoir. A summary of the hydraulic modelling outcomes is discussed in this section in the context of understanding potential geomorphologic change in Doon Doon Creek and the Tweed River.

Flow conditions downstream of the dam for existing and proposed conditions was based a hydrologic model developed using the Source software created by DPE Water. Flow data from the Source model was input to a hydraulic model developed using the HEC-RAS software, enabling predictive hydraulic outputs of flow depth, velocity, and shear stresses (including bed and critical shear stress). Shear stresses considered thresholds for a range of bed materials including silt, sand, gravel and boulders. The modelling considered hydraulic conditions and impacts along Doon Doon Creek and the Tweed River.

Key hydrology modelling outcomes described in the SWA included:

- Following the dam wall raise, the volume which can be temporarily stored above the FSL will be larger and the release rates slower.
- Management of peak inflows to the dam are predicted to be improved leading to a reduced downstream flow rate, via the spillway in Doon Doon Creek. Flow events from the spillway however are expected to occur for a longer period following peak inflow events to the dam.
- The Proposal will result in a reduction in the frequency of flows with high shear stress in Doon Doon Creek. This means that the bed materials would be mobilised in floods less frequently. There could be a small increase in the frequency of minimum flow releases from the dam which equate to a shear in the order of 30 newton metres squared, and a small reduction in the frequency of flows with shear in the order of 15 newton metres squared. These changes are not expected to have an effect on the bed materials present.

It is expected that in Doon Doon Creek:

- With an increase in frequency of minimum flow releases from the dam, flow depths within Doon Doon Creek are likely to be sustained for longer in conjunction with these releases. Flow depths within the riffle zones are predicted at 0.5 to 0.6 m which can increase by 0.1 m in higher flow events. The change in pool depth between the model scenarios was less than what was predicted in the riffle zone. Between the maximum and top 4%ile of flow events, the depths within both the pool and riffle zones are comparable with the Proposal scenario.
- Bed shears remain below 100 newton metres squared in all but the largest floods. This means that rocks larger than 10 mm are not expected to be mobilised in typical flow events.
- Changes to the spillway and reservoir routing will result in a reduction in the frequency of flows with high shear stress in Doon Doon Creek. This means that the rocky bed may be mobilised in floods less frequently.
- There could be a small increase in the frequency of flows with a shear stress of 30 newton metres squared, and a small reduction in the frequency of flows with shear in the range 15 newton metres squared. These changes are not expected to have an effect on the bed materials present.
- Minimum releases from the dam result in a minimum bed shear of around 10 newton metres squared. This is sufficient to mobilise sand size particles. As such, sand and silt make up only a small portion of the riverbed, being mobilised and moved towards the river mouth during every-day flow conditions.

As described in the SWA, raising of the dam is expected to lead to a minor decrease in the supply of sediment moving downstream along Doon Doon Creek. This will promote erosion of fine particles downstream while the decrease in high flows as described above will likely promote sedimentation and a reduction in erosion. Taken together, these effects mean that the nature of any geomorphological change is difficult to predict. However, the magnitude of each geomorphological effect is expected to be relatively small. As such, any geomorphological change which does occur is expected to occur as slow adjustments over an extended period.

In locations with a gravel/rocky bed it is likely that no geomorphological change will occur due to the Proposal. Rocks of the sizes observed in the riverbed are not expected to be affected by erosion due to changes in reservoir sedimentation.

No geomorphological changes are expected downstream from Uki as the Doon Doon Creek catchment represents only a small portion of the catchment upstream from Uki, with the remainder unregulated and unaffected by the Proposal.

6.4 McCabes Bridge construction

McCabes Bridge construction will span over the upper reaches of Doon Doon Creek including a mapped 1st order tributary. Condition of the watercourse through this section of the catchment is defined as poor with a floodplain pocket river style and a gravel bed material present throughout.

The bridge structure is proposed to be 50 m in length whilst the realignment of Commissioners Creek Road is approximately 1,000 m in length. The bridge is proposed to be relocated 40 m downstream. Rehabilitation of the existing bridge crossing is expected to occur back to a stable landform however, the area will be inundated due to the higher FSL.

The relocated bridge is proposed to include three spans and therefore potentially two piers within the channel zone. Due to the location of the bridge within the proposed FSL, scour effects from potentially higher catchment driven velocity flow events is unlikely however it is expected that the detailed design of the bridge crossing would include the specification of appropriate scour protection of the piers to the required industry standards, that considers the existing bed material and scour potential. On this basis the proposed bridge works and associated road realignment are unlikely to result in adverse impacts to geomorphology.

7 Geotechnical review

7.1 Methodology and limitations

This section has been prepared based on a review and synthesis of data, findings and interpretation presented in the following:

- *Clarrie Hall Dam Raising Concept Design Geotechnical Investigation* (NSW PWA 2018b)
- *Clarrie Hall Dam Raising Environmental Impact Statement – Geotechnical Desktop Study and Site Investigation* (Coffey 2021)
- *Clarrie Hall Dam Raising, Construction Phase Advice*, (KBR 2023).

Whilst these studies may not all be publicly available, they can be provided for reference upon request.

Further geotechnical investigations are required as part of the future detailed design and construction stages of the Proposal and further assessment of necessary Proposal elements are anticipated to be completed as part of these subsequent stages.

The focus of this geotechnical review is to present information sourced from the above studies to inform responses to the relevant SEARs regarding:

- Impacts of sourcing, importation and emplacement of fill/quarried material for the Proposal. The investigation should focus on whether sourcing of rockfill material will impact the long-term geotechnical stability of the quarry site.
- Understanding the long-term geotechnical stability of any new landforms required.
- Understanding the capacity of the site to support the increased size of the dam embankment and associated infrastructure.

7.2 Literature review of geotechnical investigations

Geotechnical surveys were conducted by the NSW Public Works (now Public Works Advisory (PWA)) at the time of the original dam construction prior to 1984. Construction geological mapping and geotechnical observations made during construction were determined by unpublished reports by Hawke (1983) as part of the Geological Survey of NSW.

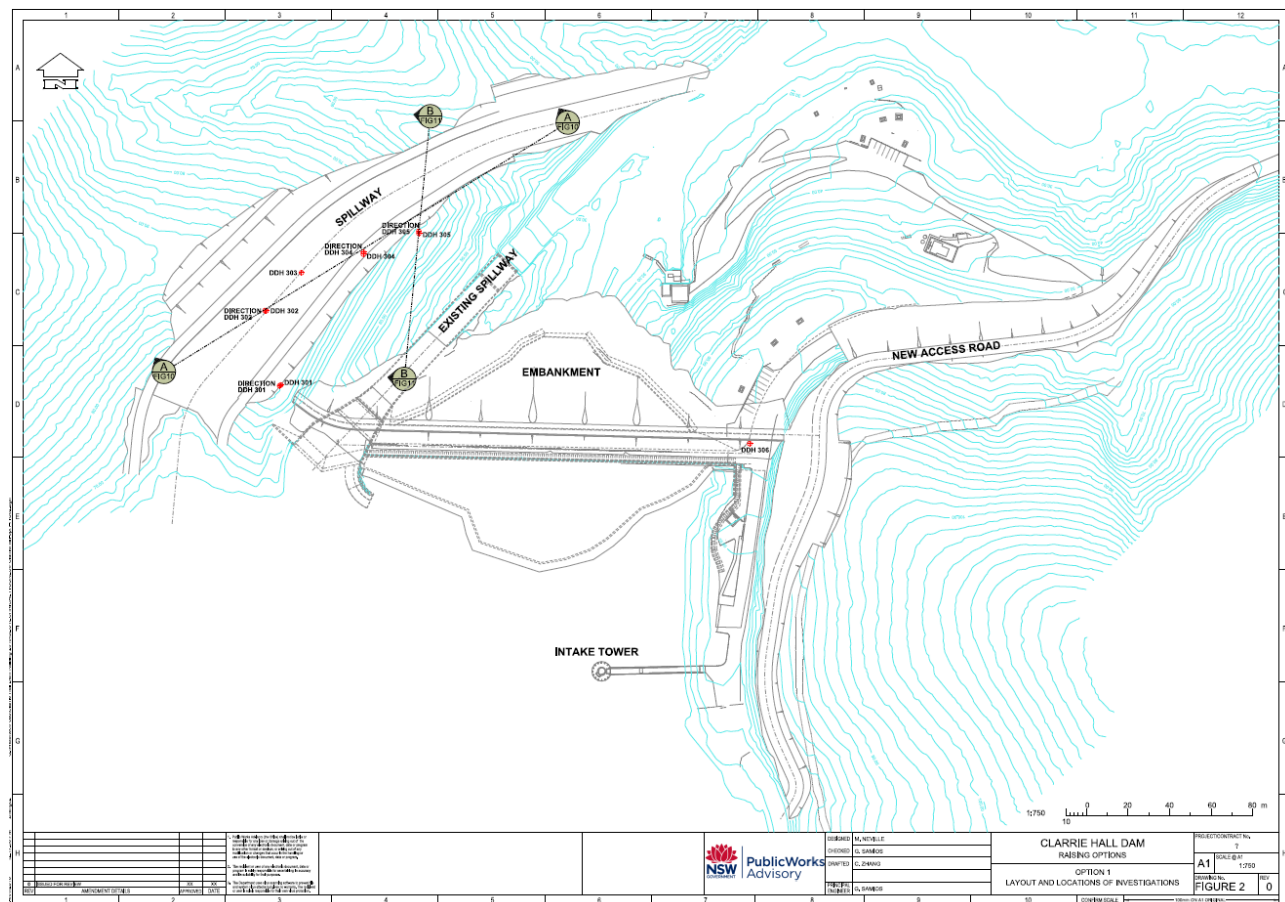
The foundational bedrock of the current dam consists of a uniform sequence of hard rhyolite with minor welded tuff. The surveys by Hawke (1981) revealed very high to extremely high uniaxial compressive strength for the major part of the rhyolitic foundation. All rock types present at the dam site, when fresh/unweathered are described as strong to very strong. Rockfill for the dams original construction was sourced from the nearby quarry which is proposed to be used again as a source of material for the Proposal.

To support the Proposal, further geotechnical investigations were conducted between July and September of 2017 (NSW PWA 2018b) with the intent to:

1. confirm the geological suitability of the raised embankment and ancillary structures
2. estimate the rock mass conditions, excavation characteristics and batter stability along the proposed spillway alignment
3. assess the suitability (weathering profile, lithology types, and potential yield) of the excavated material from the construction of the proposed spillway for use as rockfill for the raised embankment

4. assessment of the geology and remaining resources within the existing nearby rockfill quarry.

Investigation boreholes included in NSW PWA (2018a) are shown in Figure 7.1.



Source: NSW PWA (2018a)

Figure 7.1 Investigation boreholes in proposed spillway near existing dam embankment

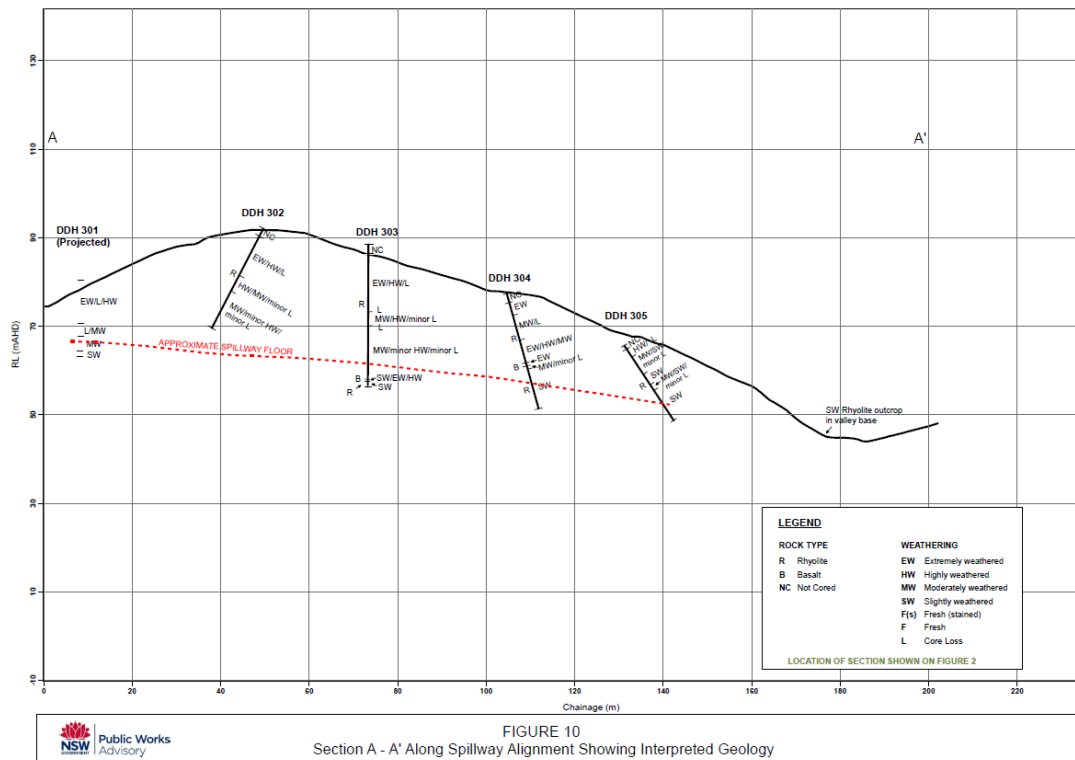
i Material sources for construction

Material for construction will be locally won from either excavation requirements of the Proposal or from the re-established quarry. It is expected that all material excavated from the Proposal will be sorted and processed on site to maximise reuse on site. This approach will require good understanding of the expected material to be encountered and local stockpiles at each construction site. Further targeted geotechnical testing as part of the design development will confirm the materials present.

ii Proposed spillway

The proposed spillway alignment, based on drilled boreholes (refer to Figure 7.2), is expected to be located within moderately and slightly weathered rock and this material is determined by NSW PWA (2018b) as suitable for floor and wall lining. The foundations of the proposed spillway will however likely require longer anchorage considerations due to the presence of moderately weathered rock compared with situations where a stronger, less weathered rock was present.

NSW PWA (2018b) noted, during construction in the event that highly weathered rock is encountered in the foundation along the spillway alignment, alternative construction methods would be required. The alternative construction methods however are unlikely to alter the Proposal footprint proposed given additional contingency areas have been considered for construction.



Source: NSW PWA (2018b)

Figure 7.2 Section along proposed spillway, interpreted geology for excavation

Key outcomes from the NSW PWA investigations (2018b) for the proposed spillway also included:

- Rock material likely won in the construction of the proposed spillway will be of a significantly weathered character and therefore will not meet the requirements of the embankment zones 3A/3B. The foundation for the spillway is however expected to be satisfactory. Material will need to be sourced from the existing rockfill quarry for the slightly weathered and unweathered rhyolite required in construction of these zones.
- Recommendations were made for further boreholes towards the end of the proposed spillway channel to confirm the rock conditions and whether any alternate construction methods to mitigate adverse foundation conditions. Currently these areas have not been investigated and the foundation conditions are only assumed for the purposes of the environmental assessment. Further geotechnical testing will inform construction requirements for the toe of the spillway channel.

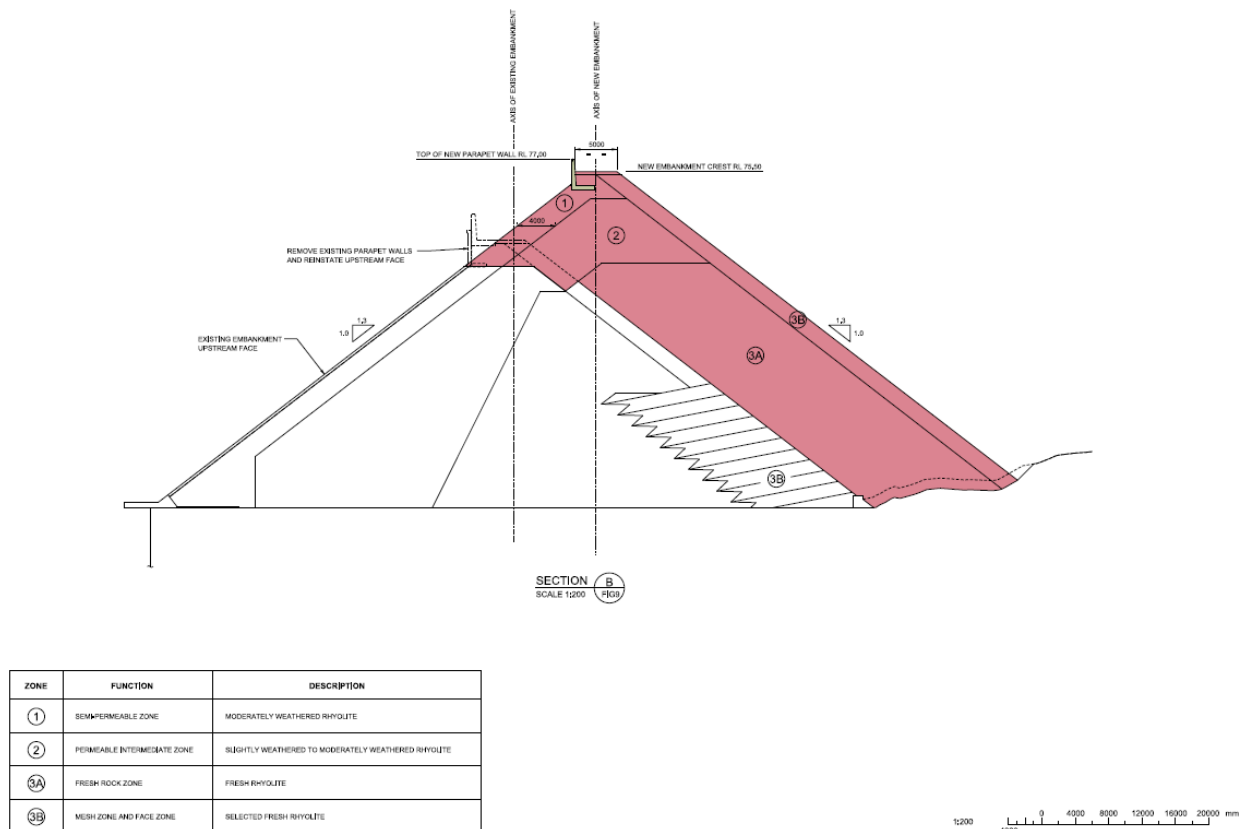
The construction sequence for the Proposal will prioritise excavation of the new spillway early. This will enable the effective reuse of material appropriate won in the dam wall or other demands. Stockpile of material from the proposed spillway will be located downstream of the existing wall. Where space is not sufficient to manage stockpile materials during the early phases, it is expected that the rockfill quarry can act as a temporary storage area for the material. The material cut volumes required to construct the proposed spillway are estimated by KBR (2023) to be 180,000 cubic metres. This will be confirmed during detailed design.

iii Proposed raised dam embankment

The embankment profile (under the upstream concrete face slab) has been constructed with four zones and is proposed to be raised based on:

- Zone 1 – semi-permeable zone comprising moderately weathered rhyolite.
- Zone 2 – permeable intermediate zone comprising slightly weathered to moderately weather rhyolite.

- Zone 3A – permeable zone comprising fresh/unweathered rhyolite.
- Zone 3B – downstream face zone comprising select fresh/unweathered rhyolite.



Source: NSW PWA (2018b)

Figure 7.3 Overview of concept raised embankment with various material zones

NSW PWA (2018b) considered sourcing local materials for each zone to potentially include:

- Zone 1 material can be sourced from the proposed spillway channel or from the lower portion of the rock quarry.
- Zone 2 material can be sourced from the proposed spillway channel or from the rock quarry. Classification of the rock from the blasted face of the quarry would determine whether material is better suited in Zone 2 or Zones 3A or 3B. NSW PWA (2018b) indicates that blasted rock from the quarry may consists of slightly to moderately weathered rock.
- Zone 3A/3B material can be sourced from the rock quarry. Zone 3B will require larger rock clasts which may limit the available sources. Fresh or unweathered rhyolite is required for Zones 3A/3B. Boreholes completed by NSW PWA (2018b) indicates that the existing spillway channel will not provide suitable rock for use as Zone 3A or 3B.

