

APPENDIX G1

Surface Water Assessment

Clarrie Hall Dam Raising EIS

Surface Water Assessment

Prepared for Tweed Shire Council

September 2024

Clarrie Hall Dam Raising EIS

Surface Water Assessment

Tweed Shire Council

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Approved by



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Executive Summary

ES1 Overview

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

This Surface Water Assessment (SWA) has been prepared by EMM Consulting Pty Limited (EMM) to support the Environmental Impact Statement (EIS) for the Clarrie Hall Dam Raising (CHDR) (the Proposal). The EIS has been prepared by Kellogg Brown & Root Pty Limited (KBR) for the planning approval application for the Proposal.

This SWA includes:

- a description of the Proposal and the SEARs relevant to surface water
- assessment methodology, including a description of the modelling approach used to estimate future effects, and the risk framework used to assess these effects
- an overview of the regulations and guidelines relevant to assessing surface water effects
- a description of the existing surface water environment, including waterways, historical gauged flow regime water quality records, and environmental receptors
- potential effects on surface water quality and flow regime during Proposal construction
- potential effects on surface water quality and flow regime during Proposal operation
- a risk assessment of each of the identified potential effects, detailing likelihood, magnitude and consequence, the likely receptor that could be affected if the risk eventuated, mitigation measures proposed, and an assessment of any residual risk remaining after application of the mitigation measures
- a surface water monitoring plan, describing locations, frequency and methods for monitoring surface water flow and quality during construction and operation.

ES2 Construction effects

ES2.1 Water quality

Construction activities will include:

- bulk earthworks
- works on the dam embankment and spillway
- concrete batching
- haulage of materials
- clearing vegetation from parts of the new larger inundation area
- quarry re-establishment and expansion

- vehicle movements
- materials laydown areas.

A key hazard to surface water quality during construction will be management of erosion and sediment. A Soil and Water Management Plan (SWMP) will be developed for the Proposal prior to the commencement of construction. This plan will contain:

- drawings of the site layout
- a narrative of how erosion control and soil and water management will be achieved on site
- description of treatment measures
- description of treatment maintenance measures
- a construction schedule, and description of how the plan will work through the various stages of construction
- design calculations for the treatment measures, including hydrologic estimations of runoff volumes and rates, and swale and sedimentation basin capacities.

Erosion and Sediment Control Plans (ESCP's) will be developed for all disturbed areas.

Two activities of particular note due to potential water quality risks are establishment of a construction area within Doon Doon Creek, and operation of a concrete batching plant, described below.

ES2.1.1 Temporary construction area downstream from the existing dam wall

Access to the dam wall, multi-level offtake (MLO) and boat ramp is currently located along the eastern bank of Doon Doon Creek. The spillway is located on the western side of the dam. Access will be required to the existing spillway, the proposed new spillway location, and the downstream face of the dam wall. It is proposed that this access would be created by creating a construction pad via importation of fill material.

It is likely that some smaller particulate material will be present within the construction pad rock matrix, either due to the grading of material during construction or due to transportation via vehicle movements. During rainfall runoff events, dust, dirt and smaller particulate matter could be transported downstream into Doon Doon Creek and the Tweed River, increasing turbidity and potentially depositing rock fragments downstream. With SWMP controls in place, the quantum of material mobilised is expected to be minor.

ES2.1.2 Concrete batching plant

When cement mixes with water it causes the pH to rise. If cement or concrete batching plant wastewater reached Doon Doon Creek or Tweed River, it is likely that the resulting pH of creek water would be detrimental to aquatic life. Management measures would be incorporated into the design of the concrete batching plant to reduce the risk as low as reasonably practicable, including:

- Maintaining separation of 'clean' rainfall from surfaces, which have contact with cement and concrete, and directing 'clean' rainfall runoff to the construction compound stormwater treatment train. This may be achieved through measures such as providing roofing over mixing, unloading and dusty areas and directing the runoff from the roof areas away from the batching plant.
- Sealing the batching plant surface with hardstand or paving so that local rainfall runoff within the plant site may be directed effectively to drains and sumps, and to prevent mud and pooling.

- Installation of a first flush system for hardstand areas, which may receive dust drift or minor quantities spilt material. The first flush system would typically capture the first 20 mm of rainfall runoff and direct it to a holding area. Subsequent rainfall runoff would then be deemed clean and could be incorporated into the construction compound stormwater management system.
- Bunding chemical and liquid storage areas.
- Installing a vehicle washdown facility for vehicles moving in and out of the batching area.
- Installing a wastewater collection and recycling system to collect contaminated water from:
    - agitator washout
    - truck washing
    - yard washdown
    - contaminated stormwater
    - concrete batching area
    - slump stand
    - any other wastewater from the batching plant operation.
- Directing process wastewater and contaminated stormwater to a settling pond, or series of ponds, such that the water can be reused in the concrete batching process. These ponds would be contained within the batching plant area and would not discharge to the laydown yard stormwater management system. The settling pond or series of ponds should be lined with an impervious liner capable of containing all contaminants found within the water they are designed to collect.
- Monitoring pond and sump water quantity and quality.

Suitable water management measures for the batching plant would be developed prior to the commencement of construction and documented as part of the SWMP.

ES2.2 Water requirements

Water would be required during the construction period for the workforce, concrete batching, and dust suppression, with dust suppression having the potential to be the larger of the three demands, depending on the construction schedule (Table ES1). For dust suppression calculations, the assessment has considered a disturbance area of 49.6 ha, being the total disturbance area proposed. It is likely that only a portion of this area will be disturbed at any one time, and that dust suppression requirements will be lower than the estimate provided.

Table ES1 Construction water

Water use	Volume (ML/year)
Personnel and facilities	7 ML/year
Concrete batching	3 ML/year
Dust suppression (estimate based on 49.6 ha disturbance area)	250 ML/year

Water use	Volume (ML/year)
Total	260 ML/year

ES3 Ongoing effects

ES3.1 Flow regime changes

ES3.1.1 Modelling method

The existing and potential future flow regime following development of the Proposal was modelled using the existing Tweed River Valley Source model. This model was developed by the former Department of Planning and Environment – Water Division (DPE-Water) in 2019–2020 using the national hydrological modelling platform eWater Source (NSW DPE-Water, 2020a).

The DPE-Water Tweed River Valley Source model encompasses the catchment area of the Tweed River and its tributaries, as well as a number of smaller coastal catchments. It is a river system model which runs using a daily timestep and simulates:

- hydrological processes of river and storage inflows, evaporative losses (from rivers and storages), and river losses
- storage releases and spills, based on water supply ordering and environmental release requirements
- water demand across various water users
- seasonal and daily irrigation requirements for various crop types
- the water sharing and resource allocation processes
- the daily river and bulk water supply system operation as implemented by Council.

In consultation with DPE-Water, EMM updated the Tweed River Valley Source model to reflect the updates in the Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2023, which was released during the EIS preparation period.

The Source model was updated by EMM to accommodate the input climate and hydrological data required to assess the Proposal, specifically:

- historical rainfall and evaporation data sequences were extended to the 31st of December 2022
- palaeo-stochastic data was obtained for the relevant climate input stations
- climate change projections were used to generate data for the relevant climate input stations
- the 'scenario input set' functionality in Source was utilised to define the input data for each modelled scenario to best accommodate the large file sizes of stochastic climate data
- the Sacramento parameters provided by DPE-Water were used to develop a runoff model within the Source platform, to convert climate data into river inflow data.

ES3.1.2 Climate data

Synthetic palaeo-stochastic climate data published by the NSW Government was used to assess the potential streamflow regime with and without the Proposal. Stochastic modelling processes use the statistical characteristics of actual climate data to generate long-term, extended synthetic datasets (stochastic data). This type of data is particularly useful for understanding climate-based risks because it includes: greater climate variability, a range of different / plausible climate sequencing not seen in the actual climate record, and periods of low or high flow with varying persistence (eg long-term droughts and significant floods).

Palaeo-stochastic climate sequences aligning with NARCliM 1.5 climate projections were used to assess the performance of the Proposal in 2060.

ES3.1.3 Proposal effects

i Hydrological effects

Long term flow modelling using palaeo-stochastic climate data illustrated:

- mean extraction volumes for town water supply would be unchanged by the Proposal
- mean managed releases from Clarrie Hall Dam would not materially change as a result of the Proposal
- the percentage of time when dam storage levels are below 13.6 GL (trigger for Stage 1 water restrictions) will reduce significantly as a result of the Proposal
- high flows will be attenuated in the larger dam, resulting in:
    - a small reduction in flood peaks within Doon Doon Creek
    - a small increase in duration of flood recession
- the frequency of minimum releases (4 ML/day) required to be released manually from the dam will increase from approximately 30% of the time to 40% of the time due to increased evaporation from the dam surface
- the increased loss of water to evaporation would be offset over the year by a minor increase in rainfall runoff upstream from the dam due to the additional reservoir area
- within 5 km downstream at Uki, most of the changes observable in Doon Doon Creek are negligible due to the contribution of the unregulated upstream reaches of the Tweed River runoff from additional catchment area and unaffected tributaries.

Modelling completed utilising climate change analysis illustrated that:

- by 2065 climate change is expected to result in significant water shortages and time with water restrictions within the Tweed Districy Water Supply if the existing infrastructure is maintained
- time in restrictions and shortfalls would decrease by 90% with the proposed larger reservoir
- the balance of evaporation and rainfall is expected to change, such that with the proposed larger reservoir additional evaporation loss could result in a decrease to end of system flow in the order of 0.5% due to the Proposal.

ii Ecological effects

The aquatic ecology assessment (appended to the EIS) identified one migratory fish species with a flow dependent migration trigger; Australian Bass. Australian Bass include a life cycle stage with a flow trigger and may migrate downstream to the estuary to spawn during May – July and then migrate upstream August - April.

Currently around 86% of years contain 5+ day flow sequences which are supportive of Australian Bass migration upstream. This is expected to increase marginally to 87% of years following dam wall raising, due to the small increase in number of days with flows above 100 ML/day.

Approximately 96% of years currently contain 5+ day flow sequences supportive of Australian Bass downstream migration. Following dam wall raising, it is expected that 96% of years will continue to contain such events.

These results indicate that the Proposal is not expected to have any significant effect on Australian Bass migration within the Tweed River.

iii Geomorphological effects

Geomorphological effects can occur downstream from reservoirs due to changes in the flow regime, and changes to the sediment load of releases. Erosion can occur if the frequency of high flows is increased (resulting in a high shear environment which can mobilise bed material), or due to a reduction in the sediment load of releases altering the balance of erosion and deposition to favour erosion. Sedimentation or deposition can occur if a significant sediment load is released with low velocities which promote settling.

Potential changes to bed shear through Doon Doon Creek and the Tweed River due to the Proposal were assessed utilising information describing the anticipated flow regime changes, hydraulic properties of the waterways, and critical shear stress data. The flow regime assessment indicated that there would be little change to the frequency or magnitude of flow events large enough to mobilise the boulders and cobbles which form the Doon Doon Creek and Tweed River beds, with changes tending to be a reduction in the magnitude of peak flows due to attenuation in the larger reservoir. As a result, it is expected that in the Tweed River between Doon Doon Creek and Uki there will be minimal change to the bed shear environment.

The efficiency of reservoirs to trap sediment is dependent on water residence time, with higher residence time allowing for additional settling. Empirical reservoir sediment trap methods provide an estimate of 94.2% of sediment currently captured by the existing reservoir, increasing to 96.8% following wall raising.

The decrease in sediment supply in Doon Doon Creek downstream from the dam following wall raising will promote erosion of fine particles downstream, where these exist, while the decrease in high flows will 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 relatively small. As such, any geomorphological change which does occur is expected to occur as slow adjustments over an extended period of time.

In locations with a gravel/rocky bed it is likely that no geomorphological change will occur due to the project. Rocks of the sizes observed in the river bed 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 project.

ES3.2 Limnological changes

ES3.2.1 Modelling method

Limnological modelling was undertaken using the AEM3D software, simulating flow and water quality within the reservoir over time in three dimensions. The model was calibrated to observations of temperature, stratification and turn-over, salinity, sediment, dissolved oxygen, nitrogen, phosphorus, and alga over the period 2015-2019.

ES3.2.2 Water quality effects

The calibrated limnology model was used to assess current conditions and the Proposal. The modelling indicated that during summer when stratification occurs, the depth of warm surface water (epilimnion) will be slightly greater following dam wall raising, but the majority of the additional depth would be below the thermocline (the hypolimnion).

i Algae

The expansion of the hypolimnion may allow additional phosphorus to accumulate (as orthophosphate) in the anoxic deep water below the thermocline. During turn over events, this accumulated phosphorus would trigger increased cyanophyte and chlorophyte concentrations. The cyanophytes (blue-green algae) are likely to remain dominant during the summer months (which is currently observed) and at higher concentrations – the modelling indicates summer peaks of up to 50% higher. In addition, their dominance is likely to be reinforced by the changes in the ambient water conditions (primarily water temperature and stratification) that may occur as a result of climate change impacts.

Previously installed mixing devices in Clarrie Hall Dam have been somewhat effective in redistributing temperature gradients and have weakened, but not eliminated, thermal stratification. The overall performance of the mixers, however, was proven unsatisfactory and Hunter H2O (2018) concluded from the monitoring data that mechanical mixers cannot maintain:

- complete thermally destratified conditions
- stable and sufficient dissolved oxygen concentrations throughout the water column
- low and stable iron and manganese concentrations
- low and stable cyanobacterial populations.

Given the increased depth of the raised dam and the predicted increase in internal loading of nutrients from the hypolimnion under anoxic conditions it is considered unlikely that a destratification system with the specifications of the previous system will effectively mitigate the water quality risks that have been identified.

Implementation of a destratification system is not a part of the Proposal.

Dam water quality monitoring will be undertaken during dam operation. If the simulated algae increases are realised, Council will apply the best available science and value for money approaches available at the time to reduce algae concentrations to acceptable levels, or otherwise mitigate algae effects. The Proposal will not preclude or prevent the adoption of physical mitigation measures (eg a bubbler or destratification system) being considered and implemented if this is ultimately warranted.

ii Cold water pollution

The slight expansion of the epilimnion would allow greater flexibility to operators regarding which level of the MLO is used to release water from the reservoir. The modelling also indicated that the epilimnion may warm by around 2°C. As a result, the risk of cold water pollution events is expected to decrease following dam wall raising.

ES4 Surface water monitoring

A surface water monitoring program is proposed to be implemented over the duration of construction. This SWA presents the framework for a monitoring plan, which would be finalised as part of the future SWMP. The monitoring plan will include requirements to monitor weather, streamflows, process water quantity and quality, stormwater quality and receiving water quality. Existing streamflow and water quality monitoring sites will

continue to be utilised for monitoring. After completion of construction, the pre-construction stream and reservoir monitoring regime would be reinstated.

ES5 Risk assessment

Potential surface water effects associated with construction activities and ongoing operation of the Proposal were assessed within a risk framework considering both likelihood and significance of potential impacts. Risk ratings also considered proposed mitigation measures. Residual risks were generally considered to be low following application of proposed mitigation measures. Where risks were assessed to be higher, impacts are considered to be manageable through development of suitable designs and management plans during the future detailed design and construction phase, and monitoring during construction and operation.

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Glossary

Acronym	Description
AEP	Annual exceedance probability
AHD	Australian height datum
BLR	Basic landholder rights
BOD	Biological oxygen demand, a water quality parameter
BoM	Bureau of Meteorology
°C	Degrees Celsius, measurement of temperature
CCA	Climate Change Authority, an independent statutory body established under the Climate Change Authority Act 2011 to provide expert advice to the Australian Government on climate change policy
CHD	Clarrie Hall Dam
Chl-a	Chlorophyll-a, a form of chlorophyll used in photosynthesis, generally proportional to algae concentration
cm	Centimetre, one hundredth of a metre
Council	Tweed Shire Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation
SWMP	Construction Soil and Water Management Plan, part of the CEMP
CWP	Cold water pollution
d	Day, measurement of time
d_{50}	Median particle size in a soil
DES	Queensland Department of Environment and Science
DPE	NSW Department of Planning and Environment (historical name)
DPE-Water	NSW Department of Planning and Environment, Water division (historical name)
DPIE	NSW Department of Planning, Industry and Environment (historical name)
d/s	Downstream
DS Act	Dam Safety Act 2015
DGV	Default guideline value for physical and chemical qualities of water
DO	Dissolved oxygen, a water quality parameter
EC	Electrical conductivity, a measurement of water's ability to conduct electricity, generally proportional to salinity
EIS	Environmental Impact Statement
ELVIS	Elevation Information System database
EMP	Environmental Management Plan

Acronym	Description
EMU	Extraction management units, a geographical region defined in the WSP
ENSO	El Niño/La Niña Southern Oscillation, a climatic effect
EOS	End of system flow, ie water flowing over BPW and entering the tidal reach of the Tweed River
EV	Environmental value
FCDV	Fixed cone dispersion valve
FSL	Full Supply Level, the water level of the reservoir when at capacity
GCM	General Circulation Models, mathematical models capable of representing physical processes of the atmosphere and ocean to simulate response of global climate to the increasing greenhouse gas emission also interchangeably called Global Climate Models
GL	Gigalitre, 1,000,000,000 litres
HEC-RAS	The US Army Corps of Engineers Hydrologic Engineering Center's River Analysis System, hydraulic simulation software
IPCC	Intergovernmental Panel on Climate Change
IQQM	A hydrologic modelling tool for modelling water resources
IWCM	Integrated water cycle management strategy
kL	Kilolitre, 1,000 litres
km	kilometre, 1,000 metres
L	Litre, measurement of volume
LGA	Local Government Area
LiDAR	Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure distances. LiDAR survey used by the Proposal consists of a digital elevation model of the ground surface (beneath the vegetation canopy) collected via fixed wing aircraft.
LTAAEL	Long-term average annual extraction limit
m	Metre, measurement of length
mg	Milligram, one thousandth of a gram
mL	Millilitre, one thousandth of a litre
MLO	Multi-level offtake
mm	Millimetre, one thousandth of a metre
ML	Megalitre, 1,000,000 litres
N	Newton, a measurement of force
NARCliM	NSW and Australian Regional Climate Modelling
NATA	National Association of Testing Authorities, the recognised national accreditation authority for analytical laboratories and testing service providers in Australia
NTU	Nephelometric Turbidity Unit, measure of turbidity
PESCP	Progressive Erosion and Sediment Control Plan

Acronym	Description
pH	a measure of how acidic/basic water is
POEO Act	Protection of the Environment Operations Act 1997
QGIS	Quantum Geographic Information System, spatial mapping software
RL	Reduced Level, a reference height datum for the project, equivalent to AHD
RWS	Regional water strategy
SAM	Southern Annular Mode, a climatic effect
SEARs	Secretary's Environmental Assessment Requirements, a set of assessment requirements released by the DPE
s	Second, measurement of time
SILO	Queensland Government Scientific Information for Land Owners, a database of climate information developed from BoM sources
Source (eWater)	A hydrologic modelling tool for modelling water resources
SSI	State Significant Infrastructure
SWA	Surface Water Assessment (this document)
τ_c	Critical shear stress
TN	Total nitrogen, a water quality parameter
TP	Total phosphorus, a water quality parameter
µg	Microgram, one millionth of a gram
µS	Microsiemen, a measure of electrical conductivity
u/s	Upstream
WAL	Water access license
WM Act	Water Management Act 2000
WQO	Water quality objective
WSP	Water Sharing Plan, statutory instruments that set out objectives for the management of water sources, rules for the management of water for environmental outcomes, the number of water access licence share components on issue at the commencement of the plan, and rules for the use and trade of those water access licences
WTP	Water treatment plant

1 Introduction

1.1 Clarrie Hall Dam Raising

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 region. Council proposes to raise the wall of Clarrie Hall Dam by 8.5 m to a height of 70 m Australian Height Datum (AHD) (RL 70 m). This will increase the capacity of the dam from 16,000 megalitres (ML) to approximately 42,300 ML (the Proposal).

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

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

The former Department of Planning and Environment (DPE) – now referred to as the Department of Planning, Housing and Infrastructure (DPHI) – 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 is discussed in the FNCRWS and would assist Council to achieve some of the objectives of the FNCRWS.

Clarrie Hall Dam is located on Doon Doon Creek, a third-order stream forming a tributary of the Tweed River. The dam is located in Doon Doon, approximately 15 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 (km^2).

The Tweed District water supply is currently a run-of-river supply augmented by releases from Clarrie Hall Dam down Doon Doon Creek via release valves in the outlet structure within the dam to the Tweed River. Raw water is drawn from upstream of Bray Park Weir, effectively a saltwater barrage, in the Tweed River. In periods of low flow in the river, flows are augmented by releases from Clarrie Hall Dam to ensure availability of water for the Tweed District water supply.

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 1a Rural).

1.2 Proposal overview

The Proposal would include the following main activities and elements:

- raising the dam wall by 8.5 m
- a new spillway channel constructed higher in the left abutment with a flip bucket at the downstream end
- re-establishment of the quarry used to construct the existing dam for the purpose of sourcing rock material to raise the dam wall
- construction of associated haul roads to transport quarry material for the proposed raising of the dam wall
- establishment of a construction area for plant, equipment, storage, material handling and offices
- establishment of stockpile sites associated with construction

- construction of work compounds and site offices
- establishment of materials storage and handling facilities
- construction of workers accommodation
- construction of a concrete batching plant
- realignment of Clarrie Hall Dam Road higher in the right abutment
- raising of the existing intake tower and bridge
- decommissioning of existing recreational facilities at the dam wall area
- construction of new dam operational facilities including signage, car parking, security fences, lighting, monitoring equipment and a boat ramp
- removing or reconstructing impacted recreational infrastructure and facilities at Crams Farm
- upgrading the Kyogle Road and Clarrie Hall Dam Road intersection
- replacing McCabes Bridge and realignment of Commissioners Creek Road
- relocating existing power and telecommunications utilities
- construction of new recreation facilities including an amenities block, public shelters, viewing areas, interpretation signage, paths, car parks, and landscaping.

The detailed design will need to check the existing tunnel, valves and control systems remain suitable for new design flow velocities and pressures from the raised dam and their condition is suitable for extended service life.

The upgraded dam operational footprint would increase the area of inundation to below the RL 70 m contour, which is the waterline boundary at full supply level (FSL).

An overview of the elements of the Proposal is provided in Figure 1.1. Further details of the Proposal are provided in section 3 of the environmental impact statement (EIS).

The construction disturbance area and associated activities include the dam wall area and ancillary areas (refer to Table 1.1 below).

The operational disturbance areas include the following:

- area of inundation increased to the area below the RL 70 m contour, which is the waterline boundary at FSL
- area between FSL and the probable maximum flood (PMF) extent
- downstream areas due to changes in flow.

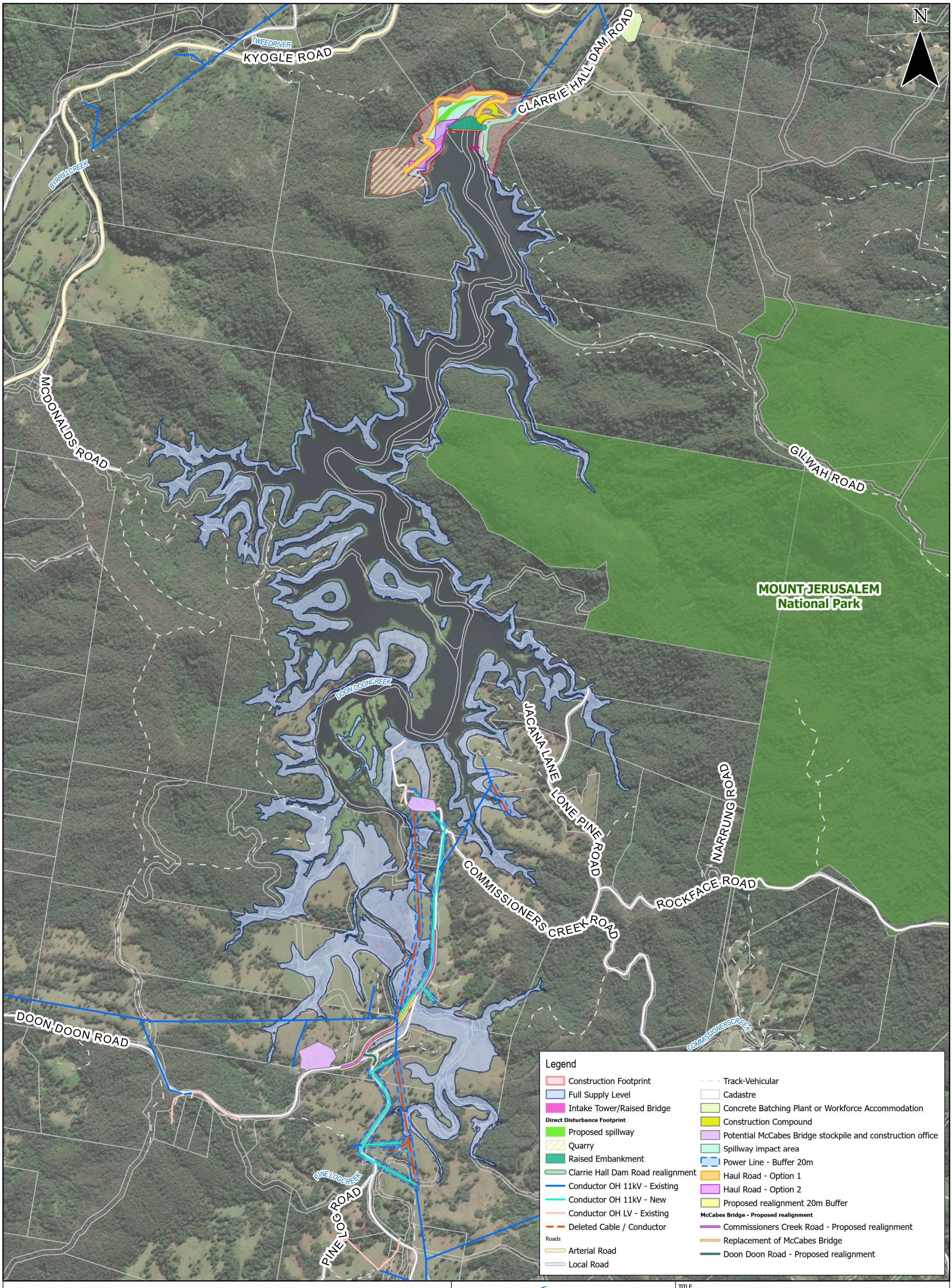
It is anticipated that construction would start in 2026, subject to obtaining all necessary approvals.

The Proposal is State significant infrastructure and is subject to approval by the NSW Minister for Planning 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 project, a description of the Proposal and statutory context is provided in the EIS.

Table 1.1 Proposal summary

Proposal element	Summary of the Proposal
Operation	
Description	Raising the embankment wall of Clarrie Hall Dam by 8.5 m
Operational footprint	An additional 209 ha inundated at the proposed FSL An additional 248 ha 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 RL 70 m 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
Ancillary works	Upgrading the intersection of Clarrie Hall Dam Road and Kyogle Road Replacing McCabes Bridge over Doon Doon Creek Realigning an approximately 1,000 metre 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 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
Cut / fill	Approximately 100,000 m^3 deficit of fill material will be derived from the quarry located 400 m from the existing dam
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 Establishing construction compounds including site offices and areas for materials stockpiling Establishing a workforce accommodation site compound.
Dewatering	Lowering dam storage by 300 mm below FSL during construction
Property	Permanent and temporary property adjustments and property access refinements



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Clarrie Hall Dam Raising Development Site (Full Extent)

Figure 1.1 Proposal overview

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A comparison of pertinent aspects of current and proposed water resource management within the Tweed Valley is provided in Table 1.2.

Table 1.2 Summary of proposed changes to water resource management

Aspect	Current	Proposed
Infrastructure		
Clarrie Hall Dam capacity	16,000 ML	42,300 ML
Full Supply Level (FSL)	RL 61.5 m	RL 70.0 m
Inundation area at FSL	226 ha	436 ha
Dam catchment area	60 km^2	Unchanged
Water supply		
Tweed district water supply	Run-of-river transfers of water from Clarrie Hall Dam via Doon Doon Creek into Tweed River to maintain flow to the pool upstream of Bray Park Weir.	Unchanged
Uki town water supply	Run-of-river flow extraction from the Tweed River at Uki	Unchanged
Tyalgum town water supply	Run-of-river flow extraction from the Oxley River at Tyalgum	Unchanged
Environmental Water		
Clarrie Hall Dam minimum release	1-4 ML/day based on flows observed in the Tweed River at upstream Palmers Road Crossing	Unchanged
Water Supply Restrictions		
Tweed Shire Council Drought Water Restriction Policy	Applied in accordance with the Policy. Triggers are based on Clarrie Hall Dam storage	Unchanged

1.3 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 environmental assessment requirements of the Secretary of the Department of Planning and Environment (SEARs) (section 1.5).

This Surface Water Assessment (SWA) has been prepared by EMM Consulting Pty Limited (EMM) to support the EIS for the Clarrie Hall Dam Raising (CHDR) (the project). The EIS has been prepared by Kellogg Brown & Root Pty Limited (KBR) for the planning approval application for the project.

This document includes:

- a description of the Proposal and the SEARs relevant to surface water (sections 1.1 to 1.5)
- assessment methodology, including a description of the modelling approach used to estimate future effects, and the risk framework used to assess these effects (sections 1.6 to 1.8)
- an overview of the regulations and guidelines relevant to assessing surface water effects (Chapter 2)
- a description of the existing surface water environment, including waterways, historical gauged flow regime water quality records, and environmental receptors (Chapter 3)

- potential effects on surface water quality and flow regime during construction (Chapter 4)
- potential effects on surface water quality and flow regime during Proposal operation (Chapter 5)
- a risk assessment of each of the identified potential effects, detailing likelihood, magnitude and consequence, the likely receptor that could be affected if the risk eventuated, mitigation measures proposed, and an assessment of any residual risk remaining after application of the mitigation measures (Chapter 6)
- a surface water monitoring plan, describing locations, frequency and methods for monitoring surface water flow and quality during and post construction (Chapter 7).

The expected effects of the Proposal on water supply security is discussed primarily in the business case. Hydrology modelling reported in Annexure A includes complementary information relating to water supply security developed via catchment water balance modelling using palaeo-stochastic climate data.

Potential effects on flooding are discussed in a separate appendix to the EIS.

An overview of the steps applied to assessing potential effects and the assessment of risk associated with those effects is illustrated in Figure 1.3.

1.4 Surface water assessment study area

The SWA has considered potential impacts from the Proposal within the Proposal footprint and affected downstream watercourses.

In outlining the Proposal, a Proposal footprint has been defined to facilitate the assessment of direct impacts from the project:

- Proposal footprint: all areas where direct impacts may be experienced during construction and/or operation.

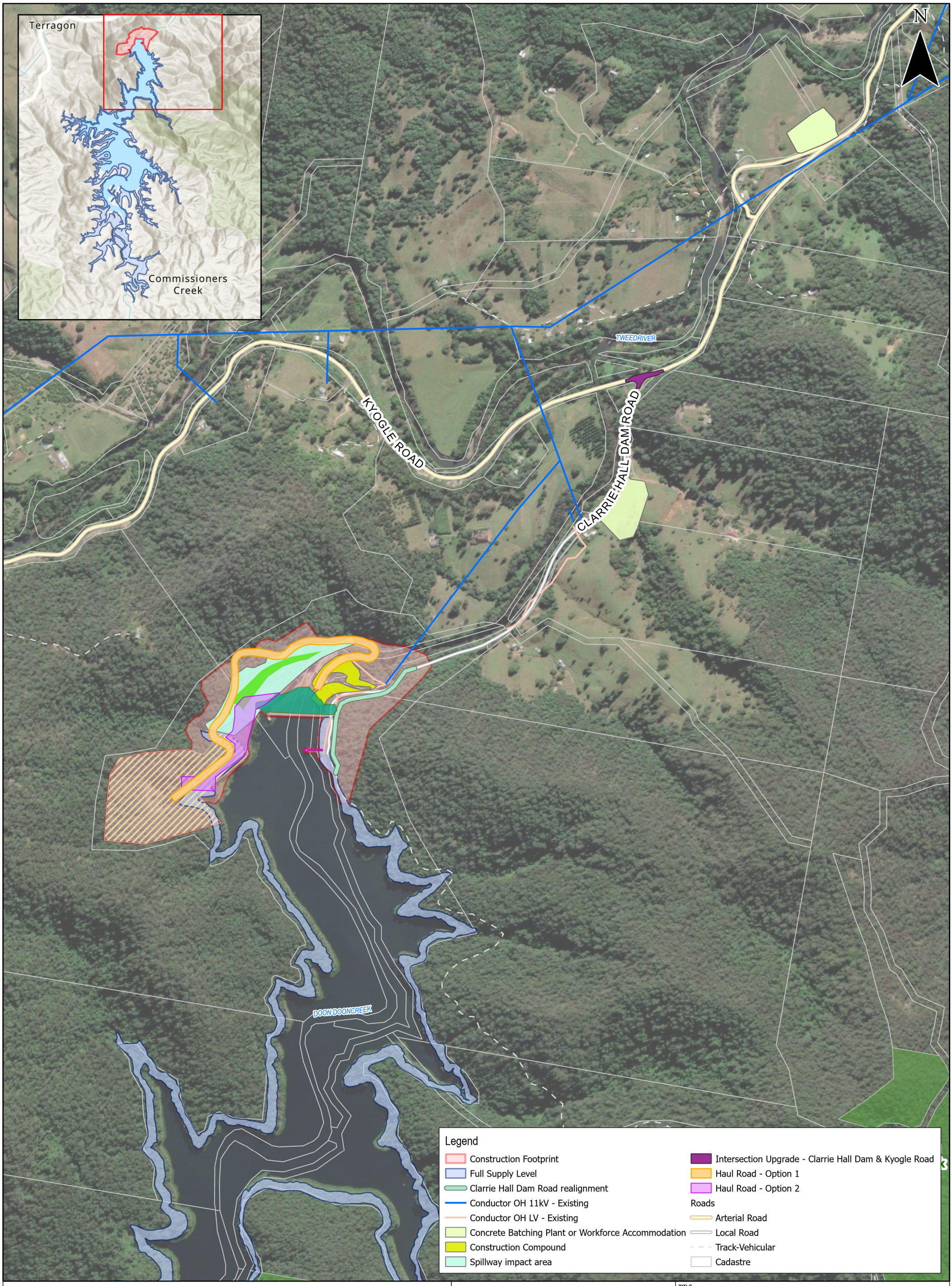
The Proposal footprint is comprised of the construction and operational footprints, of which there is some overlap:

- Construction footprint: areas where vegetation clearing and/or ground disturbance is required for raising of the dam to the FSL of RL 70 m and associated ancillary facilities
- Operational footprint: areas where there will be permanent operational elements or easements, including infrastructure needed to operate the raised Clarrie Hall Dam. The operation footprint includes the inundation area, being the area defined by the proposed FSL for the project.

The Proposal construction and operational footprints are shown in Figure 1.2.

Additional areas outside the Proposal footprint have also been considered where relevant to the assessment of Proposal impacts and include affected downstream watercourses: creek and river reaches where flow regime or water quality changes may occur due to the project. These locations are discussed in detail in this SWA and comprise:

- Doon Doon Creek from the dam wall to the Tweed River
- the Tweed River from the Doon Doon Creek confluence to Bray Park Weir.



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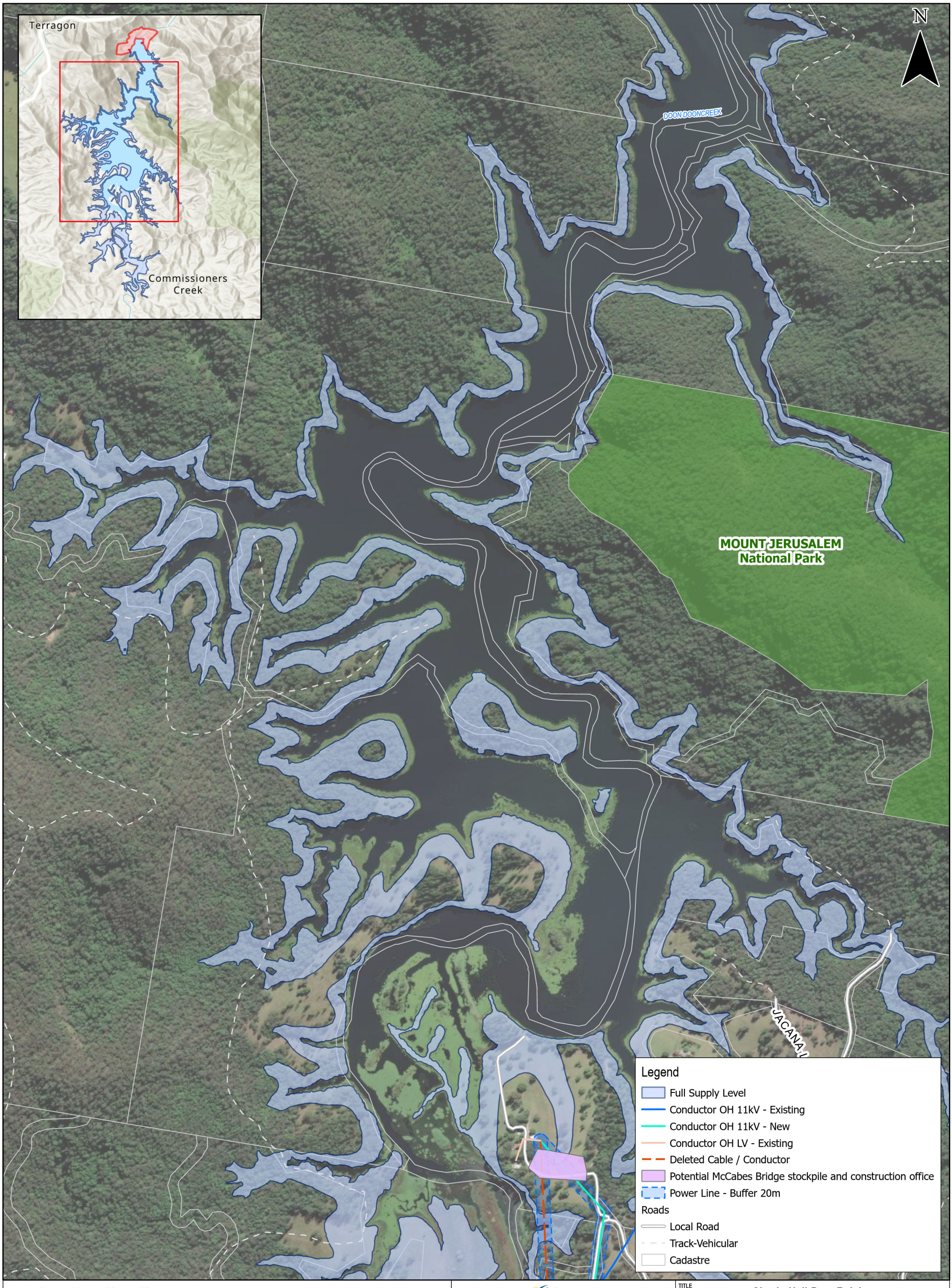
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Figure 1.2
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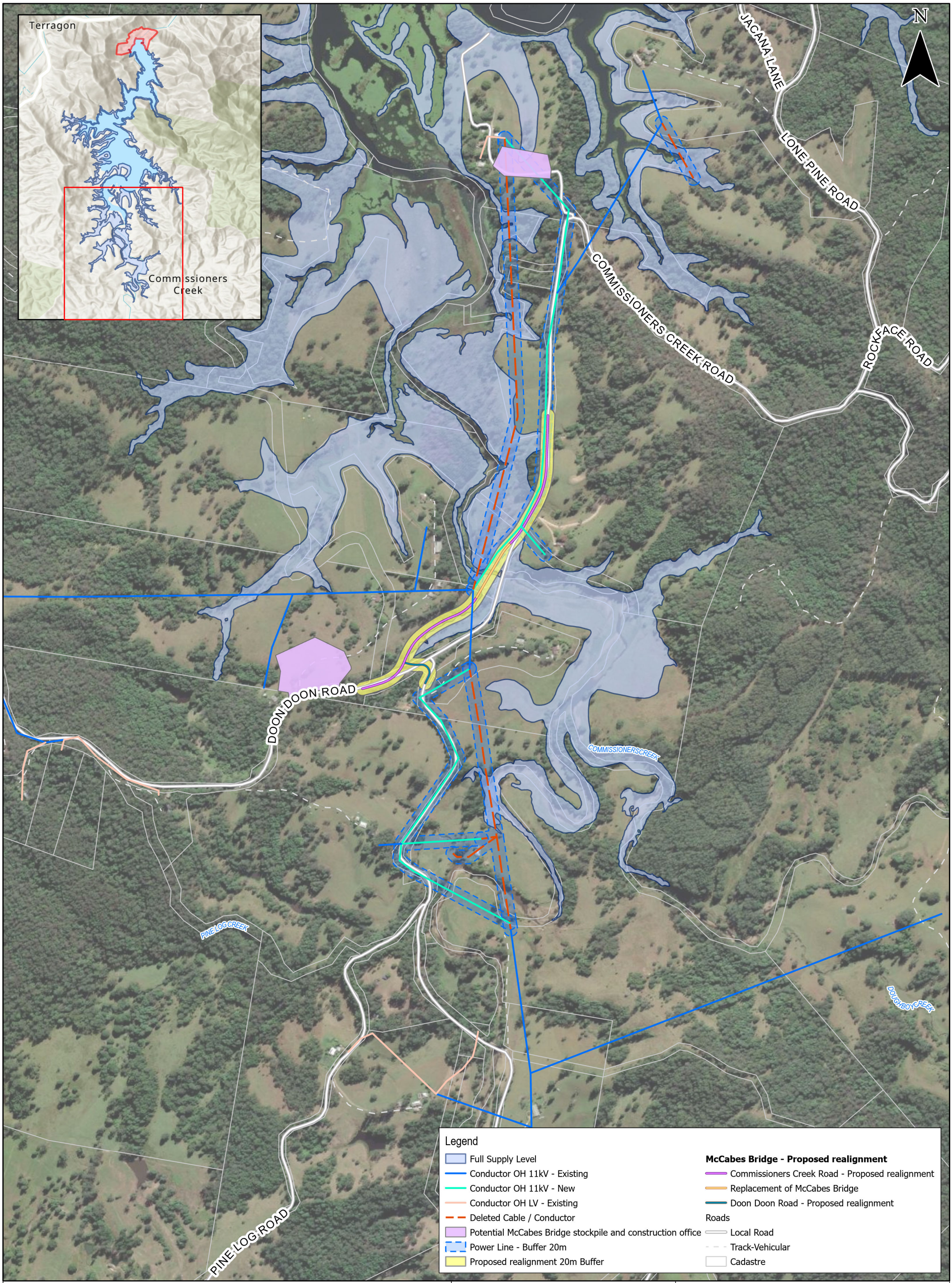
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1.5 Assessment requirements (SEARs)

This SWA has been prepared in accordance with the Secretary's Environmental Assessment Requirements (SEARs) for the Proposal as well as relevant government assessment requirements, guidelines and policies, and in consultation with the responsible government agencies.

The SEARs must be addressed in the EIS. Table 1.3 lists the matters relevant to this assessment and where they are addressed (ie in this report or another EIS Appendix).

To inform preparation of the SEARs, DPE[1] invited relevant government agencies to advise on matters to be addressed in the EIS. These matters were taken into account by the Secretary for DPE when preparing the SEARs.

Table 1.3 Relevant matters raised in SEARs

Requirements		Chapter/Section addresses
Hydrology, Flooding and Water Quality		
1.	The Proponent must describe (and map) the existing hydrological regime for surface and groundwater resources (including reliance by users and for ecological purposes) likely to be impacted by the proposal and identify any requirements for baseline monitoring of hydrological attributes. Mapping must include upstream and downstream tributaries that may potentially be impacted.	Annexure A Groundwater aspects are addressed in the Groundwater Impact Assessment – appended to EIS
2.	The Proponent must assess and model the impact of the operation of the proposal and any ancillary facilities (both built elements and discharges) on hydrology in accordance with the current guidelines, including:	
(a)	natural processes within rivers, wetlands and floodplains that affect ecological health, aquatic connectivity, and access to habitat for spawning and refuge.	Annexure A and section 5.6.3
(c)	changes to environmental water availability and flows, both regulated/licensed and unregulated/rules-based sources.	Section 5.6
(d)	direct or indirect increases in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses.	Section 5.8
3.	The Proponent must detail a framework for managing stratification within the dam and associated algal blooms and water releases from the dam that ensures impacts to upstream and downstream areas and ecosystems are minimised. The framework must include consideration of the potential rates of rise and fall in the river and timing of water releases and consider antecedent conditions within the river, flooding impacts up to the probable maximum flood and water clarity and temperature.	Section 5.7.2iv
6.	The Proponent must describe background conditions for current operations and any water resource likely to be affected by the proposal, including:	
(a)	existing surface and groundwater quality.	Section 3.9 Groundwater aspects are addressed in the Groundwater

[1] Subsequent to the issue of SEARs, the Department was renamed Department of Planning, Housing and Infrastructure (DPHI).

Table 1.3 Relevant matters raised in SEARs

Requirements		Chapter/Section addresses
		Impact Assessment – appended to EIS
(b)	frequency and quality of dam discharges including for environmental flows.	Section 3.6.1v and Section 3.9
(c)	downstream intake locations.	Section 3.7.1
(d)	Water Quality Objectives (as endorsed by the NSW Government) as appropriate that represent the community's uses and values for the receiving waters.	Section 3.9
(e)	water quality monitoring programs and indicators and trigger values/criteria.	Section 3.9
7.	The EIS must assess the impacts of the proposal on water quality, including the nature and degree of impact on receiving waters for both surface and groundwater.	Section 5.7 Groundwater aspects are addressed in the Groundwater Impact Assessment – appended to EIS
Climate change risk		
2	The Proponent must quantify specific climate change risks with reference to the NSW Government's climate projections, including relevant data and information from NSW and ACT Regional Climate Modelling partnership (NARCLiM) (data, models, simulations, guidance)., and incorporate specific actions in the design and operation where reasonable and feasible. NARCLiM 1.5 must be used, unless otherwise agrees by the Planning Secretary. Other data, projections, or information may also be used in addition to NARCLiM.	Section 5.6.2 Section 5.7.3
3	An assessment of potential future climate variability impacts on the operation and management of the dam and associated delivery works (such as water delivery by way of river operations, or pipe infrastructure), having regard to research on groundwater recharge and surface run-off and the NSW Climate Impact Profile.	Section 5.6.2 Section 5.7.3

1.6 Modelling

Three models have been developed to assist with characterising relevant aspects of the existing surface water environment and assessing potential impacts as a result of the Proposal:

- A streamflow regime model of the Tweed Valley waterways, used to investigate potential changes to dam release volumes, the timing of releases, and the effects of climate change on flow regimes (Annexure A).
- A limnology model, used to investigate the expected changes to water quality within the reservoir (Annexure B).
- A hydraulic model of Doon Doon Creek and the Tweed River, used to investigate cold water transmission downstream from the dam, stream power, depth, and velocity of water in waterways (Annexure C).

Results from the three models are summarised and presented within this SWA where relevant to assist with characterisation of key features of the existing environment (Chapter 4) and to describe and assess surface water impacts associated with the Proposal (Chapters 5 and 6).

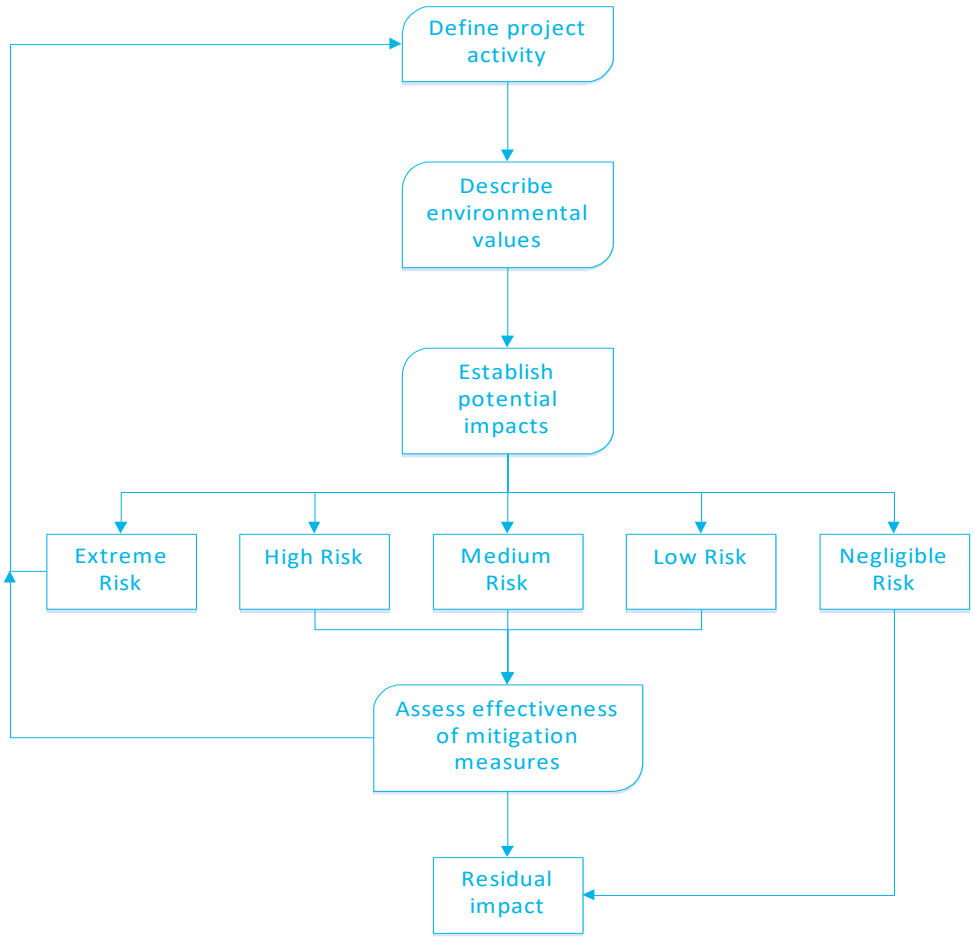


Figure 1.3 Impact assessment process

1.7 Interactions with other assessments

The results of the streamflow regime model were combined with relationships derived from hydraulic modelling to prepare data describing the frequency and magnitude of depth, velocity and stream power changes (Annexure D). This information was utilised by the Groundwater Impact Assessment and Land, Soils and Erosion Assessment.

Information provided in the Aquatic Ecology appendix to the EIS describing the fish species present in the Tweed River and their flow requirements was considered in the context of the streamflow regime model results to develop data describing the potential for the Proposal to affect fish migration patterns (section 3.8.3).

Flooding is discussed in a separate appendix to the EIS.

The current flood risk of the Tweed Valley is described in a Tweed Valley Flood Study prepared for Tweed Shire Council outside the EIS process.

The expected effects of the Proposal on water supply security are discussed primarily in the business case.

1.8 Risk analysis

Assessment of potential impacts to surface water was undertaken for construction activities (described in Chapter 4) and operational activities (described in Chapter 5) of the project. A description of each activity has been

provided, and potential impacts (or 'hazards') to surface water quality and quantity, water users and receptors, and streamflow regime have been identified and described using a risk framework.

To generate a risk rating for each of the Proposal hazards (Table 1.4), both the Significance (Table 1.5) and Likelihood (Table 1.6) of the potential impact were considered. An 'initial' risk rating was applied to each hazard based on the concept design, operational protocols, and standard mitigation measures. Proposal specific mitigation measures were then considered and a revised or 'mitigated' risk rating developed.

A summary of identified risks, mitigation measures and Proposal effects is provided in Chapter 7.

Table 1.4 Risk matrix

Likelihood	Significance				
	Negligible	Minor	Moderate	High	Severe
Rare	Low	Low	Low	Medium	Significant
Unlikely	Low	Low	Medium	Significant	High
Possible	Low	Medium	Significant	High	High
Likely	Low	Medium	Significant	High	Extreme
Almost Certain	Medium	Significant	High	Extreme	Extreme

Table 1.5 Classification of significance

Significance	Description
Severe	The impact is considered critical to the decision-making process. Impacts tend to be permanent or irreversible or otherwise long-term and can occur over large areas. Very high sensitivity of environmental receptors to impact.
High	The impact is considered likely to be important to decision-making. Impacts tend to be permanent or irreversible or otherwise long-term (>5 year recovery period). Impacts can occur over large or medium size areas. High to moderate sensitivity of environmental receptors to impact.
Moderate	The effects of the impact are relevant to decision-making including the development of environmental mitigation measures. Impacts can range from long-term to short-term in duration (1 to 4 year recovery period). Impacts occur mostly near the source, which is apparent and requires mitigation to be within limits of acceptability. Moderate sensitivity of environmental receptors to impact.
Minor	Impacts are recognisable/detectable but acceptable and may be contained on-site. These impacts are unlikely to be of importance in the decision-making process but are relevant in the consideration of standard mitigation measures. Impacts tend to be short-term (<12 month recovery period) or temporary and/or occur at a local scale.
Negligible	Minimal change to the existing situation. This could include for example impacts which are beneath the levels of detection, impacts that are within the normal bounds of variation or impacts that are within the margin of forecasting error.

Table 1.6 Classification of likelihood

Likelihood category	Description	Annual probability of occurrence
Almost Certain	A recurring event during the lifetime of an operation or project.	More than two occurrences per year
Likely	An event that will probably occur during the lifetime of an operation or project.	Around one occurrence per year
Possible	An event that may occur during the lifetime of an operation or project.	More than 10% annual probability of occurrence
Unlikely	An event that is unlikely to occur during the lifetime of an operation or project.	More than 1% annual probability of occurrence
Rare	An event with a low probability to occur during the lifetime of an operation or project.	Less than 1% annual probability of occurrence

2 Regulatory context

2.1 Overview

Water usage within the Tweed Valley is influenced by a number of legislative and non-legislative instruments, including the following (summarised in section 2.2):

- *Water Management Act 2000*
- Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2023
- *Dams Safety Act 2015*
- Dams Safety Regulation 2019
- *Protection of the Environment Operations Act 1997*
- *Water NSW Act 2014*
- Tweed Shire Council Drought and water restrictions policy 2022
- Far North Coast Regional Water Strategy 2023
- NSW Coldwater pollution strategy.

Guidelines relating to development of water infrastructure include the following (summarised in section 2.3):

- Guidelines for controlled activities on waterfront land
- NSW Floodplain development manual
- NSW Water quality and river flow objectives
- Erosion and sediment control guidelines
- ANZG Freshwater quality guidelines
- Australian drinking water guidelines.

2.2 Legislation and policy

2.2.1 Water Management Act 2000

The *Water Management Act 2000* (WM Act) sets out the legislative requirements for the sustainable and integrated management of water sources within the State, for the benefit of both present and future generations. The WM Act is based on the principles of ecologically sustainable development and recognises that water management must consider economic, environmental, social, cultural and heritage factors.

The principal instruments for the management of rivers within NSW, under the WM Act, are management plans that are developed and implemented for particular water sources (one or more rivers or creeks that have been grouped together for management purposes). This includes water sharing plans (WSPs), which are the primary instruments that set out water-sharing arrangements within NSW.

NSW has developed WSPs that cover all of the surface water and ground water sources across the state; including a plan for each river system where major dams have been constructed for the purpose of regulating the river flows ("regulated rivers"), and plans that cover one or more water sources not fully controlled by releases from a dam ("unregulated rivers"). Town water supply dams such as Clarrie Hall Dam that augment flows downstream may be present on unregulated rivers, and water users are reliant on climatic conditions and rainfall.

2.2.2 Water sharing plans

Water sharing plans (WSPs) are statutory instruments that set out objectives for the management of water sources, rules for the management of water for environmental outcomes, the number of water access licence share components on issue at the commencement of the plan, and rules for the use and trade of those water access licences. The WSPs are valid for a period of 10 years from their commencement date, but amendments can be made throughout the life of the plans to ensure that they comply with changing legislation and to facilitate their implementation.

Water resources within the Tweed Valley, including all surface water and groundwater contained in unconsolidated sediments of the alluvial aquifers, are managed under the provisions of the *Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2023* (the WSP).

Water stored in the fractured rock aquifers in the area, namely the underlying North Coast Volcanics Groundwater Source, Clarence Moreton Basin, and North Coast Volcanics, are managed separately under the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016*. Water stored in coastal sand formations below the surface of the ground are managed separately by the *Water Sharing Plan for the North Coast Coastal Sands Groundwater Sources 2016*. These water sharing plans relating solely to groundwater resources are not referred to further in this SWA.

i Water extraction limits

The WSP contains 32 water sources that are grouped into three extraction management units (EMUs) with volumes of water committed under each EMU for entitlements granted by water access licenses (WALs), and an estimate of combined annual extractions in the exercise of native title rights, harvestable rights, and domestic and stock rights (DPE, 2022). Total licensed entitlement for the WSP area is 35,346 ML/year, with a further 10,553 ML/year committed to the exercise of basic land holder rights. The combined total entitlement of 45,899 ML/year for the WSP represents the average annual potential extraction.

The WSP defines the limits to the availability of water for each EMU, which are to be assessed annually; a long-term average annual extraction limit (LTAAEL) and an annual higher flow extraction limit, as set out in Part 4 Subdivision 2 of the WSP. As of 2023 the LTAAELs are numerical values, for example the standard LTAAEL for the Tweed River Catchment EMU is 56,936 ML for the year. The Tweed River Catchment EMU is relevant to the Proposal because it manages the Doon Doon Creek Water Source and the Mid Tweed Water Source, which encompass the Proposal area.

License holders have the option to convert to a higher flow extraction license, which provides 2.5 units of high flow access for every 1 unit of a normal unregulated river licence entitlement surrendered. Higher flow access commences at the 30th percentile flow rate for the water source, which is the flow exceeded on 70% of days. This incentivises licensees to surrender water that could potentially be taken during periods of low flow, when the coastal rivers are under maximum stress, and instead extract water during periods of higher flow for storage and use later (NSW Office of Water, 2010). Higher flow extraction licenses are excluded from determining the standard LTAAEL for the water year. At the commencement of the WSP in 2023, there were no unregulated river (high flow) access licences.

The LTAAEL is a long-term use limit that reflects the effect of observed climate over the period of available climate records on diversions consistent with the combination of the water access rules set by the WSP, and a defined level of water use infrastructure and behaviour (dams, weirs, drinking water extractions, on-farm storages,

cropped areas, etc). The plan sets LTAAELs to cover all flows and a separate, specific limit for just high-flows extraction licenses for each EMU.

The WSP requires that the volume of water taken from each EMU is assessed annually to estimate the "average annual extraction" (ie the long-term average extraction of water) that could be expected under current conditions, and to determine if water use is expected to remain within the LTAAEL over the long-term. The WSP requires that the difference between the 3-year average standard extraction and the standard LTAAEL for the water year does not exceed 5%.

The standard LTAAELs are taken to be varied by a change to the amount of water committed as licensed environmental water. The plan commits water as planned environmental water by reference to the long-term average annual commitment of water resulting from compliance with the long-term average annual extraction limit.

The WSP has a total volume of surface water licensed for extraction of 34,896 ML (450 ML is groundwater), compared to an annual average flow of approximately 365,000 ML for the Tweed River at Brays Park Weir. Licensed allocation of 27,613 ML (around 79% of total license entitlement for the WSP) is for town water supply.

Access rules can vary based by the category of license held, and on the determination of the flow class in a water source (which is tied to specific flow conditions at a measured flow reference point). The WSP imposes rules on water license trading, granting works approvals, and granting new entitlements and native title access licenses.

ii Management of growth in water use

Where the assessment of compliance with the standard LTAAEL indicates that the extraction of water exceeds the 3-year average LTAAEL by more than 5%, the WSP gives the Minister powers to make a reduced available water determination for the EMU for the following water year (1 July). The intention is to reduce the available water for each category of license (unregulated river access licences and aquifer access licences) so that extractions from the extraction management unit comply with the standard LTAAEL.

Any effects of new infrastructure such as a new dam and its operating regime on the extraction of water by licensed water users would need to consider the system operation rules given in Part 6 Division 5A of the WSP. The Minister has powers to suspend or adjust these rules if deemed necessary for the purposes of maintenance, refurbishment or modification works to the dam, which may temporarily affect the flow rate or behaviour of water for at least 24 hours. The system operation rules outlined in the WSP govern the flow regime and releases from Clarrie Hall Dam.

iii Minimum releases from Clarrie Hall Dam

The WSP describes that minimum releases of water that must be made each day from Clarrie Hall Dam as per Table 2.1.

Table 2.1 Minimum releases from Clarrie Hall Dam

Flow at Oxley River Eungella gauge (201001)	Target flow rate for releases
≥ 13 ML/day	4 ML/day
>3 to < 13 ML/day	2 ML/day
≤ 3 ML/day	1 ML/day

The Minister may adjust or suspend the requirement to make minimum releases in emergency or for dam maintenance / modification.

No suspension of minimum releases is anticipated to be required through the construction period of the Project. The existing valve house and multi-level offtake (MLO) will remain functional during works on the embankment and extension of the MLO.

2.2.3 Dams Safety Act 2015

The *Dams Safety Act 2015* (DS Act) establishes Dams Safety NSW as an independent regulator charged with ensuring that any risks to public safety, the environment and economic assets that dams create are at an acceptable level to the community. Clarrie Hall Dam is categorised by Dams Safety NSW as a 'declared dam' under Section 5 of the DS Act, which will require the Tweed Shire Council (as the dam owner) to comply with the relevant safety legislation and failure impact assessment requirements.

The objects of the DS Act are:

a) to ensure that any risks that may arise in relation to dams (including any risks to public safety and to environmental and economic assets) are of a level that is acceptable to the community

b) to promote transparency in regulating dam safety

c) to encourage proper and efficient management in matters relating to dams safety

d) to encourage the application of risk management and the principles of cost benefit analysis in relation to dams safety.

2.2.4 Dams Safety Regulation 2019

The *Dams Safety Regulation 2019* applies to declared dams. A dam may be declared if it has a dam wall higher than 15 m, or if it would cause major or catastrophic level of severity of damage or loss or endanger the life of a person if it failed. Based on this definition, the raised Clarrie Hall Dam will be a declared dam and subject to the regulation.

Under Part 3 of the regulation, the owner of a declared dam must undertake a consequence assessment which describes the severity of damage and loss, which may occur if the dam were to fail, and provide this information to Dams Safety NSW.

Under Part 4 of the regulation, a declared dam owner must create operation and maintenance plans and emergency management plans. The operation and maintenance plans describing details such as operating procedures, alarms and trigger levels, and security arrangements, while the emergency management plans must describe the consequence category, dam construction, circumstances which may cause the dam to fail, descriptions of emergency warning systems, and emergency procedures. These plans must be delivered to Dams Safety NSW as soon as practical after completion and after any change.

2.2.5 Protection of the Environment Operations Act 1997

The *Protection of the Environment Operations Act 1997* (POEO Act) provides the statutory framework for managing water pollution in NSW. It is supported by the *Protection of the Environment Operations (General) Regulation 2009* (POEO Regulation), which among other functions prescribes certain matters for the purposes of the definition of water pollution.

The definition of 'water pollution' in the POEO Act sets out the general and specific circumstances that constitute pollution. At its broadest, water pollution means introducing any matter into waters which changes the physical, chemical or biological condition of the water. It also includes placing any matter where it might fall, descend, be washed, be blown or percolates into any waters (eg soil, which might be washed into a waterway from land disturbance during construction of the project).

Schedule 5 of the POEO Regulation includes a list of specific substances (prescribed matter) which, if they are introduced onto or into waters, are automatically assumed to constitute pollution of waters (ie animal matter, soil, thermal waste, any matter that contains faecal coliforms, pesticides, etc).

Schedule 3 of the POEO Regulation defines discharging water 2°C hotter or colder than the body of water into which it is discharged as water pollution. Clause 56A makes an exemption from a water pollution offence if the water is discharged from a water supply work pursuant to an approval under the WM Act that contains conditions dealing with cold water releases. Due to this exemption, potential cold water pollution (CWP) from Clarrie Hall Dam is regulated by conditions of approval under the WM Act and not regulated by the POEO Act and the 2°C temperature differential limit does not apply to dam discharges.

2.2.6 Drought and water restrictions policy 2022

The Tweed drought and water restrictions policy is part of Tweed Shire Council's *Drought and Water Restrictions Policy* 2022 and outlines the various demand and supply side drought response actions at various stages during an extended drought period. The policy enables Council's water and wastewater unit to make operational decisions about implementing, easing, and removing water restrictions for the Shire. The fundamental objective of preparing and adopting the policy is to minimise the risk of the community running out of water, and ensuring there is always sufficient water available to satisfy the basic needs of the community (TSC, 2022).

A summary of the current Tweed district water supply scheme water restriction triggers and resulting reduction in water use target is provided in Table 2.2. The drought policy presents restrictions and triggers for each of the three water supply schemes operated by Tweed Shire Council; the Tweed district water supply network, the Uki water supply, and the Tyalgum water supply.

Table 2.2 Restriction triggers for Tweed district water supply scheme

Restriction Level	Residential water-use saving target (Litres per person per day) (L/p/d)	Residential water-use target (L/p/d)	Implemented at % of dam capacity	Eased at % of dam capacity
Level 1	10	150	85	100
Level 2	20	140	75	95
Level 3	30	130	65	85
Level 4	40	120	55	75
Emergency	60	100	45	65

Other circumstances that can trigger restrictions include:

- salt water contamination
- other contamination events including floods
- treatment plant failure
- major asset failure
- power supply failure.

2.2.7 Regional water strategy

Regional water strategies (RWS's) bring together the most up-to-date information and evidence with a wide range of tools and solutions to plan and manage a region's medium and long-term water needs (DPE, 2023). The RWS relevant to the Proposal area is the Far North Coast Regional Water Strategy (DPE, 2023).

The RWS provides an overview of water resources in the region, and the water resourcing challenges, which may be encountered in the future, with a focus on climate, people, and industries. In line with the objectives set for all regional water strategies, the Far North Coast region strategy has a strong focus on working closely with communities to provide healthy, reliable and resilient water resources that:

- deliver and manage water for local communities by improving water security, water quality and flood management for regional towns and communities
- enable economic prosperity by improving water access reliability for regional industries
- promote affordability by supporting cost effective policy and infrastructure options
- protect and enhance the environment by improving the health and integrity of environmental systems and assets, including by improving water quality
- recognise and protect Aboriginal water rights, interests and access to water, as well as Aboriginal heritage assets.

The Proposal is outlined as a key initiative in the RWS to help improve water security for the region, particularly in the light of climate change, climate variability, and growing population.

The Tweed Shire Council demand management strategy (MWH, 2009) and drought management policy (2022) are key components of Council's integrated water cycle management (IWCM) strategy 2014 (Hydrosphere, 2014b). The IWCM strategy is reviewed every 6 years to incorporate results of ongoing consultations and specialist studies, to engage with community on the regional water strategy, and ensure compliance with NSW Office of Water best-practice guidelines (DWE, 2007).

2.2.8 NSW Cold Water Pollution Strategy

CWP may occur downstream of large dams due to a limited ability to selectively draw off water at different depths or from suboptimal configuration of variable offtake structures.

During the warmer months when lakes may be thermally stratified, suboptimal outlet configuration may result in water being released into the downstream river environment at temperatures that may be detrimental to aquatic organisms and processes. As a result, the NSW Cold Water Pollution Strategy (DPI, 2012) was developed in order to specify guidelines for the management of releases from major dams across the state, updated in draft form in 2017.

The main objectives of the NSW Cold Water Pollution Strategy are to define targets for WaterNSW to manage dam outlet configuration and assess performance in meeting those targets.

The NSW Government has endorsed the principle of requiring dam operators to "match the temperature of releases from individual dams as closely as possible to the natural temperature regime having regard to the associated costs and benefits". This indicates that calculating the "temperature anomaly" between the "expected natural temperature" and the "observed/measured temperature" is a useful approach. A zero anomaly would constitute an ideal outcome, but in reality, a small anomaly of a few degrees would be an acceptable outcome since it is unlikely to result in a significant ecological impact (NOW, 2011).

It is recommended that the natural temperature be estimated using either field data collected over an extended period prior to the dam being constructed, unimpacted reference sites such as the river upstream of the dam, or physics-based models.

The Inter Agency Group recommended that assessment of CWP impacts needs to:

- be based on calculations of anomalies between the “expected natural temperature” and the “observed/measured temperature”
- use reference sites which are reasonably representative of the dam site
- indicate that large but short duration temperature anomalies are problematic
- indicate that moderate but sustained temperature anomalies are also problematic (ie accommodate cumulative impacts)
- indicate that small temperature anomalies whether transient or sustained are acceptable
- be applied at an ecologically relevant as well as a managerially realistic timescale (ie more than daily, less than monthly)
- be limited to the spring/summer/autumn period when stored water is not isothermic and mimicking natural temperature is impossible.

Although somewhat arbitrary, a rolling 5 day cumulative anomaly with a minus 15 degree-days pass/fail threshold is recommended in the strategy as meeting all the above principles.

2.3 Guidelines

2.3.1 Guidelines for controlled activities on waterfront land

The WM Act defines waterfront land as the bed of any river, lake or estuary and any land within 40 m of the river banks, lake shore or estuary mean high water mark. Works undertaken on waterfront land generally require a controlled activity approval, unless defined as exempt.

Guidelines for controlled activities have been prepared by NSW Department of Industry (NRAR, 2020). These guidelines provide information on the design and construction of a controlled activity, and other ways to protect waterfront land.

A controlled activity approval exemption applies to public authorities (including local councils) as defined in the WM Act. Hence, a controlled activity approval is not required for the project.

2.3.2 NSW Water Quality and River Flow Objectives 2006

The NSW Water Quality and River Flow Objectives (DECCW, 2006) are the agreed high-level goals for surface water quality and flow management for catchments throughout the state. The river flow objectives identify the key elements of the flow regime that protect river health and water quality for ecosystems and human uses.

2.3.3 Erosion and sediment control

A key requirement for managing and mitigating environmental impacts of Proposal development, particularly through the construction phase, is addressed through the preparation of a Construction Soil and Water Management Plan (SWMP) or equivalent. The SWMP forms a key element of the overall Construction Environmental Management Plan (CEMP) and will be underpinned by Progressive Erosion and Sediment Control

Plans (PESCP's), which are designed for use as a practical guide to manage risks to soil and water associated with specific construction activities for all discrete disturbance areas.

The content requirements of the SWMP and PESCP's are prescribed in the following guidelines and best practice documents:

- Managing Urban Stormwater: Soils and Construction Volume 1 (Landcom 2008a)
- Managing Urban Stormwater: Soils and Construction Volume 2A Installation of Services (Landcom 2008b)
- Managing Urban Stormwater: Soils and Construction Volume 2C Unsealed Roads (Landcom 2008c)
- Managing Urban Stormwater: Soils and Construction Volume 2D Main Road Construction (Landcom 2008d)
- Best Practice Erosion and Sediment Control (BPESC) Books 1–6 (IECA 2008).

2.3.4 Australian and New Zealand Guidelines for Fresh and Marine Water Quality

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality, prepared by the Australian and New Zealand Environment and Conservation Council and the Agriculture and Resource Management Council of Australia and New Zealand (ANZECC & ARMCANZ, 2000a), describe the water quality objectives (WQO's) for marine and freshwater environments, aquatic ecosystems, primary industries, and recreational water.

The guidelines should be considered when setting WQO's for natural and semi-natural water resources in Australia and New Zealand sustaining current or likely future environmental values (EVs) (uses). They also set out a framework for the application of water quality trigger levels.

The guidelines are a generic reference and should be used accordingly (ie only as a default reference). It is recommended to collect and use site-specific baseline data to establish baseline conditions and develop trigger levels. Proposal impacts should be assessed using site-specific baseline data and not the generic guidelines, where adequate (typically >24 months) baseline data allows.

Further revisions to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality were made in 2018 with the release of a web-based guideline (ANZG, 2018). Default guideline values (DGV's) for physical and chemical stressors have been derived for the marine waters of the Shire coastline under the Tweed-Moreton mesoscale ecoregion under the NSW Government integrated marine and coastal regionalisation (Water Quality Australia, 2018). The revised DGV's for chemical contaminants/toxicants that are relevant to the Proposal area are consistent with ANZECC/ARMCANZ (2000) guideline values, and are presented in Section 3.9.1.

Other guidelines directly related to Australian and New Zealand Guidelines for Fresh and Marine Water Quality include:

- Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC & ARMCANZ, 2000b)
- ANZECC Guideline and Water Quality Objectives in NSW (DEC, 2006).

2.3.5 Australian Drinking Water Guidelines (ADWG)

The Australian Drinking Water Guidelines (ADWG) (NHMRC, 2011) provide a framework for good management of drinking water supplies that, if implemented, will assure safety at point of use. The ADWG have been developed after consideration of the best available scientific evidence and are designed to provide an authoritative reference on what defines safe, good quality water, how it can be achieved and how it can be assured.

Drinking water is defined as water intended primarily for human consumption, either directly, as supplied from the tap, or indirectly, in beverages, ice or foods prepared with water. Drinking water is also used for other domestic purposes such as bathing and showering.

The safety of drinking water in public health terms is determined by its microbial, physical, chemical and radiological quality; of these, microbial quality is usually the most important. As conventional water treatment methods are not designed to remove some of these compounds from raw water, it is preferable to avoid them in the raw water supply through catchment and storage management practices.

The ADWG include two different types of guideline value:

- a health-related guideline value, which is the concentration or measure of a water quality characteristic that, based on present knowledge, does not result in any significant risk to the health of the consumer over a lifetime of consumption

- an aesthetic guideline value, which is the concentration or measure of a water quality characteristic that is associated with acceptability of water to the consumer; for example, appearance, taste and odour.

3 Existing surface water environment

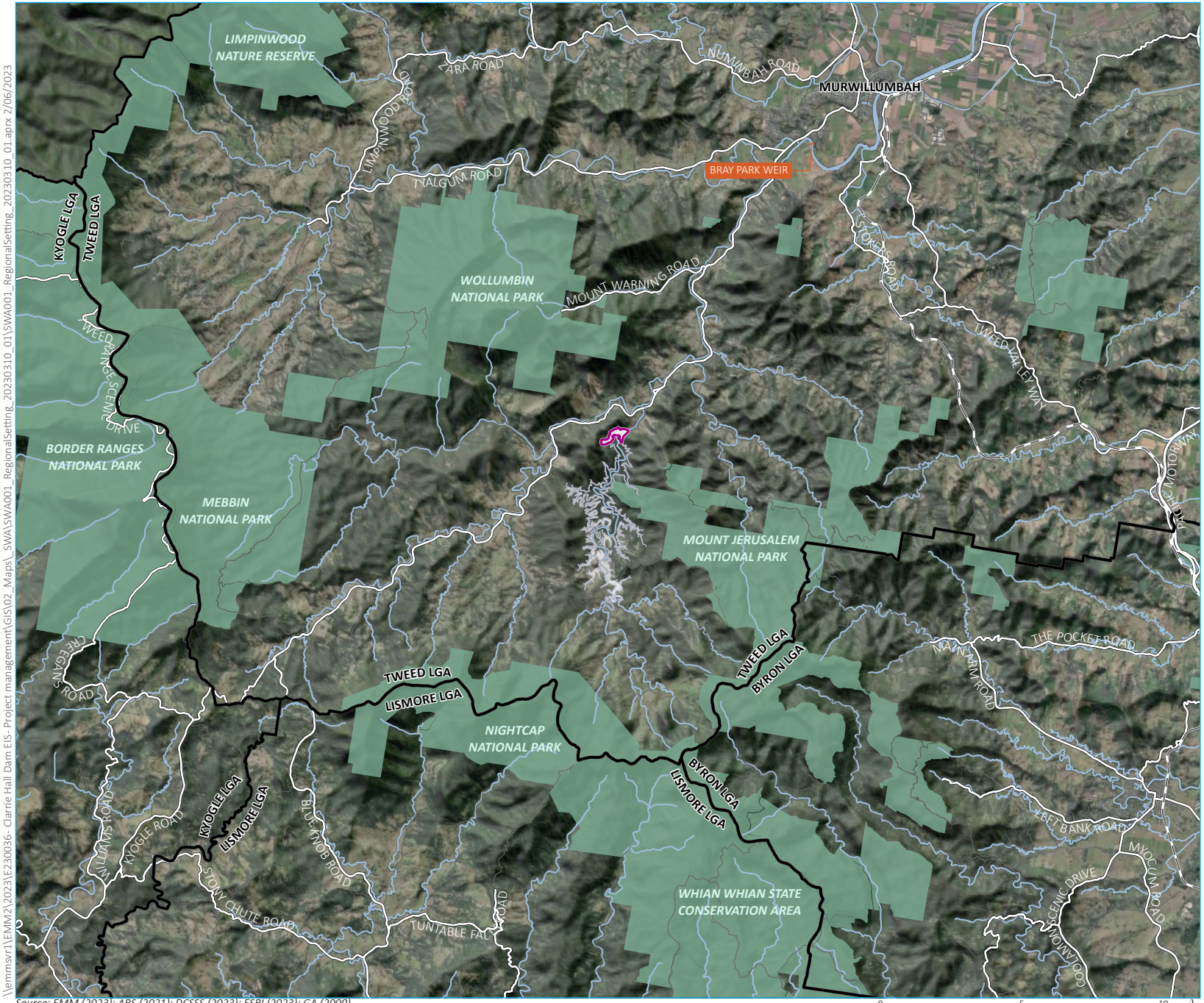
3.1 Proposal location

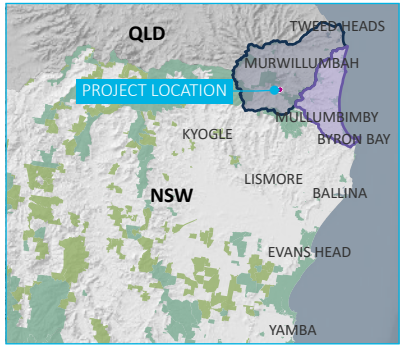
Clarrie Hall Dam is located on Doon Doon Creek in the rural locality of Doon Doon, approximately 15 km south-west of Murwillumbah in the Far North Coast region of NSW. Doon Doon Creek is a tributary of the Tweed River, located within the Tweed Shire LGA. The Tweed River provides water for irrigation and is the primary source of water supply for the Tweed Shire LGA. Clarrie Hall Dam is operated by Council to provide storage, and during drier months water is released from the dam to augment flows in the Tweed River.

The Tweed district water supply is a run of river supply augmented by releases from Clarrie Hall Dam. Bray Park Weir, located 5 km upstream of Murwillumbah, is the point of abstraction for the district water supply and effectively acts as a tidal barrage. By raising the upstream water level, the weir maintains a pool in the river which is supplied by the combined flow of the Tweed and Oxley rivers. Raw water is extracted for public water supply from the pool upstream of the weir, and during low-flow periods releases from Clarrie Hall Dam are used to top-up the weir pool. Council also maintain small water supply networks located at Uki and Tyalgum.

The Tweed River has a total catchment area of approximately 1,326 km^2 and drains the majority of the Tweed Shire LGA (1,340 km^2). The Tweed Shire LGA has a population approaching 100,000 and borders the NSW shires of Byron, Lismore and Kyogle. Murwillumbah is a town situated in the middle of the Tweed River catchment, with a population of around 9,500. The major urban area of Tweed Heads surrounds the Tweed River estuary and is home to around half of the Shire population.

The Tweed River catchment is bounded by the McPherson Range to the north on the NSW-Queensland border, the Nightcap and Burringbar Ranges to the south and south-east, and the Tweed Range to the west. These elevated areas form the southern extent of the Scenic Rim of the Great Dividing Range and parts of these areas are designated as national parks and world heritage areas. The mountains and ranges of the Tweed Valley are remnants of the Tweed Volcano, forming a large erosion caldera that encircles the volcanic plug of Mount Warning. The project's regional setting is shown in Figure 3.1.





KEY

- Construction disturbance footprint
- Development site
- Bray Park weir
- Rail line
- Major road
- Minor road
- Named watercourse
- Named waterbody
- NPWS reserve
- Local government area

INSET KEY

- NPWS reserve
- State forest
- Brunswick catchment
- Tweed catchment

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

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Regional setting

Clarrie Hall Dam EIS
Surface Water Assessment
Figure 3.1

EMM
creating opportunities

3.2 Waterways

3.2.1 Doon Doon Creek

Clarrie Hall Dam is located on Doon Doon Creek, with a 60 km^2 catchment at the dam wall. The NSW RiverStyles database (DPE, 2023) describes the Tweed River upstream from Bray Park Weir as "confined valley setting, gravel bed with floodplain pockets", aligning with field observations that the stream bed is rocky, with the bed predominantly formed from cobble sized rocks. Downstream from the dam wall, Doon Doon Creek is incised into the landscape with wooded banks (Photograph 3.1) and a rocky bed featuring sequences of pools and riffles (Photograph 3.2).



Photograph 3.1 Doon Doon Creek downstream from Clarrie Hall Dam

Hydraulic modelling (Annexure D) indicates that bed shear would remain below 100 N/m^2 in all but the largest floods. The modelling process averages shear across the model cross section, and it likely that there will be eddies, turbulence, and non-uniform flow conditions which result in shears up to an order of magnitude greater. This means that (cf Table 5.2):

- rocks larger than 100 mm are not expected to be mobilised in typical flow events
- rocks 10-100 mm could be mobilised short distances before settling in locations of lower shear
- sand and silt will be readily mobilised by typical flow events
- mobilisation of sand and silt has already occurred, leaving the rocky bed behind.

Approximately 1.4 km downstream of Clarrie Hall Dam, Doon Doon Creek joins the Tweed River, with a combined catchment area of 230 km^2.

3.2.2 Tweed River

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 (Photograph 3.3).

Several towns lie along the Tweed River and rely in its flow for water supply. In particular, Bray Park Weir at Bray Park near 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-Queensland border.



Photograph 3.2 Pool and riffle in Doon Doon Creek downstream from Clarrie Hall Dam



Photograph 3.3 Pool and riffle in the Tweed River between Uki and Doon Doon Creek

3.3 Climate

3.3.1 Data sources

Climate data were obtained from the Bureau of Meteorology (BoM), the Queensland Government Scientific Information for Land Owners (SILO), and Commonwealth Scientific and Industrial Research Organisation (CSIRO).

The BoM is Australia's national weather, climate and water agency, and routinely collects and processes climate data from climate stations across Australia. The locations of the BoM stations near the Proposal site are shown in Figure 3.3.

SILO is a database of Australian climate data from 1889 to the present. It provides daily meteorological datasets for a range of climate variables in ready-to-use formats suitable for biophysical modelling, research and climate applications. The database was developed in 1996 as a collaborative Proposal between the Queensland Government and the BoM, sponsored by the Land and Water Resources Research and Development Corporation. The datasets are updated daily from observational data obtained from the BoM, and hosted by the Queensland Department of Environment and Science (DES).

SILO uses mathematical interpolation techniques to construct spatial grids and infill gaps in time series datasets recorded at the BoM gauges. These processes produce data which are generally suitable for environmental modelling, but which may be slightly different to the nearest gauge data.

More recent periods of the SILO and BoM datasets have greater accuracy than earlier periods of the datasets due to several reasons, including:

- fewer climate stations were open in the early part of 20th century compared to now, which could be used for data interpolation and infilling
- routine digitisation of data began in 1957, and data prior may be missing or contain errors
- BoM pan evaporation data quality was improved in 1970, through measures such as fitting bird guards on evaporation pans to prevent water loss.

Data obtained from the BoM include current climate data. Data obtained from SILO include long term infilled rainfall, evaporation, humidity and air temperature data for water balance and water temperature modelling. SILO was also used to provide a description of local evaporation as the BoM climate stations near Clarrie Hall Dam do not include evaporation gauges. The BoM windspeed gauge at Murwillumbah provides daily mean observations at 9 am and 3 pm from 1972–2010.

3.3.2 Current climate

i Overview

The climate of the Proposal region is subtropical, with average summer maximum temperatures above 29°C and winter maximums of around 20°C. Rainfall occurs year-round and there is a pronounced summer/autumn wet season and a winter/spring dry season.

The main climate influences which affect Australia are depicted in Figure 3.2. Global scale influences which affect the site include the El Niño/La Niña Southern Oscillation (ENSO), the Southern Annular Mode (SAM), and the sub-tropical ridge. Regional scale influences such as easterly troughs, east coast lows and cut-off lows may also affect climate conditions at the Proposal site.