Temporary stockpiles for the construction requirements of the embankment raise will be located downstream of the existing dam wall connected to the required haul road from the rockfill quarry site, utilising the area proposed for new recreation facilities and offices. Material fill volumes required for the raised dam embankment are estimated at 133,000 cubic metres (KBR 2023). This will be confirmed during detailed design.

The existing rockfill quarry is identified as a key source of material for the Proposal. NSW PWA (2018b) investigations reviewed several studies by Hawke as part of the Geological Survey of NSW (1981) that included a series of investigation boreholes throughout the quarry area to confirm the presence of competent rock for construction. The Proposal includes the expansion of the existing quarry footprint to the north, south and west. NSW PWA (2018b) concluded from investigations and review of historical information, on the resource available in the quarry that there is remaining rock material appropriate for construction requirements for the Proposal.

Despite material being available, NSW PWA (2018b) indicated that reshaping of the quarry is required to make access safe and to enable the effective extraction of material for construction. Permanent benches are likely required due to the excavation heights necessary to extract the material required for the Proposal. Depth to slightly weathered/fresh rhyolite was generally in the order of 10 to 30 m below the existing surface. Considering depths to access the slightly weathered/fresh rhyolite a likely maximum quarry face height of 70 m is estimated from NSW PWA (2018b) investigations.

Given the likely quarry face height being greater than 30 m, further geotechnical assessment will also be required to inform the quarry design. Principal hazards associated with the quarry operations must be identified in accordance with relevant work health and safety requirements.

Geotechnical assessments recommended for quarry design and operation (*Safety Management Kit for Small-scale mines, quarries and extractive industry operations*, (DPE 2018)) provided by the NSW Resources Regulator should consider:

- slope design and its stability
- the implementation of a suitable support system (where required)
- recognition of geotechnical risk for relevant aspects of the operation
- the ongoing monitoring requirements suitable to the size and scale of the design.

The geotechnical assessment should provide an indication of the risk and consequence of failure of relevant features which may involve the application of a factor of safety calculation or could include more extensive probability analysis (NSW Resources Regulator 2018).

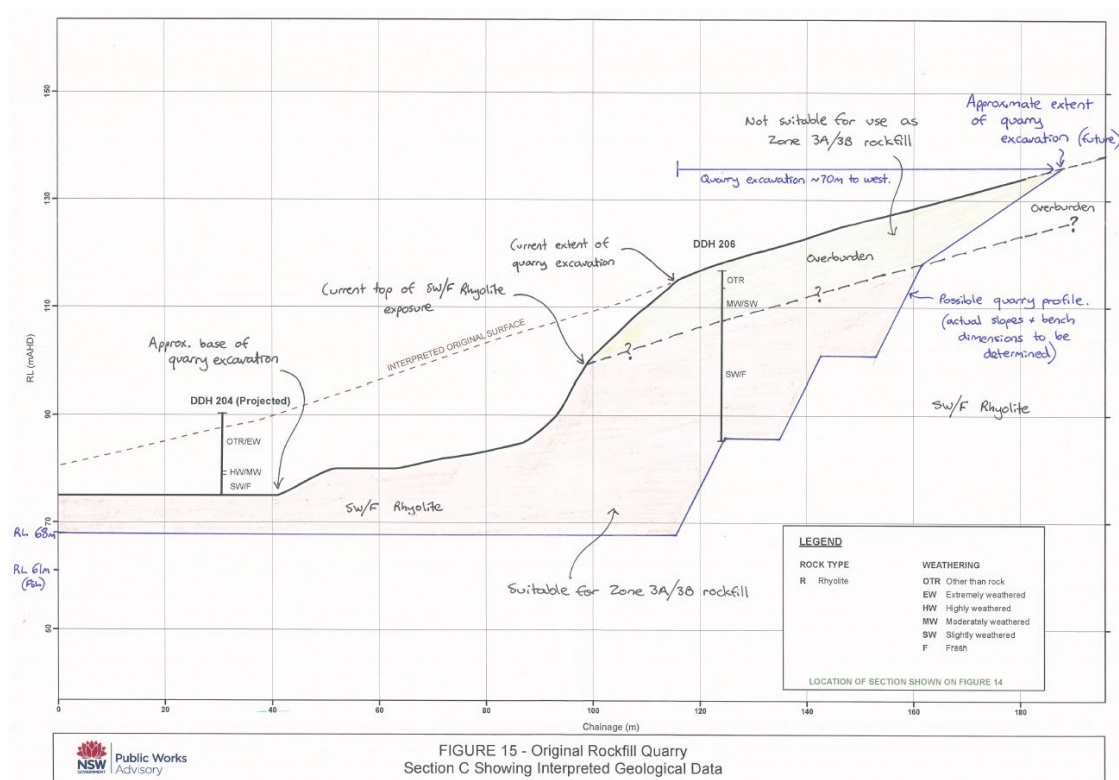
In addition to further geotechnical assessment in quarry design, bench width and heights will depend on construction or quarry equipment being used in the quarry. Targeted geotechnical drilling, strength testing and analysis across the proposed quarry expansion area will be required prior to the commencement of construction. The quarry design extent will be limited to the area currently nominated in the Proposal.

Based on the existing benching in the bedrock located adjacent to the existing spillway for the dam, over a 30 m vertical height, three benches were constructed with an average gradient of 1V:1.5H (65%) with approximately 5 m bench width. Figure 7.4 shows the existing benched batter configuration at the current spillway.

The conceptual cross section and considerations of the quarry as part of a review of the Proposal's construction requirements is presented in Figure 7.5.



Figure 7.4 Existing benched batter configuration at existing spillway (after NSW PWA 2018a)



Source: KBR (2023) using NSW PWA (2018a)

Figure 7.5 East-west section through quarry, detailing planned source of materials

Once extracted, rock material for construction will need to be transported from the quarry to the dam embankment and spillway construction site. The Proposal has considered two options for hauling this material from the quarry to where it is needed. Material movements during construction have been previously assessed by various studies in the past with the following assessment outcomes still relevant:

- Challenges exist in getting material from the existing rockfill quarry, within the elevated areas to the south west, to the toe of the existing dam wall, within a topographically constrained area. To overcome the challenges, two options are proposed (to be confirmed in detailed design):
 - Option 1 includes an appropriately designed haul road based on the vehicles proposed to be used to move materials. The haul road construction, whilst being a temporary construction requirement, are significant and present additional challenges with vehicle movement safety. Cut and fill batters for the haul road are significant with the construction of the route leading to an excess of 24,000 cubic metres of material.
 - Option 2 includes a small section of haul road from the rockfill quarry to the existing left abutment and a belt conveyor system to move material from elevated areas down to the toe of the dam wall.

Haul road design and construction will allow for two-way travel, maximum longitudinal gradients of 10%, safety windrows and crossfall of between 1 to 4%.

7.3 Landslides and mass movement

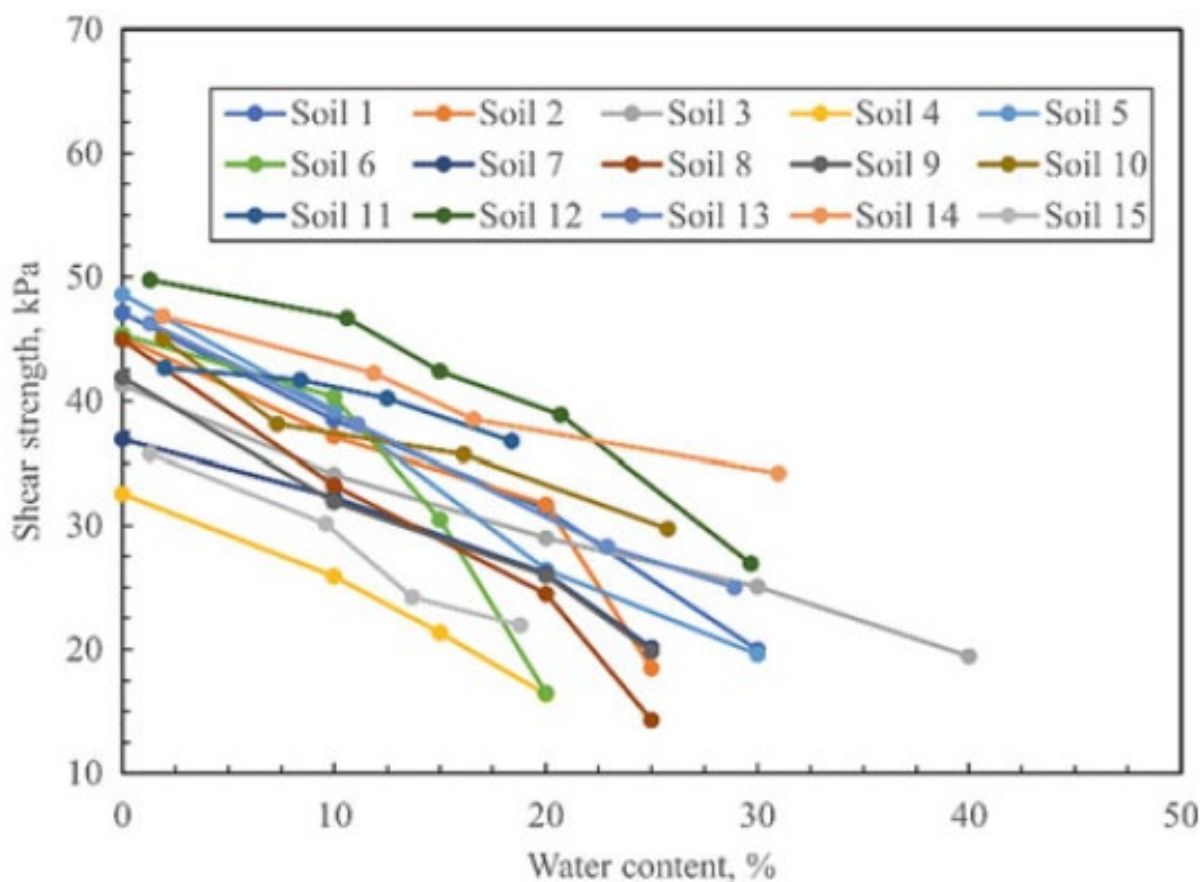
NSW DLWC (2000) discusses the main factors contributing to mass movement based on Roswell *et al.* (1992), relevant to the Proposal include:

- removal of underlying support, e.g. undercutting by water erosion
- build-up of internal pore pressure at the base of the slope mass due to high rainfall or change in groundwater levels
- existence of fractures in bedrock aligned with the slope
- materials at the base of a soil rock mass with low strength and internal cohesion
- steep slope gradient causing increased gravitational forces.

Research by Gratchev *et al.* (2023) discusses the mechanisms of rainfall-induced shallow landslides that are common across southeast Queensland and northern NSW. Results of rock/soil samples from landslide masses were obtained from laboratory testing. The results indicated a correlation between the probability of shallow slides and the presence of sandstone deposits with failure plane angle between 35–45°. Natural slopes where landslides have occurred were mainly composed of coarse-grained soils, that is suggested to influence soil strength in response to soil moisture content. The general characteristics of landslides include:

- The two most common types of failure include slides in jointed rock mass and heavily weathered rock material.
- Many slope failures were associated with geological bedding planes and folds where discontinuities created pockets of weathering and water accumulation; significantly undermining the strength of natural slopes and road cuts. Steep inclination of bedding planes also had adverse effects.

- Several observations were assessed to be the product of weathering of sedimentary units. Most landslides had similar geological features such as soft, weathered material overlaying hard bedrock. Bedrock was also found to be deeply weathered with the bedding structure associated with discontinuities was a significant factor to failure.
- Landslide observations were made where weathering of igneous units was present.
- Landslide mass was composed of coarse-grained soil with sand or gravelly sand field texture. Few landslides were observed in low plasticity, fine-grained soils.
- Natural slopes were found to be stable during dry periods. However, stability decreases during wetting cycles due to the loss of soil shear strength in response to decreasing soil suction. (i.e. loss of soil strength is proportionate to increased soil moisture content) as seen in Figure 7.6.



Source: Gratchev *et al.* (2023)

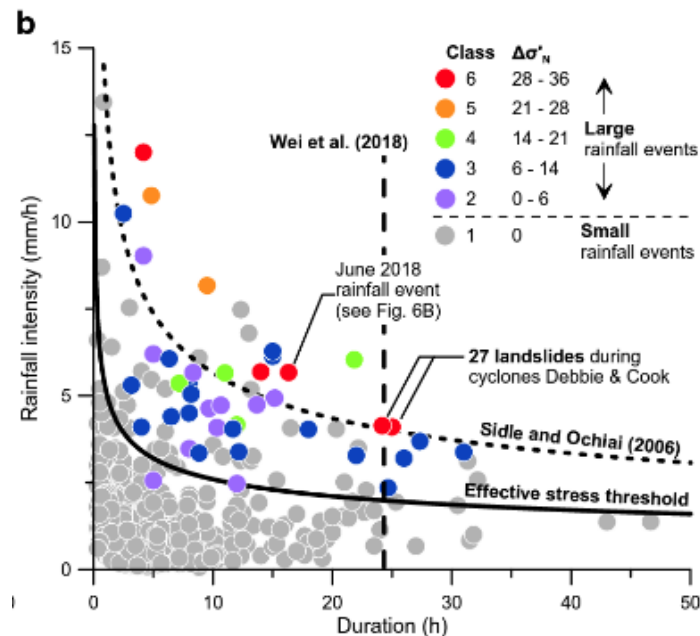
Figure 7.6 Results from shear box tests on soils from landslide sites across northern NSW, plotted as shear strength against initial water content

The major findings from this Gratchev *et al.* (2023), relevant to the risk of landslides considering the Proposal were:

- Geological factors such as rock type, bedding planes, discontinuities of rock mass and weathering are significant risk factors for landslides within the study area. Most observations were associated with jointed, bedded and weathered sandstone deposits. Potentially all present conditions surrounding the dam.
- Rainfall intensity and duration are also significant risk factors, where landslide events are closely associated with rainfall greater than 500 mm. High rainfall intensities do occur in the Proposal's locality.

- Soil strength was found to depend highly on soil moisture content, with soil shear strength greatly reduced at saturation point, greatly reducing slope stability.

Studies on weathered rhyolitic deposits composed of halloysite (aluminosilicate clays) in New Zealand (Kluger *et al.* 2020) showed critical rainfall intensity threshold limits to be 4 mm/h over 25 hr (Figure 7.7). This finding supports the concept of loss of soil strength in response to soil moisture content and appears to be consistent for sites observed in Hong Kong and Japan. This has implications for those materials that will be subject to periodic inundation around the edge of the FSL extent, where increased moisture content has the potential to reduce soil strength and result in slumping.



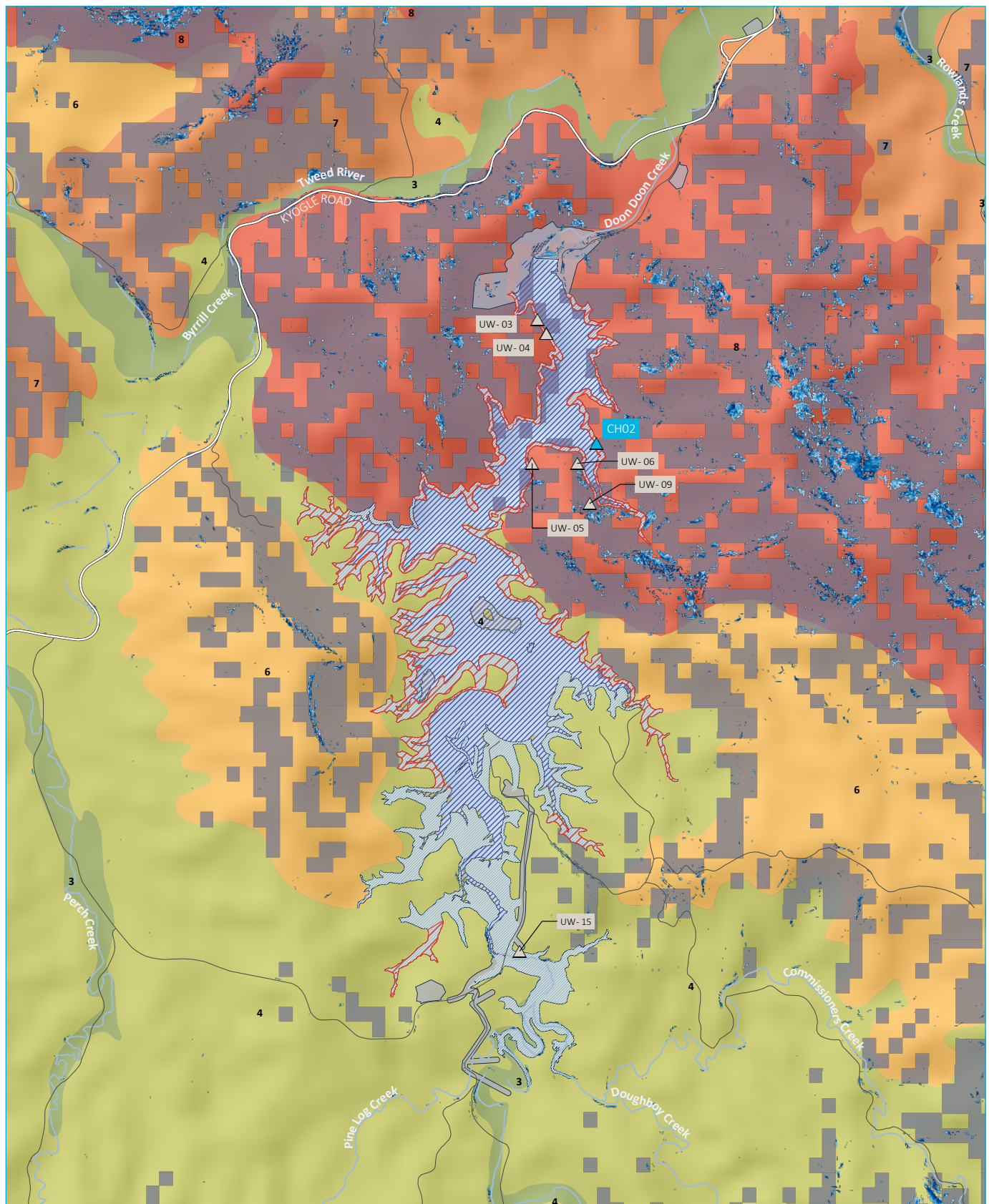
Source: Kluger *et al.* (2020)

Figure 7.7 Rainfall intensity-duration relationships of small and large rainfall events plotted on linear timescales

Mass movement is an identified hazard of the Frogs Hollow soil landscapes within the Proposal area. As part of the assessment on the Proposal by Coffey (2021), six sites surrounding the existing dam were identified as past landslide areas. As part of site investigations undertaken for this LSEA an additional site at CH02 was also identified. The locations of the seven sites are shown on Figure 7.8. The majority of these sites correlate with the extent of mapping for the Frogs Hollow landscape providing an indication that foreshore areas within the northern part of the dam are likely to have an elevated risk for slip or slumping. On review of adjacent slope percentages, existing slip sites are located within similarly steep gradient areas. To further refine steep areas, flow length and slope was considered using the data available from mapping on SEED for the RUSLE. Length slope factors were mapped across the Proposal and elevated factors, commensurate with those historical slip sites, were identified.

It is conservative to assume that all foreshore areas subject to the increased FSL of the Proposal have the potential to result in slip or slumping. Coffey (2021) conclude that slips and slumps could occur leading to exposed subsoils and additional erosion. The effect of this on the storage is unlikely to be significant due to the difference in soil volume loss and water storage volume available. To focus potential high-risk areas for the Proposal, a qualitative assessment, based on the evidence of the seven past landslide areas of area that may be subject to an increased risk was completed (refer to Figure 7.8). The outcome from the assessment was seven foreshore areas where an increased risk of landslide or mass movement may occur. Three were identified as larger areal sections of risk and four were determined as short, isolated sections.