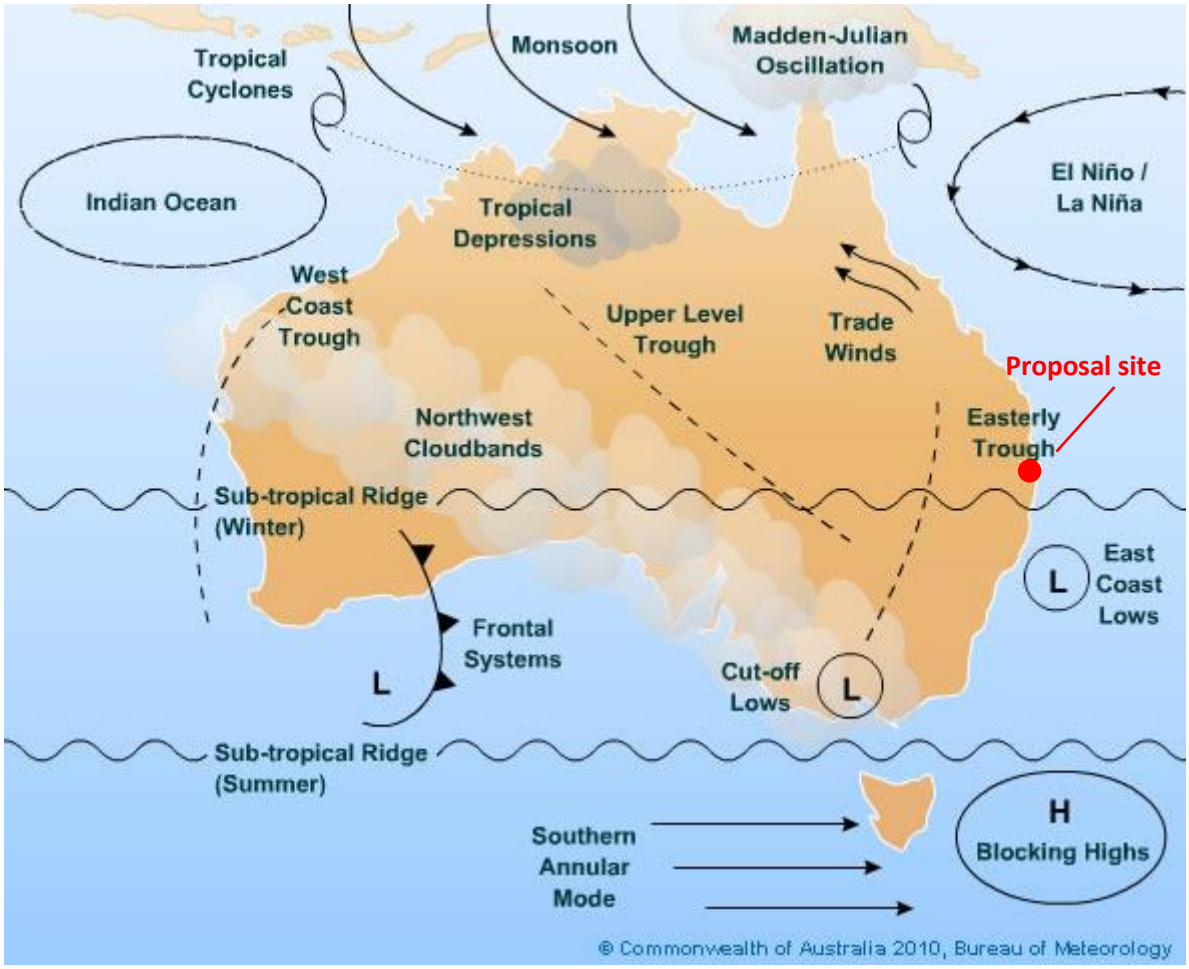
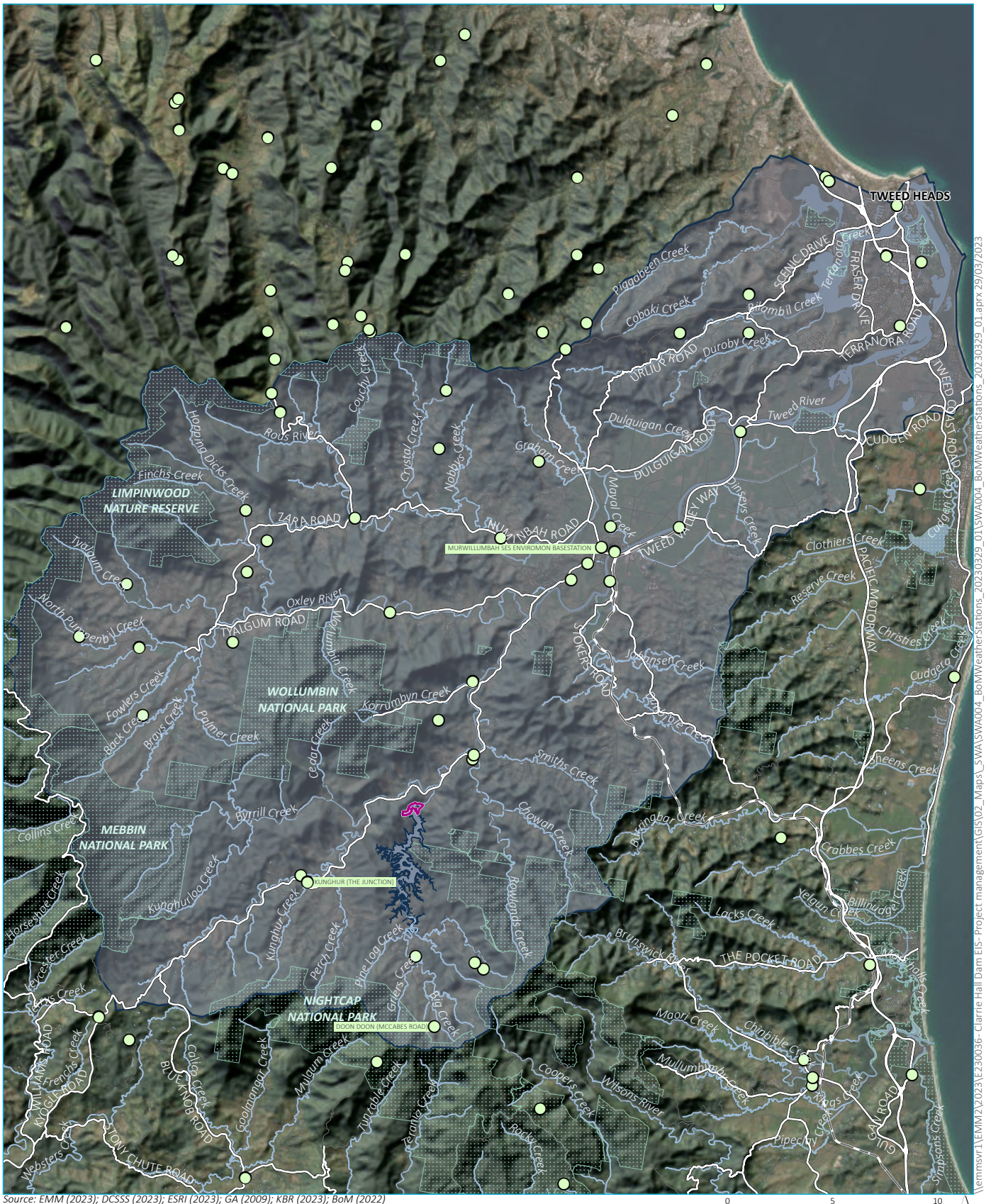


Figure 3.2 Climate influences in Australia (BoM, Australian Climate Influences, 2023)

The ENSO cycle describes the movement of cooler water from the Southern Ocean into the tropics, the effect this has on Pacific Ocean temperatures, and trade winds. During La Niña conditions, the ocean water north of Australia is warmer, and rainfall along the eastern coast of Australia is enhanced. During El Niño conditions, the warmer water occurs closer to South America, typically leading to lower rainfall along the eastern coast of Australia. ENSO event cycles generally last from 3 to 8 years.



Source: EMM (2023); DCSSS (2023); ESRI (2023); GA (2009); KBR (2023); BoM (2022)

0 5 10 km

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KEY

- Construction disturbance footprint
- Development site
- Tweed catchment
- BoM meteorology station
- Major road
- Minor road
- Named watercourse
- Cadastral boundary
- Waterbody
- NPWS reserve

Locations of BoM weather stations

Clarrie Hall Dam EIS
Surface Water Assessment
Figure 3.3

EMM
creating opportunities

The SAM describes the movement of a belt of westerly winds around Antarctica. The belt can expand northwards, bringing cold and wet weather as far north as southern Queensland. SAM events tend to last around two weeks.

The sub-tropical ridge is a belt of high pressure air that circles the globe in middle latitudes separating tropical weather systems in the north and Southern Ocean weather systems in the south. Beneath the sub-tropical ridge weather conditions tend to be stable and dry. During summer, the sub-tropical ridge is generally located south of the continent. Tropical weather systems may expand south at this time, bringing wet conditions to northern Australia, while southern Australia experiences hot and dry conditions. During winter months the sub-tropical ridge migrates north across NSW and this movement occurs on a seasonal basis.

Easterly troughs are a dominant feature during the summer months. As the land warms to the west of the Great Dividing Range a ridge of high pressure air can form, and move towards the coast. When this mass of warm air interacts with colder air, showers and thunderstorms can occur. Easterly troughs can last up to a week.

Cut-off lows are low pressure systems formed south of Australia which have broken away from the main belt of low pressure which lies south of Australia and move north as far as southern Queensland. Cut-off lows can occur at any time of the year, but are more common in winter months, and bring sustained rainfall and gusty winds. Cut-off lows typically last a few days or up to a week.

East coast lows are intense low pressure systems that form several times each year off the eastern coast of Australia and which can move onshore to affect NSW, southern Queensland, and eastern Victoria. East coast lows are generally associated with strong and gusty winds, sustained heavy rainfall and high seas. They can cause widespread damage over a very short period of time. Individual east coast lows generally only last for a few days.

ii Rainfall

BoM Station 58129 (Kunghar) recorded an average rainfall of 1,502 mm/year over the period 1966–2022 (excluding years with more than 20 days of missing data), whereas station 58019 (Doon Doon at McCabes Road) recorded an average rainfall of 2,149 mm/year between 1952–2022. Station 58129 is situated at an elevation of 61 m AHD whereas station 58019 is situated at 230 m AHD, and some of the observed difference is likely contributed by orographic lift associated with the elevated areas of the caldera. The elevation of the catchment area reporting to Clarrie Hall Dam ranges from 65 m to 800 m AHD, and the annual average rainfall across the catchment is likely to be around 1,600 mm/year.

The Tweed River catchment has one of the highest annual rainfalls of any significant catchment in NSW and in 2022, station 58019 recorded the state annual rainfall record of 4,607 mm (BoM, 2023b).

Details of the weather stations located near Clarrie Hall Dam have been presented in Table 3.1.

Table 3.1 BoM weather stations

Name	Station ID	Distance from Clarrie Hall Dam	Data used
Kunghar	58129	6.5 km south-west of the dam	Descriptive information
Doon Doon at McCabes Road	58019	10.5 km south	Rainfall (comparison)
Murwillumbah at Bray Park	58158	13 km north-east	Rainfall, Temperature, Evaporation, Wind

The subtropical climate of the Tweed Valley is characterised by a pronounced summer and autumn dominated annual rainfall regime and a winter/spring dry season (Figure 3.4). High rainfall months have been observed during most months, with high rainfall accumulations usually associated with strong east coast lows and decaying tropical cyclone events.

BoM estimates that an average of one cyclone in every two cyclone seasons is likely to affect the Tweed Valley, and most recently Cyclone Debbie delivered intense rainfall and widespread flooding in 2017.

In February 2022 a combination of weather systems and antecedent wet conditions resulted in flooding assessed to be greater than the 1% annual exceedance probability (AEP) event (CSIRO, 2022).

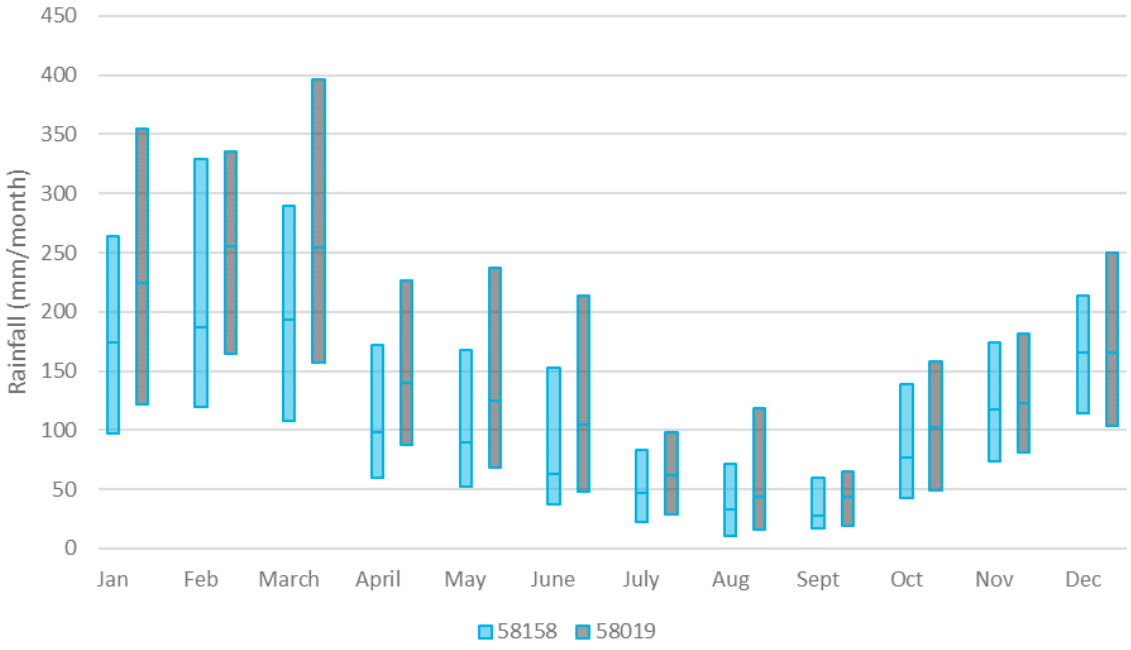


Figure 3.4 Clarrie Hall Dam monthly rainfall totals (25% to 75% quartiles)

iii Other climate elements

The median yearly pan evaporation estimated for the Murwillumbah site by SILO since 1973 is 1,529 mm/year. Evaporation is generally expected to exceed rainfall at Clarrie Hall Dam from June to January (Figure 3.5).

Average wind speeds measured at Murwillumbah range from 7 km/hour to 18 km/hour (Figure 3.6), with higher average wind speeds recorded in spring and early summer, and lower average recorded wind speeds in late summer, autumn and winter. Afternoon wind speeds tend to be higher than morning wind speeds.

Average summer maximum temperatures reach above 29°C, with winter maximums of around 21°C (Figure 3.7).

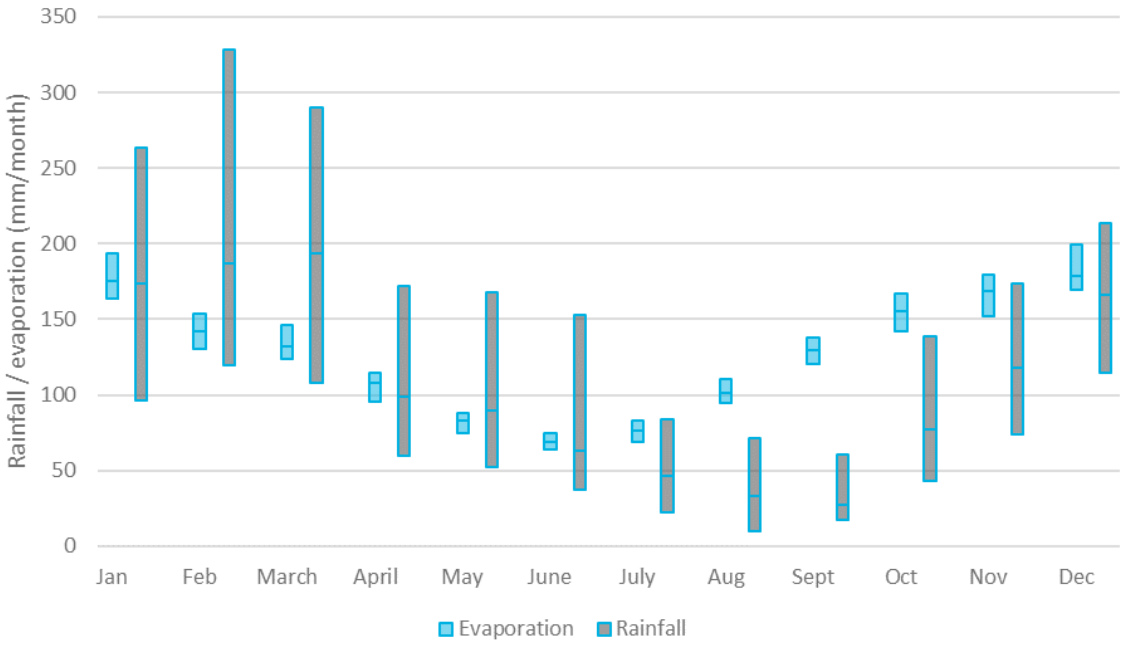


Figure 3.5 **1972–2022 evaporation (SILO) and rainfall (station 58158) monthly totals (25% to 75% quartiles) at Murwillumbah**

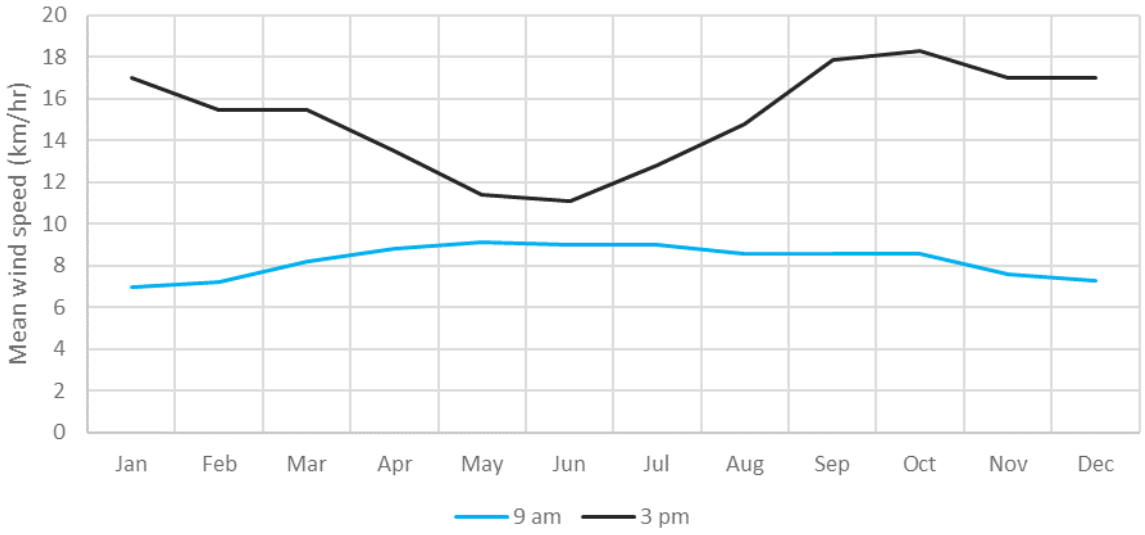


Figure 3.6 **Mean wind speed at Murwillumbah (station 58158) from 1972 to 2010**

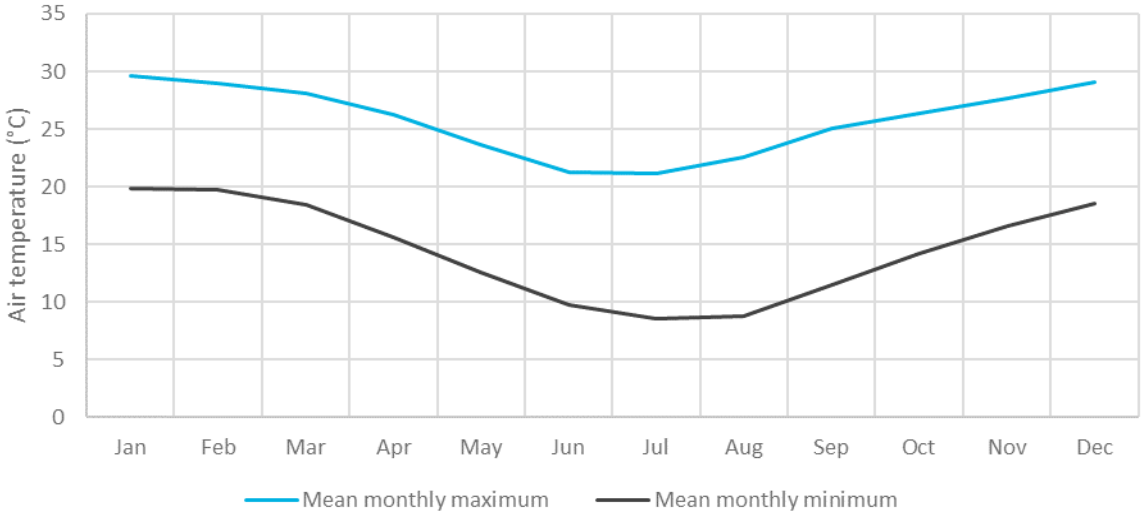


Figure 3.7 **Mean monthly maximum and minimum air temperature at Murwillumbah (station 58158) from 1972 to 2022**

3.3.3 Historical climate

The Proposal area has experienced long term climate cycles due to effects such as the ENSO and SAM climatic processes. This has resulted in wet periods and droughts, as illustrated in the long term rainfall trend shown in Figure 3.8.

Historic droughts have generally not exceeded 2 to 3 years duration. The recent drought of 2019 during a strong El Niño event is seen as being one of the worst on record, with Murwillumbah recording its lowest annual rainfall total of 717 mm. Major floods have also occurred with regularity through the period of streamflow records, with the last notable major flood on the Tweed River occurring in 2022.

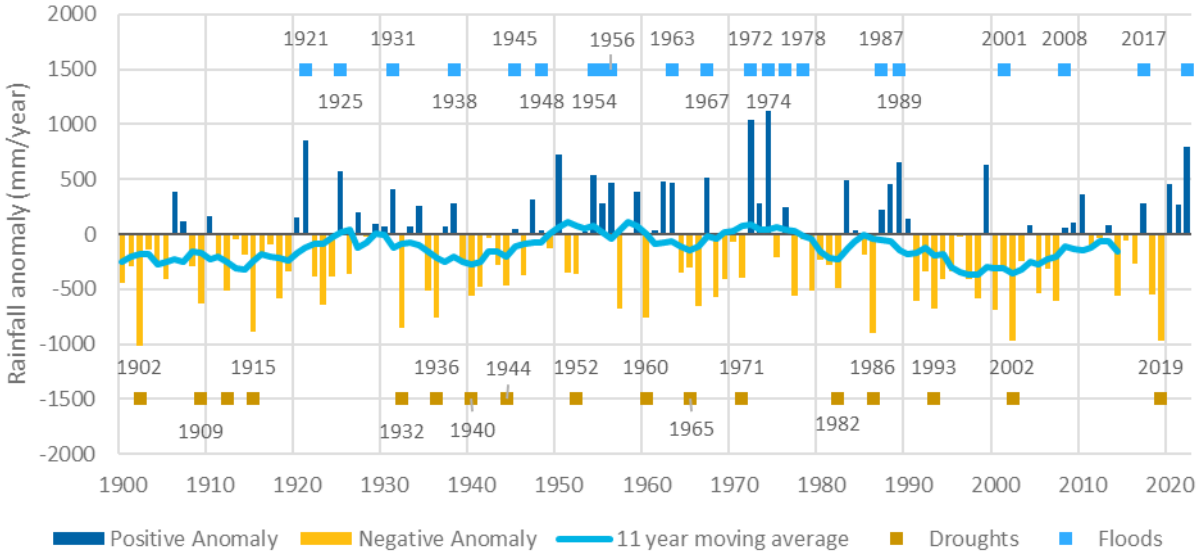


Figure 3.8 **Historical rainfall trend at Murwillumbah, and regional flood and drought markers**

From 1890 to 1998 the mean average annual temperature at Murwillumbah has fluctuated between ±1°C from the 1961-1990 base period mean annual average temperature (Figure 3.9). After 1998, temperature anomalies of greater than 1°C have occurred. The data shows a warming trend at the site since around 1966. This result is

consistent with data for other sites in NSW and Australia, which also show a long-term warming trend over roughly the same period since the mid 20th century.

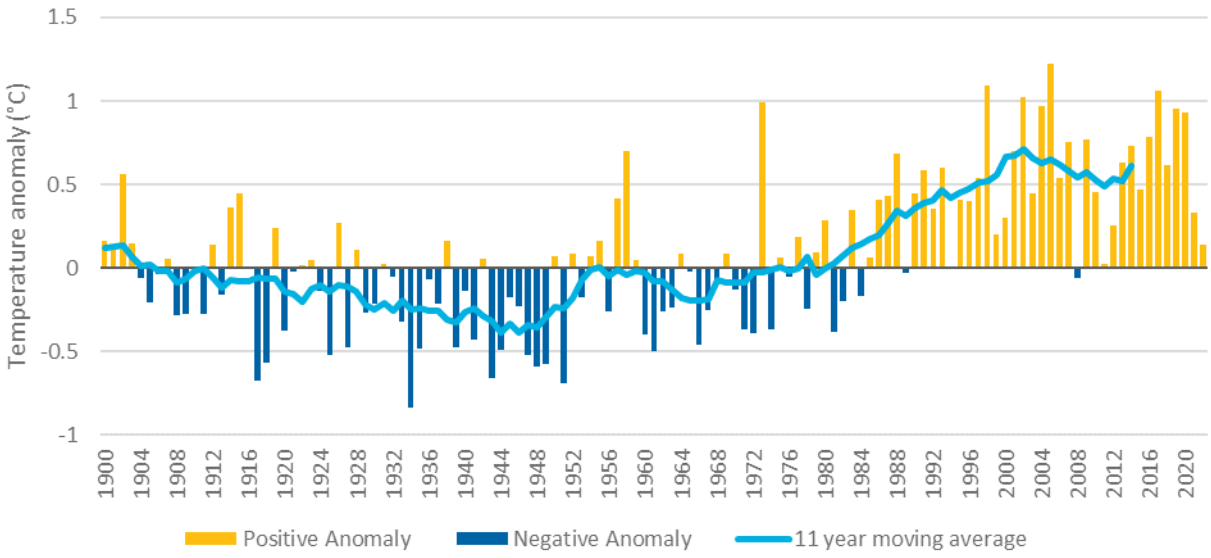


Figure 3.9 Murwillumbah annual temperature anomaly

3.3.4 Future climate

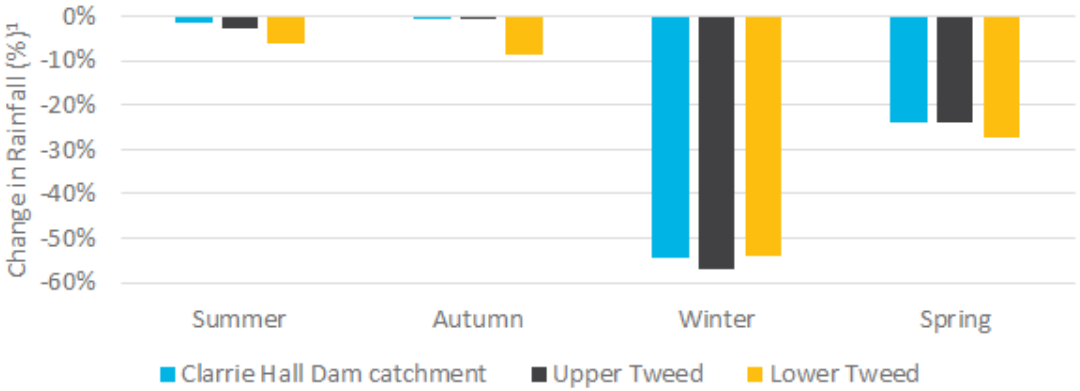
The NSW Climate Impact Profile (DECCW, 2010) provides projections of climate change and impacts of these changes on settlements, land and ecosystems of NSW. The Profile outlines some of the risks NSW faces to help decision makers develop their planning and response strategies. Expected regional climatic changes in the north coast region are:

- rising temperatures
- increasing rainfall in summer and autumn
- increasing evaporation
- ENSO years will continue to be drier than average but also become hotter, leading to more extreme impacts. La Niña years are likely to continue to be wetter than average but will also become warmer. During El Niño events, water stress is likely to be more pronounced because of higher temperatures.

A detailed description of the application of NSW and Australian Regional Climate Modelling (NARCliM) climate modelling to Proposal hydrology is provided in Annexure A. NARCliM is a collaboration led by the NSW Government with the ACT and South Australian governments with input from the University of New South Wales's Climate Change Research Centre (UNSW CCRC). It was established to produce regional climate projections and data for studies into the impacts of climate change in south-east Australia, including the Proposal area. In summary, it is expected that by 2065 there will be:

- a decrease in rainfall of approximately 20%
    - large decreases in rainfall in winter and spring (Figure 3.10)
    - little change to rainfall in summer and autumn

- an increase in evaporation of approximately 10%.



1. 2060–2079 period compared with 1990–2009 reference period, based on NARCliM climate change modelling (NSW Government, 2023)

Figure 3.10 ACESS1-3 seasonal rainfall projections (2065)

Changes in rainfall and higher evaporation rates are likely to lead to less water for streams and rivers in the Northern Rivers, which will have downstream consequences for storages and place pressure on the area's water resources. Lower flows and higher temperatures may also reduce water quality. For example, low flows, higher temperatures and elevated nutrients create a more favourable environment for potentially harmful algal blooms (CSIRO, 2007).

3.4 Streamflow

Discussion in this section is focussed on flow regimes downstream from Clarrie Hall Dam. For discussion of current flood risk along the Tweed River, see the Tweed Valley Flood Study undertaken on behalf of Council outside the Proposal EIS process.

3.4.1 Streamflow gauges

Streamflow records are available for the Tweed River at Uki (201900) since 1967 and the Oxley River at Eungella (201001) since 1957 (Figure 3.11). There is no streamflow gauge located within Doon Doon Creek downstream from Clarrie Hall Dam, however dam operators have maintained records of manual release volumes.

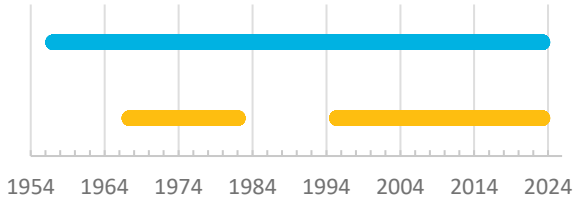


Figure 3.11 Streamflow gauge record duration

3.4.2 Current streamflow regime

The Palmers Road Crossing (201015) gauging station is located on the Tweed River upstream of the confluence with Doon Doon Creek, and therefore is not influenced by releases from Clarrie Hall Dam. Tweed River at Uki (201900) is located downstream of the Doon Doon Creek confluence, and therefore does receive releases from Clarrie Hall Dam. Both gauges demonstrate perennial conditions, with summer and autumn having higher flows than winter or spring (Figure 3.12 and Figure 3.13).

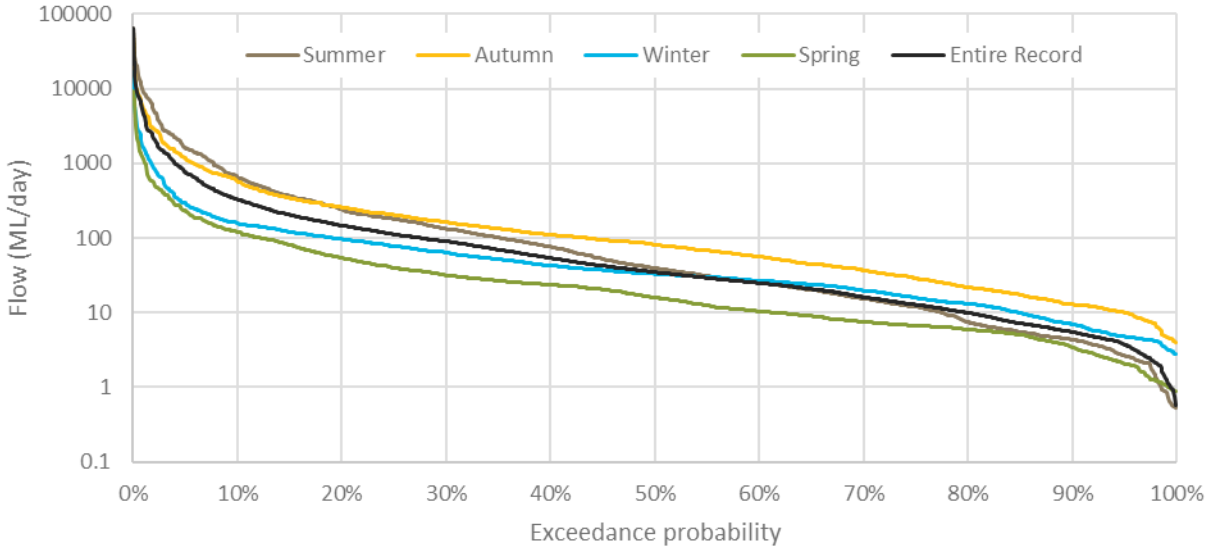


Figure 3.12 Tweed River at downstream Palmers Road Crossing (201015) seasonal flow duration curve (14 years gauge record)

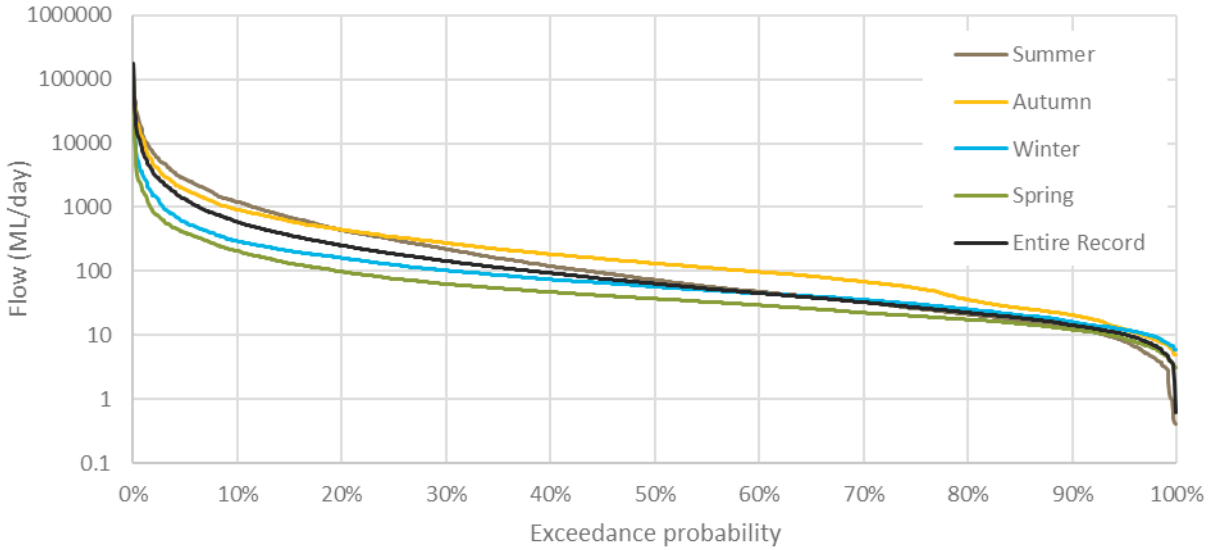


Figure 3.13 Tweed River at Uki (201900) seasonal flow duration curve (42 years gauge record)

The Oxley River, which flows into the Tweed River near Murwillumbah demonstrates a similar flow regime to the Tweed River, with summer and autumn having higher flows than winter or spring, and near perennial flow (Figure 3.14).

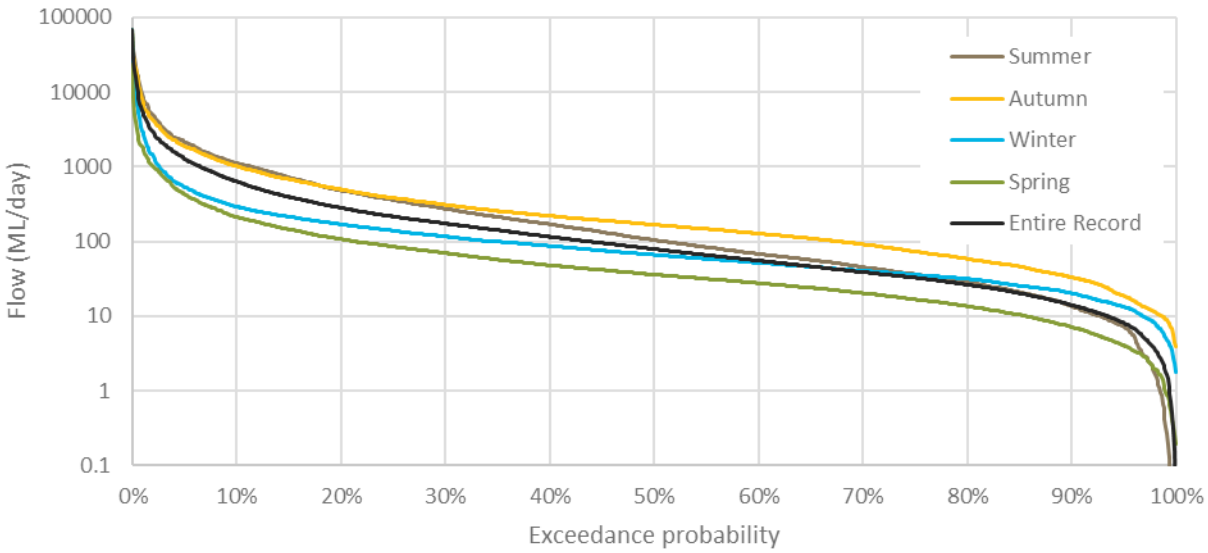


Figure 3.14 Oxley River at Eungella (201001) seasonal flow duration curve (52 years gauge record)

Doon Doon Creek is not gauged, however estimates of streamflow have been developed using the eWater Source model provided by DPIE (Figure 3.15) (further details in Annexure A), illustrating:

- perennial flow
    - supported by dam releases
    - with minimum flows of 4 ML/day supported by dam releases occurring 50% of the time during summer and spring
- flows typically (20th to 80th percentile) in the range 4 – 100 ML/day.

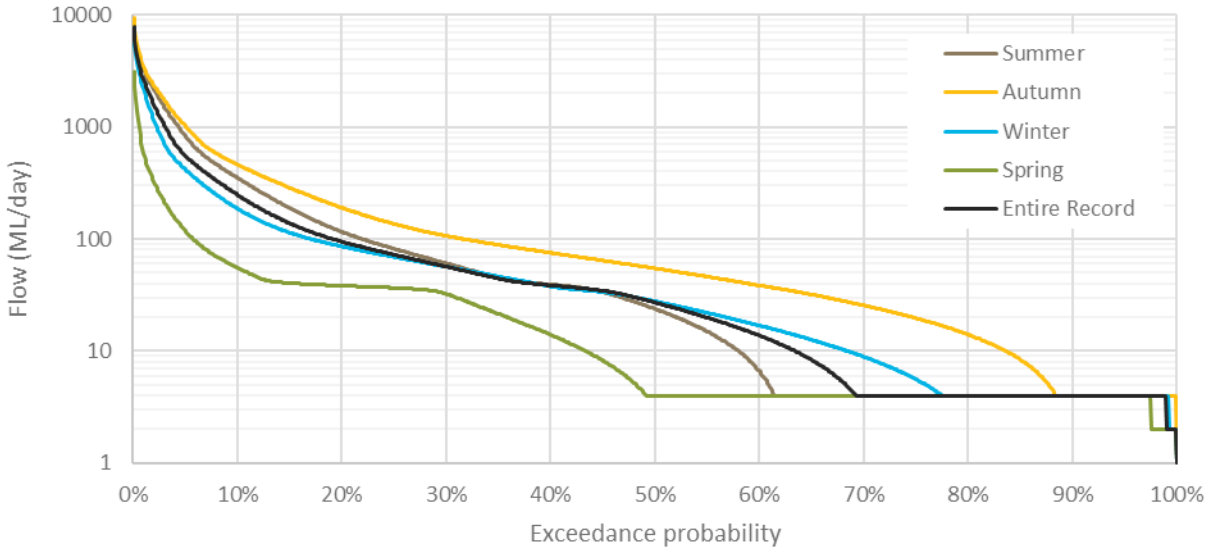


Figure 3.15 Flow duration curve at Doon Doon Creek downstream of Clarrie Hall Dam, current climate

3.4.3 Stream depth regime

Recorded stream depths at gauge locations indicate that the Tweed River at Palmers Road Crossing is typically 0.5 – 1 m deep, while at Uki the depth is typically around 1 – 1.5 m (Figure 3.16 and Figure 3.17).

Through the length of the river, depths will vary through riffles and pools and other localised features.

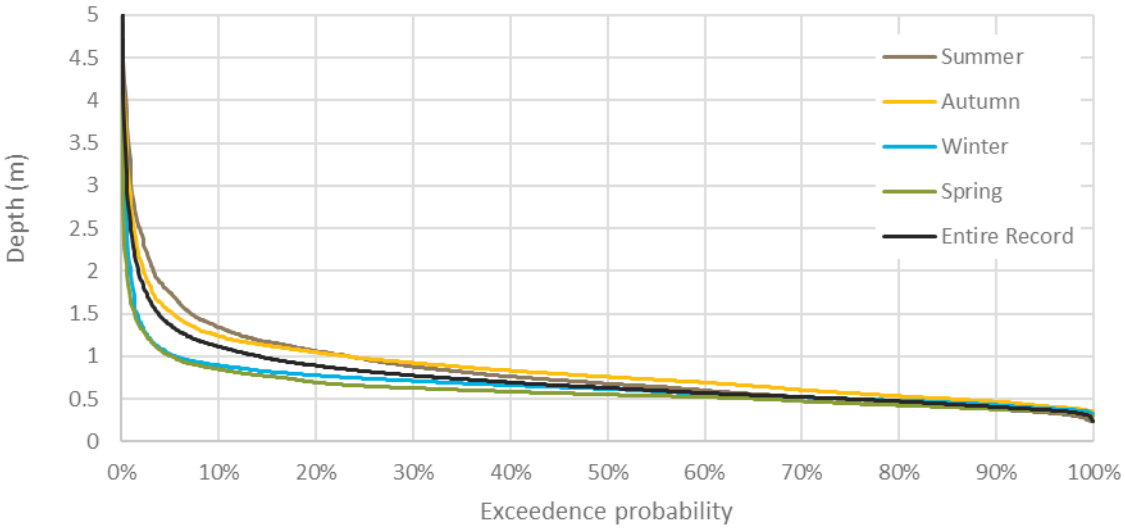


Figure 3.16 Stream depth curve for Tweed River at downstream Palmers Road Crossing (201015)

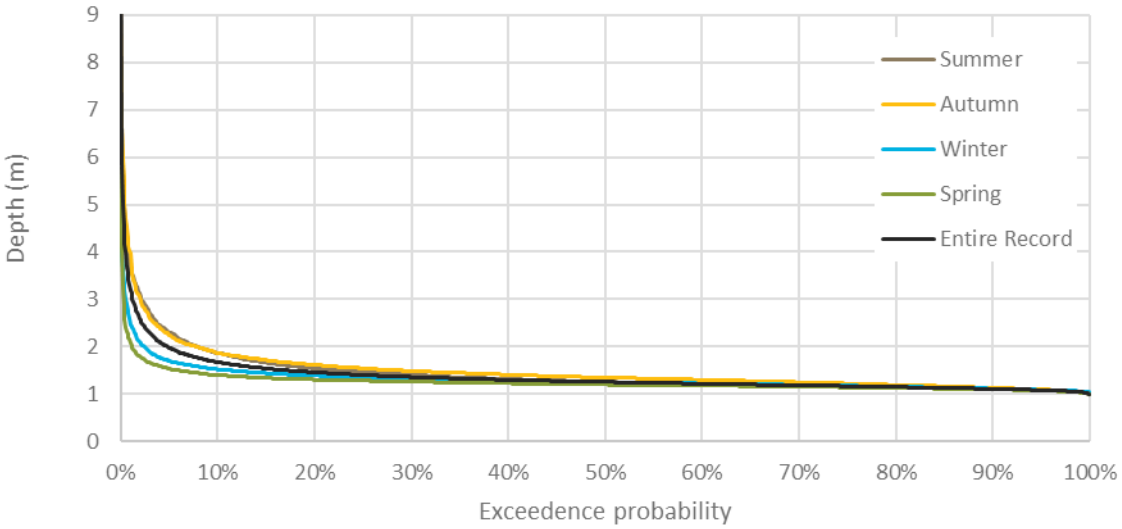


Figure 3.17 Stream depth curve for Tweed River at Uki (201900)

The modelled Doon Doon Creek hydraulics (Annexure C) and streamflow regime (Annexure A) indicate that Doon Doon Creek is typically shallow during periods of minimum release, and increases in depth by around 1 m during higher flow events (10th percentile) (Figure 3.18).

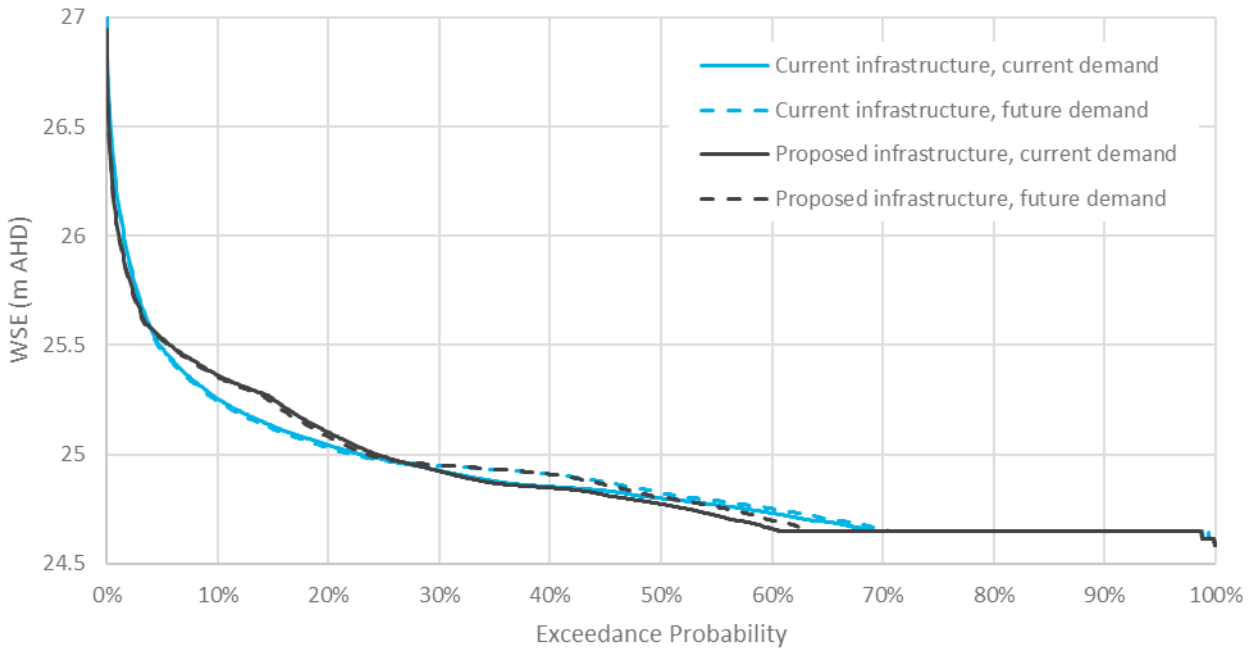


Figure 3.18 Water surface elevation, Doon Doon Creek pool

3.5 Surface water – groundwater connectivity

Between Clarrie Hall Dam and Bray Park Weir, Doon Doon Creek and Tweed River are conceptualised as gaining streams, meaning that groundwater discharges enter the waterways and contribute to baseflow (Groundwater Impact Assessment appendix to the EIS).

Total streamflow can be conceptualised as a combination of quick and slow flow components. Quick flow comprises surface runoff that is generated from rainfall excess and moves relatively quickly from the catchment surface to concentrated flow paths and then into waterways. Slow flow consists of several constituents that provide a delayed streamflow response following rainfall, including groundwater discharges, interflow, release of bank storage, and dam releases, with higher volumes occurring during wet periods when storage levels rise in the groundwater system and also other storages.

Quick flow / slow flow separation using the Lyne and Hollick filter (Ladson, Brown, Neal, & Nathan, 2013) indicates that slow flow may make up between 20-25% of total flow past Uki (Figure 3.19), with a typical range (10^{th} to 90^{th} percentile) of around 10 – 200 ML/day (Figure 3.20).

The portion of the flow past Uki contributable to slow flow ranges from 100% in drier periods, through to close to 0% during the rising limb of floods, when flows transition sharply from low flow conditions to high flow conditions following intense rain. Even though slow flow accounts for 20-25% of total flow past Uki, it makes up 100% of the river flow approximately 50% of the time (Figure 3.21).

It is likely that a substantial portion of the slow flow identified through the quick flow / slow flow separation procedure is groundwater discharge to the river, as there are no wetlands located upstream of Uki which might drain slowly, and similar results are obtained when analysing only data from before Clarrie Hall Dam was built in 1985 indicating that the procedure is not simply reporting dam releases.

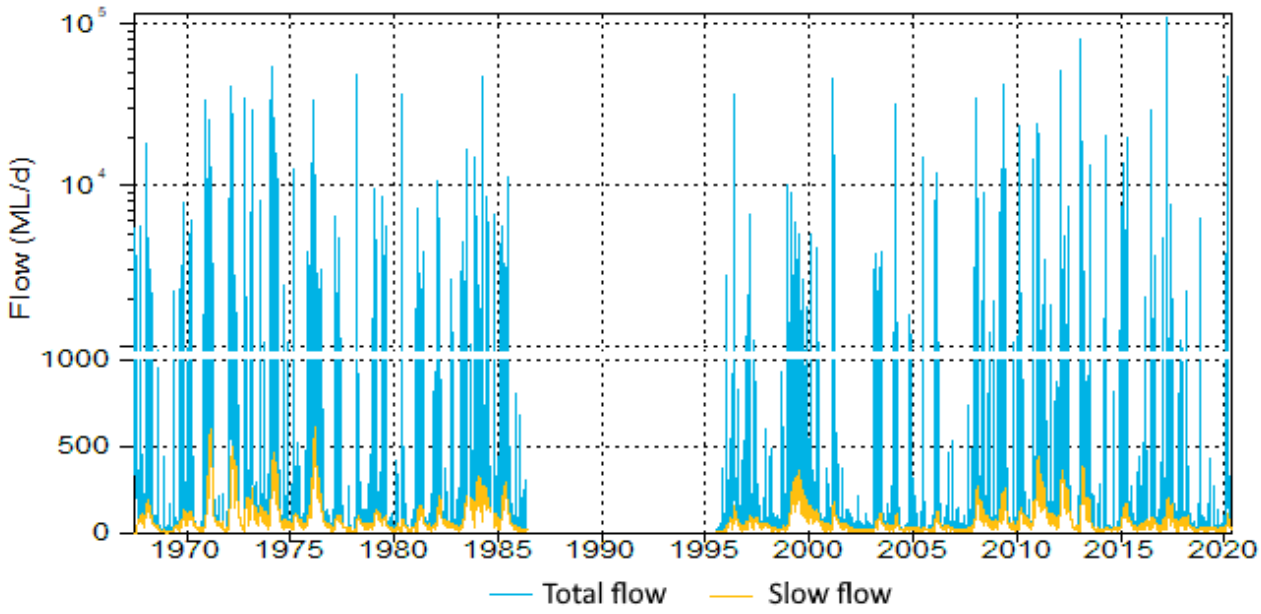


Figure 3.19 Quick flow / slow flow separation for the Tweed River at Uki

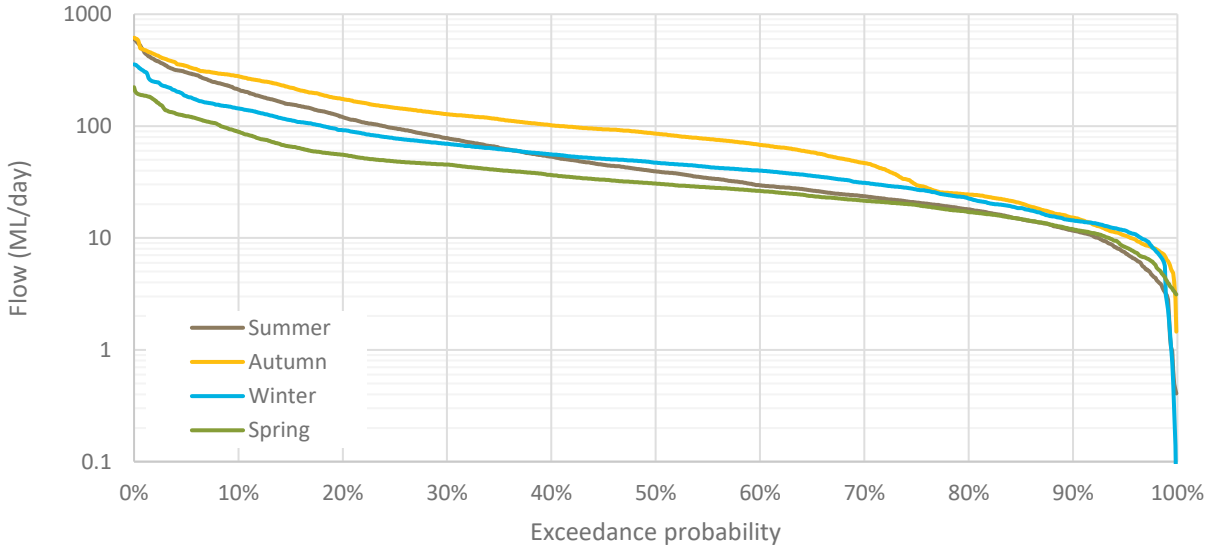


Figure 3.20 Seasonal slow flow distribution in the Tweed River at Uki

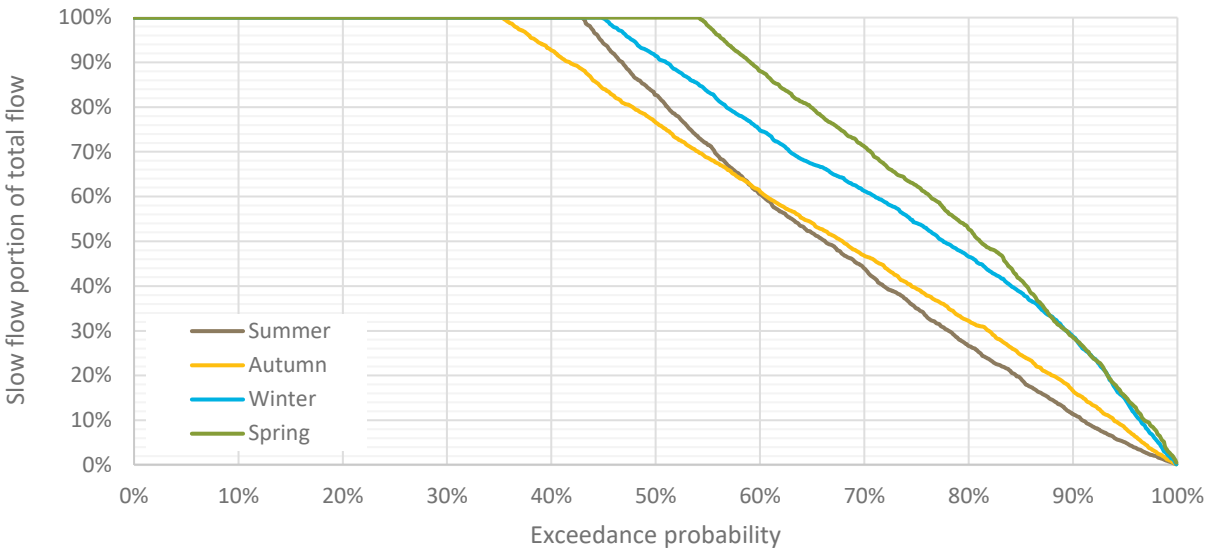


Figure 3.21 Daily slow flow portion of total flow in the Tweed River at Uki

This analysis shows that:

- in spring when flows are lowest (Figure 3.13)
    - a large proportion of the flow consists of slow flow (Figure 3.21), ie groundwater discharge becomes a more important component of the streamflow in dry periods
    - the magnitude of slow flow is lower than other seasons (Figure 3.20), ie groundwater discharges reduce in dry periods
- in autumn when flows are highest
    - a lower proportion of the flow consists of slow flow, ie quick surface runoff forms a greater portion of the flow during wet periods
    - the magnitude of slow flow is higher than in other seasons, ie groundwater discharges increase when it is wet
    - slow flow comprises 100% of the flow (baseflow index = 1) on 35% of days, ie the perennial nature of the river is dependent on groundwater discharges even in wetter periods.

3.6 Water infrastructure

3.6.1 Clarrie Hall Dam

i History

Construction of the existing Clarrie Hall Dam was completed in 1985. The dam has a height of 43 m, a crest length of 175 m, and a volume of approximately 16,000 ML at FSL based on recent LiDAR survey (LPI, 2017). The present FSL of RL 61.5 m is 8.9 m below the embankment wall crest level. The crest is lined with precast concrete parapet wall units (Photograph 3.4), which were added when the spillway was upgraded in 2014. The spillway and embankment crest were modified to meet new safety standards, increase capacity, and allow passage of the then probable maximum discharge of 1,355 ML/second (NSW PWA, 2018).



Photograph 3.4 Clarrie Hall Dam parapet wall

ii Access

Access to the dam wall and spillway area is from Clarrie Hall Dam Road, which runs south from the Kyogle Road intersection near the confluence of Doon Doon Creek and Tweed River. The southern extent of the Clarrie Hall Dam reservoir is accessed from Cram's Farm, located off Commissioners Creek Road via McCabes Bridge. The access routes will be adjusted as part of the Proposal development to accommodate the new inundation area.

iii Existing dam operations

Most of the time, the reservoir is full and water flows over the dam's spillway into Doon Doon Creek and downstream to the Tweed River. During low flow conditions, flows in the Tweed River are supplemented with releases from Clarrie Hall Dam to meet the demand for town/domestic water supply and irrigation, and to meet environmental flow requirements specified in the WSP as per Table 2.1.

The dam features a multi-level offtake (MLO) via an inlet tower (Photograph 3.5) which can be operated to draw water from various levels within the reservoir water column (Figure 3.22). Water is conveyed from the MLO via pipes/tunnel under the dam wall to the outlet structure where two fixed cone dispersion valves (FCDV's) of 400 mm and 900 mm diameter allow regulation of flow releases.

Required water is released from the dam reservoir via the spillway, one or both FCDV's, or by a combination of these approaches. .

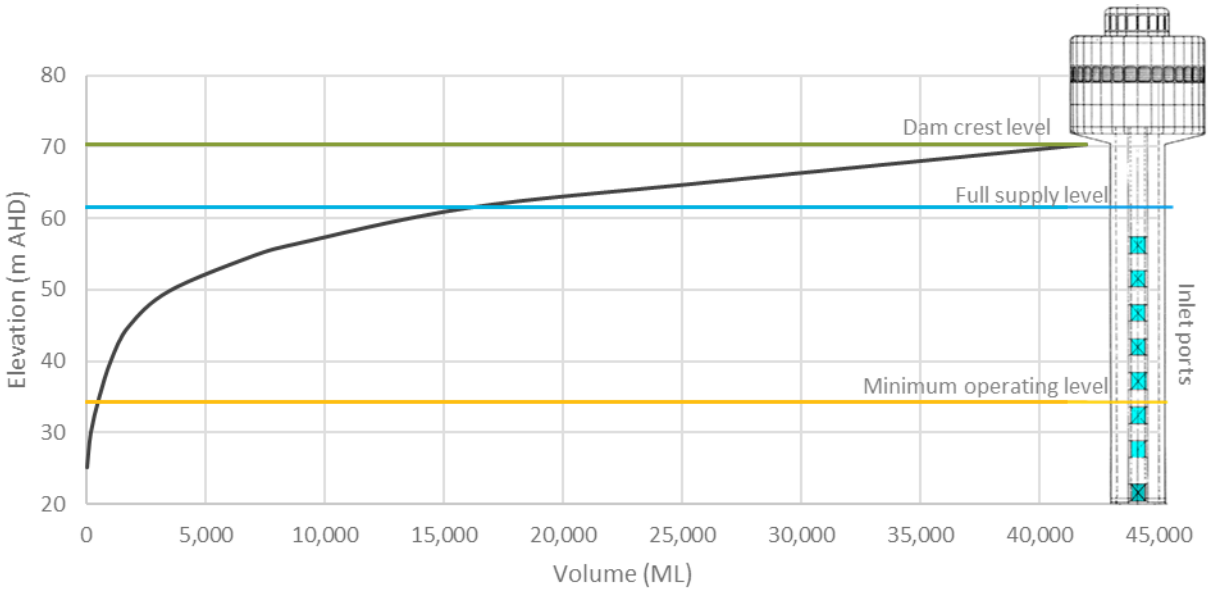


Figure 3.22 **Approximate Clarrie Hall Dam depth-volume relationship (NSW DoC, 2007) and release elevations (Council)**



Photograph 3.5 **Clarrie Hall Dam wall and multi-level offtake**

iv Volume records

The reservoir is full and overflowing the majority of the time (Figure 3.23), and drawn down in drought. The average measured storage volume over the period 2008–2023 is around 16,000 ML, approximately 100% of the full design capacity (Figure 3.24).

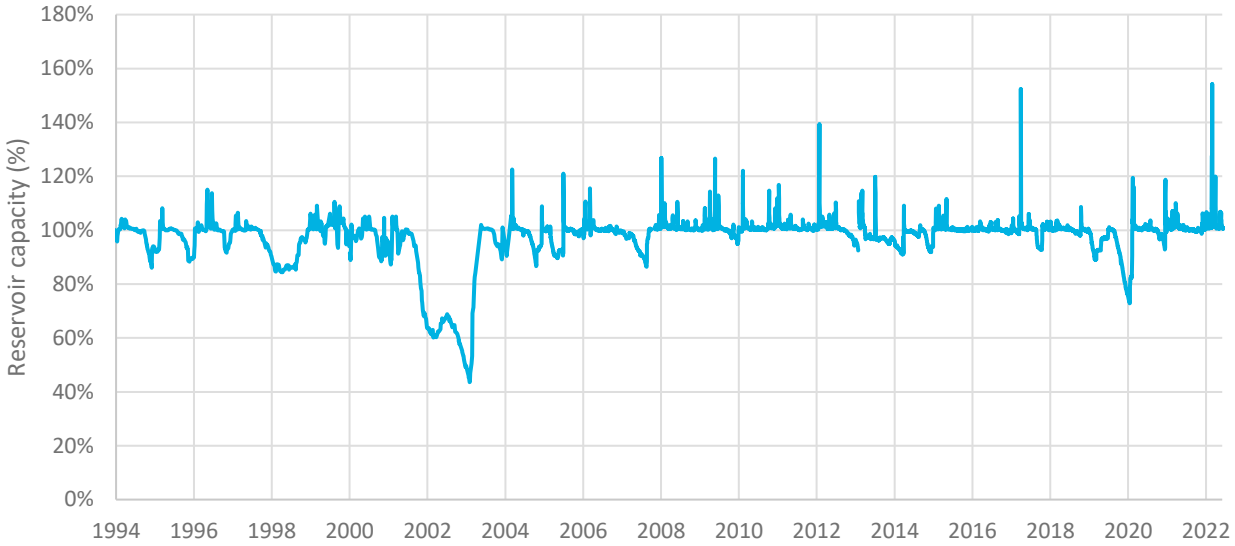


Figure 3.23 Clarrie Hall Dam recorded water volumes

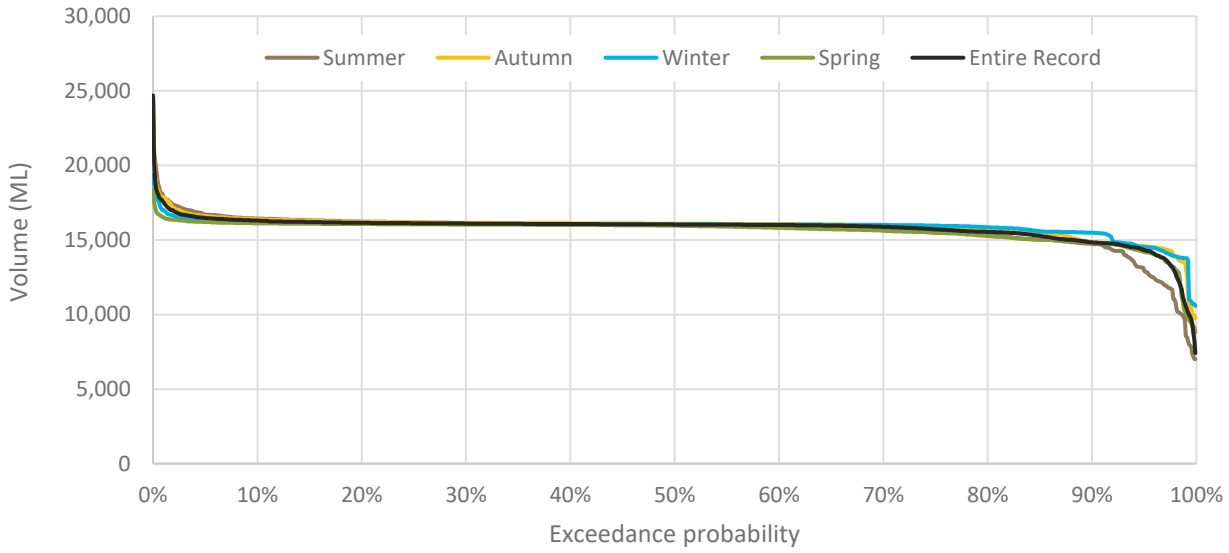
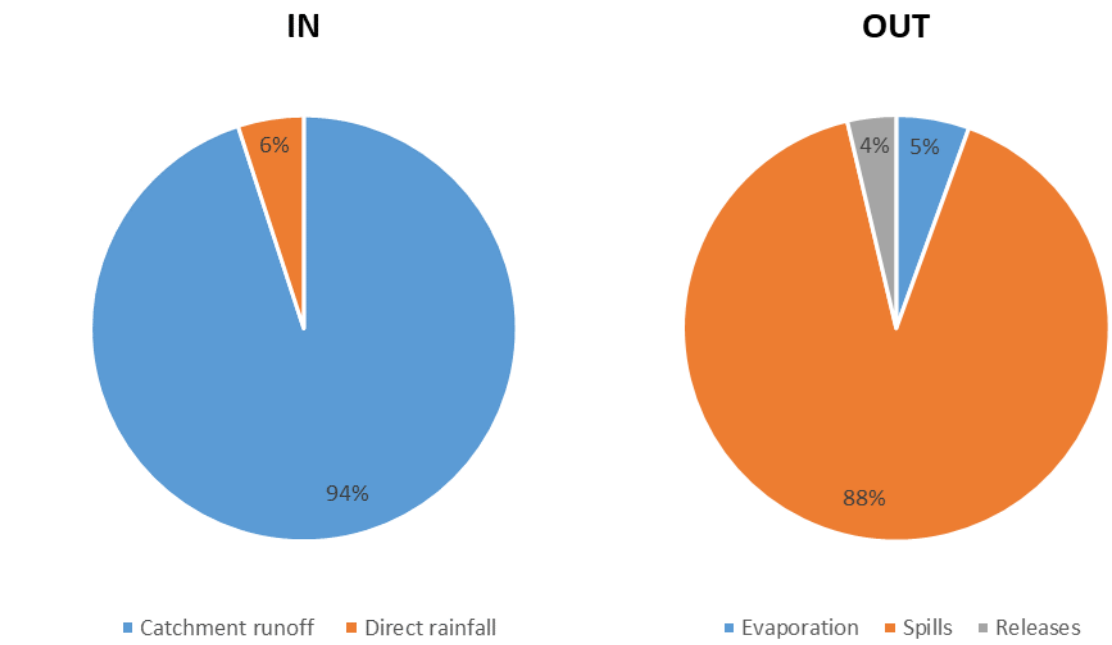


Figure 3.24 Clarrie Hall Dam recorded volumes

Dam operational data was provided by Tweed Shire Council for the period March 2008 to February 2023. During this time water flowed over the spillway for around 65% of the time. Dam operation for environmental release conditions based on reference gauge 201015 commenced in August 2011, and from this time environmental flow releases were required 32% of the time, and bulk-water releases were delivered for only 2% of the time. This is reflective of the relatively small size of the dam compared to dam inflows, and the low proportion of time flow releases are required to meet existing downstream demands.

Based on dam surveillance data from 2012–2022, the primary source of water for the dam is inflow from Doon Doon Creek flowing into storage. Rainfall falling directly on the surface of the storage only accounts for 6% of dam inflows (Figure 3.25).

Annual water balance results show that managed releases are consistently low whereas spill volumes account for the vast majority of the outflows. Spill volumes vary significantly over time, generally in response to rainfall.



100% = approx. 55,000 to 60,000 ML/year.

Figure 3.25 Average annual Clarrie Hall Dam water balance 2015–2022

v Discharges

Discharges from the dam can occur via the spillway and via manual release using values located in the outlet structure, with the following characteristics:

- The MLO can be adjusted to source water from different depths within the reservoir when water is released via the outlet structure
- The spillway discharges water once the water level in the reservoir exceeds 61.5 m AHD
- The 400 mm and 900 mm FDCVs are operated to discharge water when larger flows are required
- Two smaller valves upstream from the FDCVs can be used to release water for environmental flows when there is not enough flow from the other discharge methods to meet environmental flow requirements

Average annual discharges (2012 to 2022) from Clarrie Hall Dam are 54,530 ML via the spillway, 1,381 ML via the 400 mm FDCV, 475 ML via the 900 mm FDCV, and 362 ML via the smaller valves.

Spillway discharges occur on around 63% of days (Figure 3.26). The dam is typically full and discharges via the spillway more often and with larger volumes discharged during autumn. Discharges via the spillway are smaller and less frequent in spring. On days with no spillway discharges (ie reservoir is less than 100% FSL) releases are made via the MLO to satisfy town water and environmental water requirements.

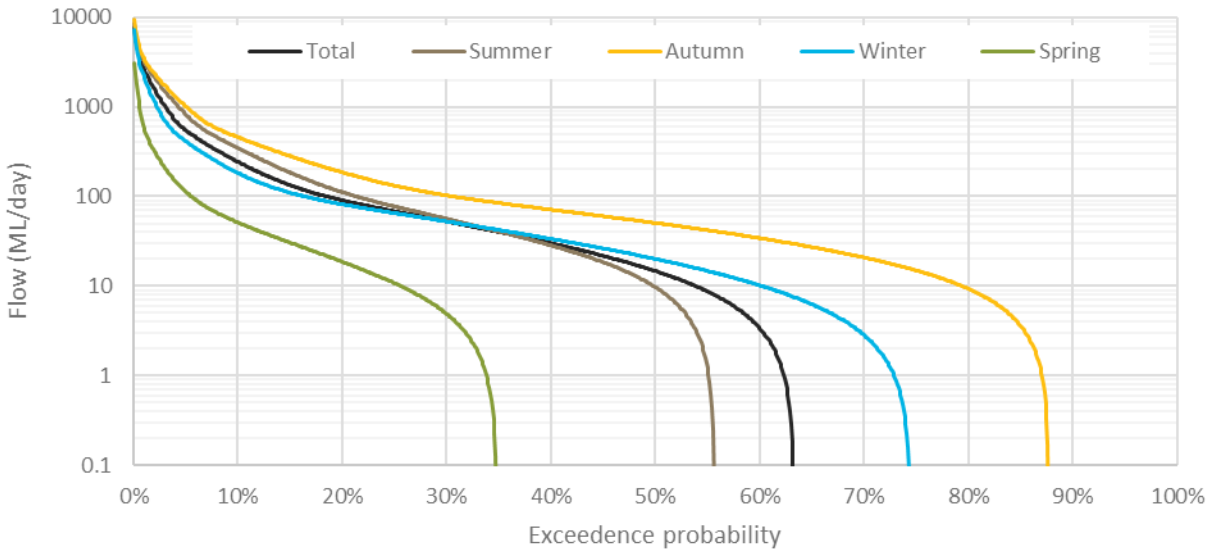


Figure 3.26 Daily spillway discharges (modelled)

Peak discharges from the existing reservoir via the existing spillway during flood events are estimated to be as per Figure 3.27. The Proposal will not affect storm inflows to the reservoir, but the larger reservoir will attenuate flows, and the new spillway will have different flow characteristics to the existing spillway.

Further detail of expected peak outflows and downstream flood effects (ie short duration effects in response to large storms) is provided in the EIS flooding appendix. This SWA and annexures describe the expected effects of the larger reservoir and new spillway on the long-term flow regime.

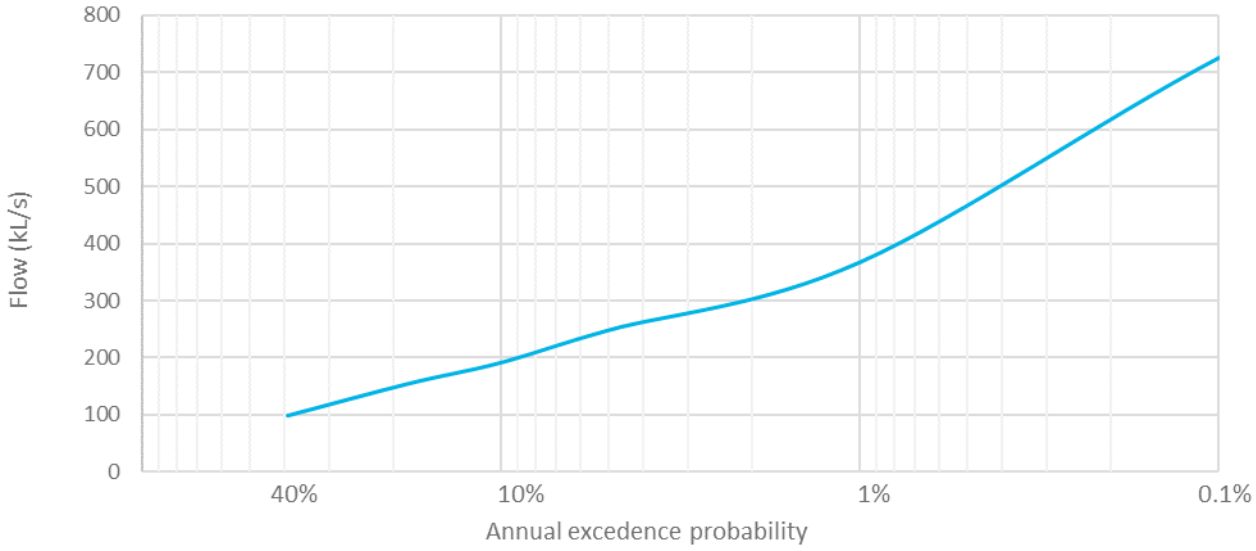


Figure 3.27 Existing spillway peak discharges (WRM, 2017)

vi Sediment capture

The efficiency of reservoirs to trap sediment is dependent on water residence time, with higher residence time allowing for additional settling. The relationship between residence time and settling is a well established science, with a commonly applied method for estimating sediment trap efficiency being that of Brune (1953). Application of Brune (1953) provides an estimate that the existing reservoir captures 94.3% of inflowing sediment.

A modified sediment trap estimation method which scales trap efficiency based on daily inflow (Lewis, et al., 2013) provided a very similar estimate of 94.2%. Further discussion of sediment capture is provided in section 5.8.2.

3.6.2 Bray Park Weir

The pool upstream of Bray Park Weir is supplied with flow from both the Tweed and Oxley rivers, and the weir acts as the dominant upstream control of the river levels near Murwillumbah. Releases are made from Clarrie Hall Dam to top up the Bray Park weir pool (NSW Office of Water, 2010) via run-of-river water transfers.

Raw water is pumped from the Tweed River from the pool immediately upstream of the Bray Park Weir and transferred to the Bray Park water treatment plant (WTP) for treatment and distribution via the Tweed district water supply network.

Tidal influence penetrates up the Tweed River to the Bray Park Weir, and so the weir acts as a saltwater barrage. The weir can be raised in response to rainfall and high tides with demountable flood barriers (concrete blocks and sandbags), to reduce the risk of overtopping and saltwater contamination of the weir pool.

A fish ladder allows upstream fish migration past the weir.

3.6.3 Tweed Shire water supply network

The three water supply systems operated by Tweed Shire Council have been summarised in Table 3.2. The Tweed district water supply network services the major urban centre of Tweed Heads, the town of Murwillumbah, and the coastal strip from Kingscliff to Pottsville including the villages of Mooball and Burringbar. Uki and Tyalgum are serviced by their own water supply networks.

Table 3.2 Water supply systems in the Tweed LGA

System	Tweed district	Uki	Tyalgum
Water Source	Doon Doon Creek	Doon Doon Creek	Upper Oxley River
Source type	Surface water storage and weir pool	Large in-stream storage and run-of-river abstraction	Weir pool and run-of-river abstraction
Storage capacity	Clarrie Hall Dam (16,000 ML), Bray Park Weir (520 ML)	Clarrie Hall Dam	Tyalgum weir pool (7.52 ML)
Serviced areas	District except for Uki and Tyalgum	Uki	Tyalgum
License entitlement as per water sharing plan	27,500 ML/y	67 ML/y	46 ML/y
Water treatment plant (WTP)	Bray Park Weir WTP 100 ML/d	Uki WTP 0.44 ML/d	Tyalgum WTP 0.25 ML/d

The Tweed district and Uki water supply networks are supplied by releases from Clarrie Hall Dam, whereas the Tyalgum water supply network is sourced from the upper Oxley River and is not affected by releases from Clarrie Hall Dam.

The total number of connections for Tweed district is expected to increase by approximately 133%, to 61,016, over the next 50 years (Hydrosphere, 2020a). The average demand is only expected to increase by approximately 89% over the same time period (Figure 3.28), due to ongoing demand management factors such as increased development of multi-residential properties with lower demand than single residential properties. Annual water demand is currently around 10,000 ML/year, but has been forecast to grow to around 17,000 ML/year by 2065.

The unrestricted dry year demand is 4.3% higher than the average demand for Tweed district water supply (Hydrosphere, 2020a).

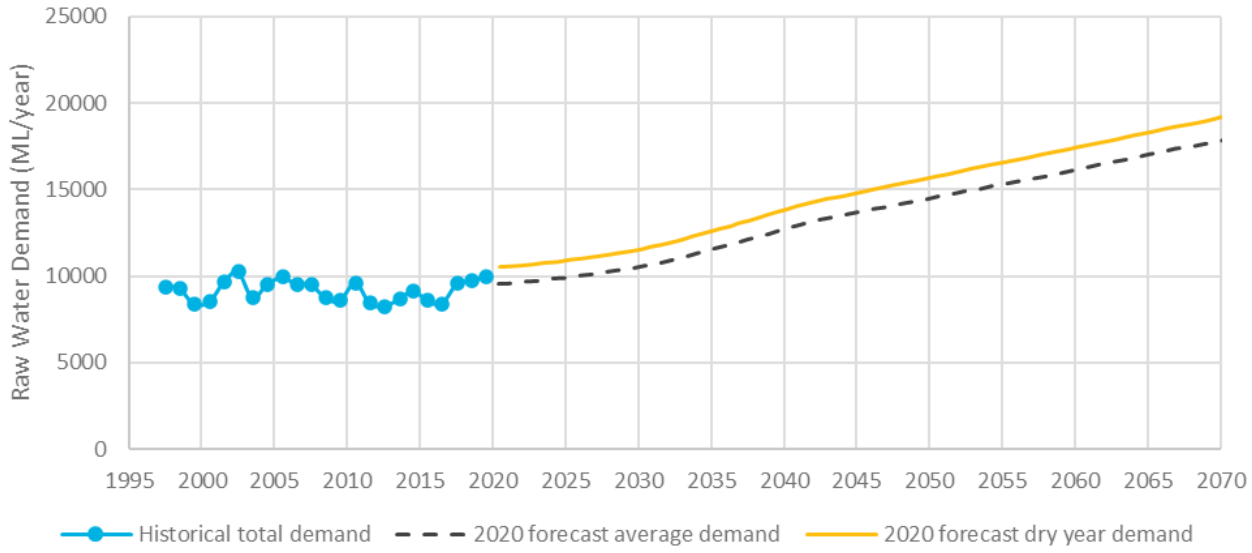


Figure 3.28 Shire-wide historical demand and 2020 demand forecasts (Hydrosphere, 2020a)

3.6.4 Waterway crossings and bridges

McCabes Bridge is located upstream of the dam, at the point Commissioners Creek Road crosses Doon Doon Creek at the southern extent of the reservoir. As part of the proposal McCabes Bridge will be raised and the approach road realigned. Kyogle Road also crosses Doon Doon Creek next to the confluence with the Tweed River. The main bridges crossing the Tweed River are:

- Kyogle Road Bridge, Byangum
- Wollumbin Street Bridge, Murwillumbah
- Cane Road Bridge, Condong
- Terranora Road Bridge, Tumbulgum
- Barneys Point Bridge, M1 Pacific Motorway, Banora Point.

3.7 Surface water use

3.7.1 Water access licenses

WaterNSW manages the NSW Water Register, which contains details of water licenses issued under the *Water Act 1912* and works approvals issued under the WM Act. Water access licenses (WALs) issued under the WM Act are fully separated from land title and are not recorded in the NSW Water Register (WaterNSW, n.d.).

The Water Access Licenses Register is maintained by NSW Land Registry Services (NSW LRS) on behalf of the Minister administering the WM Act and contains a record of every WAL in NSW (NSW LSR, 2019).

Both the NSW Water Register and the Water Access Licenses Register were reviewed to develop the following description of surface water users.

The management of the Tweed River catchment water resources is described in the WSP. Total licensed entitlement for the plan area is 35,346 ML/year, and there are 32 water sources within the plan area. Of particular relevance to the Proposal are the Doon Doon Creek Water Source and the Mid Tweed River Water Source, located in the Tweed River Catchment EMU.

Clarrie Hall Dam and the catchment area reporting to it are associated with the Doon Doon Creek Water Source. There are five Irrigation WALs and one Domestic and Stock WAL within the Doon Doon Creek Water Source, with a combined share component of 56 shares, equivalent to 56 ML/year when water availability is 100% (Table 3.3). As of 2023, there are currently no active unregulated river (high flow) access licenses.

There are three WALs in total authorising extraction for town water supply associated with the WSP, with a combined share component of 27,613 ML/year and representing 78% of the total licensed entitlement. Two of these WALs are associated with the Mid Tweed River Water Source, and authorise the pumped extraction from the Tweed River for Uki supply network and the district supply network, respectively (27,567 ML/year). One WAL is associated with the Upper Oxley River Water Source, supplying the Tyalgum water supply network (46 ML/year).

A total of 28 WALs are held in the Mid Tweed River Water Source, which represent around 82% of the total licensed entitlement for the plan area (Table 3.3). In addition to the licensed extraction, the WSP estimates a potential extraction to meet the requirements of basic landholder rights (BLR) of 2,516 ML/year across all 32 water sources, including 111 ML/year for the Mid Tweed and 72 ML/year for Doon Doon Creek. One native title determination is associated with the Doon Doon Creek Water Source and water may be taken in the exercise of these rights in accordance with the Commonwealth *Native Title Act 1993*.

Table 3.3 WAL summary for the Mid Tweed River and Doon Doon Creek Water Sources

Water source	Access license category	Number of WALs	Share component (volume available at 100% allocation)
Doon Doon Creek	Unregulated River	5	52 ML/year
	Domestic and Stock	1	4 ML/year
Total		**6**	**56 ML/year**
Mid Tweed River	Local Water Utility	2	27,567 ML/year
	Unregulated River	23	1,228 ML/year
	Domestic and Stock	2	27 ML/year
	Aquifer	1	40 ML/year
Total		**28**	**28,862 ML/year**

Unregulated River licenses are typically used for irrigation, however WAL 44764 in the Mid-Tweed with 5 ML/yr share components is associated with the Uki WTP

There are two flow classes specified in Division 3 of the WSP for the Mid Tweed River and Doon Doon Creek Water Sources, as set out in Schedule 1 (Table 3.4).

In any particular year, WALs may be limited to extraction of only part of the associated volume, as allocations may be reduced below 100%:

- in response to water availability, such as may occur during drought, or
- to maintain total average extractions within the LTAAEL.

Table 3.4 WAL flow classes for the Mid Tweed River and Doon Doon Creek Water Sources

Water source	Flow class	Flow class threshold	Flow reference point
Doon Doon Creek	Very low flow class	4 ML/day or less	Tweed River at Palmers Road gauge (201015)
	A class	More than 4 ML/day	
Mid Tweed River	Very low flow class	4 ML/day or less	
	A class	More than 4 ML/day	

3.7.2 Town water supply

Tweed Shire Council has WALs to extract 27,618 ML per year (representing 79% of the total water entitlement). Town water supply can be accessed from the Mid Tweed River Water Source (27,572 ML per year, including 72 ML per year for Uki) and 46 ML per year from the Upper Oxley River Water Source (Tyalgum). The largest use of water from the Tweed River is for drinking water supply for the rapidly growing regional city of Tweed Heads, the coastal strip from Kingscliff to Pottsville, and the town of Murwillumbah.

Under the WM Act, water utility extractions for town water supply are given higher priority than extractions for commercial purposes, such as irrigation or water bottling. The WSP recognises this by providing a full share of water for annual town water supplies, apart from in exceptional drought conditions (NRC, 2021).

3.7.3 Irrigated agriculture

Apart from urban use, other water users extract water for irrigation, and stock and domestic use. Rural Tweed, within RU1, RU2, R5, 7(d), 7(f), and 7(l) zoned land occupies 96,665 ha or around 75% of the total area of the Tweed Shire, with mainly grazing pastureland, broadacre sugarcane cropping, horticulture (bananas, tropical fruit, avocados, macadamias, stone fruit, vegetables), forestry and rural living (Urban Enterprise & EnPlan Partners, 2013).

Irrigation of the river flats is carried out for dairying, while sugarcane farming occupies large areas adjacent to the estuary. Irrigated pastures for livestock grazing on lower slopes comprises approximately 96% of irrigated land use. Tweed Shire is recognised as a state-level significant agricultural producer; in 2013 the Shire contributed approximately 30% of State product value of sugarcane and bananas and 10% of the State's tropical orchard fruit value. The land use and landscape of the region continues to maintain a predominantly agricultural outlook, with agriculture supporting 10% of the workforce (TSC, 2020).

3.8 Environmental receptors

3.8.1 Overview

Water is required within the Tweed River for ecological processes such as native fish migration, spawning and recruitment, and vegetation maintenance. Meeting the full life cycle needs of an aquatic organism (plant or animal) might require a combination of several different flow magnitudes, frequencies and durations over time.

To support environmental outcomes within Doon Doon Creek and Tweed River, the WSP specifies minimum releases from the reservoir of 1 – 4 ML/day, depending on flow in the Tweed River (section 3.6.1iii). Water quality objectives are discussed in section 3.9. Groundwater dependent ecosystems are discussed in the Groundwater Impact Assessment appendix to the EIS.

3.8.2 Terrestrial water dependent ecosystems

i Bank and floodplain vegetation

The banks and floodplains of Doon Doon Creek and the Tweed River support vegetation which draws water from a mixture of rainfall and groundwater. Groundwater in close proximity to Doon Doon Creek or the Tweed River have the potential to be affected by the flow regime of the waterways.

Downstream from the reservoir, the waterways are expected to receive groundwater discharges as baseflow the majority of the time, though the flow direction could temporarily reverse on high flow days when river water levels rise.

Around the reservoir fringes, vegetation within several vertical meters of FSL are expected to utilise groundwater sourced from the reservoir.

Groundwater dependent ecosystems are discussed further in the Groundwater Impact Assessment appendix to the EIS.

ii Stotts Island Reserve

Stotts Island Nature Reserve is located within the Tweed River approximately 33 km downstream of the study area. The reserve is low lying and subject to periodic flooding. The island is the largest remnant of subtropical floodplain rainforest remaining in NSW. Floodplain rainforest is listed as an endangered ecological community under the *Threatened Species Conservation Act 1995*. Areas of wetland also occur within the reserve. The reserve contains important habitat for at least 7 species of threatened fauna including the Mitchell's rainforest snail (NPWS, 2001).

As Stotts Island Reserve is downstream from Bray Park Weir within the estuarine reach of the Tweed River it is not likely to be affected by the project.

3.8.3 Aquatic water dependent ecosystems

i Australian Bass

Aquatic ecology surveys conducted for the Proposal (see Aquatic Ecology appendix to the EIS) indicate that of the fish species present in the Tweed River, only Australian Bass (*Percalates novemaculatea*) include a life cycle stage with a flow trigger.

Australian Bass are catadromous, meaning adults migrate downstream to spawn in estuaries. This migration occurs during flood events between May and July (Lintermans, 2007) when water temperatures are below 15°C, with fish returning between August and April. Only females are usually found upstream, whereas males tend to remain in the lower reaches of estuaries (Bray & Thompson, 2020).

Australian Bass may migrate during a series of shorter pulse flows, or during consistent moderate flows. In the Tweed River it is estimated that flows required to prompt migration are as per Table 3.5. The frequency of flows which may cue migration are discussed further in section 5.6.3.

Table 3.5 Australian Bass migration flow cues, Tweed River

Environmental Process	Months	Flow threshold (ML/d)	Duration
Spawning migration	May - July	800	Multiple 3 day pulses
		150	5 days+
Upstream migration	August - April	1700	Multiple 3 day pulses

Table 3.5 Australian Bass migration flow cues, Tweed River

Environmental Process	Months	Flow threshold (ML/d)	Duration
		150	5 days+

3.9 Water quality

3.9.1 Water quality objectives

Under the current Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018) framework, the WQO's for a water resource are dependent on the community and EV's of that resource, and the condition of the water resource.

The EV's of a water system are related to its use, from both a human and environmental perspective. The primary use of Clarrie Hall Dam is to augment river flows for drinking water abstraction, with a condition of supplying environmental flows to support a healthy downstream aquatic ecosystem. The dam is also used to supply water to primary industries (specifically agriculture).

As Clarrie Hall Dam alters flows in Doon Doon Creek and the Tweed River, and the surrounding land use is primarily agricultural, the water resource may be considered 'slightly-moderately disturbed systems'.