Coffey (2021) concluded from their assessment that the level of landslide/instability risk to upstream persons or property from a geotechnical viewpoint is considered to be low. This was determined due to the remoteness of the Proposal location and the limited presence of receptors in areas of potential instability. Whilst the likelihood of landslips in the Proposal, based on historical evidence, is possible, the significance is likely to be minor.



Source: EMM (2024); KBS (2024); Coffey (2021); DCSGS (2023)

KEY

- Study area
- Full supply level- existing
- Full supply level- proposed
- Area of elevated landslide risk
- Slope length and steepness (LS) value < 8
- Coffey identified past landslide
- EMM identified past landslide
- Potential landslide risk- Slope degrees
- 45
- 35

- Land and soil capability (LSC) class
- 3- Moderate limitation
- 4- Moderate to severe limitation
- 6- Very severe limitation
- 7- Extremely severe limitation
- 8- Extreme limitation
- Water
- Existing environment
- Major road
- Minor road
- Named watercourse

Identified historical landslide areas
(Coffey 2021) compared to LS-factor and
land soil capability

Clarrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 7.8



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7.4 Landform stability

The Tweed Heads 1:250,000 Geological Series Sheet SH 56-3 indicates the site is underlain by early Triassic aged bedrock from the Chillingham Volcanics subgroup typically comprising rhyolite, rhyolitic tuff and claystone. No major structural elements are shown on the regional geological map.

The northern elements of the Proposal will require earthworks in areas that may require significant cut faces. These cut faces will be mostly into hard rock (rhyolite or rhyolitic tuff) that will have varying degrees of weathering present. Outside of the dam wall construction, the Proposal will result in landforms including:

- The Clarrie Hall Dam Road realignment will require a vertical cut face.
- The quarry expansion will result in temporary benched batters of 1V:1.5H. Following completion of construction the quarry will be rehabilitated (backfilled) and include a stable landform.
- Temporary construction haul road options can result in significant cut and fill batters. Two options include a short and a long road option. The long road option presents higher stability risks, due to increased areas of cut and fill embankments, than the short option. Following completion of construction, remaining cut and fill batters for the haul road will be rehabilitated in accordance with the state guidelines, including the reinstatement of drainage lines.

Each of the above aspects are currently at concept level design and require further refinement as part of future detailed design to confirm stability.

On the construction of the dam wall, geotechnical investigations have revealed very high to extremely high uniaxial compressive strengths for the rhyolite rock foundation present. The concept design for the Proposal prepared by NSW PWA (2018a) has been based on up-to-date geotechnical investigations including seismic and structural assessments. The proposed 1V:1.3H embankment slopes of the raised dam wall were considered acceptable by NSW PWA and the NSW Dams Safety Committee (DSC) based on precedence and prior research. Due to this outcome, stability analysis was not required in the design of the existing and proposed Clarrie Hall Dam embankment. Trial embankment studies have been carried out which have confirmed the suitability of the proposed embankment profile and slope stability (NSW PWA 2018b).

Future stages of design on the dam wall raise, for construction, should be suitably informed and signed off by a geotechnical engineer to ensure they are stable and confirm to the nominated design criteria and factors of safety, as well remaining compliant with the requirements of the DSC and relevant industry guidance.

8 Impact assessment

The Proposal may involve potential soil and land resource impacts due to activities including the clearing of vegetation, disturbance of soils, management of construction materials, and the removal of agricultural land across the study area.

It should be noted that some of the impacts to agriculture, such as potential agricultural productivity, are intrinsically linked to the baseline land and soil conditions. Impacts to agriculture through associated impacts to land and soil quality are therefore captured under impacts to land and soil capability.

8.1 Land and soil capability

8.1.1 Construction soil impacts

i Soil disturbance and stripping

The proposed construction works will disturb soils through the following activities:

- clearing, topsoil stripping and earthworks across the construction footprint
- decommissioning of any existing Clarrie Hall Dam infrastructure
- management of construction materials (import/export and movement)
- excavation from existing borrow (quarry) areas.

The soil disturbance during construction has the potential to result in the following impacts:

- reduction in soil stability and increase susceptibility to erosion due to vegetation removal, flow concentration or soil exposure, especially where subsoils are sodic and dispersive
- reduction of soil quality, quantity and associated productivity
- loss of structure and water holding capacity due to mechanical compaction
- reduced topsoil nutrients and biological activity
- loss or degradation of topsoil material viable for use in rehabilitation
- introduction of constraints into the topsoil material if soil is inadequately managed or from imported material.

The borrow areas for the construction of the spillway and new raised dam embankment have been determined irrespective of LSC classes but rather based on potential to provide appropriate structural stability. Topsoil stripped from any areas for new infrastructure for construction should be retained for rehabilitation (general disturbance areas and the rockfill quarry).

ii Soil mixing

Impacts on soils and LSC are typically a function of topsoil loss or degradation during construction and/or soil inversion due to poor soil management. Topsoil has the highest biological activity, organic matter, and plant nutrients which are all key components of a productive soil. The potential loss of this upper layer of soil impacts the ability of the soil to provide nutrients, regulate water flow, and resist pests and disease.

Inappropriate separation of topsoil and subsoils during stripping and stockpiling can result in less fertile topsoils due to introduced constraints (such as sodicity or salinity) or potentially constrained subsoils forming the upper part of the soil profile. Mixing of the soil profile can also result in increased stoniness of surface soils impacting the ability to cultivate the soil. Given the acidic and aluminium constrained soils encountered in the study area, inappropriate soil handling practices represents a key risk for land and soil capability.

VENM/ENM may be imported to provide materials for rehabilitation purposes. The sources of VENM/ENM has the potential to result in less desirable soil physical and chemical properties than the *in-situ* subsoils present. Imported material will need to be characterised and appropriately handled during rehabilitation works to ensure that it is placed in a suitable portion of the recreated soil profile.

Loss of nutrients and nutrient holding capacity in soil can result in a less fertile environment for crop and pasture production. The organic matter and finer soil particles, primarily clays, responsible for soil fertility can be readily eroded when exposed leaving larger, less reactive particles such as sand and gravel.

iii **Compaction**

Topsoil degradation can result in organic matter reduction that can lead to soil density increases and subsequent compaction. Construction equipment, such as plant movement, can also compact the soil.

Compaction reduces the infiltration rate of water into the soil profile, available water holding capacity, gaseous exchange and plant root and shoot penetration. Lower organic matter levels are also associated with weaker soil aggregates and therefore greater risk of further erosion and soil crusting.

iv **Soil salinity**

Construction activities are not anticipated to significantly alter the soil hydrology leading to mobilisation of salt that would affect the water quality in the water storages or resulting in surface expression causing scalding. There was no soil salinity present in laboratory testing, and any salt present in subsoils will be covered by topsoil in any earthworks areas requiring rehabilitation. Overall construction activities are not expected to be impacted by or adversely impact on salinity.

v **Acid sulfate soils**

ASS risk mapping indicates that the Proposal is not located in or in proximity to areas mapped with ASS risk as per the NSW OEH Acids Sulfate Risk Map (OEH 2018) and are Bn(p4), Low Probability of Occurrence with moderate confidence per the Atlas of Australian ASS mapping (Fitzpatrick *et al.* 2011).

Due to the high elevation of the Proposal relative to coastal areas where ASS is more prevalent, it is considered that ASS would not be disturbed as part of the works and therefore not impacted. Should ASS be discovered onsite during construction, processing will cease, and the material will be managed according to the relevant guidelines, such as the NSW Acid Sulfate Soil Manual (Stone *et al.* 1998).

8.1.2 **Operational soil impacts**

Impacts to soils during operation of the Proposal are expected to include:

- permanent inundation of land due to FSL and potential inundation due to a PMF event
- localised soil erosion associated with fluctuating water levels within the reservoir area resulting in overland flow over exposed soils
- erosion and subsequent sedimentation potential from disturbed areas such as permanent unsealed tracks and drainage structures

- soil disturbance from maintenance activities such as use of machinery, vehicle traffic and excavation.

Impacts relating to soil erosion are described in Section 8.2.

i Inundation of soil resources

Raising the dam wall and FSL will inundate areas of land not previously inundated and result in additional areas subject to potential inundation in large flood events. These inundation extents include the FSL level and will result in the loss of the soil resource for other productive uses. Areas of potential inundation up to and including the PMF event are above the FSL level but are not expected to result in a loss of resource, however though it does increase the potential risk of these lands subject to flooding.

As described in Section 3.6.6, assessment of LSC has determined the study area is LSC Classes 3 to 8, but predominantly Class 4, representing a wide range of productive use capability from high to extremely low. Of the lands to be inundated, land use mapping indicates that approximately:

- 52.0% is ALUM 2.1.0, grazing native vegetation and 3.2.0, grazing modified pastures
- 36.3% is ALUM 1.3.3, residual native cover
- Remaining 11.7% is a mixture of rural residential (ALUM 5.4.0), transitional lands (ALUM 3.6.0), horticultural activities (ALUM 3.4.0), infrastructure (ALUM 5.4.0), conservation areas and plantation areas (ALUM 1.1.0 and ALUM 3.1.0).

However, the existing catchment is largely destocked to minimise impacts to water quality and therefore impacts to agricultural use of the area will be minimal. Changes in the PMF extent due to the Proposal, compared to existing predictions, will result in an increased potential inundation area subject to wetting, but this is unlikely to have any material implication for land use.

The impacts to LSC of the Proposal suitable for agriculture (LSC Classes 3–6) are not significant based on the impacted percentage (approximately 0.3%) in the Tweed Shire LGA area (refer Table 8.1) and the impacted areas will not fragment contiguous areas of potential agricultural land. Any fluctuation of the FSL including consideration of the PMF event is unlikely to materially affect the significance of these impacts.

The LSC status of lands subject to infrastructure with a small footprint or temporary disturbances will be able to be maintained or reinstated following appropriate soil management, landform design and rehabilitation.

Table 8.1 Proposal LSC impact in the Tweed Shire LGA

Area (ha)	LSC Class							
	1	2	3	4	5	6	7	8
Tweed Shire LGA	0	0	10660.47	23412.04	71.05	31472.89	46273.86	16229.73
Proposal	0	0	13.84	182.80	0	1.16	0.02	51.35
Reduction (%)	0	0	0.130	0.781	0	0.004	<0.001	0.316

Appropriate management and mitigation techniques are provided in Chapter 9.

8.2 Erosion and sediment control

The main consequences of erosion are loss of topsoil/subsoil and degraded water quality as mobilised sediments are transported into downstream watercourses and waterbodies. Loss of topsoil and subsoil will reduce the ability to reinstate disturbed areas with revegetation following completion of construction, thus exacerbating erosion impacts in the longer term.

8.2.1 Construction erosion and sediment control impacts

There is a potential soil erosion risk and related sedimentation impacts associated with the construction activities. Construction activities that clear vegetation, disturb the soil or concentrate runoff over disturbed areas have the potential to cause soil erosion and sedimentation.

Potential construction erosion and sediment control impacts include:

- off-site discharge of sediment and turbid runoff from the erosion of exposed soils particularly any dispersive subsoils:
 - degradation of water quality through nutrients and sedimentation
 - infilling of waterway pools with sediment
- mud tracking from vehicles and machinery to public roads
- increased potential for rill and gully erosion due to modification of flow conditions from sheet flow to concentrated flow from constructed landforms (roads, tracks, hardstands) and drains
- increased erosion and subsequent sedimentation due to pavement rutting and pavement degradation from increased light and heavy vehicles traffic on unsealed access roads, especially where longitudinal gradients range from 8 to 10%
- tunnel erosion under or beside foundations and along cable trenches
- dust emissions from unsealed roads, hardstands and exposed soils.

i Quarry sediment control

Quarry extraction activities have the potential to generate significant volumes of sediment and turbidity. The quarry activities will require additional management measures to be adopted to control water from entering the quarry and to prevent sediment laden water from being released to the dam.

To achieve this:

- Temporary clean water diversions will be required to the north and south around the quarry extent, draining to the dam. These diversions are to be rehabilitated as part of the quarry closure and rehabilitation.
- Sediment control structures will be required to be located at the catchment outlet from the quarry. These will be sized in accordance with *Soils and Construction – Volume 2E for Mines and Quarries* guidelines by DECC (2008) including holding capacities for an 85th percentile, 5-day management period (based on sensitive receiving environments and construction duration greater than one year).
- PMF events following the dam raise are expected to interact with the eastern edge of the quarry. This is to be considered further as part of quarry design and rehabilitation planning.

ii Haul roads and other temporary unsealed access roads

Haul roads and other temporary unsealed access roads have an increased potential for being sources of sediment. OEH (2012b) and DECC (2008b) outline minimum requirements for the configuration of unsealed roads to manage sediment. These requirements are summarised in Table 8.2 as an indication to the design constraints that exist during the construction of the Proposal.

Table 8.2 Temporary unsealed road parameters

Feature	Design parameters
Maximum longitudinal grades	8 to 12%*
Maximum flow length	50 to 60 m – recommended cross-drains*
Maximum Cut Batters	1V:1.5H for Rock – slip plane dipping toward cutting
Maximum crossfall	One-way crossfall: 1V:15H

Note: *Parameters based on a Class B soil of high erodibility

Following the completion of construction activities, cut batters for temporary access roads will require rehabilitation which OEH (2012b) indicate should consider for batters of any angle over 5 m in height, benching at intervals not exceeding 5 m and hydrogeological breaks at no greater than 5 m.

iii Temporary watercourse crossings and construction access pad

Available construction area downstream of the dam wall is expected to be constrained during the period of construction. Due to this, temporary watercourse crossings are planned for haul road options across Doon Doon Creek.

Temporary watercourse crossings will extend from the valve house into the centre of Doon Doon Creek and from the centre of Doon Doon Creek across the existing spillway. The crossings will be supported by fill to form the construction access pathway. This will also include the creation of a construction pad downstream of the dam wall.

Temporary waterway crossings are to be sized and implemented in accordance with the *Controlled activities – Guidelines for instream works on waterfront land* (DPE 2022b). Temporary culverts used in crossing Doon Doon Creek downstream of the valve house ('Outlet Flow Culverts') will allow the conveyance of intentional releases from the MLO to Doon Doon Creek. Temporary culverts used downstream of the spillway ('Spillway Culverts') will typically allow the conveyance of minor spillway discharges up to a frequency of about one exceedance per year. In spillway flow events that are greater than the culvert capacity, overtopping of the temporary crossing and construction fill is likely and may result in elevated turbidity within Doon Doon Creek and the potential transport of rock fragments downstream.

Mitigation measures for overtopping of temporary crossings and inundation of the temporary construction access pad to be located downstream of the spillway will be further developed during the detailed design phase, and are likely to include:

- hydraulic modelling of the proposed design surface and flows to determine likely shear stress
- selection of rock of a suitable diameter such that mobilisation is a low likelihood.

Similar to the requirements outlined above, less significant ephemeral tributaries draining from the western slopes will also need temporary crossings where these traverse proposed haulage and access roads.

Implementation of temporary watercourse crossings for unsealed haulage and access roads will mitigate erosion and sediment loss into the existing dam during construction of the Proposal. The volume of material potentially mobilised in a larger flow event is expected to be minor with the mitigation measures in place.

iv Concrete batching plants and laydown areas

Areas for construction equipment laydown and temporary concrete batching will be established on levelled areas and include appropriate diversion of clean water away from the operational areas. Stabilisation of these established pads would include a form of ground stabilisation such as pavement or gravel which will reduce the potential erosion, material tracking and general maintenance issues of these areas during construction.

v Offices and accommodation

Construction of offices and temporary construction accommodation areas will include establishment of levelled areas for which both permanent and temporary buildings can be established. Areas dedicated to traffic movements associated with offices and construction accommodation would be stabilised to mitigate potential erosion and soil loss.

8.2.2 Operational erosion and sediment control impacts

Potential operational erosion and sediment control impacts include:

- offsite discharge of sediment and turbid runoff from ongoing erosion from unsuitable drainage, landform and infrastructure design
- increased maintenance for ongoing stabilisation of landforms, roads, drains and infrastructure
- operation and maintenance of sediment control structures due to ongoing erosion
- decrease in dam capacity and water quality due to upstream deposition of eroded sediment
- reputational damage and litigation costs associated the non-compliance and pollution events.

Appropriate management and mitigation techniques are provided in Chapter 9.

i Water level changes

Soil structural decline associated with the wetting and drying of the in-situ soils in the dam reservoir area due to fluctuations in water level, drowning of vegetation and wave action can lead to the formation of erosion scarps in the landform from bank weakening and slumping. Concentrated flow associated with lateral gullies may result in upward migration of gully headcuts from locations where scarps are formed.

Soils within the study area were found to be relatively resistant to erosion due to their electrochemical stability and rockiness but are potentially at risk of slumping. Many of the lateral gullies were observed to have eroded to bedrock in some locations and generally have a high rock bed load and significant head cut migration is not anticipated.

Discussion on the potential for and impacts of landslips and slumping is discussed further in Section 8.4.

8.3 Geomorphological impacts

As discussed in Section 3.10, the Doon Doon Creek system downstream of the dam is a high gradient gravel-based creek system with the bed material dominated by loose gravel and larger rocks. The creek has obvious pool and riffle sequences.

Overall, there is low risk of wholesale channel shift due to the Proposal, based on the available data including flood frequency and sediment data, and observed behaviour.

The upstream catchment is highly confined by valley margin bedrock such that little variation on flow regime is expected to occur. The catchment morphometrics suggest little potential for change to sediment stores with low flood peak regimes, low relief ratio and moderate elongation ratio. That is, flood peaks are likely to be distributed over a wider surface area. However, there is evidence to suggest that land clearing and localised surface disturbances are likely to increase the erosive potential of areas adjacent to the instream water level, particularly where riparian vegetation and long woody debris has not been retained. Clearing of vegetation up to the proposed FSL would be assessed as part of detailed design. It is noted that stumps would likely be retained for soil and bank stability, and due to access issues, it is likely not all areas would be cleared. Higher risk areas for vegetation clearing includes those areas of the Proposal within the Frogs Hollow soil landscape and slopes exceeding 1H:3V. For higher risk areas additional erosion protection measures should be implemented.

Stratigraphic discontinuity suggests the active stripping and re-sedimentation of in-channel and bank-attached units, often occurring as a complex geomorphic response to peak floods. The sediment regime is dominated by cohesive materials that resist entrainment due to various inter-particle reactions. However, if threshold limits are exceeded, these materials are easily suspended into the water column and may remain suspended for considerable time; possibly having negative consequences for ecosystem quality and health risks for anyone accessing water downstream. Sedimentation of downstream systems can lead to the following impacts:

- loss of essential aquatic habitat areas (both within the pools and riffles)
- a reduction in the total submerged surface area (by infilling bed and riffle voids and other surface irregularities) thus reducing the potential aquatic food supply
- an increase in the stability of riffle rock, thus reducing the natural movement and sorting of the bed material.

There is reasonable riparian vegetation within the channel and bank areas, including large woody debris and bedrock exposures that retard the erosive potential of flow paths through wall boundary layers.

There is insufficient statistical evidence to suggest any wholesale shift is to be expected under the flow conditions observed since 2009 (limited by available data).

Hydrologic and hydraulic modelling described in the SWA indicates a potential reduction in flood peak flows that will result in reduced frequency of erosive events, and increased future geomorphological stability. Releases from the dam to meet water sharing plan rules are likely to be more frequent however bed shear stress predictions indicate flows will be less than 100 newton metres squared with negligible difference between the existing and proposed scenarios. Bed shear stress within pools downstream of the dam is expected to remain low and not be materially affected by the Proposal.

8.4 Geotechnical considerations

This section addresses selected geotechnical considerations related to sourcing, importation and management of overburden and quarried materials, landslide risk and landform stability.

8.4.1 Volume and emplacement of overburden and quarried materials

i Dam wall and spillway

The largest elements for construction of the Proposal are construction of the spillway and raising of the dam wall. Construction of the spillway would require excavation of volumes of existing material, whereas the dam wall raising would require the use of various fill materials. The NSW PWA (2018a) geotechnical surveys indicated that the dam raising would require a total material volume of 133,000 cubic metres consisting of:

- Zone 1 – 8,000 cubic metres
- Zone 2 – 30,000 cubic metres
- Zones 3A/3B – 95,000 cubic metres.

The cut volumes required for the proposed spillway would generate approximately 190,000 cubic metres. Embankment and foundation excavation for the dam wall would generate 24,200 cubic metres. The bulk of material extracted from the excavations would likely be unsuitable for Zones 3A/3B required for raising the dam embankment, hence there would be a greater reliance on sourcing material from the quarry, which geotechnical investigations indicated sufficient material of adequate quality is available (NSW PWA 2018a). Up to 125,000 cubic metres of rock-fill is proposed to be removed from the quarry for dam construction (Coffey 2021). The extents of the quarry expansion have been based on a preliminary constructability assessment and would require expansion into surrounding vegetated areas to the north, west and south. The NSW PWA estimate excavating the quarry to a floor base at an elevation of 68 mAHD would yield 100,000 cubic metres of suitable material, with an estimated quarry excavation width of 55 m. Excavation would consist of benching the quarry from the top down with haul roads running along the contours to the dam, with continual lowering in line with the descending quarry benches.

Material within the quarry is subject to further geotechnical testing such as the in-situ weathering profile, rock strength, the quality and quantity of material needed, stability concerns during cutting operations, excavation and haulage techniques, the requirement for stockpiles, and the proposed end-use objectives. Conducting a comprehensive geotechnical investigation involving targeted drilling, extensive strength testing, and thorough analysis would minimise the impacts associated with acquiring fill material and would enable the development of a safe quarry design for the extraction of rockfill material.

Stockpiling is proposed northeast of the site near the proposed concrete batching plant or in a proposed promontory area along the north-western end of the dam, which is a proposed alternative to the haul road. The promontory would create a large laydown area connecting to the quarry and allow material stockpiling from activities including spillway excavation, the rock quarry and Clarrie Hall Dam Road. Based on the current concept design, KBR (2023) determined the cut fill balance for the major construction elements would result in an excess of 206,200 cubic metres due to excavation of the spillway. Coffey (2021) indicated that the management of excess rock and overburden material from the Proposal may include exporting material offsite. However, due to the rehabilitation requirements of the rockfill quarry following construction, a significant amount of the excess volume could be used to reshape the residual quarry void. The following summary provides a basis for estimating the overall material balance:

- Assuming a rehabilitated landform, similar to those surrounding with a gradient of up to 35% (19.3 degrees) with an easterly aspect.
- Backfill of approximately 125,000 cubic metres extracted for the Proposal.
- Backfill of approximately 14,000 cubic metres extracted for the original construction of the dam. This volume is a conservative estimate considering the original dam required approximately 80,000 cubic metres (Hawke 1983, considering bulking factors) of rock from the quarry with no indication that the area was previously rehabilitated.

Through this assessment, it is evident that at least 67,200 cubic metres of material may still be remaining following construction of major Proposal components. Use of excess overburden and rock material within other elements of the Proposal is expected, however it is anticipated that a residual quantity of excess material would remain. If beneficial use cannot be found onsite, or within other nearby construction projects, the remaining material would be disposed offsite to a licensed landfill or other approved disposal site.

ii Realignment of Clarrie Hall Dam Road and intake tower

The construction assessment for the realignment of Clarrie Hall Dam Road will result in excess cut rock and overburden material being available to the Proposal (KBR 2023). The concept design material quantity estimates a total cut volume of 21,300 cubic metres of rock and overburden. The quality of material is unknown and subject to further geotechnical testing. KBR indicate that construction of this area earlier in the schedule of works may potentially mitigate rehandling of any material if suitable rock can be identified. Reuse of cut material from the road will require processing, stockpiling or emplacement local to the works area downstream of the existing dam wall. Remaining excess material will need to be disposed offsite to a licensed landfill or other approved disposal site.

The intake tower will not significantly influence the material balance of the Proposal.

iii McCabes Bridge and road alignment

Construction of the McCabes Bridge will utilise excess suitable material from the Proposal specifically the material from the proposed spillway excavation. Material will be used in the abutments and for changes in the vertical road alignment. Due to availability of land nearby this construction site, stockpiles of excess rock and overburden materials from the dam raising construction activities could be stored within this work site.

iv Haul road options

Coffey (2021) indicates that material for haul road options will likely utilise rockfill material from the proposed spillway excavation that cannot be utilised in the dam embankment raising. Option 1 haul road will likely utilise a greater volume of material than Option 2 based on road length and form. Option 1 was assessed by KBR (2023) as resulting in 24,000 cubic metres of spoil material (not allowing for bulking factors) and having significant construction requirements (i.e. cut volumes are comparable to the major construction components of the Proposal).

v General material stockpiling

Detailed design and construction planning stages will need to consider locating stockpiles in designated stockpile/laydown areas, and importantly outside of riparian zones, floodways and areas of concentrated surface water flow (at least 2 to 5 m). Stockpile placement should allow for ready access whilst limiting risks associated with erosion and stability. Guidance on recommended slope lengths for erosion are contained in Section 5.3.2ii.

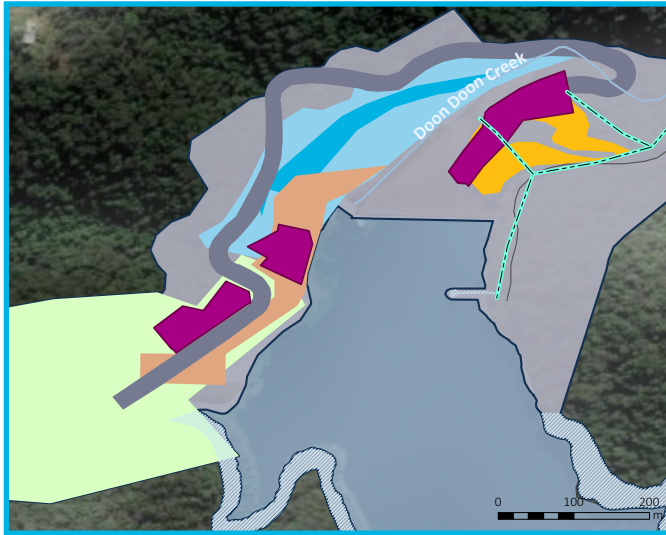
Current planned areas for material stockpiles are shown in Figure 8.1. These areas are preliminary and subject to further refinement with the design and construction planning of the Proposal.

8.4.2 Landslide risk

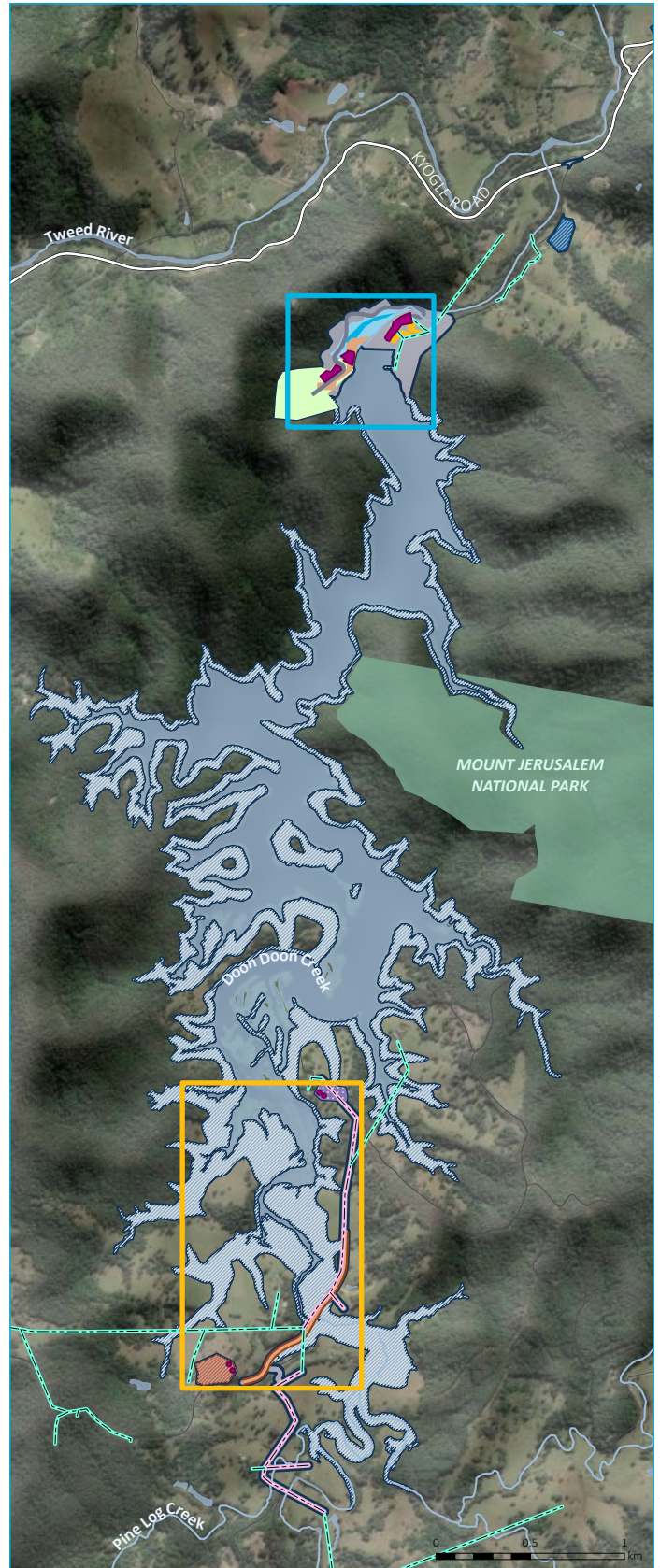
The Australian Building Codes Board released a publication *Landslide hazard: handbook* (2015), which provide an overarching regulatory perspective on the Australian Geomechanics Society published *Guidelines on Landslide Risk Management* (2007) and details when a landslide risk assessment is required. The Clarrie Hall Dam site is considered to qualify for the need for assessment due to the presence of landslide hazards and events. Rock excavations less than 7.5 m deep require Specialist Advice B (geotechnical engineer advice is recommended) and Specialist Advice C (geotechnical engineer advice is necessary) for natural slopes up to 20° (1V:3H) and between 20° to 40° (1V:1.2H) respectively.

Any construction or operational impacts that increase potential slopes or increase soil moisture content, such as the zone where water levels fluctuate, are likely to be subject to increased landslide risk. This risk is likely to increase again when located within the mapped Frogs Hollow Soil Landscape and in areas of elevated length/slope factors.

Generally, Coffey (2021) conclude that the level of landslide/instability risk to upstream persons or property from a geotechnical viewpoint is considered to be minor due to the extreme isolation, lack of access and general absence of infrastructure in areas where potential instability is likely.



Source: EMM (2024); KBS (2024); DCSSS (2023); ESRI (2024)



GDA2020 MGA Zone 56

KEY

- Study area
- Full supply level- proposed
- Proposed stockpile
- Proposed layout
- Haul Road- option 1
- Haul Road- option 2
- Office location
- Potential McCabes Bridge stockpile and construction office complex
- Quarry impact area

- Proposed spillway
- Spillway impact area
- Concrete batching plant or workforce accommodation
- Potential McCabes Bridge stockpile and construction office
- McCabes Bridge proposed realignment
- Transmission line
- Existing
- New

- Existing environment
- Rail line
- Major road
- Minor road
- Named watercourse
- Waterbody
- NPWS reserve

Proposed stockpile areas during construction

Clarrrie Hall Dam EIS
Land, Soils and Erosion Assessment
Figure 8.1

8.4.3 Dam embankment stability

NSW PWA (2018b) states that design analyses are not necessary for a conventional concrete face rockfill dam. The presence of a concrete face ensures that the rockfill remains dry and free from pore pressure.

According to the DSC guidance (NSW PWA 2018b), concrete faced rockfill dams constructed with free draining rockfill can often be designed based on past successful performance, and such a design approach is acceptable to the dam safety regulators.

The existing Clarrie Hall Dam embankment is constructed using fresh to slightly weathered free draining rockfill and features upstream and downstream slopes with a ratio of 1V:1.3H. The foundation consists of a uniform sequence of hard rhyolite rock with some minor welded tuff. The embankment slopes of 1V:1.3H have been maintained in the proposal and were originally selected based on precedent and previous research without the need for stability calculations.

In options studies undertaken for the Proposal, it was determined that there were no engineering impediments to raising the dam in this location (NSW Department of Commerce 2008).

Coffey (2021) as part of their investigative works on the Proposal concluded:

- Based on the well documented geotechnical information of the site historically and as part of the Proposal, the dam wall raising is located on slightly weathered to fresh rock that is of very high to extremely high strength therefore suitable to support the increased embankment foundations.
- The new spillway is proposed to be anchored in various conditions of rock as per drilling results by NSW PWA (2018a). Coffey and NSW PWA indicate that to provide the best founding conditions, additional engineering controls such as longer anchoring bolts, may be necessary. Despite these additional controls the proposed spillway can be supported by the existing geological conditions.
- Proposed access roads, road alignments, bridges and intersections will be designed and constructed in accordance with appropriate design standards and geological conditions present. The dam access road will require cut batters into rock that will be confirmed for stability by an appropriately qualified geotechnical engineer.
- Utilisation of the existing rockfill quarry to supply construction materials to the Proposal has been confirmed through documentation of assessments by NSW PWA and historical reporting by GSNSW and Hawke. The proposed expansion extent of the quarry has been conceptualised however a quarry design is required as part of the proceeding stages of the Proposal to be confirmed by an appropriately qualified geotechnical engineer. Analogues within the existing dam site are present to support long term stable steep cut faces and bench configurations.

9 Rehabilitation strategy

A suitable rehabilitation management plan (RMP) should be developed with the objective to guide the development of safe, stable and non-polluting landforms that can support and sustain future land uses. The dam is not expected to be decommissioned into the future. The RMP is specific to its transition from construction to operation and should cover post-construction rehabilitation requirements.

The RMP should:

- identify the final land uses for the site with consideration of existing and surrounding land uses
- identify the conceptual final landform(s), including any to be constructed from waste spoil
- identify site-specific risks to rehabilitation establishment and long-term success (e.g. landform design and stability; soil capability, quality and availability; climate and rainfall and other)
- identify rehabilitation methodologies to suit the site, with consideration of identified risks
- describe how rehabilitation performance will be monitored (and provide evidence to demonstrate that rehabilitation completion criteria have been achieved)
- nominate conceptual rehabilitation objectives, completion criteria and performance indicators for relevant aspects (e.g. landform stability, agricultural productivity, native vegetation, groundwater, surface water)
- nominate proposed rehabilitation maintenance programs to address any deviation from desired rehabilitation standards and/or progress.

Aspects relating to identified land and soils constraints and values are identified below to provide a summary overview of potential rehabilitation and closure options and considerations.

9.1 Rehabilitation objectives

The overarching rehabilitation objective should be to achieve final landforms that are:

- safe, stable and non-polluting
- sympathetic with the surrounding landscape
- appropriate to the nominated final land uses.

Conceptual rehabilitation objectives and completion criteria for specific environmental aspects, and phases of rehabilitation should be developed. The objectives will describe what is to be achieved, and the completion criteria are the principles or standards (either qualitative or quantitative) that will be used to demonstrate that objectives have been met.

Formal rehabilitation objectives and completion criteria for the Proposal, including associated rehabilitation performance indicators and measurement methods, will be addressed within RMP for the Proposal.

Consistent with rehabilitation planning principles it is expected that rehabilitation objectives, criteria, performance indicators and measurement methods will be refined over time as the state of knowledge of the environment and site-specific rehabilitation techniques evolves.

9.2 Rehabilitation risks and controls

Table 9.1 summarises the rehabilitation risks and proposed controls for the Proposal that will be considered as part of future design stages and RMP development.

Table 9.1 Rehabilitation risks and controls

Aspect	Risk	Control
Geotechnical stability	Due to the steep nature of the terrain, current knowledge of geology and spoils and the nature of the proposed constructed landforms and structures, geotechnical instability is a key risk.	Increased geotechnical design detail will be provided during the detailed design stage, and subsequent stages, informed by further geotechnical investigations and testing.
Erosion	Ongoing erosion can potentially impact on constructed slopes and landforms undergoing rehabilitation, resulting in re-work, loss of material and generating turbid runoff. As described in Chapter 5, the Proposal has a generally high erosion hazard due to high slopes and rainfall with moderately erodible soils.	Landform and drainage design will therefore need to be appropriate for the soils present, as well as management of steep slopes (i.e. greater than 20% gradients). Final landforms will need to be designed and constructed to achieve sustainable rates of soil loss. Active stabilisation will be required for areas of timber harvesting within the FSL. Timber harvesting would involve cutting trees to stump height with the root mass left <i>in situ</i>.
Revegetation	Revegetation opportunities are limited on rocky ground or overburden materials, especially when slopes are steep, limiting soil depth.	Where suitable topsoil does not exist, or slopes are too steep for topsoil placement, the material emplacements will be seeded and protected from erosion using hydraulically applied growth mediums or rolled erosion control products. Riparian revegetation should aim to enhance existing native vegetation through exotic weed clearing. Where dead wood debris has been removed or cleared as part of the construction, consideration should be made on reinstating equivalent features to reinstate flood resistance (channel roughness).
Rehabilitation soil resources	Availability, suitability and quality of soils across the Proposal are highly variable due to a combination of terrain (topography) and soil physical and chemical constraints. In some areas, steep terrain is likely to prohibit the safe access and operation of preferred surface mobile equipment (e.g. bulldozers) to undertake soil stripping and future soil reinstatement works. Soils in steeper areas are also generally variable in depth, which impedes accurate stripping and separation of the topsoil and subsoil horizons and result in the undesirable mixing of soil layers.	The assessment of actual topsoil and subsoil resources available for recovery can only be determined through detailed soil assessments prior to ground clearing works and where soils/cover vegetation to be cleared is assessed as having low or no weed load. Where a deficit of soil exists, alternative growth media – such as commercial hydraulic and pneumatically applied growing media such as straw mulches and compost blankets, will be required to provide a suitable growing medium in addition to erosion protection while the vegetation establishes.
Biosecurity	Weeds have the potential to exclude and out-compete native vegetation and desirable pasture species. The presence of exotic weed species is most likely in lower lying areas (e.g. foothills and floodplain areas) and less likely in upper/elevated areas. Pest species can damage establishing vegetation through grazing pressure and damage to soils/growth media (digging and burrowing), compete with native fauna for resources (food, water and habitat) and prey on native fauna and livestock.	Weed and pest survey and control will be required through the construction, operations and rehabilitation phases of the Proposal in areas of, and surrounding disturbance activities. Management of red imported fire ants is an active concern for the region. The Proposal will require active treatment and management of material stockpiles both imported and extracted from the Proposal. Treatment and management of this pest will be in accordance with the requirements of NSW DPI and the National Fire Ant Eradication Program.

Aspect	Risk	Control
Public safety	Retained infrastructure may result in harm to members of the public, livestock, and native fauna.	Controls will be implemented to minimise the potential for impacts on public and fauna safety, such as fencing and warning signs (for example, at access points to reservoir embankments and open water).
Bushfire	Uncontrolled bushfires can impact rehabilitating systems (both establishing and mature revegetation) and destroy, or substantially delay, rehabilitation trajectory.	Fire management controls to be implemented in coordination with the NSW Rural Fire Service and other authorities, as relevant.
Landform design	Unsuitable design of the final landform could prevent or constrain the intended end land use(s).	Landform design should consider the limitations and mitigate the identified risks suitably.

10 Mitigation measures

Recommended safeguards and mitigation measures for land, soils and erosion are listed in Table 10.1.