There are several sources from which to derive WQO values, including:

- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG, 2018)
- NSW Water Quality Objectives – Tweed River catchment (NSW WQOs) (DECCW, 2006)
- Australian Drinking Water Guidelines (ADWG) (NHMRC, 2011).

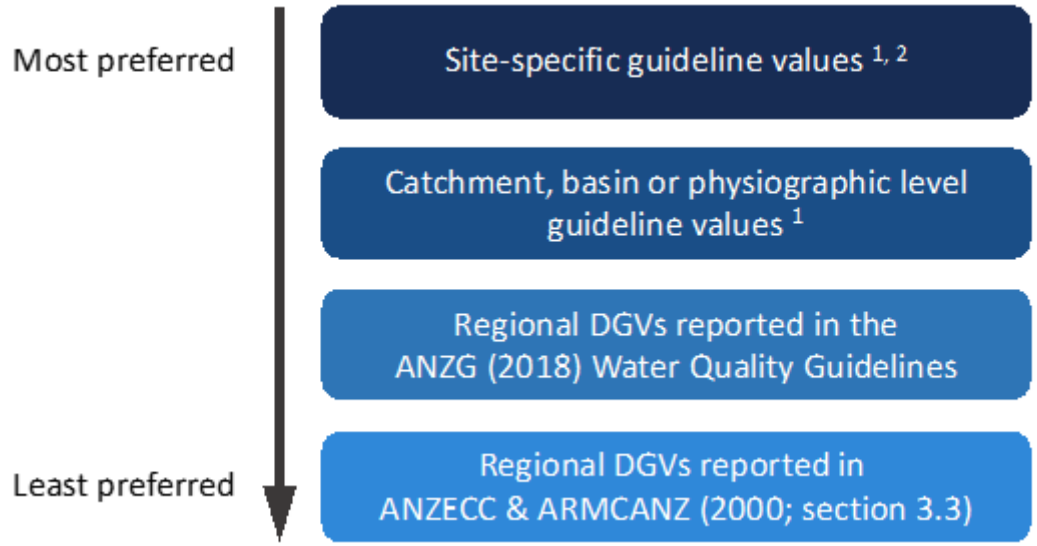
ANZG 2018 supersedes ANZECC/ARMCANZ 2000 as the primary guideline for water quality management and assessment in Australia. However, many government guidelines still refer to ANZECC/ARMCANZ 2000, including the NSW WQOs, hence both guidelines are referenced here. ANZG 2018 is largely consistent with ANZECC/ARMCANZ 2000 in terms of DGV's, although some values have changed with the inclusion of additional data.

The ANZG 2018 guidelines provide guidance on the hierarchy of available data sources, with the preference to use the most locally relevant dataset available (Figure 3.29).

In this case, the NSW WQOs provides the most relevant objectives and has therefore been adopted, although the targets in the NSW WQOs are limited to PC stressors (pH, electrical conductivity [EC], dissolved oxygen, turbidity, nitrogen, and phosphorus). ANZG (2018) DGV's are used in this assessment for toxicants (metals).

ADWG thresholds are relevant to water quality delivered by the Shire to potable water customers after water treatment, but are not required to be met in raw water sources prior to treatment.

A comparison of the WQOs from the sources listed above is provided in Table 3.6, as well as the WQOs adopted for this assessment. It should be noted that WQO values are used here to generally characterise current water quality conditions against high level targets. DGV's and catchment level targets are not intended to be used to monitor compliance during construction and operational stages.



Source: ANZG 2018, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Australian and New Zealand Governments and Australian state and territory governments, retrieved 15 October 2020 from https://www.waterquality.gov.au/anzguidelines/your-location

Figure 3.29 Preferred hierarchy of guideline values for physical and chemical stressors

Table 3.6 Water quality objectives

Environmental value	Water quality parameter	ANZECC/ARMCANZ 2000[1] and NSW WQO	ANZG 2018	ADWG	Adopted WQO
Aquatic ecosystems	**Physical and chemical stressors**				
	Total phosphorus	20 µg/L	20 µg/L	-	20 µg/L
	Total nitrogen	250 µg/L	250 µg/L	-	250 µg/L
	Oxidised nitrogen	15 µg/L	15 µg/L	*Nitrite*: Health: 3 mg/L *Nitrate*: Health: 50 mg/L	15 µg/L
	Ammonium	13 µg/L	13 µg/L	-	13 µg/L
	Dissolved oxygen (% saturation)	90–110	90–110	Health: - Aesthetic: >85%	90–110
	pH	6.5–8.0	6.5–8.0	Health: - Aesthetic: 6.5–8.5	6.5–8.0
	Salinity (electrical conductivity)	350 µS/cm	350 µS/cm	-	350 µS/cm
	Turbidity	2–25 NTU	2–25 NTU	Health: - Aesthetic: 5 NTU	2–25 NTU

Table 3.6 Water quality objectives

Environmental value	Water quality parameter	ANZECC/ARMCANZ 2000[1] and NSW WQO	ANZG 2018	ADWG	Adopted WQO
	Temperature	Between 20th and 80th percentile of natural monthly water temperature	Between 20th and 80th percentile of natural monthly water temperature	-	Between 20th and 80th percentile of natural monthly water temperature
	Toxicants				
	Aluminium	55 µg/L	55 µg/L	Health: - Aesthetic: 200 µg/L	55 µg/L
	Copper	1.4 µg/L	1.4 µg/L	Health: 2000 µg/L Aesthetic: 1000 µg/L	1.4 µg/L
	Manganese	1.9 mg/L	1.9 mg/L	Health: 0.5 mg/L Aesthetic: 0.1 mg/L	1.9 mg/L
	Iron	-	-	Health: - Aesthetic: 0.3 mg/L	-
	All other toxicants	ANZECC 2000 default guideline values for the protection of 95% of freshwater species[2]	ANZG 2018 default guideline values for the protection of 95% of freshwater species[2]	Values from ADWG 2011 Table 10.6 – *Guideline values for physical and chemical characteristics*	ANZG 2018 default guideline values for the protection of 95% of freshwater species[2]
Primary contact recreation	Blue-green algae	15,000 –20,000 cells/mL	-	-	15,000 –20,000 cells/mL

Notes 1. Values presented are for south-east Australia, slightly to moderately disturbed systems, upland rivers (defined as rivers with elevation >150m AHD).

2. Guideline value for protection of 99% of freshwater species is to be used for bioaccumulating toxicants.

3. Values presented are for the Upland region of the catchment. The reservoir catchment includes both Upland and Lowland areas.

3.9.2 Water quality monitoring

Routine water quality monitoring is undertaken by Tweed Shire Council at around 60 water sampling sites distributed across seven water quality reporting zones in the Shire. Monitoring efforts focus on the catchment sources as well as the storages and assets associated with the three water supply networks. The monitoring aims to determine treatment efficacy and compliance, to inform system operation, and to track trends and problem areas within source catchments.

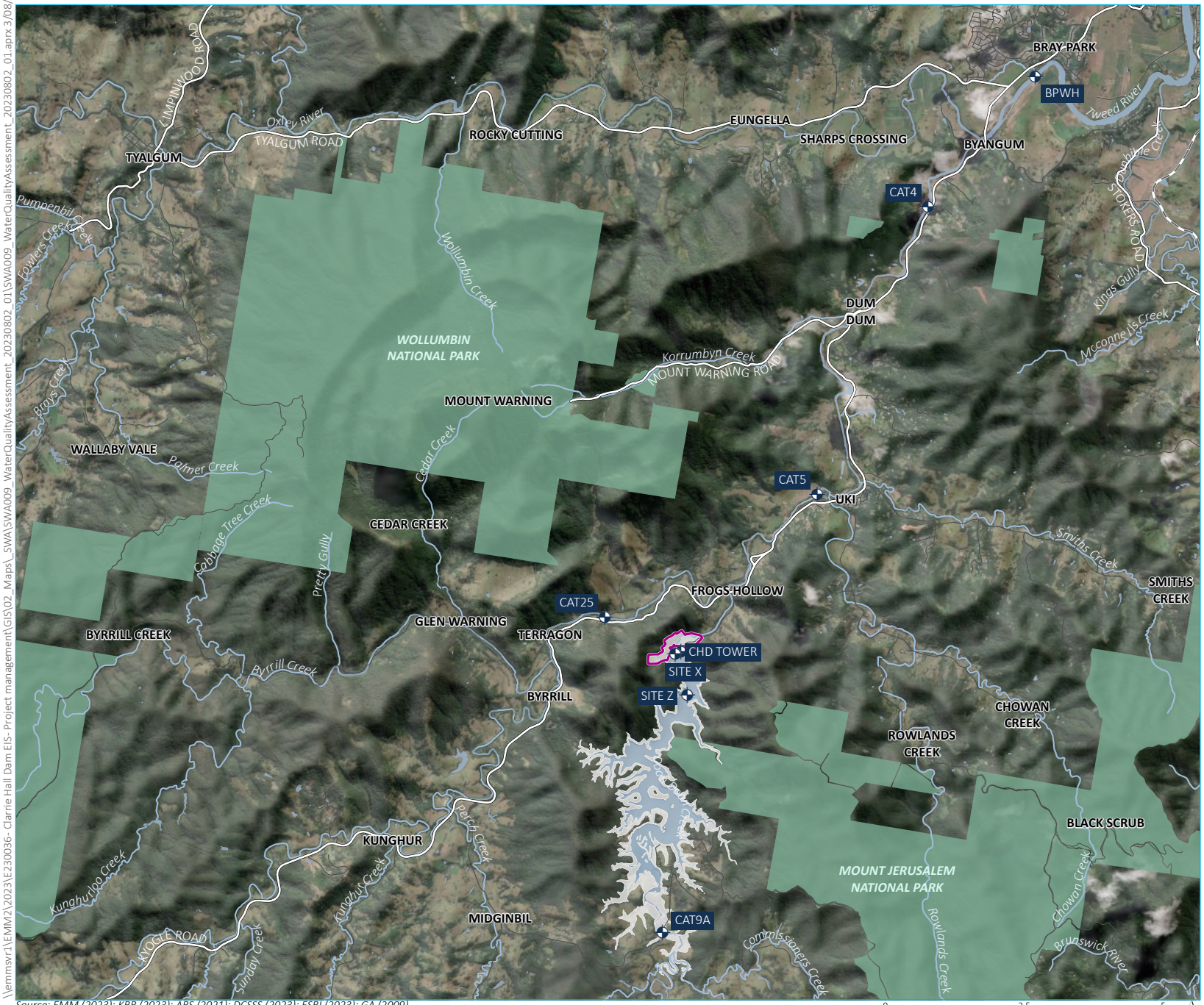
This baseline assessment focuses on selected monitoring locations in the Upper Tweed catchment, which encompasses the freshwater reaches of Doon Doon Creek, the Tweed River catchment down to Bray Park Weir, Clarrie Hall Dam, and Uki and Bray Park WTP intakes. The selected sites are listed in Table 3.7 and highlighted in Figure 3.30. Bray Park Weir pool is the downstream limit of this baseline assessment.

Monthly monitoring of catchment sites typically includes general water quality characteristics (pH, EC, turbidity, temperature, dissolved oxygen, biochemical oxygen demand, total suspended solids), major ions, nutrients (total nitrogen, total phosphorus), algae, aluminium, and indicators of faecal contamination. Infrequent results for some other parameters are also available but are not reported here.

Monthly and weekly samples from sites within Clarrie Hall Dam reservoir (Site X, Site Z, and CHD intake tower) and from Bray Park Weir (BPWH) monitor an expanded suite of analytes, typically including alkalinity, hardness, calcium, colour, manganese, iron, silica, with additional algae and pathogens.

Table 3.7 Sampling sites used in water quality baseline assessment

Site name	Description
CAT25	Palmers Rd crossing, u/s of Doon Doon Creek junction
CAT9a	Doon Doon Creek u/s of dam, sampled at McCabes Bridge
Site Z	Clarrie Hall Dam at 2 m depth, taken 900 m u/s of dam wall, regularly sampled at regular intervals from the surface (0 m) down to a depth of 20 m, with occasional samples below 20 m depth (up to 30 m)
Site X	Clarrie Hall Dam at 2 m depth, taken u/s of spillway near the dam wall, regularly sampled at regular intervals from 0 – 20 m, with occasional samples below 20 m depth (up to 30 m)
CHD Tower 2m	Taken from the MLO, regularly sampled at 2 m depth
CAT5	Tweed River 400 m d/s of Smiths Creek, 800 m d/s of Uki Village.
CAT4	Tweed River 1.75 km u/s of Byangum Bridge
BPWH	Bray Park Weir pool u/s, surface sample



KEY

- Water quality assessment sample location
- Construction disturbance footprint
- Development site

Existing environment

- Rail line
- Major road
- Minor road
- Named watercourse
- NPWS reserve
- State forest

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

0 2.5 5 km

GDA2020 MGA Zone 56

N

Water quality assessment sample location

Clarrie Hall Dam EIS
Surface Water Assessment
Figure 3.30

EMM creating opportunities

\\emmsvr1\EMM2\2023\E230036- Clarrie Hall Dam EIS- Project management\GIS\02_Maps_SWA\SWA009_WaterQualityAssessment_20230802_01\SWA009_WaterQualityAssessment_20230802_01.aprx 3/08/2023

i Electrical conductivity

EC is well below the WQO of 350 µS/cm at all monitoring sites (Figure 3.32). Elevated concentrations of dissolved salts in solution increase electrical conductance, and so higher EC indicates higher salinity.

Slightly lower conductivities are observed in the dam reservoir and Bray Park Weir pool (BPWH) than in the Tweed River upstream of the confluence with Doon Doon Creek (CAT25, refer Figure 5.23) and the Doon Doon Creek headwater site (CAT9a). This result may occur due to stratification within the larger water bodies; as water density increases with salinity, salt will tend to occur in higher concentration at the base of water storages with fresher water near the surface.

EC observations within the reservoir indicate relatively constant EC at surface, with more variability at depth (Figure 3.33). The seasonal pattern present in the data is largely correlated to seasons, with increasing EC during periods with lower inflows, and rapid reduction in EC during higher inflows.

Additional discussion of observed data for sites located within Clarrie Hall Dam is provided in Annexure B.

ii pH

WQO's for pH are generally met at the MLO (Figure 3.33).

The balance of carbon dioxide and carbonate within the water column can affect pH, with decaying leaf litter allowing formation of carbon dioxide and a reduction in pH, and algal growth consuming carbon dioxide and leading to a rise in pH.

The reservoir pH tends to fall during periods of high inflows, potentially due to:

- influx of rainfall, which can be slightly acidic
- influx of organic material
- lower algal counts during higher flow periods

During the low inflow period in 2019, pH and algal counts were both observed to increase, whereas the onset of wet conditions in 2022 resulted in decreased pH and algal counts (eg Figure 3.31, additional data presented in Figure 3.33 and Figure 3.37).

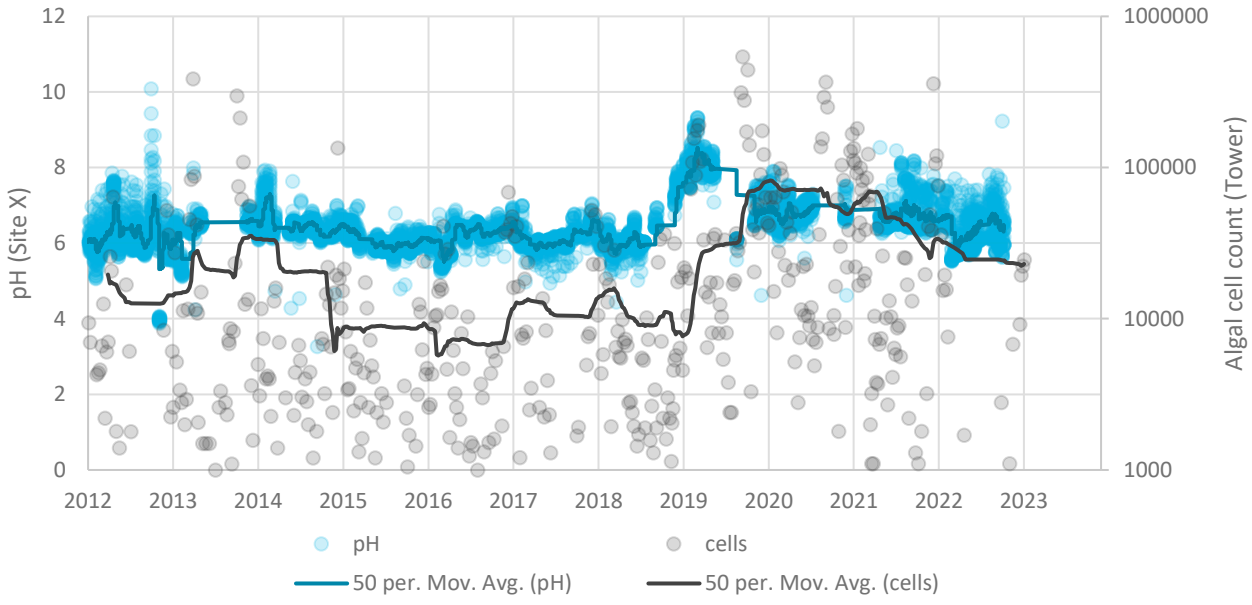


Figure 3.31 Comparison of Clarrie Hall Dam algal cell counts and pH

iii Turbidity

The turbidity WQO range is generally met at all monitoring locations (Figure 3.32), with infrequent results up to an order of magnitude greater than the WQO range observed in the dam reservoir (Figure 3.33). These turbidity spikes are typically associated with rainfall-runoff events, most notably the record flood events that occurred in March 2017 and March 2022. The results indicate good overall water clarity throughout the catchment with elevated turbidity during rainfall events (Hydrosphere, 2017b). In Clarrie Hall Dam following the large inflow event in March 2017 the stratification during this period was disrupted due to lower temperatures, light availability, and higher turbidity (Annexure B).

iv Dissolved oxygen

Historical dissolved oxygen (DO) observations have generally been within WQO's for most sites, with some sites below WQO's and with occasional spikes. None of the selected catchment sites demonstrate obvious temporal trends, and fluctuations over time have been attributed to natural variation, sampling method, and influxes of organic matter following flood events which can lead to deoxygenation of the water column.

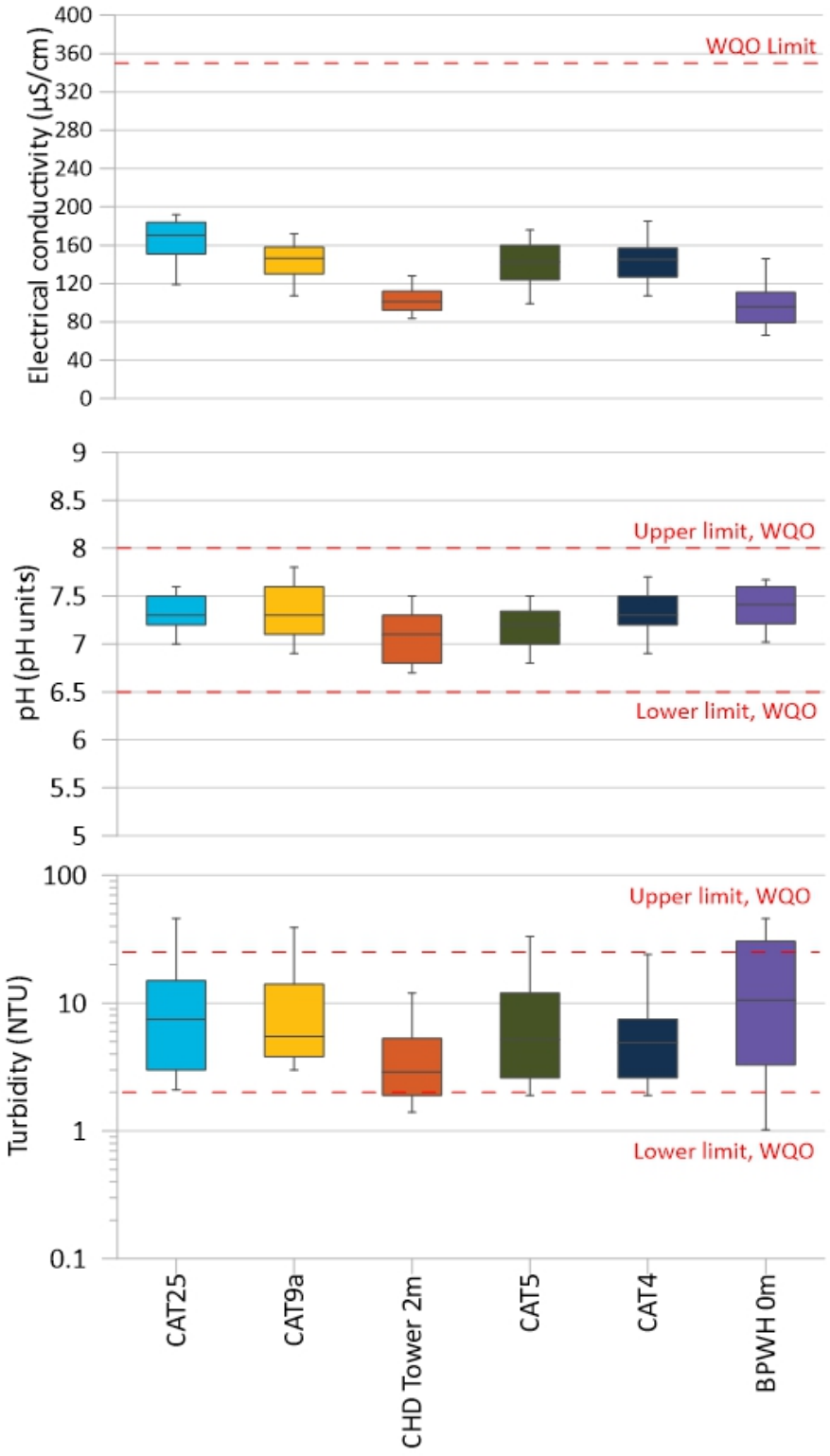
DO concentrations reach 4–6 mg/L throughout the full depth of the Clarrie Hall Dam reservoir during the winter months when fully mixed (Annexure B). During summer months, photosynthesis by algae in the surface layer increases DO concentrations whereas the interstitial waters between surface and sediment are devoid of oxygen (anoxic). De-oxygenation in deeper layers rapidly follows inflow events due to the settling and breakdown of organic matter and sediments, which increases oxygen demand and contributes to the onset of seasonal anoxia. The March 2017 inflow event was a notable example of this and a long period of anoxia at depth was triggered that persisted until July 2018.

v Nutrients

Median total nitrogen (TP) and total phosphorous (TN) concentrations are regularly above the WQO limits (Figure 3.34), with elevated TP concentrations in upper catchments attributed to erosion of rich volcanic soils (Hydrosphere, 2015).

The median TN concentrations are higher within the dam and lower at sites upstream and downstream of the dam (Figure 3.34), whereas TP concentrations generally demonstrate the opposite trend with lower concentrations within the dam and higher concentrations at upstream and downstream locations. This is consistent with the dam limnology modelling detailed in Annexure B.

Nutrient concentrations in the dam are generally higher following high-flow events, with runoff and eroded soils entering waterways from catchment agricultural areas. Distinct peaks in TP can be observed for the 2017 and 2022 flood events, while TN concentrations demonstrate more regular spikes (Figure 3.37).



Data ranges for the above charts are summarised below: CAT25 (2016-2023), CAT9a (2016-2023), Z (2001-2022) X (2001-2022), CHD Tower (2000-2023), CAT5 (2000-2023), CAT4 (2000-2023), BPWH (2020-2023)

Figure 3.32 Regional electrical conductivity, pH and turbidity ranges

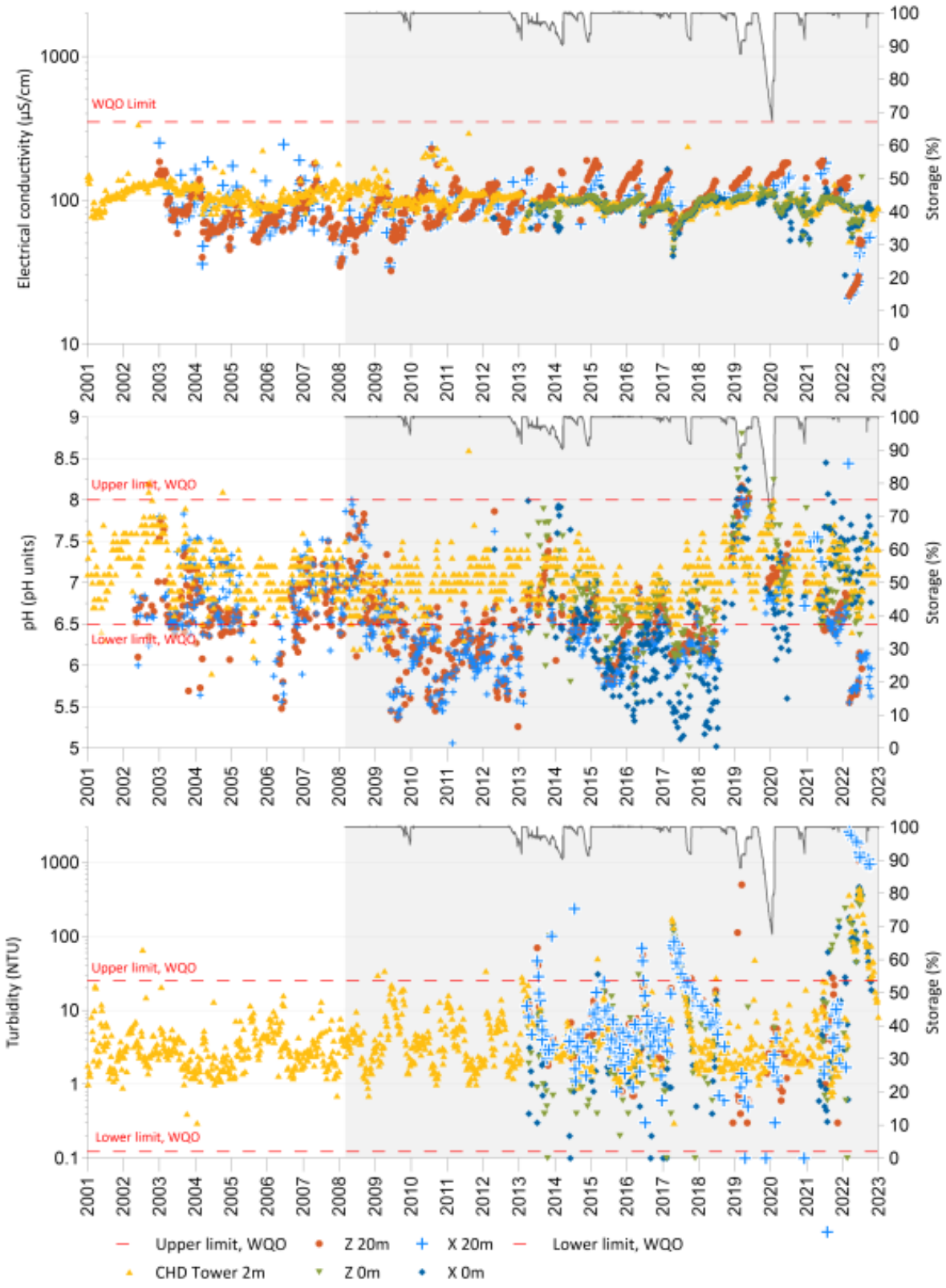


Figure 3.33 **Clarrie Hall Dam salinity, pH and turbidity**

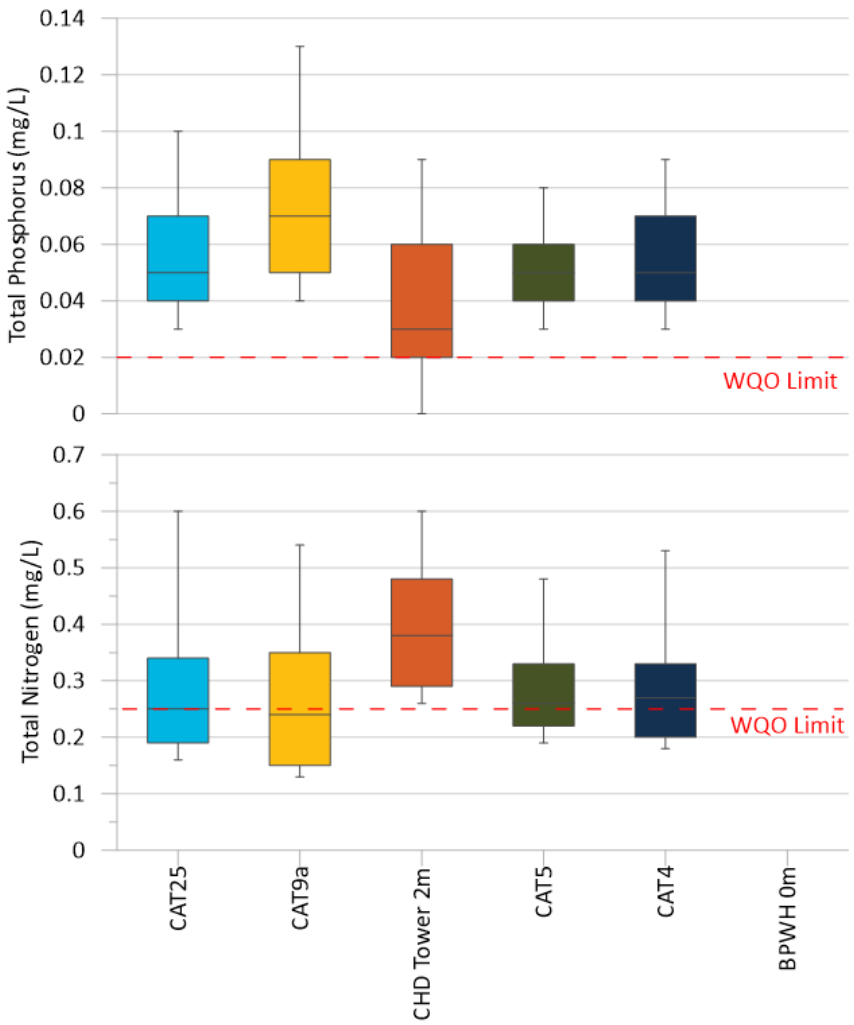


Figure 3.34 Regional nitrogen and phosphorus ranges

vi Cyanobacteria (blue-green algae)

Monitoring for cyanobacteria is undertaken upstream from Clarrie Hall Dam (site CAT 9a, Figure 3.35), within the reservoir (site X and Z, Figure 3.37), and downstream from the dam (sites CAT 4 and CAT 5, Figure 3.35).

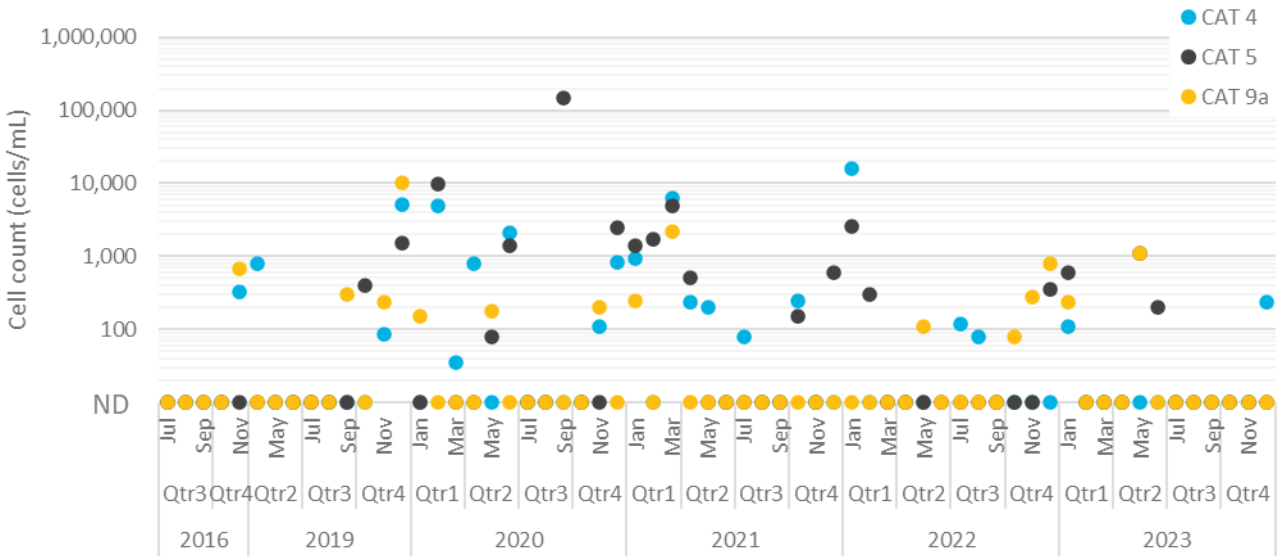
Within Doon Doon Creek and the Tweed River, it is common for there to be no detection of cyanobacteria. When detected, cell counts tend to be in the order of 100 – 1000 cells/mL during winter months, and 1,000 – 10,000 cells/mL in summer months.

Within the reservoir, cyanobacteria are more common, with cell counts ranging from 1,000 – 100,000 cells/mL. Algal concentrations at the reservoir surface are regularly above the WQO range during the summer months when surface layer temperature and stability, and nutrient availability are favourable to growth (Figure 3.37).

It is difficult to draw a direct link between algal counts in the reservoir and algal counts downstream at CAT 4 and CAT 4 (Figure 3.36). Although algae within the reservoir might be expected to exit via the spillway and seed the river downstream, the data show that there are frequent non-detections of cyanobacteria downstream, even when the reservoir is full and spilling water from surface layers (where algae may be present). Higher counts of cyanobacteria observed in the river often occur when lower counts are observed in the reservoir, and vice versa.

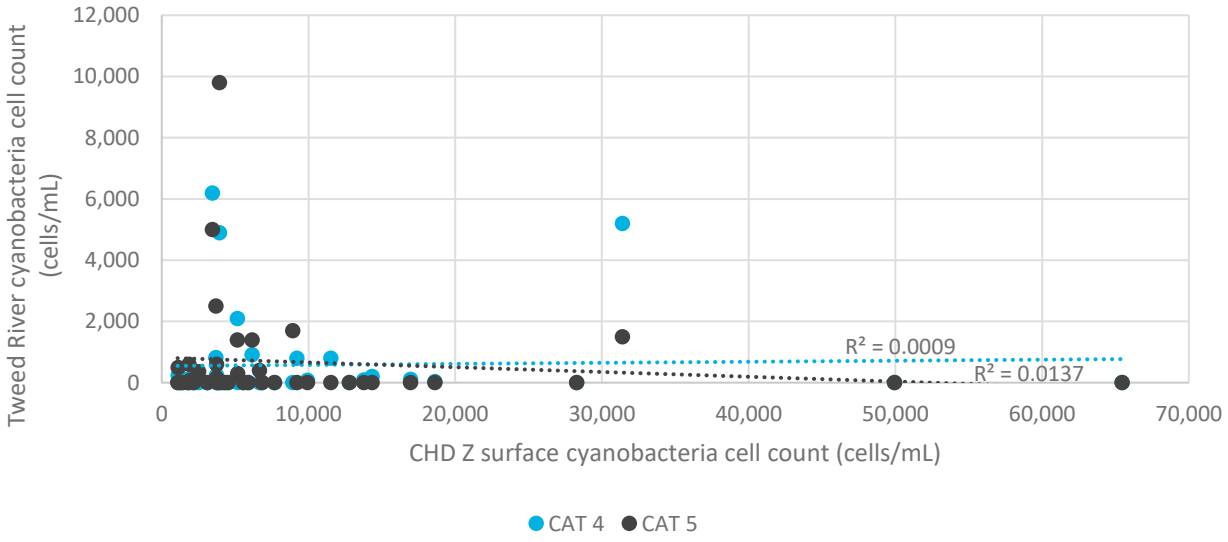
Factors affecting lower algal counts downstream from the reservoir include dilution with flows from unregulated catchments, and lotic (flowing) conditions in the river rather than lentic (still and deep water) conditions in the reservoir).

Historical algal counts within the Tweed River have not affected the supply of water within the Tweed district water supply, as WTP's are equipped with appropriate filter technology.



ND: No detection

Figure 3.35 Doon Doon Creek US from CHD (CAT 9a) and Tweed River (CAT 4 and 5) cyanophyta



The low R^2 values indicate low or no correlation between the algae count in the reservoir (CHD Z) and the Tweed River.

Figure 3.36 Reservoir and Tweed River cyanobacteria cell counts

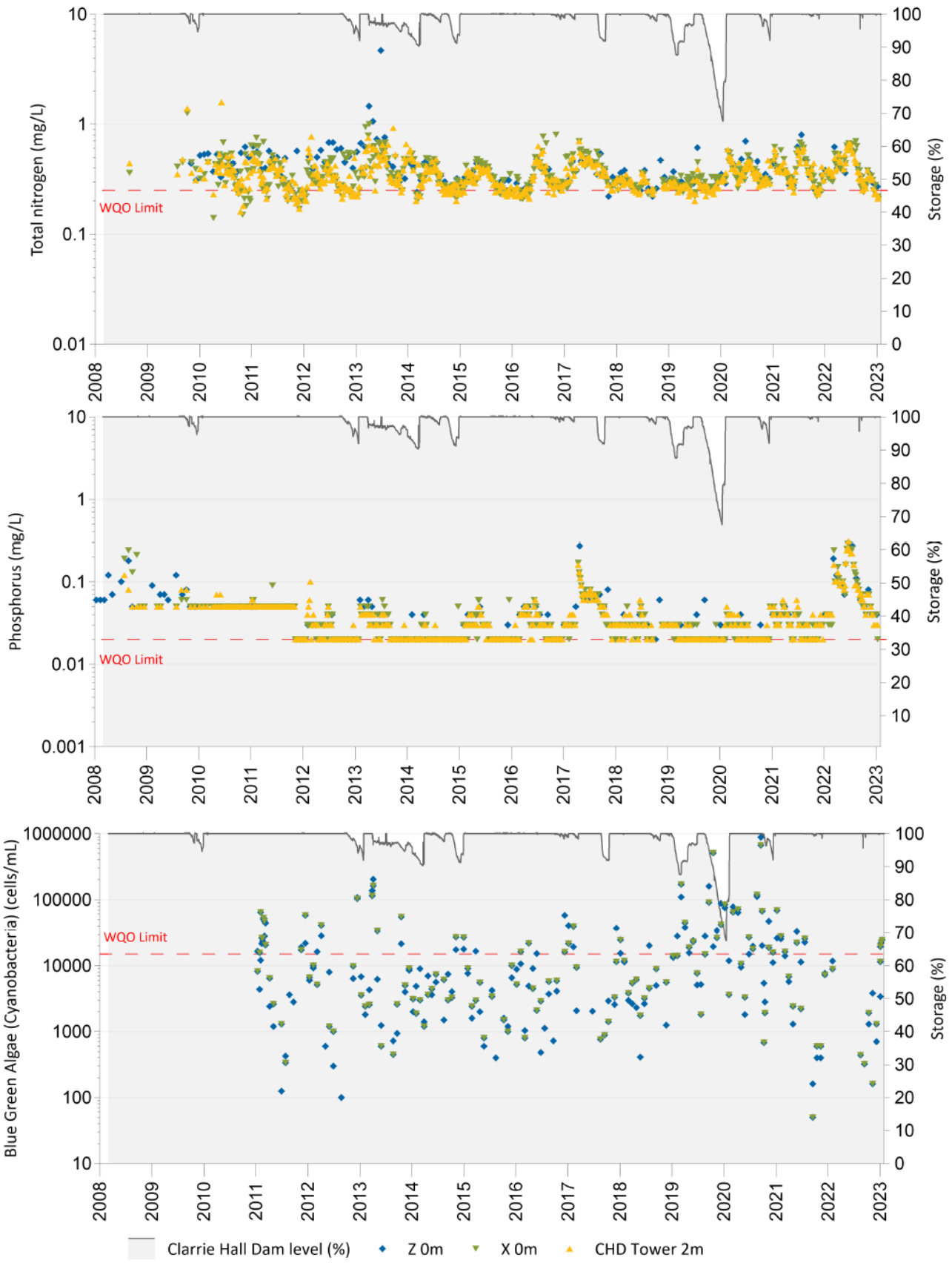
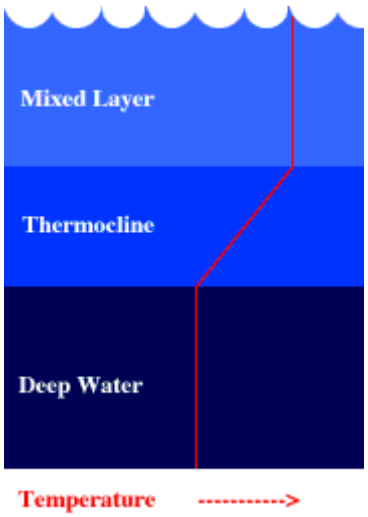


Figure 3.37 **Clarrie Hall Dam nitrogen, phosphorus, cyanobacteria**

3.9.3 Reservoir temperature and thermal stratification

The development of thermally distinct layers in a reservoir is known as thermal stratification. Clarrie Hall Dam is a warm monomictic reservoir, which means it stratifies once per year during summer when the surface of the waterbody absorbs heat (solar radiation from the sun), and is generally well mixed during winter. As the top of the water column heats up during the warmer months (late spring to early autumn) a density gradient develops, and the water column separates into distinct layers.

Thermally stratified water bodies contain warmer water near the surface, a transitional zone called a thermocline, and cooler water near the base (Figure 3.38). When stratified, water near the surface tends to be better mixed by wind and waves, and contain higher oxygen levels, while cooler water near the reservoir bed tends to have lower oxygen content, and can contain higher mineral and organic content due to interaction with sediments.

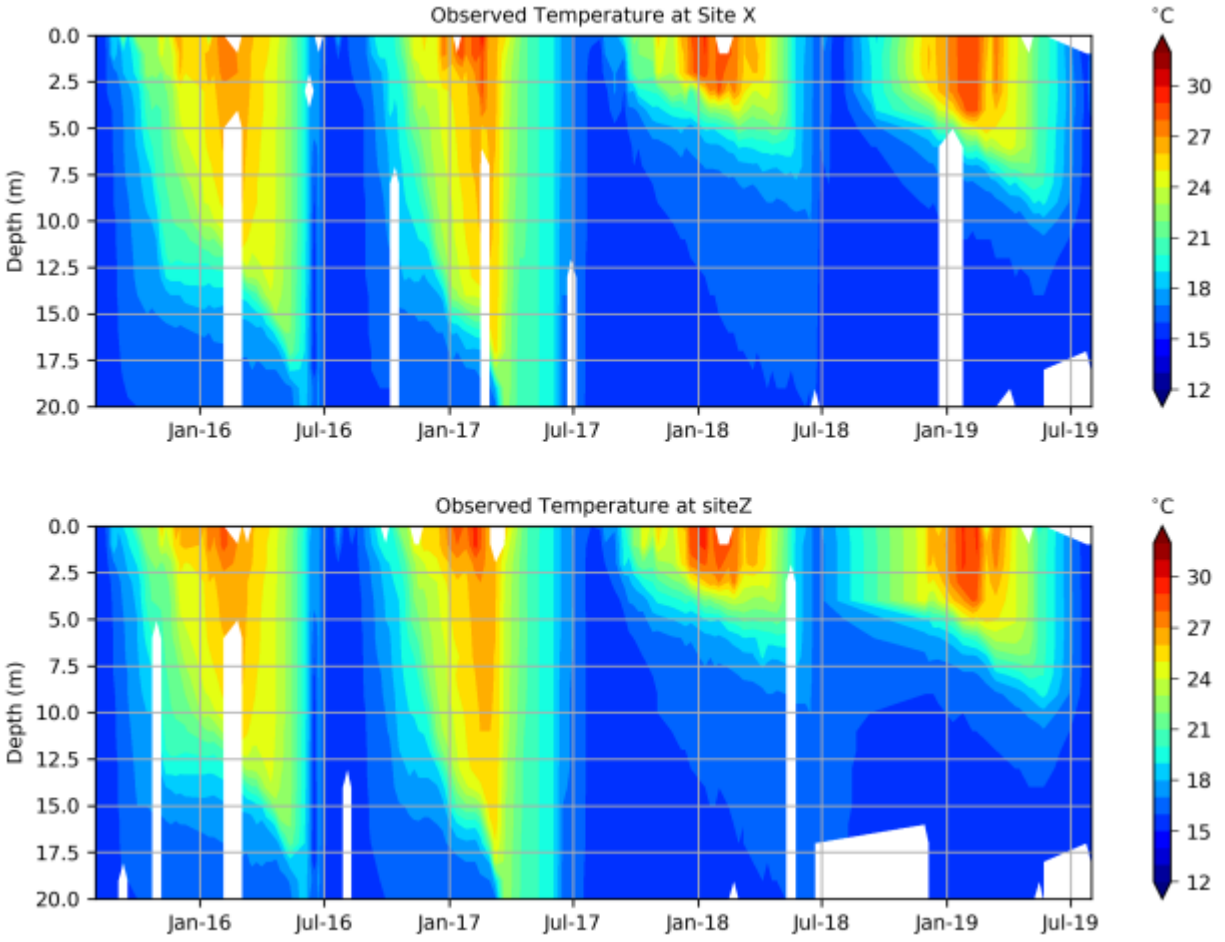


Stratification can promote algae growth near the surface, as the upper water layer remains warm, well oxygenated, and has high exposure to sunlight. When possible, operators will utilise the MLO to take water from the warm upper layer. However, during algae blooms it may be necessary to utilise an offtake within the thermocline. Due to these factors, thermal stratification is a key process contributing to CWP.

CWP is defined as water released from reservoirs that is at least 2°C cooler than the ambient water temperature (NOW, 2011), and can have effects on aquatic ecosystems. In particular, some fish species can receive thermal shock when water suddenly changes temperature, as can occur when a dam release starts.

Water temperature data is recorded by Tweed Shire Council within Clarrie Hall Dam using sensors deployed from floating buoys at depths of 2 m, 4 m, 6 m, 10 m, and 18 m below the water surface, with data recorded at weekly intervals since 7 May 2001. These data show that temperatures are typically around 15°C throughout the water column in winter, and that there is stratification during summer (Figure 3.39).

An artificial mixer operated between 2002 and 2017 (additional detail in Annexure B). During the period the mixer was operating, the temperature during summer at 10 m depth at Site X was approximately 4°C cooler than near the surface. After the mixer was damaged in 2017, a stronger temperature gradient developed during warm months, with temperature differences of around 10°C between 2 m and 10 m below the surface (Figure 3.39). Without the mixer, temperatures at depth remained around 15°C throughout the year, whereas with the mixer the warm water from the surface was circulated to the base of the reservoir (Figure 3.40).



Mechanical mixer in operation 2002 - 2017

Figure 3.39 Reservoir temperature profile

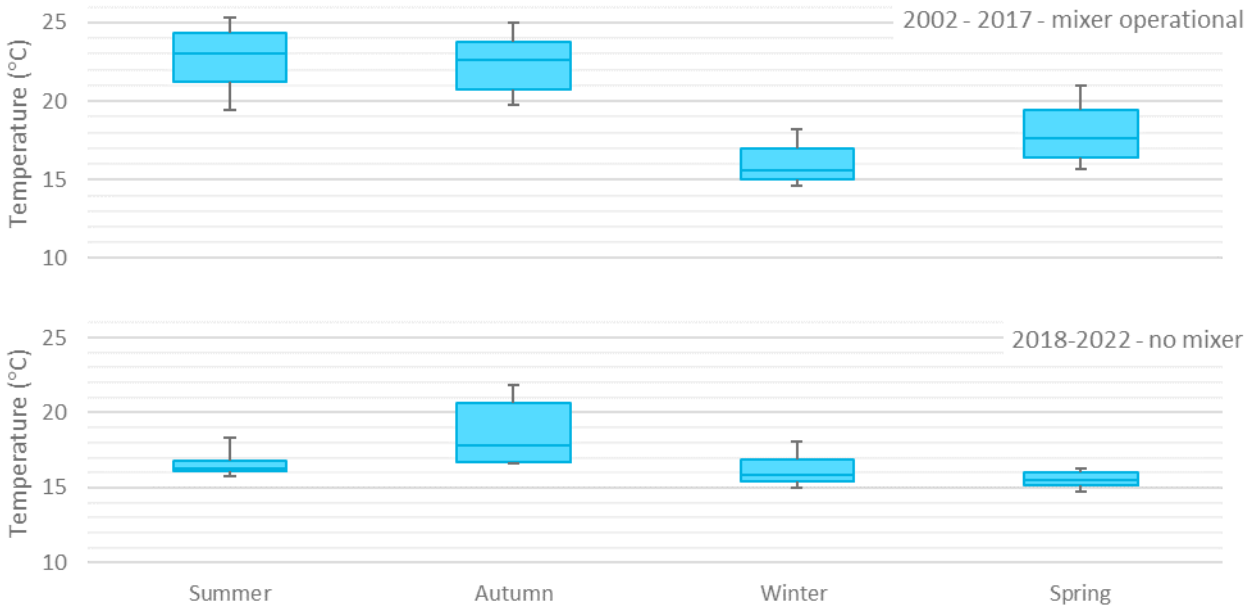


Figure 3.40 Recorded temperature ranges in Clarrie Hall Dam, location X at 10 m depth

CWP effects are currently mitigated through the use of a MLO (Figure 3.41). In a review of available cold water pollution mitigation measures, the University of Sydney Water Research Lab developed Table 3.8 describing the advantages and disadvantages of MLOs, before concluding that:

- Overall, MLOs are suitable for mitigating downstream cold water pollution, however variations in dam water levels and thermal stratification may reduce the effectiveness of these systems. As such these systems typically require suitable extraction depths for a given application, as well as well-defined operational strategies.

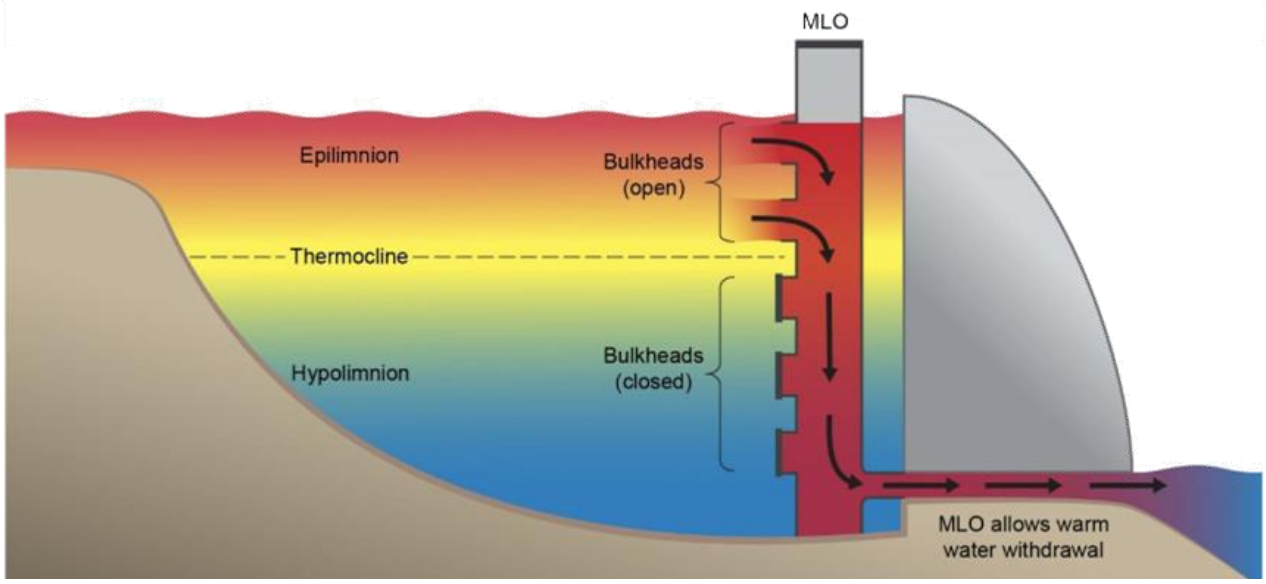


Figure 3.41 Conceptual diagram showing the use of a multi-level offtake (Chaaya & Miller, 2022)

Table 3.8 Advantages and disadvantages of multi-level offtakes (Chaaya & Miller, 2022)

Advantages	Disadvantages
Selective withdrawal from warm waters above the thermocline can reduce cold water pollution to the downstream environment	Larger withdrawals can result in the entraining and withdrawal of unwanted waters, which may reduce the benefit of the MLO
Selective withdrawal can be utilised to avoid poor quality hypolimnion water	Withdrawal volumes may be limited by the temperature and water quality requirements, given each offtake point is limited to a particular flow rate
Selective withdrawal can be utilised to avoid discharging toxic cyanobacteria to the downstream environment, by withdrawing from waters below the surface	Time and labour (in the order of 1 day) are required to move bulkheads to adjust for variations in stratification structure and reservoir levels
Multi-level offtakes could theoretically be operated as a means of restoring environmental flows[1]	Maintenance may be complicated and laborious, depending on offtake depths
Selective deep withdrawal could be used to enhance vertical mixing, which may improve the overall quality of water in the reservoir	Withdrawal from particular layers in a reservoir may deplete the waters ideal for fish to live in
Operationally lower cost than other alternatives	

1. The MLO at Clarrie Hall Dam is used to release environmental flows as required by the WSP

3.9.4 River temperature

To support the Project, Tweed Shire Council monitored water temperature in Doon Doon Creek, Tweed River and Oxley River from March 2023 (Figure 3.42). The monitoring data illustrated that:

- river water temperatures vary approximately 1-2°C between day and night
- water temperature can vary through the river system by around 3-4°C on any particular day
- summer river water temperatures were 25 – 30 °C, similar to the temperature in the upper layer of the Clarrie Hall Dam reservoir (Figure 3.39)
- winter river water temperatures were around 15 – 17 °C, similar to winter reservoir temperatures (Figure 3.39).

In April 2023, Council released a cold water slug from the reservoir for 12 hours to provide data for CWP model calibration (Annexure C).

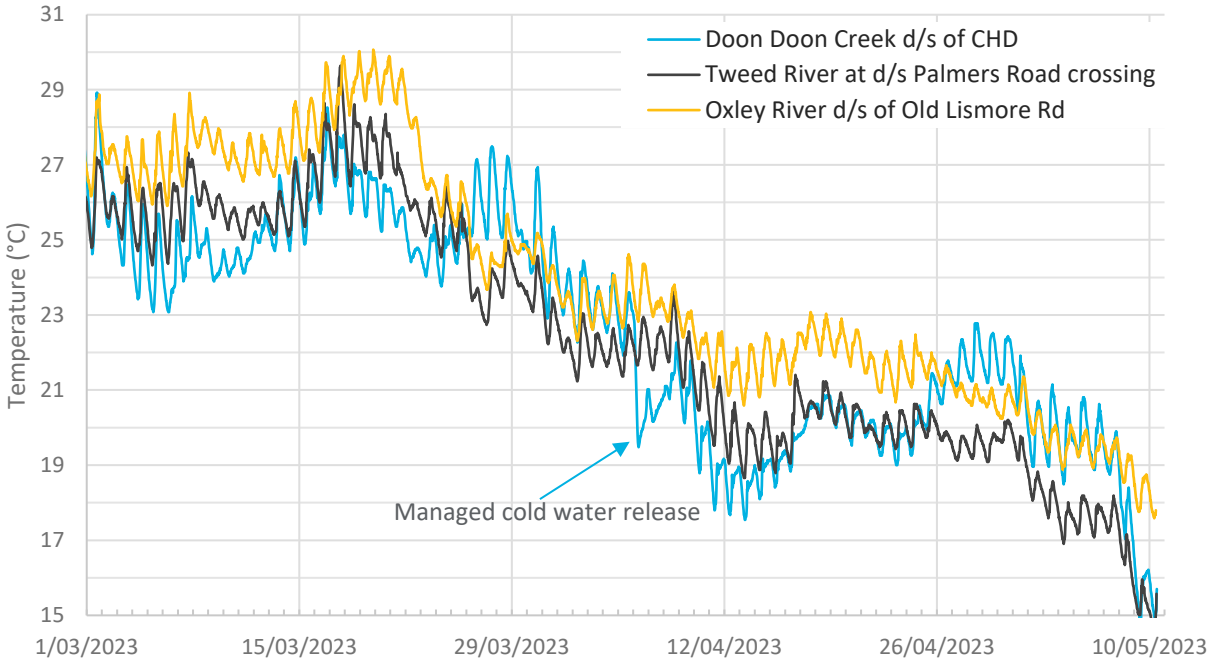


Figure 3.42 Recorded temperature data in Doon Doon Creek, Tweed River and Oxley River

CWP modelling (Annexure C) scenarios investigated cold water releases in summer, with:

- released water 9°C colder than the ambient Tweed River water temperature
- flows ranging from 10 ML/day to 70 ML/day, approximately the range required for managed water releases for town water supply.

The modelling found that if cold water releases of up to 70 ML/day were made from Clarrie Hall Dam, for example for town water during a period of algal management, CWP effects could reach up to 11 km downstream of the dam before the released water warmed due to interaction with the receiving environment (Figure 3.43). With smaller release rates, the length of river affected by CWP would reduce (Figure 3.44).

The CWP modelling described the receiving environment (ie the Tweed River and Doon Doon Creek), and applies equally to the current reservoir and the proposed larger reservoir.

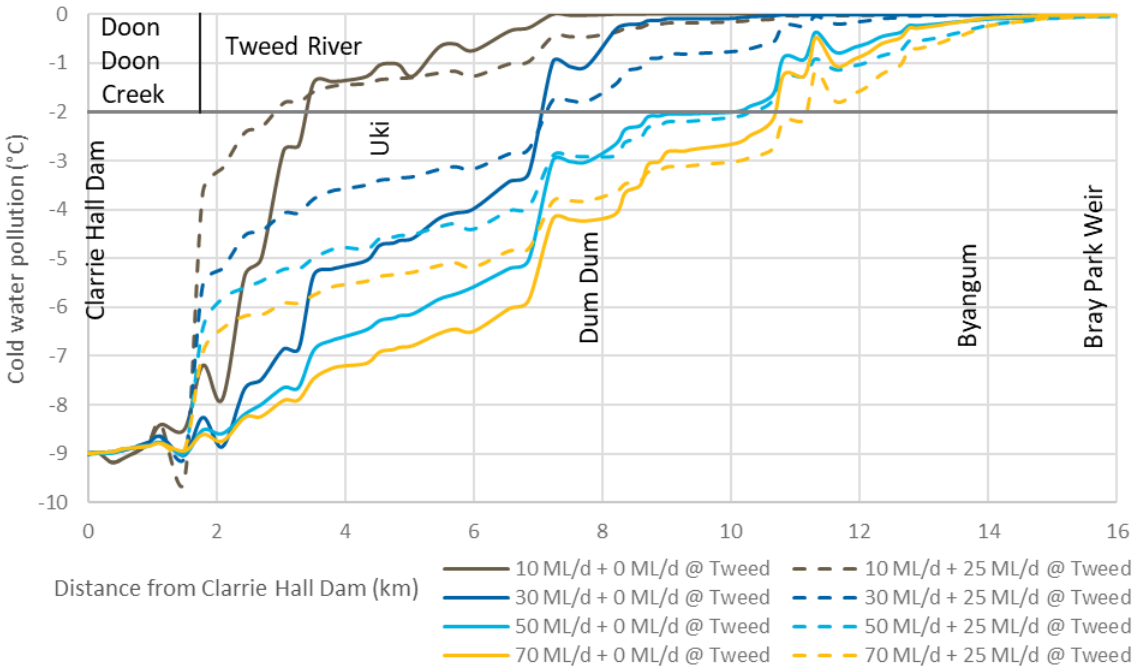


Figure 3.43 **Modelled cold water pollution travel distances with 0 ML/d and 25 ML/d inflow at the Tweed River, releases of 16°C water into 25°C water for the 2018 scenario**

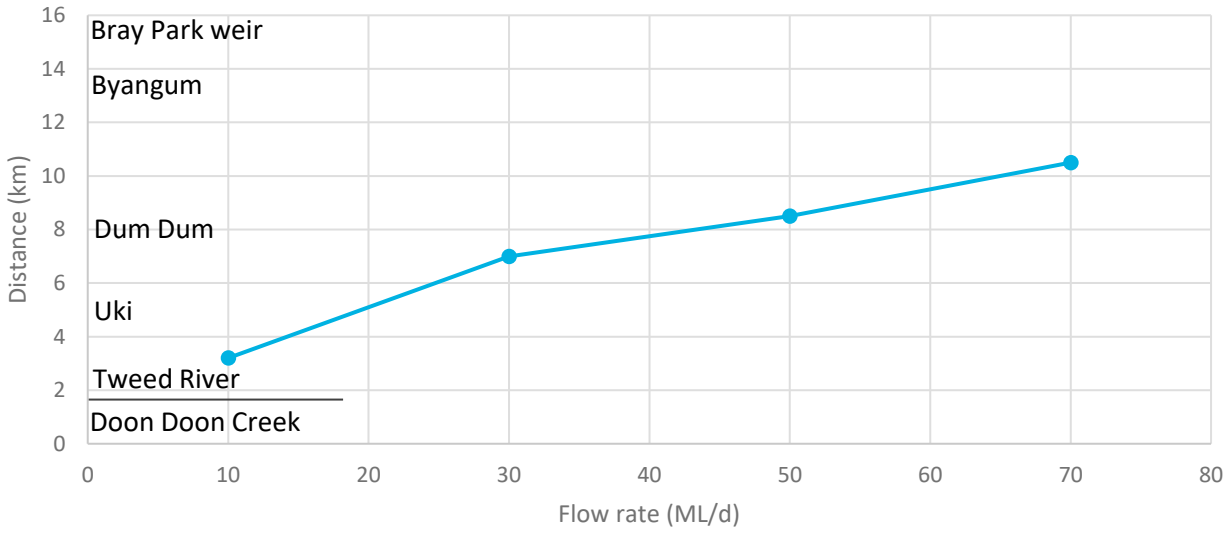
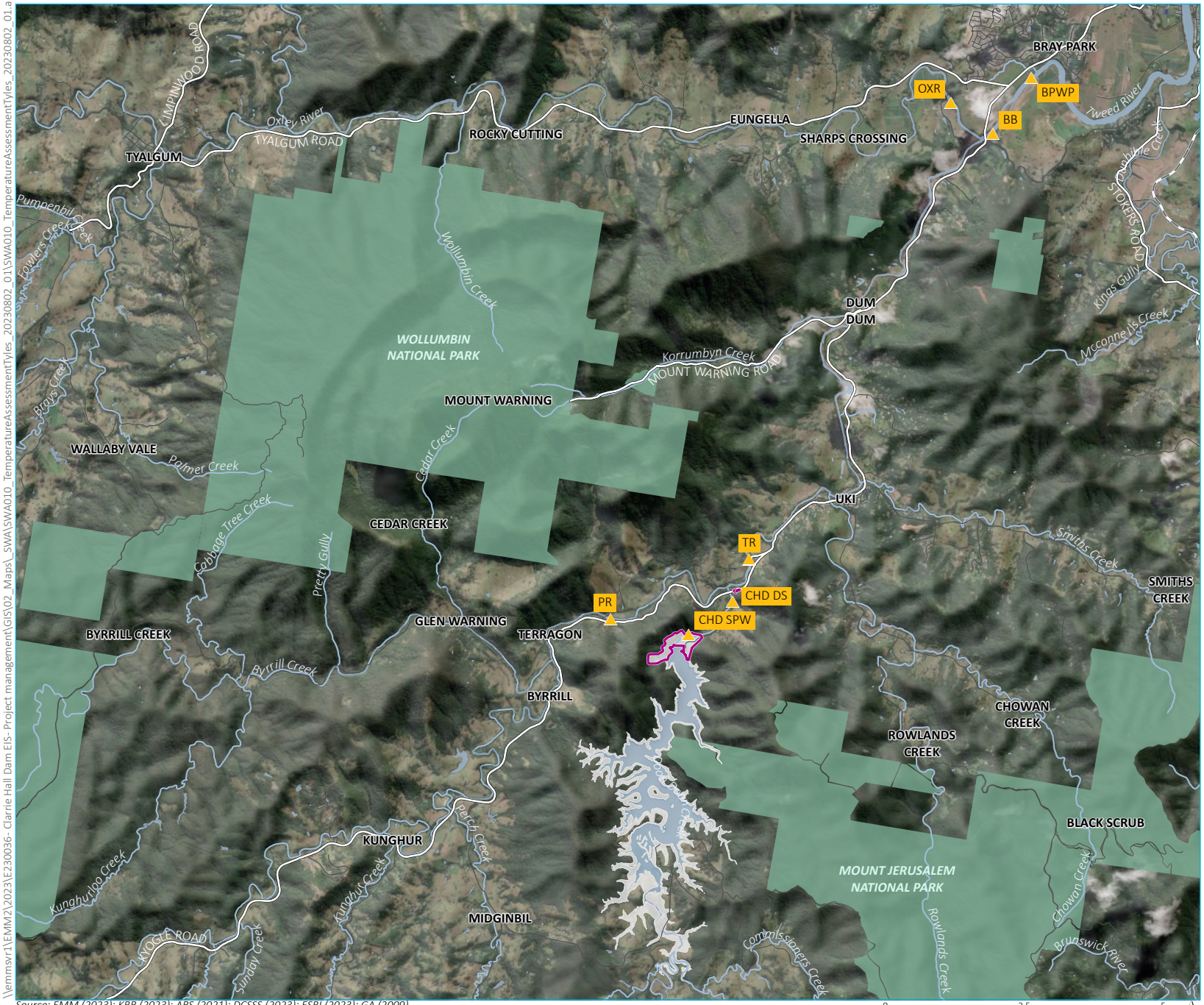


Figure 3.44 **Distance before water released at 16°C warms to 23°C**



KEY

- Water temperature assessment location
- Construction disturbance footprint
- Development site

Existing environment

- Rail line
- Major road
- Minor road
- Named watercourse
- NPWS reserve
- State forest

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

0 2.5 5 km

GDA2020 MGA Zone 56

N

Locations of Tweed Shire Council water temperature assessment sites

Clarrie Hall Dam EIS
Surface Water Assessment

Figure 3.45

EMM creating opportunities

\\emmsvr1\EMM2\2023\E230036- Clarrie Hall Dam EIS- Project management\GIS\02_Maps_SWA\SWA010_TemperatureAssessmentTyles_20230802_01\SWA010_TemperatureAssessmentTyles_20230802_01.aprx 3/08/2023

4 Potential construction effects

4.1 Introduction

This section identifies and describes potential surface water effects associated with construction of the Proposal. Data and modelling results associated with the potential effects are provided and used to discuss the expected magnitude and frequency of potential effects.

Potential effects during operation of the Proposal are discussed in Chapter 5.

An impact assessment is provided in Chapter 6, comprising of:

- A risk assessment of potential effects
- A summary of proposed mitigation measures
- A description residual risk following mitigation

4.2 Erosion and sediment control

A key hazard to surface water quality during construction will be management of erosion and sediment. Small construction sites may adequately manage sediment using measures such as sediment ponds and filter strips, while larger sites often require more detailed plans for site water management and water reuse to prevent discharge of affected water.

A Soil and Water Management Plan (SWMP) will be developed for the Proposal prior to the commencement of construction. This plan will contain:

- assess and detail the requirements to comply with relevant policies guidelines, legislation and other approvals
- be developed in accordance with the principles and requirements in *Managing Urban Stormwater – Soils and Construction, Volume 1 (Landcom 2004)* 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
- 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.

An overarching ESCP and Progressive Erosion and Sediment Control Plans (PESCP)s will be developed for all disturbed areas.

The design of treatment measures would take into account local design rainfall rates, and local soil erosion hazard (see Land, Soils and Erosion Assessment).

The overall Proposal would be split into several construction compounds for the purposes of managing stormwater, and that erosion and sediment at the smaller sites may be suitably managed using PESCPs while the larger sites would require a SWMP (supported by PESCPs).

Soils at the Proposal site have been assessed as having high erosion risk due to slope and low cohesivity, but also low dispersivity (see Land Soils and Erosion Assessment), so common methods for removing sediment from runoff are expected to be effective. It is recommended that sediment management infrastructure be designed in accordance with 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).

For further detail on erosion risk and appropriate management measures see the Land, Soils and Erosion Assessment.

4.3 Dam construction

4.3.1 Bulk earthworks

The bulk earthworks required for Clarrie Hall Dam raising involve:

- establishing a temporary construction area downstream of the existing dam wall embankment
- open cut excavation of the west and east abutments for the upstream concrete toe slab extension
- stripping the foundation downstream of the existing embankment for the raised embankment footprint
- re-establishing the old quarry and access haul road with associated crossing over Doon Doon Creek
- excavation higher on the west abutment for the raised spillway.

The primary equipment to be used during these construction activities are excavators and dump trucks, however, blasting may be required in the lower downstream areas of the new spillway, and in the quarry, depending on the material encountered.

i Temporary construction area downstream from the existing dam wall

Access to the dam wall, MLO and boat ramp is currently located along the eastern bank of Doon Doon Creek. The spillway is located on the western side of the dam.

Access will be required to the existing spillway, the proposed new spillway location, and the downstream face of the dam wall. It is proposed that this access would be created by creating a construction pad via importation of fill material as per the concept presented in Annexure E. To convey water across this construction pad, temporary waterway crossings will be designed and implemented in accordance with the *Controlled activities – Guidelines for instream works on waterfront land* (DPE 2022b):

- 'Outlet flow culverts' would convey intentional releases from the MLO via the valve house to Doon Doon Creek downstream from the construction pad.
- 'Spillway culverts' would convey minor spillway discharges in the order of the 1 EY (exceedances per year) flow event from the toe of the spillway to a point in Doon Doon Creek downstream from the proposed construction pad.

During larger rainfall events, the 'spillway culverts' capacity would be exceeded, and a portion of rainfall runoff would traverse the construction pad. With low probability, a significant rain event such as the 10% AEP (1 in 10 year) storm could occur. In such an event, a more significant volume of water would traverse the construction pad.

During the detailed design phase, the shear stress generated by the flow of water over the construction pad would be determined via hydraulic modelling. Lower shear stresses will have reduced capacity to move the pad material. Shear stresses could be reduced if the geometry of the pad is selected for the purpose of spreading flows out and energy dissipation. Alternatively, the pad geometry could be selected such that shear stresses are concentrated in a defined area where armouring against erosion could be employed. In either case, rock diameters would be specified such that the probability of mobilisation of the material is low. The pad design and rock selection would consider design storms up to a certain threshold (eg the 5% AEP or 1 in 20 year storm). Regardless of the design storm considered there will always be a residual risk that a larger storm could occur and could cause washout, though with low likelihood.

It is likely that some smaller particulate material will be present within the construction pad rock matrix, either due to the grading of material during construction or due to transportation via vehicle movements. During rainfall runoff events, dust, dirt and smaller particulate matter could be transported downstream into Doon Doon Creek and the Tweed River, increasing turbidity and potentially depositing rock fragments downstream. With the SWMP controls in place, the quantum of material mobilised is expected to be minor.

Following completion of construction works, the construction pad would be partially removed, to remove the ongoing risk of erosion and mobilisation of pad materials.

4.3.2 Dam wall embankment

A concrete toe slab extension will be constructed in the west and east abutments, followed by percussion drilling and pressure grouting of holes to extend the grout curtain through the upstream toe slab extension in the east and west abutments. The upstream concrete face slabs will be extended and the raised embankment will be filled with suitable rockfill (rhyolite).

The rockfill emplaced in the raised embankment will follow a similar zoning profile to the existing embankment. Fresh rock (slightly weathered rhyolite) for the downstream part of the embankment will be excavated from the old quarry site, and moderately weathered rock will be recovered from the excavation on the west abutment for the raised spillway.

Access road upgrades and the temporary construction area will be established when construction commences. The precast concrete parapet wall units will be removed from the existing dam embankment and stored for re-use on the raised dam embankment and abutting the raised portions of the upstream concrete face. The crest pavement will be removed from the embankment to expose the existing underlying rockfill.

4.3.3 Spillway

The spillway construction would involve open cut excavation followed by the establishment of the spillway concrete structures. Blasting will be required to extract the rock from the quarry and areas of spillway excavation (lower elevations) (NSW PWA, 2018a).

When excavation of the spillway has progressed sufficiently, construction of concrete spillway structures would commence. The spillway would generally be comprised of reinforced concrete walls and slabs, with the exception being the ogee crest spillway and side walls, which would largely be comprised of mass concrete.

A PESCP would be developed to prevent local rainfall runoff from the construction site from mobilising and transporting construction materials to Doon Doon Creek. This plan will incorporate measures such as creating a cut off berm or drain on the up-slope edge of the excavation to prevent stormwater from entering the site, and directing local stormwater runoff to sedimentation basins for holding and settling.

If explosives are required during excavation of the spillway, these would be stored outside of flood prone areas and in accordance with the Explosives Regulation 2013 and applicable Australian Standards. Drill and blast methods of spillway excavation have the potential to generate trace amounts of chemical residue on the blasted

material, particularly including nitrogen compounds. A number of measures will be used to reduce the risk of chemical residues from entering the surface water environment:

- a blast management plan would specify conditions for blasting, resulting in efficient chemical reactions and reduced quantities of by-products
- the PESCP will specify measures to limit the mobilisation potential during rainfall events
- blasted material will be used in construction of the dam when rock characteristics are suitable, where it would be encapsulated.

Rock unsuited to dam construction would be placed as backfill in the quarry area upstream from the dam wall where, following inundation, trace quantities of blast chemicals would be subject to dilution by reservoir water prior to movement offsite. Residual water quality impacts are expected to be negligible.

4.3.4 Inundation area

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

Decomposing vegetation can release nutrients which increase the risk of eutrophication and algal blooms. Where possible, vegetation within the new full supply inundation area would be cut to stump height and left in situ. Erosion protection materials may be placed around the reservoir area shoreline. The requirements and locations for any erosion protection works and need for clearing within the reservoir area would be determined during detailed design. Some trees won't be removed due to landslip hazards, erosion hazard, and BDAR advice.

The removal of vegetation to stump level will reduce the potential nutrient load within the reservoir, and reduce the likelihood and magnitude of eutrophication and algal blooms. Stumps will be left in situ as grubbing activities would likely create significant soil disturbance, which could lead to erosion and increased reservoir turbidity.

Vegetation, which decomposes in oxygen poor conditions within deep reservoirs can generate methane, whilst the same vegetation decomposing in oxygen rich conditions at the surface may generate carbon dioxide. Methane is a more potent greenhouse gas than carbon dioxide therefore removing vegetation prior to inundation of the reservoir will minimise methane production and greenhouse gas effects.

4.4 Ancillary infrastructure

4.4.1 Quarry expansion, stockpiles and materials storage management

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 600 m upstream of the existing dam wall. 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 spillway, 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 to backfill the quarry void and develop the final landform.

Rock processing on site will be a significant source of dust and slimes from crushing, grading and washing.

Recycling of wash water would occur using a series of tanks and clarifiers. These systems are typically 'sealed' therefore less susceptible to storm flows and overflow events than open lagoons.

Rainfall runoff from the quarry and stockpile areas has the potential to contain elevated levels of suspended solids (ie turbidity). A PESCP would be developed with sediment control measures appropriate to the site layout, which would seek to minimise transport of sediment beyond the disturbed construction areas. Any residual sediment mobilised during larger rainfall runoff events that exceed the capacity of temporary sediment control measures would run off to the Clarrie Hall Dam reservoir, which would allow additional settling of particles prior to release to the surface water environment of Doon Doon Creek downstream from the dam.

4.4.2 Roads

Clarrie Hall Dam Road would be the main access and haul road for the construction and operation of the new Clarrie Hall Dam. A section of Clarrie Hall Dam Road would be upgraded to ensure alignment of the road with the new FSL, higher in the landscape.

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 raised to 72.6 m AHD. A realignment of Commissioners Creek Road is also required to facilitate the bridge upgrade and approach roads.

Where roads are realigned or widened, clearing and track construction works may represent a risk of soil mobilisation. A PESCP will be developed to manage runoff and potential sediment mobilisation from road construction sites.

Where road widening or realignment results in new or extended culverts or other drainage features, rock energy dissipation or riprap armouring will be applied downstream in accordance with AustRoads (2013) drainage design guidelines to prevent runoff causing erosion.

Tracks and roads used by Proposal construction vehicles will be monitored for erosion. If road damage is observed, maintenance activities will be undertaken to increase the safety of the road while also reducing the risk of further erosion and loss of road material.

4.4.3 Dam wall and spillway construction access pad

Construction access to the downstream face of the dam and the spillway would be created via importation of fill to the site as per Figure E.3. Key tasks associated with creating access will be:

- install temporary culverts from the valve house to a location in Doon Doon Creek approximately 100 m north of the valve house
- install temporary culverts downstream form the existing spillway to a location approximately 100 m north of the valve house
- fill the existing creek bed to create construction access across both sets of culverts.

The temporary culverts from the valve house would be designed to pass the volumes required. Releases from the valve house are controlled by operators, and so the likelihood of the capacity of the temporary culverts being exceeded is negligible.

The temporary culverts from the spillway have not yet been designed. In order for the potential magnitude of effects to be assessed, the following design parameters have been considered:

- spillway width: 15 m
- maximum design velocity 1.5 m/s
- maximum standard culvert height: 3 m

A 15 m wide bank of culverts matching the spillway width could pass in the order of 60 kL/s. From Figure 3.27, the 40% AEP spillway flow (occurring approximately once every two years) is 100 kL/s. This indicates that the culverts may be able to pass minor flows from unremarkable rainfall events but their capacity would be readily exceeded during significant rainfall events in the order of the 1 in 1 year storm or larger. When the culvert capacity is exceeded, water will flow over the temporary fill.

Measures to prevent mobilisation of fill material (erosion) and transportation downstream during flow events which exceed the spillway culvert capacity will be 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.

4.4.4 Concrete batching plant

The concrete batching plant will produce up to 17,500 m^3 of concrete through the construction period. Cement, aggregate and clean water would be delivered by truck to the plant, where mixing and concrete production would take place. Concrete would then be delivered by truck to construction site areas including the spillway and intake tower.

There are a range of environmental risks associated with concrete batching but with proper management and good site design they can be eliminated or reduced to as low as reasonably practicable by a range of controls well understood and regularly applied within the construction industry. The key environmental risks posed by the concrete batching plants are:

- polluted wastewater
- inappropriate disposal of waste.

This SWA considers the risk of polluted wastewater.

When cement mixes with water it causes the pH to rise. If cement or concrete batching plant wastewater reached Doon Doon Creek or Tweed River, it is likely that the resulting pH of creek water would be detrimental to aquatic life. There may also be other chemical or liquid storage at the plant site, which will need to be managed.

Management measures would be incorporated into the design of the concrete batching plant to reduce the risk as low as reasonably practicable, including:

- Maintaining separation of 'clean' rainfall from surfaces, which have contact with cement and concrete, and directing 'clean' rainfall runoff to the construction compound stormwater treatment train. This may be achieved through measures such as providing roofing over mixing, unloading and dusty areas and directing the runoff from the roof areas away from the batching plant.
- Sealing the batching plant surface with hardstand or paving so that local rainfall runoff within the plant site may be directed effectively to drains and sumps, and to prevent mud and pooling.
- Installation of a first flush system for hardstand areas, which may receive dust drift or minor quantities spilt material. The first flush system would typically capture the first 20 mm of rainfall runoff and direct it to a holding area. Subsequent rainfall runoff would then be deemed clean and could be incorporated into the construction compound stormwater management system.
- Bunding chemical and liquid storage areas.
- Installing a vehicle washdown facility for vehicles moving in and out of the batching area.

- Installing a wastewater collection and recycling system to collect contaminated water from:
    - agitator washout
    - truck washing
    - yard washdown
    - contaminated stormwater
    - concrete batching area
    - slump stand
    - any other wastewater from the batching plant operation.
- Directing process wastewater and contaminated stormwater to a settling pond, or series of ponds, such that the water can be reused in the concrete batching process. These ponds would be contained within the batching plant area and would not discharge to the laydown yard stormwater management system. The settling pond or series of ponds should be lined with an impervious liner capable of containing all contaminants found within the water they are designed to collect.
- Monitoring pond and sump water quantity and quality.

Suitable water management measures for the batching plant would be developed prior to the commencement of construction and documented as part of the SWMP.

4.4.5 Laydown yard

Laydown areas will contain temporary stockpiles of materials, which are imported to site for the purpose of building the dam and ancillary infrastructure. Materials could include sand, crushed rock, steel reinforcing, and cement. The laydown area will experience frequent heavy vehicle movements, which could result in loose soil.

Stormwater management will be required to prevent the mobilisation of sediment and construction materials from the laydown yard into Doon Doon Creek and/or Tweed River. To reduce the likelihood of construction material mobilisation, the following measures have been adopted:

- the compound will be located above the 1% AEP (1 in 100 year) flood level to reduce the risk of inundation mobilising construction materials
- levelling the site area will reduce rainfall runoff velocity and erosion potential
- stormwater runoff will be diverted to swales and sedimentation basins for treatment prior to discharge.

Soils at the Proposal site have been assessed as being non-dispersive (see Land Soils and Erosion Assessment), so common methods for removing sediment from runoff are expected to be effective. It is recommended that sediment management infrastructure be designed in accordance with *Managing Urban Stormwater: Soils and Construction – Volume 1* (Landcom, 2004) and *Volume 2A Installation of services* (Landcom, 2008b).

A SWMP incorporating ESCPs will be developed in construction management plans describing surface water management in the construction compound. The SWMP would contain at a minimum:

- drawings of the site layout
- a narrative of how erosion control and soil and water management will be achieved on site

- description of treatment measures
- description of treatment maintenance measures
- a construction schedule, and description of how the plan will work through the various stages of construction
- design calculations for the treatment measures, including hydrologic estimations of runoff volumes and rates, and swale and sedimentation basin capacities.

The design of treatment measures would take into account local design rainfall rates, and local soil erosion hazard (see Land, Soils and Erosion Assessment).

4.5 Construction water requirements and sources

Construction office facilities will be located within the construction compound and would include offices, toilets, canteens, and storerooms. Workforce accommodation suitable for 100 to 120 personnel would be developed, including cabins, facilities, and car parking. Workforce water demand at the construction site would be approximately 20 kL/day (7 ML/year), supplied from the reservoir with treatment via a portable package filtration plant.

Wastewater (sewage) will be collected via a plumbed storage tank for road tanker collection and exported to an existing licensed wastewater treatment facility for disposal by a commercial operator.

Approximately 3 ML/year of water is required for concrete batching.

Dust suppression of stockpiles and tracks may be required during dry conditions. An estimate of dust suppression volumes was made on the basis of:

$$Volume = Disturbed\ area \times \sum(Daily\ Evaporation - Daily\ Rainfall) \times 0.5$$

The 0.5 multiplier accounts for several factors:

- evaporation rates from soils are typically lower than from Class A evaporation pans as capillary action within soil matrices results in a 'suction' force which reduces evaporation rates
- not all disturbed surfaces will require dust suppression
    - some tracks may have low traffic volume, or be sheltered from wind, and so generate little dust
    - rock faces may not require dust suppression.

Locations which may require dust suppression include tracks, pads, laydown areas, the quarry, and construction compounds, for a total of 49.6 ha (Table 1.1). Construction will occur in stages, and it is not expected that the area requiring dust suppression will equal 49.6 ha for the duration of construction. Nevertheless, potential dust suppression volumes were calculated using the total disturbance area, providing an upper estimate of potential water requirements. Dust suppression volumes would be higher in summer and lower in winter (Figure 4.1), primarily due to the higher evaporation rates in summer. From this analysis, total yearly dust suppression water use could reach 250 ±20% ML.

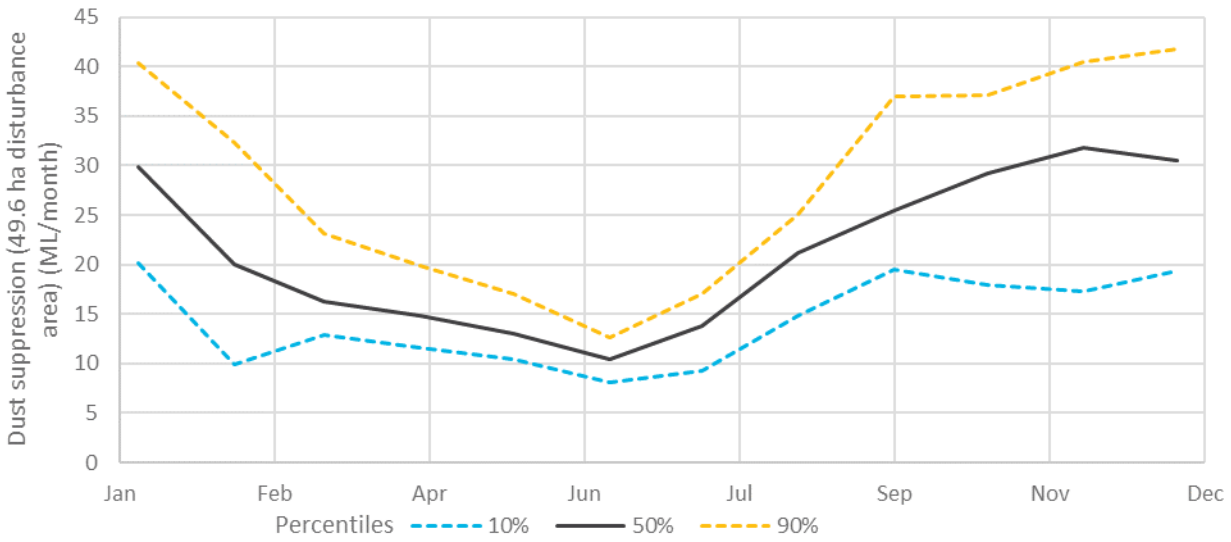


Figure 4.1 **Estimate of dust suppression requirements**

Table 4.1 **Construction water**

Water use	Volume (ML/year)
Personnel and facilities	7 ML/year
Concrete batching	3 ML/year
Dust suppression	250 ML/year
Total	260 ML/year

Infrastructure supporting the construction water supply would include:

- One or more pump suction points located within the reservoir, Doon Doon Creek, or Tweed River in the vicinity of the works.
    - The locations may change during the works, with water required at the dam construction compound, at McCabes Bridge, for concrete batching, and at the accommodation compound.
- Skid mounted mobile pumps.
- Temporary above ground pipework from the pump to storage tanks.
- Water storage tanks located within the construction compound.
    - Offtake and valve arrangements would be suitable for construction activities, and could include pipe connections and/or standpipes for water truck filling.
- A packaged filtration plant.

The suction points and pumps would be located at places where there is existing access. No new clearing would be required to accommodate pumps or pipework.

If diesel pumps are used, the pumps would be bunded to prevent any spills during refuelling from entering the reservoir.

Diesel fuel would be stored within bunded tanks in accordance with Australian Standard AS1940. This standard specifies bunding requirements, maximum liquid levels within tanks, and spill responses.

4.6 Flow regime during construction

Clarrie Hall Dam is typically full, with water discharging over the spillway (see chapter 3).

During early stages of construction there will be no change to the existing spillway, and the flow regime will be unchanged. Tasks undertaken at this stage include site establishment, removal of the concrete parapet wall, abutment preparation, and downstream foundation preparation.

Construction of the new spillway will occur prior to decommissioning of the existing spillway. Following construction of the new spillway, the dam wall will be raised and the intake tower will be raised. During the dam wall raise the FSL will remain at the level of the existing spillway crest. The flow regime of water released over the existing spillway will remain unchanged during this stage.

4.7 Initial filling

Following completion of the dam wall raise, the existing spillway will be plugged and the new reservoir volume will begin to fill. Spillway discharges will cease until the reservoir reaches the new FSL. During this period, minimum flow releases will be maintained via the valve house.

The raised dam will have a volume of 42,300 ML, an increase of 26,300 ML from the current volume of 16,000 ML. On average, the current dam discharges in excess of 50,000 ML via the spillway each year (Figure 3.25), and so it is expected that it will take less than 1 year for the reservoir to fill to the new FSL and for the existing flow regime to be reinstated.

5 Potential effects post-construction

5.1 Introduction

This section identifies and describes potential ongoing surface water effects associated with operation of the Proposal. Data and modelling results associated with the potential effects are provided and used to discuss the expected magnitude and frequency of potential effects.

Potential effects during construction of the Proposal are discussed in Chapter 4.

An impact assessment is provided in Chapter 6, comprising of:

- a risk assessment of potential effects
- a summary of proposed mitigation measures
- a description of residual risk following mitigation.

5.2 Modelling methods

Assessment of ongoing effects to streamflow hydrology and the reservoir water balance utilised hydrologic modelling as described in Annexure A. The NSW Government's Tweed River Valley Source model was used to simulate streamflow with the existing dam in place, and then modified to simulate streamflow with the Proposal, allowing a comparative assessment of the effects of the Proposal.

Hydrologic modelling utilised palaeo-stochastic climate data published by the NSW Government. This data combines the observed climate record from the SILO database (DES, 2024) with multi-decadal estimates of Pacific Decadal Oscillation (PDO), Indian Ocean Dipole (IOD), and El Niño – Southern Oscillation (ENSO) climate mechanisms based on long term proxy climate records such as tree rings and coral cores (Henley, Thyer, Kuczera, & Franks, 2011), which together add approximately 500 years' worth of climate sequence information. Stochastic climate modelling was then applied by the University of Adelaide to create 10,000 year synthetic climate sequences with similar characteristics to the instrumental record, such as mean, variance, and Lag-1 autocorrelation, but with different sequences of wet/dry years (Armstrong, Beecham, Dutta, & Higgins, 2023). Metadata available with the data describe the goodness of fit to daily, monthly, annual and consecutive year rainfall totals, but do not describe goodness of fit to multi-day rainfalls.

The NSW Office of the Chief Scientist and Engineer has recommended that the palaeo-stochastic data be used to inform NSW's regional water strategies (NSW Government, 2020), representing a major advance over the use of the instrumented climate record when considering the risk of climate variability to the management of water resources.

5.3 Dam water balance

The dam raising will have minor effects on the reservoir water balance, primarily related to the larger surface area of the reservoir.

During smaller rainfall events, only a portion of rainfall runs off the catchment, with the remainder wetting the soil and either infiltrating or evaporating after the event. In contrast, rain landing on the reservoir waterbody immediately becomes part of the stored water volume. The larger reservoir surface area resulting from the dam wall raising will result in approximately 3,300 ML/year additional water captured each year which otherwise would have evaporated from the landscape around the reservoir fringes (Table 5.1).

The larger reservoir surface area will also be subject to evaporation, with an additional 3,200 ML/year on average evaporating from the larger water surface.

While of a very similar magnitude, the increases in evaporation and rainfall will occur across different time scales and so the effects do not perfectly balance. The Proposal is expected to result in a slight increase in the number of days when the reservoir water level is below the spillway crest, and so instead of discharging via the spillway water would be released via the valve house.

Table 5.1 Overview of model results with the current climate

Demand:		**2025 demands**		**2065 demands**	
Infrastructure:		**Existing**	**Raised**	**Existing**	**Raised**
Characteristic:	Units:				
Capacity	ML	16,000	42,300	16,000	42,300
FSL	m AHD	61.5	70	61.5	70
Mean managed releases (valve house)	ML/year	2,170	2,143	3,664	3,726
Mean spills (spillway flows)	ML/year	52,081	52,073	50,612	50,507
Mean evaporation volume	ML/year	3,222	6,619	3,115	6,420
Mean rainfall capture volume	ML/year	3,379	6,619	3,297	6,558

Over the long term, the existing and raised Clarrie Hall Dam would both be expected to be full approximately 70% of the time (Figure 5.1). The effects of increased evaporation discussed above would reduce the volume of water which is discharged over the spillway, but would not cause significant drawdown of the reservoir below FSL.

During droughts the volume of the reservoir is expected to be drawn down. During periods when the reservoir is drawn down no water would be discharged via the spillway, and releases would occur via the valve house.

Due to the small size of the reservoir relative to the upstream catchment, the reservoir tends to fill quickly during drought breaking rains (Figure 5.2).

Further details of the future reservoir water balance are provided in Annexure A.

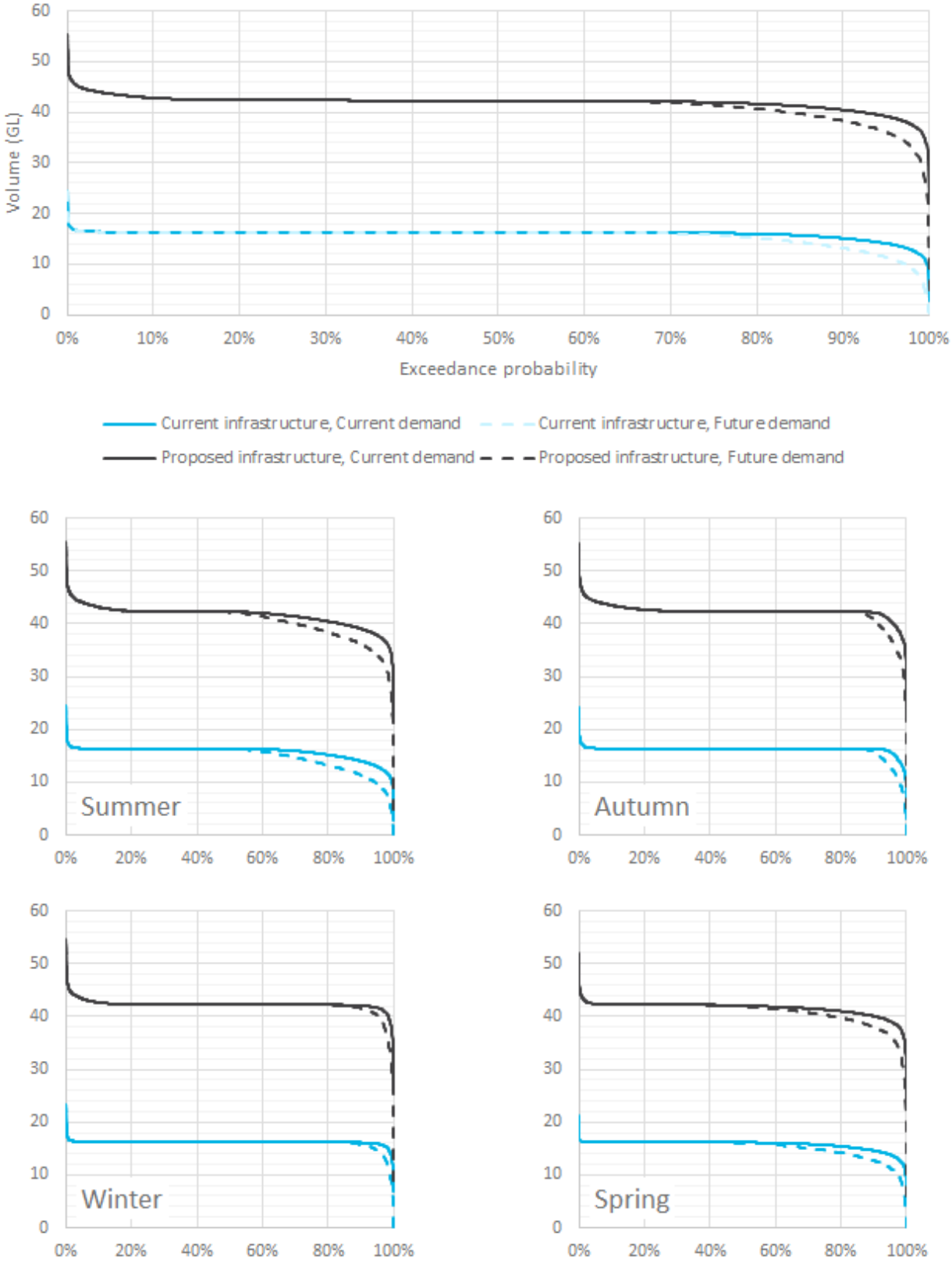


Figure 5.1 **Clarrie Hall Dam stored water volume, current climate (palaeo-stochastic climate data)**

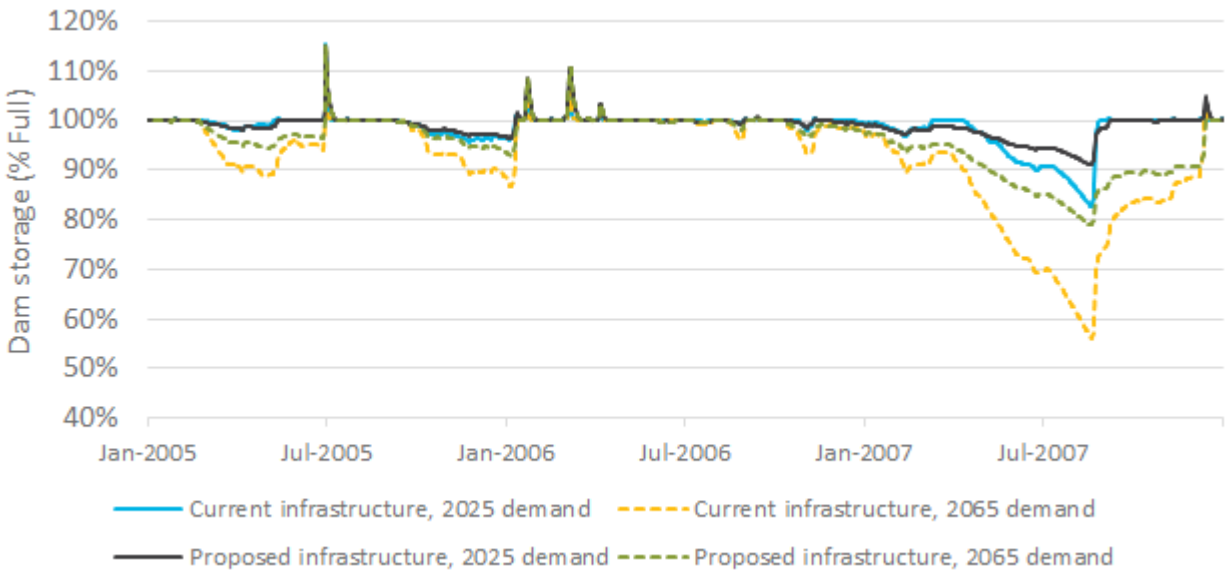


Figure 5.2 Modelled storage levels in Clarrie Hall Dam, historical climate (2005-2007)

5.4 Spillway operations

5.4.1 Frequency of spillway discharges

In each season, the number of days that the spillway operates is expected to decrease with the larger reservoir (Figure 5.3), from around 63% of days on average to 55% of days. This effect is anticipated due to the increased surface area subject to evaporation.

As an example, if:

- the reservoir is full
- inflows are 15 ML/day
- daily evaporation equals the yearly average

then:

- with the existing dam, 9 ML/day would evaporate, leaving 6 ML/day to flow over the spillway
- with the raised dam, 18 ML/day would evaporate, drawing the reservoir down by 3 ML/day, and requiring environmental releases to be made via the valve house.

The frequency of spillway discharge is expected to decrease overall as well as during each season.

The periods when spillway flows do not occur may be described as 'inter-event' periods. When inter-event durations become excessively long, the reduction in flow and change to the existing flow regime have the potential to affect established processes such as fish migration and floodplain vegetation recruitment. Hydrology modelling using palaeo-stochastic climate data indicates a moderate increase in the duration of periods with no spillway flow (Figure 5.4).

For example, it is expected that with the current infrastructure 90% of days with no flow over the spillway would be part of inter-event periods that are up to 9.5 months long (Figure 5.4). Following dam wall raising, 90% of days with no flow over the spillway are expected to be part of inter-event periods that are up to 10.5 months long.

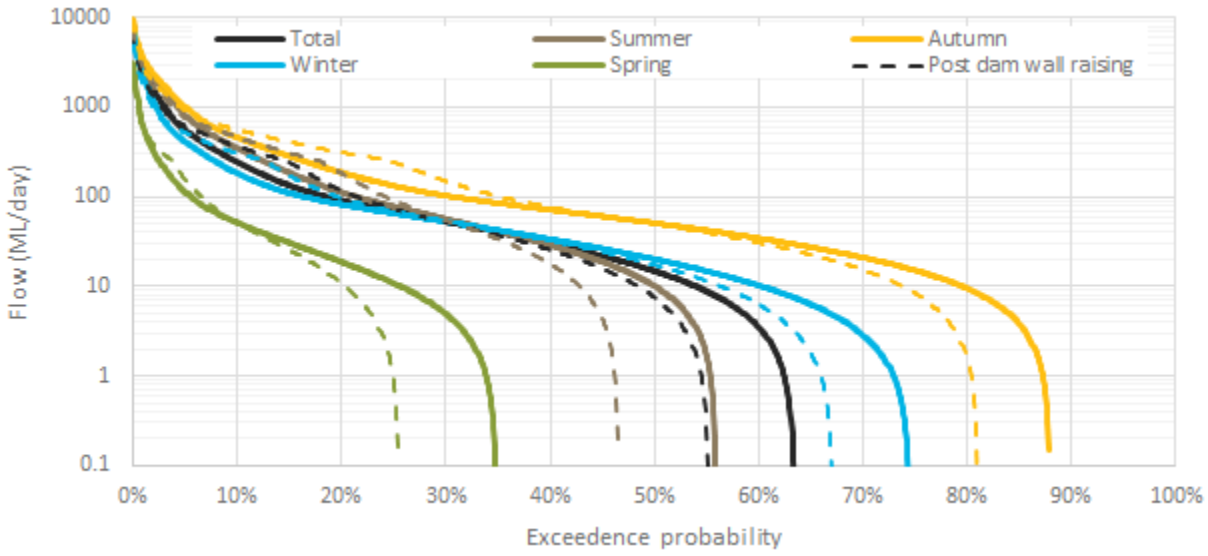
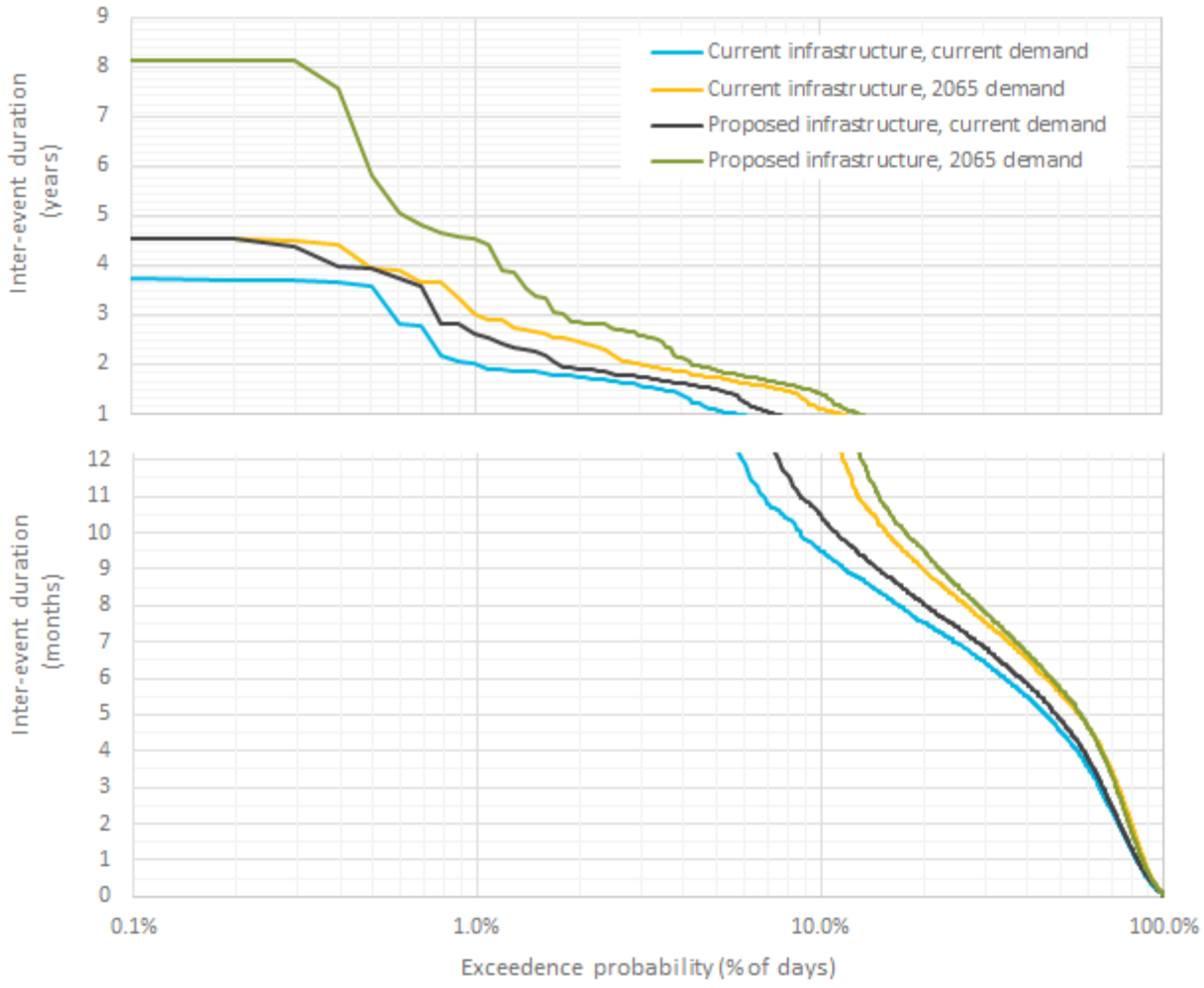


Figure 5.3 **Potential changes to spillway discharges (palaeo-stochastic climate data)**



The abscissa (x) axis indicates the percentage of days with no spillway discharge which are part of an inter-event period exceeding the duration indicated by the ordinate (y) axis

Figure 5.4 **Potential changes to spillway discharge inter-event duration (palaeo-stochastic climate data)**

During rare extended drought events (ie 0.1% - 1% portion of Figure 5.4), the hydrology modelling indicates that inter-event periods could extend for 3 – 4.5 years with the current dam and with the raised dam. By 2065, increased demands are expected to reduce the frequency of dam filling due to the rain which falls during drought periods. The hydrology modelling indicates that by 2065:

- with the raised dam wall, 0.3% of days with no spillway flow may occur within inter-event periods that are up to 8 years long (Figure 5.4)
- with the existing dam wall, 0.3% of days with no spillway flow may occur within inter-event periods that are up to 4.5 years long (Figure 5.4).

In these cases:

- drought conditions existed in the model for approximately 8 years
- at the end of 8 years, drought breaking rains were sufficient to fill the reservoir regardless of whether the dam wall was at its current height or raised (Figure 5.5)
- at around the mid-point of the drought, rains occurred which were sufficient to fill the current reservoir, but not the raised dam reservoir (eg 'proposed infrastructure, 2065 demand' series in Figure 5.5)
- these rains allowed for a brief period of spill before the next extended inter-event period occurred.

The raised Clarrie Hall Dam will allow greater water availability in these circumstances.

There are three periods in the 10,000 year palaeo-stochastic data set which have the potential to create droughts of 8 years.

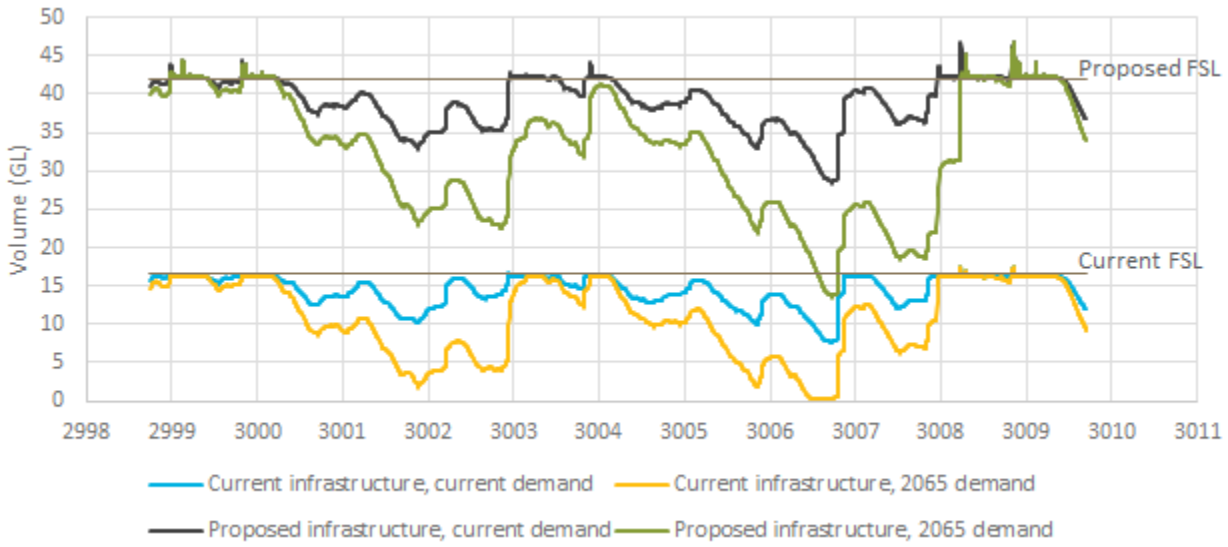


Figure 5.5 Example of Clarrie Hall Dam volume during an 8 year drought sequence (palaeo-stochastic climate data)

On days with no discharge via the spillway, releases would be made via the valve house to satisfy town water supply and environmental demands as per Table 2.1.

5.4.2 High flows

The frequency of spillway discharges of flows exceeding 100 ML/day is expected to increase with the raised dam for two reasons:

- The larger reservoir surface area will capture additional rainfall, leading to greater total volume to be discharged during a rain event.
- The spillway design and reservoir routing effects combined will result in reduced peak discharges, and greater attenuation of flood flows in the reservoir over the days following large rainfall. This will result in a decrease to discharged flood peaks, and an increase in the number of days of moderate to high discharge in the flow recession period as the flood waters drain more slowly from the larger reservoir.

5.5 Changes to dam operations

No direct changes to dam operations are anticipated due to the project. The reservoir would continue to be used to store and release water primarily for town water supply use, with release volumes and timing of releases governed by the WSP and urban demand.

Urban demands are not anticipated to be affected by the Proposal (other than by safeguarding urban supply and reducing the likelihood of supply failure).

Indirect changes to dam operations include an increase in the frequency that water would be released via the valve house as described in sections 5.1 and 5.4.

5.6 Changes to the Tweed River flow regime

5.6.1 Flow regime with current (2025) climate and town water demand

Doon Doon Creek and the flows released from Clarrie Hall Dam play a minor role in Tweed River hydrology. As described in section 3.2 at the confluence of Doon Doon Creek and the Tweed River the total catchment area is 230 km^2, with 60 km^2 (26%) of this upstream from Clarrie Hall Dam. The remaining 74% of the catchment at this location is unaffected by the project.

At Uki (Rowlands Creek – Tweed River junction) the total upstream catchment area is 270 km^2. The Clarrie Hall Dam catchment accounts for 22% of the Uki catchment. The changes to spillway discharges discussed in section 5.4 have a negligible effect on the flow frequency curves at this location (Figure 5.6).

At Bray Park Weir, the total catchment area is 570 km^2, with the Clarrie Hall Dam catchment accounting for 11% of this area. The potential changes to spillway discharges discussed in section 5.4 have an imperceptible effect on the flow frequency curves at this location (Figure 5.7).

5.6.2 Flow regime with future (2065) climate and town water demand

As described in section 3.3.4, the Tweed River catchment is expected to receive reduced winter and spring rainfall in the future, and rising temperatures are expected to increase evaporation rates.

By 2065 there is also expected to be a 70% growth in town water demand, due in part to increased population.

These factors will affect the Clarrie Hall Dam operations and reliability of supply, and form part of the business case for developing the project.

Following climate change and population increase to 2065, the effect of the Proposal on the Tweed River flow frequency is expected to remain negligible at Uki (Figure 5.8) and imperceptible at Bray Park Weir (Figure 5.9).

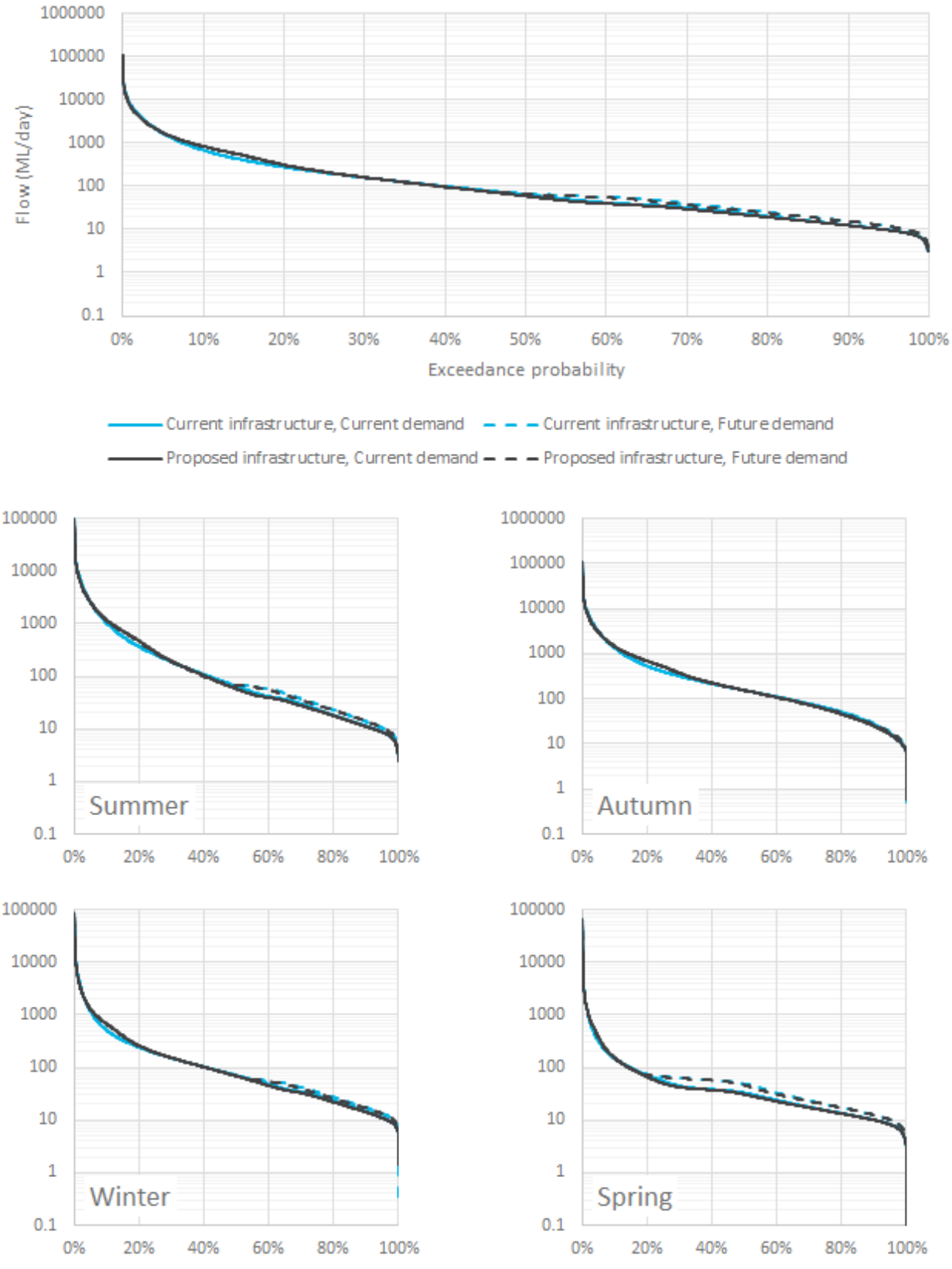


Figure 5.6 **Flow duration curve for Tweed River at Uki (201900), current climate (palaeo-stochastic climate data)**

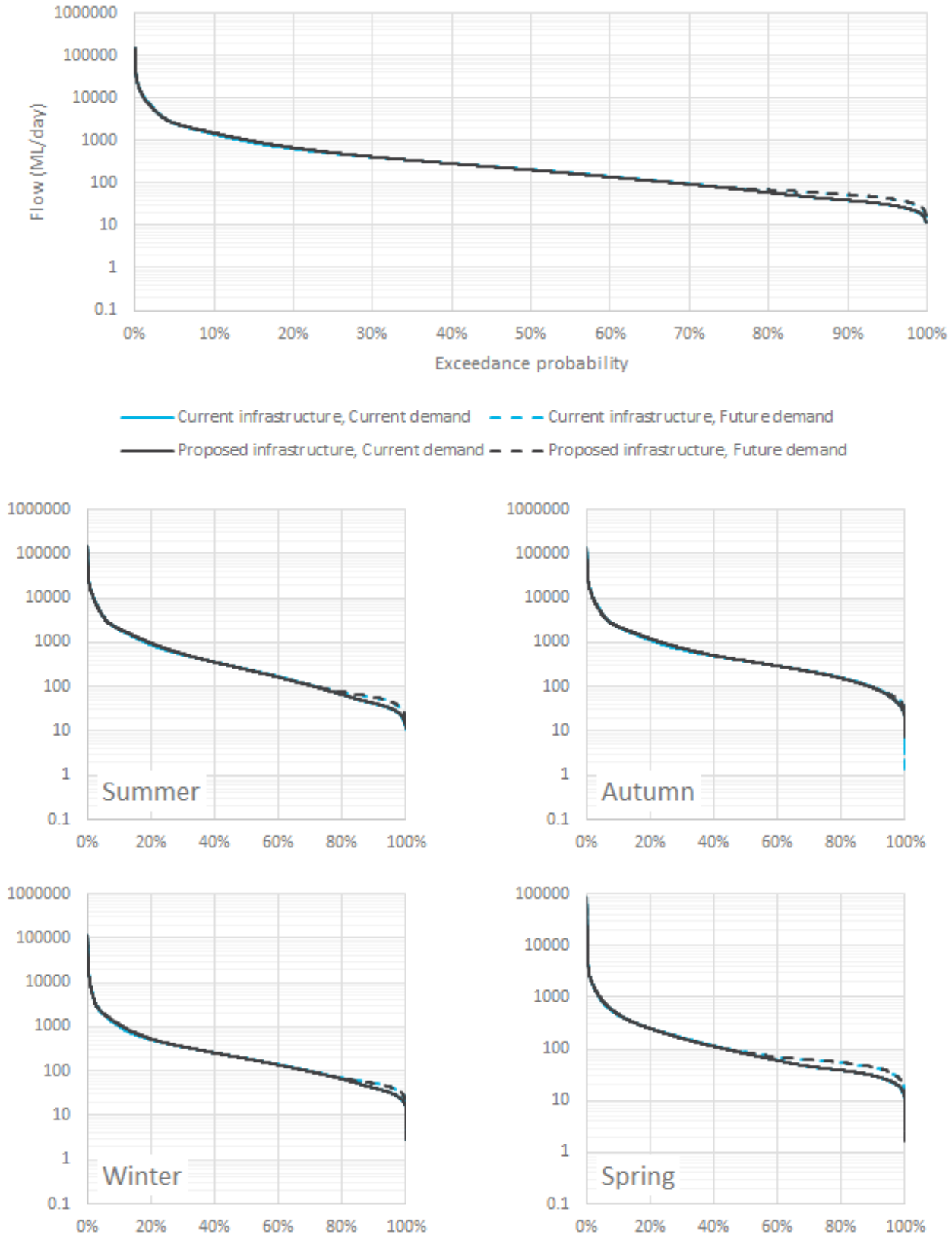


Figure 5.7 **Flow duration curve for Tweed River downstream of Bray Park Weir, current climate (palaeo-stochastic climate data)**

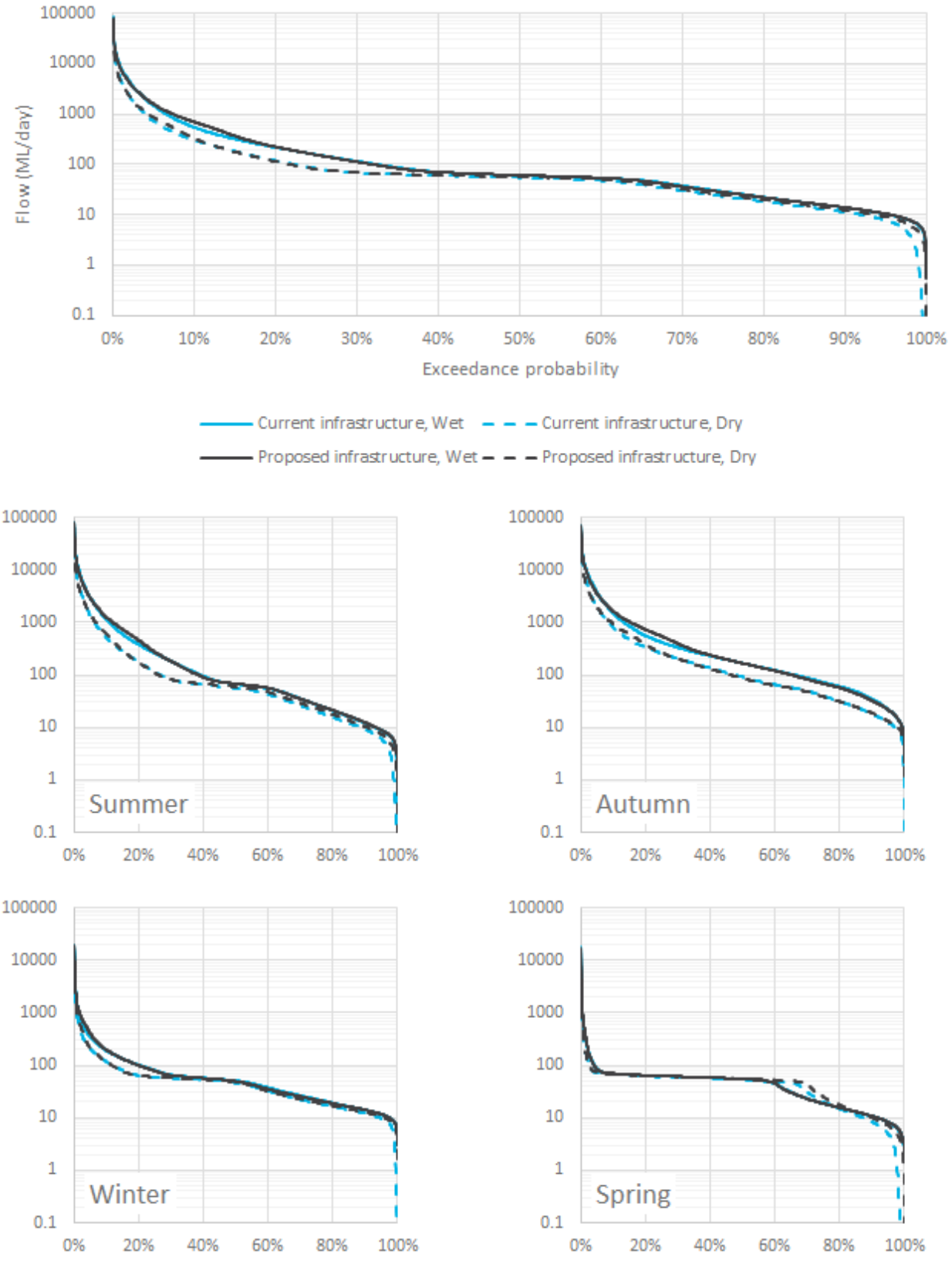


Figure 5.8 **Flow duration curve for Tweed River at Uki (201900), future climate and demand (palaeo-stochastic climate data)**

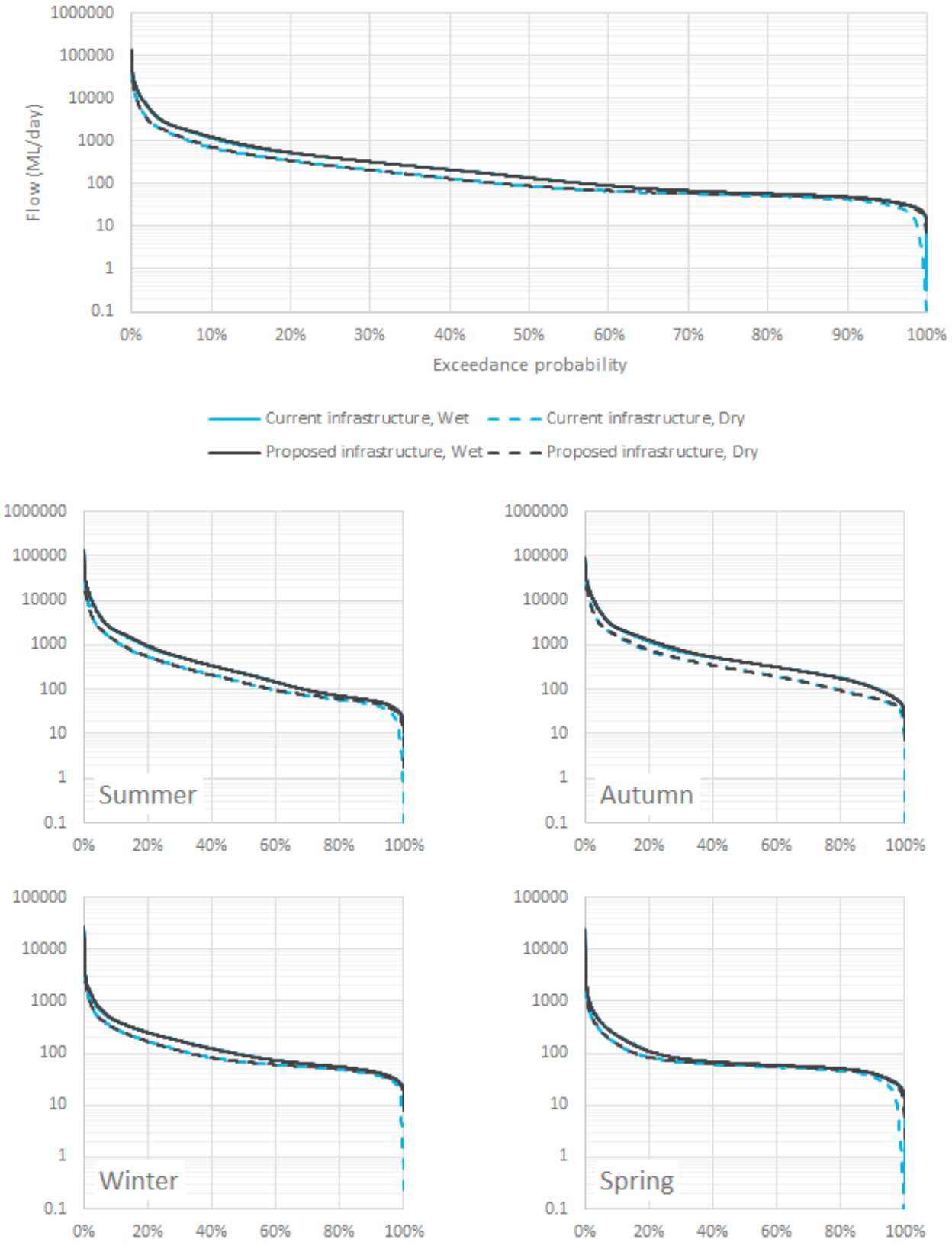


Figure 5.9 **Flow duration curve for Tweed River downstream of Bray Park Weir, future climate (palaeo-stochastic climate data)**

5.6.3 Australian Bass migration cues

As described in section 3.8, Australian Bass include a life cycle stage with a flow trigger and may migrate downstream to the estuary to spawn during May – July and then migrate upstream August - April.

The modelled long term flow regime (Annexure A) indicates that longer duration moderate flows are more common in the Tweed River than higher flow rate pulse flows (Figure 5.10).

Currently around 86% of years contain 5+ day flow sequences which are supportive of Australian Bass migration upstream (Figure 5.10). This is expected to increase marginally to 87% of years following dam wall raising, due to the small increase in number of days with flows above 100 ML/day (section 5.4).

Approximately 96% of years currently contain 5+ day flow sequences supportive of Australian Bass downstream migration. Following dam wall raising, it is expected that 96% of years will continue to contain such events.

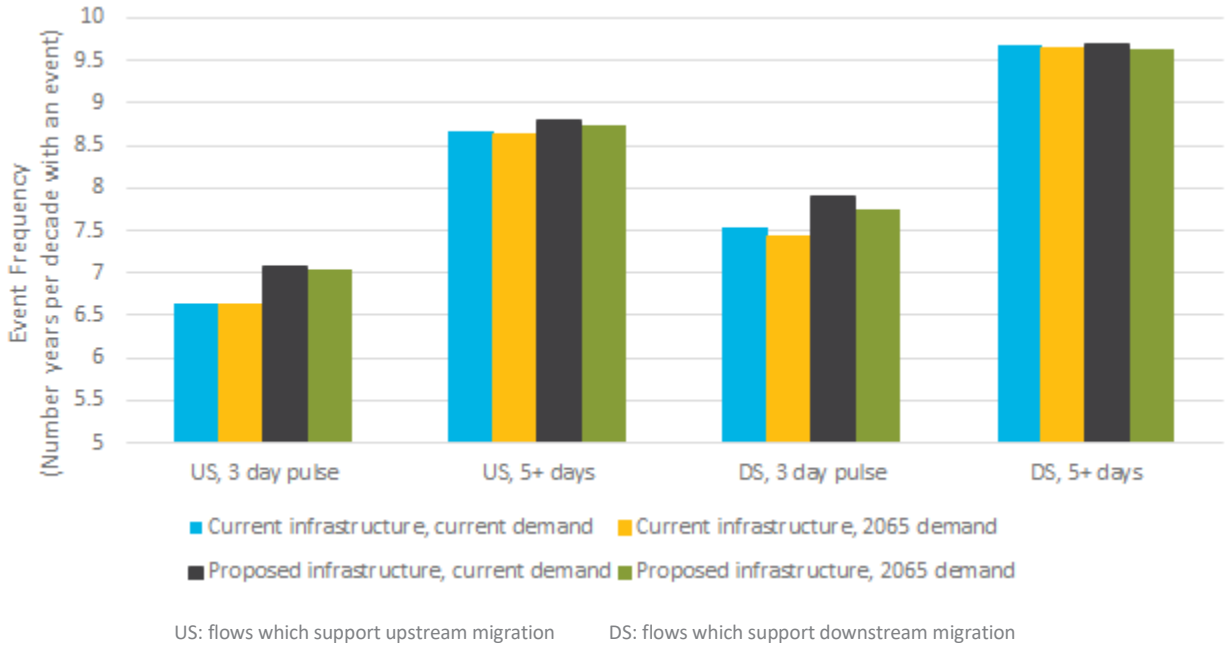


Figure 5.10 Number of years per decade with flows supportive of Australian Bass migration (palaeo-stochastic climate data)

Each season can feature multiple events which support migration. Marginal increases in the total number of events that promote Australian Bass migration are expected (Figure 5.11).

During drought there may be periods when flows which promote migration do not occur, which can be described as 'inter-event' periods. Currently the 95th percentile inter-event durations are 23 months for upstream migration flows and 9 months for downstream migration flows (Figure 5.12). The minimum possible inter-event duration is 6 months given the seasonal nature of migration. 95th percentile inter-event durations may decrease by approximately 1 month following dam wall raising.

These results indicate that the Proposal is not expected to have any significant effect on Australian Bass migration within the Tweed River.

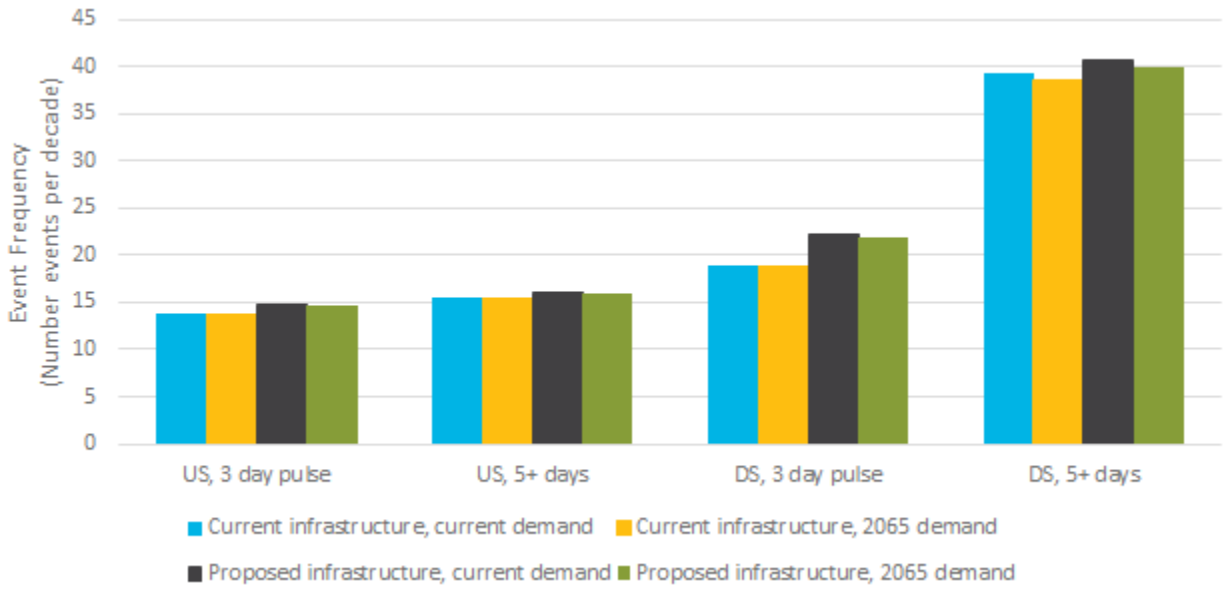


Figure 5.11 **Number events per decade supportive of Australian Bass migration (palaeo-stochastic climate data)**

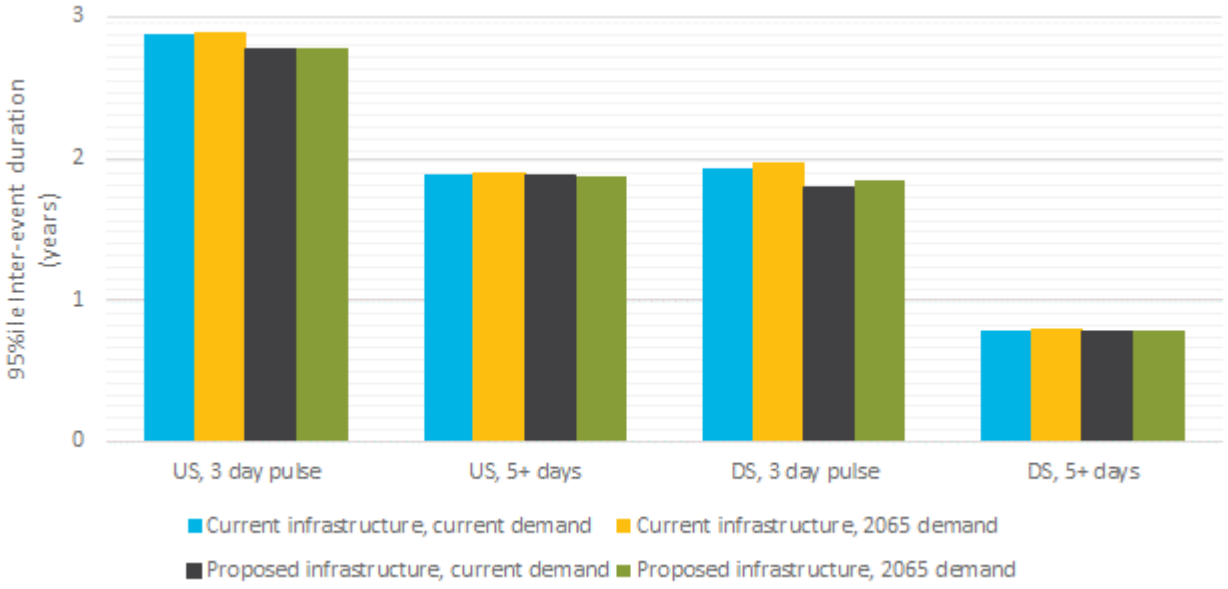


Figure 5.12 **Inter-event duration for Australian Bass migration flows (palaeo-stochastic climate data)**

5.7 Water quality

5.7.1 Transient effects following initial filling

Following initial filling, organic matter will be submerged within the newly inundated area. The nutrients contained in the soils and vegetation will take some time to move into the waterbody following inundation, leading to reduced and/or more variable water quality water during the first few years after the commissioning of

the raised dam. In general, the initial filling of the reservoir may be characterised by water having higher turbidity, lower DO, higher BOD, higher chlorophyll-a and higher nutrients.

It is not possible to create an accurate model of the decomposition and nutrient cycle processes, which may occur within the new (shallow edge) reaches of the enlarged reservoir due to the number of complex chemical, biological and climatic processes which occur and interact, however data recorded at other dams indicates that the 'proving' period may be approximately 4-5 years, during which time the new reservoir banks may experience some erosion, and submerged organic matter decay.

The initial filling effects will be minimised through catchment preparation as described in section 4.3.4.

5.7.2 Physical and chemical water quality with current (2025) climate

i Water quality effects overview

Reservoir water quality is expected to vary on a seasonal and interannual basis in response to runoff from local catchments, and biogeochemical processes occurring within the reservoir. The warming or cooling of the waterbody will affect the amount of dissolved oxygen and suspended solids contain in the water column and influence the chemical reactions, which take place. Mixing and circulation processes will be important in determining the physical (temperature), chemical (nutrients) and biological properties (algae).

There is the potential for water quality impacts during operation of the new Clarrie Hall Dam may occur due to:

- eutrophication, leading to algal blooms
- low oxygen content in sediments and deeper parts of the water column, leading to:
    - release of metals from sediments, particularly iron and manganese
    - in extreme cases, fish kills.

These effects are inter-related, with algal blooms contributing to anoxic conditions at depth, and stratification leading to enhanced risk of algal growth in summer.

ii Cold water pollution and algae

Numerical limnology modelling was undertaken using the AEM3D software to investigate the potential changes to stratification, nutrient distribution, and algae growth which could occur due to dam wall raising (Annexure B). The model indicated that following dam wall raising:

- During summer when the reservoir is stratified, the warm surface layer may become 2-3 m thicker due to additional surface area exposed to wind energy (Figure 5.13).
- With a larger vegetated perimeter and an increase in shallow fringes, the total nutrient (TN and TP) content of the reservoir is expected to increase. This effect is balanced by the increase in reservoir storage volume such that the average nutrient concentrations are expected to decrease. With additional surface area exposed to wind energy, nutrients will be dispersed more evenly through the water column during turn over.
- In the existing reservoir, algal growth is constrained by phosphorus concentration near the surface. After dam raising, additional phosphorus will be available in the surface layer at the commencement of summer (Figure 5.14), leading to increased frequency and severity of algal blooms (Figure 5.15), with a 50% increase in chlorophyll-a production at 2 m depth.

Algal blooms affecting the upper 7 m of the water column (Figure 5.15) pose a risk to water quality released from the dam. When the reservoir is full and spilling, operators have little control over the release of algae from the

reservoir. When releases are made via the valve house, algae water quality risks can be avoided through use of the MLO, by drawing water from depths of 7-9 m. Operators would preferentially draw water from the highest point in the water column that is not affected by algae as deeper water has lower dissolved oxygen and higher risk of CWP.

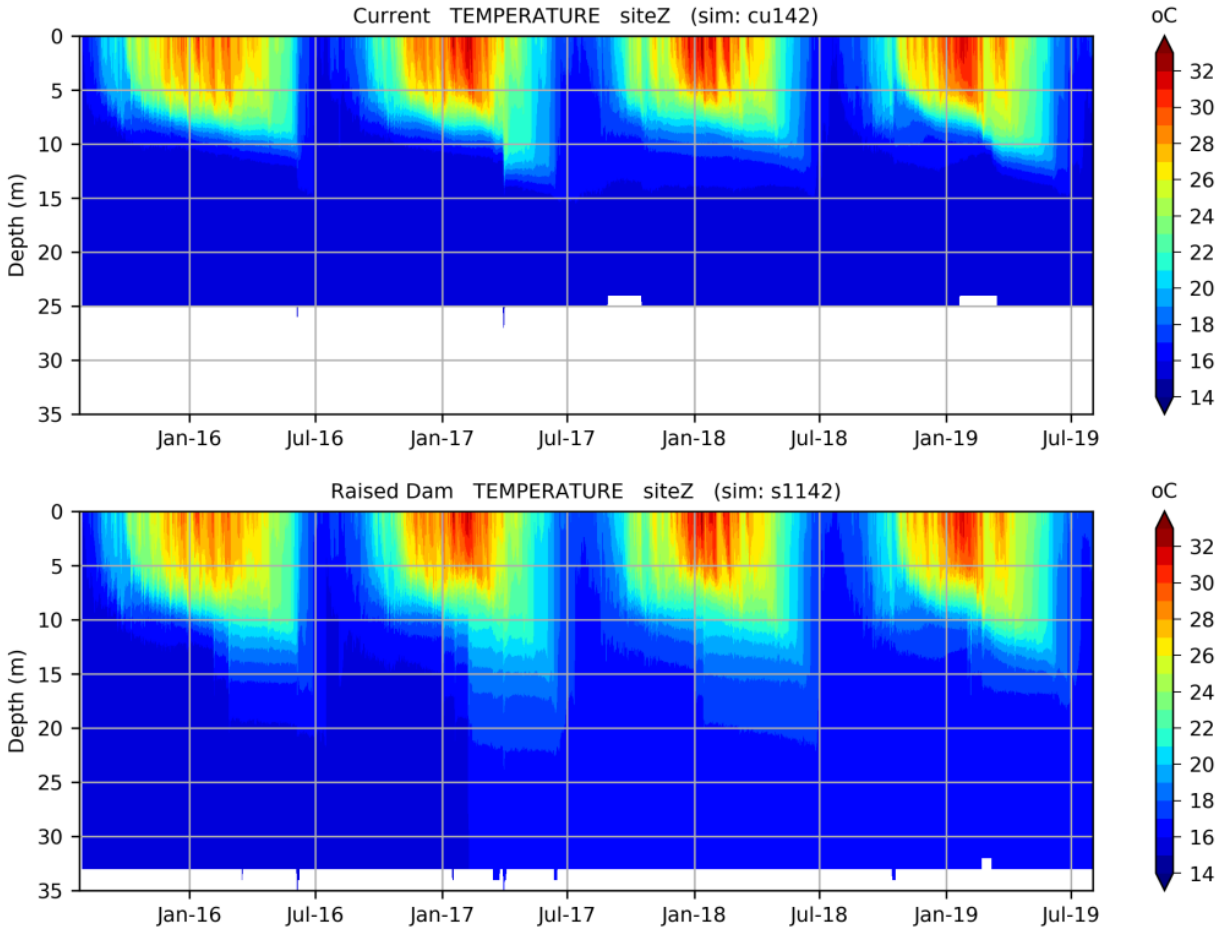


Figure 5.13 Simulated temperature within the existing dam and raised dam (HydroNumerics, 2021)

The frequency of flows over the spillway during summer is expected to decrease from 55% of the time to 45% of the time following dam wall raising (Figure 5.3). Simplifying the simulation results to single representative values to demonstrate typical magnitude and likelihood, the following are considered to be typical:

- Summer downstream water temperature is around 27°C (Figure 3.42).
- At 7 m depth, the reservoir water temperature in summer is around:
  - 22°C with the existing dam (Figure 5.13). CWP of releases from this depth is thus around Δ5°C
  - 24°C with the raised dam (Figure 5.13). CWP of releases from this depth is thus around Δ3°C.
- At 15 m depth, the reservoir water temperature in summer is around:
  - 16°C with the existing dam (Figure 5.13). CWP of releases from this depth is thus around Δ11°C
  - 18°C with the raised dam (Figure 5.13). CWP of releases from this depth is thus around Δ9°C.
- Summer near surface algae concentrations are extremely variable, but may be characterised as often reaching:

- 40,000 cells/mL with the existing dam (Figure 3.37)
- +50% (ie 60,000) cells/mL with the raised dam.

These simplified data illustrate that the magnitude of CWP and algae effects on downstream waterways may vary by a factor of 2 (increase for algae magnitude and a decrease for CWP), while the frequency varies by around 20%.

Simulated releases and river flows (Annexure A) indicate that, with releases from 7 m depth as per the above assumptions, rolling 5 day CWP at the Doon Doon Creek – Tweed River junction may currently exceed the 15 degree-day target (cf section 2.2.8) (Figure 5.18). This effect is expected to have a relatively small geographic extent, with significant warming occurring upstream from Uki under normal flow conditions (Annexure C).

With warmer reservoir temperatures predicted following dam wall raising, the degree-day target is expected to be achieved.

As a result, the overall risk of CWP to the downstream environment is expected to decrease following dam wall raising (Figure 5.16), while the risks associated with release of algae are expected to increase (Figure 5.17).

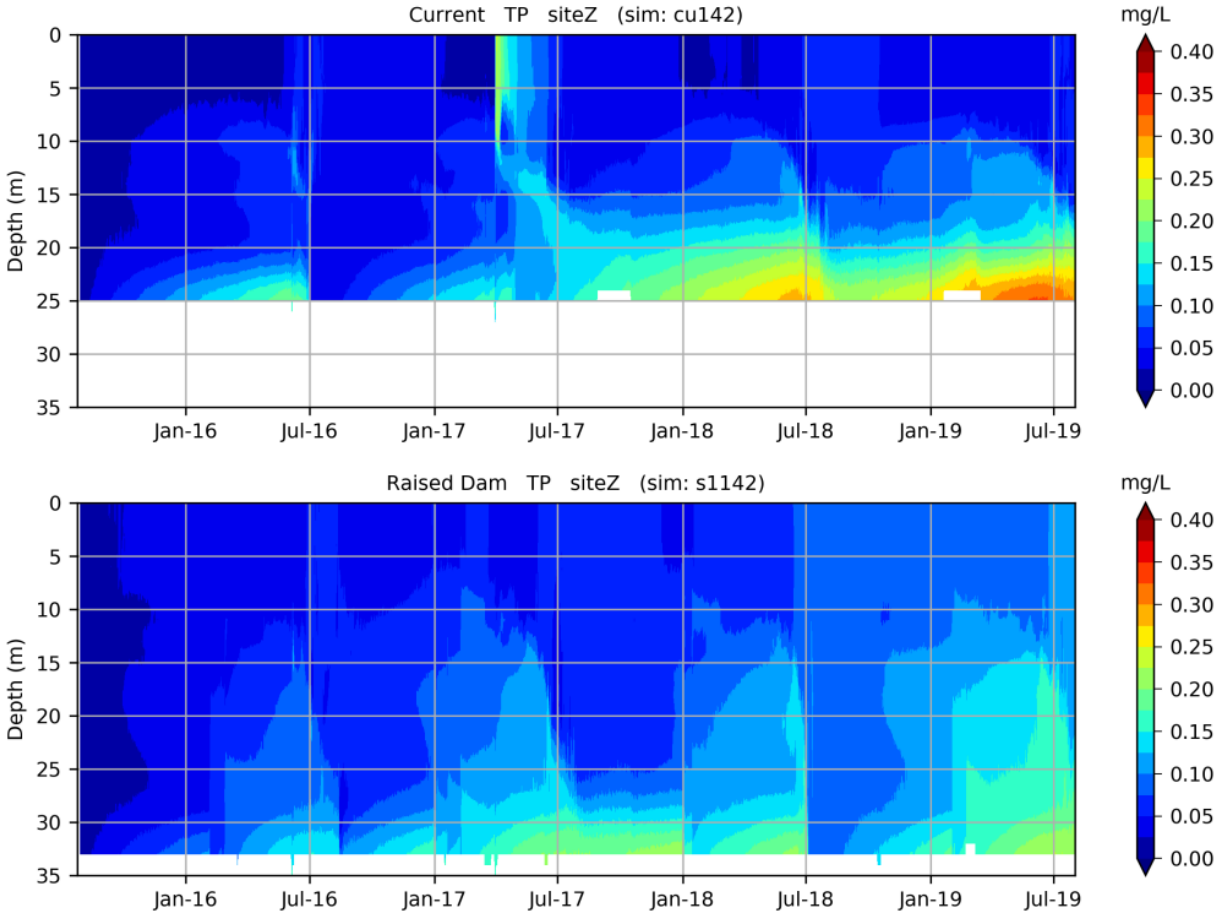


Figure 5.14 Simulated phosphorus concentration within the existing dam and raised dam (HydroNumerics, 2021)

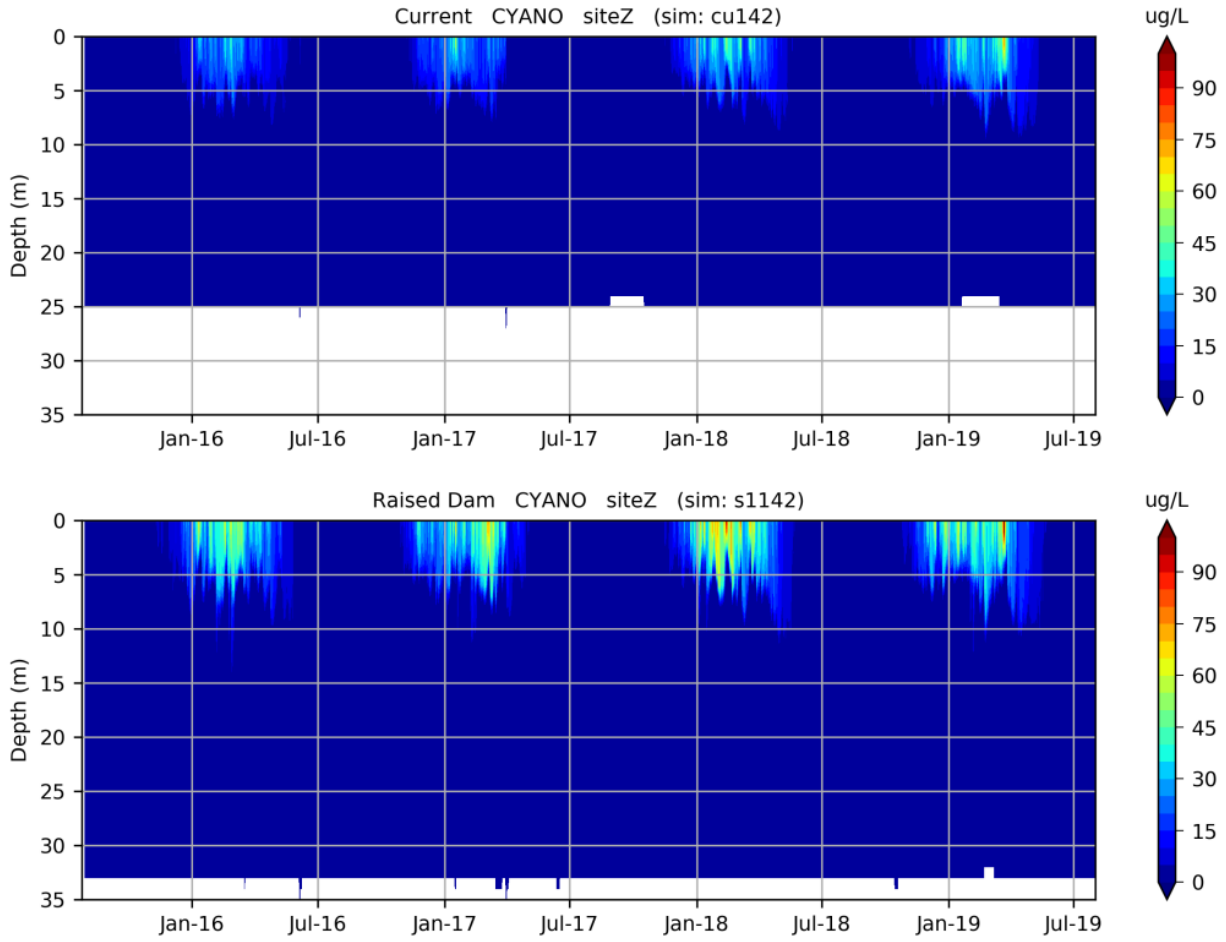
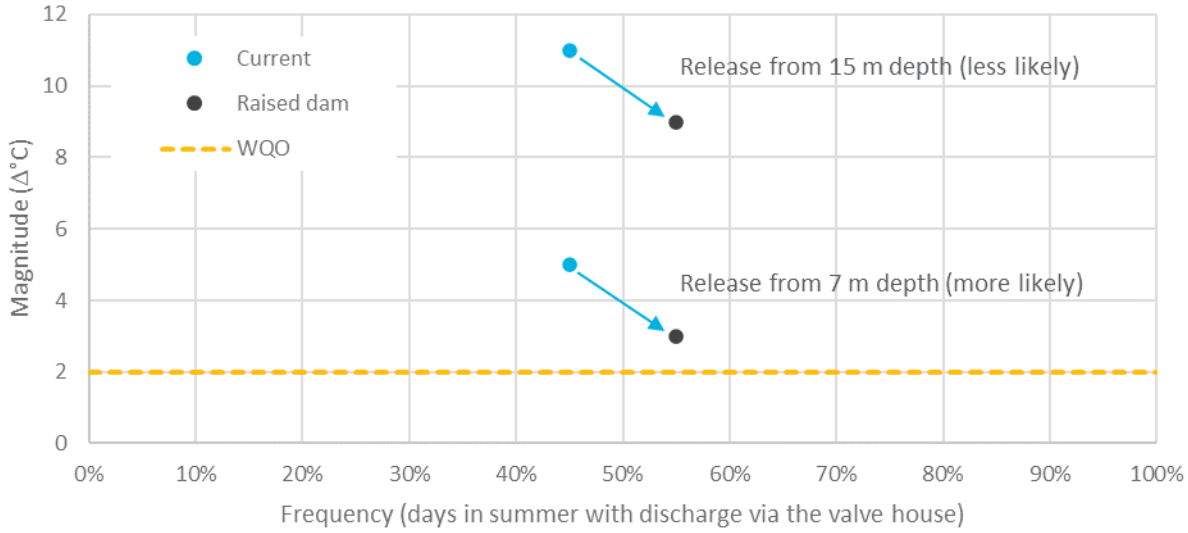


Figure 5.15 **Simulated algae concentration within the existing dam and raised dam (HydroNumerics, 2021)**



Magnitude is described immediately downstream from the dam wall, and reduces with distance downstream

Figure 5.16 **Change to risk of cold water pollution release (typical simulated values)**

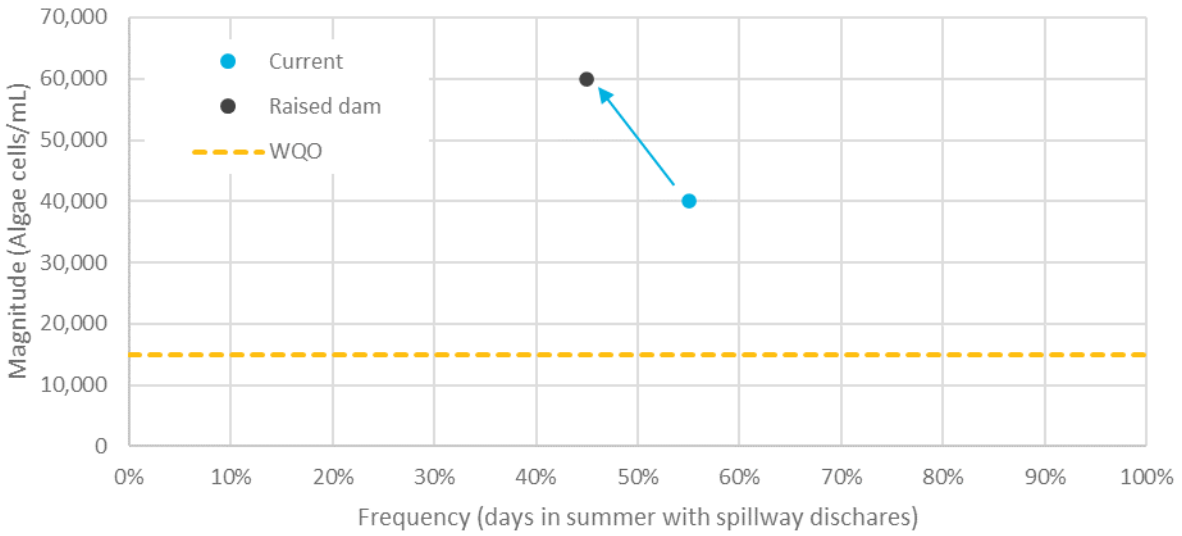


Figure 5.17 Change to risk of algae release (typical simulated values)

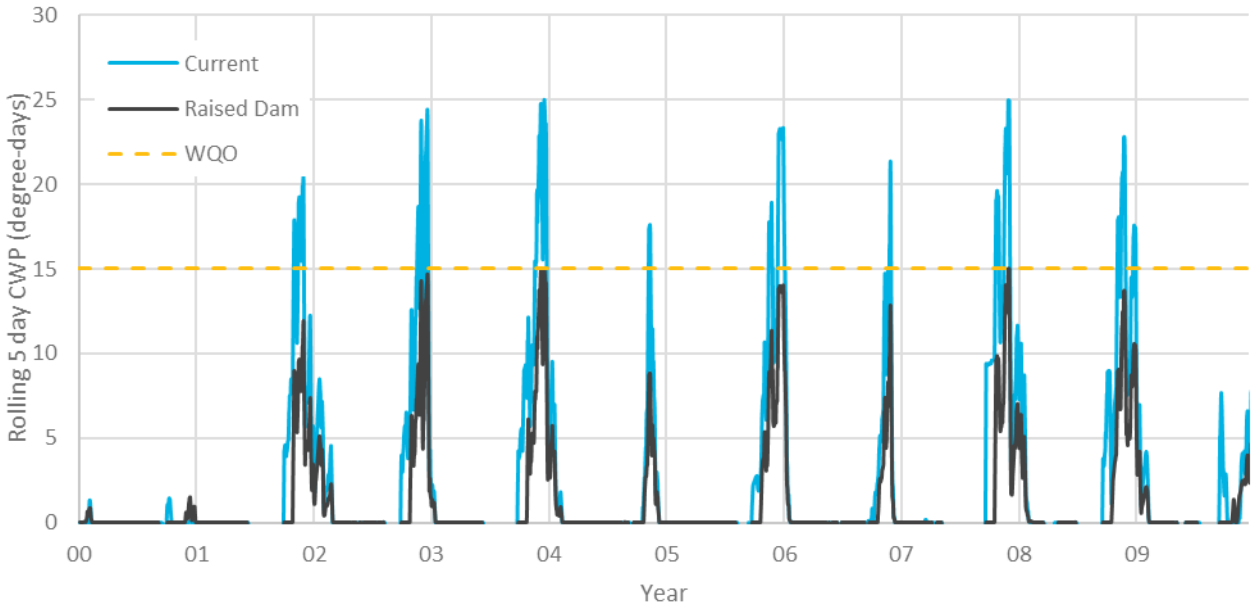


Figure 5.18 Rolling simulated 5 day cold water pollution at Doon Doon Creek – Tweed River junction

iii Dissolved oxygen

Dissolved oxygen concentrations (Figure 5.19) are expected to increase near the surface following dam wall raising due to increased surface area capturing wind energy, leading to greater surface movement. The deeper thermocline following dam wall raising is also expected to result in a deeper oxycline, meaning a larger body of water will be oxygenated.

Near the reservoir bed, oxygen concentrations are expected to be <1 mg/L currently and after wall raising (ie no change).

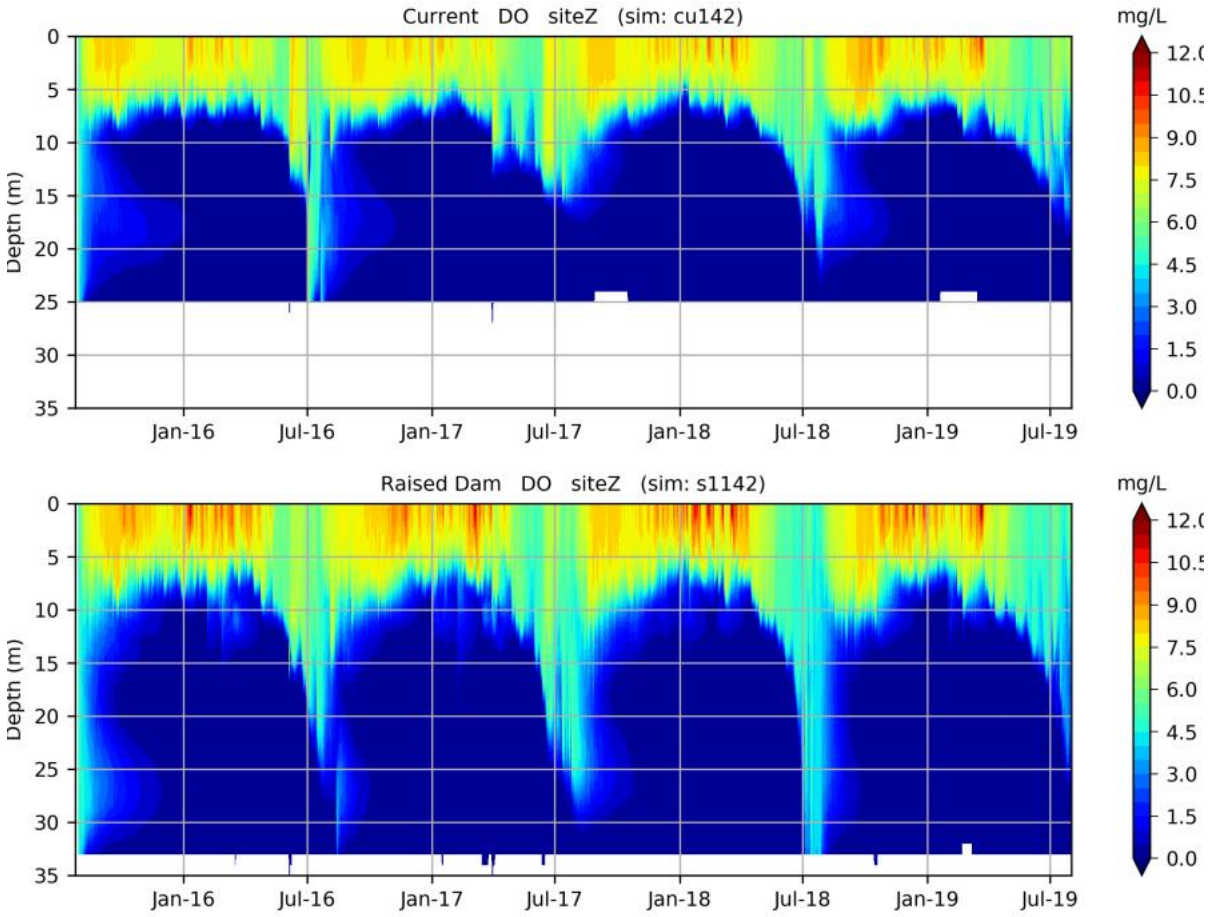


Figure 5.19 Simulated dissolved oxygen within the existing dam and raised dam (HydroNumerics, 2021)

iv Stratification management

Reservoir destratification may be undertaken for a number of discrete reasons, including:

- management of water quality (eg dissolved oxygen or turbidity) at water supply offtake locations, and subsequent water treatment costs
- management of temperature with the waterbody, to reduce the risk of CWP causing harm to aquatic fauna
- management of algae, as algae can generate a number of toxins and reduce dissolved oxygen, both of which are harmful to aquatic fauna.

Water released from Clarrie Hall Dam is delivered via run-of-river to water supply offtake locations. During these transfers, the water becomes oxygenated through general exposure to the atmosphere, and in particular through turbulence induced by riffle zones. As such, reservoir destratification is not required for management of the quality of water delivered to water supply offtakes.

Section 5.7.2ii described that the risk of CWP is expected to decrease following dam raising. The larger reservoir surface area is expected to receive greater input of wind energy, leading to a deeper thermocline, warmer water at depth, and reduction in the magnitude of CWP released from the dam to the degree that effects at the Doon Doon Creek – Tweed River junction are expected to meet NOW recommendations for cold water management (NOW, 2011).

Strategies to minimize the likelihood and magnitude of eutrophication and to reduce the risk of algal bloom impacts may be difficult to implement and/or ineffective at the reservoir scale.

Destratification near the reservoir offtakes will not prevent warm nutrient rich pockets forming in the upper shallower reaches of the reservoir, where algae may grow prolifically. Therefore, the main options available include regular monitoring of catchment and reservoir water quality and the implementation of dam operational protocols to lessen the likelihood of algal rich surface waters (during a bloom event) being released via environmental flows or as run-of-river transfers to the downstream WTPs.

Algae released from the dam has the potential to seed algae growth within Bray Park Weir, affecting water treatment and general amenity of the waterway adjacent to Murwillumbah. Algae blooms currently occur from time to time within the weir pool, expected to continue following dam wall raising.

Water quality management measures proposed for the raised Clarrie Hall Dam include:

- raising (extending) the existing MLO
- regular monitoring of reservoir water quality during the operation of the new dam
- selective withdrawal of the highest quality raw water based on monitoring information from the MLO operation
- ongoing maintenance and application of existing systems, procedures, programs and processes used by Council to manage the water storage including:
    - water quality management systems consistent with the ADWG
    - risk management practices including identification and assessment of potential water quality hazards and implementation of appropriate controls
    - utilisation of carbon filters at the Murwillumbah water treatment plant in the event of an algae bloom within Bray Park Weir pool.

5.7.3 Physical and chemical water quality with future (2065) climate

Limnology modelling (Annexure B) indicated that following dam raising, climate change (to 2065) may have the following effects on the reservoir waterbody:

- increase in water temperature by +1-2°C
- no meaningful change to suspended solids, dissolved oxygen, nitrogen compounds, or phosphorus compounds
- ±10% cyanophyte algal cell counts (ie unchanged, with an uncertainty range)
- -50% chlorophyte algal cell counts (ie counteracting the increase expected from dam wall raising).

The large reduction in chlorophyte cell counts is associated with the change in water temperature, with a reduced period in the year with optimal water temperatures.

Changes in water temperatures will favour cyanophyte (blue-green) algae, and it is possible that these species could become more common through the cooler parts of the year when they would typically die off.

5.7.4 Water treatment

Council operates WTP's according to river water quality conditions.

For several years after the initial reservoir filling, organic matter and nutrients may be elevated in water released from the reservoir (section 5.7.1), and there may be an ongoing a risk of increased algae counts (section 5.7.2). Council operated WTP's are already equipped to respond to these conditions, such that town water supplies would continue to meet ADWG parameter thresholds.

5.8 Geomorphological effects

5.8.1 Bed shear

The NSW RiverStyles database (DPE, 2023) describes the Tweed River upstream from Bray Park Weir as "confined valley setting, gravel bed with floodplain pockets". Field observations confirmed that the stream bed is rocky, with the bed predominantly formed from cobble sized rocks (Photograph 3.2 and Photograph 3.3)

Potential changes to bed shear through Doon Doon Creek and the Tweed River due to the Proposal were assessed (Annexure D) utilising information describing the anticipated flow regime changes (Annexure A), hydraulic properties of the waterways (Annexure C), and critical shear stress data (Table 5.2).

Table 5.2 Critical shear stress for selected bed materials

Bed material	Representative particle size (d_{50}) (m)	Critical shear stress (τ_c) (N/m^2)
Silt	0.00001	0.1
Sand	0.001	10
Gravel	0.01	100
Cobbles – present in Tweed River bed	0.1	1000
Boulder	0.5	5,000

Based on the Shields equation $\tau_c = \theta_c g d(\rho_s - \rho)$ with Shields parameter θ of 0.6, and particle specific gravity ρ_s of 2.65

In Doon Doon Creek:

- Modelled bed shear remains below 100 N/m^2 in all but the largest floods. The modelling process averages shear across the model cross section, and it likely that there will be eddies, turbulence, and non-uniform flow conditions which result in shears up to an order of magnitude greater. This means that:
    - rocks larger than 100 mm are not expected to be mobilised in typical flow events
    - rocks 10-100 mm could be mobilised short distances before settling in locations of lower shear
    - sand and silt will be readily mobilised by 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 (Figure 5.20). This means that the bed materials would be mobilised in floods less frequently.
- There could be a small increase in the frequency of flows with shear in the order of 30 N/m^2, and a small reduction in the frequency of flows with shear in the order of 15 N/m^2. 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 N/m^2. 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.

It is expected that in the Tweed River between Doon Doon Creek and Uki there will be minimal change to the bed shear environment (Figure 5.21).

Further information relating to shear, velocity and depth are included in Annexure D.

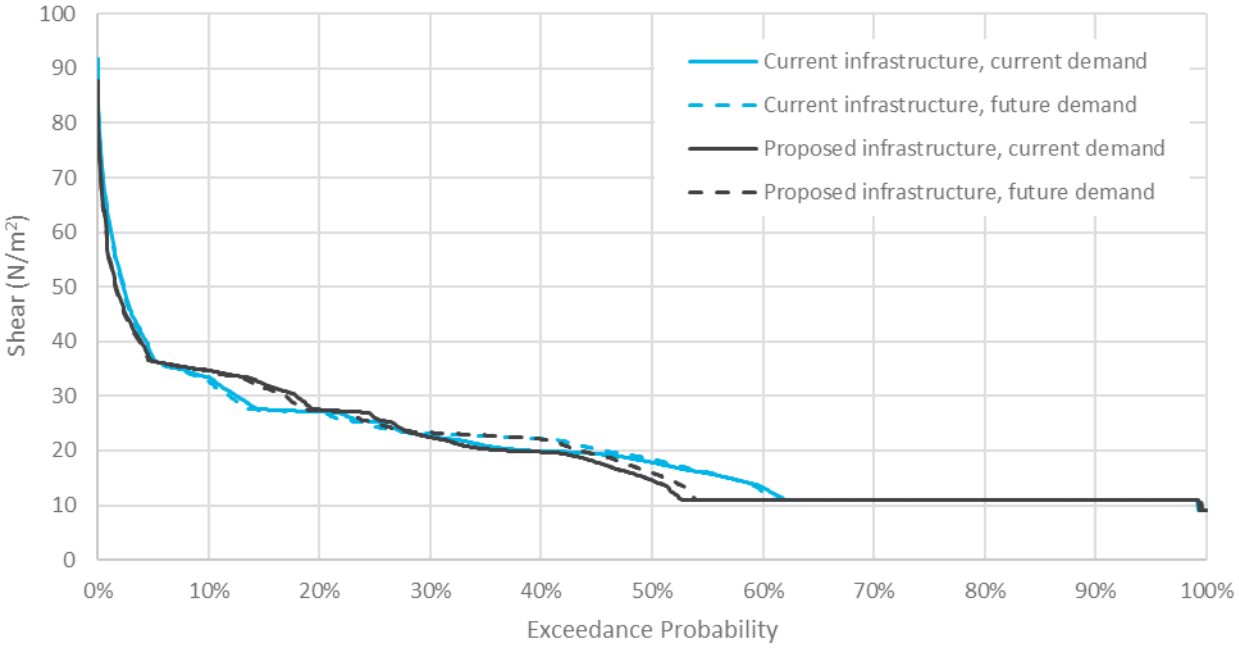


Figure 5.20 Bed shear stress, Doon Doon Creek riffle

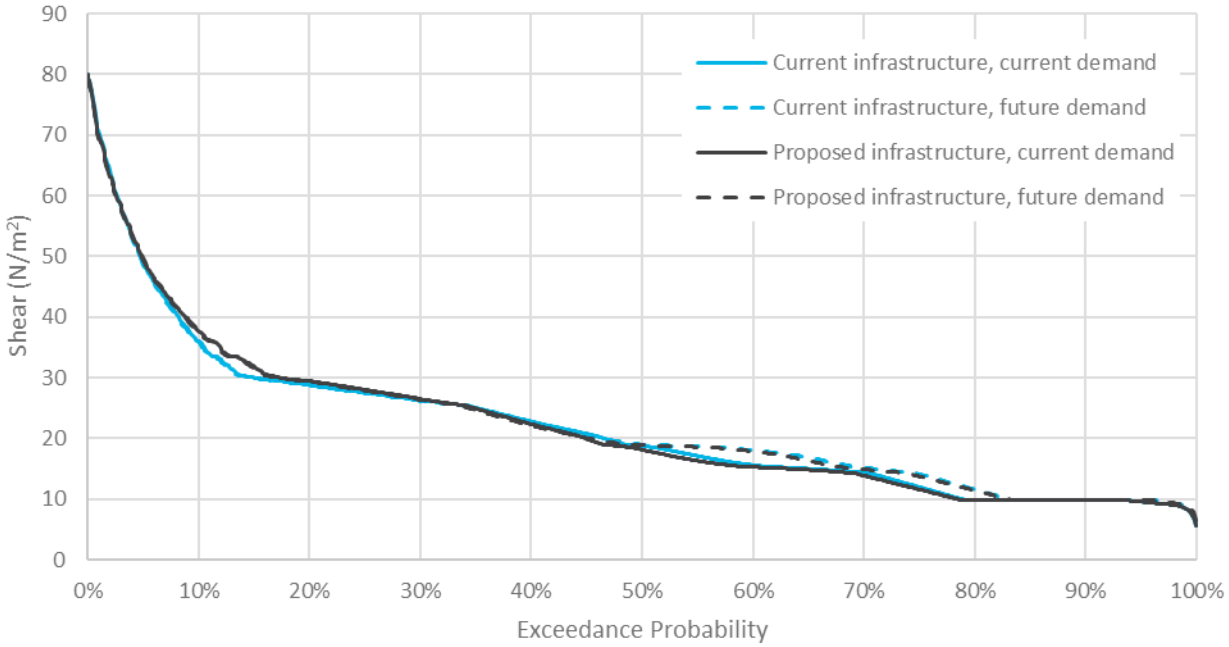


Figure 5.21 Bed shear stress, Tweed River riffle

5.8.2 Reservoir sedimentation

The efficiency of reservoirs to trap sediment is dependent on water residence time, with higher residence time allowing for additional settling. The relationship between residence time and settling is a well established science, with a commonly applied method for estimating sediment trap efficiency being that of Brune (1953) (Figure 5.22). Based on the relationship developed by Brune based on study of 44 reservoirs, it is estimated that the existing Clarrie Hall Dam likely captures approximately 94.5% of inflowing sediment.