Table 10.1 Mitigation measures

Ref#	Aspect/Impact	Mitigation measure	Responsibility	Timing
Land and Soil Capability				
LSE_01	Administrative controls	A Soil and Water Management Plan (SWMP) will be prepared and implemented as part of the Construction Environmental Management Plan (CEMP). The SWMP will identify all reasonably foreseeable risks relating to soil erosion and water pollution and describe how these risks will be addressed during construction. The SWMP will: • Assess and detail the requirements to comply with relevant policies guidelines, legislation and other approvals. • De developed in accordance with the principles and requirements in <i>Managing Urban Stormwater – Soils and Construction, Volume 1 (Landcom 2004)</i> and other relevant volumes. • Contain Erosion and Sediment Control Plans (ESCPs) for all work sites. ESCPs will be implemented in advance of site disturbance and will be updated as required as the work progresses and the sites change. • Contain management procedures for activities, which may result in water pollution or to minimise the risk of erosion and sedimentation. • Outline management requirements of excess materials including stockpiling and disposal options and requirements for unsuitable construction materials. • A construction schedule, and description of how the plan will work through the various stages of construction. • Detail the review and inspection processes for onsite measures to mitigate erosion and sedimentation and water quality risks. • Detail the responsibilities for the management and implementation of the SWMP. • Be complementary to the Landscaping and Revegetation Plan, and RMP.	Contractor	Pre-construction Construction Post-construction

Ref#	Aspect/Impact	Mitigation measure	Responsibility	Timing
LSE_02	Soil stripping and management plan	As part of the SWMP for the Proposal, soil management measures are recommended to ensure the preservation of soil resources, including: • Assessment of topsoil depths to be stripped prior to stripping to minimise the mixing of topsoil and subsoil. • Preserving as much of the topsoil as possible. • Attempt to strip and manage different soils orders or mapping units separately. • Avoid mixing topsoil with subsoil during soil handling operations. • Where subsoils exhibit variance of constraints with depth consider managing subsoils in separate layers to minimise introduction of constraints higher into the soil profile. • Avoid stripping soil following heavy rain periods that leaves the soil structure saturated. • Avoid compaction of soil during stripping and stockpiling operations. • Amelioration of topsoil and, where necessary, subsoil during stripping operations in accordance with a soil scientists' recommendations. Ameliorants should be applied prior to stripping of their respective layers, to maximise mixing of the ameliorants during the stripping process. • Stockpile topsoil separately from subsoil (if it is necessary to strip subsoil). • Ensuring reinstatement of soil horizons in the correct order and depths, where possible. • Where practical and possible, the subsoils and topsoils should be located so that stockpiled material is placed on the same underlying soil unit. • Protection of stockpiles from erosion using soil stabilising polymers, cover crops or other forms of stabilisation. • Revegetation of long-term topsoil stockpiles with native plant community types to minimise stockpile water logging, the generation of anaerobic conditions, help maintain topsoil biological viability and to create a seed store. • Test stockpiled subsoil and topsoil to determine amelioration requirements prior to reinstatement. • VENM/ENM will be imported into the quarry to provide materials for rehabilitation purposes. The VENM/ENM potentially has less desirable soil physical and chemical properties than the in-situ subsoils and will need to be characterised and appropriately handled during rehabilitation works to ensure that it is placed in a suitable portion of the recreated soil profile. • Weed and pest survey and control will be required through the construction, operations and rehabilitation phases of the Proposal in areas of, and surrounding disturbance activities. • Management of red imported fire ants is an active concern for the region. The Proposal will require active treatment and management of material stockpiles both imported and extracted from the Proposal. Treatment and management of this pest will be in accordance with the requirements of NSW DPI and the National Fire Ant Eradication Program.	Contractor	Pre-construction Construction Post-Construction
LSE_03	Soil stripping and management	Strip and save topsoil resources from disturbance areas that will be inundated to use for rehabilitation (if suitable) of other Proposal related disturbed areas.	Contractor	Construction

Ref#	Aspect/Impact	Mitigation measure	Responsibility	Timing
LSE_04	Rehabilitation	Preparation of a RMP. Final rehabilitation of lands to be undertaken in accordance with approved completion criteria.	Contractor	Pre-construction Construction Post-construction
Erosion and sediment control				
LSE_05	Administrative controls (for all areas)	It is recommended to implement erosion and sediment control measures and site rehabilitation and revegetation in accordance with industry standard practice comprising Managing Urban Stormwater: Soils and Construction – Volume 1 (Landcom 2004), Volume 2A, Volume 2C, Volume 2E (DECC 2008a, 2008b, 2008c) and Best Practice Erosion and Sediment Control (IECA 2008). Preparing an overarching ESCP and Progressive Erosion and Sediment Control Plans (PESCPs) for all Proposal disturbances and phases, including: • access roads • internal roads and haul roads • powerline tracks and pads • any upstream and downstream coffer dams • laydown and stockpile areas • concrete batching plants • accommodation camp and associated facilities • quarry areas • dam construction site • spoil disposal areas • any existing dam decommissioning areas. The ESCPs shall be prepared and certified by a suitably qualified and experienced certified professional in erosion and sediment control. Measures and principles should include: • minimising the extent and duration of land disturbance • controlling water movement through the site • minimising soil erosion • promptly stabilising disturbed areas • maximising sediment retention on site • maintain drainage, erosion and sediment control measures • monitor and adjust drainage, erosion and sediment control practices to achieve the desired performance standard • construction of suitable watercourse crossings.	Contractor	Pre-construction

Ref#	Aspect/Impact	Mitigation measure	Responsibility	Timing
Geomorphology				
LSE_06	Avoid disturbance to waterways	Avoid disturbance of the riparian area to minimise sedimentation, bank damage and enhance soil and water quality. Instream works to be undertaken in accordance with state guidelines including: - Controlled activities – guidelines for riparian corridors on waterfront land. - Controlled activities – guidelines for watercourse crossings on waterfront land. - Controlled activities – guidelines for outlet structures on waterfront land. - Controlled activities – guidelines for instream works on waterfront land.	Contractor	Construction Post-construction
LSE_07	Avoid disturbance to waterways	Detailed design of the bridge crossing to include the specification of appropriate scour protection of the piers to the required industry standards including: Guide to Bridge Technology Part 8: Hydraulic Design of Waterway Structures.	Contractor	Pre-construction Construction
Geotechnical considerations				
LSE_08	Additional geotechnical investigation	Undertake detailed geotechnical investigation suitable for construction in conjunction with detailed design phase of the Proposal including: - in-situ weathering profile - rock strength - the quality and quantity of material needed - stability concerns during cutting operations - excavation and haulage techniques - requirement for stockpiles - proposed end-use objectives - landslide risk.	Contractor	Pre-construction Construction
LSE_09	Quarry design	A quarry extraction plan will be developed in accordance with relevant standards and requirements outlined by the NSW Resources Regulator. Quarry stability to be confirmed by appropriately qualified geotechnical engineer.	Contractor	Pre-construction Construction
LSE_10	Landslide risk management	A geotechnical investigation by a professional with specialist knowledge on landslide risk management will: - identify potential landslide hazards and conducting an assessment and evaluation of associated risks - verify that geotechnical works are incorporated within the engineered design - verify that the sub-surface conditions exposed during construction are consistent with those included in the risk assessment - provide evidence of conformance of geotechnical works within the construction of the proposed works.	Contractor	Pre-construction Construction

Ref#	Aspect/Impact	Mitigation measure	Responsibility	Timing
LSE_11	Design and construction	Design and construction stages to consider: - the requirement to stockpile materials and make suitable allowances for stockpiling of materials as required - suitable design to ensure suitable long term topographical and geotechnical stability - strength and quality of materials to ensure suitable material is available.	Contractor	Pre-construction Construction

11 Conclusion

This LSEA supports the EIS for the Proposal and addresses the relevant SEARs. It documents the assessment methodology, results and the mitigation and management measures proposed to address any unavoidable and significant residual impacts to land and soils arising from the Proposal.

Potential land and soils related impacts associated with the Proposal were assessed, including impacts to:

- soil quality and quantity
- erosion hazard
- agriculture
- geomorphology.

The report also describes selected geotechnical considerations raised in the SEARs related to sourcing, importation and management of fill and quarried materials, landform stability and the potential for landslides.

Key findings are described in the following sections.

11.1 Soils

Assessment of the existing conditions for the Proposal consisted of a review of available regional data and mapping for factors such as climate, hydrology, geology and soils. A detailed soil survey was conducted across the development footprint and included:

- classification of soil orders as per the ASC
- description of soil characteristics and grouping of profiles into SPCs.

The Frogs Hollow (fh) and Kunghur (ku) soil landscapes are dominant in the study area. They are modelled as host to Dermosol and Kurosol soil orders respectively. The erosion hazards discussed for all soil landscapes present is commonly high to extreme when surface cover is low (including cultivation) or when overland flows become concentrated. The modelled LSC and inherent soil fertility indicate the more valuable land for agricultural productivity will be associated with the Kurosols of the Kunghur and Kunghur 'variant a' soil landscape (LSC Class 4) and Dermosols of the Terania and Oxley soil landscape (LSC Class 3).

A soil survey was undertaken within the study area. Soil profiles were described at five locations, with single soil samples taken at a further four locations. Soil profiles across the study area were grouped into three SPCs, based primarily on classification under the ASC, with the site consisting predominantly of non-cracking clay Dermosols and acidic, texture contrast Kurosols with minor areas of poorly developed alluvial Rudosols, generally consistent with regional soil mapping.

The study area soils are relatively stable from an assessment of soil chemistry, with no sodicity and typically balanced Ca:Mg ratios, indicating the potential for soil dispersion is low. This is inconsistent with the potential for erosion and dispersion identified in the soil landscape soil materials, which should be considered. Erosion risk is increased in the sandier, less developed profiles (SPC03) as their reduced cohesion means they are likely to be susceptible to movement and erosion. There is no apparent soil salinity limitations present in the study area based on the soil samples submitted for laboratory analysis.

The primary chemical limitation identified, consistent with some of the soil landscape soil materials, is the acidic soil pH and potential for aluminium toxicity which could be a constraint to revegetation and should be considered in selection of species utilised in rehabilitation activities.

Soil stripping and management are likely to be highly constrained by topographic constraints of the Proposal footprint. The presence of shallow, constrained soils across the site necessitates the implementation of soil management measures to minimise impacts and ensure the preservation of soil quality and quantity suitable for use in rehabilitation.

Recommended mitigation measures to further minimise impacts to soils include:

- development and implementation of a SWMP, including an ESCP with progressive plans, soil stripping and management measures
- development and implementation of a RMP.

11.2 Erosion hazard

Erosion hazard was assessed as per Section 4.4.1 of Landcom (2004). The erosion potential of soils that will be disturbed, expressed as K-factor, is moderate. Assessment of rainfall erosivity indicates erosion hazard will be high for areas where slopes exceed 5%. The study area has a high erosion hazard based on the mean slope typical of the local topography.

SLCs were calculated to map erosion risk for Proposal specific slopes and soil characteristics. Assessing changes in the SLCs with associated change in slope gives an indication of potential erosion hazard across different SPCs, which is shown in Table 5.7. Generalising across the SPCs, high erosion hazard occurred at slopes exceeding 8% (based on a flow length of 80 m).

It will be necessary to implement suitable erosion and sediment control measures, as recommended, to minimise erosion and manage any sedimentation that does occur.

Recommended mitigation measures to further minimise erosion potential include development and implementation of an ESCP with progressive plans, (as part of the overarching SWMP), limiting flow lengths on disturbed areas with steep gradients (typically 17% or greater), and implementing temporary groundcover options in the event of significant or prolonged rainfall.

11.3 Agriculture

The assessment of Proposal impacts to agricultural land has been based on desktop assessment of available agricultural land use and productivity at a regional level, primarily based on the Tweed Shire LGA within the North Coast NRM Region of NSW.

Much of the study area is too steep and isolated for viable agricultural production. Given the utilisation of the dam for local drinking water supply, the Council has endeavoured to remove all agricultural practices, such as excluding stock, from proximity of the dam to protect the dam catchment from degradation and minimise water quality impacts associated with sedimentation and agricultural runoff.

Indicative dollar per hectare (\$/ha) values were developed based on available regional land use and productivity data. These provide a broad indication of potential land productivity for agricultural land use categories and the relative impacts on agricultural productivity associated with the Proposal.

Extrapolating from the indicative annual commodity values (Table 3.18), the FSL area, if fully developed, would encompass some 73.6 ha of grazing land, as per Section 3.7, valued at approximately \$25,097 in annual productivity value based on calculated agricultural values for the Tweed Shire LGA (Table 3.17). Given agricultural activities ceased to prevent impacts to drinking water quality, the estimated agricultural impacts are likely to be further reduced compared to those values calculated in Table 3.17.

No mitigation measures are required to further minimise impacts to agriculture.

11.4 Geomorphology

A geomorphic analysis was conducted on the catchment of the Clarrie Hall Dam and downstream receiving watercourse of Doon Doon Creek.

The catchment, due to its moderately elongated shape with low form factor and relief ratios, typically has low to moderate peak flood regimes with a corresponding low headwater erosion potential. The greater catchment for Doon Doon Creek borders Mt Jerusalem National Park, but large areas of land clearing have occurred for agricultural land uses and various infrastructure.

The upper catchment is largely bedrock or valley margin confined with exposures of igneous and sedimentary rock throughout. Weathering processes of these igneous and sedimentary rock is the likely origin of sediments stored and suspended upstream of the dam wall. The soil environment at the existing water line are deep non-cracking clays with variable dispersion risk. The dam wall itself offers some protection from downstream transport of larger particles with suspended loads commonly overcoming the spillway. Laminar flow regimes in low flow phases offer some settling capacity from the dam reservoir.

Bank stability within upstream watercourses is influenced by the degree of cohesiveness of material present and the presence of vegetation and other supporting debris. Topsoils, based on sampling undertaken for the Proposal indicated the presence of cohesive sediments (CH04 to CH08) and some localised cobbles and gravels that are likely provide some protection from periodic inundation. However due to the occurrence of mass movement in the catchment, the potential for bank failure, often following periods processes like undercutting is possible. The consequence of this potential bank instability is expected to be minor.

Doon Doon Creek downstream of the spillway is wholly confined by bedrock valley margin with little capacity for channel adjustment. Finer sediments are captured and stored in large woody debris, bedrock, or boulders located within the instream cross section. Pool and riffle sequences are common due to localised undulations of the channel bed, inducing further deposition at low flow flood phases. Finer sediments are likely to be flushed from the system at bankfull and overbank flood phases.

Lower reaches of Doon Doon Creek transition to be laterally unconfined as the channel incises into vast sediment stores of alluvial material of the Tweed River floodplain. Landscape scarring suggests historical shifting of the channel, which indicates a precedence for future channel movement in response to flood events. Historical channel widening is observed midway between the dam spillway and confluence with the Tweed River.

The presence of compound bank-attached features suggests that the creek is currently in a depositional phase, with fine sediment present in the channel cross-section, likely deposited through low flow processes over time. This depositional process may ultimately result in the channel's contraction over time accelerated by riparian regeneration.

The condition of the riparian corridor of Doon Doon Creek is moderate to poor, with moderate sections above the reservoir and poor sections below the dam wall. In-stream vegetation below the dam wall is plentiful but also weed infested, and large woody debris offers multiple contraction points to reduce bed and bank shear. The riparian canopy is sparse and large gaps are present laterally and longitudinally due to localised land clearing for agriculture and access roads. The likelihood of floodplain stripping is increased by the absence of established canopy-bearing vegetation.

In-stream and bank-attached units and assemblages suggest a stable regime with periodic stripping and subsequent depositional phases. Bed and bank armouring is present in the form of large cobbles that resist erosive events. Reaches that are subject to valley floor aggradation in response to upstream disturbance commonly have coarser material atop banks. Selective reworking of less cohesive materials results in stepped depositional bank morphology as observed across 750 m downstream from the dam wall (Transect B in Figure 6.1).

Floodplain sediment stores are predominately cohesive materials. If entrainment thresholds are exceeded, these sediments are vulnerable to reworking and/or stripping. Clay particles are likely to become suspended in the water column and may have downstream turbidity effects.

The overall risk to Doon Doon Creek is assessed to be minor based on localised evidence of mass failure and bank erosion, which typically precedes bed erosion, within areas downstream on Doon Doon Creek. Furthermore, based on the expected changes in the operation of the dam, hydrologic and hydraulic modelling indicates only minor changes in flow regime and associated hydraulic conditions will occur as a result of the Proposal which are not expected to materially influence sediment mobilisation and transport within the existing watercourses.

No mitigation measures are required to further minimise impacts to geomorphology. However, consideration should be given to activities associated with the rehabilitation of riparian areas that include the removal of weeds, enhancement of native vegetation, and the replacement of natural debris that needs removal during construction.

11.5 Geotechnical considerations

The geological setting of the dam comprises a uniform sequence of hard rhyolite with minor welded tuff for the foundational bedrock. Geotechnical surveys have identified different zones within the subterranean embankment profile, ranging from semi-permeable moderately weathered rhyolite to downstream mesh and face zones of unweathered rhyolite.

Geotechnical investigations completed to date have concluded that:

- Weathering of rock material is a key constraint to sourcing construction material.
- Underlying the existing dam is slightly weathered and fresh rock described as strong to very strong.
- Excavation of the new spillway will not produce viable construction material for the raising of the dam wall however it is expected that the existing rockfill quarry has sufficient construction material present.
- Quarry stability needs to be informed by an extraction plan and design. This extraction plan and design will be informed by existing and additional testing data to propose a layout that achieves stable batters and confirms the material required can be extracted within the proposed footprint. Using site and external analogues for rhyolite quarry extraction activities, batters of 1V to 1.5H and 5 m wide benches at least every 10 m vertically, conceptually work and can be stable long-term.

Management of cut and fill materials has been considered by KBR (2023) including a number of areas identified where material can be stockpiled through construction. Material reuse between various construction elements would depend on the quality of materials encountered. The major construction components of the dam wall, spillway and access road have been quantified. From these components, and rehabilitation requirements of the quarry, it is possible that the Proposal will have an excess of material remaining following construction and rehabilitation. Remaining material will be reused where possible, such as at the McCabes Bridge construction site. Other options for excess material include within external nearby construction projects or disposed offsite to a licensed landfill or other approved disposal site.

With regard to landslide risk, studies have shown a correlation between geological factors, rainfall intensity and duration, and the probability of shallow slides. The stability of natural slopes is influenced by factors such as soil depth and moisture, rock type, bedding planes, discontinuities, and weathering. Based on past landslide incidents, identified soil hazards, and length/slope factors, areas of elevated risk were identified for the Proposal however it is difficult to predict the occurrence of such events across the Proposal. Areas of identified elevated risk does not preclude events in other areas of the study area from occurring. It should be considered that the potential for landslides is across the entire study area, as regional mapping supports. The consequence of such an event is considered minor due to the absence of receptors in areas of elevated risk (such as people, property and other infrastructure). The volume of soil entering the dam due to a landslip occurring is unlikely to significantly influence the total volume of the dam but may result in some localised turbidity within the dam itself around the site of the instability.

Embankment stability analysis is not required for a conventional concrete face rockfill dam like Clarrie Hall Dam. The existing embankment slopes, constructed using fresh to slightly weathered free draining rockfill, were selected based on precedent and prior research. For the proposed raised embankment, a similar approach has been considered, utilizing fresh to slightly weathered free draining rockfill and matching the slope ratio of the existing wall. Other Proposal elements requiring construction are unlikely to present an elevated landform stability risk due to these aspects being of a typical form and function.

11.6 Summary

Overall, potential land and soils related impacts during construction and operation of the Proposal are considered minor and can be adequately managed through the implementation of recommended mitigation measures. Key issues to be addressed for which mitigation measures have been developed include construction issues associated with landform stability, and erosion and sediment control.