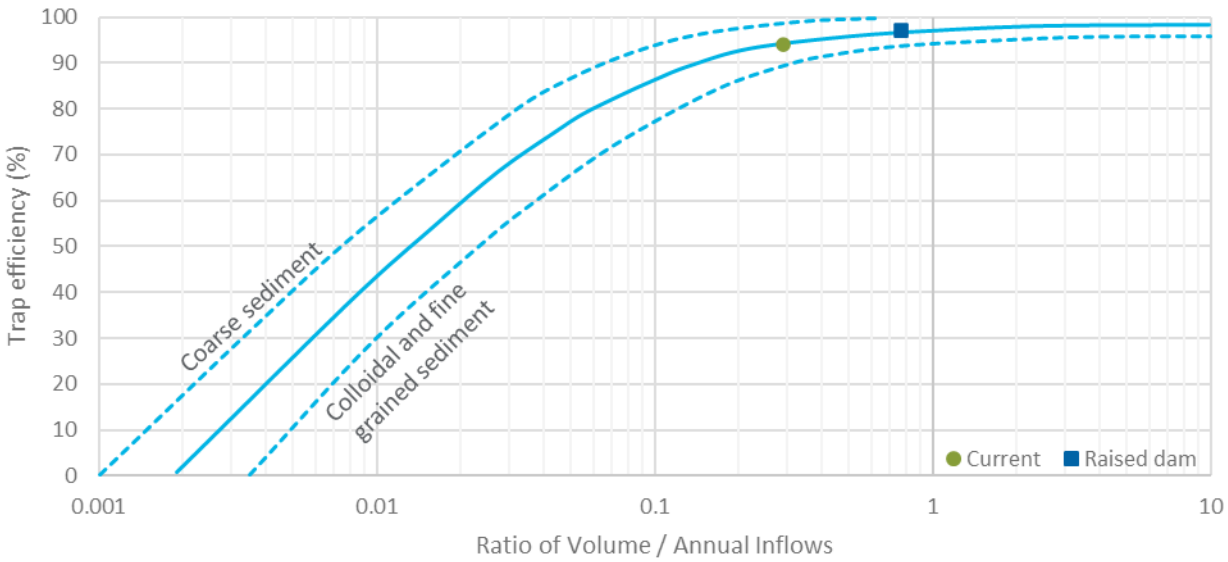


Figure 5.22 Estimated sediment trapping efficiency (Brune, 1953)

Peak concentrations of suspended solids near the surface of the reservoir are likely to be greatly attenuated in the raised dam (Figure 5.23) due to increased retention time allowing for settling of fine particles, with the result that sediment trap efficiency is likely to increase to 97% (Figure 5.22).

A modified sediment trap estimation method which scales trap efficiency based on daily inflow (Lewis, et al., 2013) provided very similar estimates of 94.2% and 96.8% sediment trapping for the existing and raised dam. On this basis 5.8% of sediment from the catchment upstream from the dam might currently be discharged downstream of the dam, and this could fall to 3.2% of sediment following dam wall raising.

This change in sediment trap efficiency represents a large proportional change (45% less sediment exiting the reservoir following dam wall raising), but small absolute change (little sediment currently exits the dam, and this is not expected to change).

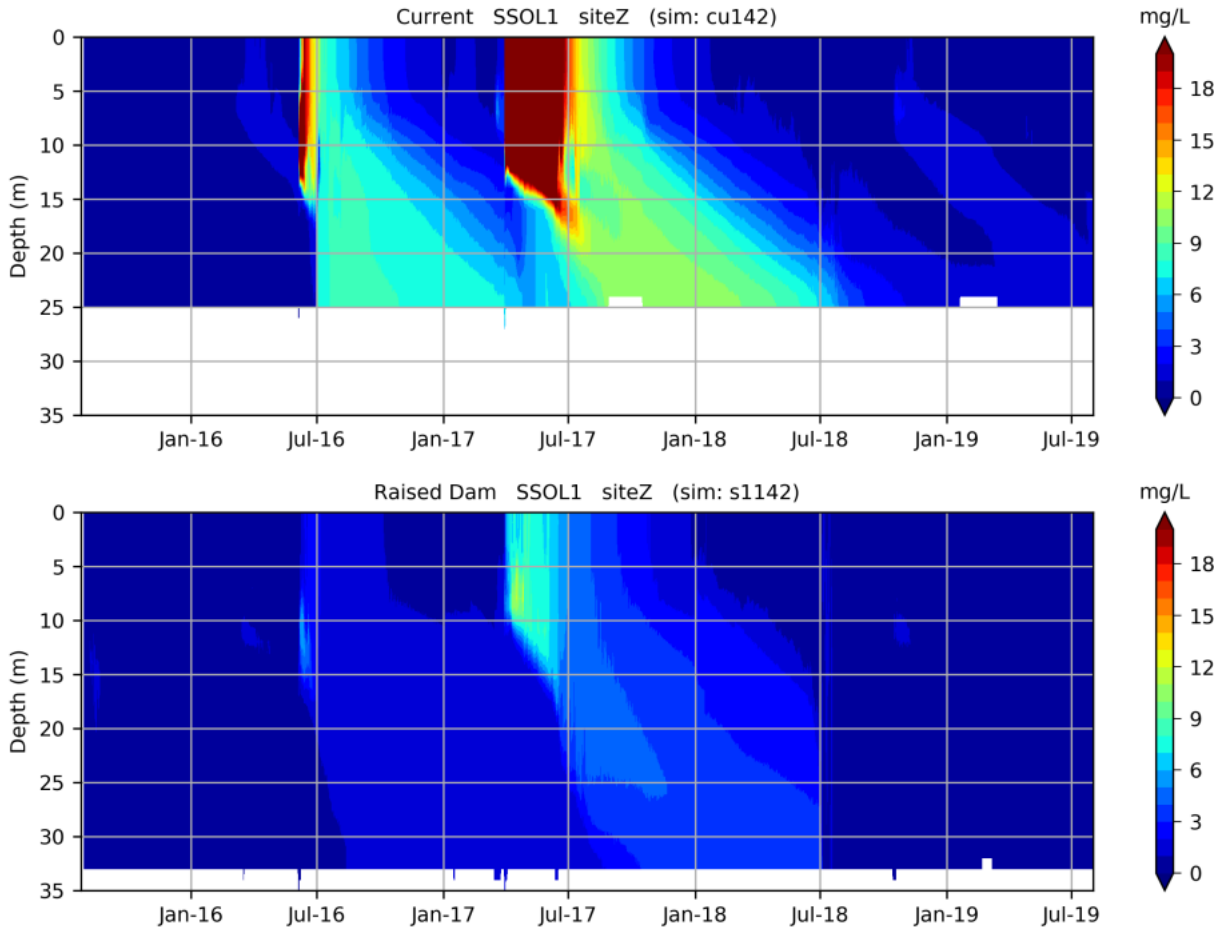


Figure 5.23 Simulated fine clay concentrations within the existing dam and raised dam

5.8.3 Potential for geomorphic change

The decrease in sediment supply in Doon Doon Creek downstream from the dam following wall raising will promote erosion of fine particles downstream, where these exist, while the decrease in high flows will 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 relatively small. As such, any geomorphological change which does occur is expected to occur as slow adjustments over an extended period of time.

In locations with a gravel/rocky bed it is likely that no geomorphological change will occur due to the project. Rocks of the sizes observed in the river bed 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 project.

5.9 Water sharing plan changes required

No changes to the WSP are required to accommodate raising the Clarrie Hall Dam wall.

However, it may be desirable to amend flow triggers in the WSP which reference reservoir capacity. Currently the WSP provides rules that govern target flow releases from Bray Park Weir based on the storage volume in Clarrie Hall reservoir (Table 5.3). Such amendments are not essential for Proposal operation, and can be considered via a separate process after Proposal approval.

Table 5.3 Bray Park Weir flow triggers

Trigger	Flow target
Clarrie Hall reservoir <75% capacity	≥ 8 ML/d
Clarrie Hall reservoir 50-75% capacity	≥ 5 ML/d
Clarrie Hall reservoir <50% capacity	≥ 3 ML/d

6 Surface water impact assessment

6.1 Construction

Potential surface water effects associated with construction activities identified and discussed in Chapter 4 are presented in a risk framework in Table 6.1 with reference to the risk assessment method discussed in Section 1.8.

After application of proposed mitigation measures, one potential hazard retained a risk rating greater than 'low', discussed further in section 6.3.

6.2 Ongoing

Potential surface water effects associated with the ongoing operation of the raised Clarrie Hall Dam are identified and discussed in Chapter 5 and presented in a risk framework in Table 6.2 with reference to the risk assessment method discussed in Section 1.8.

After application of proposed mitigation measures, one potential hazard retained a risk rating greater than 'low', discussed further in section 6.3.

6.3 Residual risk

6.3.1 Construction

i Mobilisation of fill material placed in Doon Doon Creek to provide access to the spillway construction area and downstream face of the dam wall

Erosion modelling and pad design has not been undertaken as part of the EIS, but would be completed prior to construction. Given the size of proposed construction pad area, the mass of material mobilised in a larger flood could be in the order of 1,000 m^3 if no mitigation measures were undertaken, reducing to the order of 0-10 m^3 with SWMP mitigation measures.

6.3.2 Ongoing

i Algae and associated water quality effects in Don Doon Creek and Tweed River

Limnology modelling indicated that an increase in primary production, meaning rate of algae growth, is likely following dam wall raising.

The modelling illustrated that releases of PO_4 from sediment in the enlarged hypolimnion of the raised dam would result in an increase to concentrations of total phosphorus, PO_4 and consequently Chl-a. Compounding this risk is the prediction that cyanophytes (blue-green algae), which are currently dominant during the summer months, may become more dominant throughout the year as a result of climate change impacts (in particular the direct and indirect impacts of increased air temperature).

Previously installed mixing devices in Clarrie Hall Dam have been somewhat effective in redistributing temperature gradients and have weakened, but not eliminated, thermal stratification. The overall performance of the mixers, however, has proven unsatisfactory and Hunter H2O (2018) conclude from the monitoring data that mechanical mixers cannot maintain:

- complete thermally destratified conditions
- stable and sufficient dissolved oxygen concentrations throughout the water column
- low and stable iron and manganese concentrations

- low and stable cyanobacterial populations.

Given the increased depth of the raised dam and the predicted increase in internal loading of nutrients from the hypolimnion under anoxic conditions is it considered unlikely that a destratification system with the specifications of the previous system will effectively mitigate the water quality risks that have been identified.

Implementation of a destratification system is not a part of the Proposal.

Historical monitoring of algae within Doon Doon Creek, the reservoir, and the Tweed River has indicated frequent non-detection of blue-green algae within the Tweed River downstream from the reservoir even when the dam is full and spilling (section 3.9.2vi). When detections occur in the Tweed River, cell counts are typically one or more orders of magnitude lower than in the reservoir. There is no strong correlation between algal counts in the reservoir and algal counts in the Tweed River, and as such it is likely that increased algal counts in the reservoir due to raising will not result directly in a commensurate increase in algal counts in the river.

Dam water quality monitoring is proposed. If the simulated algae increases are realised, Council will apply the best available science and value for money approaches available at the time to reduce algae concentrations to acceptable levels, or otherwise mitigate algae effects. The Proposal will not preclude or prevent the adoption of physical mitigation measures (eg a bubbler or destratification system) being considered and implemented if this is ultimately warranted.

Table 6.1 Summary of construction activity effects

Section	Hazard					Unmitigated risk			Mitigation measures	Mitigated risk		
	Description	Type	Source	Pathway	Receptor	Likelihood	Significance	Risk		Likelihood	Significance	Risk
4.3	**Dam wall embankment construction**											
	Mobilisation of sand or earth to Doon Doon Creek	Water quality	Earthworks	Rainfall runoff	Doon Doon Creek	Almost Certain	Moderate	High	Sediment and erosion management plan. Monitoring and adaptive management.	Unlikely	Minor	Low
4.3.3	**Spillway construction**											
	Mobilisation of rock fragments to Don Doon Creek	Water quality	Earthworks	Rainfall runoff	Doon Doon Creek	Almost Certain	Moderate	High	Sediment and erosion management plan for events up to the 1% AEP.	Unlikely	Minor	Low
	Transport of unused explosives to Don Doon Creek	Water quality	Explosives storage	Inundation of explosives storage	Don Doon Creek	Possible	Moderate	Significant	Storage of explosives according to Australian Standards and legislation. Sediment and erosion management plan for events up to the 1% AEP. Site located outside 1% AEP flood zone.	Unlikely	Minor	Low
	Transport of explosives residue to Don Doon Creek	Water quality	Blasting	Rainfall runoff or inundation	Don Doon Creek	Possible	Minor	Medium	Blast management plan. Erosion and sediment control plan. Use of blasted rock on site. Monitoring and adaptive management.	Rare	Negligible	Low
4.4	**Construction compound**											
	Transport of construction materials to Doon Doon Creek during site clearing and construction	Water quality	Earthworks	Rainfall runoff	Doon Doon Creek	Almost Certain	Moderate	High	Construction Soil and Water Management Plan including swales and sediment basins. Monitoring and adaptive management.	Unlikely	Minor	Low
	Transport of concrete batching materials to Doon Doon Creek	Water quality	Concrete batching plant	Rainfall runoff	Doon Doon Creek	Almost Certain	High	Extreme	Separation of clean and dirty water. Bunding. Vehicle washdown. Industrial wastewater collection and recycling. Monitoring and adaptive management. Concrete batching area located outside 1% AEP flood zone. Water Management Plan.	Unlikely	Minor	Low
	Transport of construction materials to Doon Doon Creek from stockpiles	Water quality	Laydown yard stockpiles	Rainfall runoff	Doon Doon Creek	Almost Certain	Moderate	High	Integrated Water Cycle Plan including swales and sediment basins. Construction area located outside 1% AEP flood zone. Monitoring and adaptive management.	Unlikely	Minor	Low
4.4.1	**Quarries and borrow areas**											
	Transport of construction materials to Clarrie Hall Dam from quarry areas	Water quality	Earthworks	Rainfall runoff	Clarrie Hall Dam reservoir	Almost Certain	Moderate	High	Separation of clean and dirty water. Construction Soil and Water Management Plan including swales and sediment basins. Monitoring and adaptive management.	Unlikely	Minor	Low
4.4.2	**Road construction**											
	Soil mobilisation during road widening or construction	Water quality	Earthworks and road construction	Rainfall runoff	Doon Doon Creek	Likely	Minor	Medium	Erosion and sediment control plan.	Unlikely	Minor	Low
	Soil mobilisation from existing tracks to Doon Doon Creek	Water quality	Vehicle movements	Rainfall runoff	Doon Doon Creek	Possible	Negligible	Low	Potential to pave high traffic roads if experiencing damage.	Unlikely	Negligible	Low

Table 6.1 Summary of construction activity effects

Section	Hazard					Unmitigated risk			Mitigation measures	Mitigated risk		
	Description	Type	Source	Pathway	Receptor	Likelihood	Significance	Risk		Likelihood	Significance	Risk
	Fill mobilisation from spillway and dam wall access pad to Doon Doon Creek	Water quality	Fill deposited downstream from the dam wall to allow access	Spillway discharge following rainfall	Doon Doon Creek	Almost certain	Moderate	High	Install culverts with capacity to pass minor flows. Utilise larger diameter rock which will be resistant to mobilisation.	Possible	Moderate	Significant
	McCabes Bridge construction material transported to the creek	Water quality	Bridge construction within creek	Streamflow	Clarrie Hall Dam reservoir	Possible	Moderate	Significant	Construction Soil and Water Management Plan including measures for pile bore effluent management. Silt and soil traps. Undertake pile construction work when no rain is forecast.	Unlikely	Minor	Low
	Erosion near McCabes Bridge piers or abutments in high flow	Water quality	Altered creek geometry	Streamflow	Clarrie Hall Dam reservoir	Possible	Moderate	Significant	Design and construct to current standards, with reference to known flood regime.	Rare	Minor	Low
4.5	**Construction water requirements and sources**											
	Insufficient construction water available	Water quantity	Construction water demand	Construction program	Tweed Shire Council	Likely	High	High	Water volumes required identified. Arrangements to be made with Council for supply from Clarrie Hall Dam.	Unlikely	Minor	Low
	Insufficient potable water available	Water quantity	Construction crew and concrete production water demand	Construction program	Tweed Shire Council	Likely	High	High	Water volumes required identified. Supply via packaged filtration plant.	Unlikely	Minor	Low
	Diesel spill during water pump refuelling, with diesel flowing into the reservoir	Water quality	Diesel	Downhill slope from spill site to reservoir	Clarrie Hall Dam reservoir	Unlikely	Minor	Low	Bunding of pump diesel tanks. Spill kits. Pumps located on flatter ground away from slopes where possible.	Rare	Negligible	Low
	Diesel spill at fuel storage location	Water quality	Diesel	Downhill slope from spill site to a waterway	Doon Doon Creek or Tweed River	Unlikely	Moderate	Medium	Bunding of diesel tanks. Spill kits. Tanks located on flat ground. Storage in accordance with AS1940.	Rare	Negligible	Low
4.6	**Flow regime during construction**											
	Blocking natural creek flows during dam construction, leading to a change in streamflow regime	Flow regime	Embankment construction	Construction schedule	Doon Doon Creek	Possible	Minor	Medium	Construction of new spillway prior to closing the existing spillway.	Rare	Negligible	Low

Table 6.2 Summary of post construction ongoing effects

Section	Hazard					Unmitigated risk			Mitigation measures	Mitigated risk		
	Description	Type	Source	Pathway	Receptor	Likelihood	Significance	Risk		Likelihood	Significance	Risk
5.6	**Changes to the flow regime**											
	Change in the frequency of flow events which prompt fish migration	Flow regime	Fish migration requirements	Reduction in spillway flows Reduction in peak flood flows Larger reservoir capacity leading to occasional extended periods with minimum releases only	Fish species, in particular Australian Bass	Unlikely	Minor	Low	No mitigation planned	Unlikely	Minor	Low
5.7	**Limnology**											
	Cold shock to fish or other biota in Doon Doon Creek	Water quality	Release of cold water	Stratification in summer and algal bloom leading to take off from deeper in the water column	Doon Doon Creek biota	Possible	Moderate	Significant	Use of existing multi-level outlet. Monitoring of stratification via temperature and other physical/chemical indicators. Slow ramp up of water releases to prevent sudden temperature changes. This risk is not expected to increase due to the Proposal.	Unlikely	Minor	Low
	Algae and associated water quality effects in Don Doon Creek and Tweed River	Water quality	High algae content in reservoir	Water releases	Don Doon Creek and Tweed River biota, Council water treatment plants	Possible	Minor	Medium	Use of existing multi-level outlet.	Possible	Minor	Medium
	High nutrient concentration in the reservoir proving period	Water quality	Reservoir inundation	Aerobic / anaerobic breakdown of submerged vegetation	Reservoir water quality	Likely	Minor	Medium	Remove biomass prior to reservoir commissioning as far as practical (ie biomass may remain on steeper slopes and locations which are difficult to access).	Likely	Negligible	Low
	High turbidity during the reservoir proving period	Water quality	Reservoir inundation	Runoff from disturbed areas within the new or old reservoir extent	Reservoir water quality	Likely	Minor	Medium	Leave stumps in place when clearing vegetation. Sediment and erosion plans for all construction activity. Rehabilitation plan for the existing reservoir.	Likely	Negligible	Low
5.8	**Geomorphology**											
	Reduced deposition of fine sediment in low energy zones of the river system	Geomorphology	Capture of sediment in new dam	Reduced suspended sediment delivery to the river system downstream of the dam	Doon Don Creek bed and banks	Unlikely	Negligible	Low	No mitigation planned.	Unlikely	Negligible	Low
	Slow change to Doon Doon Creek morphology, unpredictable direction and magnitude	Geomorphology	Decreased frequency of higher flow events	Decreased frequency of bed material mobilisation in Doon Doon Creek	Doon Doon Creek bed and banks	Unlikely	Negligible	Low	Manage offtake operations to minimise impact. Either allow river channel to alter morphology and accept the changes, perhaps with offsets, or undertake selected channel mitigation works in response to identified problems.	Unlikely	Minor	Low
	Slow change to Tweed River morphology, unpredictable direction and magnitude	Geomorphology	Decreased frequency of higher flow events	Decreased frequency of bed material mobilisation in Tweed River	Tweed River bed and banks	Rare	Negligible	Low	Manage offtake operations to minimise impact.	Rare	Minor	Low

7 Surface water monitoring plan

7.1 Overview

This section of the report describes a surface water monitoring program that will be implemented over the duration of construction. The primary objectives of the monitoring program are to:

- provide additional monitoring of baseline conditions
- enable the effectiveness of water quality controls to be assessed
- identify and quantify any water quality impacts
- identify and quantify any potential impacts on streamflows
- enable compliance with relevant consent and licence conditions to be assessed.

The following sections outline the proposed water monitoring strategy.

After completion of the proposed works, the pre-construction stream and reservoir monitoring regime would be reinstated.

7.2 Monitoring program

The monitoring program, including monitoring locations and frequency, will be developed and documented as part of the SWMP for the project, following Proposal approval. This would include:

- determination of ongoing monitoring locations
- determination of frequency of required monitoring (typically would include continuous, regular interval and event based and event-based monitoring)
- development of a targeted analytical suite
- formalisation of a reporting strategy for water quality monitoring results.

The monitoring program includes requirements to monitor weather, streamflows, process water quantity and quality, stormwater quality and receiving water quality. Existing streamflow and water quality monitoring sites will continue to be utilised as part of the monitoring plan. However, any gaps in the coverage of this network will be addressed through the development of the plan.

Table 7.1 provides a summary of the recommended monitoring program and indicative monitoring locations for the Proposal.

Table 7.1 Surface water monitoring program framework

Aspect	Objectives	Monitoring locations	Monitoring methods
Weather	Record rainfall and other meteorological conditions. Provide improved coverage of rainfall monitoring during construction phase.	Within the Clarrie Hall Dam catchment. At the new Clarrie Hall Dam site.	Review options to install and operate a weather station at the new Clarrie Hall Dam site. Explore options to access real-time data for Bureau of Meteorology gauges.
Streamflow	Measure continuous streamflows at locations potentially affected by Proposal activities.	Locations to be determined during planning. Existing NSW Government monitoring network.	Review options for stream gauge installation immediately upstream and downstream from the Clarrie Hall Dam reservoir. Continue to operate stream gauges (and associated water quality monitoring) across the study area catchments.
Process water quantity	Measure all process water uses, sources and controlled discharge volumes.	All process water use points including dust suppression and the concrete batching plant. Construction site stormwater runoff captured in management ponds. Water supplied from other sources.	Cumulative flow meters will be installed at all monitoring locations. Meter readings will be recorded weekly.
Receiving water quality	Monitor receiving water quality to: • establish baseline conditions • identify impacts to water quality.	Receiving waters upstream and downstream of discharge sites to include: • existing Clarrie Hall Dam (prior to decommissioning) • raised Clarrie Hall Dam (post construction) • existing water quality gauge sites.	A minimum of 12 samples per year will be collected from each monitoring location. Sampling will be undertaken during base flow, wet weather and after wet weather conditions. All samples will be analysed for a comprehensive suite of parameters[1].
Process water quality	Monitor the quality of water within the process water management system.	Tanks and sumps used for recycling process water.	Sampling will be undertaken on a monthly basis. All samples analysed for a comprehensive suite of parameters[1].
Stormwater quality	Monitor the quality of water within stormwater management basins.	Construction area stormwater basin(s) for all sites.	A minimum of 12 samples per year will be collected from each monitoring location. Sampling will be undertaken during base flow, wet weather and after wet weather conditions. All samples analysed for a comprehensive suite of parameters[1].
Access road runoff	Monitor the quality of runoff from access roads during construction	Monitoring will be undertaken at six random discharge locations each monitoring round.	Event based sampling[1] and inspection of sediment and erosion controls will be undertaken following material wet weather events[2].

Table 7.1 Surface water monitoring program framework

Aspect	Objectives	Monitoring locations	Monitoring methods
		Discharge locations refer to any location where access road drainage enters a clean water drainage system. This may be overflow from a swale, sedimentation basin or sediment trap.	A minimum of 4 samples per year will be collected from each monitoring location during wet weather conditions. All samples analysed for a comprehensive suite of parameters[1].
Construction disturbance area	Monitor the quality of runoff from areas disturbed by construction. To include (as a minimum) all construction areas, access roads and existing Dungowan Dam decommissioning.	Monitoring locations will be established as part of the detailed sediment and erosion control plans that will be prepared for each construction zone.	Event sampling[1] and inspection of sediment and erosion controls will be undertaken following material wet weather events[2]. A minimum of 4 samples per year will be collected from each monitoring location during wet weather conditions. All samples analysed for a comprehensive suite of parameters[1].
Reservoir water quantity	Monitor reservoir storage volume.	Dam wall or MLO tower.	Continuous reading from a calibrated pressure sensor.
Reservoir water quality	Monitor the quality of water within the new reservoir during filling and operation.	Locations to be determined during planning.	A minimum of 12 samples per year will be collected from each monitoring location. Samples will be collected at surface and regular depth intervals. All samples to be analysed for a comprehensive suite of parameters including algal cell counts[1].
Reservoir water temperature	Monitor reservoir thermal stratification.	Locations to be determined during planning.	Continuous temperature monitoring at surface and regular depth intervals via water temperature probe.
Doon Doon Creek and Tweed River water temperature	Monitor cold water pollution mitigation effectiveness.	Downstream of the dam, within 1 km of the dam outlet. Within the Tweed River Creek near Uki.	Continuous temperature monitoring via water temperature probe for a period of 2 years post commissioning.

Notes: 1. Refer to section 7.3 for more information on the monitoring regime, sampling analytes and analysis methods.
2. A material wet weather event refers to any rainfall event that results in the discharge of surface water from the project's water management dams.

7.3 Monitoring regime and methods

Table 7.2 details the indicative monitoring regime for each monitoring category, while Table 7.3 details the proposed sampling analytes and analysis methods.

Table 7.2 Indicative monitoring regime

	Continuous	Monthly	Low flows	Wet weather (comprehensive)	After wet weather	Wet weather (Basic)
Frequency	**Continuous**	**Monthly**	**Quarterly**	**Quarterly**	**Quarterly**	**Event Based**
Method	**Automated gauge**	**Comprehensive**	**Comprehensive**	**Comprehensive**	**Comprehensive**	**Basic**
Stream gauge	X					
Receiving water			X	X	X	
Process water		X				
Stormwater				X	X	X
Access road				X		X
Construction area				X		X
Reservoir	X	X				

Table 7.3 Indicative monitoring methods

Category	Proposed sampling analytes	Analysis method
	Basic monitoring	
Physio-chemical properties	pH, electrical conductivity, turbidity, dissolved oxygen, temperature, redox potential	To be measured using a portable water quality meter in the field.
Inspection	Visual inspection	Inspection of erosion and sediment controls and downstream drainage.
	Comprehensive monitoring	
Physio-chemical properties	pH, electrical conductivity, turbidity, dissolved oxygen, temperature, redox potential	To be measured using a portable water quality meter in the field.
	Major cations (Na, K, Mg, Ca) and major anions (Cl, SO_4, HCO_3 and CO_3)	Analysis to be undertaken by a NATA certified laboratory.
	Total suspended solids, total dissolved solids, total hardness, total recoverable hydrocarbons	
Nutrients	Total nitrogen, ammonia, nitrate, nitrite and total Kjeldahl nitrogen	

Table 7.3 Indicative monitoring methods

Category	Proposed sampling analytes	Analysis method
	Total phosphorus and reactive phosphorous	
	Total organic carbon, dissolved organic carbon	
Metals (dissolved)	Al, As, Ag, B, Ba, Cr (total), Co, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Se, V and Zn	
	Reservoir monitoring	
Physio-chemical properties	pH, electrical conductivity, turbidity, dissolved oxygen, temperature, redox potential	To be measured using a portable water quality meter in the field.
	Major cations (Na, K, Mg, Ca) and major anions (Cl, SO_4, HCO_3 and CO_3)	Analysis to be undertaken by a NATA certified laboratory.
	Total suspended solids, total dissolved solids, total hardness, total recoverable hydrocarbons	
Nutrients	Total nitrogen, ammonia, nitrate, nitrite and total Kjeldahl nitrogen	
	Total phosphorus and reactive phosphorous	
	Total organic carbon, dissolved organic carbon	
Metals (dissolved)	Al, As, Ag, B, Ba, Cr (total), Co, Cd, Cu, Fe, Hg, Mn, Ni, Pb, Se, V and Zn	
Algae cell counts	Total blue green algae cell counts	
Temperature	Water temperature	To be measured in the field using permanently installed equipment.
Volume	Pressure at the base of the reservoir	

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Annexure A
Flow modelling

EMM
creating opportunities

Flow modelling

Surface water assessment

Prepared for Tweed Shire Council

August 2024

Flow modelling

Surface water assessment

Tweed Shire Council

E230039 Annexure A

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This report has been prepared in accordance with the brief provided by Tweed Shire Council and has relied upon the information collected at the time and under the conditions specified in the report. All findings, conclusions or recommendations contained in the report are based on the aforementioned circumstances. The report is for the use of Tweed Shire Council and no responsibility will be taken for its use by other parties. Tweed Shire Council may, at its discretion, use the report to inform regulators and the public.

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Glossary

Key terminology is briefly defined as follows to assist in interpretation of this technical annexure.

Allocation	
Water Allocation	The volumetric quantity of water that can actually be taken during any year, consequent to Water Allocation Announcement(s).
Allocation Announcement	The basis upon which Water Allocation is calculated from time to time. It may take the form of an Initial Announcement at the beginning of the Water Year or a Supplementary Announcement during the Water Year. It is expressed as a percentage of Entitlement.
d/s	Downstream.
Entitlement	The volumetric quantity of water specified on the licence as being the maximum that can be taken during any year, subject to Allocation Announcement(s).
Flow regime	A description of the quantity and timing of streamflows, including the seasonal frequency of events such as no flow and flood flows.
Historical	In the context of this report, 'historical' refers to: - records of observed climate - the SILO interpolation of observed climate records - results of model simulations which used either of the above climate data sources.
IPCC	Intergovernmental Panel on Climate Change
Regulated river	A river for which a licensed entitlement regime exists with centralised allocation, and from which orders may be placed for upstream release of a licensed allocation. A necessary, but not sufficient, condition for a river to be regulated is that it is located downstream of a surface water storage.
Source (model)	eWater Source. Australia's National Hydrological Modelling Platform (NHMP). A software model platform designed to simulate all aspects of water resource systems to support integrated planning, operations and governance from urban, catchment to river basin scales including human and ecological influences.
TWS	Town water supply.
u/s	Upstream.
WSP	Water Sharing Plan. A statutory document that establishes the rules for sharing water between the environment and water users, and between competing water users. The relevant WSP for the Clarrie Hall Dam raising project is the 'Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2023'. Note that this plan commenced on 1 July 2023 and replaces the previous plan: 'Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources Order 2010'.

WRP	Water Resource Plan.

1 Introduction

1.1 Project description

Tweed Shire Council (Council) has resolved to undertake the planning and land acquisitions for the Clarrie Hall Dam Raising (CHDR) (the Proposal) as the preferred option to secure water supply for the Tweed Shire until approximately 2065. The Proposal is to raise the wall of Clarrie Hall Dam by 8.5 metres to a height of 70 metres Australian Height Datum (AHD RL70), thereby increasing the capacity of the dam from 16,720 megalitres (ML) to 42,300 ML for the purpose of water supply augmentation.

This streamflow analysis report is a technical annexure to the Surface Water Assessment and outlines the results of the river system modelling that was undertaken to inform the Environmental Impact Statement (EIS) for the Proposal. Modelling was carried out by EMM utilising the existing NSW Department of Planning and Environment – Water (DPE-Water) eWater Source model of the Tweed River System.

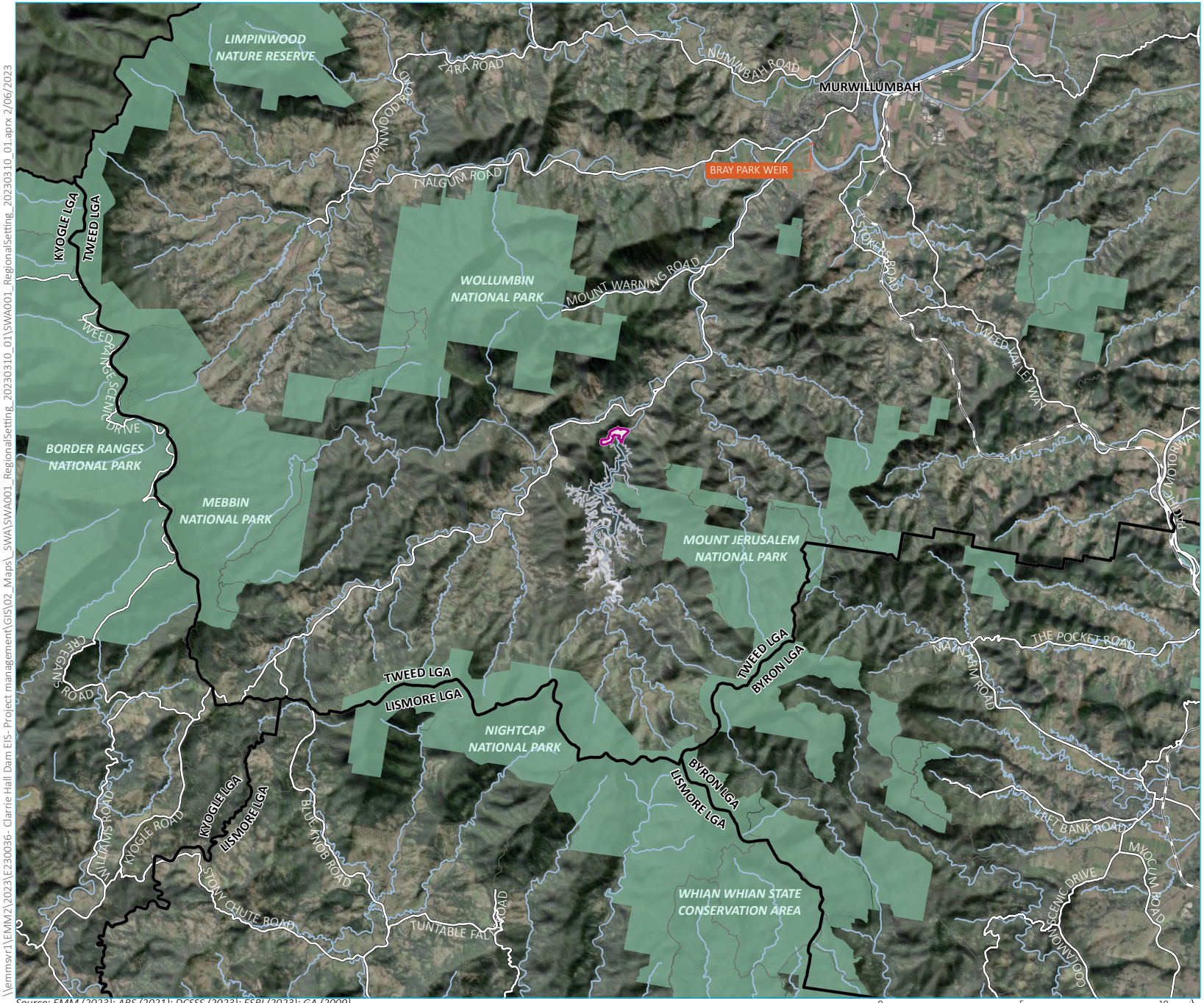
1.2 Project location

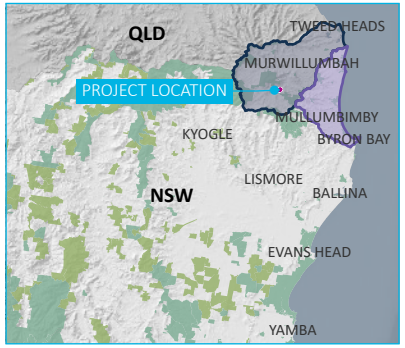
Clarrie Hall Dam is located on Doon Doon Creek in the small rural locality of Doon Doon, approximately 15 km south-west of Murwillumbah in the Far North Coast region of NSW. Doon Doon Creek is a tributary of the Tweed River, located within the Tweed Shire Local Government Area (LGA). The Tweed River provides water for irrigation and is the primary source of water supply for the Tweed Shire LGA. Clarrie Hall Dam is operated by Council to provide storage, and during drier months water is released from the dam to augment flows in the Tweed River.

The Tweed district water supply is a run of the river supply augmented by releases from Clarrie Hall Dam. Bray Park Weir, located 5 km upstream of Murwillumbah, is the point of abstraction for the district water supply and effectively acts as a tidal barrage. By raising the upstream water level, the weir maintains a pool in the river supplied by the combined flow of the Tweed and Oxley rivers. Raw water is extracted for public water supply from the pool upstream of the weir, and during low-flow periods releases from Clarrie Hall Dam are used to top-up the weir pool. Tweed Shire Council also maintain small water supply networks located at Uki and Tyalgum.

The Tweed River has a total catchment area of approximately 1,326 square kilometres (km^2) and drains the majority of the Tweed Shire LGA (1,340 km^2). The Tweed Shire LGA has a population approaching 100,000 people and borders the NSW shires of Byron, Lismore and Kyogle. Murwillumbah is a town situated in the middle of the Tweed River catchment, with a population of around 9,500. The major urban area of Tweed Heads surrounds the Tweed River estuary and is home to around half of the Shire population.

The Tweed River catchment is bounded by the McPherson Range to the north on the NSW-Queensland border, the Nightcap and Burringbar Ranges to the south and south-east, and the Tweed Range to the west. These elevated areas form the southern extent of the Scenic Rim of the Great Dividing Range and parts of these areas are designated as national parks and world heritage areas. The mountains and ranges of the Tweed Valley are remnants of the Tweed Volcano, forming a large erosion caldera that encircles the volcanic plug of Mount Warning. The regional setting of the Proposal is shown in Figure 1.1 and Figure 1.2 shows the major waterways and relevant streamflow gauges in the vicinity of the Proposal.





KEY

- Construction disturbance footprint
- Development site
- Bray Park weir
- Rail line
- Major road
- Minor road
- Named watercourse
- Named waterbody
- NPWS reserve
- Local government area

INSET KEY

- NPWS reserve
- State forest
- Brunswick catchment
- Tweed catchment

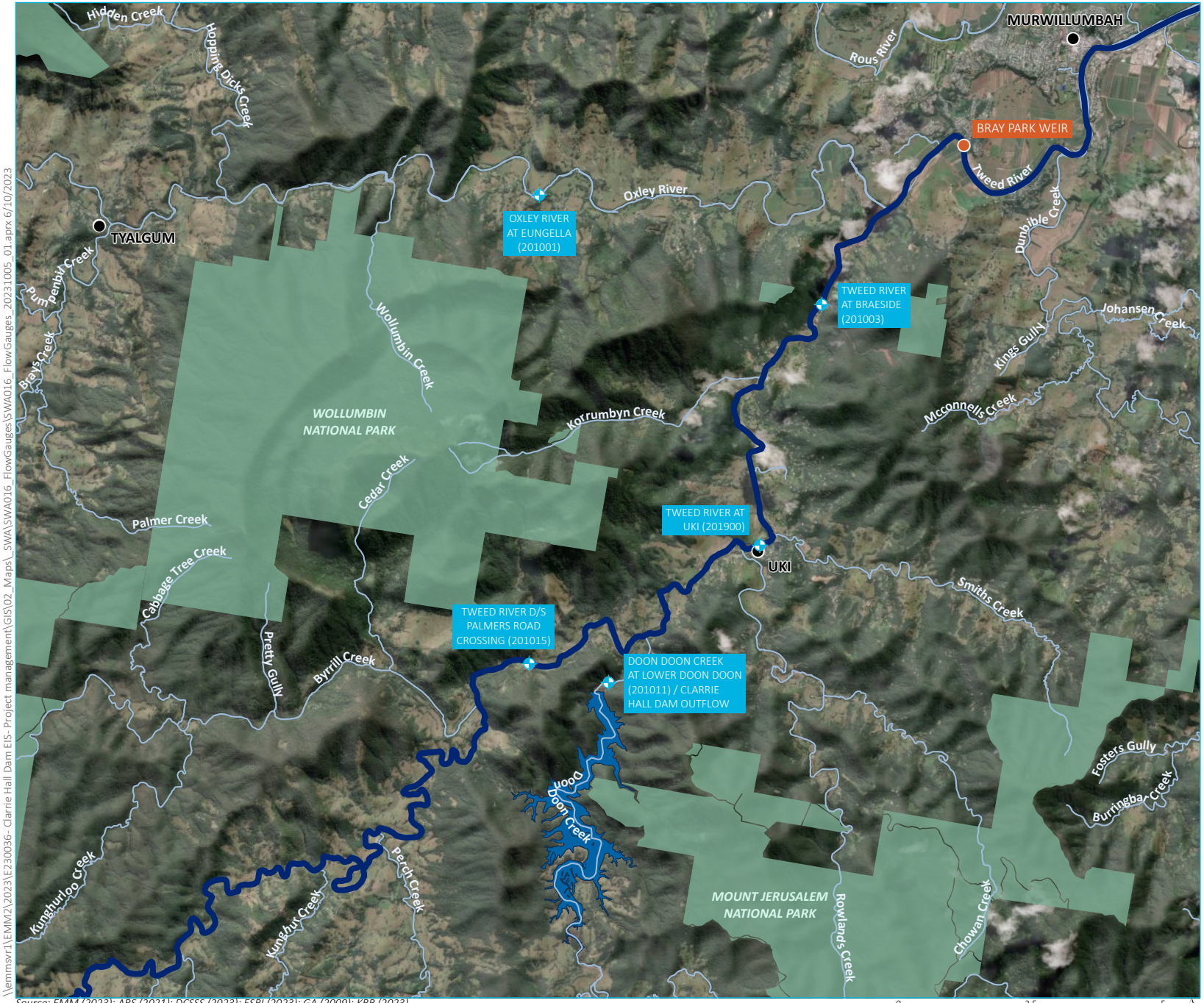
Source: EMM (2023); ABS (2021); DCSSS (2023); ESRI (2023); GA (2009)

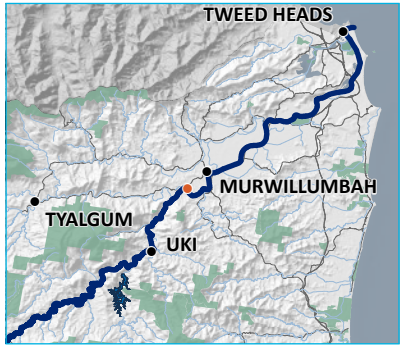
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Regional setting

Clarrie Hall Dam EIS
Surface Water Assessment
Figure 1.1

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KEY

- Stream flow gauge used for analysis
- Urban centre
- Bray Park weir
- Clarrie Hall Dam at current FSL
- Tweed River
- Waterway
- Named waterbody
- NPWS reserve

INSET KEY

- Major road
- NPWS reserve

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

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Waterways and relevant flow gauges in the vicinity of the project

Clarrie Hall Dam EIS
Streamflow Analysis
Annexure A to the Surface Water Assessment
Figure 1.2

EMM
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1.3 Annexure structure

This annexure is structured as follows:

- Chapter 2 describes the historical streamflow regime of Doon Doon Creek and the Tweed River, based on analysis of historical gauge records.
- Chapter 3 gives an overview of:
  - the NSW DPE eWater Source model of the Tweed River system which was utilised for this assessment
  - project-specific changes that were made to the model
- Chapter 4 details:
  - the input data used for analysis
  - changes made to the Source model
  - the scenarios modelled
- Chapter 5 presents results that describe the possible future streamflow regime (i.e. once the raised Clarrie Hall Dam is operational), including:
  - seasonal flow duration curves
  - tables of average annual flows and dam releases
  - statistics describing the dam storage volumes
- Chapter 6 describes the possible future streamflow regime following population growth and climate change

2 Historical flow regime

2.1 Overview

Data from a number of gauging stations was used to assess the existing flow regime of Doon Doon Creek, the Tweed River and within the Tweed Valley more broadly. Data was obtained via the Bureau of Meteorology (BoM) and from the NSW Water Data Online portal.

Streamflow in Doon Doon Creek was recorded for a 12-year period prior to the opening of Clarrie Hall Dam. Additionally, there is a record of Clarrie Hall Dam outflows (i.e. streamflow in Doon Doon Creek downstream of Clarrie Hall Dam) available from 2008 (total outflow is the sum of releases and flow over the spillway). Streamflow records for the Tweed River and the Oxley River are typically longer, with some records starting in the 1950s.

Figure 2.1 lists the streamflow gauges that were used and shows their period of record.

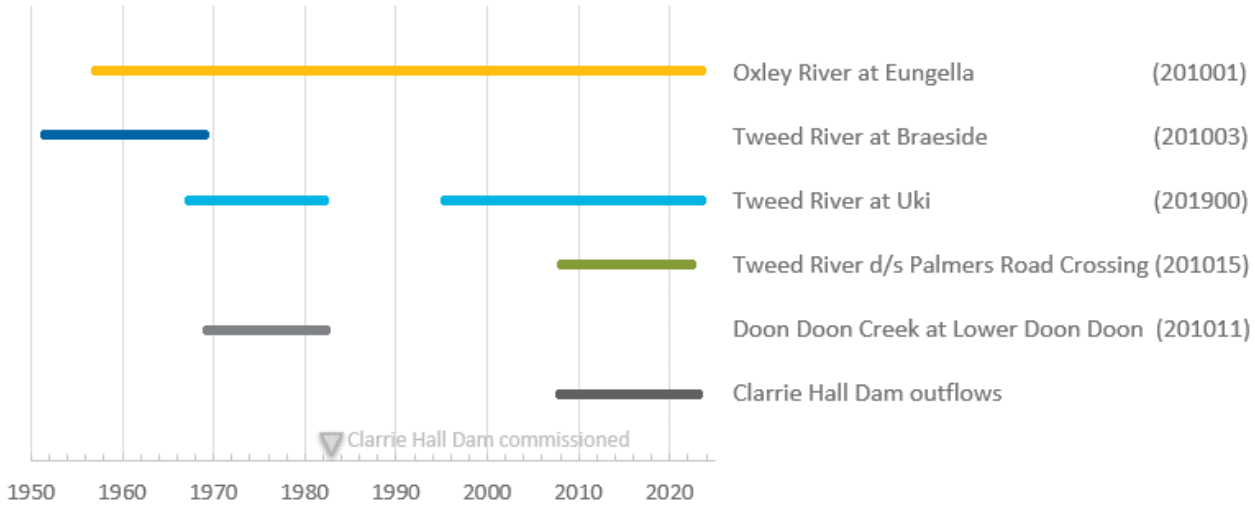


Figure 2.1 Streamflow gauge record duration

Flow regimes in the Tweed Valley follow a broadly similar pattern and are primarily driven by seasonal variation in rainfall and evaporation (Figure 2.2). Generally, streamflow is highest in Autumn, when rainfall is high and evaporation is low, and in Summer. Lower flows occur in Spring and Winter, coinciding with lower rainfall.

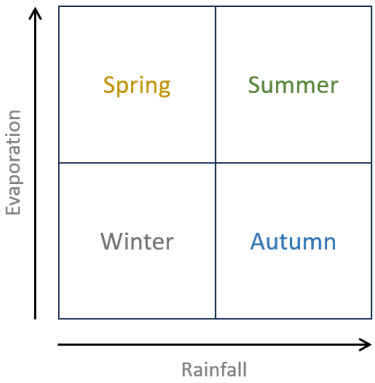


Figure 2.2 Seasonal variation in rainfall and evaporation in the Tweed Valley

Using the reference period 2009 to 2021, when there is overlap between streamflow records, Figure 2.3 shows overall and seasonal flow statistics for key streamflow gauges, along with a map showing the location of the

gauges. By using a reference period for this analysis, the varying influence of wet and dry periods on the streamflow records is removed and comparison can be made. This figure shows that:

- flows are highest in summer and autumn across all gauges
- across the total record and all seasons, median flow is below mean flow indicating that the dataset is skewed. The mean is increased by a relatively few number of days with high or very high flow, while the median reflects many days of lower flows. This is most pronounced in summer, likely due to the combination of more extreme rainfall events and drier overall conditions producing low flows.
- gauges with a larger contributing catchment area have higher flows across all statistics and seasons:
    - Oxley River at Eungella (201001), which is located on the Oxley River upstream of the confluence with the Tweed River and has a contributing catchment area of approximately 215 km^2
    - Tweed River at Uki (201900), which is located on the Tweed River upstream of the confluence with the Oxley River and has a contributing catchment area of approximately 275 km^2
- Clarrie Hall Dam outflows are the lowest flows across all statistics and seasons, corresponding to a contributing catchment area of approximately 60 km^2 for Clarrie Hall Dam.
- Clarrie Hall Dam outflows exhibit less variation in flow across the seasons compared with Tweed River d/s Palmers Croad Crossing (201015), which is located on the Tweed River upstream of the confluence with Doon Doon Creek and also has a smaller contributing catchment area of 155 km^2. This is likely due to the regulating effect of the dam on the natural streamflow regime (i.e. capturing and attenuating higher flows and meeting minimum flow release requirements).

The following sections present additional detail for these gauge locations.

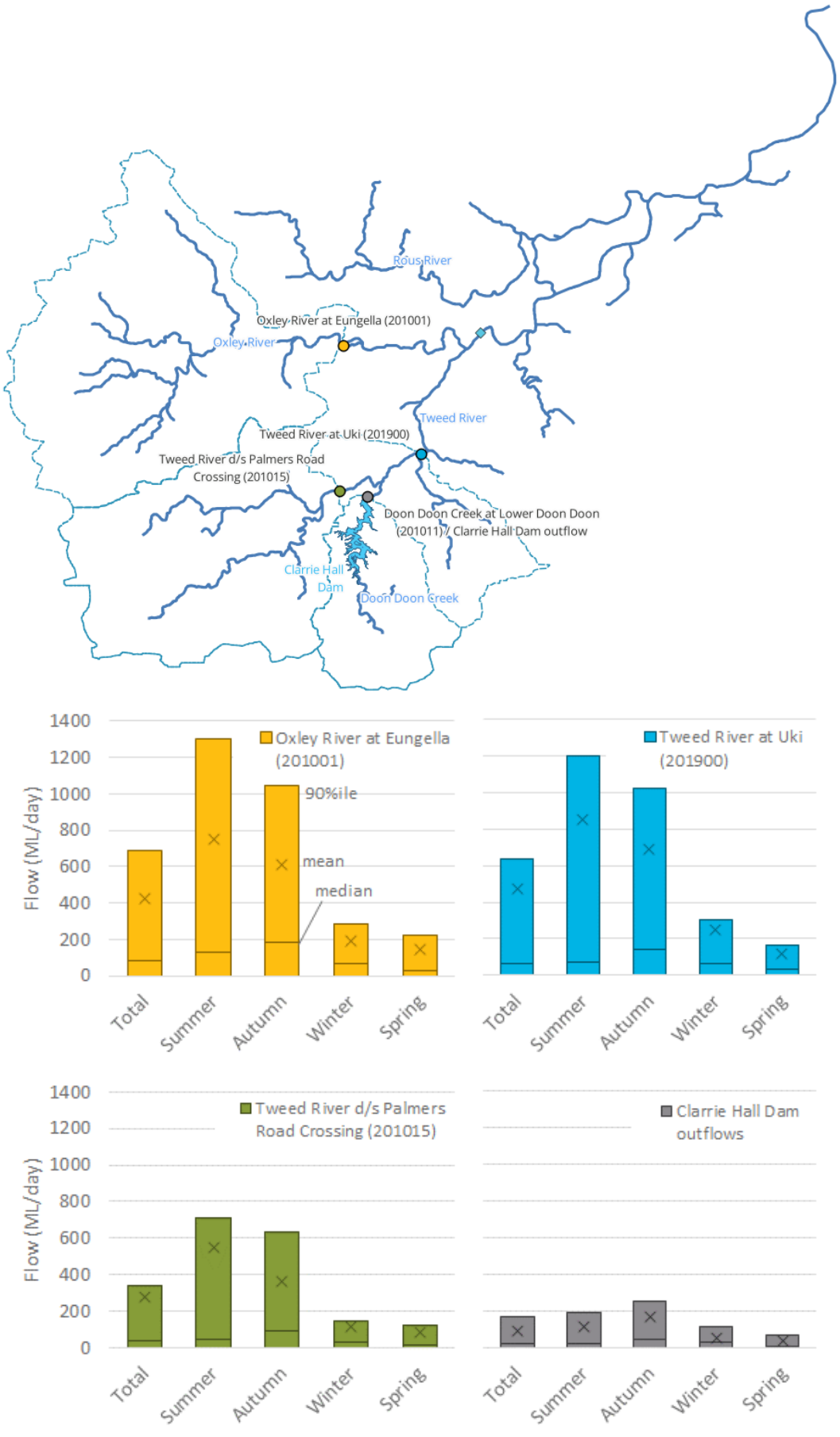


Figure 2.3 **Overall and seasonal flow percentiles for key streamflow gauges (2009–2021)**

Figure 2.4 shows the Tweed River streamflow record from January 2019 to May 2020, alongside storage levels in Clarrie Hall Dam and Clarrie Hall Dam outflows. This period includes low flow conditions in 2019, and higher flow conditions from the start of 2020.

Following drawdown in Clarrie Hall Dam in early 2019 and again in early 2020, there is a period in the streamflow record when higher flow is recorded at the Tweed River at Uki (201900) and d/s Palmers Road Crossing (201015) and only a very small release is made from Clarrie Hall Dam as storage levels recover (see 'A1' and 'A2'). This is due to runoff from the catchment area upstream of Clarrie Hall Dam being retained in the reservoir. Flow is higher at Uki due to inflows from additional catchment area.

Between September 2019 and January 2020, records show significant drawdown of Clarrie Hall Dam coinciding with very low flow recorded in the Tweed River d/s Palmers Road Crossing (201015). Flow recorded at Uki during this period is likely due to releases made from Clarrie Hall Dam for water supply purposes (see 'B') and may be lower than dam releases due to losses along the creek.

From February 2020, the streamflow record shows higher flow in the Tweed River for all gauges. Storage levels in Clarrie Hall Dam were full (i.e. > 61.5 m AHD), and during this period and the streamflow recorded at Uki is greater than that recorded at the gauge d/s Palmers Road Crossing and released from Clarrie Hall Dam (see 'C').

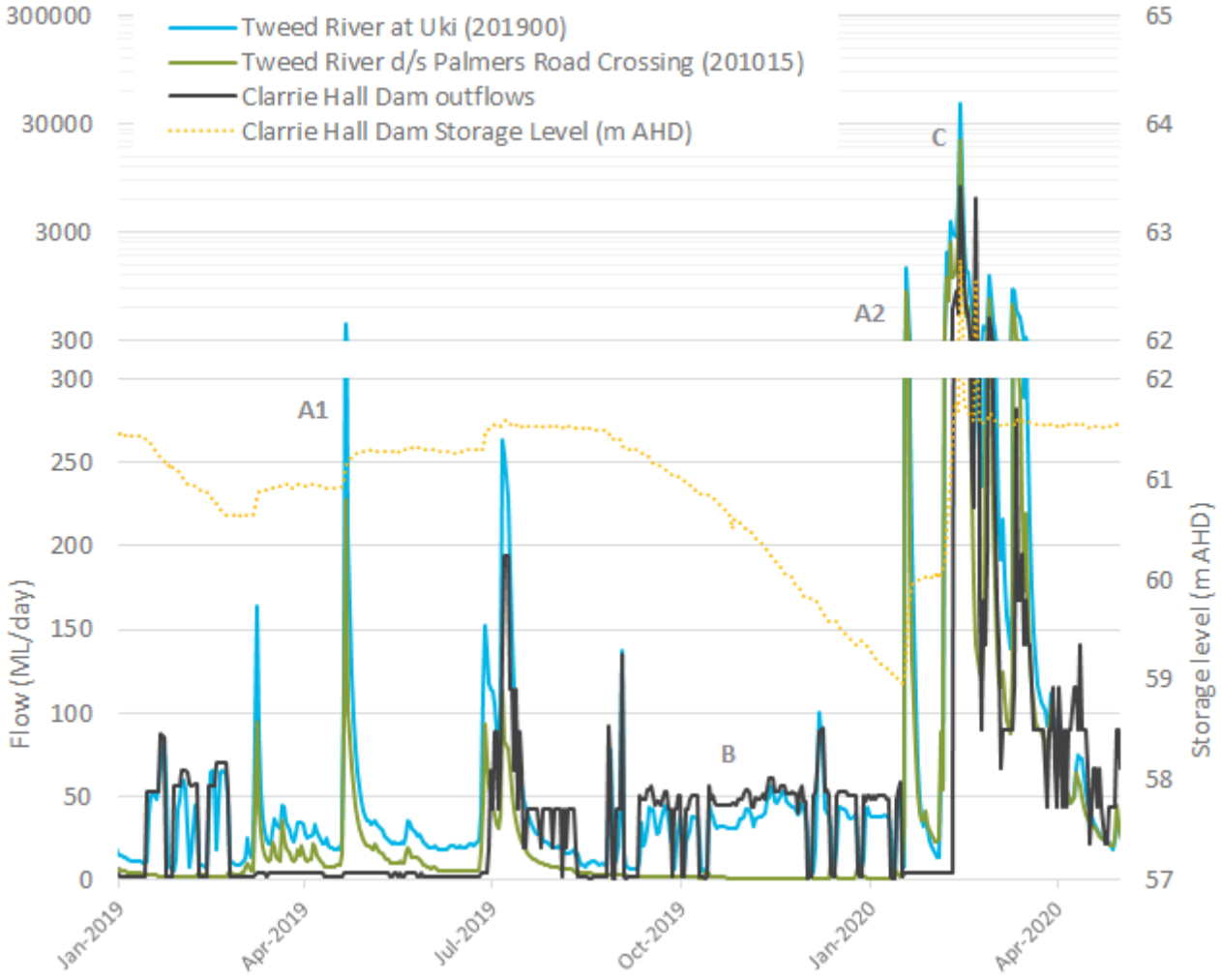


Figure 2.4 **Tweed River streamflow records, Clarrie Hall Dam outflow and storage level January 2019 to May 2020**

2.2 Doon Doon Creek seasonal flow duration curves

Flow duration curves illustrating the statistical representation of the frequency of various flow rates were produced for the Doon Doon Creek using the historical streamflow record.

The streamflow gauge on Doon Doon Creek at Lower Doon Doon (201011) was operational prior to Clarrie Hall Dam being open and therefore does not represent the current flow regime in Doon Doon Creek. However, with a contributing catchment area of approximately 55 km^2, it was located close to the current Clarrie Hall Dam and is therefore indicative of the flow regime both for inflows to Clarrie Hall Dam and for other smaller catchments within the Tweed Valley.

Flow duration curves for Doon Doon Creek at Lower Doon Doon (201011) (Figure 2.5) show that:

- in the absence of the dam, the creek is almost perennial, with no-flow on ~4% of days, with a slightly higher probability of no-flow days occurring during summer
- the flow duration curve for summer is steeper than for other seasons. Peak flows are higher in summer (i.e. with < 20% probability of exceedance), likely caused by a higher frequency of extreme rainfall events, and low flows are lower in summer (i.e. with > 80% probability of exceedance), likely due to drier catchment conditions following spring
- although flow is generally lower during winter than in summer and autumn, flow is perennial. This is likely due to wetter catchment conditions following autumn
- flows are lowest in spring

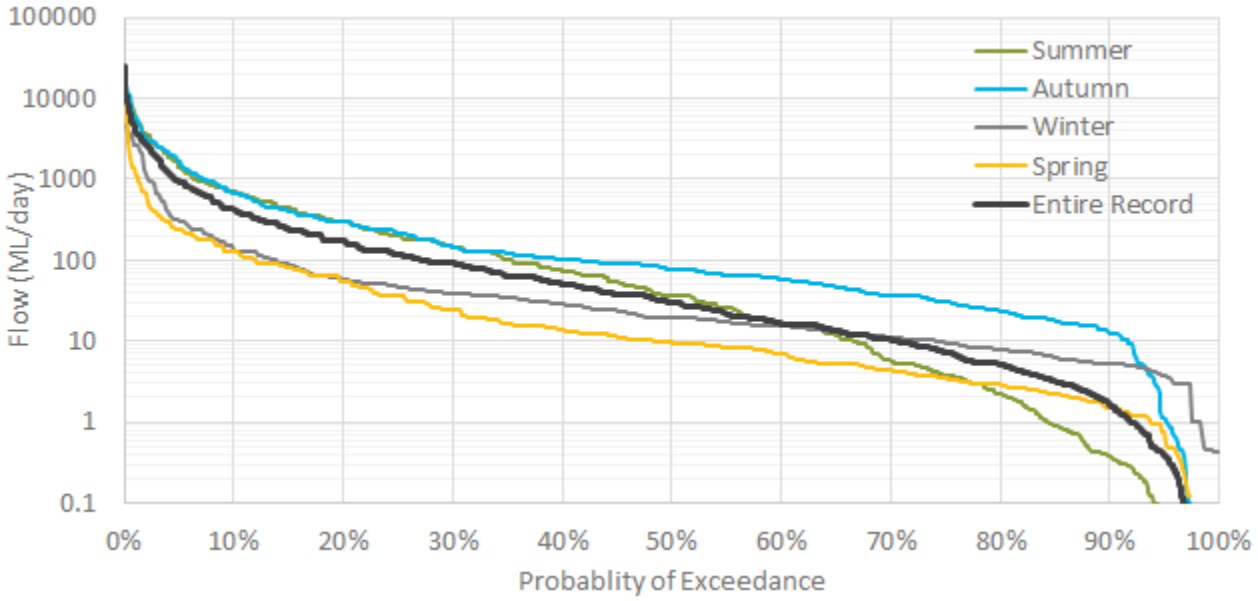


Figure 2.5 Doon Doon Creek at Lower Doon Doon (201011) seasonal flow duration curve (12 years gauge record) [Note: prior to Clarrie Hall Dam coming online]

Records for other gauges indicate that flow in the Tweed Valley is generally perennial, other than headwater catchments.

2.3 Tweed River seasonal flow duration curves

The Palmers Road Crossing (201015) gauging station is located on the Tweed River upstream of the confluence with Doon Doon Creek, and therefore is not influenced by releases from Clarrie Hall Dam. The contributing catchment area is approximately 155 km^2.

The gauging station on the Tweed River at Uki (201900) is located downstream of the Doon Doon Creek confluence and receives releases from Clarrie Hall Dam. The contributing catchment area is approximately 275 km^2.

The gauging station at Braeside (201003) is located on the Tweed River approximately 5 km downstream of the gauge at Uki. The contributing catchment area is approximately 320 km^2. It is no longer operational.

Gauges on the Tweed River demonstrate a relatively consistent flow regime through the seasons (Figure 2.6 to Figure 2.8) with:

- higher peak flows in summer than in other seasons (i.e. with < 20% probability of exceedance), likely driven by higher frequency extreme rainfall events
- higher flows in autumn than in other seasons (20%–80% probability flows) driven by higher overall rainfall and lower evaporation
- lower flows during spring than in other seasons (20%–90% probability flows), driven by lower rainfall and higher evaporation

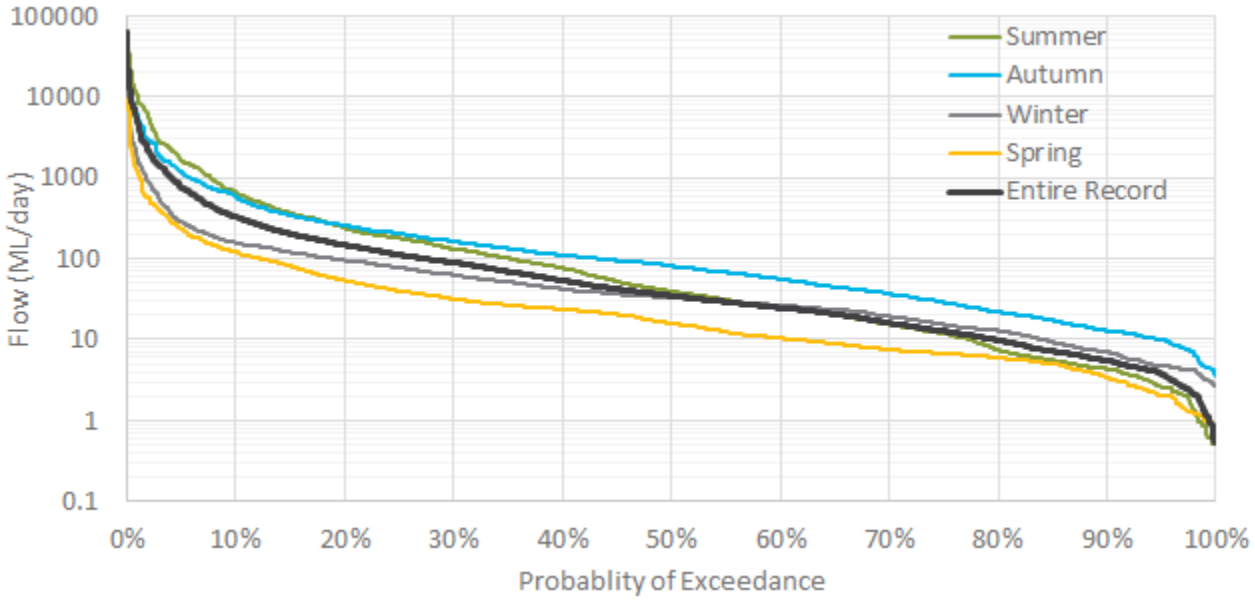


Figure 2.6 Tweed River d/s Palmers Rd Crossing (201015) seasonal flow duration curve (14 years of record)

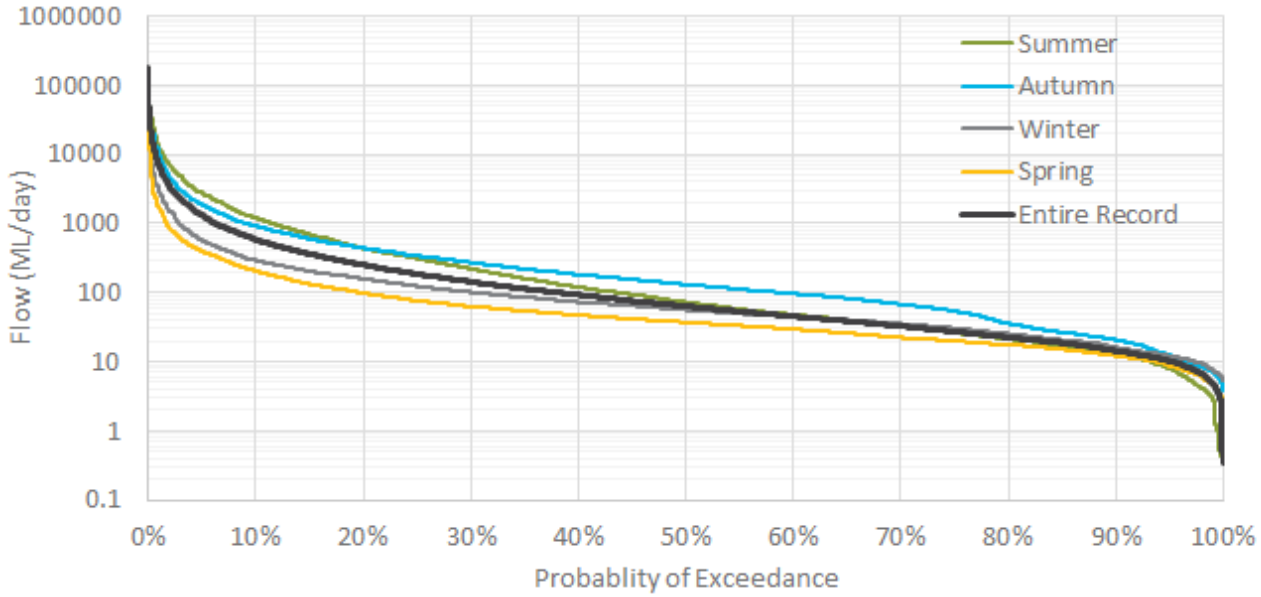


Figure 2.7 Tweed River at Uki (201900) seasonal flow duration curve (43 years gauge record)

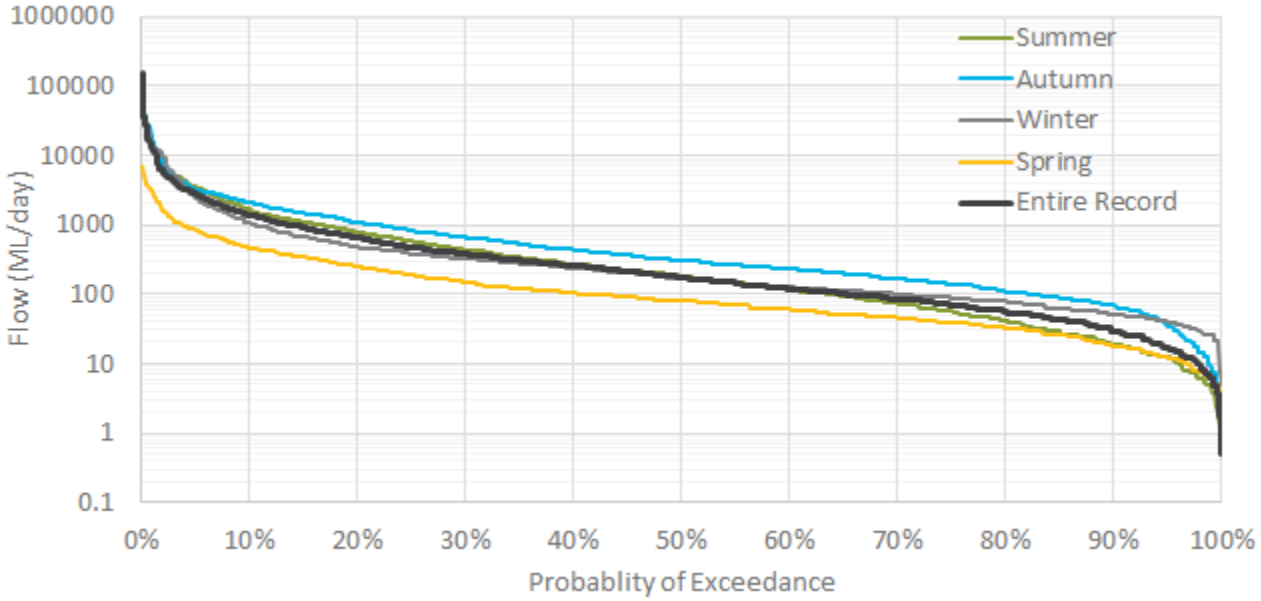


Figure 2.8 Tweed River at Braeside (201003) seasonal flow duration curve (17 years of record)

2.4 Oxley River seasonal flow duration curves

The Eungella (201001) gauging station on the Oxley River has a catchment area of approximately 215 km^2. It has the longest streamflow record in the Tweed Valley.

The Oxley River joins the Tweed River just upstream of Bray Park Weir and is unaffected by releases from Clarrie Hall Dam. Flow duration curves for the Oxley River (Figure 2.9), demonstrate a flow regime that is consistent with what is described for the Tweed River above.

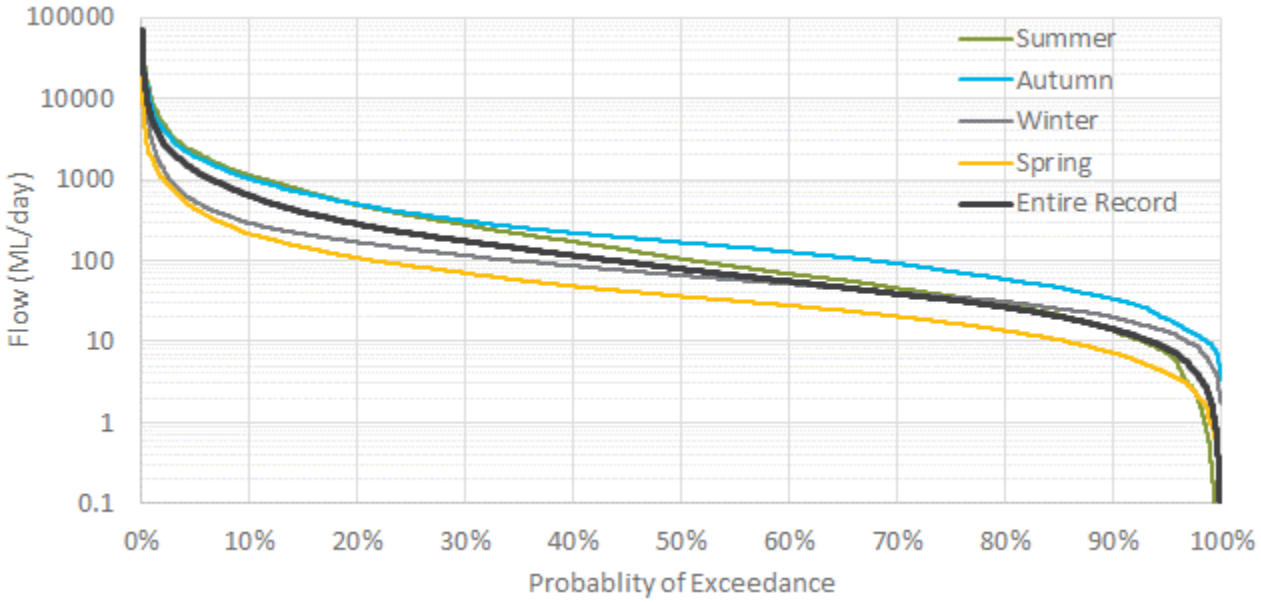


Figure 2.9 **Oxley River at Eungella (201001) seasonal flow duration curve (52 years of record)**

3 Hydrology model setup and assumptions

The existing and potential future flow regime following development of the Proposal was modelled using the existing DPE-Water Tweed River Valley Source model. This model was developed by DPE-Water in 2019–2020 using the national hydrological modelling platform eWater Source and replaced the previous Tweed River IQQM Model, which was originally developed in around 2006 (NSW DPE-Water, 2020a).Source is a hydrological modelling platform originally developed by the eWater Cooperative Research Centre (CRC) until June 2012, with development post June 2012 undertaken by eWater Limited. It is focussed on modelling both catchment hydrologic responses to climate conditions, and river operations.

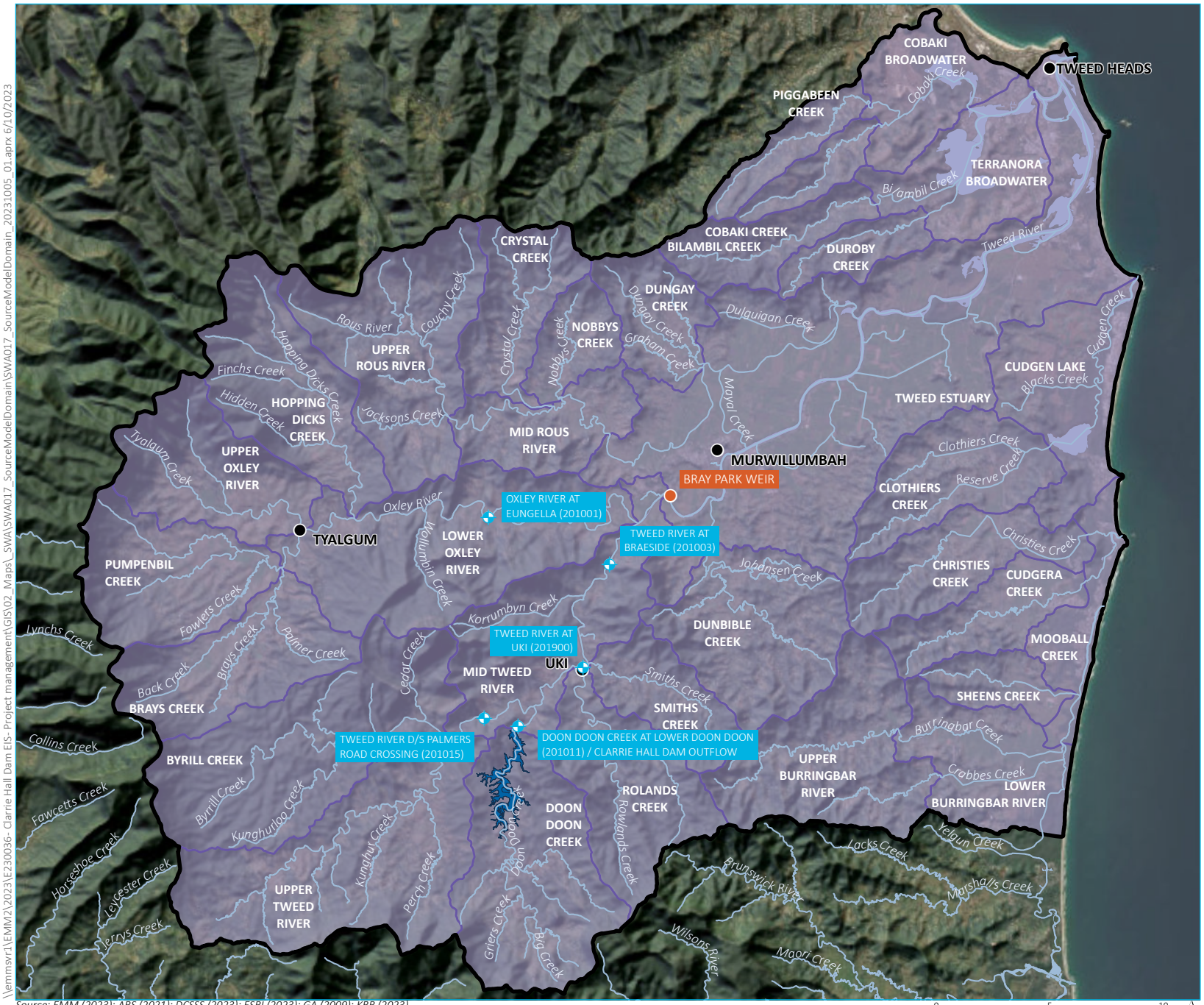
DPE-Water provided EMM with the Tweed River Valley Source model as well as input climate and hydrological data, calibrated rainfall-runoff model parameters, and available documentation. While the DPE-Water Tweed River Valley Source model, parameters and input datasets were used to model the effects of the proposed dam raising and produce results for analysis and inclusion in this report and the EIS, DPE-Water is not responsible for any data or results generated by EMM.

It is noted that because the relevant Water Sharing Plan (WSP) was updated subsequent to initial model development, EMM has updated the model in consultation with DCCEEW to reflect the current WSP. Changes to the model to reflect the current WSP are described in Section 3.3.

3.1 DPE-Water Tweed River Valley Source model

The DPE-Water Tweed River Valley Source model encompasses the catchment area of the Tweed River and its tributaries, as well as a number of smaller coastal catchments (Figure 3.1). It is a river system model which runs using a daily timestep and simulates:

- hydrological processes of river and storage inflows, evaporative losses (from rivers and storages), and river losses (note that groundwater is not explicitly modelled, and river losses are estimates only)
- storage releases and spills (Clarrie Hall Dam and Bray Park Weir), based on water supply ordering and environmental release requirements
- water demand across various water users as outlined in the Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2023 (2023 WSP), including: basic landholder rights, stock and domestic users, unregulated river access (i.e. irrigation users), aquifer demands, and local water utility access for urban water demand. Irrigation demand and urban water demand are simulated as variable daily demands based on recent climate variables through the use of crop modelling and irrigation deficit modelling. The model does not include the application of water restrictions and associated reductions in urban water demands.
- seasonal and daily irrigation requirements for various crop types
- the water sharing and resource allocation processes
- the daily river and bulk water supply system operation as implemented by Council (simplified for modelling purposes)



KEY

- Model domain
- Clarrie Hall Dam at current FSL
- Catchment
- Stream flow gauge used for analysis
- Urban centre
- Bray Park weir
- Waterway
- Named waterbody

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

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DPE-Water Tweed River Valley source model domain

Clarrie Hall Dam EIS
Streamflow Analysis
Annexure A to the Surface Water Assessment
Figure 3.1

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Tributaries of the Tweed River include (refer to Figure 3.1):

- the Oxley River, which flows into the Tweed River upstream of Bray Park Weir, above the tidal limit
- a number of creeks systems, including Doon Doon Creek
- the Rous River, which enters the Tweed River below Bray Park Weir

Streamflow input data for the Source model are generated via a separate modelling process, utilising either historical or stochastic climate data (rainfall and evaporation) and rainfall-runoff models (Sacramento Model) developed and calibrated by DPE-Water for each subcatchment. Climate data inputs are also required in the Source model directly to simulate rainfall and evaporation from river and storages water surfaces and to estimate irrigation and urban water demands. More information about the climate data used is given in Section 4.1. The relationship of these elements to the Source model is given by Figure 3.2.



Figure 3.2 Model element relationships

The model includes water supply to Tweed Shire Council Town Water Supply (i.e. Tweed Heads and Murwillumbah) and to the smaller villages of Uki and Tyalgum. More information about demands in the model is given in Section 4.3. Clarrie Hall Dam and Bray Park Weir storages are included in the model and these work together to service the Town Water Supply.

3.2 Model adequacy

DPE provided EMM with the calibration report for the Tweed River Valley Source model (NSW DPE-Water, 2020b), which notes that the model was developed using available data and current accepted standard methodologies, and concludes that overall, it models the behaviour of the catchment under current WSP rules (i.e. current WSP at the time of model calibration) and operational rules and gives a fair approximation of observed operational behaviour. Calibration statistics for streamflow gauges within the model ranged from "satisfactory" to "very good", based on performance evaluation criteria provided in (Moriasi, Gitau, Pai, & Daggupati, 2015) for the hydrologic model statistical performance measures used.

A second DPE-Water report detailing the conceptualisation of the Tweed River Valley Source model explicitly confirms that the current model schematisation is suitable for use in assessing the proposed raising of Clarrie Hall Dam, meaning that there is no need to change the node/link configuration of the model for this assessment, and that the current calibration is valid (NSW DPE-Water, 2020a).

EMM undertook model checking and validation to ensure the adequacy of the model and input files received from DPE-Water, including water balance checks, comparisons of modelled results with those presented in the calibration report, and modelling of the historical climate record to ensuring that major events were appropriately

represented. The model performed as expected (e.g. illustrated low flow during the Federation Drought, Millennium Drought and the 2019 drought, and significant flood flows in 1974 and 2022).

Operation of Clarrie Hall Dam within the model was also broadly checked against the '*Clarrie Hall Dam Operations and Maintenance Plan Revision 4.2*' (Tweed Shire Council, 2022) to ensure the most up-to-date information about current dam operations was adequately reflected by operating rules within the model.

3.3 Update of model for Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2023

The water use, water sharing and resource allocation processes in the model provided by DPE-Water were based on the Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2010 (2010 WSP). During the preparation of the EIS, the 2010 WSP was superseded by the 2023 WSP, which came into effect on the 23rd of June 2023.

In consultation with DPE-Water, EMM updated the Tweed River Valley Source model to reflect the updates in the 2023 WSP, by changing the following:

- a rule was introduced whereby no pumping from Doon Doon Creek or Mid Tweed Water Sources is allowed when the flow at Tweed River d/s Palmers Road Crossing (201015) is between 45–147 ML/day
- the amount of water required to satisfy basic landholder rights and the share components specified for access licences have changed slightly. Overall, there is a reduction
- rules for extraction in the Mid Tweed Water Sources is now based on flow at Tweed River d/s Palmers Road Crossing (201015), whereas previously they were based on flow at Oxley River at Eungella (201001)
- minor changes to the flow rates defining flow classes at reference sites which underpin rules for extraction
- entitlement volumes and pumping capacities for licenced water users represented in the model were updated using the latest information from the NSW Water Register, as provided to EMM by DPE-Water

There were no changes to the environmental water release requirements relating to Clarrie Hall Dam.

3.4 Proposal assessment

To simulate the effects of the Proposal, EMM implemented changes to the DPE-Water Tweed River Valley Source model. A high-level summary of the changes made is outlined below, with details of model changes and input data given in Chapter 4.

3.4.1 Source model version

The Source model and plugins were brought into the version of Source current at the time of modelling (Source version 5.20.0.12549 and SourcePlugin.AllocationAndUtilities version 5.5.0.4 respectively).

3.4.2 Input data (rainfall, evaporation, and streamflow)

The Source model was updated to accommodate the input climate and hydrological data required to assess the Proposal (described in Section 4.1), specifically:

- historical rainfall and evaporation data sequences were extended to the 31st of December 2022
- palaeo-stochastic data was obtained for the relevant climate input stations

- climate change projections were used to generate data for the relevant climate input stations
- the 'scenario input set' functionality in Source was utilised to define the input data for each modelled scenario to best accommodate the large file sizes of stochastic climate data
- the Sacramento parameters provided by DPE-Water were used to develop a runoff model within the Source platform, to convert climate data into river inflow data

3.4.3 Demand

Water supply to Tweed Shire Council Town Water Supply (i.e. Tweed Heads and Murwillumbah) and to the smaller villages of Uki and Tyalgum, were updated to reflect current demand (at 2025, when the Proposal will be operational) and future projected demand (at 2065) (described in Section 4.3).

3.4.4 Clarrie Hall Dam storage node

The storage node for Clarrie Hall Dam was updated to reflect recent Computational Fluid Dynamics (CFD) modelling of the existing spillway (GHD, 2023).

For scenarios where the dam wall is raised, the storage node for Clarrie Hall Dam was updated to include (described in Section 4.1):

- the proposed spillway
- the proposed new full supply level (FSL) and volume
- updated storage curves (i.e. depth-volume-surface area data) above the current FSL, based on recent LiDAR data from 2017
- updated outlet discharge relationships which reflect proposed changes to the FSL and outlet tower

4 Model scenarios and input data

Table 4.1 gives a summary of the scenarios that were modelled. The input data and assumptions for these modelling scenarios are detailed in this Chapter.

Table 4.1 Summary of scenarios modelled

Scenario	Infrastructure		Climate			Demand	
	Current	Proposed	Historical	Palaeo-stochastic	Climate change projections	Current (2025)	Future (2065)
1	X		X			X	
2	X		X				X
3	X			X		X	
4	X			X			X
5	X				X		X
6		X	X			X	
7		X	X				X
8		X		X		X	
9		X		X			X
10		X			X		X

4.1 Infrastructure scenarios

There were two infrastructure scenarios considered in the EIS modelling (Table 4.2):

- Current infrastructure – existing system with Clarrie Hall Dam at a FSL of 61.5 m AHD, storage capacity of 16 GL, and current configuration. This is the base case.
- Proposed infrastructure – Clarrie Hall Dam raised by 8.5 metres to a height of 70 m AHD, thereby increasing the storage capacity of the dam to 42.3 GL for the purpose of water supply augmentation.

Table 4.2 Model scenarios - infrastructure

	Current infrastructure	Proposed infrastructure
Clarrie Hall Dam		
Volume	16 GL	42.3 GL
Full supply level (FSL)	61.5 m AHD	70 m AHD
Spillway	Existing spillway	New spillway (Option 1B)
Intake tower	Existing intake tower and water inlet ports	Intake tower raised by 8.5 m with three additional water inlet ports

Table 4.2 Model scenarios - infrastructure

	Current infrastructure	Proposed infrastructure
Outlets	400 mm diameter fixed cone dispersion (FCD) valve 900 mm diameter FCD valve	400 mm diameter FCD valve 900 mm diameter FCD valve

4.1.1 CHD spillway

CFD modelling of the existing spillway was undertaken in 2023, and a new rating curve was generated. EMM has updated the DPE-Water Tweed River Valley Source model with the new rating curve for the current infrastructure scenarios.

CFD modelled was undertaken for proposed spillway options in 2018. Option 1B was chosen for the new spillway and was implemented in the Source model for proposed infrastructure scenarios.

Figure 4.1 shows the rating curves for current spillway at Clarrie Hall Dam and for the new spillway once Clarrie Hall Dam is raised.

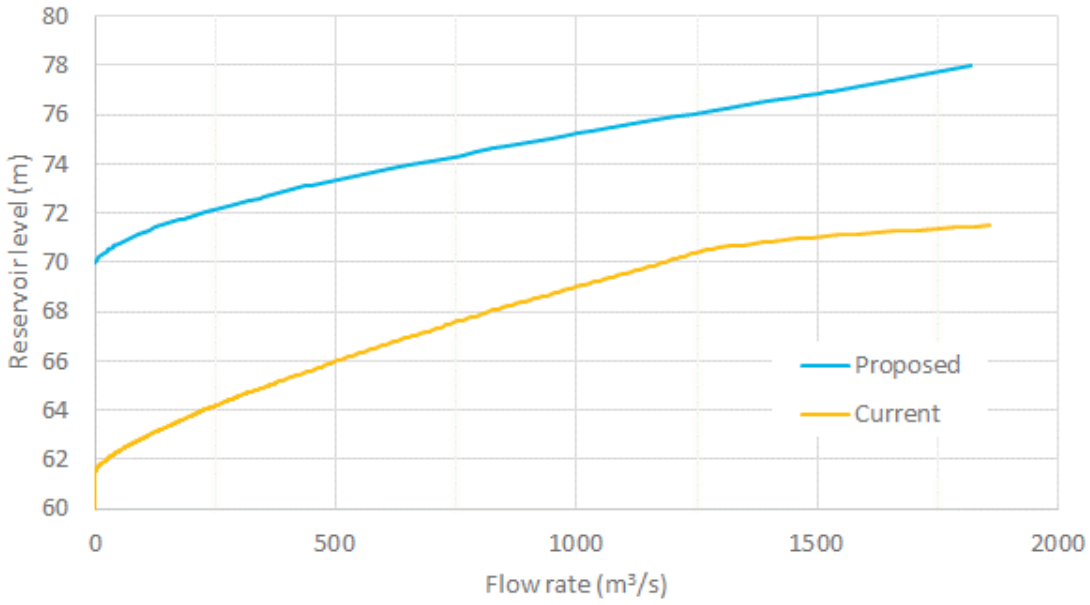


Figure 4.1 Spillway rating curves for the Clarrie Hall Dam based on CFD modelling (GHD, 2023) (Advisian, 2018)

4.1.2 CHD storage relationships

A comparison of storage relationships for Clarrie Hall Dam was undertaken as part of the concept design for the Proposal (Tweed Shire Council, 2018). LiDAR data collected in 2017 was used to generate an improved storage curve for Clarrie Hall Dam between 61.5 m AHD and 77 m AHD – shown in Figure 4.2.

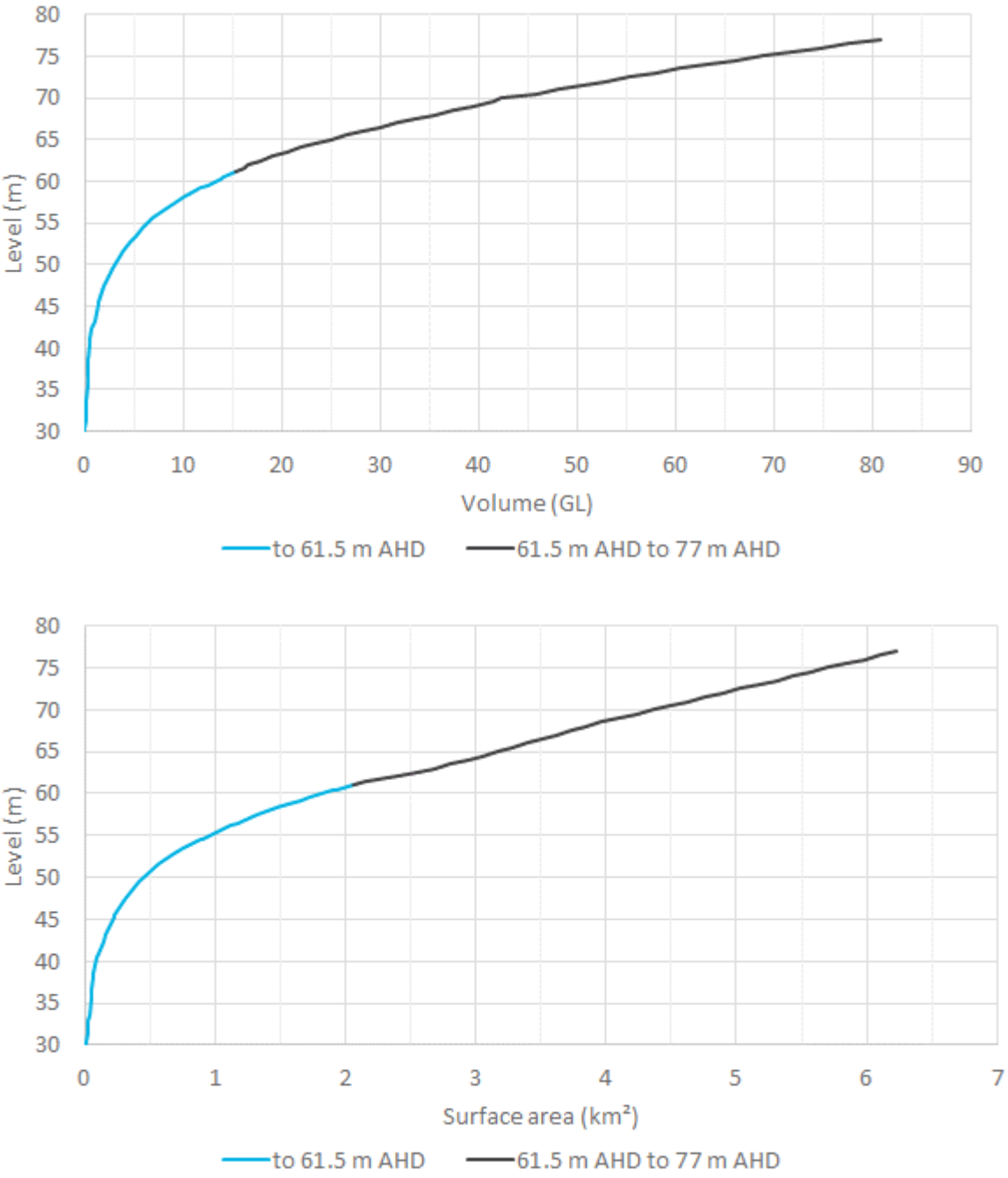


Figure 4.2 Clarrie Hall Dam storage and volume curves (Tweed Shire Council, 2018)

4.1.3 CHD outlets

Currently, managed releases from Clarrie Hall Dam are regulated via two fixed cone dispersion (FCD) valves of 400 mm diameter and 900 mm diameter. Under the proposed infrastructure scenario, the inlet tower will be raised by 8.5 m and will have an additional three water inlet ports. The outlet pipework and outlet valves will remain as they are.

The Source model includes outlet discharge curves for each of the FCD valves, which represent maximum discharge rate vs dam storage level. The discharge capacity of FCD valves reduces with storage level and maximum discharge rate can be represented via the relationship: $Q = C_d A\sqrt{2gH}$, where Q is discharge, C_d is the discharge coefficient of the valve, A is cross-sectional area, g is gravitational constant, and H is the upstream head.

EMM updated the outlet discharge curves for the two FCD valves to include the higher FSL of Clarrie Hall Dam once it is raised. Maximum discharge rates were calculated using: outlet discharge curves in the existing Source model; the discharge relationship for FCD valves (given above); detailed information about proposed changes to the intake tower (Tweed Shire Council, 2018); standard hydraulic relationships for head loss; and detailed information about the outlet works at Clarrie Hall Dam from the operations and maintenance Plan (Tweed Shire Council, 2022).

4.2 Climate sequences

The DPE-Water Tweed River Valley Source model and associated rainfall-runoff models were calibrated using climate data from 17 climate stations across the Tweed region.

Within the Source model, daily rainfall and evaporation data is used to simulate rainfall onto and evaporation from rivers and storages and is a factor in determining daily demand. The catchment rainfall runoff models (Sacramento Model) use daily rainfall and evaporation data to generate streamflow inputs for the Source model.

The following three climate sequences were modelled:

1. Historical climate – observed climate records for the period 1889 to 2022 (134 years)

2. Current climate – palaeo-stochastic climate data generated by the University of Adelaide in association with DPE-Water for use in developing the NSW regional water strategies (10,000 years)

3. Future climate – the palaeo-stochastic climate data described in 2. perturbed by NARCLiM climate change projections to create plausible future climate data (10,000 years).

4.2.1 Historical climate: observed climate data

The 134-year period from the 1st of January 1889 to the 31st of December 2022 was modelled using the observed historical climate record with data from the SILO database (https://www.longpaddock.qld.gov.au/silo/).

The SILO database catalogues Australian climate data from 1889 to the present. It provides daily meteorological datasets for a range of climate variables in ready-to-use formats suitable for biophysical modelling, research and climate applications (The State of Queensland, 2023). Point rainfall and evaporation data for the 17 climate stations required for modelling was extracted from the SILO database in March of 2023. Most rainfall stations within the vicinity of the Proposal have records from the 1950s onwards, however a couple have records dating back to the 1890s.

Model results using the historical climate data were used to present historical flow sequences for illustration.

4.2.2 Current climate: palaeo-stochastic climate data

Stochastic modelling processes use the statistical characteristics of actual climate data to generate long-term, extended synthetic datasets (stochastic data). This type of data is particularly useful for understanding climate-based risks because it includes: greater climate variability, a range of different / plausible climate sequencing not seen in the actual climate record, and periods of low or high flow with varying persistence (e.g. long-term droughts and significant floods).

The New South Wales Government, in conjunction with the University of Newcastle and the University of Adelaide, has developed 10,000 year daily stochastic climate datasets for use in river system modelling to inform Regional Water Strategies. The stochastic datasets were developed based on:

- the 130-year observed historical climate record

- understanding of prevailing climate drivers (e.g. Interdecadal Pacific Oscillation, east coast lows)

- 500 years of reconstructed palaeo-climate data (e.g. tree rings, river sediments and ice cores)

The approach used to develop these stochastic datasets is outlined in Figure 4.3 and described in the report "*New climate analysis informs NSW's regional water strategies*" (State of New South Wales, 2020) and in Attachment A.

The stochastic climate datasets are available for a large number of climate stations across NSW and are grouped by region. The 17 climate stations required for modelling are within the "Far North Coast" region. The data was downloaded from the NSW seed portal (https://www.seed.nsw.gov.au/): "*Water Modelling-Stochastic Climate Data: Far North Coast*". This dataset was used in river system modelling using the DPE-Water Tweed River Valley Source model to inform the Far North Coast Regional Water Strategy (NSW DPE-Water, 2023).

Model results using the palaeo-stochastic climate data were used to develop the description of project effects with "current climate" in Chapter 5.

4.2.3 Future climate: climate data perturbed using climate change projections

i Background

Internationally, data for use in climate change assessments is managed and distributed by the Intergovernmental Panel on Climate Change (IPCC), which is the United Nations body for assessing science related to climate change (IPCC, 2023). The objective of the IPCC is to provide regular assessment reports of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation, and to provide governments at all levels with scientific information that they can use to develop climate policies. At a global level, climate data is actively curated by the IPCC to ensure traceability, stability, availability and transparency of data and scenarios related to the assessment reports of the IPCC. To date, the IPCC has released 6 assessment reports, each describing a suite of Global Climate Models (GCMs) and emissions scenarios.

Table 4.3 gives a high-level summary of recommendations for three most recent IPCC Assessment Reports, which are relevant to data that is available for use in this project.

Table 4.3 Summary of relevant IPCC assessment reports

Assessment Report	GCMs CMIP[1] (suite of GCMs)	Emissions scenarios
Fourth Assessment Report (AR4)	CMIP3	SRES[2] scenarios: B1, A1T, B2, A1B, A2, A1FI
Fifth Assessment Report (AR5)	CMIP5	RCPs[3]: RCP2.6, RCP4.5, RCP6.0, RCP8.5
Sixth Assessment Report (AR6)	CMIP6	SSPs[4]: SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5

1. Coupled Model Intercomparison Project – suite of GCMs that underpin the Assessment Report
2. Special Report on Emissions Scenarios (SRES)
3. Representative Concentration Pathways (RCPs)
4. Shared Socioeconomic Pathways (SSPs)

In general, GCMs are more accurate at describing changes to temperature and evaporation than rainfall, which has greater inherent variability. Additionally, GCMs are unable to predict detailed future climate conditions at a regional scale. Therefore, at a national and state level, government agencies are responsible for determining and providing guidance on data use for climate change assessments in Australia, including which GCMs are suitable for different locations, and methods for downscaling global data for regional use. Of most relevance to this project, advice is provided by:

- CSIRO and Bureau of Meteorology, via the Climate Change in Australia website (CSIRO and Bureau of Meteorology, 2023)
- the NSW government, via the AdaptNSW website (and related portals, reports) (NSW Government, 2023).

The NSW and Australian Regional Climate Modelling (NARCliM) is a collaboration led by the NSW Government with the ACT and South Australian governments and input from the University of New South Wales's Climate Change Research Centre (UNSW CCRC). It was established to produce regional climate projections and data for studies into the impacts of climate change in south-east Australia, including the Proposal area. [Note: NARCliM was formerly known as the NSW and ACT Regional Climate Modelling project prior to inclusion of South Australia]. At the time of assessment, there have been two NARCLiM releases, while a third is in development but not available at the time of modelling; these are summarised in Table 4.4.

Table 4.4 Summary of NARCLiM releases and their basis

NARCLiM release	Release Date	IPPC assessment report used	GCMs	Emissions scenarios
NARCLiM 1.0	2014	AR4, CMIP3	MPI-M ECHAM5, JAMSTEC MIROC, CSIRO QCCCE, CSIRO-MK3, CCCma CGCM 3.1	SRES A2
NARCLiM 1.5	2020	AR5, CMIP5	CSIRO BOM ACCESS1.3, CSIRO BOM ACCESS 1.0, CCCma CanESM2	RCP4.5, RCP8.5
NARCLiM 2.0	in development	AR6, CMIP6	n/a	n/a

ii Available dataset

Utilising the stochastic datasets described in Section 4.2.2, the NSW government produced 10,000-year daily climate datasets for the Regional Water Strategies, which incorporate climate change projections. The following steps were used to produce these "climate perturbed" datasets (see Attachment A, Figure 4.3):

1. The driest global climate model (GCM) for the high emissions scenario at 2060-79 was selected for NSW from the NARCLiM1.0 suite of climate projections. This was a deliberate decision intended to represent a 'worst case' scenario to identify vulnerabilities in meeting water related outcomes.
2. Daily stochastic data was scaled using monthly climate factors developed from the climate projection.

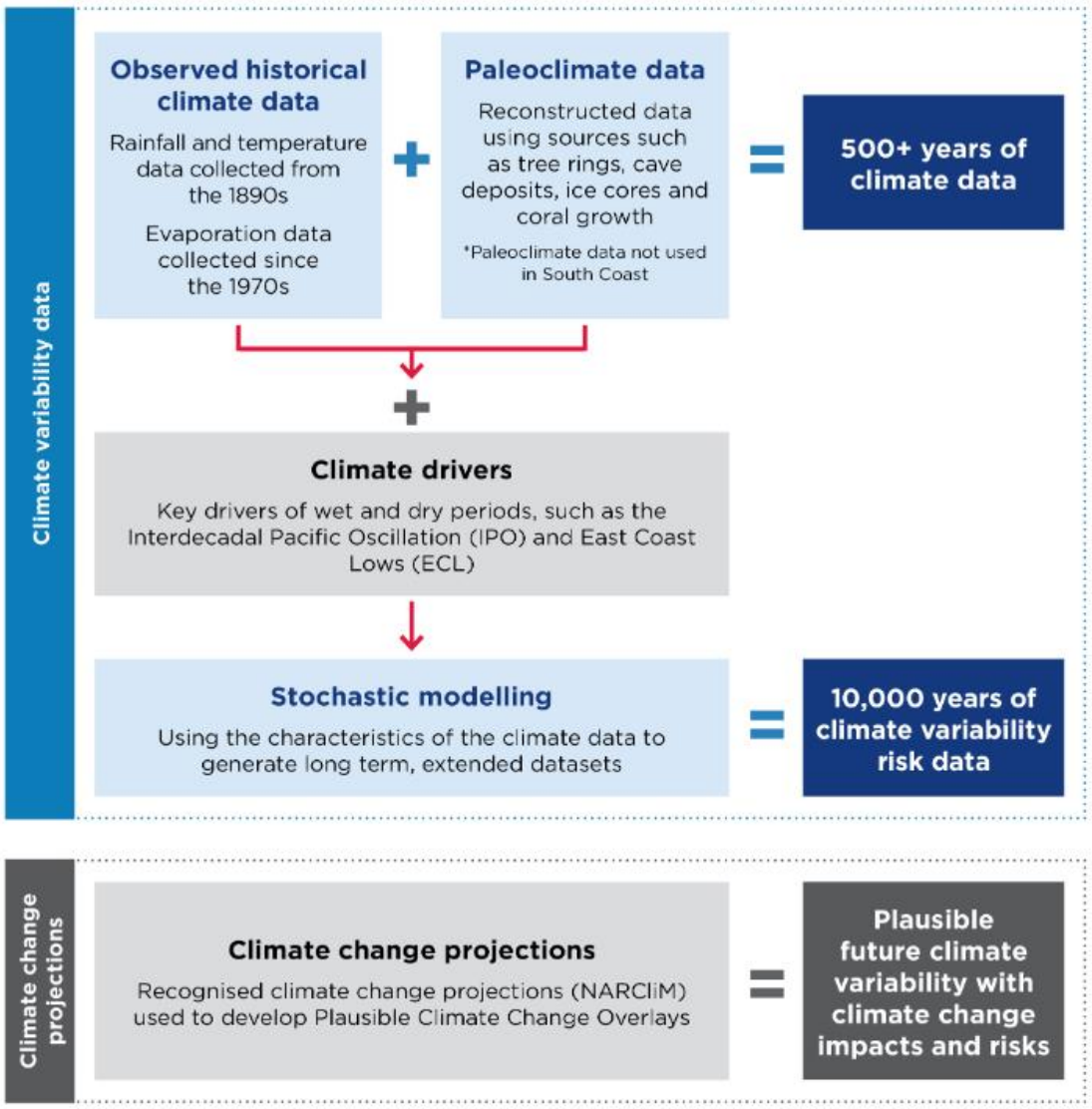


Figure 4.3 Climate data used in the Far North Coast regional water strategy (NSW DPE-Water, 2020)

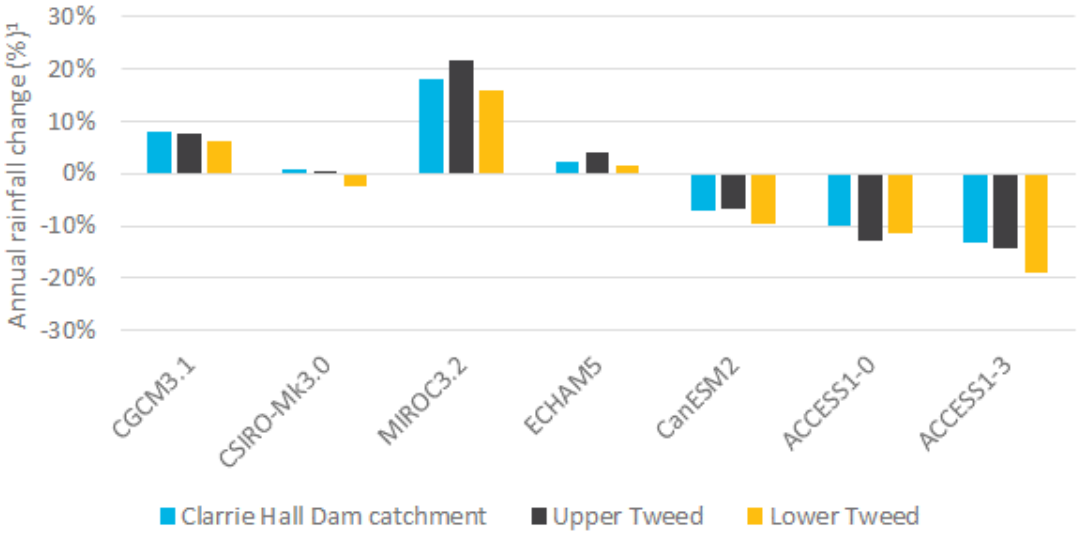
The method used to produce this data was reviewed and endorsed by an independent panel of experts, coordinated by the Office of the Chief Scientist and Engineer. However, the panel noted that this science is still developing and recommended ongoing work to continuously improve the method and keep up to date with the latest scientific findings (State of New South Wales, 2020).

A new climate perturbed climate dataset was generated for use in this project because:

- the climate change projection used for the Regional Water Strategies did not appropriately represent the future climate drying potential at the Proposal location in the Tweed River Valley, as described Climate Change in Australia (CCA) website (https://www.climatechangeinaustralia.gov.au/en/projections-tools/summary-data-explorer)
- the climate change projection used for the Regional Water Strategies was generated before the NARCLIM1.5 datasets were available
- as mentioned above, continuous improvement and application of up-to-date climate data is recommended

iii Project-specific dataset

NARCLiM1.0 and NARCLiM1.5 gridded data was downloaded from the NSW government climate data portal (https://climatedata-beta.environment.nsw.gov.au**Error! Hyperlink reference not valid.**). Using monthly gridded precipitation data, the driest GCM for the high emissions scenario at 2060–2079 was found to be "CSIRO BOM ACCESS1.3" for the Tweed region (Figure 4.4), based on comparison with the historical reference period (1990–2009). CSIRO BOM ACCESS1.3 is a GCM from the CMIP5 suite and was downscaled for NSW as part of NARCLiM1.5.

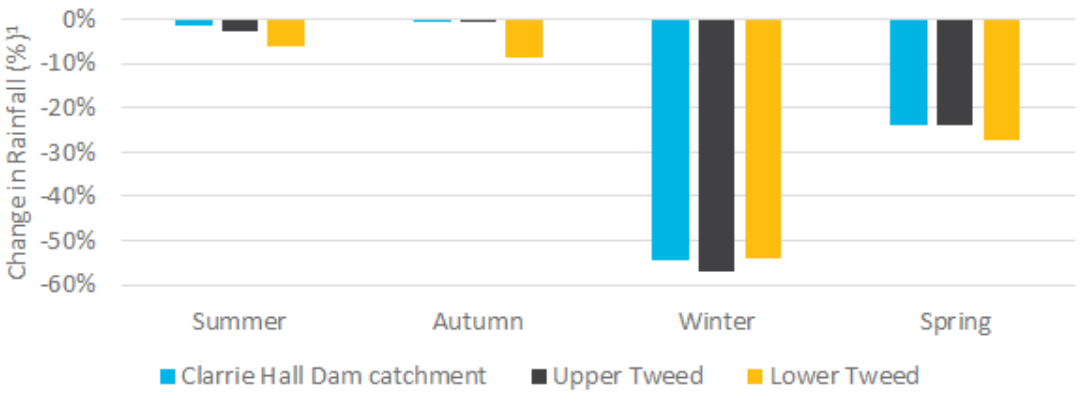


1. 2060–2079 period compared with 1990–2009 reference period, based on NARCliM climate change modelling (NSW Government, 2023)

Figure 4.4 Comparison of GCM rainfall projections (2065)

Monthly scaling factors were calculated for rainfall and evaporation at each of the 17 climate stations required for modelling using the monthly gridded data. Overall, there was:

- a decrease in rainfall of approximately 20%
    - large decreases in rainfall in winter and spring (Figure 4.5)
    - little change to rainfall in summer and autumn.
- an increase in evaporation of approximately 10%



1. 2060–2079 period compared with 1990–2009 reference period, based on NARCliM climate change modelling (NSW Government, 2023)

Figure 4.5 ACESS1-3 seasonal rainfall projections (2065)

Monthly scaling factors were applied to the palaeo-stochastic datasets described in Section 4.2.2 to create 10,000 year daily "climate perturbed" climate datasets for modelling.

Model results using the climate perturbed climate data were used to develop the description of project effects with "future climate". This is presented in Chapter 6, along with an overview of the methodology used to assess these model results.

As described in Section 6.1, DPE-Water have developed a climate change assessment methodology for water storage projects, which is included as Attachment A. Following this methodology, the rainfall decreases presented in Figure 4.4 and Figure 4.5 were not applied in the model directly, but rather, periods of data with rainfall statistics matching those provided on the CCA website for the Tweed Region were extracted from the climate perturbed dataset for analysis. The reason for selecting a model with dry predictions (i.e. ACCESS1.3) was so that there would be sufficient periods of 126 years that matched the CCA statistics and met the definitions for wet and dry conditions set out in the DPE-Water methodology. Other GCMs with higher rainfall did not allow production of climate sequences with rainfall reduced enough to meet the dry climate definition.

4.3 Demand growth

4.3.1 Urban demand

The DPE-Water Tweed River Valley Source model includes water supply to Tweed Shire Council Town Water Supply (i.e. Tweed Heads and Murwillumbah) and to the smaller villages of Uki and Tyalgum.

Two demand cases were considered in the Source model:

1. Current demand – demand at 2025, when the Proposal is expected to be operational
2. Future demand – demand at 2065, taken to coincide with the future climate data

Annual usage within the Source model was updated for these two demand cases based on the study into future water demand which was commissioned by Council (Hydrosphere, 2020a). Forecast demands for the Tweed District, Uki and Tyalgum are shown in Figure 4.6, with the years 2025 and 2065 highlighted.

Urban water demand is simulated as variable daily demands based on recent climate variables using an irrigation deficit model. The Source model does not currently include the application of water restrictions and associated reductions in urban water demand.

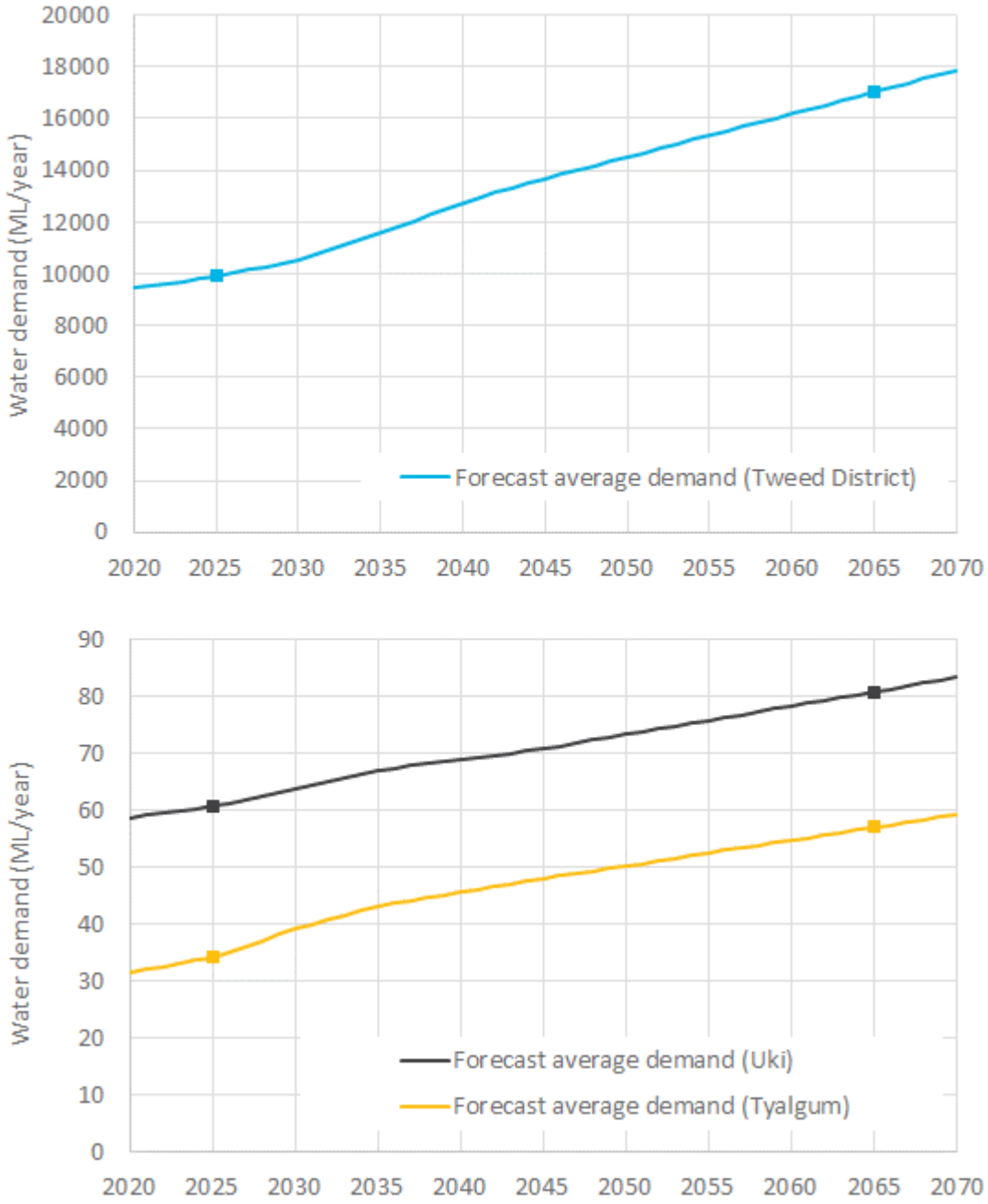


Figure 4.6 **Forecast average demands for the Tweed District (top), Uki and Tyalgum (bottom) (Hydrosphere, 2020a)**

4.3.2 Other demands

In addition to urban water demand, the Source model simulates demand for: basic landholder rights, stock and domestic users, unregulated river access (i.e. irrigation users), and aquifer demands. The model estimates seasonal and daily irrigation requirements for various crop based on recent climate variables using crop modelling.

Across the demand cases modelled, demand other than urban demand, remains unchanged based on the following assumptions: crop type, irrigated area and crop requirements do not change, the WSP rules do not significantly change.

4.4 Environmental water releases

Key assumptions that are implemented in the Source model and which are relevant to Clarrie Hall Dam, are outlined in Table 4.5.

Currently, the WSP specifies water storage levels for Clarrie Hall Dam as a percentage. It has been assumed in the Source modelling that specified water storage levels translate to volumes that would remain constant once Clarrie Hall Dam is raised (i.e. that a specified water storage of "50%" in the WSP is equivalent to 8 GL, which is equivalent to a water storage of 19% for the raised dam). These volumes are outlined in italics in Table 4.5 under the heading "*Proposed infrastructure"*.

Table 4.5 Water release requirements relating to Clarrie Hall Dam in the WSP (DPIE, 2023)

Releases from Bray Park Weir A release at least equal to the target flow rate specified must be made from Bray Park Weir through the fish ladders each day the water storage level of Clarrie Hall Dam is at the level specified.		
Water storage levels—Clarrie Hall Dam		**Target flow rate**
Current infrastructure	***Proposed infrastructure***	
Equal to or greater than 75%	*Equal to or greater than 12 GL (28% of raised dam volume)*	8 ML/day
Greater than 50% and less than 75%	*Greater than 8 GL and less than 12 GL*	5 ML/day
Less than or equal to 50%	*Less than or equal to 8 GL* *(19% of raised dam volume)*	3 ML/day
Releases from Clarrie Hall Dam in the Doon Doon Creek water source A release at least equal to the target flow rate specified, including releases for local water utility purposes, must be made from Clarrie Hall Dam each day the flow measured at the flow reference point is at the level specified. The flow reference point means the Oxley River at Eungella gauge (201001) in the Lower Oxley River Water Source.		
Flow at flow reference point		**Target flow rate**
Equal to or greater than 13 ML/day		4 ML/day
Greater than 3 ML/day and less than 13 ML/day		2 ML/day
Less than or equal to 3 ML/day		1 ML/day

5 Model results with current climate

5.1 Overview

An overview of model results is provided in Table 5.1, which illustrates that:

- mean extraction volumes for town water supply (TWS) would be unchanged by the Proposal
- mean managed releases from Clarrie Hall Dam would not materially change as a result of the Proposal
- the percentage of time when dam storage levels are below 13.6 GL will reduce significantly as a result of the Proposal
    - 13.6 GL is 85% of the current capacity of Clarrie Hall Dam and corresponds to the dam storage level below which level 1 restrictions are imposed, , 7.2 GL is 45% of the current capacity of Clarrie Hall Dam and corresponds to the dam storage level below which emergency restrictions are imposed (Tweed Shire Council, 2022).
    - storage levels fall below 13.6 GL (the current threshold volume for water restrictions) approximately 12% of the time with the 2065 demands. With the Proposal, this is reduced to 0.1% of the time
    - storage levels fall below 7.2 GL (the current threshold volume for water restrictions) approximately 1% of the time with the 2065 demands. With the Proposal, this is reduced to 1% of the time
- the amount and frequency of potential demand shortfall is reduced as a result of the Proposal. Note: demand management measures which would be implemented to prevent shortfalls, are not modelled in the Source model
    - with the 2065 demands, demand shortfalls occur in 0.8% of years, roughly corresponding to the frequency of very low dam levels. This reduces to 0.1% of years with the Proposal.
- Evaporation will increase by around 3 GL/year due to the larger dam surface area, however this is offset by around 3 GL/year increased rainfall capture over the same area.
- Mean spill volumes from Clarrie Hall dam reduce by around 50 ML/year to 100 ML/year due to the Proposal, which is considered negligible in the context of Tweed River yearly flows of 163,000 ML/year past Uki.
- The Proposal has little effect on mean streamflow in the Tweed River.

Water restrictions and associated reductions in urban water demand are not modelled explicitly in the Source model because the water restrictions policy in the Tweed Valley is still relatively new and the resulting water savings are as yet unclear. If the Proposal results in less time in water restrictions, it is possible that water use over the long term may be slightly higher.

Model results in Chapter 5 were developed using palaeo-stochastic climate generated by DPE-Water (described in Section 4.2.2) other than where explicitly described as using historical climate data.

Table 5.1 Overview of model results with the current climate

Infrastructure scenario:		Current		Proposed	
Demand case:		**Current (2025)**	**Future (2065)**	**Current (2025)**	**Future (2065)**
Clarrie Hall Dam:					
capacity	ML	16,000	16,000	42,300	42,300
FSL	m AHD	61.5	61.5	70	70
mean managed releases	ML/year	2,170	3,664	2,143	3,726
mean spills	ML/year	52,081	50,612	52,073	50,507
mean evaporation volume	ML/year	3,222	3,115	6,498	6,420
mean rainfall volume	ML/year	3,379	3,297	6,619	6,558
TWS:					
mean extraction at Bray Park Weir	ML/year	9,728	16,543	9,728	16,546
mean demand shortfall	ML/year	0.0	3.5	0.0	0.0
% of years with shortfall	%	0.0%	0.8%	0.0%	0.1%
time below 13.6 GL (85% of current infrastructure – equates to Level 1 restrictions[1])	%	3.6%	11.6%	0.0%	0.1%
time below 7.2 GL (45% of current infrastructure – equates to Emergency level water restrictions[1])	%	0.1%	1.0%	0.0%	0.0%
River flows:					
mean flow in Doon Doon Creek d/s of Clarrie Hall Dam	ML/year	54,251	54,277	54,216	54,234
mean flow in the Tweed River at Uki	ML/year	163,811	163,735	163,734	163,642
mean flow in the Tweed River at Braeside	ML/year	191,808	191,741	191,634	191,553
mean flow at Bray Park Weir	ML/year	285,604	285,748	285,179	285,291
Project effect at end of system (EOS)	%	-	-	-0.1%	-0.2%

1. (Tweed Shire Council, 2022)

5.2 Flow regime

5.2.1 Historical flow sequences

Flow hydrographs were developed by running the model with historical climate sequences. Two sequences are presented below to illustrate the effect of the Proposal during dry (Figure 5.1 to Figure 5.5) and wet periods (Figure 5.6 to Figure 5.10).

Historical climate data were used in the model to prepare Figure 5.1 to Figure 5.10. All other analysis presented in this chapter was prepared using the results of simulations using stochastic climate data.

i Dry sequence (2005 – 2007)

The drier sequence (2005 to 2007) illustrates that:

- the proposed dam would not be drawn down as far as the existing dam during drought (Figure 5.1)
- the proposed dam will take longer to fill and spill following drawdown during dry periods (Figure 5.1 and Figure 5.2)
- water releases to satisfy town water demands will be higher in the future (2065 demand reported) (Figure 5.2)
    - this effect was simulated but is not caused by the Proposal
- increased water demand in the future (2065 demand reported) will increase the time required for the dam to fill and spill following a dry period (Figure 5.1)
    - this effect was simulated but is not caused by the Proposal

Of these effects:

- the increased releases for town water supply affects Tweed River flow from Doon Doon Creek through to Bray Park Weir (Figure 5.3 to Figure 5.5)
- reduced spills following dam drawdown affects Tweed River flow from Doon Doon Creek to Uki (Figure 5.8), but effects become less noticeable at Braeside (Figure 5.9) and Bray Park Weir (Figure 5.10) due to the large unregulated upstream catchments

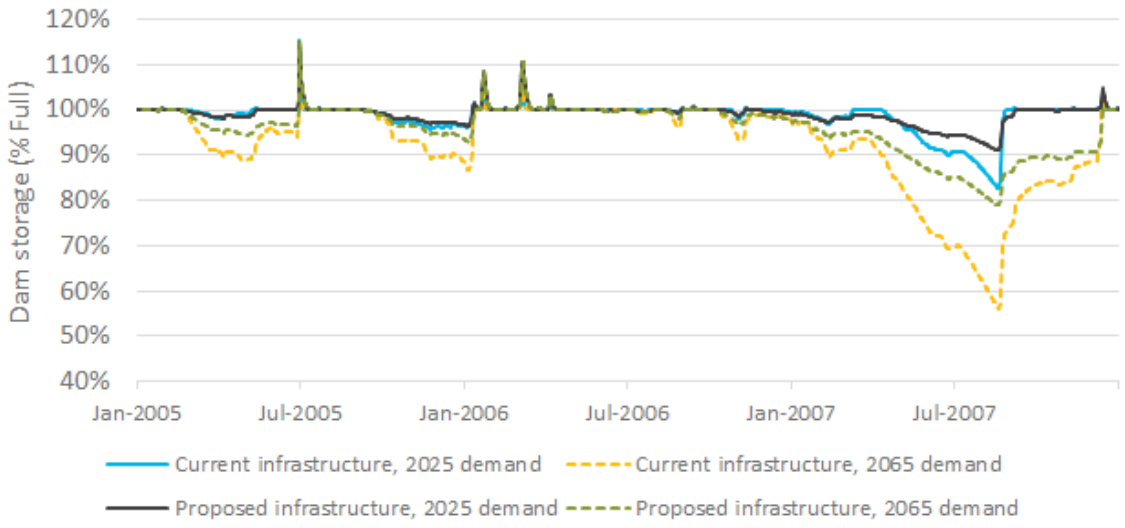


Figure 5.1 Modelled storage levels in Clarrie Hall Dam, historical climate (2005-2007)

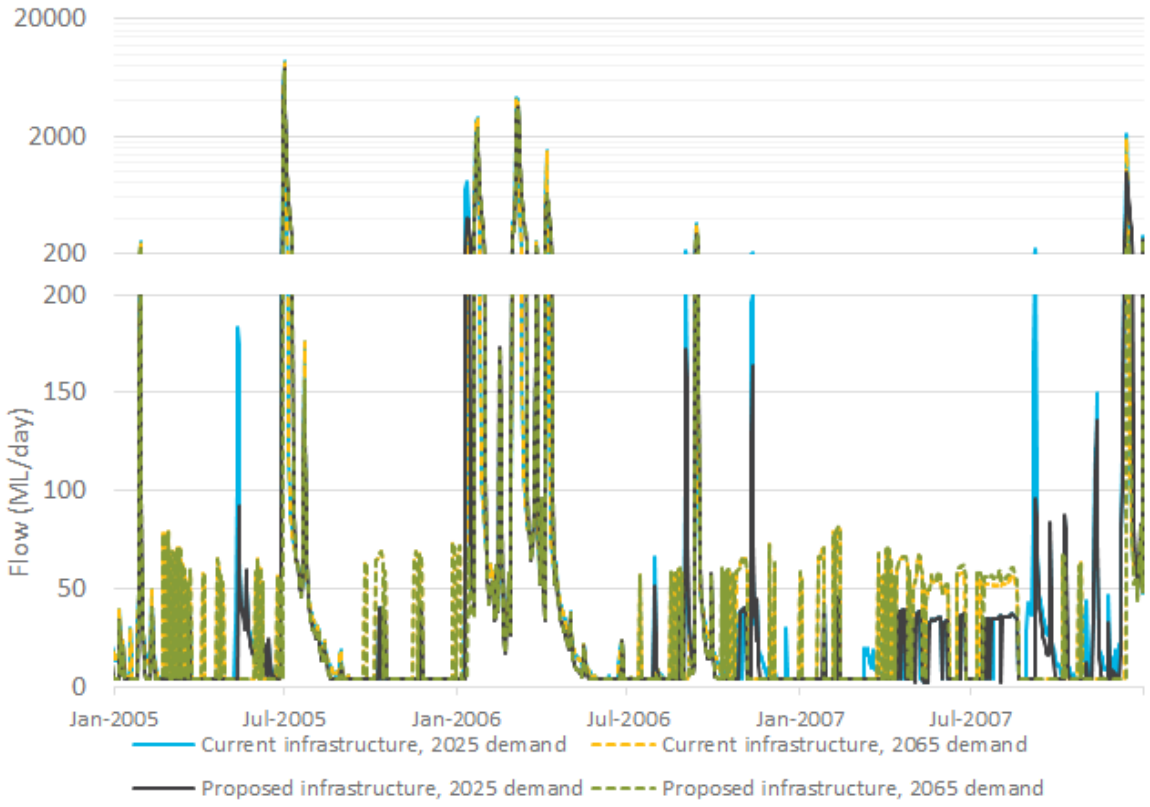


Figure 5.2 **Modelled flow in Doon Doon Creek downstream of Clarrie Hall Dam, historical climate (2005-2007)**

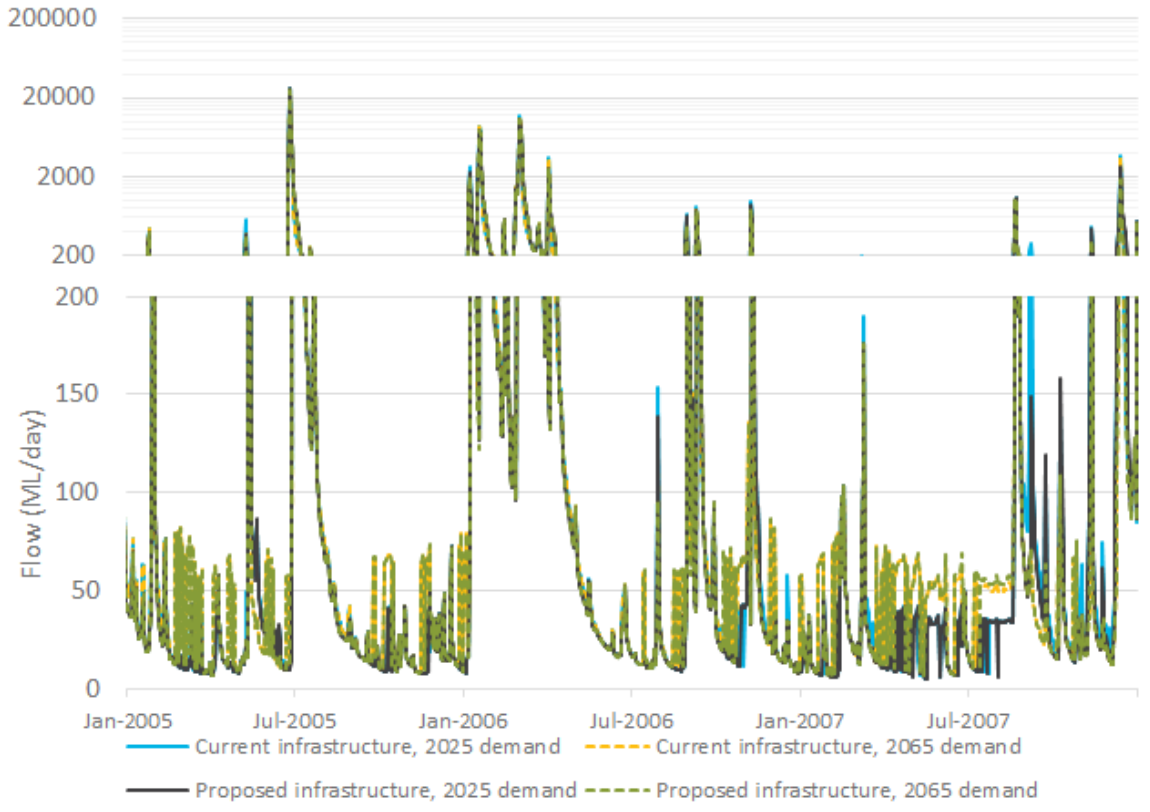


Figure 5.3 **Modelled flow in the Tweed River at Uki (201900), historical climate (2005-2007)**

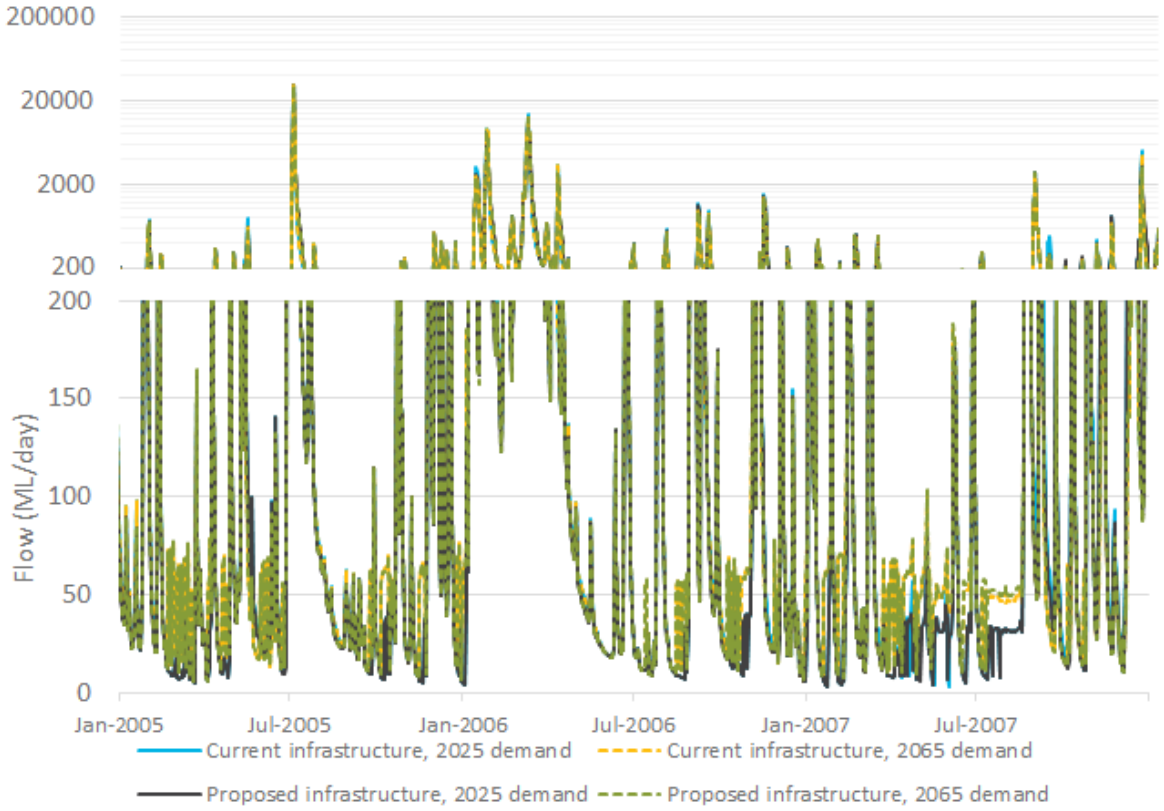


Figure 5.4 **Modelled flow in the Tweed River at Braeside (201003), historical climate (2005-2007)**

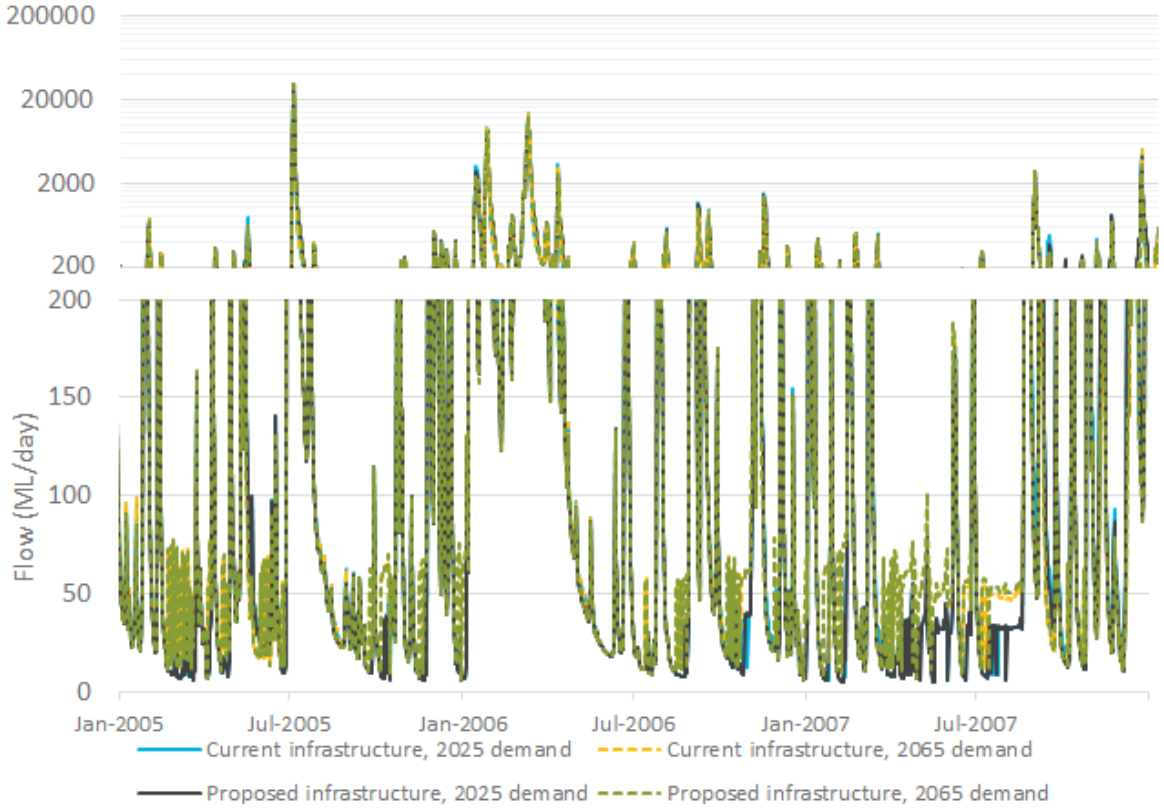


Figure 5.5 **Modelled flow downstream of Bray Park Weir, historical climate (2005-2007)**

ii Wet sequence (1976)

The wetter sequence (1976) illustrates that high flows will be attenuated in the larger dam:

- flood volumes will accumulate in the larger dam to a greater degree (Figure 5.6)
- flood peaks released to Doon Doon Creek will reduce (Figure 5.7)
- the flow recession period following peak flow will occur for a longer duration (Figure 5.7).

In the sequence presented, peak flows flowing over the spillway reduce by around 1,000 ML/day (from 6,000 ML/day to 5,000 ML/day in the first flood peak, and from 1,500 ML/day to 600 ML/day in the last flood peak). This effect is reproduced at each reporting location downstream, e.g. 3,000 ML/day reduces to 2,000 ML/day at Uki (Figure 5.8).

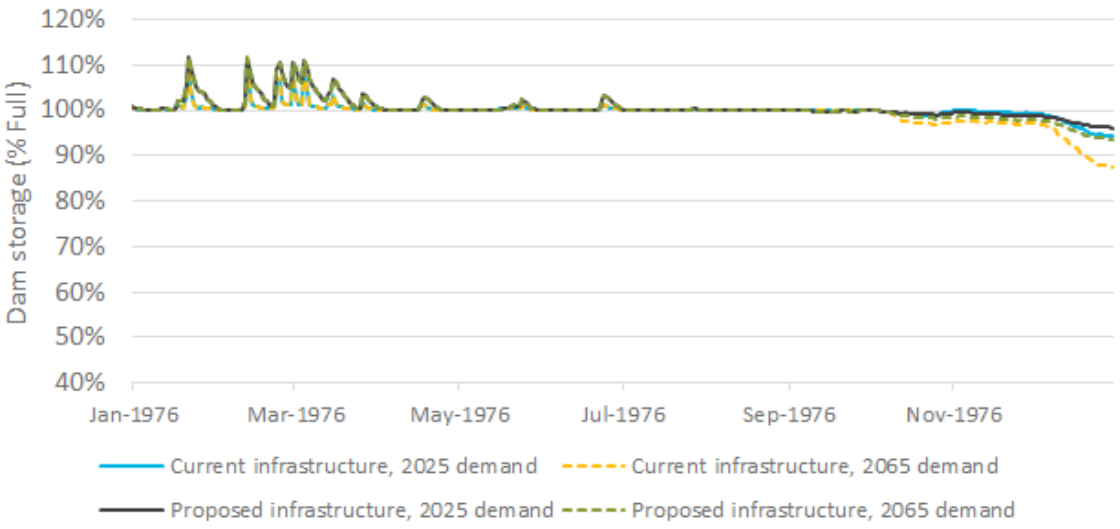


Figure 5.6 Modelled storage levels in Clarrie Hall Dam, historical climate (1976)

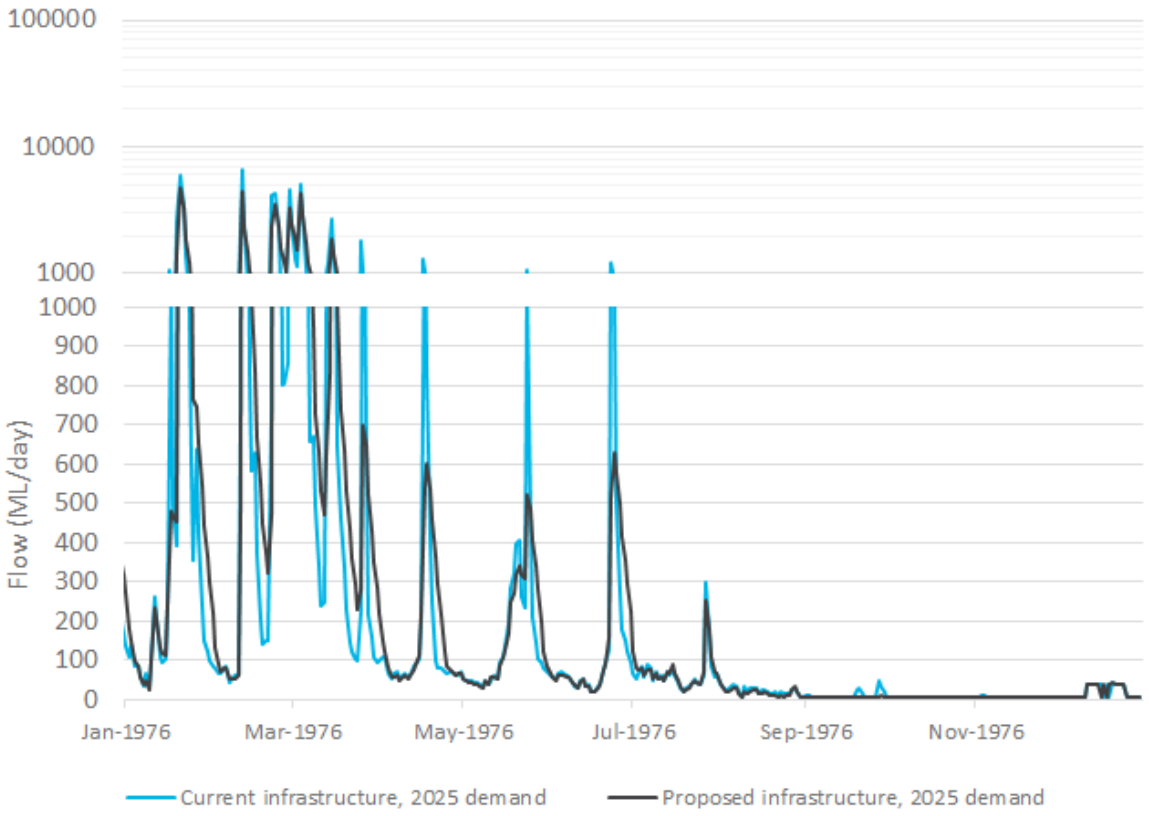


Figure 5.7 **Modelled flow in Doon Doon Creek downstream of Clarrie Hall Dam, historical climate data (1976)**

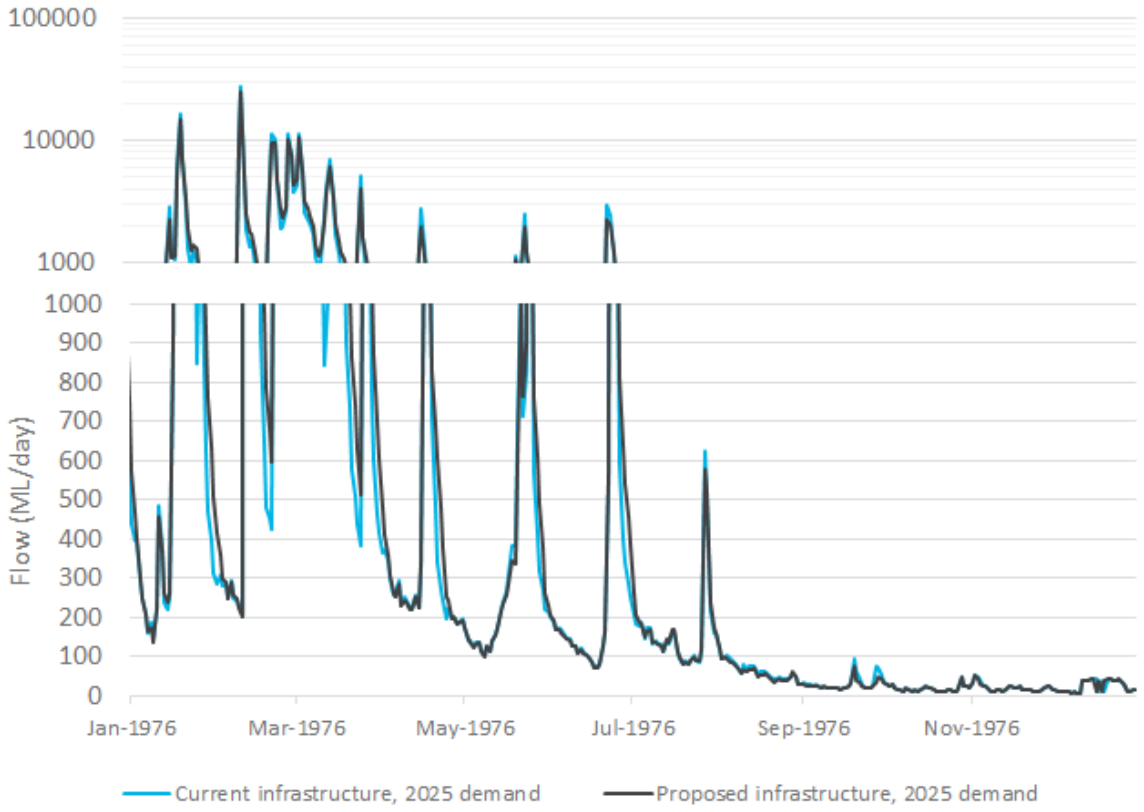


Figure 5.8 **Modelled flow in the Tweed River at Uki (201900), historical climate (1976)**

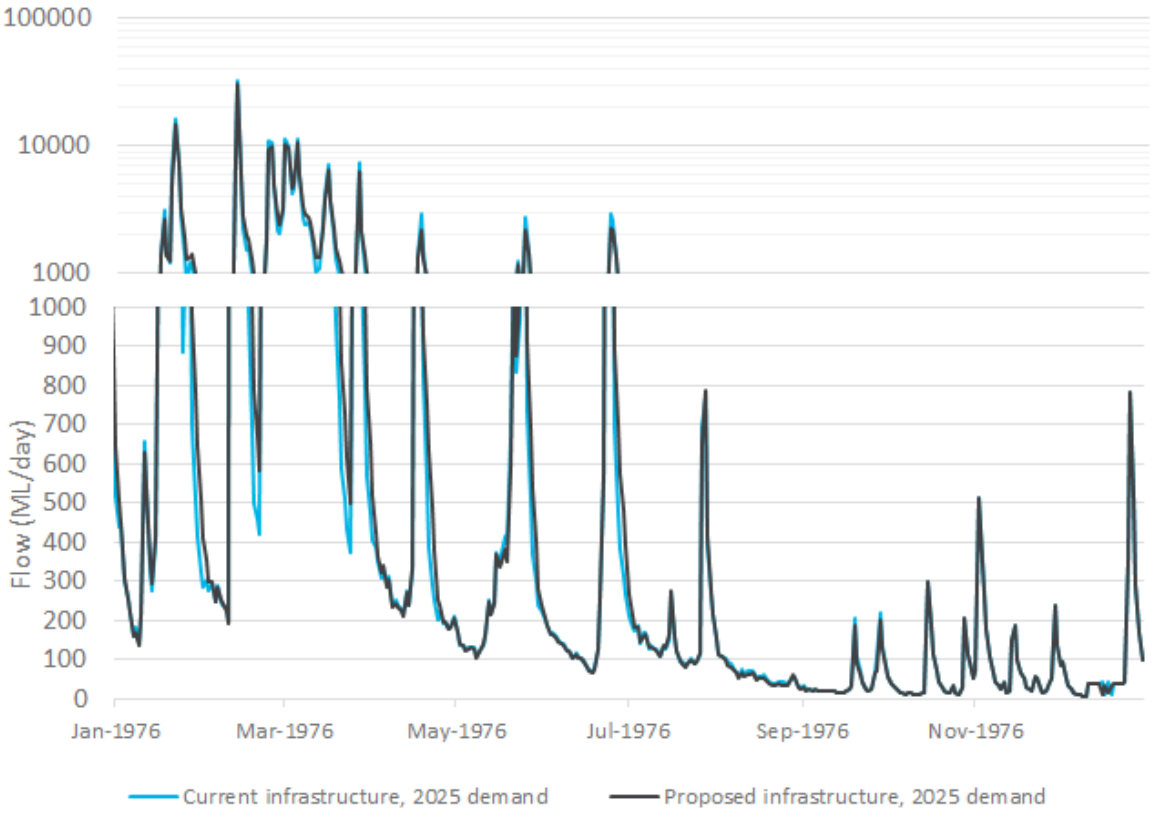


Figure 5.9 **Modelled flow in the Tweed River at Braeside (201003), historical climate (1976)**

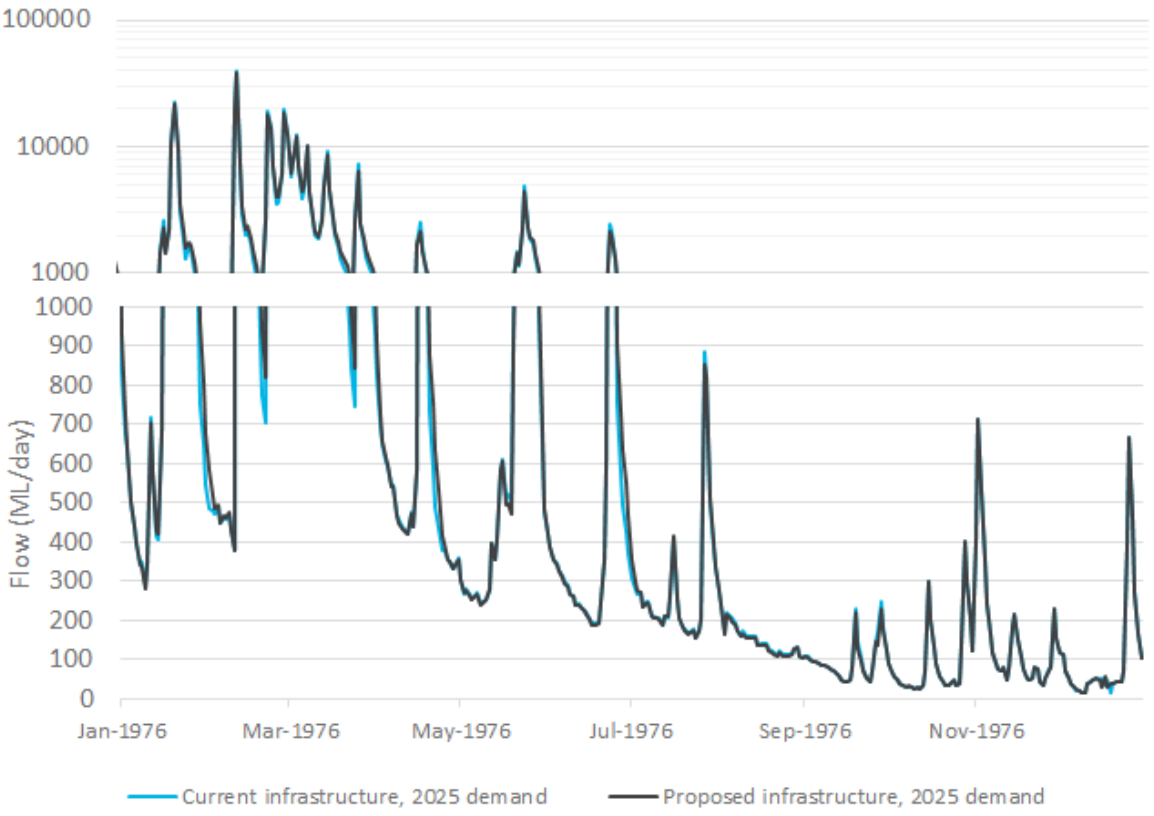


Figure 5.10 Modelled flow downstream of Bray Park Weir, historical climate (1976)

5.2.2 Flow duration curves

Seasonal flow duration curves (Figure 5.11 to Figure 5.13) were developed from the flow results of simulations using palaeo-stochastic climate data.

Flow duration curves for Doon Doon Creek (Figure 5.11) show that:

- the reduction in flood peak flow rate due to the larger dam (Section 5.2.1ii) is associated with the low probability (0% - 3%) section of the curve
- the extended recession period following a high flow event (Section 5.2.1ii) is seen in the 3% - 20% section of the curve, with flows of 100 – 500 ML/day occurring on more days
    - this effect is less pronounced in Spring, when conditions are driest and there are fewer flood events
- through the typical daily operations part of the curve (30% - 65%), future (2065) demand results in increased flows by around 6 ML/day
- minimum releases are expected to currently occur around 30% of the time (from 70% to 100% on the curve), but this would increase to 40% of the time (from 60% to 100% on the curve) with the larger dam
    - this is caused by the increased surface area of the dam resulting in higher volumes evaporated from the dam surface, which in turn results in the dam spilling less often. Manual releases of the minimum flow would then be required.

Within 5 km downstream at Uki (Figure 5.12), most of the changes observable in Doon Doon Creek are negligible due to the contribution of the unregulated upstream reaches of the Tweed River runoff from additional catchment area and unaffected tributaries. The reduction in high flow events and increase in moderate flow events due to the increased flood capture and attenuation capacity of the dam and longer flood recession, are still present but have reduced influence on the flow statistics.

Flow duration curves for the Tweed River at Braeside (Figure 5.13) and Bray Park Weir (Figure 5.14), 7.5 km and 10 km downstream of the dam respectively, show that there is negligible change in the long term Tweed River flow regime due to the proposed infrastructure.

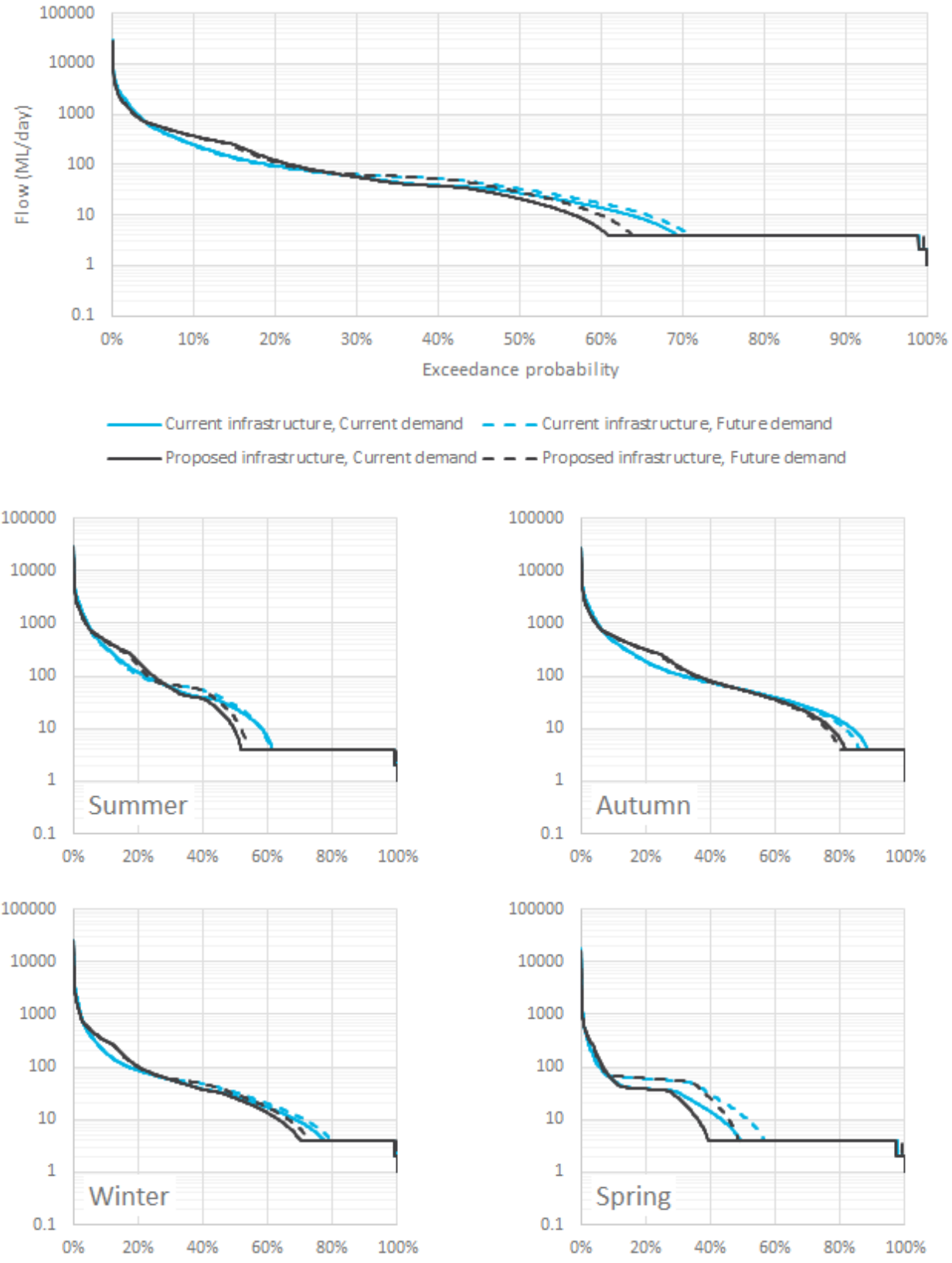


Figure 5.11 **Flow duration curve at Doon Doon Creek downstream of Clarrie Hall Dam, current climate**

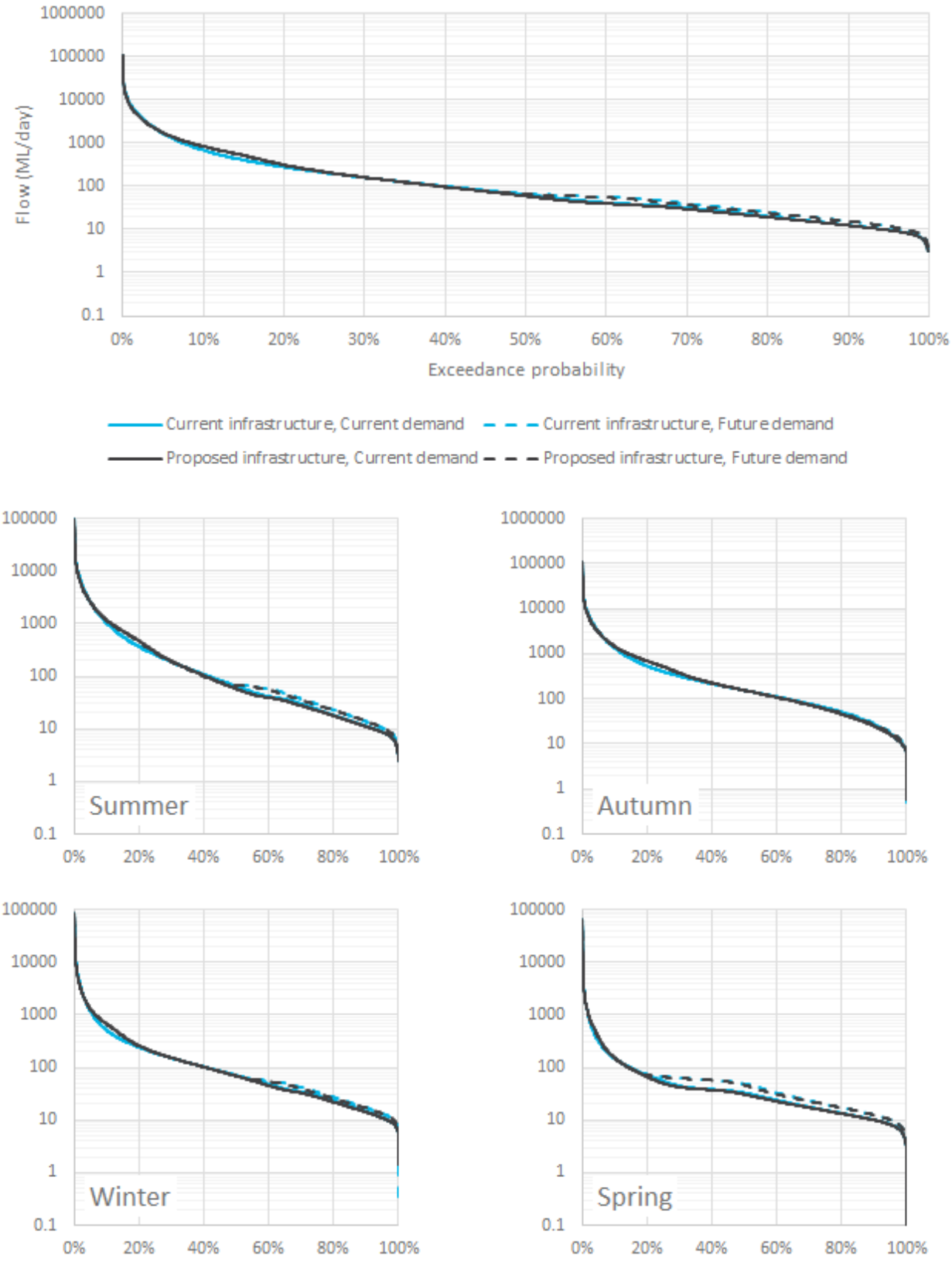


Figure 5.12 Flow duration curve for Tweed River at Uki (201900), current climate

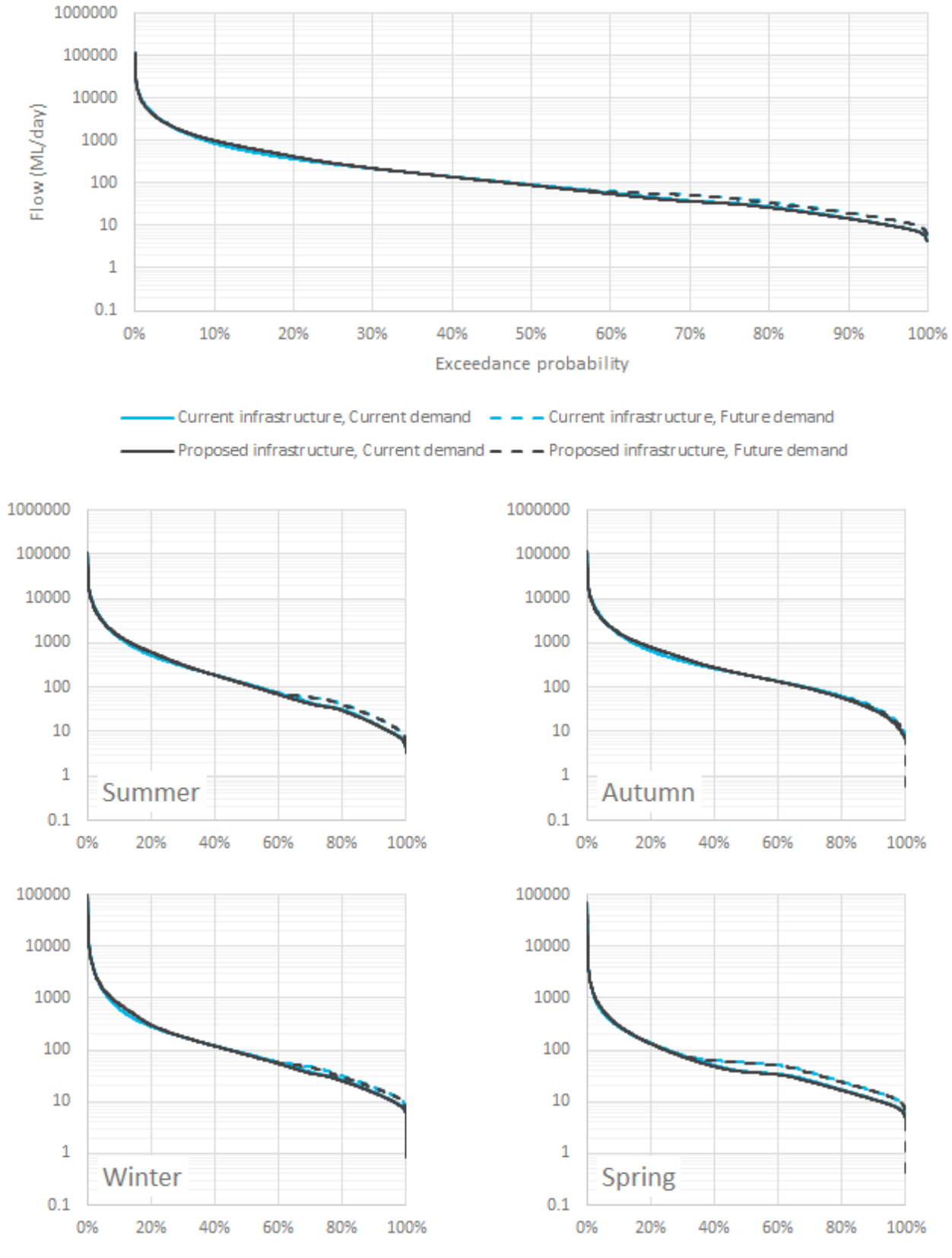


Figure 5.13 Flow duration curve for Tweed River at Braeside (201003), current climate

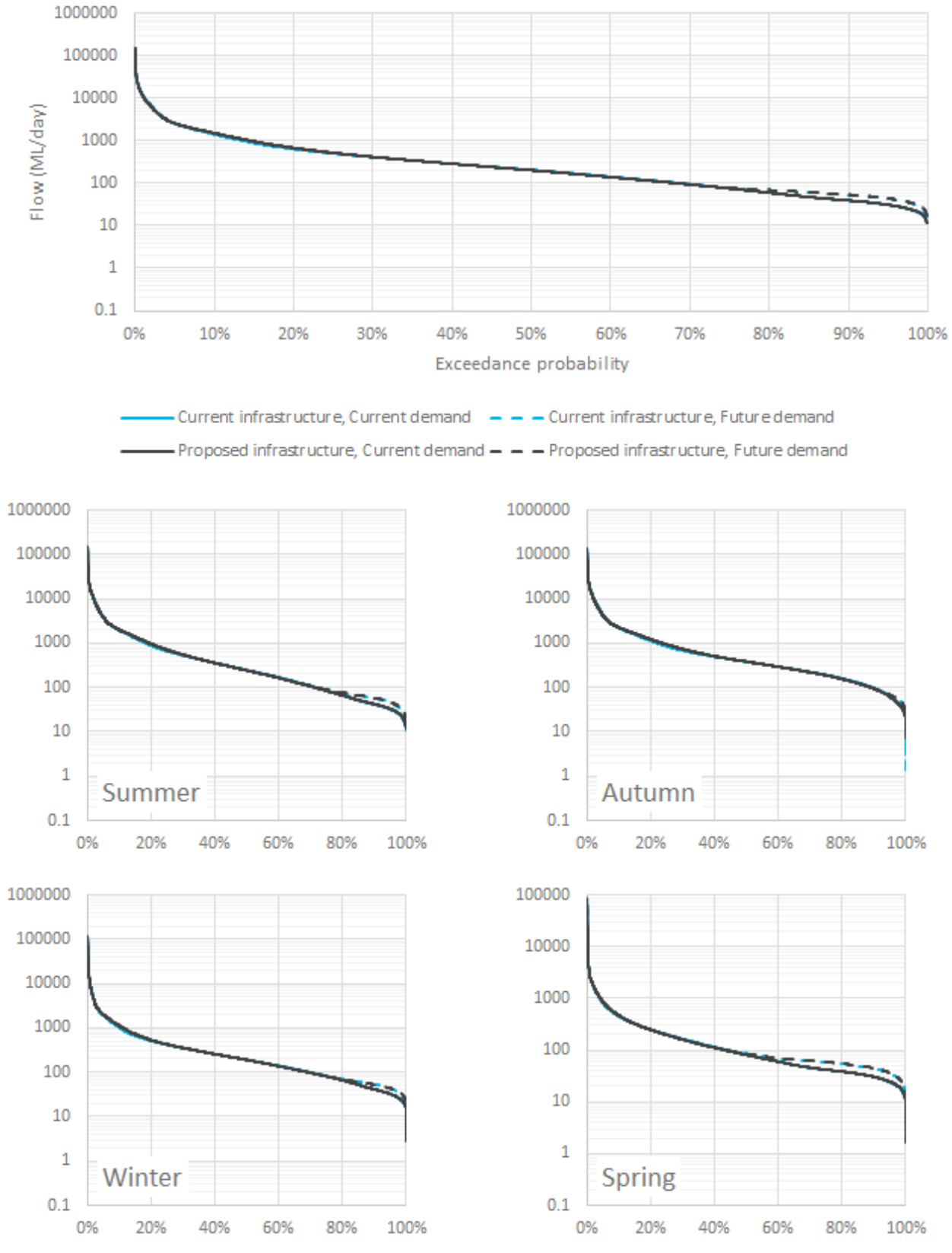


Figure 5.14 Flow duration curve for Tweed River downstream of Bray Park Weir, current climate

5.3 Clarrie Hall Dam storage

Figure 5.15 shows probability of exceedance curves for Clarrie Hall Dam storage levels, developed from the flow results of simulations using palaeo-stochastic climate data.

This figure shows that:

- Under both infrastructure scenarios (i.e. with and without the Proposal):
    - Clarrie Hall Dam would be full approximately 70% of the time under both current and future demand cases
    - storage levels would exceed FSL only very infrequently (0% - 3%)
    - storage levels would be lower under the future demand case, as more releases are made from the dam for water supply purposes
- Without the Proposal, storage levels fall below FSL approximately 25% of the time (between 75% and 100% on the probability of exceedance curve). However, this corresponds to falling below 13.6 GL – which is 85% of the current capacity of Clarrie Hall Dam and corresponds to the dam storage level below which level 1 restrictions are imposed (Tweed Shire Council, 2022) – approximately 4% of the time with current demand and 12% of the time with future demand. This is most likely to occur during summer and spring.
- with the Proposal, storage levels fall below FSL for approximately the same amount of time (i.e. 25% of the time), however storage levels remain above 30 GL (i.e. approximately 70% of proposed capacity), 99% of the time under current and future demand cases

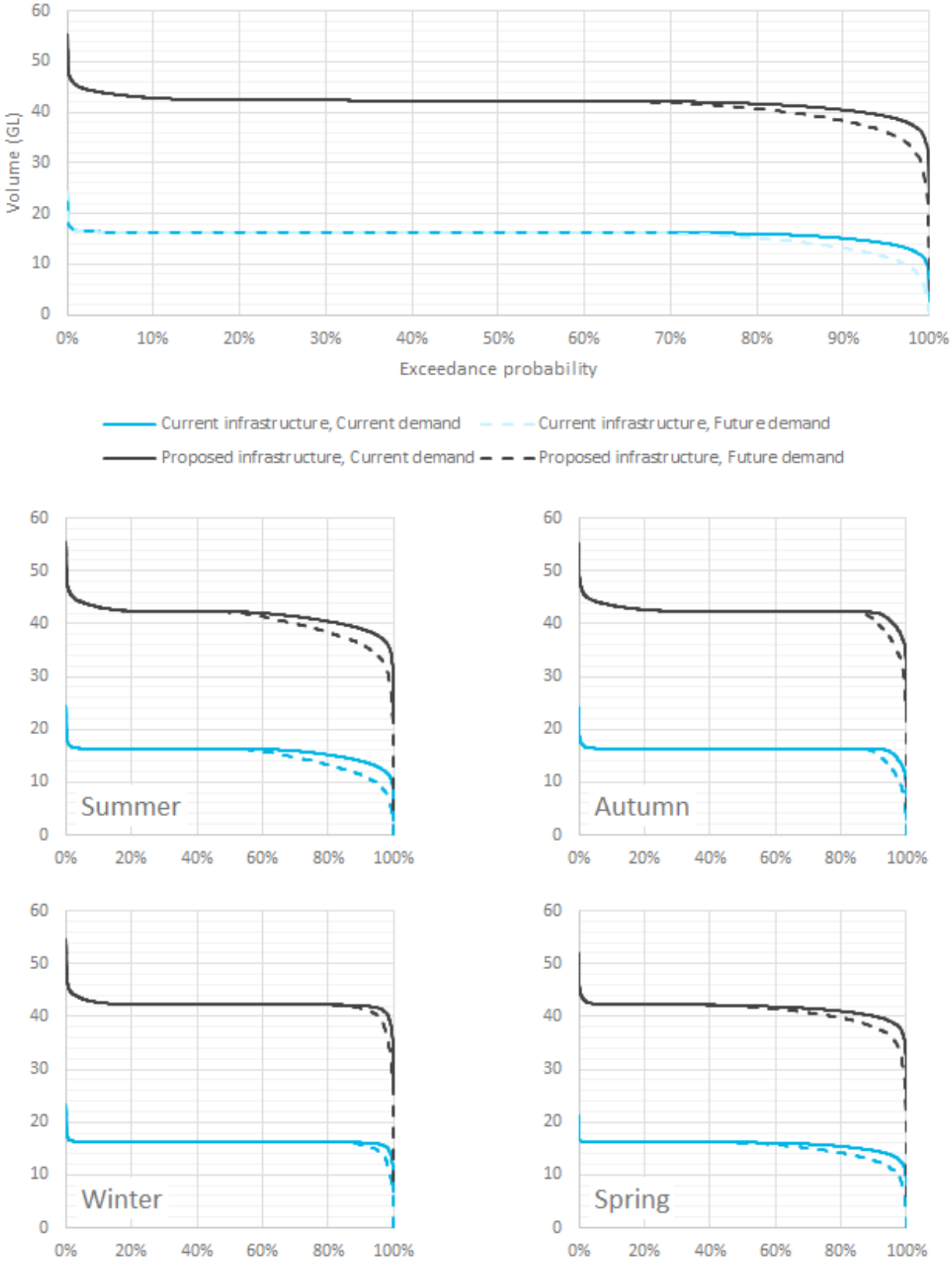


Figure 5.15 Duration curve for storage volumes at Clarrie Hall Dam, current climate

6 Model results with future climate

6.1 Assessment approach

6.1.1 Future climate

DPE-Water have developed a climate change assessment methodology for water storage projects, included as Attachment A. This methodology describes a method of selecting discrete periods of data from the perturbed palaeo-stochastic climate data set for analysis rather than analysis of the data in its entirety. By doing so, the variance which could be generated through selecting one climate model over another is reduced, as the periods selected for analysis are selected based on descriptive statistics presented on the Climate Change in Australia (CCA) website.