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Abbreviations

Abbreviation	Definition
ACLUMP	Australian Collaborative Land Use and Management Program
AHD	Australian Height Datum
ALUM	Australian Land Use and Management
ASC	Australian Soil Classification
ASS	acid sulfate soils
BGL	below ground level
BoM	Bureau of Meteorology
CEMP	Construction Environmental Management Plan
DEM	digital elevation model
DPE	Department of Planning and Environment
DSC	NSW Dams Safety Committee
ECEC	effective cation exchange capacity
ENM	excavated natural material
EP&A Act	Environmental Planning and Assessment Act 1979
ESCP	Erosion and Sediment Control Plan
FNCRWS	Far North Coast Regional Water Strategy
FSL	full supply level
GIA	Groundwater Impact Assessment (EMM, 2024b)
GL	gigalitre
ha	hectare
IECA	International Erosion Control Association
kV	kilovolt
LGA	local government area
LSEA	Land, Soils and Erosion Assessment
ML	megalitre
NSW PWA	NSW Public Works Advisory
PMF	probable maximum flood
RARC	Rapid Appraisal of Riparian Condition
RMP	Rehabilitation Management Plan
RUSLE	revised universal soil loss equation
SEARs	Secretary's Environment Assessment Requirements Environment
SEED	Sharing and Enabling Environmental Data

Abbreviation	Definition
SLC	Soil Loss Class
SPC	Soil Profile Class
SWA	Surface Water Assessment (EMM, 2024a)
SWMP	Soil and Water Management Plan
TSC	Tweed Shire Council
VENM	virgin excavated natural material

Appendix A

Soil data sheets

SITE DESCRIPTION SHEET

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SITE DESCRIPTION SHEET

MAP REFERENCE																MAP SHEETS																AIR PHOTO REFERENCE																ANNUAL RAINFALL																SOIL OR LAND CLASS																GREAT SOIL GROUP																PRINCIPAL PROFILE FORM																SURVEY																SITE																CARD																																																																																																																																																															
Easting or Longitude 102																Northing or Longitude 103																Zone 104																Scale 105																Sheet Number 106																Film Number 107																Run No. 108																Frame No. 109																East 110																North 111																RUN OFF PERM. 112																DRAINAGE 113																ANNUAL RAINFALL 114																SOIL OR LAND CLASS 115																GREAT SOIL GROUP 116																PRINCIPAL PROFILE FORM 117																SURVEY 118																SITE 119																CARD 120															
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SITE DESCRIPTION SHEET

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NOTES AND DIAGRAMS

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Appendix B

Soil chemistry data

B.1 Soil chemistry data – SPC01

B.1.1 Site CH04

Table B.1 Site CH04 – nutrient chemistry data

Depth (cm)	pH (H ₂ O)	Nitrate nitrogen (mg/kg)	Soil Fertility ¹								Organic matter (%)	Boron (mg/kg)	Sulfate sulfur (mg/kg)	Trace Elements (Extractable)			
			Total nitrogen		Bicarbonate extr. P (Colwell)		Total organic carbon		Exch. Potassium cations					Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
			(%)	Rating	(mg/kg)	Rating	(%)	Rating	(cmol(+)/kg)	Rating							
0–10	4.67	<1.00	0.32	H	12.10	L	5.16	VH	0.57	H	8.88	0.63	3.79	<0.20	0.36	8.6	72.8

Notes: 1. Ratings as described in Section 4.1.4.

Table B.2 Site CH04 – soil profile chemistry data

Depth (cm)	Particle size (%) ¹					pH (H ₂ O)	EC (dS/m)	EC rating ²	Cl ⁻ (mg/kg)	Exchangeable cations (cmol(+)/kg)						ESP (%)	Sodicity (NS, S, SS)	EAT Class	Ca:Mg ratio	Critical Aluminium levels ³
	Clay	Silt	Fine Sand	Coarse Sand	Gravel					Al ⁺³	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	CEC					
0–10	36.3	28.0	17.3	14.6	3.9	4.67	0.03	VL	20.1	8.48	6.38	1.83	0.57	0.41	17.66	2.3	NS	7	3.5	E
20–30	47.5	25.4	13.5	9.6	4.0	4.87	0.01	VL	10.6	16.80	7.37	1.33	0.46	0.41	26.36	1.5	NS	5	5.6	E
50–60	55.3	32.8	8.2	2.7	1.0	4.58	0.02	VL	11.6	20.90	7.48	0.76	0.43	0.34	29.91	1.2	NS	5	9.8	E
80–90	56.7	23.7	13.4	4.2	2.0	4.55	0.03	VL	58.3	12.10	5.87	0.38	0.30	0.29	18.94	1.6	NS	6	15.6	E

Notes: 1. Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 µm), Clay (<2 µm)
2. Rayment & Lyons (2011) – very low salinity (VL), low salinity (L), moderately saline (M), highly saline (H), extremely saline (E)
3. Hazelton & Murphy (2016) – affects very sensitive plants (M), sensitive plants (H), tolerant plants (VH) and very tolerant plants (E).

Table B.3 Site CH04 – images

Soil profile ¹	Landscape
	
Photograph B.1 CH04 soil profile	Photograph B.2 CH04 landscape

Notes: 1. Surface top left, 0.3 m increments.

B.1.2 Site CH05

Table B.4 Site CH05 – nutrient chemistry data

Depth (cm)	pH (H ₂ O)	Nitrate nitrogen (mg/kg)	Soil Fertility ¹								Organic matter (%)	Boron (mg/kg)	Sulfate sulfur (mg/kg)	Trace Elements (Extractable)			
			Total nitrogen		Bicarbonate extr. P (Colwell)		Total organic carbon		Exch. Potassium cations					Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
			(%)	Rating	(mg/kg)	Rating	(%)	Rating	(cmol(+)/kg)	Rating							
0–5	5.15	<1.00	0.26	H	40.70	H	2.82	H	0.73	H	4.85	0.51	10.7	0.72	10.6	10.2	419

Notes: 1. Ratings as described in Section 4.1.4.

Table B.5 Site CH05 – soil profile chemistry data

Depth (cm)	Particle size (%) ¹					pH (H ₂ O)	EC (dS/m)	EC rating ²	Cl ⁻ (mg/kg)	Exchangeable cations (cmol(+)/kg)						ESP (%)	Sodicity (NS, S, SS)	EAT Class	Ca:Mg ratio	Critical Aluminium levels ³
	Clay	Silt	Fine Sand	Coarse Sand	Gravel					Al ⁺³	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	CEC					
0–5	11.1	6.0	20.7	54.0	8.3	5.15	0.03	VL	16.5	1.13	5.43	1.35	0.73	0.18	8.81	2.0	NS	7	4.0	M
20–30	49.9	11.6	15.4	22.6	0.6	4.50	0.04	VL	27.8	9.63	7.24	0.41	0.53	0.19	18.00	1.1	NS	6	17.7	E
50–60	45.2	11.5	16.6	26.2	0.6	4.22	0.05	VL	29.4	8.84	6.02	0.44	0.49	0.43	16.22	2.6	NS	6	13.5	E
110–120	32.5	15.6	19.5	32.4	<0.1	4.23	0.08	VL	36	9.91	5.62	0.36	0.44	0.17	16.49	1.0	NS	6	15.7	E

Notes: 1. Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 µm), Clay (<2 µm).
2. Rayment & Lyons (2011) – very low salinity (VL), low salinity (L), moderately saline (M), highly saline (H), extremely saline (E).
3. Hazelton & Murphy (2016) – affects very sensitive plants (M), sensitive plants (H), tolerant plants (VH) and very tolerant plants (E).

Table B.6 Site CH05 – images

Soil profile ¹	Landscape
	

Photograph B.3 CH05 soil profile

Photograph B.4 CH05 landscape

Notes: 1. Surface top left, 0.3 m increments.

B.1.3 Site CH06

Table B.7 Site CH06 – nutrient chemistry data

Depth (cm)	pH (H ₂ O)	Nitrate nitrogen (mg/kg)	Soil Fertility ¹								Organic matter (%)	Boron (mg/kg)	Sulfate sulfur (mg/kg)	Trace Elements (Extractable)			
			Total nitrogen		Bicarbonate extr. P (Colwell)		Total organic carbon		Exch. Potassium cations					Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
			(%)	Rating	(mg/kg)	Rating	(%)	Rating	(cmol(+)/kg)	Rating							
0–10	5.60	1.6	0.32	H	12.10	L	3.24	H	0.33	M	5.57	0.65	14.4	0.24	1.26	11.6	153

Notes: 1. Ratings as described in Section 4.1.4.

Table B.8 Site CH06 – soil profile chemistry data

Depth (cm)	Particle size (%) ¹					pH (H ₂ O)	EC (dS/m)	EC rating ²	Cl ⁻ (mg/kg)	Exchangeable cations (cmol(+)/kg)						ESP (%)	Sodicity (NS, S, SS)	EAT Class	Ca:Mg ratio	Critical Aluminium levels ³
	Clay	Silt	Fine Sand	Coarse Sand	Gravel					Al ⁺³	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	CEC					
0–10	5.4	8.4	16.4	66.5	3.3	5.60	0.04	VL	20.3	0.18	7.20	1.77	0.33	0.13	9.61	1.4	NS	7	4.1	-
30–40	10.7	7.7	20.9	58.4	2.4	5.60	0.02	VL	5.00	0.15	3.58	0.81	0.16	0.11	4.82	2.3	NS	5	4.4	-
50–60	28.5	8.4	14.1	46.2	2.8	4.95	0.01	VL	5.00	5.82	7.01	1.68	0.23	0.22	14.96	1.5	NS	5	4.2	E
110–120	32.9	8.5	14.4	43.4	0.8	4.53	0.01	VL	11.4	12.90	2.39	0.67	0.27	0.16	16.39	1.0	NS	6	3.5	E

Notes: 1. Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 µm), Clay (<2 µm).
2. Rayment & Lyons (2011) – very low salinity (VL), low salinity (L), moderately saline (M), highly saline (H), extremely saline (E).
3. Hazelton & Murphy (2016) – affects very sensitive plants (M), sensitive plants (H), tolerant plants (VH) and very tolerant plants (E).

Table B.9 Site CH06 – images

Soil profile ¹	Landscape
	 EMM Clarrie Hall Dam CH06 28.03.2023 13:41 -28.47609, 153.29845 Doon Doon NSW 2484
Photograph B.5 CH06 soil profile	Photograph B.6 CH06 landscape

Notes: 1. Surface top left, 0.3 m increments.

B.2 Soil chemistry data – SPC02

B.2.1 Site CH07

Table B.10 Site CH07 – nutrient chemistry data

Depth (cm)	pH (H ₂ O)	Nitrate nitrogen (mg/kg)	Soil Fertility ¹								Organic matter (%)	Boron (mg/kg)	Sulfate sulfur (mg/kg)	Trace Elements (Extractable)			
			Total nitrogen		Bicarbonate extr. P (Colwell)		Total organic carbon		Exch. Potassium cations					Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
			(%)	Rating	(mg/kg)	Rating	(%)	Rating	(cmol(+)/kg)	Rating							
2–10	5.21	27.1	0.43	H	20.20	M	4.50	H	0.48	M	7.74	0.33	9.53	0.54	2.16	21.6	125

Notes: 1. Ratings as described in Section 4.1.4.

Table B.11 Site CH07 – soil profile chemistry data

Depth (cm)	Particle size (%) ¹					pH (H ₂ O)	EC (dS/m)	EC rating ²	Cl ⁻ (mg/kg)	Exchangeable cations (cmol(+)/kg)						ESP (%)	Sodicity (NS, S, SS)	EAT Class	Ca:Mg ratio	Critical Aluminium levels ³
	Clay	Silt	Fine Sand	Coarse Sand	Gravel					Al ⁺³	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	CEC					
2–10	11.8	18.2	24.6	39.0	6.4	5.21	0.05	VL	22.1	0.42	6.11	2.01	0.48	0.19	9.20	2.1	NS	7	3.0	-
20–30	20.7	9.7	19.4	47.1	3.1	5.27	0.02	VL	10.4	0.15	4.22	0.68	0.32	0.18	5.54	3.2	LS	6	6.2	-
50–60	32.1	9.5	17.5	39.9	1.1	5.63	0.01	VL	5.00	0.02	6.46	1.18	0.27	0.20	8.12	2.5	NS	6	5.5	-
80–90	39.0	10.0	16.0	34.4	0.6	5.37	0.01	VL	10.7	0.02	4.15	1.64	0.26	0.21	6.28	3.3	LS	6	2.5	-
110–120	40.2	7.8	17.6	33.8	0.6	5.53	0.01	VL	7.14	0.12	3.58	1.83	0.28	0.18	5.99	3.0	LS	6	2.0	-

Notes: 1. Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 µm), Clay (<2 µm).
2. Rayment & Lyons (2011) – very low salinity (VL), low salinity (L), moderately saline (M), highly saline (H), extremely saline (E).
3. Hazelton & Murphy (2016) – affects very sensitive plants (M), sensitive plants (H), tolerant plants (VH) and very tolerant plants (E).

Table B.12 Site CH07 – images

Soil profile ¹	Landscape
	

Photograph B.7 CH07 soil profile

Photograph B.8 CH07 landscape

Notes: 1. Surface top left, 0.3 m increments.

B.3 Soil chemistry data – SPC03

B.3.1 Site CH08

Table B.13 Site CH08 – nutrient chemistry data

Depth (cm)	pH (H ₂ O)	Nitrate nitrogen (mg/kg)	Soil Fertility ¹								Organic matter (%)	Boron (mg/kg)	Sulfate sulfur (mg/kg)	Trace Elements (Extractable)			
			Total nitrogen		Bicarbonate extr. P (Colwell)		Total organic carbon		Exch. Potassium cations					Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
			(%)	Rating	(mg/kg)	Rating	(%)	Rating	(cmol(+)/kg)	Rating							
0–10	5.64	2.1	0.30	H	138.00	VH	2.57	H	2.03	VH	4.42	0.42	18.4	<0.20	0.54	2.72	26.8

Notes: 1. Ratings as described in Section 4.1.4.

Table B.14 Site CH08 – soil profile chemistry data

Depth (cm)	Particle size (%) ¹					pH (H ₂ O)	EC (dS/m)	EC rating ²	Cl ⁻ (mg/kg)	Exchangeable cations (cmol(+)/kg)						ESP (%)	Sodicity (NS, S, SS)	EAT Class	Ca:Mg ratio	Critical Aluminium levels ³
	Clay	Silt	Fine Sand	Coarse Sand	Gravel					Al ⁺³	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	CEC					
0–10	6.7	18.4	27.7	43.9	3.3	5.64	0.03	VL	14.4	0.07	12.34	5.41	2.03	0.25	20.10	1.3	NS	5	2.3	-
50–60	15.3	18.7	34.4	30.8	0.8	6.10	0.01	VL	5.00	0.02	16.96	5.78	1.01	0.37	24.14	1.5	NS	5	2.9	-

Notes: 1. Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 µm), Clay (<2 µm).
2. Rayment & Lyons (2011) – very low salinity (VL), low salinity (L), moderately saline (M), highly saline (H), extremely saline (E).
3. Hazelton & Murphy (2016) – affects very sensitive plants (M), sensitive plants (H), tolerant plants (VH) and very tolerant plants (E).

Table B.15 Site CH08 – images

Soil profile ¹	Landscape
	

Photograph B.9 CH08 soil profile

Photograph B.10 CH08 landscape

Notes: 1. Surface top left, 0.3 m increments.

B.4 Soil chemistry data – Sample sites

B.4.1 Site CH01

Table B.16 Site CH01 – nutrient chemistry data

Depth (cm)	pH (H ₂ O)	Nitrate nitrogen (mg/kg)	Soil Fertility ¹								Organic matter (%)	Boron (mg/kg)	Sulfate sulfur (mg/kg)	Trace Elements (Extractable)			
			Total nitrogen		Bicarbonate extr. P (Colwell)		Total organic carbon		Exch. Potassium cations					Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
			(%)	Rating	(mg/kg)	Rating	(%)	Rating	(cmol(+)/kg)	Rating							
5–15	4.85	<1.00	0.13	L	7.19	VL	1.45	L	0.64	H	2.49	0.69	4.67	<0.20	0.38	1.88	78.9

Notes: 1. Ratings as described in Section 4.1.4.

Table B.17 Site CH01 – soil profile chemistry data

Depth (cm)	Particle size (%) ¹					pH (H ₂ O)	EC (dS/m)	EC rating ²	Cl ⁻ (mg/kg)	Exchangeable cations (cmol(+))/kg						ESP (%)	Sodicity (NS, S, SS)	EAT Class	Ca:Mg ratio	Critical Aluminium levels ³
	Clay	Silt	Fine Sand	Coarse Sand	Gravel					Al ⁺³	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	CEC					
5–15	41.2	37.7	12.6	7.0	1.5	4.85	0.02	VL	15.1	2.23	6.08	0.79	0.64	0.31	10.04	3.1	LS	5	7.7	VH
20–30	38.8	37.5	14.4	8.1	1.2	4.90	0.02	VL	18.9	2.52	7.63	0.75	0.69	0.32	11.91	2.7	NS	5	10.1	VH

Notes: 1. Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 µm), Clay (<2 µm).
2. Rayment & Lyons (2011) – very low salinity (VL), low salinity (L), moderately saline (M), highly saline (H), extremely saline (E).
3. Hazelton & Murphy (2016) – affects very sensitive plants (M), sensitive plants (H), tolerant plants (VH) and very tolerant plants (E).

Table B.18 **Site CH01 – images**

Soil profile ¹	Landscape
	
Photograph B.11 CH01 soil profile	Photograph B.12 CH01 landscape

Notes: 1. 0.15 m trowel blade.

B.4.2 Site CH02

Table B.19 Site CH02 – nutrient chemistry data

Depth (cm)	pH (H ₂ O)	Nitrate nitrogen (mg/kg)	Soil Fertility ¹								Organic matter (%)	Boron (mg/kg)	Sulfate sulfur (mg/kg)	Trace Elements (Extractable)			
			Total nitrogen		Bicarbonate extr. P (Colwell)		Total organic carbon		Exch. Potassium cations					Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
			(%)	Rating	(mg/kg)	Rating	(%)	Rating	(cmol(+)/kg)	Rating							
0–10	5.02	5.0	0.08	L	9.64	VL	0.53	L	0.49	M	0.91	0.57	25.7	<0.20	0.28	2.86	37.8

Notes: 1. Ratings as described in Section 4.1.4.

Table B.20 Site CH02 – soil profile chemistry data

Depth (cm)	Particle size (%) ¹					pH (H ₂ O)	EC (dS/m)	EC rating ²	Cl ⁻ (mg/kg)	Exchangeable cations (cmol(+)/kg)						ESP (%)	Sodicity (NS, S, SS)	EAT Class	Ca:Mg ratio	Critical Aluminium levels ³
	Clay	Silt	Fine Sand	Coarse Sand	Gravel					Al ⁺³	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	CEC					
0–10	44.9	25.2	22.0	5.8	2.1	5.02	0.03	VL	13.8	2.28	4.07	2.33	0.49	0.20	9.38	2.2	NS	6	1.7	VH
20–30	45.5	23.3	22.3	6.2	2.8	4.86	0.02	VL	14.3	1.73	5.62	2.50	0.42	0.26	10.52	2.4	NS	6	2.2	M

Notes: 1. Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 µm), Clay (<2 µm).
2. Rayment & Lyons (2011) – very low salinity (VL), low salinity (L), moderately saline (M), highly saline (H), extremely saline (E).
3. Hazelton & Murphy (2016) – affects very sensitive plants (M), sensitive plants (H), tolerant plants (VH) and very tolerant plants (E).

Table B.21 Site CH02 – images

Soil profile	Landscape
	

Photograph B.13 CH02 soil profile

Photograph B.14 CH02 landscape

B.4.3 Site CH03

Table B.22 Site CH03 – nutrient chemistry data

Depth (cm)	pH (H ₂ O)	Nitrate nitrogen (mg/kg)	Soil Fertility ¹								Organic matter (%)	Boron (mg/kg)	Sulfate sulfur (mg/kg)	Trace Elements (Extractable)			
			Total nitrogen		Bicarbonate extr. P (Colwell)		Total organic carbon		Exch. Potassium cations					Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
			(%)	Rating	(mg/kg)	Rating	(%)	Rating	(cmol(+)/kg)	Rating							
0–10	4.78	1.1	0.46	H	27.70	M	7.28	VH	1.15	VH	12.52	1.25	6.45	<0.20	0.74	4.49	90.5

Notes: 1. Ratings as described in Section 4.1.4.