For the East Coast (South) NRM sub-cluster, the CCA website provided the following projections for 2070:

- 90th percentile (wet future): +22.2% rainfall (average 2,375 mm/year)
- 50th percentile (median future): -0.8% rainfall (average 1,929 mm/year)
- 10th percentile (dry future): -18.3% rainfall (average 1,587 mm/year)

Three wet, dry and median sequences of 126 years were extracted from the stochastic model results (Table 6.1), with each of these sequences having different temporal characteristics (i.e. sequencing and variability).

Table 6.1 Data sequences analysed (each 125 years)

	Start date	End date	Average Rainfall (mm)
Wet	1/01/7769	31/12/7894	2,116
	1/01/8002	31/12/8127	2,120
	1/01/5504	31/12/5629	2,058
Median	1/01/1790	31/12/1915	1,932
	1/01/5472	31/12/5597	1,918
	1/01/7660	31/12/7785	1,913
Dry	1/01/667	31/12/792	1,692
	1/01/5677	31/12/5802	1,690
	1/01/8484	31/12/8609	1,644

6.1.2 Future demand

Future climate effects were assessed using the future demand case (i.e. demand at 2065), as both climate change and demand growth relate to future events.

6.2 Overview

A summary of project effects with future climate data and future demand is presented in Table 6.2, which illustrates that:

- mean extraction volumes for TWS would be unchanged
- managed releases from Clarrie Hall Dam would become more frequent as a result of the Proposal (+3% to +10%)
- the percentage of time when dam storage levels are low will reduce significantly as a result of the Proposal
    - 13.6 GL is 85% of the current capacity of Clarrie Hall Dam and corresponds to the dam storage level below which level 1 restrictions are imposed, 7.2 GL is 45% of the current capacity of Clarrie Hall Dam and corresponds to the dam storage level below which emergency restrictions are imposed (Tweed Shire Council, 2022).
    - Storage levels fall below 13.6 GL (the current threshold volume for Stage 1 water restrictions) approximately 45% of the time in a dry sequence. With the Proposal, this is reduced to 3.4% of the time.
    - Storage levels fall below 7.2 GL (the current threshold volume for Emergency level water restrictions) approximately 14% of the time in a dry sequence. With the Proposal, this is reduced to 1.7% of the time.
- the amount and frequency of demand shortfall is significantly reduced as a result of the Proposal. Note: demand management measures which would be implemented to prevent shortfalls, are not modelled in the Source model
    - in a dry sequence, demand shortfalls occur in 9% of years, similar to the frequency of very low dam levels. This reduces to 2.6% of years with the Proposal.
- The Proposal could result in a decrease in mean flow past BPW of around 0.5%. This is likely due to increased net evaporation from the dam surface. This is particularly pronounced in a dry sequence where there is increased evaporation over the dam surface which is not offset by a similar increase in rainfall.

Table 6.2 Overview of model results with the future climate

Infrastructure scenario:		**Current**			**Proposed**		
Demand case:		Future (2065)	Future (2065)	Future (2065)	Future (2065)	Future (2065)	Future (2065)
		wet	median	dry	wet	median	dry
Clarrie Hall Dam:							
capacity	ML	16,000	16,000	16,000	42,300	42,300	42,300
FSL	m AHD	61.5	61.5	61.5	70	70	70
mean managed releases	ML/year	5,677	6,164	7,189	5,838	6,439	7,846
mean spills	ML/year	44,875	35,649	23,536	44,266	34,617	21,839

Table 6.2 Overview of model results with the future climate

Infrastructure scenario:		Current			Proposed		
Demand case:		Future (2065)	Future (2065)	Future (2065)	Future (2065)	Future (2065)	Future (2065)
		wet	median	dry	wet	median	dry
mean evaporation volume	ML/year	3,184	3,054	2,744	6,841	6,724	6,369
mean rainfall volume	ML/year	3,074	2,684	2,116	6,284	5,615	4,648
TWS:							
mean extraction at Bray Park Weir	ML/year	17,258	17,367	17,489	17,269	17,410	17,681
mean demand shortfall (assuming full demand, unaffected by restrictions)	ML/year	11	44	219	0	1	27
% of years with shortfall		0.8%	3.2%	9.0%	0.3%	0.5%	2.6%
Time below 13.6 GL (Current Stage 1 restrictions trigger)	%	25.40%	31.70%	45.30%	0.10%	0.60%	3.40%
Time below 7.2 GL (current Emergency level water restrictions trigger)	%	2.20%	5.20%	13.50%	0.00%	0.10%	1.70%
River flows:							
mean flow in Doon Doon Creek d/s of Clarrie Hall Dam	ML/year	50,552	41,813	30,725	50,104	41,056	29,684
mean flow in the Tweed River at Uki	ML/year	157,285	128,139	92,648	156,795	127,342	91,549
mean flow in the Tweed River at Braeside	ML/year	185,033	153,532	114,074	184,456	152,690	112,971
mean flow at Bray Park Weir	ML/year	268,765	222,150	163,391	268,100	221,348	162,514
Project effect on EOS	%	-	-	-	-0.2%	-0.4%	-0.5%

6.3 Flow regime

6.3.1 Flow duration curves

Seasonal flow duration curves for Doon Doon Creek and the Tweed River with future climate and demand are shown in Figure 6.1 to Figure 6.4.

Flow duration curves for Doon Doon Creek (Figure 6.1) show that:

- There is an increase of approximately 6-7% in the amount of time flow is due to minimum releases in Doon Doon Creek in a dry climate versus a wet climate. The effect due to climate is consistent with and without the Proposal, however minimum releases also occur more frequently due to the Proposal (an increase of approximately 5-6%), which may be due to increased evaporation from the larger dam surface area under a drier climate.

- There is a corresponding decrease in spill from the dam in a dry climate versus a wet climate, associated with the lower probability (0% - 15%) section of the curve. This is likely due to less rainfall and higher evaporation levels causing reduced runoff from the catchment area during rainfall events and because dam storage levels are at less than FSL more of the time (Figure 6.5) meaning flow entering the dam is captured.

- The “stepped” nature of the flow duration curves is due to the majority of flow from the dam being managed releases – with an increase from environmental releases of 4 ML/day to releases for water supply, which are approximately 40 ML/day under future demand conditions. This is most pronounced under dry sequences and during spring, when conditions are driest.

Within 5 km downstream at Uki (Figure 6.2), most of the changes observable in Doon Doon Creek are negligible due to the contribution of the unregulated upstream reaches of the Tweed River runoff from additional catchment area and unaffected tributaries. The reduction in high flow events and increase in moderate flow events due to the increased flood capture and attenuation capacity of the dam and longer flood recession, are still present but have reduced influence on the flow statistics.

Flow duration curves for the Tweed River at Braeside (Figure 6.3) and Bray Park Weir (Figure 6.4), 7.5 km and 10 km downstream of the dam respectively, show that there is negligible change in the long term Tweed River flow regime due to the proposed infrastructure under future climate conditions. In general, flows are lower during dry sequences. This was simulated but is not caused by the Proposal.

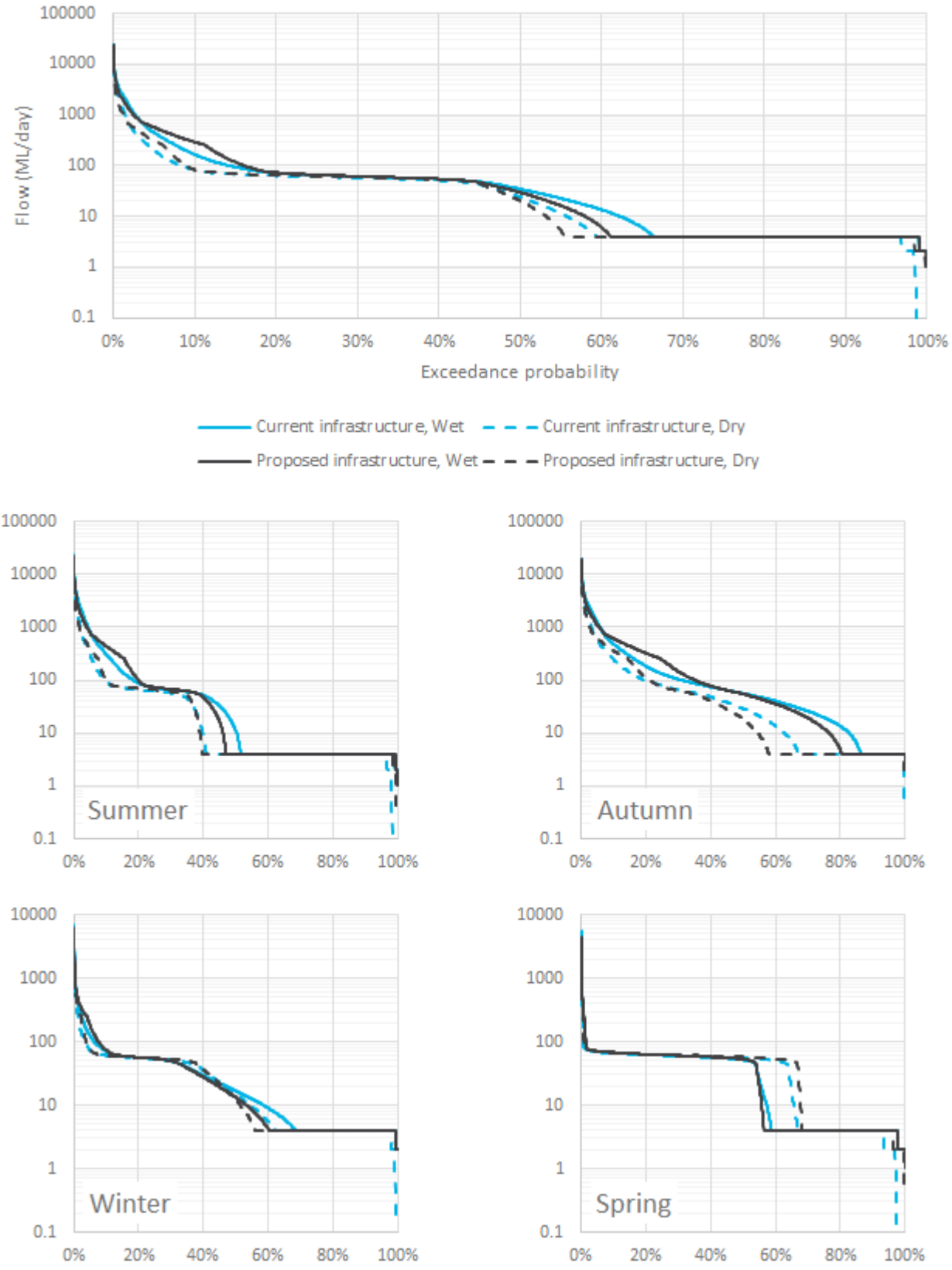


Figure 6.1 **Flow duration curve at Doon Doon Creek downstream of Clarrie Hall Dam, future climate**

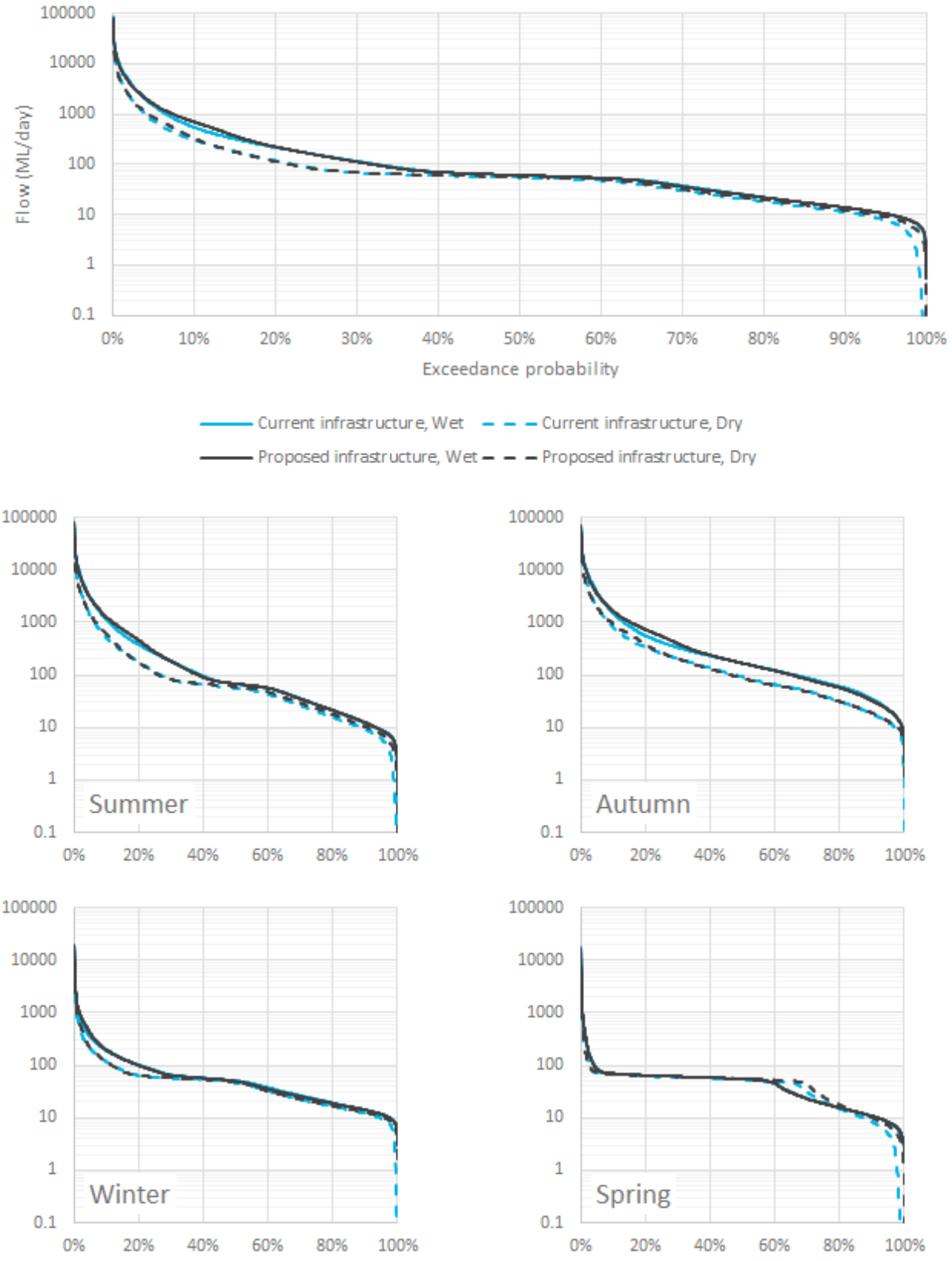


Figure 6.2 **Flow duration curve for Tweed River at Uki (201900), future climate**

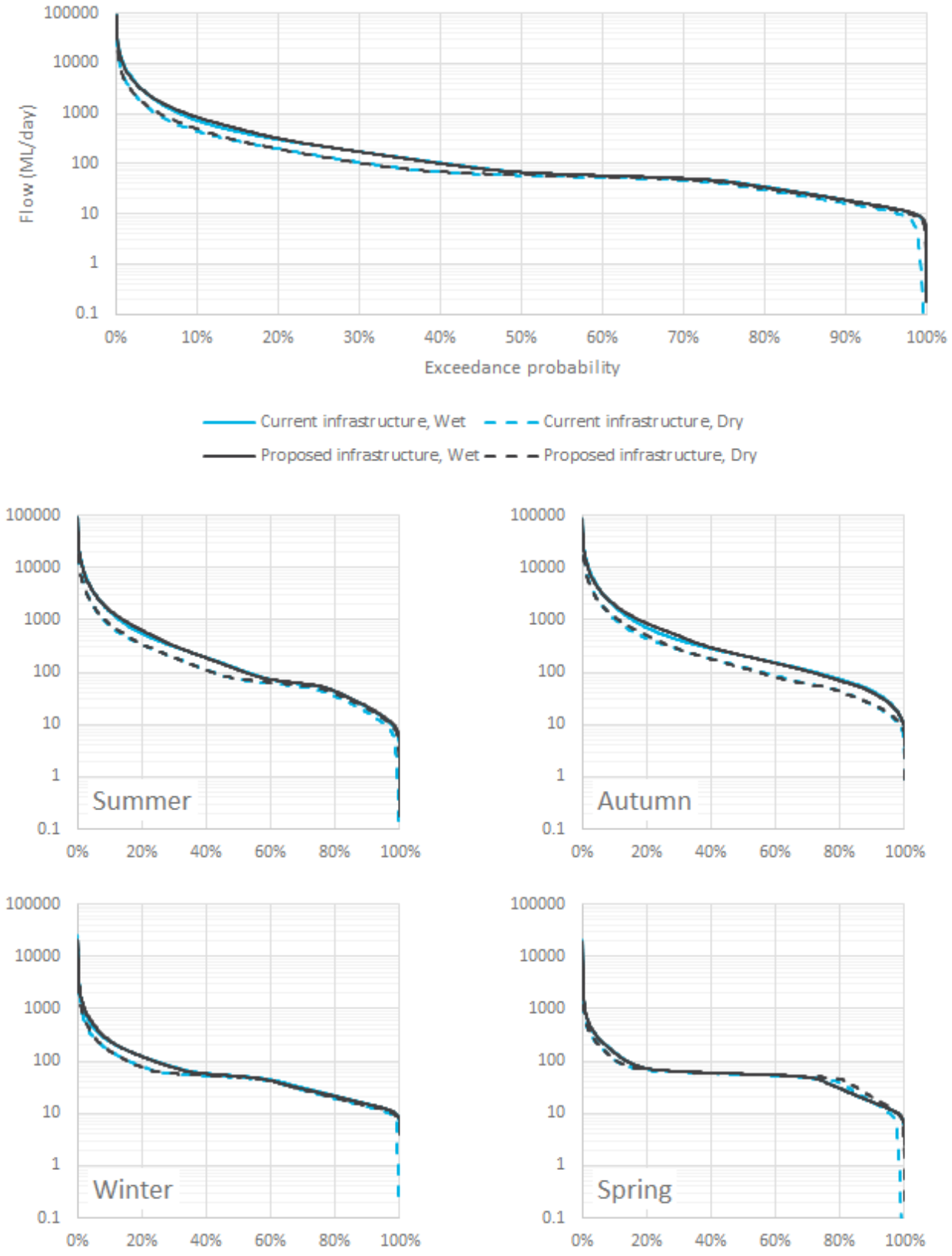


Figure 6.3 **Flow duration curve for Tweed River at Braeside (201003), future climate**

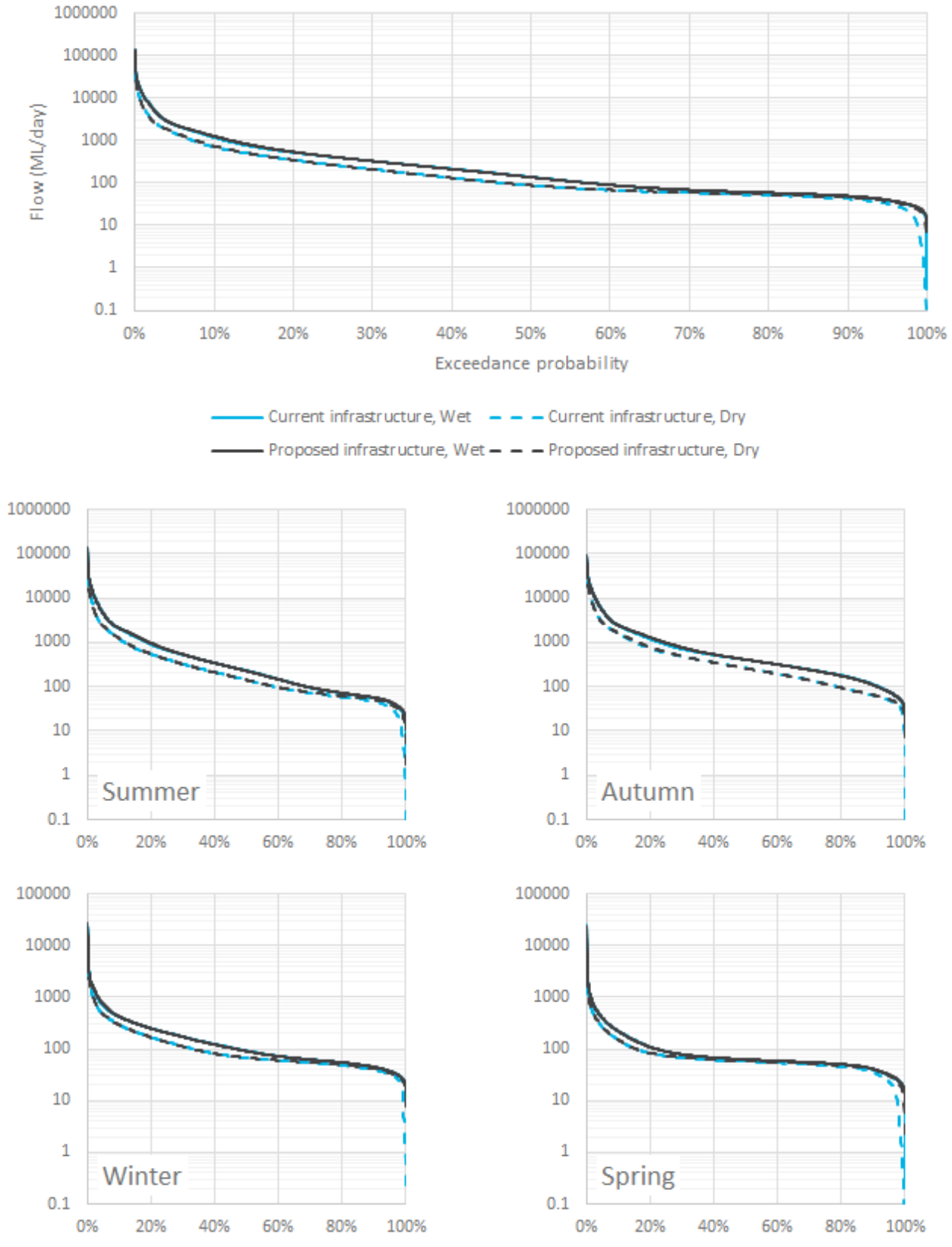


Figure 6.4 **Flow duration curve for Tweed River downstream of Bray Park Weir, future climate**

6.4 Clarrie Hall Dam Storage

Figure 6.5 shows probability of exceedance curves for Clarrie Hall Dam storage levels, developed from the flow results of simulations using future climate data.

This figure shows that under both infrastructure scenarios (i.e. with and without the Proposal):

- storage levels significantly exceed FSL only very infrequently (0% - 3%)
- Clarrie Hall Dam is full approximately 35% of the time, even in dry sequences. In wet sequences, this increases to just over 50% of the time
- in Spring and Summer, however, dam storages are full less than 20% of the time under dry sequences

In general, storage levels are lower during dry sequences.

Modelling indicates that during a dry future with the existing infrastructure, Stage 1 water restrictions would be required 46% of the time. This would reduce to 4% of the time with the larger dam. Emergency restrictions would be required 14% of the time with the existing infrastructure, reducing to 2% of the time with the Proposal.

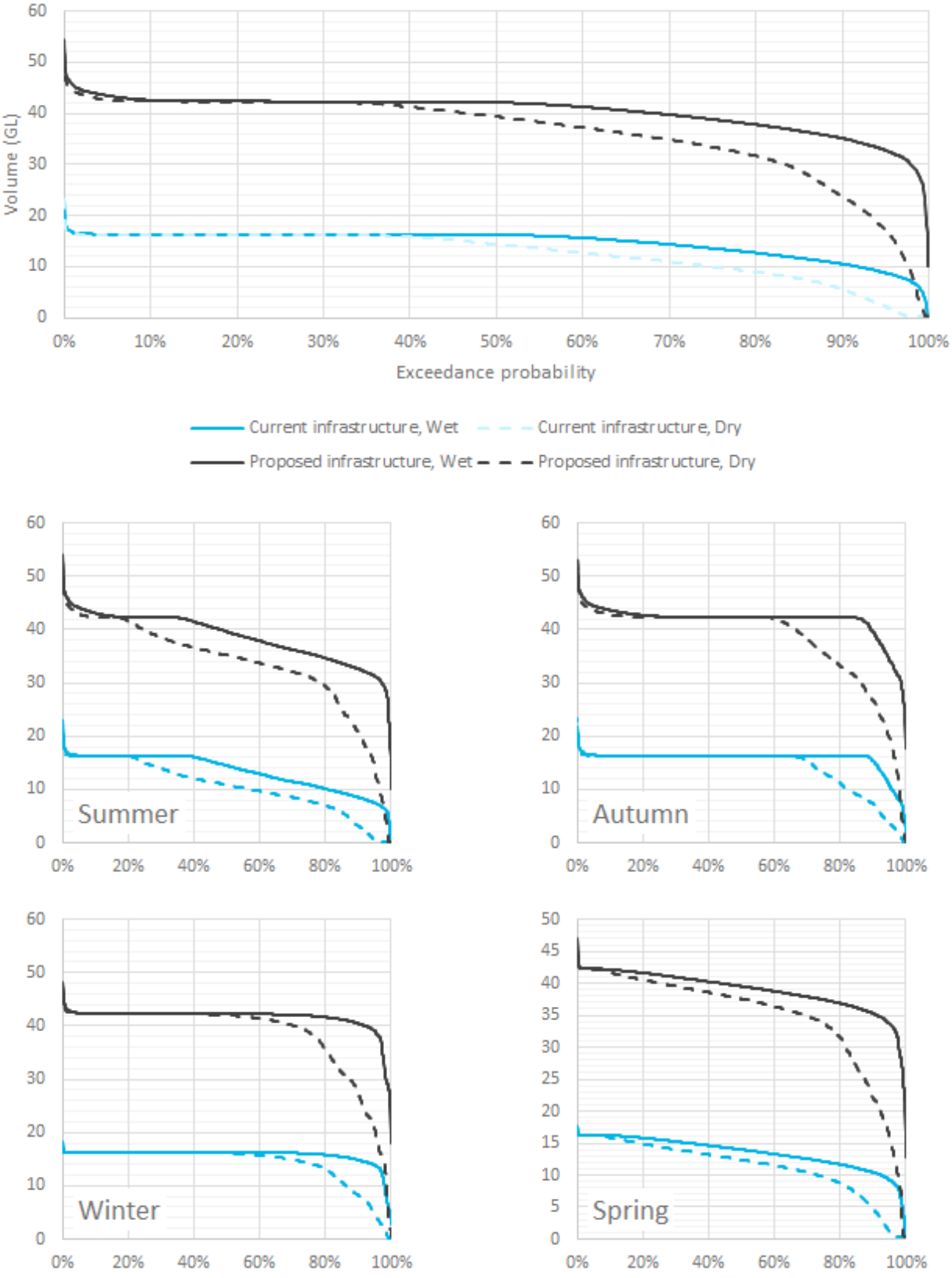


Figure 6.5 **Probability of exceedance curve for storage volumes at Clarrie Hall Dam, future climate**

7 Summary

Long term flow modelling using palaeo-stochastic climate data has illustrated:

- mean extraction volumes for TWS would be unchanged by the Proposal
- mean managed releases from Clarrie Hall Dam would not materially change as a result of the Proposal
- the percentage of time when dam storage levels are below 13.6 GL (trigger for Stage 1 water restrictions) will reduce significantly as a result of the Proposal
- high flows will be attenuated in the larger dam, resulting in:
  - reduced flood peaks in Doon Doon Creek
  - longer duration of flood recession
- the frequency of minimum releases (4 ML/day) required to be released manually from the dam will increase from approximately 30% of the time to 40% of the time due to increased evaporation from the dam surface
- the increased loss of water to evaporation would be offset over the year by a minor increase in rainfall runoff upstream from the dam due to the additional reservoir area
- within 5 km downstream at Uki, most of the changes observable in Doon Doon Creek are negligible due to the contribution of the unregulated upstream reaches of the Tweed River runoff from additional catchment area and unaffected tributaries.

Further modelling completed utilising DPE Water advice regarding climate change analysis has illustrated that:

- by 2065 climate change is expected to result in significant water shortages and time with water restrictions within the Tweed Valley if the existing infrastructure is maintained
- time in restrictions and shortfalls would decrease by 90% with the proposed larger reservoir
- the balance of evaporation and rainfall is expected to change, such that with the proposed larger reservoir additional evaporation loss could result in a decrease to end of system flow (i.e. flow past Bray Park Weir) in the order of 0.5%

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Attachment A

Climate change assessment for water infrastructure proposals

EMM
creating opportunities

Climate change assessment for water infrastructure proposals

Water Analytics has proposed a method to use the climate risk data sets developed for Regional Water Strategies to assess climate change impacts relating to infrastructure projects

Introduction

The extreme climate conditions experienced in south-east Australia in recent years has highlighted the importance of our understanding these conditions so we can best manage river systems to provide for key water dependent sectors. The patterns of drought and flood experienced in observational climate record since the later 1890s provide a guide to the climate we need to plan for. However, we also know from other evidence in the physical environment that more extreme conditions occurred before then. We also have strong evidence from climate science and modelling that increased emissions of CO_2 and other greenhouse gases will increase temperatures, may intensify extreme conditions, and alter rainfall seasonality.

DPE Water has acknowledged the need to better represent the full extent of climate conditions by developing climate risk data sets that takes account of past records of climate variability and modelled projections of climate change. This data is used to support the objectives of our Regional Water Strategies through our water computer simulation models.

We use these computer simulation models to inform how our river systems in NSW respond to climate and water management. These models transform climate into water availability that varies in time and space. The models also simulate how natural climatically determined patterns of water availability are changed by infrastructure, water access arrangements, and consumptive water use. Using outputs from these models, we can report on how much water key water dependent sectors receive under different climate conditions and/or water management conditions. These management conditions may include changes to water sharing rules or water infrastructure.

Purpose of this paper

This paper is intended to explain the rationale and method for undertaking climate change assessments for water infrastructure proposals targeting a range of climate change projections, while retaining consistency with the methods and data sets developed for the Regional Water Strategies and endorsed by an independent expert panel.

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Background

Earlier work

Water management in NSW was until recently informed by water modelling relying solely on observational data from the late 1890s till present. However, climate conditions such as experienced for the Millennium Drought in the 2000s highlighted the need to consider climate conditions outside that historically observed. The department in the mid-2010s undertook the first water strategy in the Greater Hunter Region to better understand water security for key economic sectors and identified drought length as a significant climate risk factor. Risk mitigation options included infrastructure options, including pipelines to transfer water across different sub-regions.

The basis for this work was the water models developed of the regulated Upper Hunter and Lower Hunter river systems, with climate as the main input. Decisions to invest in these risk mitigation options requires understanding their robustness to more extreme climate conditions. The department engaged researchers to develop stochastic climate data sets as input to the water models. These were perturbed with higher evaporation rates to represent climate change impacts.

Regional water strategy climate risk approach

Following completion of this strategy, the department then established a program to develop water strategies for all rural catchments in NSW. A similar approach to that used in the Greater Hunter Region was implemented to develop climate risk data sets. Key enhancements were made to the method to include paleo-climate data to generate stochastic climate data and incorporate information from the NARCliM climate program to represent projections of climate change.

A design choice was made to select the NARCliM 1.0 projections with the largest annual decrease in rainfall, to provide an approximation of a worst-case scenario. This approach was reviewed and endorsed by an independent expert panel. A full description of the method is provided on the department's website from this link.

The data sets developed are 10,000 years of daily rainfall and evaporation at all rain gauge data points used in our modelling. The inclusion of the paleo-climate data produces and enhanced representation of the multi-decadal wet and dry cycles apparent in our observational record.

The 10,000 years of daily rainfall data has been aggregated to annual total rainfall and graphed as an annual time series (light blue columns), showing a wide range of inter-annual variability. A 100-year moving average filter has been applied to this annual time series to highlight the comparative wetness and dryness of long periods or rainfall. Those periods circled would have had extended periods of below average rainfall and would manifest in our modelling results as periods with low water availability.

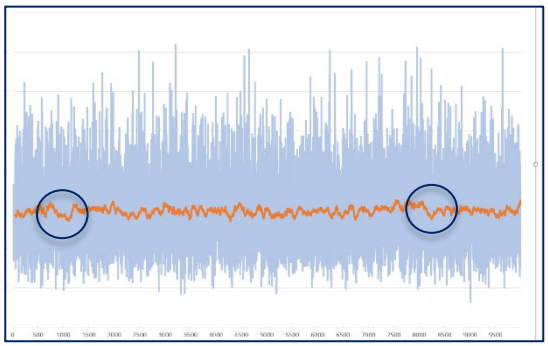


Figure 1. 10,000 years of annual rainfall totals from RWS paleo-stochastic climate data sets

The multi-millennial data sets used have the advantage compared with the shorter observational data of comprehensively representing climate variability, with multiple examples of wet and dry periods of different lengths occurring within.

The way we incorporate climate change projections with this dataset is to apply average monthly factors of changes in mean rainfall for each month at every climate station used in modelling. These factors vary across NSW consistent with the NARCliM modelled results. The average monthly factors were based on results from modelled projections of far-future (2060-79) high emission scenario using the CSIRO mk3.0 General Circulation Model (GCM), dynamically downscaled to a high spatial resolution using high resolution regional climate models (RCMs). RCMs are based on the Weather Research Forecasting (WRF) modelling system. Our factors were the multi-model mean of three RCM replicates.

A typical set of factors in northern NSW looks like that shown in Figure 2 with an increase in late summer to early autumn rainfall, followed by a decrease through to spring.

Applying these factors to the stochastic data set generally broadly preserves patterns of inter-annual variability, while decreasing overall rainfall totals. However, for years with high rainfall in the summer period this might paradoxically result in an increase in total rainfall for those years

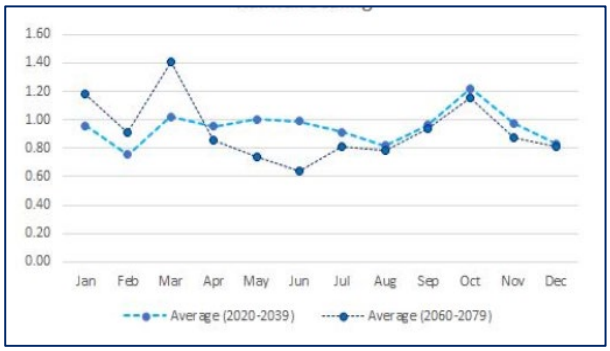


Figure 2. NARCliM Rainfall factor for used for RWS climate change projections

We have also used changes in potential evaporation from the NARCliM program, which has increased across all months of the year. The combination of lower rainfall and higher potential evaporation has resulted in a large reduction in modelled water availability, with commensurate adverse modelled outcomes for key water dependent sectors.

The Regional Water Strategies has adopted an approach of using the historical climate as a reference condition, and the full 10,000-year paleo-stochastic datasets, with and without climate factors applied, to report on water security related outcomes. They have also used multiple 40-year replicates sampled from the 10,000-year datasets to provide results for economic analysis.

Using this data for climate change assessment

The datasets developed represents most of the uncertainty regarding what our climate could be in the foreseeable future, and together with our water models provide a sound basis for our Regional Water Strategies to identify vulnerabilities in our regulated and unregulated river systems, and to then formulate and test risk mitigation options. The 10,000-year data sets also provide some insights into the probability of occurrence of these vulnerabilities.

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Issues with using regional water strategies climate risk datasets.

Feedback provided by practitioners and decision makers indicate two characteristics of this data set that presented difficulties in interpreting; (i) results arising from the length of data and (ii) the severity of climate change imposed.

Difficulties interpreting dataset length are in part is perceptual as well as relating to our skill to analyse and report critically important results. Whereas we can relate to datasets that are part of our lived experience for example, how do we then visualise and process outcomes over periods which are a hundred times longer and compare these with the shorter time periods.

As the datasets include much wetter or much drier periods, a challenge in using this longer time series is to present the modelled results in a way that informs a particular outcome, for example, changes in frequency of environmentally important flow events or water security for a town. The combining of results from the full period may obscure important results from more critical extreme climate conditions within that dataset.

The second characteristic is our design decision to select the driest NARCliM 1.0 scenario to factor our paleo-stochastic datasets. The decision was intended to represent a 'worst case' scenario to identify vulnerabilities in meeting water related outcomes, especially regarding testing the robustness of mitigation options. Feedback on this dataset was that it produced results that were too severe to constructively inform decision making. The comments relating to analysis and reporting of 10,000-year data sets also apply to using the factored sequence.

However, this does not at first glance align with approaches adopted elsewhere that test a range of modelled projected climate changes, which may vary from much wetter to much drier. Decision makers have indicated they would like to see how infrastructure options would perform under conditions that not as dry as the worst-case scenario, or even wetter than the historical period.

Method

Overview

The method proposed to assess climate change for infrastructure environmental impact assessment addresses this feedback by aligning the length of climate risk data analysed with that of the historical period, and by assessing a range of change in mean rainfall compared with historical. It does this while being consistent with the climate risk datasets development method endorsed by the independent expert panel. The method identifies suitable shorter periods of data within the longer 10,000-year data set for detailed analysis and reporting. The suitability of data is based on the mean rainfall over this period.

The method takes advantage of a characteristic of the 10,000-year dataset having significant interannual and multidecadal variability that results in different 100-year periods having mean rainfall that vary considerable compared to the historical mean.

To understand the range of changes to rainfall we should be testing for, we have adopted the results from the CSIRO and Bureau of Meteorology analysis of results from the climate models used for the recent IPCC assessment.

To understand the range of changes to rainfall we should be testing for, we have adopted the results from the CSIRO and Bureau of Meteorology analysis of results from the climate models used for the recent IPCC assessments[1]. The site reports the distribution of modelled seasonal rainfall changes compared to a reference period for different emission scenarios at different periods of time in the future Figure 3.

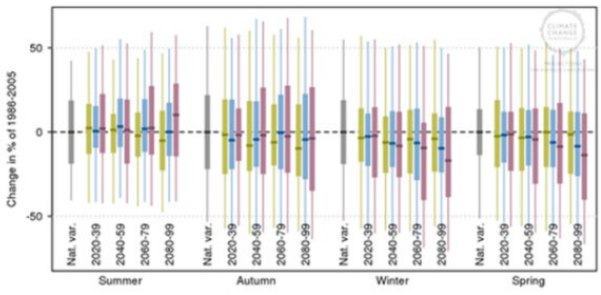


Figure 3. Distribution of modelled projected seasonal changes in rainfall[1]

These results are analysed to determine what changes in mean rainfall we should be analysing for. We then select periods for the 10,000-year data set factored with NARCliM factors with this mean rainfall. The usage of the NARCliM factors is important to account for the modelled changes in seasonality of rainfall changes.

[1] CSIRO and Bureau of Meteorology, Climate Change in Australia website (http://www.climatechangeinaustralia.gov.au/), cited [*17/03/2022*]

Detailed steps

The detailed steps in developing the datasets to assess climate change for our infrastructure projects is set out in Figure 4 and described in Table 1, noting that steps 1.0, 2.0, 2.1, 3.0 and 3.1 were completed in developing the RWS climate risk datasets.

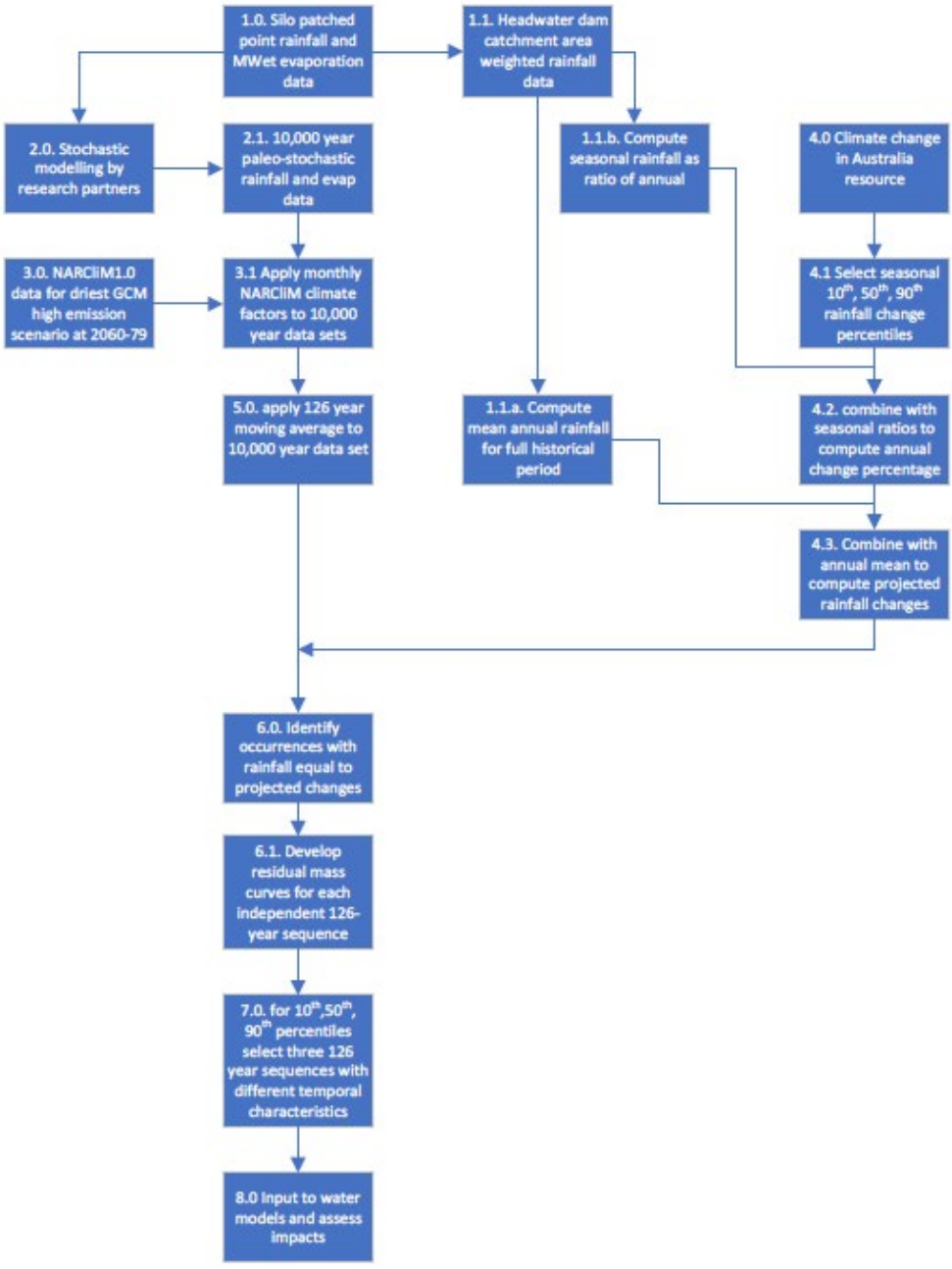


Figure 4. Detailed steps for climate change scenarios for infrastructure

Table 1. Description of steps for developing climate change scenarios for infrastructure assessment

Step	Description
1.1	*Headwater dam catchment area weighted rainfall data*. The subregion of our water sources that dominate the water related outcomes is the catchment that inflows. Here we take the weighting factors from our rainfall runoff modelling and multiply them by the daily rainfall data at that station, and aggregate to a single daily rainfall time series.
1.1.a	*Compute mean annual rainfall for full historical period.* Sum the total rainfall to annual totals and take the mean of these annual totals.
1.1.b	Compute seasonal rainfall as ratio of annual. Sum the rainfall for each season and compute the ratio of the total annual rainfall. This allows for the conversion of seasonal changes from the Climate Change in Australia resource to an annual change
4.0	*Go to Climate Change in Australia resource.* Select the appropriate region and rainfall in the Climate Change in Australia Summary Data explorer[2] on the Climate Change website
4.1	*Select seasonal 10th, 50th and 90th rainfall change percentiles.* From the graphical depiction of the distribution of modelled percentage changes in seasonal rainfall (see Figure 3 for example) read off the seasonal percentage changes for the above percentiles for greenhouse gas concentration pathway scenario RCP8.5 for the 2060-2079 time period. This step covers the range of change estimates from 80% of the climate models, including instances where we may see an increase in rainfall.
4.2	*Combine with seasonal ratio to computer annual change percentage*. Multiplying the seasonal ratios from observed data by the percentage projected change for this seasonal rainfall, and aggregating, we can get an approximation of the changes to annual rainfall for each percentile. Our NARCliM factored 10,000-year daily time series rainfall datasets already include a climate change affected seasonal pattern, so applying these factors directly to this data set would double account the seasonal changes.
4.3	*Combine with annual mean to compute projected rainfall changes*. Multiplying the computed change in mean annual rainfall by the computed area weighted observed mean rainfall produces the mean rainfall for 126 years we would like sample for from our datasets.
5.0	*Apply 126 year moving average filter to NARCliM factored 10,000-year dataset.* This produces a product that can be used to identify when and how often rainfall is at the target means over 126-year periods. A graphical representation of that is shown at Figure 5.
6.0	*Identify occurrences with rainfall equal to projected changes*. These need to be non-overlapping periods. An example for simulated flow from dam inflow catchment rainfall is shown at Figure 6.

[2] Summary Data Explorer (climatechangeinaustralia.gov.au)

Step	Description
6.1	*Develop residual mass curves for each independent 126-year occurrence.* In most cases, there will be multiple occurrences of non-overlapping periods, and this graphical technique can be used to identify sequences with materially different characteristics. An example is shown at Figure 7
7.0	*Select maximum of three 126-year sequences with based on different temporal characteristic displayed by residual mass curves*. An advantage of the stochastic method is that it accounts for variability along with long term mean. Periods with the same mean rainfall may produce quite different outcomes for a water system, depending on sequences of significant events and lengths of floods. Testing of the water system with samples with the same means allows for a statement of confidence in the robustness of these outcomes.
8.0	*Input to water models and assess impacts.* In many cases this modelling has already been completed, and results of existing models can be assessed independently for the sequences identified in step 7.0

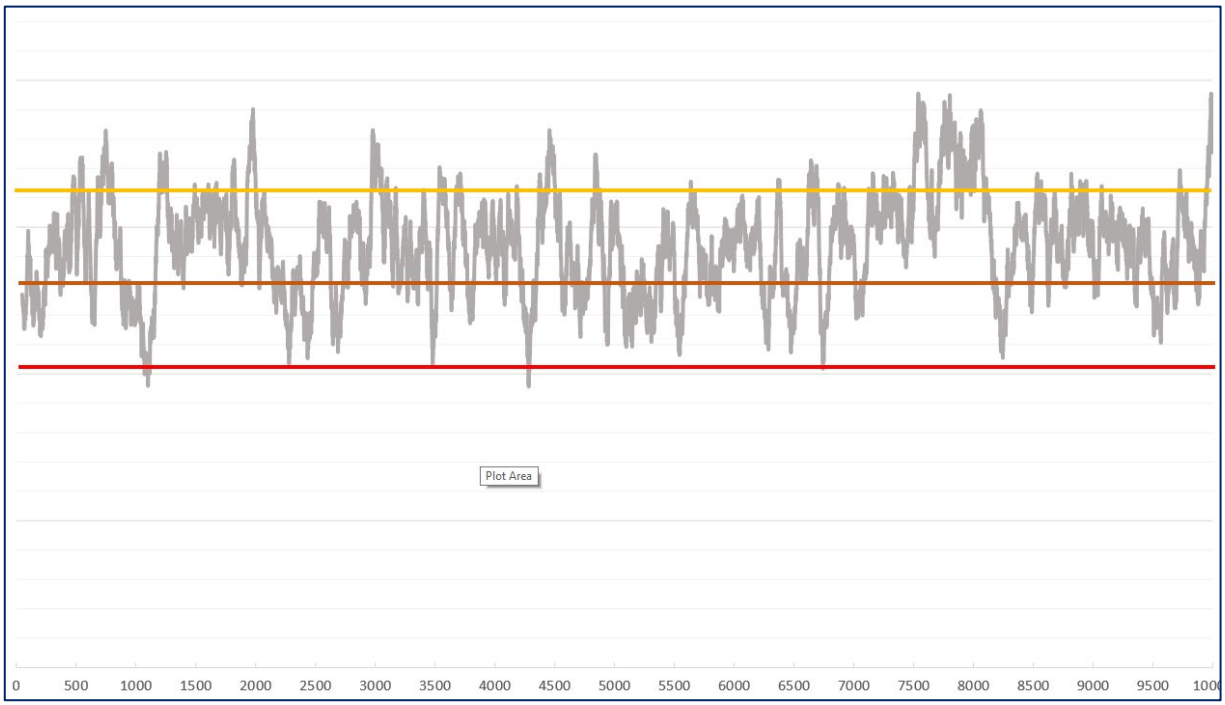


Figure 5. 126 year moving average of a NARCliM factored paleo-stochastic rainfall data set (grey line) with pindicative lines showing mean annual rainfalls for further analysis (yellow, brown and red for 10th, 50th and 90th percentiles respectively)

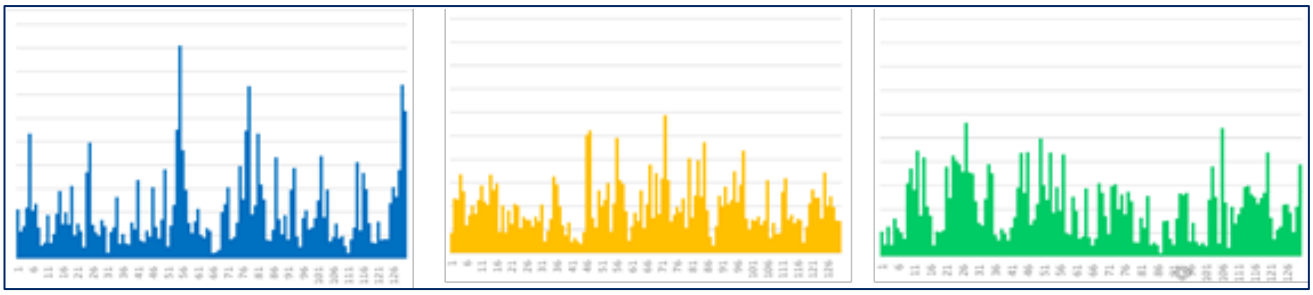


Figure 6. Three non-overlapping samples from 10,000-year time series of annual time series of flows with the same average for a 126-year period

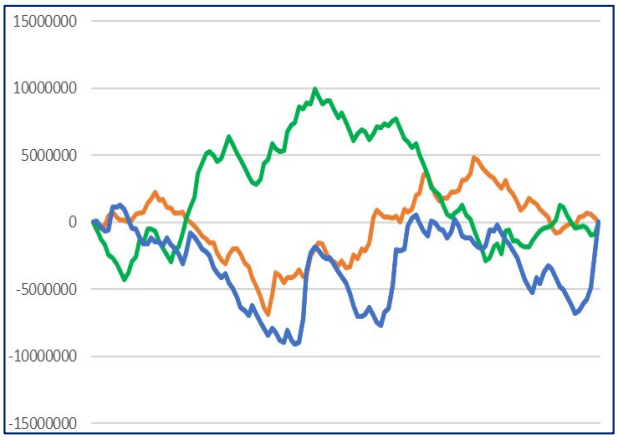


Figure 7. Residual mass curves (a.k.a. cumulative departure from mean) of three annual time series from Figure 6, with trends and changes of direction of gradient highlighting sequences of wet and dry periods

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Annexure B
Limnology

EMM
creating opportunities

B.1 Note on limnological modelling

Limnological modelling was undertaken by HydroNumerics in 2020-2021 for an unpublished assessment of the potential effects of Clarrie Hall Dam wall raising led by EcoLogical Australia (ELA). The limnology modelling report refers to ELA due its provenance, however ELA were not involved in the preparation of the current EIS or SWA. The limnological assessment undertaken by HydroNumerics was provided by Council to KBR and EMM for the purposes of EIS preparation, and is included in B.2.

The following references within the limnology modelling report are not current:

- references to 'the EIS' and EIS sections refer to the previous unpublished assessment
- references to 'the SOURCE model' refer to a catchment model prepared by ELA to support the limnological model, and are not references to the DPE Water Tweed River Catchment model described in this SWA
- references to SEARs are superseded by the SEARs supplied for this EIS.

The modelled scenarios include the existing reservoir and the Proposal, and as such the results remain informative of expected effects.

B.2 Limnology modelling report

See overleaf.

HydroNumerics

Environmental Impact Statement for the Clarrie Hall Dam Raising

Reservoir Modelling

Final

Version 4

August 2021

Prepared for Eco Logical Australia Pty Ltd

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EXECUTIVE SUMMARY

Eco Logical Australia Pty Ltd (ELA) was engaged by Tweed Shire Council (Council) to prepare an Environmental Impact Statement (EIS) for the raising of Clarrie Hall Dam (the Proposal). This reservoir modelling assessment has been undertaken to support the EIS, which is required under Part 5 of the Environmental Planning and Assessment Act 1979 (EP&A Act). The Proposal is classified as State Significant Infrastructure (SSI) under the State Environmental Planning Policy (State and Regional Development) 2011.

Clarrie Hall Dam (CHD) is located on Doon Doon Creek approximately 15 kilometres south-west of Murwillumbah in New South Wales. The dam structure has a height of 43 metres with a full supply level (FSL) at 61.5 m AHD and length of 175 m, providing a storage capacity of 16,000 ML. CHD functions as the water supply storage for Tweed region where water is released from the intake tower down the Tweed River and then drawn-off at Bray Park Weir (15 km downstream) for treatment and distribution. The passing flow reaches the river mouth at Tweed Heads near the Queensland border.

The Proposal would increase the dam wall height by 8.5 metres (m) to provide a Full Supply Level (FSL) height of 70 m Australian Height Datum (AHD) (RL70 m), thereby increasing the capacity of the dam from 16,000 megalitres (ML) to approximately 42,300 ML. To assess potential water quality changes in the raised dam, the EIS required the preparation of a water quality model of the dam to model water quality parameters so that the impact on water quality and subsequent impact on aquatic ecology of a raised dam can be determined.

This report provides a description of the Proposal and the limnology of the existing reservoir, which is focussed on physical and water quality data that have been collected over the past 4 years. The report then describes the development of a model for the existing reservoir and the application of the model to raised dam scenarios (including climate change) to predict the future water quality in CHD. The report concludes with a summary of potential risks that relate to water quality and recommendations for future management.

The three-dimensional Aquatic Ecosystem Model (AEM3D) was applied to CHD and calibrated using historical water quality data collected over the period from July 2015 to July 2019. The model was configured to simulate the hydrodynamics of the reservoir, including the temperature and stratification, the dissolved oxygen, suspended solids, nutrients (phosphorus and nitrogen) and the growth of cyanophytes and chlorophytes. The model boundary conditions consisted of Bureau of Meteorology (BoM) meteorological data, inflows and extractions determined as part of the concurrent hydrological modelling study (Eco Logical, 2021) and derivations of inflow event constituents from literature publications.

A number of algorithm parameters in the model were assigned values from previously reported studies and the remainder were adjusted to calibrate the model against the observed water quality data. A sensitivity analysis indicated that the model was most sensitive to the meteorological forcing data, which was synthesised from a series of nearby BoM meteorological stations in the absence of sufficiently high-resolution data at the CHD site. Because of this

sensitivity, meteorological data was adjusted to account for local topography and improve the simulation result. The calibrated model results demonstrated that the model was able to reproduce the key observed processes of stratification and mixing, inflow event response, nutrient cycling and algal growth to the extent that it was fit-for-purpose as a scenario modelling tool.

The calibrated model was then used to assess a range of scenarios that included the current conditions, raised dam (by 8.5 m) and climate related changes to the hydrology and meteorology. The changes to hydrology and meteorology were derived as part of the Eco Logical (2021) hydrology modelling. The modelling indicated that in terms of key risks as a result of raising the dam wall, there is a predicted increase in the internal loading of nutrients from the sediments (most importantly phosphorus as orthophosphate) in the larger anoxic hypolimnion of the raised dam. When the phosphorus that accumulates in the hypolimnion is then mixed into the surface during complete or partial mixing events, the increased phosphorous concentrations alleviate phosphorus limited algae growth and trigger increased cyanophyte and chlorophyte concentrations. The cyanophytes (blue-green algae) are likely to remain dominant during the summer months (which is currently observed) and at higher concentrations – the modelling indicates summer peaks of up to 50% higher. In addition, their dominance is likely to be reinforced by the changes in the ambient water conditions (primarily water temperature and stratification) that may occur as a result of climate change impacts.

Whilst not explicitly modelled herein there is the additional risk that for at least some period after filling the raised dam may have depleted dissolved oxygen in the surface waters due to the decomposition of inundated vegetation and soil organic matter. This is likely to have implications for establishing a desired raised-dam ecology and the period over which this impact may be experienced has not been established.

The modelling study also leads to the following recommendations:

- Higher frequency monitoring to the full depth for a larger suite of variables (e.g. including different nutrient speciation) should be considered as part of an ongoing management plan to assist with tracking the water quality and investigating the key processes that impact the future water quality;
- Detailed assessment of options should be undertaken for artificial mixing that targets a reduction in hypolimnetic anoxia to generate a decrease in internal loading of nutrients (and potentially metals) and decrease in primary productivity; and
- Implementation of a means for adaptive offtake height configuration in the raised dam to provide the capacity to avoid discharge of poor quality water.

HydroNumerics

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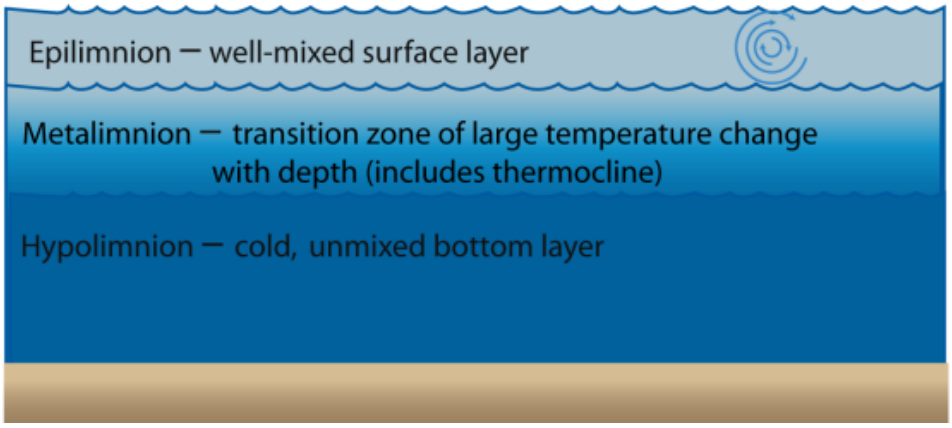
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GLOSSARY, ACRONYMS, INITIALISMS AND ABBREVIATIONS

AHD	Australian Height Datum
Anoxic water	Water with zero oxygen concentration.
BoM	Australian Bureau of Meteorology
CHD	Clarrie Hall Dam
Chlorophyll-a (Chl-a)	A green photosynthetic pigment common to all algae, which absorbs energy from sunlight and the concentration of which is an indicator of total phytoplankton biomass in a lake or reservoir.
Council	Tweed Shire Council
Cyanophytes	A unique group of prokaryotic phytoplankton often described as 'blue-green algae'. Various species of this group are toxic to humans and animals.
Diurnal	Occurring within the cycle of a day.
DO	Dissolved Oxygen
DOC	Dissolved organic carbon.
DPE	Department of Planning and Environment
Eco Logical	Eco Logical Australia Pty Ltd
ELA	Eco Logical Australia Pty Ltd
EP&A Act	Environmental Planning and Assessment Act 1979
Epilimnion	Top-most layer in a stratified lake or reservoir, occurring above the metalimnion and deeper hypolimnion.
Euphotic zone	Region in a water column where light can penetrate and photosynthesis can occur.
Hypolimnion	Dense, bottom layer of water in a stratified lake or reservoir. It is the layer that lies below the thermocline.
Metalimnion	Layer in which density changes more rapidly with depth than it does in the layers above (epilimnion) or below (hypolimnion). Includes the thermocline.



Indicative lake layering (source: https://wetlandinfo.des.qld.gov.au/wetlands/ecology/aquatic-ecosystems-natural/lacustrine/non-floodplain-soil-lake/hydrology.html)

ML	Megalitres
NTU	Nephelometric Turbidity Units
PAR	Photosynthetically available radiation (light)
POC	Particulate Organic Carbon
PON	Particulate Organic Nitrogen
POP	Particulate Organic Phosphorus
Proposal	Clarrie Hall Dam Raising Proposal
RL	Reference Level, equivalent to m AHD for CHD
Thalweg	A line connecting the lowest points of successive cross-sections along the course of a valley or river
Thermocline	Region in a stratified water body where vertical temperature gradients are highest.
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSC	Tweed Shire Council
TSS	Total Suspended Solids
WQ	Water Quality

1 Introduction

Eco Logical Australia Pty Ltd (ELA) was engaged by Tweed Shire Council (Council) to prepare an Environmental Impact Statement (EIS) for the raising of Clarrie Hall Dam (the Proposal). This reservoir modelling assessment has been undertaken to support the EIS, which is required under Part 5 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The Proposal is classified as State Significant Infrastructure (SSI) under the *State Environmental Planning Policy (State and Regional Development) 2011*.

1.1 Clarrie Hall Dam Raising Proposal

Clarrie Hall Dam is located in the Tweed Shire Local Government Area (LGA), 15 kilometres (km) south-west of Murwillumbah in northern New South Wales (NSW). It is operated by Council to provide a drinking water supply to the Tweed Shire.

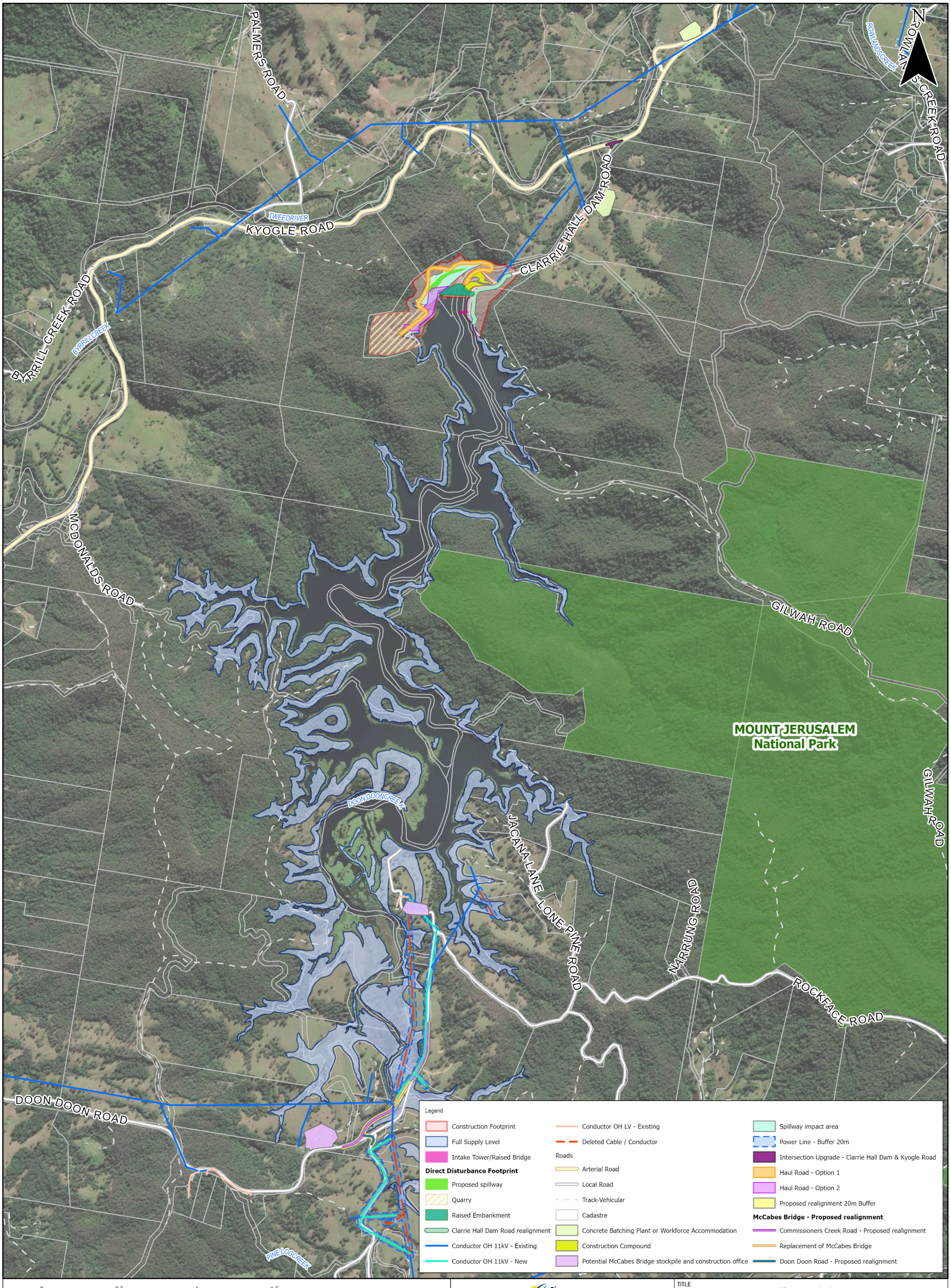
The Proposal would increase the dam wall height by 8.5 metres (m) to provide a full supply level (FSL) of 70 m Australian Height Datum (AHD) (RL70 m), thereby increasing the capacity of the dam from 16,000 megalitres (ML) to approximately 42,300 ML. It is estimated the increased capacity will provide a secure water supply for the Tweed Shire until at least 2046.

The Proposal includes:

The key elements of the Proposal are:

- constructing access roads to the construction areas and establishing the construction site
- re-establishing the quarry used to construct the dam
- removing and storing parapet walls for reuse
- increasing the base width of the valley-side abutment and raising the embankment crest to RL 75.5
- increasing the height of the concrete-faced rockfill embankment and 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 at the dam, including an amenities block, public shelters, viewing areas, interpretation signage, paths, car parks, landscaping, security fences, lighting, monitoring equipment and boat ramp
- removing or reconstructing impacted infrastructure at Crams Farm
- upgrading the Kyogle Road and Clarrie Hall Dam Road intersection.

Figure 1.1 shows the expected direct disturbance footprint of the Proposal.



0 0.5 1 1.5
Kilometres

Scale at A3 1:22,000

SOURCE
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FILE PATH	COORDINATE SYSTEM	DATE
O:\G&I\GIS\PCS00120_CHDR\Maps\APRX\SEN351-001-CHDR Project Description - resave4	GDA 1994 MGA Zone 56	01 Jul 2024

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201 Kent Street, Sydney, NSW 2000

Prepared: MG
Checked: KB

TITLE

Figure 1.1

Clarrie Hall Dam Raising Development Site (Full Extent)

DOCUMENT NO.	REV.
SEN351-M001 - Development Site	I

1.2 Secretary's Environmental Assessment Requirements (SEARs)

The Secretary's Environmental Assessment Requirements (SEARs) were issued by the NSW Department of Planning, Industry and Environment (formerly Department of Planning and Environment) on 23 April 2019, replacing the previous version of 15 August 2018. The SEARs outline the specific requirements to be addressed by the EIS for the Proposal. Table 1.1 presents the SEARs relevant to this assessment and includes a summary of each component of the SEARs addressed in this report.

Table 1.1 Relevant Key Issues SEARs for CHD reservoir assessment.

SEARs Desired Performance Outcome	**Guidelines for Health and Safety as listed in SEARs**	**Relevant Requirements**	**Where addressed in this report**
6. Climate Change Risk	Australian Government's Climate Change Impacts and Risk Management – A Guide for Business and Government (2006) AS/NZS 31000:2009 Risk Management – Principles and Guidelines	2. The Proponent must quantify specific climate change risks with reference to the NSW Government's climate projections and incorporate specific adaptation actions in the design.	Section 4.3 (*for the CHD reservoir only)*
9. Hydrology, Flooding and Water Quality	NSW Water Quality and River Flow Objectives at http://www.environment.nsw.gov.au/ieo/ Using the ANZECC Guidelines and Water Quality Objectives in NSW (DEC, 2006) Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/RMCANZ, 2000) NSW Aquifer Interference Policy (DPI, 2012) Risk Assessment Guidelines for Groundwater Dependent Ecosystems (Office of Water, 2012)	6. The Proponent must describe background conditions for current operations and any water resource likely to be affected by the proposal, including:	
		(a) existing surface and groundwater quality	Section 5.1 and 5.2 (*for the CHD reservoir only)*
		(b) frequency and quality of dam discharges including for environmental flows	Section 5.1. (*for the CHD reservoir only)*
		(e) water quality monitoring programs and indicators and trigger values/criteria.	Section 5.4 (*for the CHD reservoir only)*

		7. The EIS must assess the impacts of the proposal on water quality, including the nature and degree of impact on receiving waters for both surface and groundwater	Section 5.1 and 5.2 (*for the CHD reservoir only)*

Table 1.2 Relevant Key Department Issues for CHD reservoir assessment.

Department of Industry (NSW) comments on SEARs	**Relevant Requirements**	**Where addressed in this report**
Management of Environmental Flows and Dam Releases	Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.	Section 5.1, 5.2 and 5.3 (*for the CHD reservoir only)*
OEH standard environmental assessment	**Relevant Requirements**	**Where addressed in this report**
Water and soils	11. The EIS must describe background conditions for any water resource likely to be affected by the Clarrie Hall dam raising project, including:	
	a. Existing surface and groundwater.	Section 2.6 and 5.1 (*for the CHD reservoir only)*
	c. Water Quality Objectives (as endorsed by the NSW Government including groundwater as appropriate that represent the community's uses and values for the receiving waters.	Section 5.1 (*for the CHD reservoir only)*
	d. Indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government.	Section 5.1 (*for the CHD reservoir only)*
Transport for NSW standard environmental assessment requirements	**Relevant Requirements**	**Where addressed in this report**
Water - Quality	(a) state the ambient NSW Water Quality Objectives (NSW WQO) and environmental values for the receiving waters relevant to the proposal, including the indicators and associated trigger values or criteria for the identified environmental values;	Section 5.1 (*for the CHD reservoir only)*
	(d) assess the significance of any identified impacts including consideration of the relevant ambient water quality outcomes;	Section 5.2 (*for the CHD reservoir only)*

	(i) identify proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality.	Section 5.4 (*for the CHD reservoir only)*

1.3 Purpose of this Report

Hydronumerics Pty Ltd was engaged by ELA to assist with the preparation of the EIS with regards to predictive modelling of the water quality in Clarrie Hall Dam (CHD) in response to the proposed dam raising. This study is focussed solely on the development and application of a water quality (WQ) model for the CHD reservoir and has been undertaken by developing a three-dimensional numerical model to simulate the hydrodynamics (i.e. the physics) and key water quality variables in CHD. Inputs into the CHD model include bathymetric data, hydrological flows and inflow water quality parameters, that have been determined by Eco Logical using the SOURCE model, and meteorological data provided by the Bureau of Meteorology (BoM).

Raised dam bathymetry and climate change-modified hydrology and meteorology have been applied to the model to assess the likely limnological behaviour of CHD as part of the EIS assessment criteria.

This report provides the following information:

- Description of the limnology of CHD (Chapter 2)
- Description of the model; model development, calibration and performance (Chapter 3)
- Description and outputs of model scenarios for the raised dam under current climate and projected climate change conditions (Chapter 4)
- Summary of potential water quality risks and recommendations for mediation and mitigation (Chapter 5).

2 Clarrie Hall Dam

2.1 Location

Clarrie Hall Dam (Figure 2.1) is located on Doon Doon Creek, approximately 15 kilometres south-west of Murwillumbah in New South Wales. Doon Doon Creek is a tributary of the South Arm of the Tweed River. The existing dam structure has a height of 43 metres and length of 175 m, with a full supply level (FSL) at 61.5 m AHD providing a storage capacity of about 16,000 ML. There is an uncontrolled spillway chute that is capable of discharging 590 m^3/s during overflow events.

CHD functions as a water supply storage for the Tweed region, with water released from the intake tower into Doon Doon Creek and flowing down the Tweed River to be drawn-off at Bray Park Weir, 15 km downstream.

CHD is fed by a catchment area of approximately 60 km^2. The Tweed Shire Council (TSC) manages approximately 10 km^2 of native regrowth forest within the catchment with additional State-owned forest adjoining the dam (Everson, 2011) providing a buffer zone for the reservoir. CHD is also open for recreational uses, such as bushwalking, nature appreciation (bird watching, nature photography), picnicking, recreational fishing, sailing, canoeing, kayaking and rowing, motor boating (electric motors only – fuel motors to be removed from boats) and special uses approved by council (such as fuel motor boats for research and monitoring).



Figure 2.1 Regional map showing the location of Clarrie Hall Dam.

2.2 Meteorology

The closest continuous meteorological record is provided by the BoM weather station at Bray Park (15 km downstream of CHD at Murwillumbah), which has been recording since 1972. A summary table of minimum and maximum temperatures (Table 2.1) show mean maximum temperatures of over 29°C in the summer months from December through to February that cool to below 22°C during the winter months of June and July. The mean minimum temperatures range from approximately 19 - 20°C in summer down to 9 - 10°C in winter.

Windspeed records from 9 am in the morning and 3 pm in afternoon (Figure 2.2) illustrate the dominance of weak (< 20 km/hr) westerlies and south-westerlies in the mornings and moderate (typically less than < 30 km/hr) north-easterly to south-easterly breezes in the afternoons.

Table 2.1 Summary of minimum (top) and maximum (bottom) air temperatures at Bray Park since 1972 (sourced from BoM).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	19.8	19.7	18.4	15.6	12.5	9.9	8.5	8.7	11.4	14.2	16.7	18.5	14.5
Lowest	17.5	18.2	16.3	13.7	9.9	6.3	5.9	5.7	9.0	11.4	14.4	16.3	12.8
5th percentile	18.4	18.3	16.8	14.6	10.7	8.0	6.0	6.3	9.9	12.3	15.2	16.7	13.6
10th percentile	18.8	18.7	17.2	14.7	10.9	8.4	6.3	7.2	10.1	12.5	15.5	17.3	13.6
Median	19.8	19.9	18.4	15.4	12.6	10.2	8.4	8.7	11.4	14.1	16.6	18.6	14.7
90th percentile	21.0	20.8	19.6	16.7	13.8	11.4	11.0	10.2	12.5	15.5	18.2	19.8	15.1
95th percentile	21.1	20.9	19.8	16.8	14.0	11.6	11.2	10.4	13.5	15.7	18.3	20.0	15.4
Highest	21.3	21.2	20.1	17.0	14.6	11.8	12.6	11.7	13.9	17.4	19.0	20.4	15.5

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	29.7	29.0	28.1	26.2	23.6	21.3	21.1	22.5	25.1	26.4	27.8	29.2	25.8
Lowest	27.0	26.7	25.9	24.0	22.2	20.0	19.7	20.4	22.9	23.7	25.5	26.1	24.8
5th percentile	27.9	27.5	26.5	24.9	22.4	20.4	19.9	21.3	23.4	24.5	25.8	27.0	25.0
10th percentile	28.1	27.5	27.0	25.0	22.6	20.4	20.0	21.4	23.6	24.7	26.0	27.4	25.1
Median	29.6	28.9	28.2	26.2	23.6	21.3	21.1	22.5	24.8	26.2	27.8	29.0	25.7
90th percentile	30.9	30.6	29.3	27.4	24.5	22.2	22.0	23.7	27.2	27.9	29.3	30.9	26.5
95th percentile	31.2	30.8	29.4	27.7	25.3	22.4	22.4	24.1	27.9	28.0	29.4	31.6	26.6
Highest	32.0	31.7	30.5	28.1	26.1	23.2	22.7	25.5	28.2	28.6	30.0	32.1	26.9

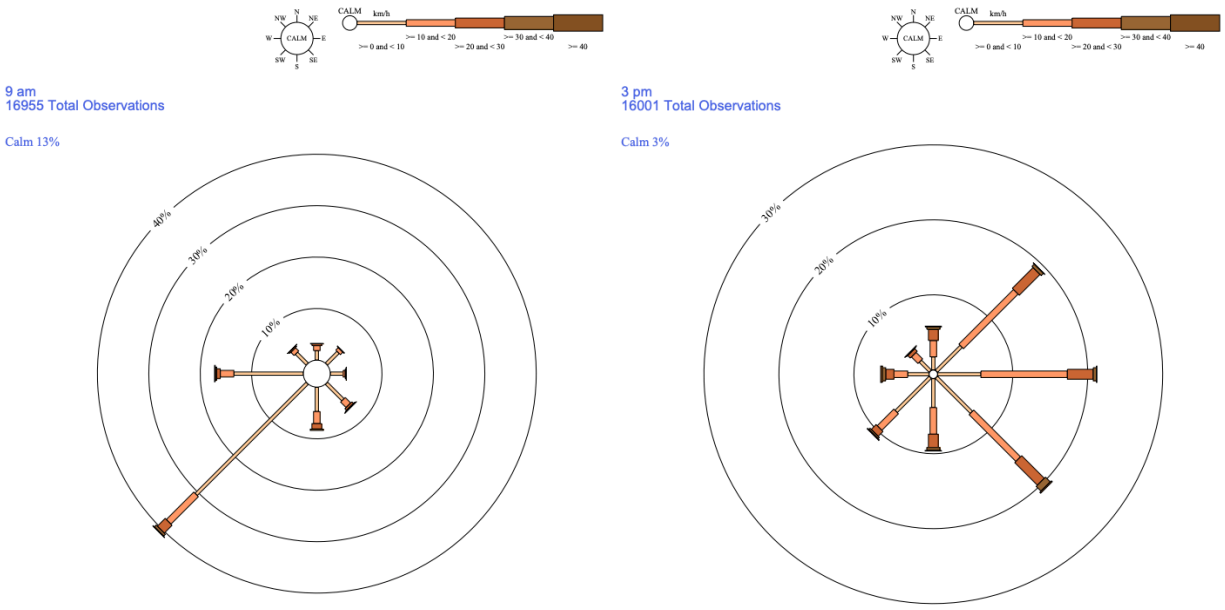


Figure 2.2 Wind roses for data collected at Bray Park since 1972 at 9am (left) and 3 pm (right) (sourced from BoM).

2.3 Rainfall and Hydrology

A detailed summary of the hydrology of CHD is provided in the hydrology modelling report (Eco Logical, 2021). Interpolated hourly rainfall used to calibrate the Oxley River stream gauge (BoM gauge number 201001 – 10 km north of CHD) is shown in Figure 2.3. The data illustrate peaks of up of 60 to 80 mm/hr during large rainfall events (6 over the 43-year period shown), with consistent seasonal events between 10 and 30 mm/hr in most years in the record.

Calibrated SOURCE catchment model outputs (Eco Logical, 2021) for the last 4 years of record (Figure 2.4) illustrate the significant variation in Doon Doon Creek inflow rates. The largest flow event in March 2017 has been assessed as a 1:100 annual return interval (ARI) event that was associated with ex-tropical cyclone Debbie (*pers comm*, Eco Logical, 2021). The flow rates during this event were up to 10 times the largest flow rates in subsequent years.

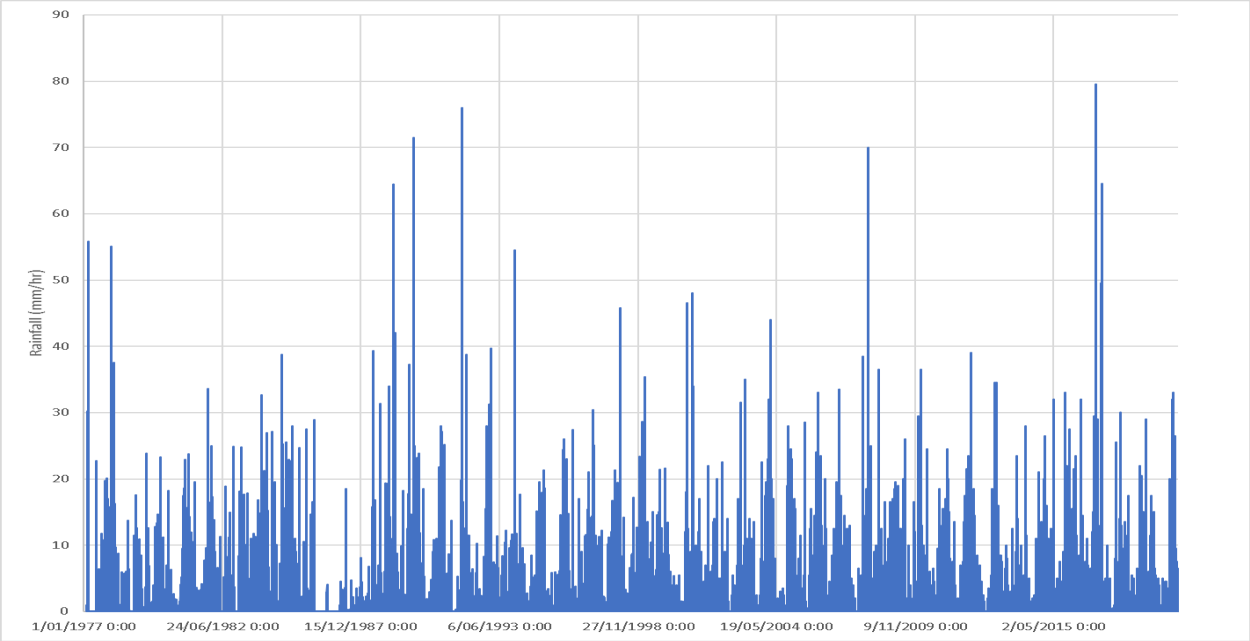


Figure 2.3 Oxley River hourly rainfall time series (Eco Logical 2021)

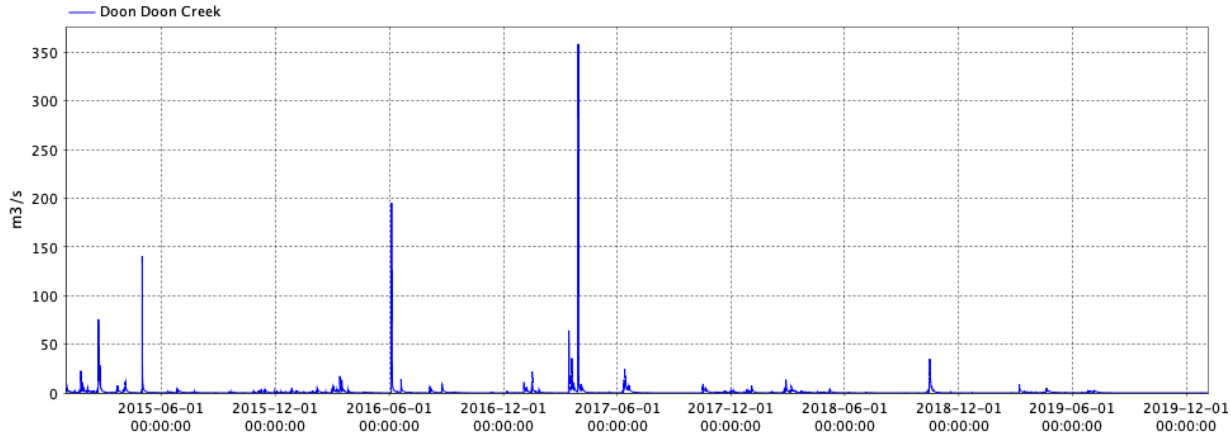


Figure 2.4 Doon Doon Creek flow rates generated by calibrated SOURCE model.

2.4 Bathymetry

Figure 2.5 illustrates the bathymetry of CHD. Broad shallow upper reaches less than 5 m deep to the south near the headwaters give way to an increasingly narrow and deepening channel with reaches over 30 m deep near the dam wall to the north. There are several dendritic arms that join the upper- and mid-sections of the main channel that consist of shallow valleys with complex topography.

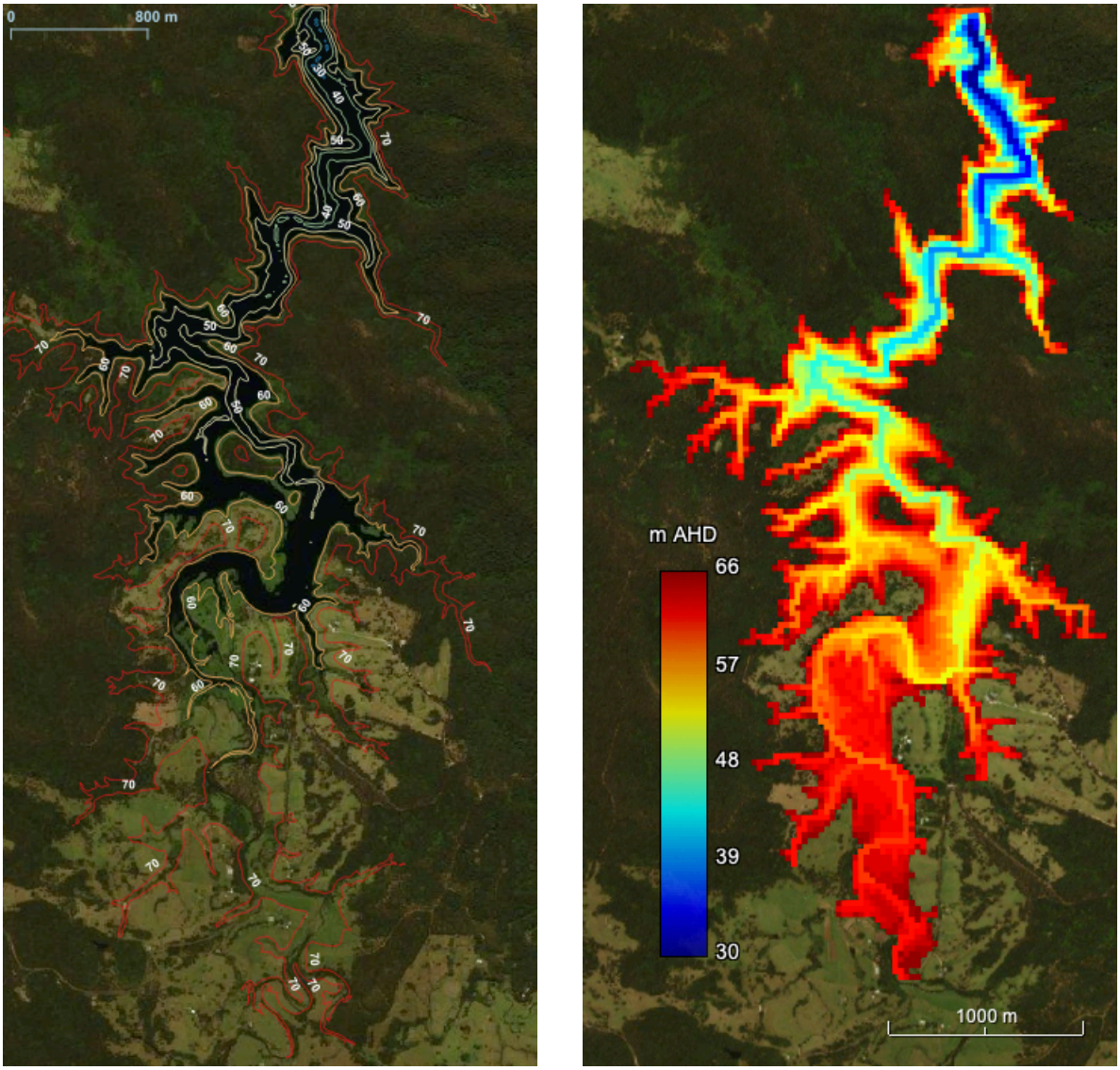


Figure 2.5 Elevation contours from DEM and bathymetry survey data (m AHD; left, data provided by Eco Logical) and reservoir model bathymetric grid (30 m horizontal resolution; right). Background image sourced from Bing Maps.