Table B.23 Site CH03 – soil profile chemistry data

Depth (cm)	Particle size (%) ¹					pH (H ₂ O)	EC (dS/m)	EC rating ²	Cl ⁻ (mg/kg)	Exchangeable cations (cmol(+)/kg)						ESP (%)	Sodicity (NS, S, SS)	EAT Class	Ca:Mg ratio	Critical Aluminium levels ³
	Clay	Silt	Fine Sand	Coarse Sand	Gravel					Al ⁺³	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	CEC					
0–10	22.1	20.8	22.0	23.1	12.1	4.78	0.04	VL	42.5	5.73	6.06	2.83	1.15	0.29	16.05	1.8	NS	7	2.1	E

Notes: 1. Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 µm), Clay (<2 µm).
2. Rayment & Lyons (2011) – very low salinity (VL), low salinity (L), moderately saline (M), highly saline (H), extremely saline (E).
3. Hazelton & Murphy (2016) – affects very sensitive plants (M), sensitive plants (H), tolerant plants (VH) and very tolerant plants (E).

Table B.24 **Site CH03 – images**

Soil profile	Landscape
 Photograph B.15	 Photograph B.16
CH03 soil surface	CH03 landscape

B.4.4 Site CH09

Table B.25 Site CH09 – nutrient chemistry data

Depth (cm)	pH (H ₂ O)	Nitrate nitrogen (mg/kg)	Soil Fertility ¹								Organic matter (%)	Boron (mg/kg)	Sulfate sulfur (mg/kg)	Trace Elements (Extractable)			
			Total nitrogen		Bicarbonate extr. P (Colwell)		Total organic carbon		Exch. Potassium cations					Copper (mg/kg)	Zinc (mg/kg)	Manganese (mg/kg)	Iron (mg/kg)
			(%)	Rating	(mg/kg)	Rating	(%)	Rating	(cmol(+)/kg)	Rating							
5–15	5.58	2.7	0.27	H	8.24	VL	4.97	H	0.75	H	8.55	0.77	7.88	0.24	1.4	7.64	25.2

Notes: 1. Ratings as described in Section 4.1.4.

Table B.26 Site CH09 – soil profile chemistry data

Depth (cm)	Particle size (%) ¹					pH (H ₂ O)	EC (dS/m)	EC rating ²	Cl ⁻ (mg/kg)	Exchangeable cations (cmol(+)/kg)						ESP (%)	Sodicity (NS, S, SS)	EAT Class	Ca:Mg ratio	Critical Aluminium levels ³
	Clay	Silt	Fine Sand	Coarse Sand	Gravel					Al ⁺³	Ca ⁺²	Mg ⁺²	K ⁺	Na ⁺	CEC					
5–15	13.9	22.0	24.0	22.2	17.9	5.58	0.03	VL	17	0.16	7.33	2.66	0.75	0.34	11.23	3.0	LS	7	2.8	-

Notes: 1. Gravel (>2 mm), Coarse sand (0.2–2 mm), Fine sand (0.02–0.2 mm), Silt (2–20 µm), Clay (<2 µm).
2. Rayment & Lyons (2011) – very low salinity (VL), low salinity (L), moderately saline (M), highly saline (H), extremely saline (E).
3. Hazelton & Murphy (2016) – affects very sensitive plants (M), sensitive plants (H), tolerant plants (VH) and very tolerant plants (E).

Appendix C

Soil laboratory report



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ANALYSIS REPORT SOIL

PROJECT NO: EW230927

Date of Issue: 09/05/2023

Customer: EMM Consulting

Report No: 1

Address: Suite 01 20 Chandos Street ST
LEONARDS NSW 2065

Date Received: 11/04/2023

Matrix: Soil

Attention: Harry Savage

Location: CHD

Phone: 0416 295 292

Sampler ID: Client

Fax:

Date of Sampling: 6/04/2023

Email: hsavage@emmconsulting.com.au

Sample Condition: Acceptable

Results apply to the samples as submitted. All pages of this report have been checked and approved for release.

Signed: Anne Michie



East West is certified by the Australian-Asian Soil & Plant Analysis Council to perform various soil and plant tissue analysis. The tests reported herein have been performed in accordance with our terms of accreditation.

This report must not be reproduced except in full and EWEA takes no responsibility of the end use of the results within this report.

This analysis relates to the sample submitted and it is the client's responsibility to make certain the sample is representative of the matrix to be tested.

Samples will be discarded one month after the date of this report. Please advise if you wish to have your sample/s returned.

results you can rely on



ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID					CH01	CH01	CH02	CH02
					5-15	20-30	0-10	20-30
DEPTH								
Test Parameter	Method Description	Method Reference	Units	LOR	230927-1	230927-2	230927-3	230927-4
pH (1:5 in H2O)	Electrode	R&L 4A1	pH units	na	4.85	4.90	5.02	4.86
pH (1:5 in CaCl2)	Electrode	R&L 4B2	pH units	na	4.30	4.23	4.26	4.30
Chloride Soluble	DA	DAP-06	mg/kg	5	15.1	18.9	13.8	14.3
Electrical Conductivity	Electrode	R&L 3A1	dS/m	0.01	0.02	0.02	0.03	0.02
Total N (LECO)	LECO	R&L 7A5	mg/kg	50	1270	NA	800	NA
Extractable Nitrate-N	DA	DAP-03	mg/kg	1	<1.00	<1.00	4.96	3.63
Ammonium - N (Ex)	ExKCl/UV-Vis	PMS-22	mg/kg	2	3.15	3.63	12.1	7.46
Phosphorus (Total)	HNO3/HClO4 ICP	ICP-03	mg/kg	40	231	NA	288	NA
Organic Carbon (LECO)	LECO	R&L 6B3	%	0.2	1.45	1.01	0.53	0.54
Phosphorus (Colwell)	Bicarb/UV-Vis	R&L 9B1	mg/kg	5	7.19	NA	9.64	NA
Sulphate-Sulphur	KCl40/ICP	R&L 10D1	mg/kg	3	4.67	NA	25.7	NA
Extractable Copper	DTPA/ICP	R&L 12A1	mg/kg	0.2	<0.20	NA	<0.20	NA
Extractable Zinc	DTPA/ICP	R&L 12A1	mg/kg	0.2	0.38	NA	0.28	NA
Extractable Manganese	DTPA/ICP	R&L 12A1	mg/kg	1	1.88	NA	2.86	NA
Extractable Iron	DTPA/ICP	R&L 12A1	mg/kg	1	78.9	NA	37.8	NA
Extractable Boron	Hot CaCl2/ICP	R&L 12C2	mg/kg	0.2	0.69	NA	0.57	NA
Exchangeable Aluminium	KCl/ICP	R&L 15G1	mg/kg	2	201	227	205	156
Exchangeable Aluminium	Calculation	R&L 15J1	cmol/kg	na	2.23	2.52	2.28	1.73
Total Cadmium	ICP-OES	AS4479.2	mg/kg	0.5	<0.5	NA	0.9	NA
Total Chromium	ICP-OES	AS4479.2	mg/kg	0.5	3.3	NA	32.8	NA
Total Copper	ICP-OES	PMS-09	mg/kg	0.5	1.6	NA	7.7	NA
Total Iron	ICP-OES	PMS-09	mg/kg	0.5	24200	NA	39500	NA
Total Lead	ICP-OES	AS4479.2	mg/kg	0.5	13.5	NA	12.8	NA
Total Manganese	ICP-OES	PMS-09	mg/kg	0.5	46.2	NA	238	NA
Total Nickel	ICP-OES	AS4479.2	mg/kg	0.5	0.8	NA	9.8	NA
Total Zinc	ICP-OES	PMS-09	mg/kg	0.5	36.3	NA	45.4	NA



ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID					CH01	CH01	CH02	CH02
					5-15	20-30	0-10	20-30
DEPTH								
Test Parameter	Method Description	Method Reference	Units	LOR	230927-1	230927-2	230927-3	230927-4
Total Potassium	ICP-OES	PMS-09	mg/kg	0.5	1230	NA	1030	NA
Texture	Field	Northcote	Class	na	CL	CL	CL	CL
Total Calcium	ICP-OES	PMS-09	mg/kg	100	1380	NA	1340	NA
Total Magnesium	ICP-OES	PMS-09	mg/kg	50	434	NA	1530	NA
Total Sodium	ICP-OES	PMS-09	mg/kg	40	134	NA	190	NA
Total Sulphur	ICP-OES	PMS-09	mg/kg	40	147	NA	168	NA
Total Aluminium	ICP-OES	PMS-09	mg/kg	100	53400	NA	77200	NA
Emerson Aggregate Test	Class	PMS-21	Number	na	5	5	6	6
Exchangeable Potassium	ICP-OES	R&L 15D1	mg/kg	10	250	268	190	164
Exchangeable Calcium	ICP-OES	R&L 15D1	mg/kg	20	1215	1526	814	1123
Exchangeable Magnesium	ICP-OES	R&L 15D1	mg/kg	10	94.5	90.3	280	300
Exchangeable Sodium	ICP-OES	R&L 15D1	mg/kg	10	70.7	73.8	47.1	58.9
Gravel >2.0mm	Sieve	ASTMD422-63	%	na	1.5	1.2	2.1	2.8
Coarse Sand 0.2-2.0mm	Sieve	ASTMD422-63	%	na	7.0	8.1	5.8	6.2
Fine Sand 0.02-0.2mm	Sieve	ASTMD422-63	%	na	12.6	14.4	22.0	22.3
Silt 0.002-0.02mm	Hydrometer	ASTMD422-63	%	na	37.7	37.5	25.2	23.3
Clay <0.002mm	Hydrometer	ASTMD422-63	%	na	41.2	38.8	44.9	45.5





ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID					CH03	CH04	CH04	CH04
					0-10	0-10	20-30	50-60
DEPTH								
Test Parameter	Method Description	Method Reference	Units	LOR	230927-5	230927-6	230927-7	230927-8
pH (1:5 in H2O)	Electrode	R&L 4A1	pH units	na	4.78	4.67	4.87	4.58
pH (1:5 in CaCl2)	Electrode	R&L 4B2	pH units	na	3.96	3.96	3.88	3.77
Chloride Soluble	DA	DAP-06	mg/kg	5	42.5	20.1	10.6	11.6
Electrical Conductivity	Electrode	R&L 3A1	dS/m	0.01	0.04	0.03	0.01	0.02
Total N (LECO)	LECO	R&L 7A5	mg/kg	50	4610	3210	NA	NA
Extractable Nitrate-N	DA	DAP-03	mg/kg	1	1.09	<1.00	<1.00	<1.00
Ammonium - N (Ex)	ExKCl/UV-Vis	PMS-22	mg/kg	2	19.4	18.5	7.46	3.15
Phosphorus (Total)	HNO3/HClO4 ICP	ICP-03	mg/kg	40	373	435	NA	NA
Organic Carbon (LECO)	LECO	R&L 6B3	%	0.2	7.28	5.16	0.82	NA
Phosphorus (Colwell)	Bicarb/UV-Vis	R&L 9B1	mg/kg	5	27.7	12.1	NA	NA
Sulphate-Sulphur	KCl40/ICP	R&L 10D1	mg/kg	3	6.45	3.79	NA	NA
Extractable Copper	DTPA/ICP	R&L 12A1	mg/kg	0.2	<0.20	<0.20	NA	NA
Extractable Zinc	DTPA/ICP	R&L 12A1	mg/kg	0.2	0.74	0.36	NA	NA
Extractable Manganese	DTPA/ICP	R&L 12A1	mg/kg	1	4.49	8.60	NA	NA
Extractable Iron	DTPA/ICP	R&L 12A1	mg/kg	1	90.5	72.8	NA	NA
Extractable Boron	Hot CaCl2/ICP	R&L 12C2	mg/kg	0.2	1.25	0.63	NA	NA
Exchangeable Aluminium	KCl/ICP	R&L 15G1	mg/kg	2	516	763	1512	1879
Exchangeable Aluminium	Calculation	R&L 15J1	cmol/kg	na	5.73	8.48	16.8	20.9
Total Cadmium	ICP-OES	AS4479.2	mg/kg	0.5	<0.5	<0.5	NA	NA
Total Chromium	ICP-OES	AS4479.2	mg/kg	0.5	5.4	22.5	NA	NA
Total Copper	ICP-OES	PMS-09	mg/kg	0.5	2.4	5.7	NA	NA
Total Iron	ICP-OES	PMS-09	mg/kg	0.5	19500	25500	NA	NA
Total Lead	ICP-OES	AS4479.2	mg/kg	0.5	12.2	12.4	NA	NA
Total Manganese	ICP-OES	PMS-09	mg/kg	0.5	64.5	116	NA	NA
Total Nickel	ICP-OES	AS4479.2	mg/kg	0.5	2.3	3.8	NA	NA
Total Zinc	ICP-OES	PMS-09	mg/kg	0.5	17.1	16.2	NA	NA



ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID DEPTH					CH03	CH04	CH04	CH04
					0-10	0-10	20-30	50-60
Test Parameter	Method Description	Method Reference	Units	LOR	230927-5	230927-6	230927-7	230927-8
Total Potassium	ICP-OES	PMS-09	mg/kg	0.5	2910	2350	NA	NA
Texture	Field	Northcote	Class	na	L	L	LMC	LMC
Total Calcium	ICP-OES	PMS-09	mg/kg	100	1451	1640	NA	NA
Total Magnesium	ICP-OES	PMS-09	mg/kg	50	1130	865	NA	NA
Total Sodium	ICP-OES	PMS-09	mg/kg	40	169	258	NA	NA
Total Sulphur	ICP-OES	PMS-09	mg/kg	40	338	245	NA	NA
Total Aluminium	ICP-OES	PMS-09	mg/kg	100	27800	27500	NA	NA
Emerson Aggregate Test	Class	PMS-21	Number	na	7	7	5	5
Exchangeable Potassium	ICP-OES	R&L 15D1	mg/kg	10	447	223	178	167
Exchangeable Calcium	ICP-OES	R&L 15D1	mg/kg	20	1212	1275	1474	1495
Exchangeable Magnesium	ICP-OES	R&L 15D1	mg/kg	10	339	219	159	91.3
Exchangeable Sodium	ICP-OES	R&L 15D1	mg/kg	10	66.2	94.3	93.5	79.3
Gravel >2.0mm	Sieve	ASTMD422-63	%	na	12.1	3.9	4.0	1.0
Coarse Sand 0.2-2.0mm	Sieve	ASTMD422-63	%	na	23.1	14.6	9.6	2.7
Fine Sand 0.02-0.2mm	Sieve	ASTMD422-63	%	na	22.0	17.3	13.5	8.2
Silt 0.002-0.02mm	Hydrometer	ASTMD422-63	%	na	20.8	28.0	25.4	32.8
Clay <0.002mm	Hydrometer	ASTMD422-63	%	na	22.1	36.3	47.5	55.3



ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID					CH04	CH05	CH05	CH05
					80-90	0-5	20-30	50-60
DEPTH								
Test Parameter	Method Description	Method Reference	Units	LOR	230927-9	230927-10	230927-11	230927-12
pH (1:5 in H2O)	Electrode	R&L 4A1	pH units	na	4.55	5.15	4.50	4.22
pH (1:5 in CaCl2)	Electrode	R&L 4B2	pH units	na	3.92	4.41	3.97	3.86
Chloride Soluble	DA	DAP-06	mg/kg	5	58.3	16.5	27.8	29.4
Electrical Conductivity	Electrode	R&L 3A1	dS/m	0.01	0.03	0.03	0.04	0.05
Total N (LECO)	LECO	R&L 7A5	mg/kg	50	NA	2610	NA	NA
Extractable Nitrate-N	DA	DAP-03	mg/kg	1	<1.00	<1.00	<1.00	1.01
Ammonium - N (Ex)	ExKCl/UV-Vis	PMS-22	mg/kg	2	5.55	5.31	11.8	8.87
Phosphorus (Total)	HNO3/HClO4 ICP	ICP-03	mg/kg	40	NA	761	NA	NA
Organic Carbon (LECO)	LECO	R&L 6B3	%	0.2	0.44	2.82	0.59	NA
Phosphorus (Colwell)	Bicarb/UV-Vis	R&L 9B1	mg/kg	5	NA	40.7	NA	NA
Sulphate-Sulphur	KCl40/ICP	R&L 10D1	mg/kg	3	NA	10.7	NA	NA
Extractable Copper	DTPA/ICP	R&L 12A1	mg/kg	0.2	NA	0.72	NA	NA
Extractable Zinc	DTPA/ICP	R&L 12A1	mg/kg	0.2	NA	10.6	NA	NA
Extractable Manganese	DTPA/ICP	R&L 12A1	mg/kg	1	NA	10.2	NA	NA
Extractable Iron	DTPA/ICP	R&L 12A1	mg/kg	1	NA	419	NA	NA
Extractable Boron	Hot CaCl2/ICP	R&L 12C2	mg/kg	0.2	NA	0.51	NA	NA
Exchangeable Aluminium	KCl/ICP	R&L 15G1	mg/kg	2	1089	102	867	796
Exchangeable Aluminium	Calculation	R&L 15J1	cmol/kg	na	12.1	1.13	9.63	8.84
Total Cadmium	ICP-OES	AS4479.2	mg/kg	0.5	NA	<0.5	NA	NA
Total Chromium	ICP-OES	AS4479.2	mg/kg	0.5	NA	9.9	NA	NA
Total Copper	ICP-OES	PMS-09	mg/kg	0.5	NA	5.7	NA	NA
Total Iron	ICP-OES	PMS-09	mg/kg	0.5	NA	18500	NA	NA
Total Lead	ICP-OES	AS4479.2	mg/kg	0.5	NA	14.8	NA	NA
Total Manganese	ICP-OES	PMS-09	mg/kg	0.5	NA	116	NA	NA
Total Nickel	ICP-OES	AS4479.2	mg/kg	0.5	NA	3.0	NA	NA
Total Zinc	ICP-OES	PMS-09	mg/kg	0.5	NA	68.6	NA	NA



ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID DEPTH					CH04	CH05	CH05	CH05
					80-90	0-5	20-30	50-60
Test Parameter	Method Description	Method Reference	Units	LOR	230927-9	230927-10	230927-11	230927-12
Total Potassium	ICP-OES	PMS-09	mg/kg	0.5	NA	884	NA	NA
Texture	Field	Northcote	Class	na	LC	FSL	LMC	LC
Total Calcium	ICP-OES	PMS-09	mg/kg	100	NA	1240	NA	NA
Total Magnesium	ICP-OES	PMS-09	mg/kg	50	NA	602	NA	NA
Total Sodium	ICP-OES	PMS-09	mg/kg	40	NA	136	NA	NA
Total Sulphur	ICP-OES	PMS-09	mg/kg	40	NA	264	NA	NA
Total Aluminium	ICP-OES	PMS-09	mg/kg	100	NA	16300	NA	NA
Emerson Aggregate Test	Class	PMS-21	Number	na	6	7	6	6
Exchangeable Potassium	ICP-OES	R&L 15D1	mg/kg	10	118	285	206	190
Exchangeable Calcium	ICP-OES	R&L 15D1	mg/kg	20	1174	1085	1448	1203
Exchangeable Magnesium	ICP-OES	R&L 15D1	mg/kg	10	45.2	162	49.2	53.3
Exchangeable Sodium	ICP-OES	R&L 15D1	mg/kg	10	67.8	41.1	43.8	98.7
Gravel >2.0mm	Sieve	ASTMD422-63	%	na	2.0	8.3	0.6	0.6
Coarse Sand 0.2-2.0mm	Sieve	ASTMD422-63	%	na	4.2	54.0	22.6	26.2
Fine Sand 0.02-0.2mm	Sieve	ASTMD422-63	%	na	13.4	20.7	15.4	16.6
Silt 0.002-0.02mm	Hydrometer	ASTMD422-63	%	na	23.7	6.0	11.6	11.5
Clay <0.002mm	Hydrometer	ASTMD422-63	%	na	56.7	11.1	49.9	45.2



ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID					CH05	CH06	CH06	CH06
					110-120	0-10	30-40	50-60
DEPTH								
Test Parameter	Method Description	Method Reference	Units	LOR	230927-13	230927-14	230927-15	230927-16
pH (1:5 in H2O)	Electrode	R&L 4A1	pH units	na	4.23	5.60	5.60	4.95
pH (1:5 in CaCl2)	Electrode	R&L 4B2	pH units	na	3.86	4.94	4.91	4.15
Chloride Soluble	DA	DAP-06	mg/kg	5	36.0	20.3	<5.00	<5.00
Electrical Conductivity	Electrode	R&L 3A1	dS/m	0.01	0.08	0.04	0.02	0.01
Total N (LECO)	LECO	R&L 7A5	mg/kg	50	NA	3150	NA	NA
Extractable Nitrate-N	DA	DAP-03	mg/kg	1	<1.00	1.60	2.98	<1.00
Ammonium - N (Ex)	ExKCl/UV-Vis	PMS-22	mg/kg	2	4.11	9.81	3.15	3.63
Phosphorus (Total)	HNO3/HClO4 ICP	ICP-03	mg/kg	40	NA	495	NA	NA
Organic Carbon (LECO)	LECO	R&L 6B3	%	0.2	0.24	3.24	NA	0.90
Phosphorus (Colwell)	Bicarb/UV-Vis	R&L 9B1	mg/kg	5	NA	12.1	NA	NA
Sulphate-Sulphur	KCl40/ICP	R&L 10D1	mg/kg	3	NA	14.4	NA	NA
Extractable Copper	DTPA/ICP	R&L 12A1	mg/kg	0.2	NA	0.24	NA	NA
Extractable Zinc	DTPA/ICP	R&L 12A1	mg/kg	0.2	NA	1.26	NA	NA
Extractable Manganese	DTPA/ICP	R&L 12A1	mg/kg	1	NA	11.6	NA	NA
Extractable Iron	DTPA/ICP	R&L 12A1	mg/kg	1	NA	153	NA	NA
Extractable Boron	Hot CaCl2/ICP	R&L 12C2	mg/kg	0.2	NA	0.65	NA	NA
Exchangeable Aluminium	KCl/ICP	R&L 15G1	mg/kg	2	892	15.8	13.3	524
Exchangeable Aluminium	Calculation	R&L 15J1	cmol/kg	na	9.91	0.18	0.15	5.82
Total Cadmium	ICP-OES	AS4479.2	mg/kg	0.5	NA	<0.5	NA	NA
Total Chromium	ICP-OES	AS4479.2	mg/kg	0.5	NA	4.1	NA	NA
Total Copper	ICP-OES	PMS-09	mg/kg	0.5	NA	2.2	NA	NA
Total Iron	ICP-OES	PMS-09	mg/kg	0.5	NA	8350	NA	NA
Total Lead	ICP-OES	AS4479.2	mg/kg	0.5	NA	5.1	NA	NA
Total Manganese	ICP-OES	PMS-09	mg/kg	0.5	NA	206	NA	NA
Total Nickel	ICP-OES	AS4479.2	mg/kg	0.5	NA	1.5	NA	NA
Total Zinc	ICP-OES	PMS-09	mg/kg	0.5	NA	10.4	NA	NA



ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID DEPTH					CH05	CH06	CH06	CH06
					110-120	0-10	30-40	50-60
Test Parameter	Method Description	Method Reference	Units	LOR	230927-13	230927-14	230927-15	230927-16
Total Potassium	ICP-OES	PMS-09	mg/kg	0.5	NA	257	NA	NA
Texture	Field	Northcote	Class	na	LMC	FSL	FSL	FSL
Total Calcium	ICP-OES	PMS-09	mg/kg	100	NA	2190	NA	NA
Total Magnesium	ICP-OES	PMS-09	mg/kg	50	NA	474	NA	NA
Total Sodium	ICP-OES	PMS-09	mg/kg	40	NA	140	NA	NA
Total Sulphur	ICP-OES	PMS-09	mg/kg	40	NA	312	NA	NA
Total Aluminium	ICP-OES	PMS-09	mg/kg	100	NA	9260	NA	NA
Emerson Aggregate Test	Class	PMS-21	Number	na	6	7	5	5
Exchangeable Potassium	ICP-OES	R&L 15D1	mg/kg	10	171	129	63.5	88.5
Exchangeable Calcium	ICP-OES	R&L 15D1	mg/kg	20	1123	1439	716	1402
Exchangeable Magnesium	ICP-OES	R&L 15D1	mg/kg	10	42.8	212	97.5	202
Exchangeable Sodium	ICP-OES	R&L 15D1	mg/kg	10	39.8	30.7	25.8	50.8
Gravel >2.0mm	Sieve	ASTMD422-63	%	na	<0.1	3.3	2.4	2.8
Coarse Sand 0.2-2.0mm	Sieve	ASTMD422-63	%	na	32.4	66.5	58.4	46.2
Fine Sand 0.02-0.2mm	Sieve	ASTMD422-63	%	na	19.5	16.4	20.9	14.1
Silt 0.002-0.02mm	Hydrometer	ASTMD422-63	%	na	15.6	8.4	7.7	8.4
Clay <0.002mm	Hydrometer	ASTMD422-63	%	na	32.5	5.4	10.7	28.5





ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID					CH06	CH07	CH07	CH07
					110-120	2-10	20-30	50-60
DEPTH								
Test Parameter	Method Description	Method Reference	Units	LOR	230927-17	230927-18	230927-19	230927-20
pH (1:5 in H2O)	Electrode	R&L 4A1	pH units	na	4.53	5.21	5.27	5.63
pH (1:5 in CaCl2)	Electrode	R&L 4B2	pH units	na	3.84	4.64	4.74	5.16
Chloride Soluble	DA	DAP-06	mg/kg	5	11.4	22.1	10.4	<5.00
Electrical Conductivity	Electrode	R&L 3A1	dS/m	0.01	0.01	0.05	0.02	0.01
Total N (LECO)	LECO	R&L 7A5	mg/kg	50	NA	4250	NA	NA
Extractable Nitrate-N	DA	DAP-03	mg/kg	1	<1.00	27.1	3.19	1.06
Ammonium - N (Ex)	ExKCl/UV-Vis	PMS-22	mg/kg	2	4.65	8.40	8.87	6.03
Phosphorus (Total)	HNO3/HClO4 ICP	ICP-03	mg/kg	40	NA	1093	NA	NA
Organic Carbon (LECO)	LECO	R&L 6B3	%	0.2	<0.20	4.50	NA	0.74
Phosphorus (Colwell)	Bicarb/UV-Vis	R&L 9B1	mg/kg	5	NA	20.2	NA	NA
Sulphate-Sulphur	KCl40/ICP	R&L 10D1	mg/kg	3	NA	9.53	NA	NA
Extractable Copper	DTPA/ICP	R&L 12A1	mg/kg	0.2	NA	0.54	NA	NA
Extractable Zinc	DTPA/ICP	R&L 12A1	mg/kg	0.2	NA	2.16	NA	NA
Extractable Manganese	DTPA/ICP	R&L 12A1	mg/kg	1	NA	21.6	NA	NA
Extractable Iron	DTPA/ICP	R&L 12A1	mg/kg	1	NA	125	NA	NA
Extractable Boron	Hot CaCl2/ICP	R&L 12C2	mg/kg	0.2	NA	0.33	NA	NA
Exchangeable Aluminium	KCl/ICP	R&L 15G1	mg/kg	2	1164	37.8	13.9	<2.00
Exchangeable Aluminium	Calculation	R&L 15J1	cmol/kg	na	12.9	0.42	0.15	0.02
Total Cadmium	ICP-OES	AS4479.2	mg/kg	0.5	NA	<0.5	NA	NA
Total Chromium	ICP-OES	AS4479.2	mg/kg	0.5	NA	19.2	NA	NA
Total Copper	ICP-OES	PMS-09	mg/kg	0.5	NA	6.5	NA	NA
Total Iron	ICP-OES	PMS-09	mg/kg	0.5	NA	24600	NA	NA
Total Lead	ICP-OES	AS4479.2	mg/kg	0.5	NA	9.0	NA	NA
Total Manganese	ICP-OES	PMS-09	mg/kg	0.5	NA	574	NA	NA
Total Nickel	ICP-OES	AS4479.2	mg/kg	0.5	NA	9.8	NA	NA
Total Zinc	ICP-OES	PMS-09	mg/kg	0.5	NA	42.0	NA	NA



ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID DEPTH					CH06	CH07	CH07	CH07
					110-120	2-10	20-30	50-60
Test Parameter	Method Description	Method Reference	Units	LOR	230927-17	230927-18	230927-19	230927-20
Total Potassium	ICP-OES	PMS-09	mg/kg	0.5	NA	456	NA	NA
Texture	Field	Northcote	Class	na	FSCL	L	L	CL
Total Calcium	ICP-OES	PMS-09	mg/kg	100	NA	1460	NA	NA
Total Magnesium	ICP-OES	PMS-09	mg/kg	50	NA	1010	NA	NA
Total Sodium	ICP-OES	PMS-09	mg/kg	40	NA	155	NA	NA
Total Sulphur	ICP-OES	PMS-09	mg/kg	40	NA	501	NA	NA
Total Aluminium	ICP-OES	PMS-09	mg/kg	100	NA	36000	NA	NA
Emerson Aggregate Test	Class	PMS-21	Number	na	6	7	6	6
Exchangeable Potassium	ICP-OES	R&L 15D1	mg/kg	10	104	186	123	106
Exchangeable Calcium	ICP-OES	R&L 15D1	mg/kg	20	477	1221	844	1291
Exchangeable Magnesium	ICP-OES	R&L 15D1	mg/kg	10	80.8	241	81.5	141
Exchangeable Sodium	ICP-OES	R&L 15D1	mg/kg	10	37.9	43.5	41.2	46.6
Gravel >2.0mm	Sieve	ASTMD422-63	%	na	0.8	6.4	3.1	1.1
Coarse Sand 0.2-2.0mm	Sieve	ASTMD422-63	%	na	43.4	39.0	47.1	39.9
Fine Sand 0.02-0.2mm	Sieve	ASTMD422-63	%	na	14.4	24.6	19.4	17.5
Silt 0.002-0.02mm	Hydrometer	ASTMD422-63	%	na	8.5	18.2	9.7	9.5
Clay <0.002mm	Hydrometer	ASTMD422-63	%	na	32.9	11.8	20.7	32.1





ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID					CH07	CH07	CH08	CH08
					80-90	110-120	0-10	50-60
DEPTH								
Test Parameter	Method Description	Method Reference	Units	LOR	230927-21	230927-22	230927-23	230927-24
pH (1:5 in H2O)	Electrode	R&L 4A1	pH units	na	5.37	5.53	5.64	6.10
pH (1:5 in CaCl2)	Electrode	R&L 4B2	pH units	na	4.96	4.79	5.08	5.37
Chloride Soluble	DA	DAP-06	mg/kg	5	10.7	7.14	14.4	<5.00
Electrical Conductivity	Electrode	R&L 3A1	dS/m	0.01	0.01	0.01	0.03	0.01
Total N (LECO)	LECO	R&L 7A5	mg/kg	50	NA	NA	2950	NA
Extractable Nitrate-N	DA	DAP-03	mg/kg	1	2.79	1.01	2.06	1.10
Ammonium - N (Ex)	ExKCl/UV-Vis	PMS-22	mg/kg	2	5.07	10.0	13.5	3.15
Phosphorus (Total)	HNO3/HClO4 ICP	ICP-03	mg/kg	40	NA	NA	2102	NA
Organic Carbon (LECO)	LECO	R&L 6B3	%	0.2	NA	0.39	2.57	0.94
Phosphorus (Colwell)	Bicarb/UV-Vis	R&L 9B1	mg/kg	5	NA	NA	138	NA
Sulphate-Sulphur	KCl40/ICP	R&L 10D1	mg/kg	3	NA	NA	18.4	NA
Extractable Copper	DTPA/ICP	R&L 12A1	mg/kg	0.2	NA	NA	<0.20	NA
Extractable Zinc	DTPA/ICP	R&L 12A1	mg/kg	0.2	NA	NA	0.54	NA
Extractable Manganese	DTPA/ICP	R&L 12A1	mg/kg	1	NA	NA	2.72	NA
Extractable Iron	DTPA/ICP	R&L 12A1	mg/kg	1	NA	NA	26.8	NA
Extractable Boron	Hot CaCl2/ICP	R&L 12C2	mg/kg	0.2	NA	NA	0.42	NA
Exchangeable Aluminium	KCl/ICP	R&L 15G1	mg/kg	2	<2.00	10.9	6.15	<2.00
Exchangeable Aluminium	Calculation	R&L 15J1	cmol/kg	na	0.02	0.12	0.07	0.02
Total Cadmium	ICP-OES	AS4479.2	mg/kg	0.5	NA	NA	0.9	NA
Total Chromium	ICP-OES	AS4479.2	mg/kg	0.5	NA	NA	24.8	NA
Total Copper	ICP-OES	PMS-09	mg/kg	0.5	NA	NA	14.0	NA
Total Iron	ICP-OES	PMS-09	mg/kg	0.5	NA	NA	38000	NA
Total Lead	ICP-OES	AS4479.2	mg/kg	0.5	NA	NA	5.9	NA
Total Manganese	ICP-OES	PMS-09	mg/kg	0.5	NA	NA	646	NA
Total Nickel	ICP-OES	AS4479.2	mg/kg	0.5	NA	NA	21.8	NA
Total Zinc	ICP-OES	PMS-09	mg/kg	0.5	NA	NA	95.1	NA



ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID DEPTH					CH07	CH07	CH08	CH08
					80-90	110-120	0-10	50-60
Test Parameter	Method Description	Method Reference	Units	LOR	230927-21	230927-22	230927-23	230927-24
Total Potassium	ICP-OES	PMS-09	mg/kg	0.5	NA	NA	1370	NA
Texture	Field	Northcote	Class	na	CL	CL	L	L
Total Calcium	ICP-OES	PMS-09	mg/kg	100	NA	NA	3040	NA
Total Magnesium	ICP-OES	PMS-09	mg/kg	50	NA	NA	3850	NA
Total Sodium	ICP-OES	PMS-09	mg/kg	40	NA	NA	241	NA
Total Sulphur	ICP-OES	PMS-09	mg/kg	40	NA	NA	305	NA
Total Aluminium	ICP-OES	PMS-09	mg/kg	100	NA	NA	32700	NA
Emerson Aggregate Test	Class	PMS-21	Number	na	6	6	5	5
Exchangeable Potassium	ICP-OES	R&L 15D1	mg/kg	10	103	111	791	395
Exchangeable Calcium	ICP-OES	R&L 15D1	mg/kg	20	829	716	2467	3391
Exchangeable Magnesium	ICP-OES	R&L 15D1	mg/kg	10	197	219	649	694
Exchangeable Sodium	ICP-OES	R&L 15D1	mg/kg	10	47.7	41.4	58.3	85.5
Gravel >2.0mm	Sieve	ASTMD422-63	%	na	0.6	0.6	3.3	0.8
Coarse Sand 0.2-2.0mm	Sieve	ASTMD422-63	%	na	34.4	33.8	43.9	30.8
Fine Sand 0.02-0.2mm	Sieve	ASTMD422-63	%	na	16.0	17.6	27.7	34.4
Silt 0.002-0.02mm	Hydrometer	ASTMD422-63	%	na	10.0	7.8	18.4	18.7
Clay <0.002mm	Hydrometer	ASTMD422-63	%	na	39.0	40.2	6.7	15.3





ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID					CH09			
DEPTH					5-15			
Test Parameter	Method Description	Method Reference	Units	LOR	230927-25			
pH (1:5 in H2O)	Electrode	R&L 4A1	pH units	na	5.58			
pH (1:5 in CaCl2)	Electrode	R&L 4B2	pH units	na	4.92			
Chloride Soluble	DA	DAP-06	mg/kg	5	17.0			
Electrical Conductivity	Electrode	R&L 3A1	dS/m	0.01	0.03			
Total N (LECO)	LECO	R&L 7A5	mg/kg	50	2670			
Extractable Nitrate-N	DA	DAP-03	mg/kg	1	2.67			
Ammonium - N (Ex)	ExKCl/UV-Vis	PMS-22	mg/kg	2	11.2			
Phosphorus (Total)	HNO3/HClO4 ICP	ICP-03	mg/kg	40	392			
Organic Carbon (LECO)	LECO	R&L 6B3	%	0.2	4.97			
Phosphorus (Colwell)	Bicarb/UV-Vis	R&L 9B1	mg/kg	5	8.24			
Sulphate-Sulphur	KCl40/ICP	R&L 10D1	mg/kg	3	7.88			
Extractable Copper	DTPA/ICP	R&L 12A1	mg/kg	0.2	0.24			
Extractable Zinc	DTPA/ICP	R&L 12A1	mg/kg	0.2	1.40			
Extractable Manganese	DTPA/ICP	R&L 12A1	mg/kg	1	7.64			
Extractable Iron	DTPA/ICP	R&L 12A1	mg/kg	1	25.2			
Extractable Boron	Hot CaCl2/ICP	R&L 12C2	mg/kg	0.2	0.77			
Exchangeable Aluminium	KCl/ICP	R&L 15G1	mg/kg	2	14.3			
Exchangeable Aluminium	Calculation	R&L 15J1	cmol/kg	na	0.16			
Total Cadmium	ICP-OES	AS4479.2	mg/kg	0.5	<0.5			
Total Chromium	ICP-OES	AS4479.2	mg/kg	0.5	4.9			
Total Copper	ICP-OES	PMS-09	mg/kg	0.5	2.9			
Total Iron	ICP-OES	PMS-09	mg/kg	0.5	20700			
Total Lead	ICP-OES	AS4479.2	mg/kg	0.5	42.8			
Total Manganese	ICP-OES	PMS-09	mg/kg	0.5	806			
Total Nickel	ICP-OES	AS4479.2	mg/kg	0.5	2.3			
Total Zinc	ICP-OES	PMS-09	mg/kg	0.5	65.1			



ANALYSIS REPORT

PROJECT NO: EW230927

Location: CHD

CLIENT SAMPLE ID					CH09			
DEPTH					5-15			
Test Parameter	Method Description	Method Reference	Units	LOR	230927-25			
Total Potassium	ICP-OES	PMS-09	mg/kg	0.5	1380			
Texture	Field	Northcote	Class	na	L			
Total Calcium	ICP-OES	PMS-09	mg/kg	100	1630			
Total Magnesium	ICP-OES	PMS-09	mg/kg	50	815			
Total Sodium	ICP-OES	PMS-09	mg/kg	40	173			
Total Sulphur	ICP-OES	PMS-09	mg/kg	40	234			
Total Aluminium	ICP-OES	PMS-09	mg/kg	100	52900			
Emerson Aggregate Test	Class	PMS-21	Number	na	7			
Exchangeable Potassium	ICP-OES	R&L 15D1	mg/kg	10	292			
Exchangeable Calcium	ICP-OES	R&L 15D1	mg/kg	20	1465			
Exchangeable Magnesium	ICP-OES	R&L 15D1	mg/kg	10	319			
Exchangeable Sodium	ICP-OES	R&L 15D1	mg/kg	10	78.5			
Gravel >2.0mm	Sieve	ASTMD422-63	%	na	17.9			
Coarse Sand 0.2-2.0mm	Sieve	ASTMD422-63	%	na	22.2			
Fine Sand 0.02-0.2mm	Sieve	ASTMD422-63	%	na	24.0			
Silt 0.002-0.02mm	Hydrometer	ASTMD422-63	%	na	22.0			
Clay <0.002mm	Hydrometer	ASTMD422-63	%	na	13.9			

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Soils are air dried at 40°C and ground <2mm.

NB: LOR is the Lowest Obtainable Reading.

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