2.5 Artificial Mixer

The depth of the reservoir near the dam wall is sufficient to generate seasonal stratification in the water column. Tweed Shire Council installed a mechanical mixer (Figure 2.6) between site X and Z (see Figure 2.7) in 2002 to de-stratify the water column and improve water quality. The mixer was a WEARs-type propeller and draft tube system as shown during installation in Figure 2.6. An assessment of the mixer (Hunter H_2O, 2018) concluded that it had been underperforming because destratification had only been maintained over the cooler months from May to September with a marked decline in performance since mid-2005. As a result, sufficient dissolved oxygen concentrations have not been maintained through the water column and the targets of low stable iron, manganese and cyanobacterial concentrations have not been achieved. The mixer was damaged during a storm in 2017 and consequently removed from CHD.



Figure 2.6 Mechanical mixer being Installed in CHD (WEARS, 2006 - Figure 1-3 from Hunter H_2O, 2018)

2.6 Limnology

2.6.1 *Summary of Data*

Table 2.2 provides a summary of the water quality data that has been collected in CHD over the past 32 years at the monitoring sites shown in Figure 2.7. Illustrations of the data are presented in Appendix A. In the sections that follow, the 4 years of data from July 2015 to July 2019 have been used to describe the basic limnology of CHD that can be observed from the data. These 4 years of record have then been used to develop and calibrate the model described in Chapter 3.

The 4-year data set consists of a combination of:

- Monthly samples from Doon Doon Creek upstream of CHD;
- Weekly profiling of temperature, conductivity, dissolved oxygen, turbidity and pH at 1 m depths intervals at site X and site Z collected using a CTD probe;
- Weekly to monthly bottle samples of nutrients and metal variables from 4, 8, 12, 16 and 20 m deep at site X and site Z; and
- Weekly to monthly samples from 2 m deep adjacent to the intake tower.

The period includes the first two summers of 2015/16 and 2016/17 when the mechanical mixer was operating, followed by the last two years after the mixer was removed.

Table 2.2 Summary of water quality parameter monitoring in CHD. For site locations refer to Figure 2.7.

Parameter	CAT9	CAT9a	Site Z	Site X	Tower (2m)
Temperature	3-monthly 1998-2015	monthly 2016-2020	weekly 2001-2020	weekly 2001-2020	N/A
Conductivity	3-monthly 1988-2015	monthly 2016-2020	weekly 2002-2020	weekly 2002-2020	weekly 1997-2020
pH	3-monthly 1988-2015	monthly 2016-2020	weekly 2001-2020	weekly 2001-2020	weekly 1997-2020
Turbidity	3-monthly 1988-2015	monthly 2016-2020	weekly 2013-2018	weekly 2013-2018	weekly 1997-2020
Suspended Solids	3-monthly 1988-2015	monthly 2016-2020	N/A	N/A	monthly 1997-2020
Solids TDS (calc)	N/A	N/A	N/A	N/A	weekly 2000-2020
BOD5	3-monthly 1988-2015	monthly 2016-2020	N/A	N/A	monthly 1997-2010
TOC	N/A	N/A	weekly 2001-2020	weekly 2001-2020	monthly 2010-2020

Parameter	CAT9	CAT9a	Site Z	Site X	Tower (2m)
DOC	N/A	N/A	N/A	N/A	monthly 2010-2020
Apparent Colour	N/A	N/A	N/A	N/A	weekly 1997-2020
True Colour	N/A	N/A	N/A	N/A	weekly 1997-2020
DO	3-monthly 1998-2015	monthly 2016-2020	weekly 2001-2020	weekly 2001-2020	N/A
DO % Sat	3-monthly 1998-2015	monthly 2016-2020	N/A	N/A	N/A
Nitrate	3-monthly 1988-2015	monthly 2016-2020	monthly 2006-2009	monthly 2006-2009	monthly 1997-2020
Nitrite	limited 2011-2015	monthly 2016-2020	N/A	N/A	monthly 2010-2020
Ammonia	3-monthly 1988-2015	monthly 2016-2020	N/A	N/A	monthly 1997-2020
Nitrogen Oxidised	limited 2011-2015	monthly 2016-2020	monthly 2001-2003	monthly 2001-2003	monthly 2010-2020
TKN	3-monthly 1992-2015	monthly 2016-2020	monthly 2001-2003	monthly 2001-2003	monthly 1997-2020
Total Nitrogen	limited 2011-2015	monthly 2016-2020	Weekly 2001-2020	Weekly 2001-2020	monthly 2010-2020
Orthophosphate	3-monthly 1988-2015	monthly 2016-2020	N/A	N/A	monthly 1997-2020
Total Phosphorus	3-monthly 1988-2015	monthly 2016-2020	Weekly 2001-2020	Weekly 2001-2020	monthly 1997-2020
Chlorophyll a	3-monthly 1988-2015	monthly 2016-2020	N/A	N/A	monthly 1997-2020
Algal Biovolume	N/A	monthly 2016-2020	[1]Monthly 2007-2020	[1]Monthly 2007-2020	weekly 1997-2020
Algal Counts	3-monthly 1995-2009	monthly 2016-2020	[2]weekly/monthly 2007-2020	[2]weekly/monthly 2007-2020	weekly 1997-2020
Coliforms Escherichia	N/A	monthly 2016-2020	N/A	N/A	weekly 2010-2020
Coliforms Thermotolerant	3-monthly 1988-2015	monthly 2016-2020	N/A	N/A	weekly 1997-2020

Parameter	CAT9	CAT9a	Site Z	Site X	Tower (2m)
Total Coliforms	N/A	N/A	N/A	N/A	weekly 2010-2020
Total Calcium	limited 2008-2015	N/A	N/A	N/A	weekly 2010-2020
Hardness Calcium	3-monthly 1988-2015	N/A	N/A	N/A	weekly 1997-2020
Total Hardness	3-monthly 1988-2015	N/A	N/A	N/A	weekly 1997-2020
Alkalinity	limited 2008-2015	N/A	N/A	N/A	weekly 2000-2020
Aluminium	N/A	N/A	N/A	N/A	weekly 2000-2020
Soluble Iron	limited 2008-2015	N/A	Weekly 2001-2020	Weekly 2001-2020	weekly 2010-2020
Total Iron	3-monthly 1988-2015	N/A	Weekly 2001-2020	Weekly 2001-2020	weekly 1997-2020
Soluble Manganese	limited 2008-2015	N/A	Weekly 2001-2020	Weekly 2001-2020	weekly 2005-2020
Total Manganese	limited 1990-2015	N/A	Weekly 2001-2020	Weekly 2001-2020	weekly 1997-2020
Soluble Silica	N/A	N/A	N/A	N/A	weekly 2005-2020
Total Silica	N/A	N/A	N/A	N/A	weekly 2010-2020
Total Silicon	N/A	N/A	N/A	N/A	weekly 2014-2020

Table notes on algae data:

1. Algal Biovolume was measured monthly form October 2007 to March 2020 including:
    - Planktolyngbya sp. (Cyanophyta)
    - Aphanocapsa (Cyanophyta)
    - Cyanogranis (Cyanophyta)
    - Planktothrix (Cyanophyta)
    - Sphaerospermopsis (Cyanophyta)
    - Total Cyanophyta

- Total PotentiallyToxic Species
- Cyanophyta Detected (True, False)

2. Algal Counts were made weekly or monthly from July 2001 to March 2020 including:
    - Chlorophyta (Chlorophyta)
    - Planktolyngbya sp. (Cyanophyta)
    - Aphanocapsa (Cyanophyta)
    - Cyanogranis (Cyanophyta)
    - Diatoms (Bacillariophyta)
    - Dinophyta (Dinophyta)
    - Planktothrix (Cyanophyta)
    - Sphaerospermopsis (Cyanophyta)
    - Total Cyanophyta
    - Total Potentially Toxic Species
    - Cyanophyta Detected (True, False)
    - Others prior to 2020.



Figure 2.7 Water quality monitoring sites in CHD. Parameters are listed in Table 2.2.

2.6.2 *Temperature and Stratification*

Figure 2.8 illustrates the temperature profile data for the years 2015 to 2019. When the mixer was not operating (see 2018 and 2019) the natural state of the reservoir was to strongly stratify during the warmer months of the year with surface temperatures reaching 31°C in February when solar radiation and atmospheric temperatures are highest. At 5 m below the surface the temperatures were approximately 5°C less during the peak of stratification and at 10 m deep the temperatures were more than 10°C below the surface temperatures. At 15 m and deeper the temperatures were relatively consistent at 15 - 17°C throughout the year and increased only slowly during the warmer months. The strong summer stratification was maintained by solar heating and high air-temperatures coupled with only weak convective mixing (through night-time cooling) and weak wind-driven mixing to deepen and weaken the temperature stratification.

With the onset of Autumn, surface waters cool and by July the stratification had weakened to the extent that complete mixing (overturn) occurs and temperatures were approximately 15 - 16°C throughout the water column. The duration of complete mixing was brief and by September the surface temperatures increased again and stratification began to build.

During 2015 and 2016 the mechanical mixer altered the cycle of stratification by introducing an additional source of mixing energy that eroded the stratification. During operation of the mixer the temperatures in the surface 5 m were comparable to other years. Temperatures from 10 to 15 m, however, increased by up to 10°C during summer; waters at 20 m were up to 5°C warmer. This occurs because the mixer displaced warm surface waters down to the base of the draft tube (at 10 m deep) where it exited into deeper, cooler surrounding waters. This action creates lenses of water with intermediate temperature (and hence density) that rise to vertical positions of neutral buoyancy and then propagate laterally across the reservoir, thus weaking stratification throughout the reservoir. In addition, weakened stratification is more susceptible to additional disruption from convective and wind-driven mixing which hastens the onset of complete mixing in autumn.

Stratification can be quantified using the buoyancy frequency, N, which is given by:

$$N^2 = -g/\rho_0(d\rho(z)/dz)$$

where: g is acceleration due to gravity, ρ_0 is the reference density, and $d\rho(z)/dz$ is the vertical (z) density gradient.

High values of N^2 occur where stratification is strongest in the metalimnion (*the transition zone between the shallow, well-mixed epilimnion and the deeper unmixed hypolimnion*), reaching a peak at the thermocline (*the zone of greatest temperature change*). Low values denote weak stratification and a value of zero indicates that the water column is fully mixed. Low values of N occur in the epilimnion above the metalimnion, and in the hypolimnion below the metalimnion.

Figure 2.9 illustrates the buoyancy frequency calculated from 2015 to 2019 at Site X. When the mixer was not operating the stratification was strongest between 2.5 and 7.5 m deep, gradually becoming deeper during the stratification cycle. N^2 peaked in mid-summer before decreasing through autumn. The stronger and shallower stratification during 2017/18 was most likely the

result of high turbidity from the inflow events of March 2017 (see description of turbidity below), which trapped more solar radiation (which increases heating) close to the surface.

When the mixer was operating, N^2 is lower (i.e. weaker stratification) and the metalimnion deepened from 10 to 20 m over the warmer months. Despite the operation of the mixer, intermittent stratification persisted in the top 5 m, reaching strengths that were comparable to the metalimnion.

The sampling frequency was too low to ascertain whether these features are diurnal stratification produced by the daily cycles of heating and cooling or stratification that persists for multiple days during calm, warm weather. However, the data does indicate that the water column above the deepened metalimnion was not persistently well-mixed.

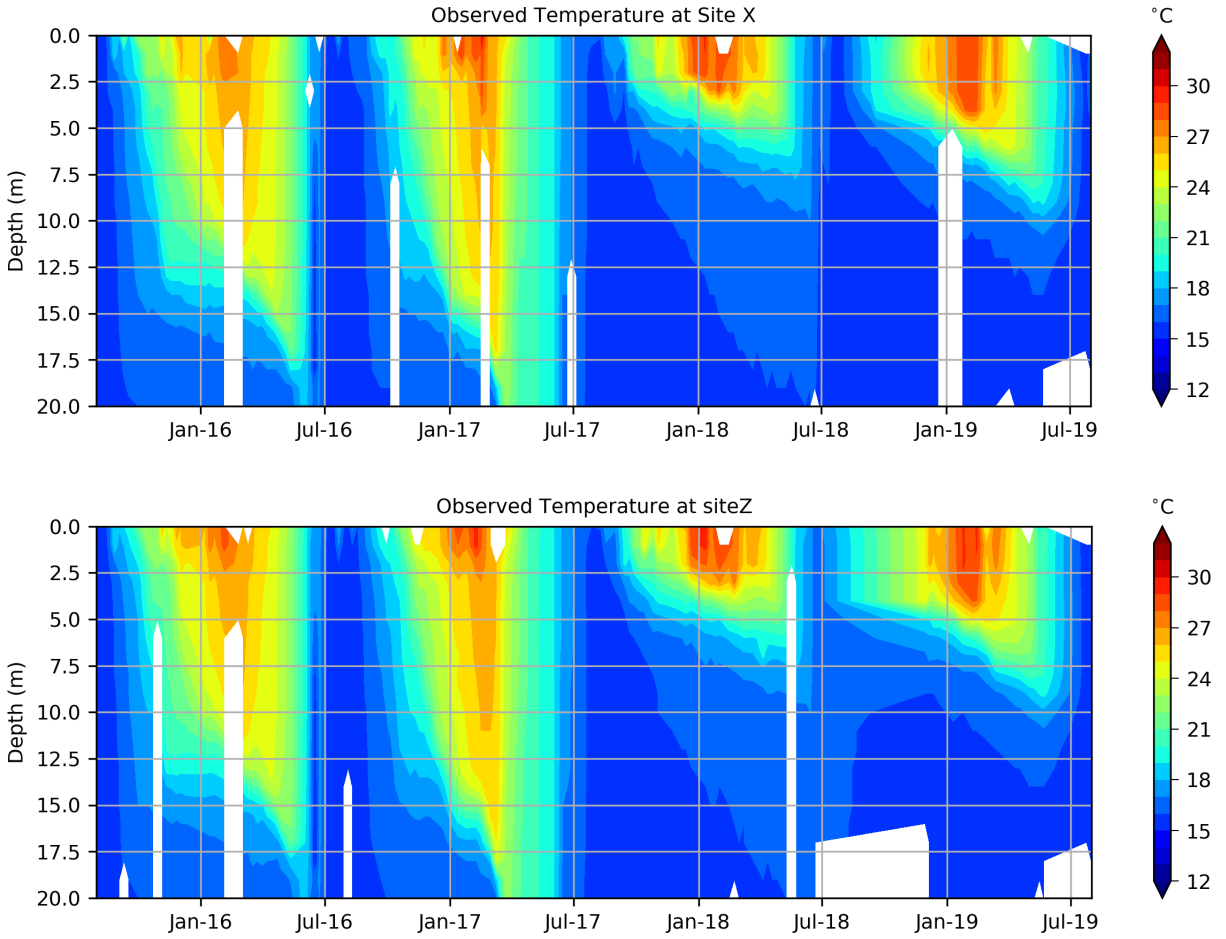


Figure 2.8 Temperature profile data from 2015 to 2019 collected at Site X (top panel) and Site Z (bottom panel). White patches with no contouring in this and other contour plots below indicate where there is insuffient data to produce an accurate contour.

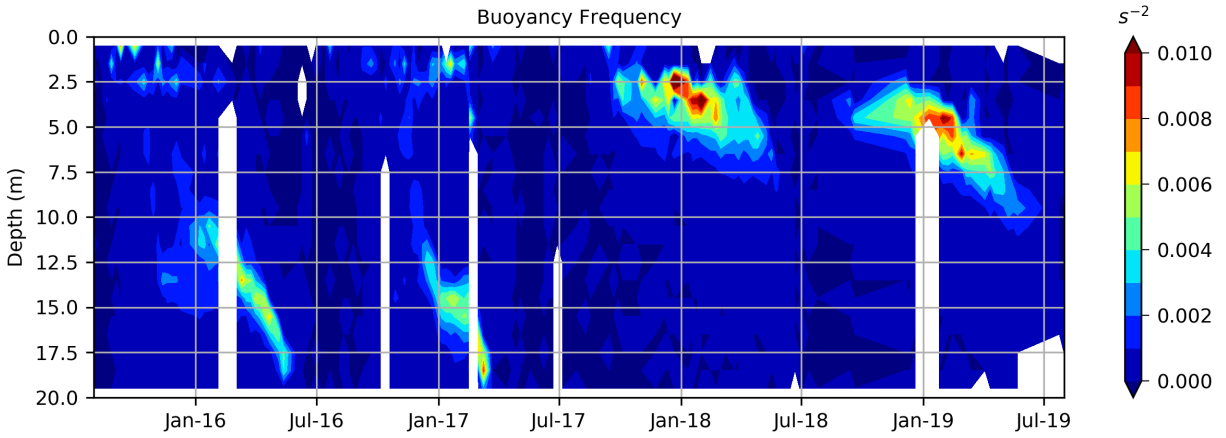


Figure 2.9 Buoyancy frequency (N^2) calculated from temperature profiles recorded at Site X from 2015 to 2019.

2.6.3 *Salinity*

Observed salinity at sites X and Z are shown in Figure 2.10, where the salinity has been calculated from the conductivity measurements. Salinity was generally low and inflows from the catchment lowered the salinity further. The stagnant waters that remain in-situ for long periods increased in salinity, presumed to be due to salts released from the sediments and/or evaporation that concentrated the salts near the lake surface. The waters with the highest salinity in the record were those that reside in the hypolimnion beneath the stratification during the warmer months and were not diluted by inflow events. In the latter years when the mixer was not operating the salinity build-up occurs over greater depth and for a longer period, which is partially the result of a shallower epilimnion, but also because there was a lack of large inflows compared to previous years (see Section 2.3).

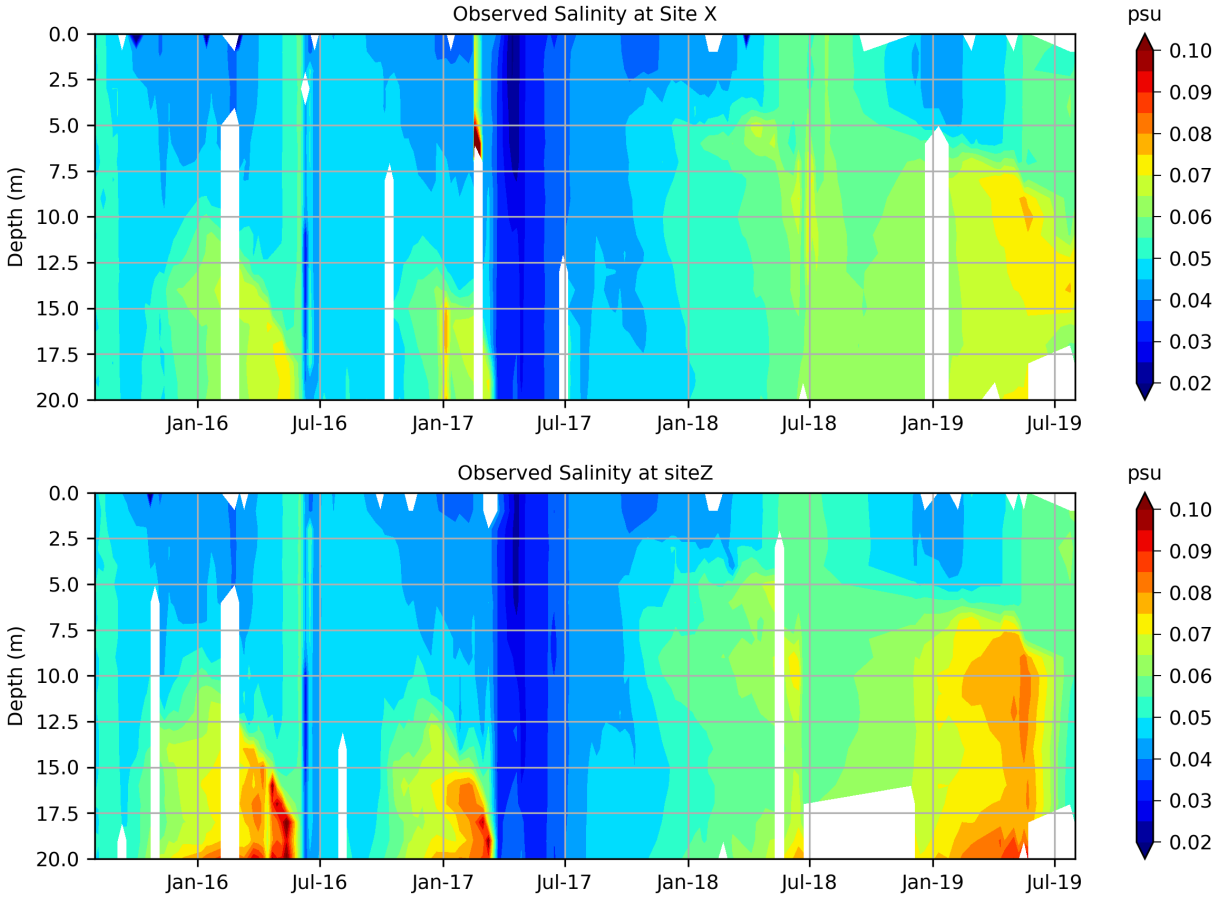


Figure 2.10 Salinity profile data from 2015 to 2019 collected at Site X (top panel) and Site Z (bottom panel).

2.6.4 *Turbidity*

Figure 2.11 and Figure 2.12 illustrate the observed turbidity in CHD from 2015 to 2019. The two figures illustrate the same data using different colour scales to highlight the extent of large turbidity events recorded in CHD. The observations show that the background turbidity was typically less than 10 NTU with the exception of weeks to months after the large flow events of June 2016 and March 2017, when the turbidity reached 40 NTU and more than 100 NTU, respectively (Figure 2.12).

In the first and smaller turbidity event of June 2016 the inflow entered the reservoir with higher density than the ambient well-mixed waters as it was cooler and laden with sediment. As a result, the inflow plunges into the hypolimnion, producing a peak in turbidity below 10 m deep. Shortly afterwards, the turbid waters were mixed through the water column as the reservoir underwent winter mixing. Although the inflow event occurred when the reservoir was entering a stage of complete breakdown of the stratification, the event itself may have also contributed to more rapid on-set of complete mixing.

The second and larger recorded event occurred in March 2017, when the stratification was stronger and the inflow was warmer (and hence of lower density) than the ambient water. This

inflow initially propagated through the reservoir in the surface 10 - 12 m, where the highest turbidity was recorded (Figure 2.12). The arrival of this large flow event prior to winter weakened the stratification enough to trigger the early on-set of complete mixing, which distributed the suspended solids throughout the water column. The effects of this mixing event are also observed in temperature and salinity profiles (see Figure 2.8 and Figure 2.10, respectively).

Over a period of three or more months, the high-turbidity material delivered to the reservoir during these inflow events settled into the deeper waters (at least to 20 m deep, the limit of sampling) and the turbidity in the surface waters returned to background levels. This timeframe for settling suggests a large portion of the material consisted of particles with settling velocities of less than 3 x 10^{-6} m/s. Applying Stokes Law that describes the settling velocity of materials in a liquid we can deduce that if the material consisted of quartz material with a specific gravity of 2.65 this settling velocity yields an estimated particle diameter of 2 or less microns (i.e. fine clay). For high-content organic matter (80-100%) the specific gravity reduces to approximately 1.5 (Huat et al. 2009), hence the diameter range increases to approximately 4 microns to maintain comparable settling velocities. The nutrient observations (see Section 2.6.7) indicate that the inflowing material observed at site X and Z was likely to contain considerable contributions of organic matter, so it is therefore likely that the inflowing material that reaches Site X and Z is made up of a mix of both suspended fine clay and organic matter that then settles slowly from the water column.

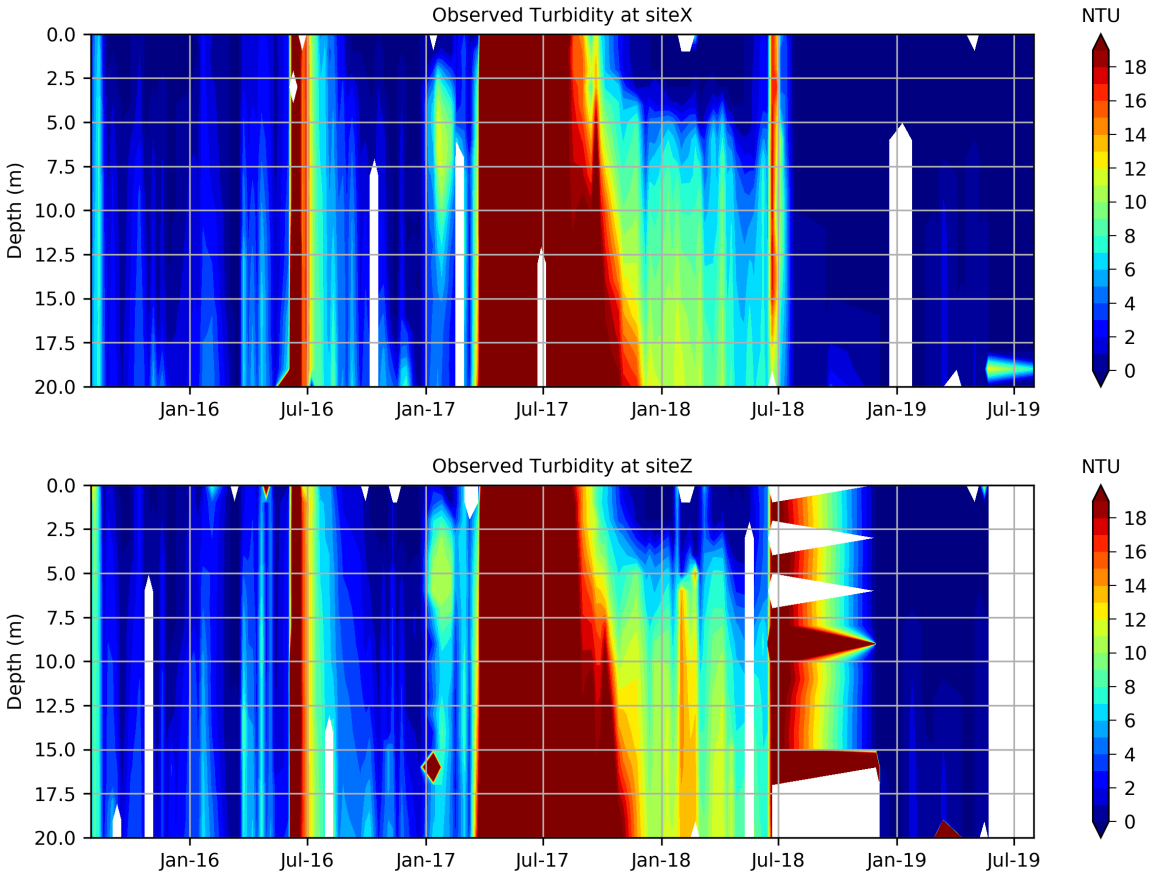


Figure 2.11 Turbidity profile data from 2015 to 2019 collected at Site X (top panel) and Site Z (bottom panel). Colour scale 0-18 NTU.

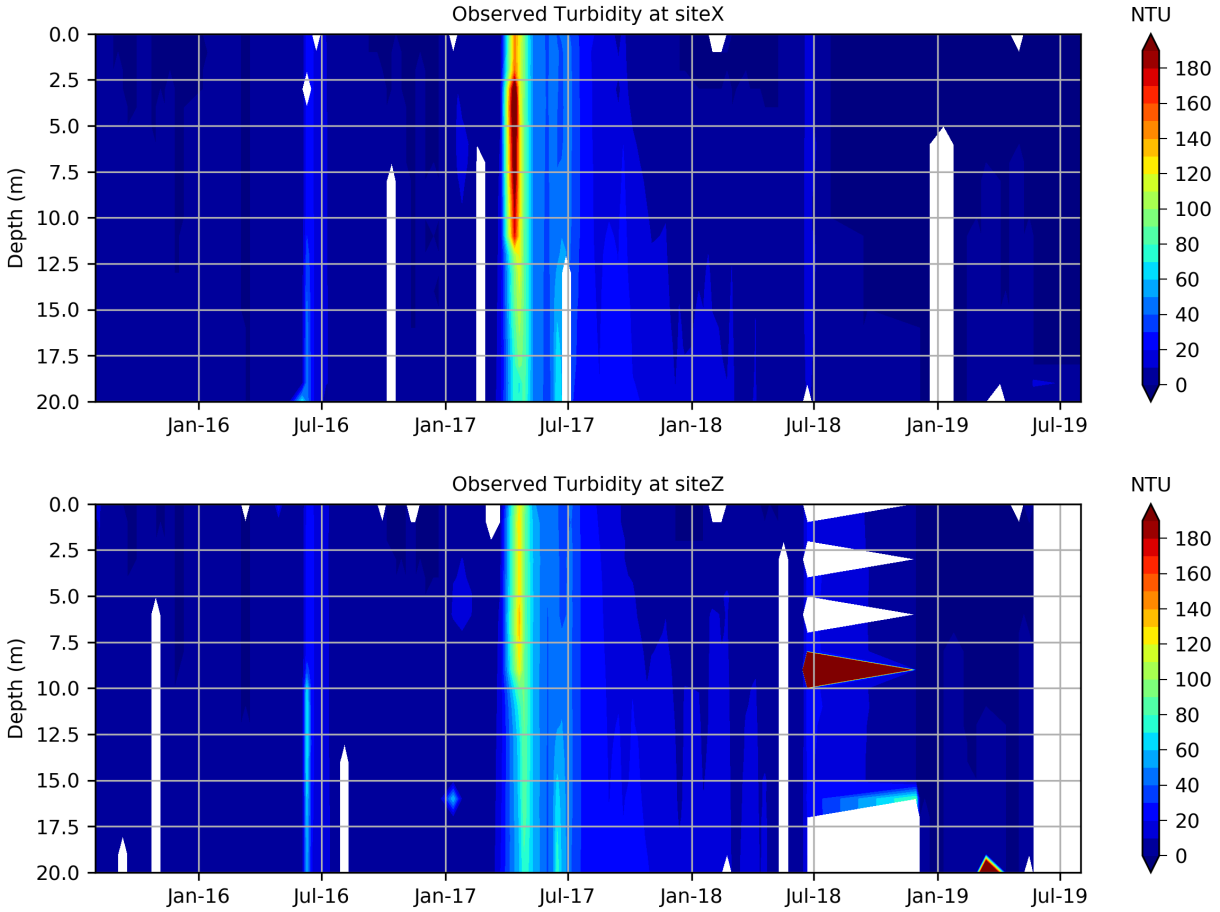


Figure 2.12 Turbidity profile data from 2015 to 2019 collected at Site X (top panel) and Site Z (bottom panel). Colour scale 0-180 NTU.

2.6.5 *Organic Matter*

The contribution that the large inflows made to organic matter can be seen in the recorded total organic carbon (TOC) concentrations (see Figure 2.13), which peaked at the same time as the turbidity. Background levels of ~4 mg/L TOC were maintained for much of the time, with peaks above 7 mg/L during the inflow events.

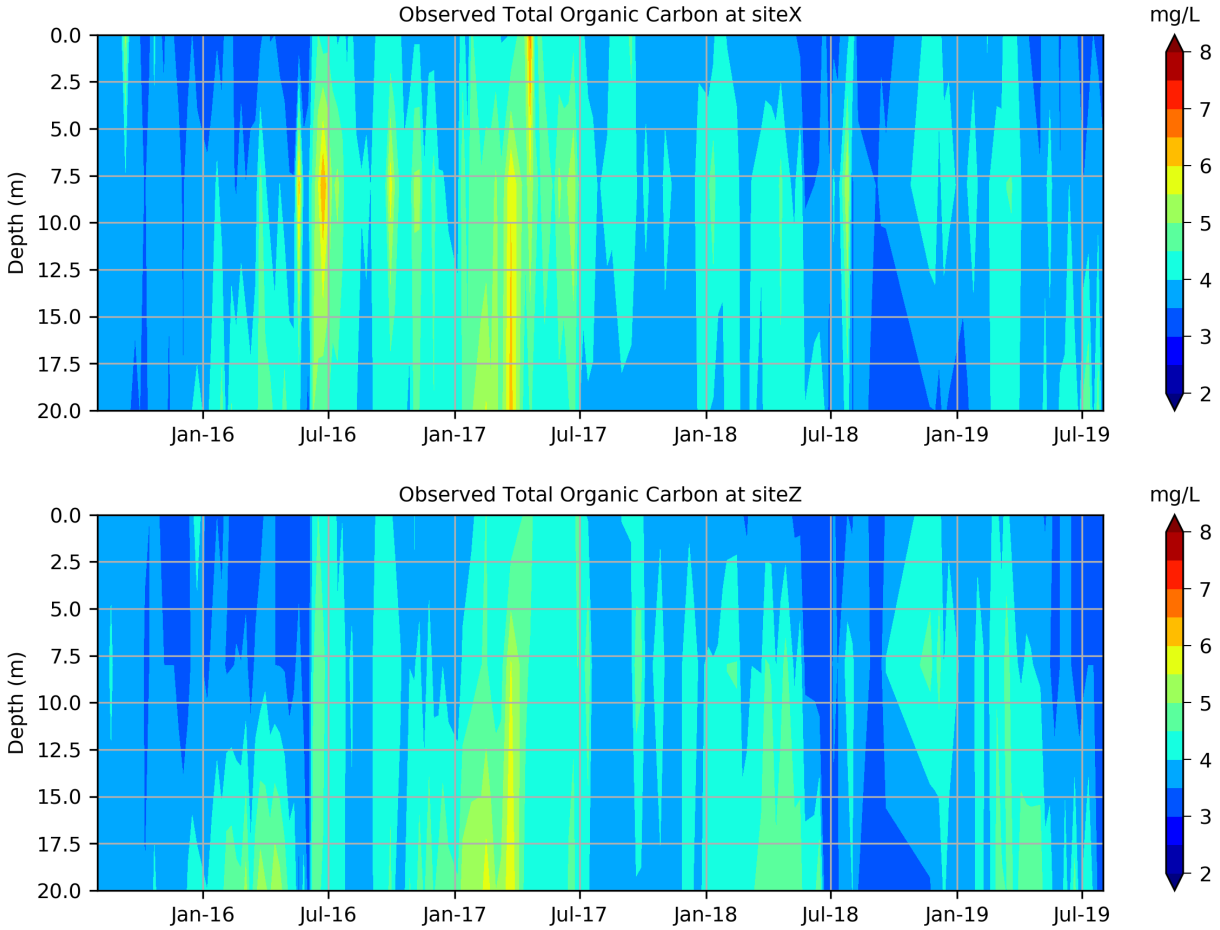


Figure 2.13 Total Organic Carbon (TOC) profile data from 2015 to 2019 collected at Site X (top panel) and Site Z (bottom panel).

2.6.6 *Dissolved Oxygen*

The observed changes to dissolved oxygen (DO) concentrations (Figure 2.14) were in step with the cycles of stratification and mixing, with aberrations occurring when catchment inflows were high. When the reservoir was mixed over the cooler months, DO reached 4-6 mg/L throughout the full depth of the reservoir. When the stratification started in spring the stratification prevented the transfer of oxygen from the atmosphere (via mixing) into waters below approximately 5 m. In addition to this, photosynthesis by algae growing in the euphotic zone near the surface increase DO. Beneath the epilimnion the DO concentrations rapidly declined to less than 2 mg/L as the DO was depleted by biogeochemical processes that consume oxygen in the water column and sediments. As a result, for extended periods of the record from spring to autumn the metalimnion and hypolimnion were devoid of oxygen.

During the mixing period of mid-2018, when the mixer was not operating, the replenishment of oxygen at depth was limited (reaching 4 mg/L) and short-lived, when compared to the years when the mixer was operating and extending the period of complete mixing and hypolimnetic oxygenation. However, once the stratification became established, the effects of the mixer on

re-oxygenation of water below 5 m was limited despite the depth of the metalimnion being 10 to 20 m below the surface. This occurs because the oxygen demand below the metalimnion exceeds the rate at which oxygen can be mixed to depth, even with the assistance of the mixer. The mechanical mixer relies on the ability to erode the stratification and promote deeper mixing of oxygen during wind and inflow events. Whilst the mixer was effective in forcing the stratification to be deeper, the events that mix oxygen into the surface layers and subsequently down to depth are insufficient (in terms of strength and frequency) to overcome the oxygen demand of the water column and sediments. This is consistent with the observed local peaks in the buoyancy frequency (see Figure 2.9) above 5 m, which indicate the development of shallow layers of stratification that inhibit regular mixing.

Following large inflows events there was rapid de-oxygenation of the water column over most (in the first event) and all (in the second event) of the water column. This occurs due to the sudden increase in the oxygen demand within the water column that follows the breakdown of the organic matter loads that enter during the inflow events. As this organic material settles, the oxygen demand in the deeper waters and sediments also increases as breakdown continues, contributing to the rapid onset of seasonal anoxia in the hypolimnion that was observed in the years that followed the March 2017 inflow event.

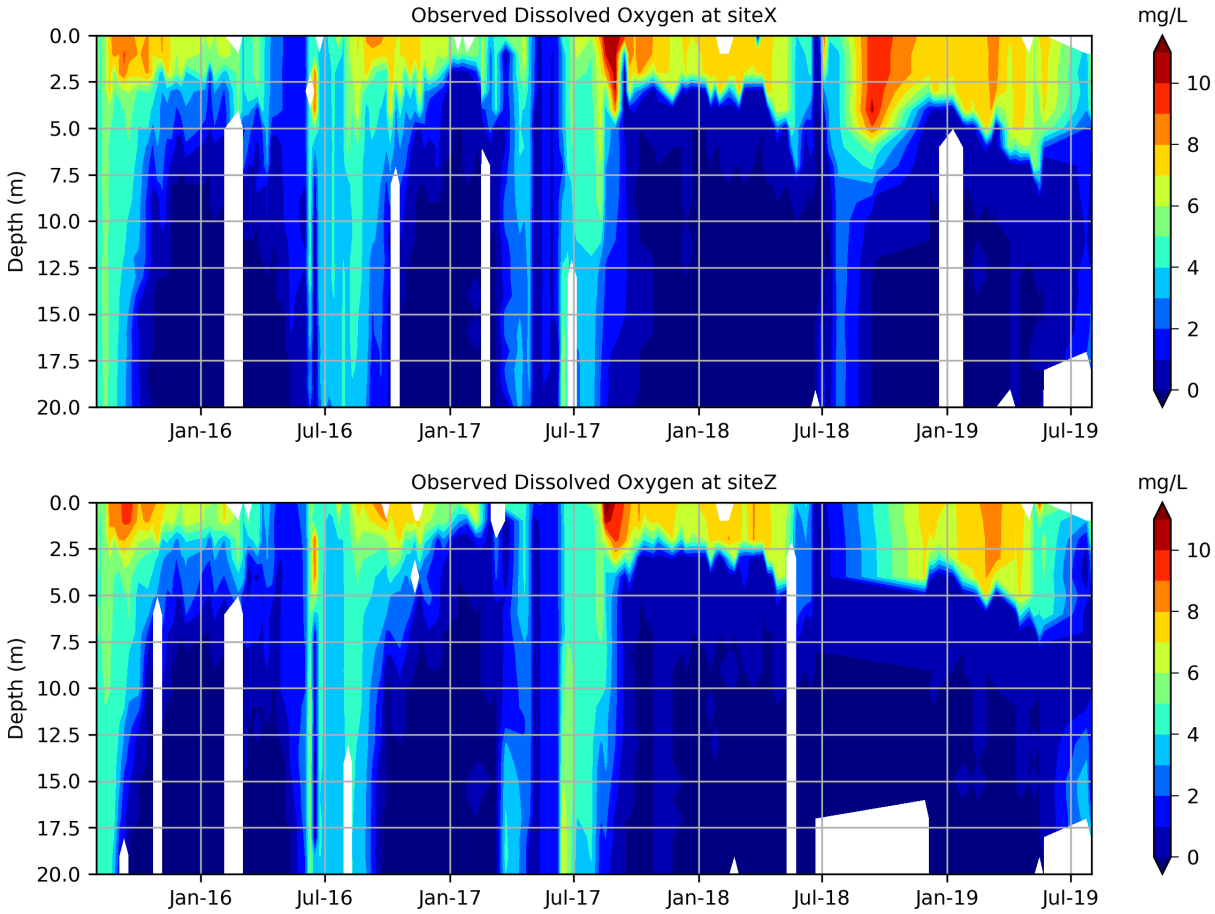


Figure 2.14 Dissolved Oxygen (DO) profile data from 2015 to 2019 collected at Site X (top panel) and Site Z (bottom panel).

2.6.7 *Nutrients*

Figure 2.15 illustrates observations of total nitrogen (TN) at Site X and Z for the 2015 to 2019 period. Background concentrations are typically ~0.4 mg/L and increase in response to two processes. The first is the response to inflow events, most notably the large events that occurred in June 2016 and March 2017, when the TN rises to 1-1.2 mg/L. In addition to the inflow contributions, there were increases in TN in the hypolimnion, which is likely the result of reduced forms of N (NH_4) being released from the sediments (or settled organic material) during anoxia in the hypolimnion. However, there are no records of NH_4 measurements deeper in the water column to confirm this process.

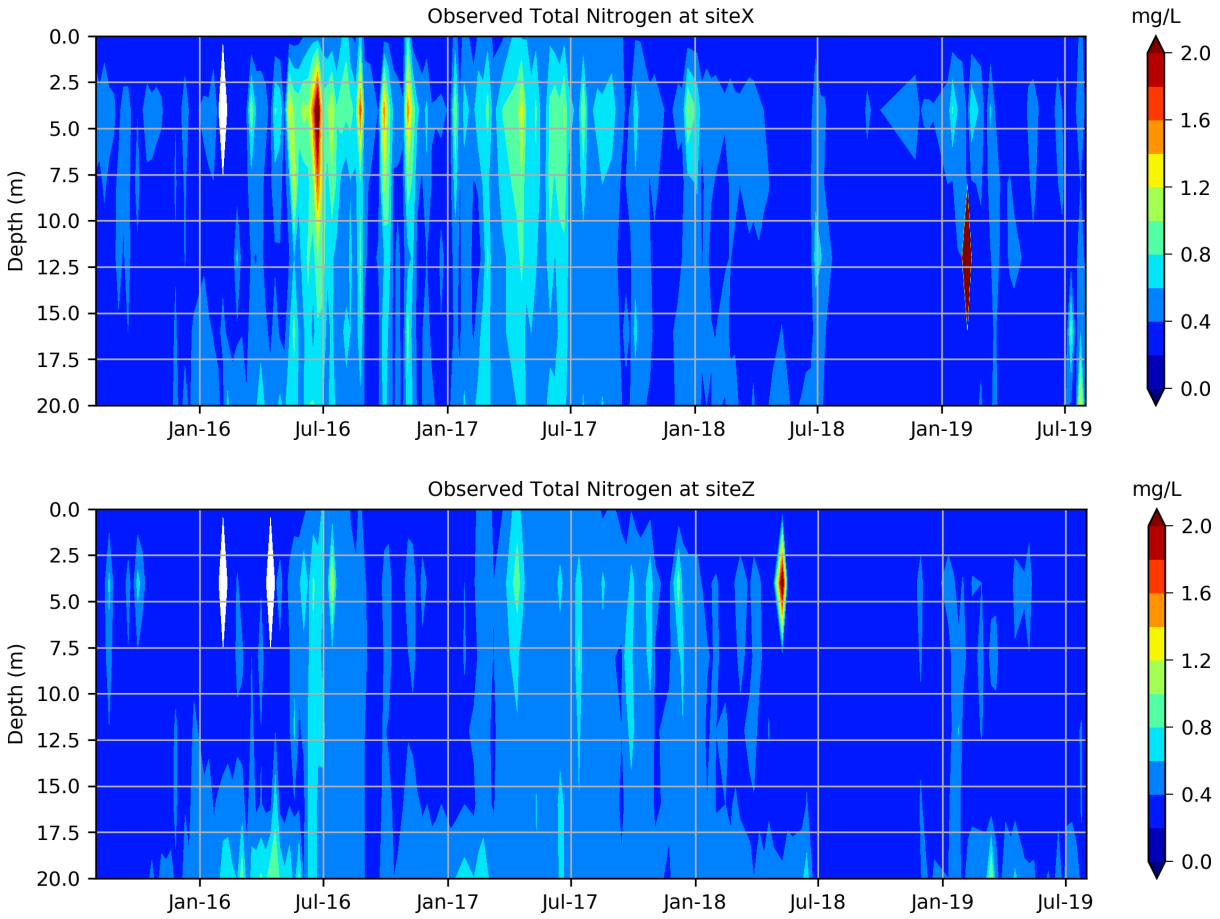


Figure 2.15 Total Nitrogen (TN) profile data from 2015 to 2019 collected at Site X (top panel) and Site Z (bottom panel).

Total phosphorus (TP) concentrations (Figure 2.16) also increased during the inflow events, particularly during the larger second event of March 2017. The data suggests that the release of reduced P (as orthophosphate) from the sediments was a significant process in increasing the concentrations of TP in the hypolimnion in all four years, reaching concentrations of up to 0.18 mg/L. Observations indicate that the release was greatest during the summer of 17/18 after the large flow events of the winter beforehand. This is likely due to the large contribution that the inflow loads would have made to sediment-P as the material settled to the bed. This occurred prior to a long period of hypolimnetic anoxia that persisted until July 2018, allowing for a continual

build-up of P in the hypolimnion. By the summer of 2018/19 the release from the sediments appears to return to similar levels to those observed in the summers of 2015/16 and 2017/19 prior to the large inflow event of March 2017. As is the case with the NH_4 there are no records of orthophosphate measurements deeper in the water column to confirm this process.

Despite the 10-fold increase in concentrations of P in the hypolimnion during stratification the concentrations that were observed near the surface after complete mixing were considerably less (~0.04-0.06 mg/L) and short-lived. The initial mixing of a concentrated but volumetrically small hypolimnion, with a volumetrically much larger and of lower concentration epilimnion leads to a large initial dilution. This is followed by a rapid biological uptake by phytoplankton and potential adsorption to solids followed by settling. Therefore, with the exception of inflow events and shortly after mixing the concentrations in the epilimnion, where P is available for phytoplankton growth, were typically 0.02-0.04 mg/L.

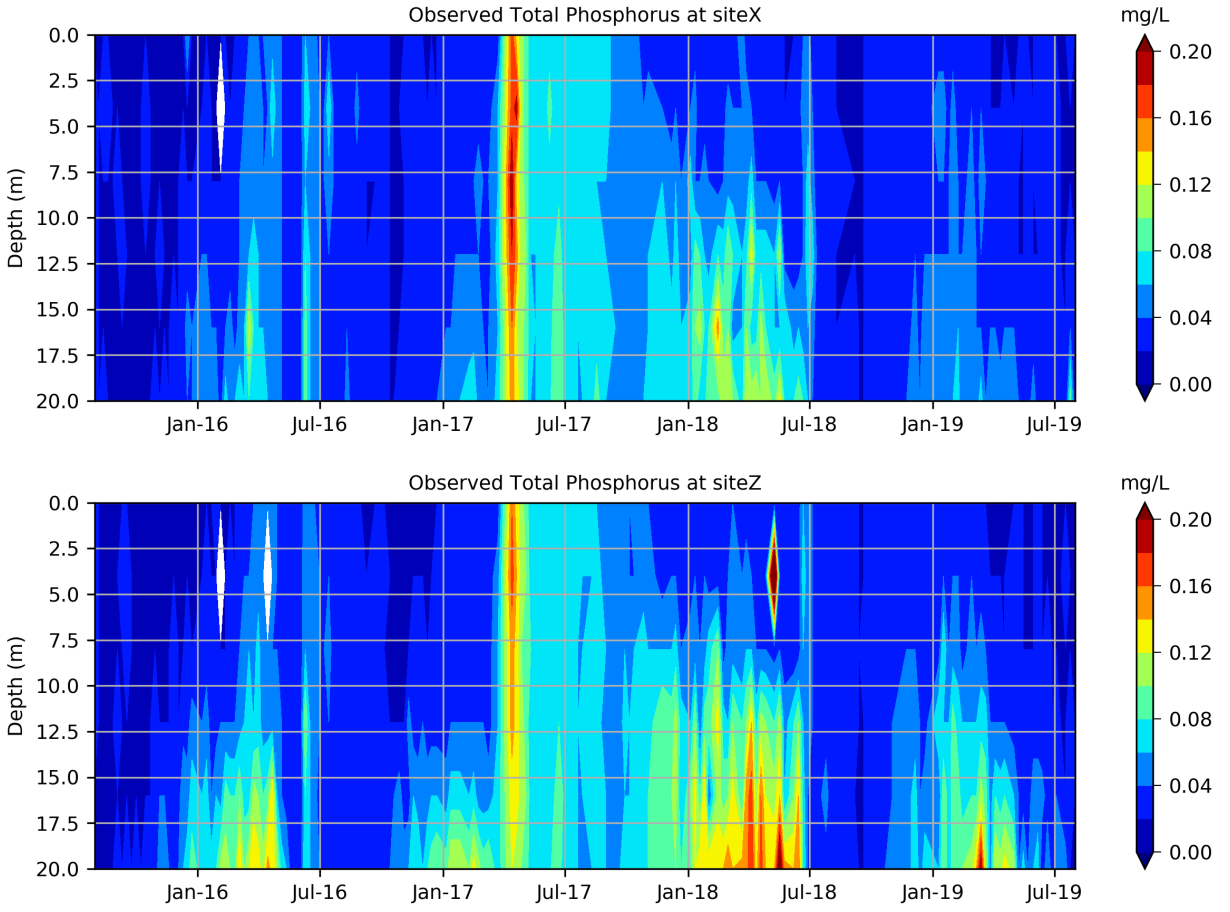


Figure 2.16 Total Phosphorus (TP) profile data from 2015 to 2019 collected at Site X (top panel) and Site Z (bottom panel).

The stochiometric Redfield ratio of C:N:P in the surface water (to 5 m deep) of the epilimnion of CHD during January was approximately 440:22:1. Comparing this to the primary production measure of 106:16:1 (Redfield, 1958) provides a high-level indication that primary production in the surface was likely to be limited by the availability of phosphorus, noting this does not take into account that some of the phosphorus in the measure of TP may be organic or bound to sediments and not readily available for biological uptake. Limited field measurements of

biologically available PO_4 at the tower indicate concentrations of ~0.02 mg/L, which potentially shifts the stochiometric N:P ratio towards 40:1, suggesting an even more severe P limitation than indicated by the total nutrient concentrations.

2.6.8 *Algae*

Observed populations of cyanophytes (blue-green algae), chlorophytes and diatoms are shown on a monthly basis at the surface at site X over the duration from 2015 to 2019 in Figure 2.17. The data show that the algal populations typically peak during the warmer months of the year, with the cyanophytes reaching concentrations of 20,000 cell/mL or more and chlorophytes reaching smaller peaks of 10,000 cell/mL or more. Diatoms contribute to only a small portion of the biovolume compared to the other two groups.

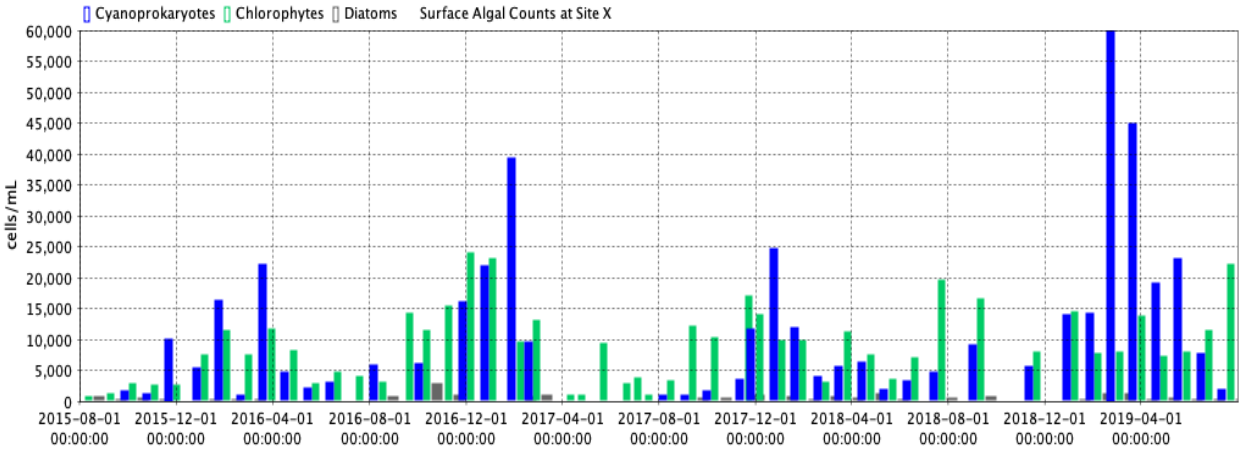


Figure 2.17 Cells counts of Cyanophytes (blue), Chlorophytes (green) and Diatoms (grey) at the lake surface at Site X from 2015 to 2019.

The chlorophytes reach peak concentrations in the months before the cyanophytes and do not suffer the same extent of decline during Autumn. This is most likely owing to their ability to better inhabit cooler, mixed layers when compared to the cyanophytes, which typically thrive in stable, warmer layers and therefore dominate the phytoplankton assemblage during the peak of summer. The data indicates that the operation of the mixer did not substantially reduce phytoplankton populations and more specifically the cyanophytes population. This is linked to the conditions in the euphotic zone near the surface (temperature, stability and nutrient availability), which were not persistently disrupted by the operation of the mixer as evident in the temperature and buoyancy frequency observations (Figure 2.8 and Figure 2.9, respectively). The most notable deviation from the growth cycles occurred after the large inflow event of March 2017, when cyanophytes were absent for 3-4 months and in the final (2019) summer during which considerably higher cyanophyte concentrations were observed.

Despite the high concentrations of nutrients delivered during the large inflow of March 2017, as compared to the same time in other years, the stratification during this period was disrupted. Temperatures were lower and light availability decreased (due to higher turbidity). This combination of factors may have limited phytoplankton growth, in particular cyanophytes.

The second notable deviation in normal patterns was a significantly higher cyanophyte growth during the summer of 2018/19, reaching a peak of 60,000 cells/mL by March 2019, followed by a decline to low levels by June 2019. Over this period the cyanophytes were particularly dominant compared to previous years and the growth of the chlorophyte population was delayed until later in the year.

There is a combination of factors that potentially explain these observations. Firstly, the warmer months and stratification followed winter mixing that entrained hypolimnion phosphorus released from the sediments into the epilimnion. As discussed above (Section 2.6.7), the availability of phosphorus is likely to be a significant factor in controlling the growth of phytoplankton during summer, when other factors such as light availability and temperature are favourable, so increased phosphorous would drive increased growth. Moreover, despite high TP concentrations in previous years due to surface inflows (Figure 2.16), the orthophosphate mixed up from depth, that was released from the lake floor sediments, is more readily available for uptake.

As the stratification built, the 2018/19 summer led to the most prolonged period of stable stratification over the four-year period shown, which is indicated by the prolonged duration of high buoyancy frequency in the metalimnion (see Figure 2.9). These warm stable conditions are likely to favour the cyanophytes, which by February 2019 had significantly higher cell counts compared to the chlorophytes. Their dominance was maintained until June when the stratification erodes and the water cools.

2.6.9 *Large Inflow Events*

The large inflow events are significant drivers of lake water quality. Hence, to analyse the characteristics of the large inflow events into CHD that are shown in the 4-year data record we refer to the observations of Grinham et al. (2012), who derived ratios of total suspended solids (TSS) to carbon and nutrients for Wivenhoe Dam (150 km north of CHD) after similar large flow events. This has been undertaken to assist with the synthesis of inflow timeseries for the large inflow events that are used in the development of the CHD model, described in Section 3.2.4.

Applying the Grinham et al. (2012) observed TSS:NTU ratio of 0.85 for Wivenhoe Dam, the estimated TSS during the CHD inflow events spans approximately 85-170 mg/L. Applying their observed TOC:TSS ratio of ~0.03, TOC concentrations would be expected to reach approximately 2.5-5 mg/L during the inflow events. This is lower than observed in the CHD data.

Grinham et al. (2012) also indicate, however, that, compared to the large Wivenhoe Dam, smaller reservoirs in the same region, with sizes comparable to CHD, have 2-3 times higher contribution of organic matter relative to measured TSS in the water column. This suggests TOC concentrations of up to 5-10 mg/L may be expected during the observed CHD events, which is consistent with the range observed in the CHD data.

Grinham et al. (2012) also derived a TSS:TN relationship from their observations and the corresponding expected TN concentration during the CHD inflow events would be 0.6-1.2 mg/L, which is consistent with the observations in CHD.

TP concentrations in CHD reach 0.1-0.2 mg/L during the inflows, which is also consistent with the observations of TSS:TP of Grinham et al. (2012), allowing for the higher fraction of organic matter expected in CHD compared to Wivenhoe.

The observations indicate that the inflow response in CHD is broadly consistent with the relationships observed by Grinham et al. (2012). These relationships have therefore been applied and refined during the model set-up (see Section 3.2.4).

3 Reservoir Model

3.1 Aquatic Ecosystem Model 3D

3.1.1 *Hydrodynamics Model*

The three-dimensional Aquatic Ecosystem Model (AEM3D, see http://www.hydronumerics.com.au/software/aquatic-ecosystem-model-3d) was used to simulate the hydrodynamics and water quality of CHD with current and proposed configurations. The transport equations in AEM3D are unsteady Reynolds-averaged Navier-Stokes equations and scalar transport equations with the Boussinesq approximation with no non-hydrostatic pressure terms. The free surface evolution is governed by an evolution equation developed by a vertical integration of the continuity equation applied to the Reynolds-averaged kinematic boundary condition.

The equations are solved using the TRIM numerical scheme (Casulli and Cheng 1992), with modifications to improve accuracy, scalar conservation, numerical diffusion and implementation of a mixed-layer turbulence closure scheme. Solutions are made on an orthogonal Arakawa C-grid within which flow velocity is defined on the cell faces and the free-surface height and scalar concentrations are solved at the cell centre. The free-surface height in each column of grid cells moves vertically through the grid to improve computational efficiency and allows sharper vertical gradients to be maintained with coarse grid resolutions.

AEM3D computes solutions at time steps of order of minutes using the following steps:

- introduce surface heating/cooling in the surface layer;
- mix scalar concentrations and momentum using a mixed-layer model;
- introduce wind energy as a momentum source in the wind-mixed layer;
- solve the free-surface evolution and velocity field;
- apply horizontal diffusion of momentum;
- advection of scalars; then
- horizontal diffusion of scalars.

Heat exchange through the surface is governed by bulk transfer models reported in the literature of Amorocho and Devries (1980), Imberger and Patterson (1981) and Jacquet (1983). The energy transfer across the free surface is separated into non-penetrative components of long-wave radiation, sensible heat transfer, and evaporative heat loss, complemented by penetrative shortwave radiation. Non-penetrative effects are introduced as sources of temperature in the surface-mixed layer, whereas penetrative effects are introduced as source terms in one or more grid layers on the basis of an exponential decay and a light extinction coefficient in accordance with Beer's Law. Salt is conserved on the basis of advective, diffusive and evaporative processes.

AEM3D is a recent update (first released in 2016) of ELCOM-CAEDYM that was previously developed by the Centre for Water Research, University of Western Australia, and has been extensively published in peer-reviewed scientific literature (Trolle et al. 2012).

3.1.2 *Sediment Model*

Sediment dynamics in AEM3D are modelled concurrently with the hydrodynamics. Sediments are treated as a concentration of inert particles with user-defined diameter and density. The particles are introduced into the model with boundary conditions that describe the terrestrial flow or resuspended from an initialised bed load. The particles are transported with the flow and undergo settling based on a Stokes Law settling derivation. Resuspension rates are determined for each particle size based on the particle density, bottom shear stress (above a critical shear stress) and a user-defined erosion rate. Bottom shear is determined from currents resolved by the hydrodynamic solver AEM3D in response to winds, tides, river inputs and internal waves. In addition, the resuspension and deposition of the sediments changes the bottom morphology.

3.1.3 *Water Quality Model*

AEM3D houses a series of mathematical algorithms to represent biogeochemical processes that govern water quality, including primary and secondary production, nutrient cycling, oxygen dynamics and sediments. AEM3D simulates variables at the chemical and biological species level and solves for the atmospheric and sediment interactions of chemical species that is based on physical mixing processes, chemical reaction and biologically mediated change. The rates of reaction are dictated by the water properties including species concentration, temperature and pH and the configuration is flexible so that the user can select to model the processes that are of interest or within the limitations set by the availability of data and parameters.

This modelling study has focussed on the application of AEM3D to simulate the oxygen dynamics, nutrient cycles and the algae growth. Figure 3.1 and Figure 3.2 illustrate the nutrient cycles that are simulated in the model. The cycles are made up of variables (e.g. NH_4 and NO_3) and fluxes between the variables, whereby with each flux the budget is conserved by transferring nutrients from one variable to another, including inflow addition and loss, atmospheric loss (for nitrogen), and transfer into and out of the sediment. Each flux from one variable or another (illustrated by the arrows) occurs at a rate that is determined during each time-step and at each cell of the model using algorithms that incorporate dependencies on other variables and user-defined parameters. For example, the decomposition of particulate organic matter will contribute N and P into the dissolved nutrient variables at a rate that will depend on a user defined optimal decomposition rate that is adjusted internally in the model depending on the concentration of dissolved oxygen and the water temperature. In addition, the variables on which the fluxes depend will also be adjusted to account for any consumption or production that occurs as a consequence of the flux.

The algorithms used to determine these fluxes are derived from the scientific literature and the parameters used in the algorithms are derived from literature where possible or determined as part of the model calibration to available data.

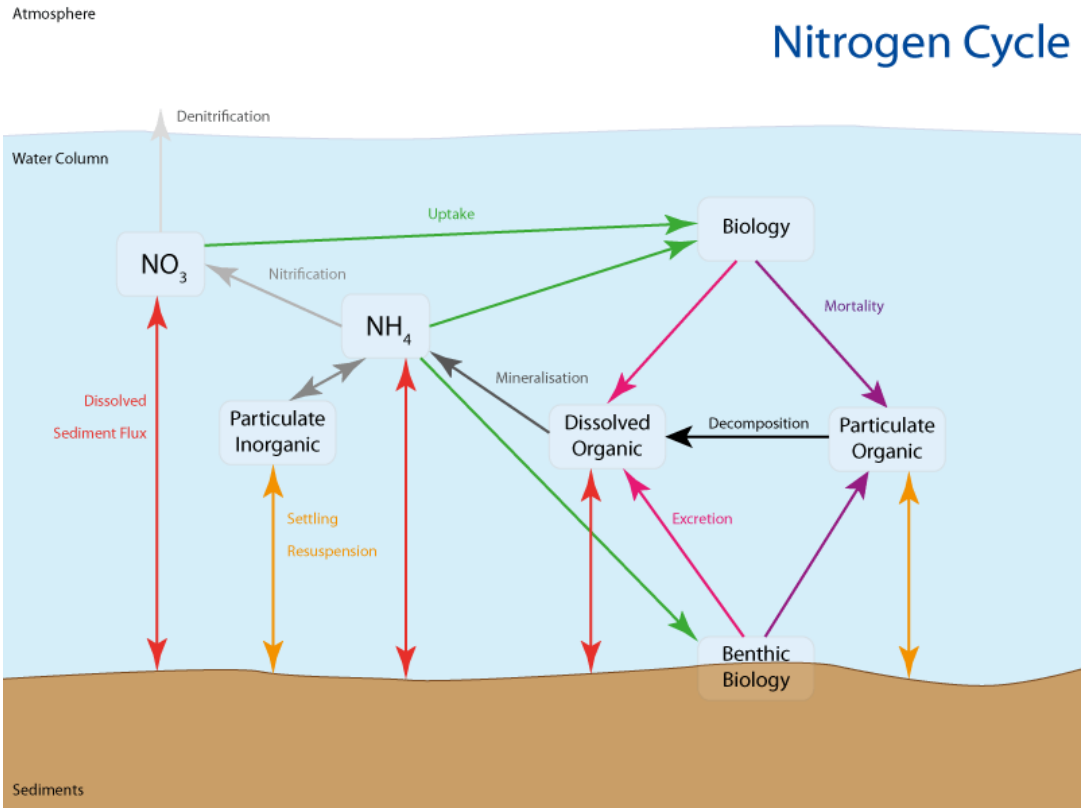


Figure 3.1 Nitrogen cycle in AEM3D showing the nitrogen variables (boxes) and fluxes (arrows) between the variables.

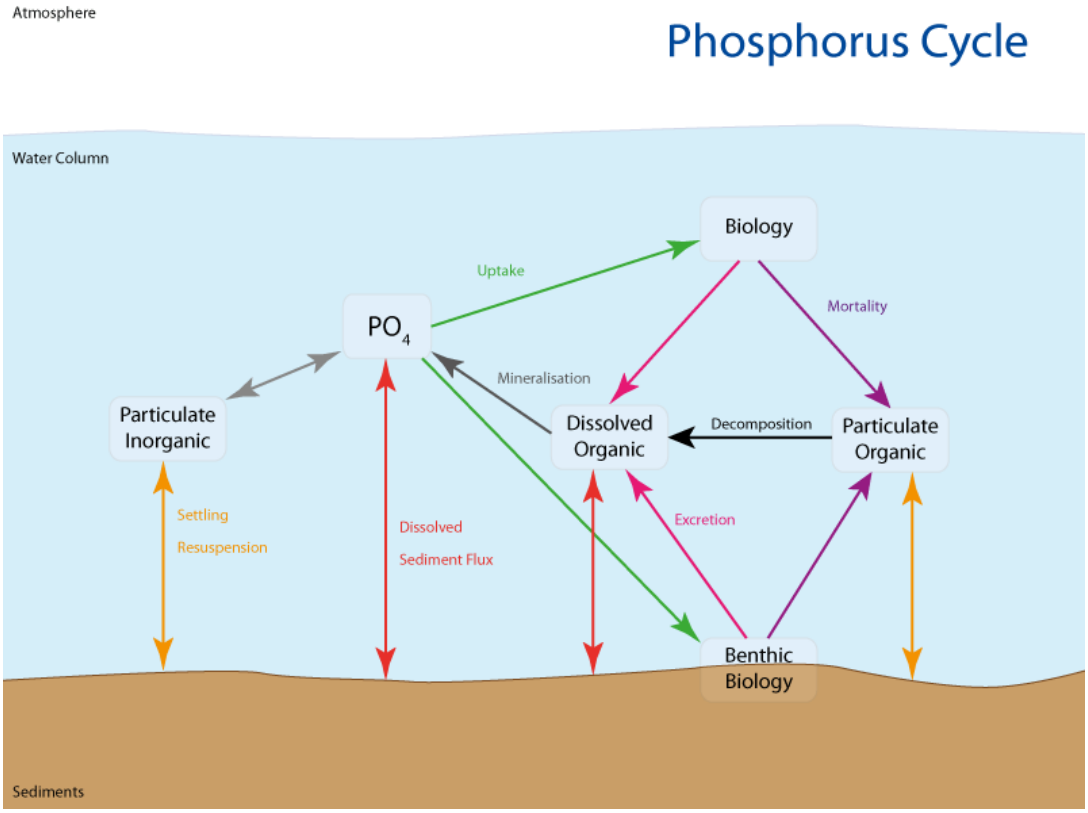


Figure 3.2 Phosphorus cycle in AEM3D showing the nitrogen variables (boxes) and fluxes (arrows) between the variables.

3.1.4 *Algae Model*

To simulate algae, the model seeks to solve an equation for algae concentration in each cell of the model. This solution is a function of a series of other modelled variables (such as nutrients and light) that themselves have a range of dependencies and numerous feedback pathways. Therefore, accurately modelling algal concentrations is a complex task, even before considering the competition and predation than occurs within communities of aquatic biota. In this study we have made steps to simplify the model where possible based on a series of key assumptions that are described below.

Algae concentrations in AEM3D are derived by solving a growth term and then accounting for losses in each model cell. These terms are shown in Figure 3.3, where the arrows indicate either a gain, loss or two-way flux path (e.g. settling and resuspension). A number of key simplifications have been made at this conceptual level. Firstly, model grazing by higher order biology has not been considered as it would require modelling of zooplankton. Secondly, the mortality, respiration and excretion rates have been aggregated into a single loss term (K_m). Thirdly, although settling and resuspension have been included in the model based on buoyancy effects, algal migration by other means has not been included. Finally, whilst Figure 3.3 includes notation for internal nutrient budgets in the algal model (i.e. IC:IN:IP), which refer to internal stores of nutrients that can accumulate when availability outpaces the physiological demands for growth, a simplified approached has been adopted whereby algal growth is a function of nutrient availability in the water column. This means that growth cannot continue in the absence of sufficient nutrients in the water column at the time the growth is determined by the model, a condition that is not necessary if internal nutrients are available to sustain growth until the internal stores are exhausted. This also means that the rate of uptake of nutrients from the water column is controlled solely by the growth rate, which is moderated by other limitations associated with nutrients, light, temperature and competition.

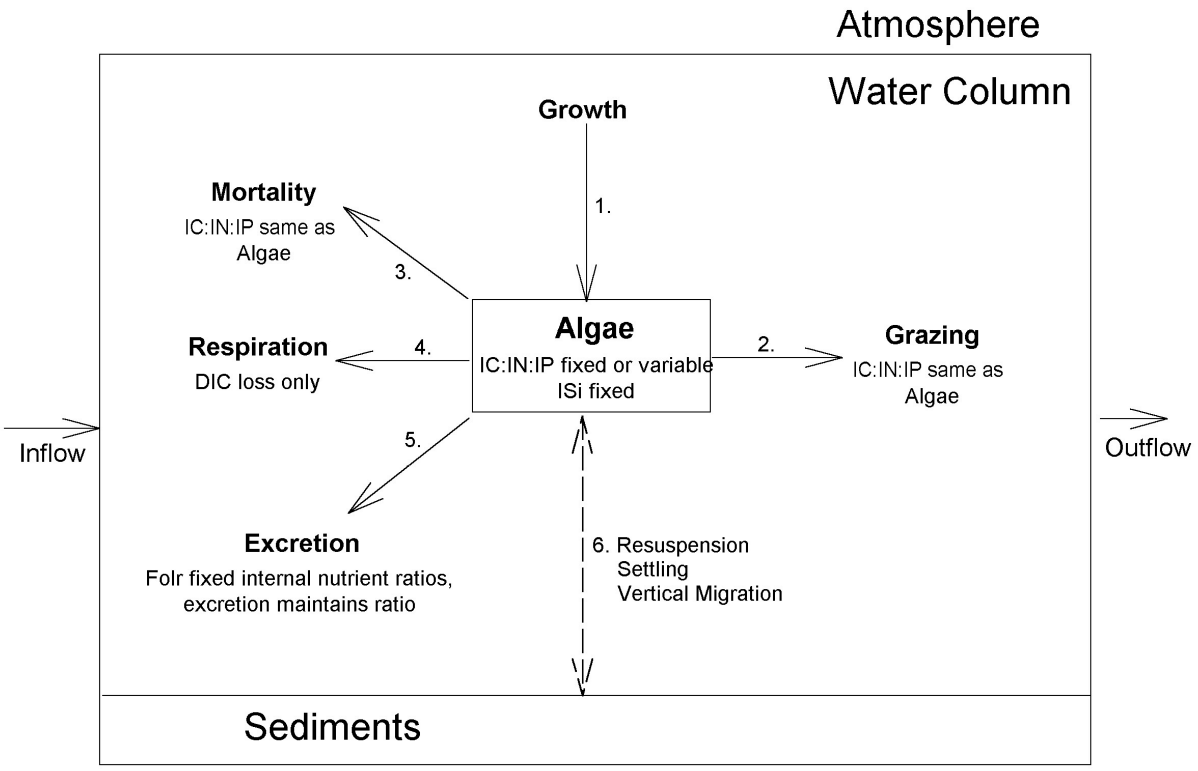


Figure 3.3 Algae growth and fluxes that are simulated in AEM3D.

The algae growth rate is a function of the availability of nutrients and light and the water temperature, which is given by the growth rate equation for algae species *a*:

$$\mu_g^a = \mu_{max}^a f_T^a min\,[f(I)_a, f(N)_a, f(P)_a]$$

where μ_g is the growth rate (day^{-1}). The user can define any number of algal species, but $a > 1$ increases the model complexity significantly and therefore in this study we have adopted a simple approach of modelling only two dominant groups: cyanophytes and chlorophytes. μ_{max} is the maximum growth rate of the algae under fixed conditions (usually 20 ^{o}C with no light or nutrient limitations) and is a physiological property that is different for different algae species. f_T is an algal-dependent temperature multiplier that is set by the user and increases the rate of growth to a peak at an optimal temperature, with a decrease for cooler or warmer conditions than optimum. *f(I)* is a limitation function for light (*I*), with a value between 0 to 1. The value is a function of the modelled availability of light (which enters at the surface and is attenuated as is passes through the water column at a rate determined by dissolved and solids concentrations) and the optimal light level for maximum growth. At low light *f(I)* approaches zero so μ_g approaches zero and as light increases (which occurs over the morning, or higher in the water column) *f(I)* approaches one. If there is too much light then photo-inhibition may occur and *f(I)* begins to decrease again. The optimal light level and the rate at which *f(I)* changes with an increase in *I* are algal specific parameters (see Section 3.1.5 below) than define the shape of *f(I)*.

f(N) is a limitation function for nitrogen (N) that approaches 1 as availability of N in the water column increases to match growth requirements. The shape of the function is a simple Michaelis-

Menten equation and is defined by available N and algae-specific variables. For algae that are capable of fixing atmospheric N, this limitation is negated. *f(P)* is a limitation function for phosphorous (P) that approaches 1 as availability of P in the water column increases. *A* limitation function for silica (Si) is a requirement for diatom growth.

Function f_T defines a curve that increases normally to a standard temperature, T_{std}, plateaus to optimal temperature T_{opt}, and is followed by inhibition at higher temperatures to a value of zero at maximum temperature, T_{max}. μ_{max} is typically determined for a standard temperature of 20 °C; therefore, a temperature multiplier is included in the function whereby the value of f_T increases above unity in favourable conditions.

The light limitation function *f(I)* is given by

$$f(I) = 1 - \exp\left(\frac{-I}{I_k}\right)$$

where *I* is the incoming irradiance and I_k defines the initial slope of the light limitation curve. If light saturation is applied, *f(I)* is set to decrease for $I > I_s$, a saturation irradiance.

Function *f(P)* is given by the Michaelis-Menten equation:

$$f(P)_a = \frac{FRP}{FRP + K_{P_a}}$$

where *FRP* is the filterable reactive phosphorus (PO_4) that is available for phytoplankton update and K_{Pa} is an algal specific half-saturation coefficient that defines the shape of the function. The availability of PO_4 is modelled as part of the phosphorus cycle (Figure 3.2), with sources and sinks that are external (i.e. fluxes in and out of the model cells that are resolved by the hydrodynamics) and internal, which arise from in-lake cycling of P and with the sediments (sources and sinks). The *f(N)* limitation function or nitrogen follows the same form.

3.1.5 *Model Parameters*

In this study two algae groups were configured (cyanophytes and chlorophytes) and algorithms were initially applied with default parameters (see Hodges and Dallimore, 2019). Key water quality algorithm parameters that have been assigned values based on the literature or adjusted to calibrate the model against the available data are shown in Table 3.1. The sensitivity of the model to the model inputs and calibrated parameters has been described in Appendix B.

Table 3.1 Key WQ parameters used in the application of AEM3D.

Parameter	Description	Value	Reference
Light			
K_d	Background PAR light extinction coefficient.	1.0 m^{-1}	Calibrated
Suspended Solids			
D_s	Diameter of inflows sediments	1-2 microns	Based on observation data (see Section 2.6.4)
SG_{sed}	Specific gravity of inflowing sediments	2.25	Based on observation data (see Section 2.6.4)
D_{POM}	Diameter of particular organic matter	3 microns	Based on observation data (see Section 2.6.4)
SG_{POM}	Specific gravity of particular organic matter	1.5	Based on observation data (see Section 2.6.4)
Cyanophytes			
u_{max}	Maximum growth rate	0.8 /day	van der Linden et al. 2015
K_m	Mortality rate	0.09 /day	van der Linden et al. 2015
K_{FRP}	PO_4 half saturation	0.009 mg/L	van der Linden et al. 2015
I_k	Light slope parameter	130 uE/m^2/s	van der Linden et al. 2015
T_m	Temperature growth multiplier	1.09	van der Linden et al. 2015
T_{std}	Temperature growth standard	24 ^oC	van der Linden et al. 2015
T_{opt}	Temperature growth optimal	30 ^oC	van der Linden et al. 2015
T_{max}	Temperature growth maximum	39 ^oC	van der Linden et al. 2015
V_{set}	Settling velocity (positive down)	8.5 x 10^{-6} m/s	Added to account for buoyant algae
Chlorophytes			
u_{max}	Maximum growth rate	1.2 /day	van der Linden et al. 2015
K_m	Mortality rate	0.1 /day	van der Linden et al. 2015
K_{PO4}	PO_4 half saturation	0.008 mg/L	van der Linden et al. 2015
I_k	Light slope parameter	100 uE/m^2/s	van der Linden et al. 2015
T_m	Temperature growth multiplier	1.07	van der Linden et al. 2015

Parameter	Description	Value	Reference
T_{std}	Temperature growth standard	20 ^oC	van der Linden et al. 2015
T_{opt}	Temperature growth optimal	22 ^oC	van der Linden et al. 2015
T_{max}	Temperature growth maximum	35 ^oC	van der Linden et al. 2015
Biogeochemical			
DO_{sed}	Sediment oxygen demand	2 $g/m^2/day$	Calibrated
P_{sed}	Sediment release rate (PO_4-P)	0.003 g/m2/day	Calibrated

3.2 Model Set-up and Inputs

3.2.1 *Simulation Periods*

The CHD model was applied using boundary forcing data from July 2015 to July 2019. According to dam operational records this included the first 20 months with the mechanical mixer in operation until April 2017, followed by 28 months during which the mixer was no longer in operation.

3.2.2 *Bathymetry*

Model bathymetric grids of 30 x 30 m and 90 x 90 m lateral resolution with a 0.5 to 1 m vertical grid resolution were applied (Figure 3.4). The course grid allowed rapid simulation to refine the model parameters and the fine grid provided more details, particularly in the upper reaches of the reservoir. Comparisons between the models using the different grids are illustrated in Appendix B.

The grids were generated using a 1 m horizontal resolution (dx) raster provided by Eco Logical. The raster was sub-sampled to 5 m dx and exported as xyz data that was used to create the 30 m and 90 m dx model grids. Adjustments were made manually to the bathymetries to smooth grid anomalies produced by the data discretisation along the thalweg, so they did not impede simulated flow.

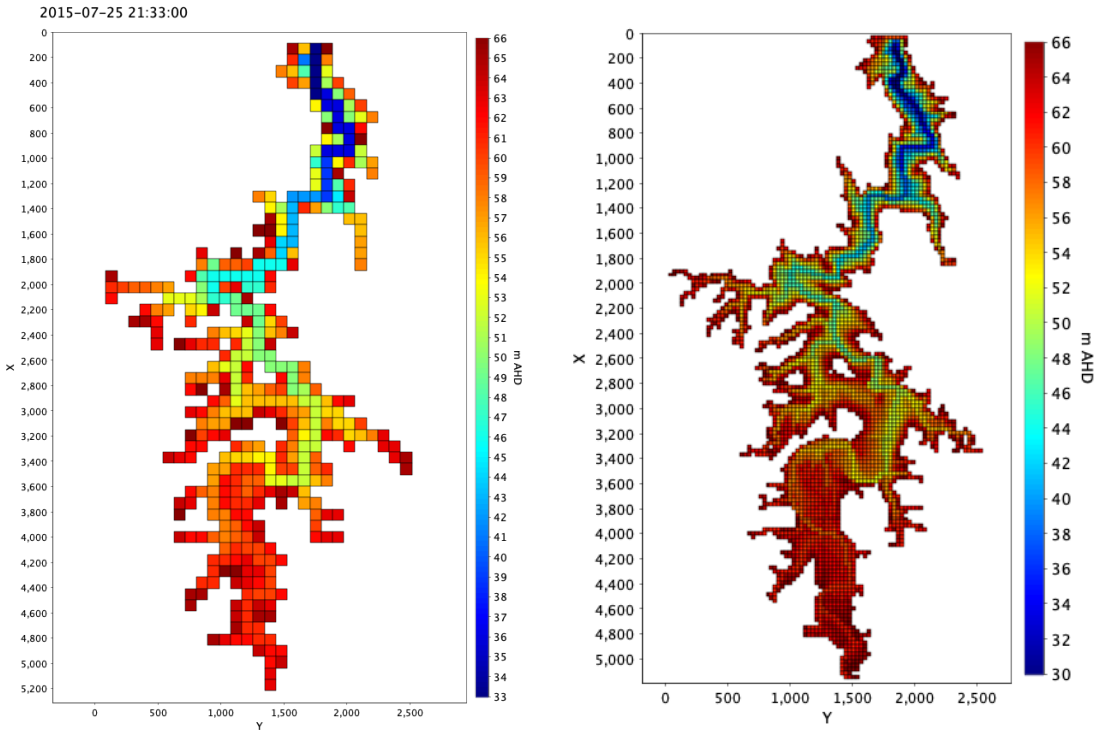


Figure 3.4 Model grid bathymetries with 90 x 90 m (left side) and 30 x 30 (right side) horizontal resolution. Horizontal axes and vertical scales are in metres.

3.2.3 *Meteorology*

The CHD model requires sub-hourly meteorological conditions to define the surface boundary conditions. These boundary conditions include solar radiation, air temperature, relative humidity, wind speed and direction, longwave radiation or cloud cover and rainfall. Records from Bray Park have insufficient temporal resolution for the model, hence higher frequency data available from the following nearby Bureau of Meteorology (BoM) observation stations (see Figure 3.5) were assessed for use:

- Canungra, 45 km north of CHD
- Coolangatta, 36 km north east of CHD
- Cape Byron, 39 km south east of CHD
- Lismore, 44 km south of CHD.

These records included half-hourly observations of air temperature, relative humidity and wind speed and direction. Solar radiation data was available from satellite-derived hourly irradiance data (also from BoM). Cloud cover was estimated from the difference between theoretical (clear sky) solar radiation and the BoM irradiance data. AEM3D uses the cloud cover estimate to derive the longwave radiation flux at the water surface. Rainfall data was available from dam operator records and hourly gauge data provided by Eco Logical (see Eco Logical, 2021).

Time series of air temperature, relative humidity and wind speed and direction were synthesised using the mean of observations from Coolangatta and Lismore to account for the mid-way location of CHD. Observations from Canungra only began in 2018, and wind speeds at Byron were too high (due to coastal influence), so these data were omitted from the calculations.

An analysis of the available data and model sensitivity testing has been described in Appendix B; these tests indicated that an adjustment of a 10% reduction in derived windspeed improved the model results. This adjustment is likely to account for the differences in local topography between CHD and the available monitoring sites, with CHD in the most mountainous setting.



Figure 3.5 Location of weather stations that provided meteorological data for the study.

3.2.4 *Inflows and Outflows*

Inflows and outflows for the CHD reservoir simulations were defined using SOURCE model outputs that are described in detail by Eco Logical (2021). SOURCE outputs include flow rate and water quality variables for the waterways that enter CHD from four sub-catchments: the largest at the headwaters (Doon Doon Creek) and smaller contributions distributed in the dendritic arms. The relative contributions from the upstream catchments in terms of monthly total streamflow is shown in Figure 3.6. Through an extensive series of testing the SOURCE inputs were adjusted so that the AEM3D model could reproduce the responses that were observed in the limnological data. Table 3.2 below summarizes the SOURCE data and adjustments that have been made.

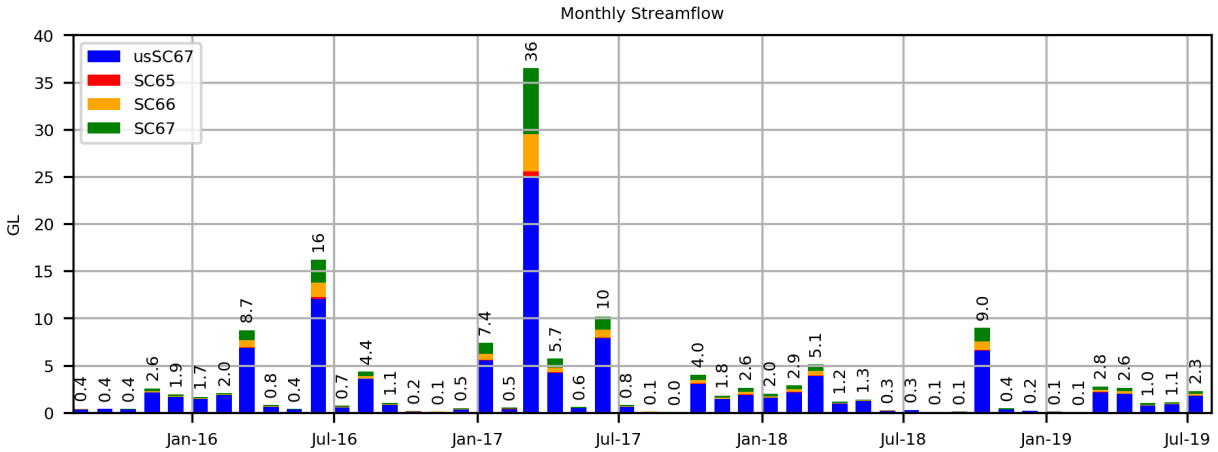


Figure 3.6 Monthly totals of streamflow entering CHD from SOURCE; colours indicate contribution from each sub-catchment. SC65 and SC66 (tributaries near dam wall), SC67 (tributaries in central section of reservoir) and upstream of SC67 (including Doon Doon Creek).

The turbidity data recorded in the reservoir (see Section 2.6.4) indicates that inflowing particles that penetrate into the reservoir are fine and settle slowly. During persistent high turbidity events recorded in Lake Wivenhoe (150 km north of CHD, Grinham et al. 2012), turbidity is maintained by particles with median sizes of less than 3.9 μm (with 10th percentile less than 1 μm), which is consistent with the estimates from the fall-out rate derived from the CHD data. Inflowing suspended solids into the CHD model were therefore assigned evenly between 1μm and 2 μm, both of which will settle slowly, but at different rates.

In-lake measurements of TSS in CHD show that SOURCE considerably under-estimates the peak sediment concentrations during the recorded large inflow events. To account for this TSS was derived from a power law relationship based on flow rate. The coefficients were determined from comparisons to in-lake suspended solids and turbidity measurements, e.g. by scaling modelled TSS to peak at ~180 mg/L during the March 2017 inflow event (based on TSS:NTU ratio of 0.85). Particulate organic matter (POC, PON and POP) were assigned as fractions of TSS derived by Grinham et al. (2012) and are consistent with the observations that are discussed in Section 2.6.7. Numerous iterations of the inflow configurations were undertaken to test and ensure that AEM3D replicated the responses observed in the data.

Extractions from the tower were allocated at the tower location at 4 and 7 m below the FSL of 61.5 m AHD. Discharge via the spillway is determined by the sharp crested weir equation as a function of the simulated water level (above spillway height) and spillway size and shape.

Table 3.2 Boundary condition inflow used in the AEM3D model.

Inflow Variable	**AEM3D Inflows**
Flow (Q)	Direct from SOURCE
Temperature	3-day moving average of air temperature
Salinity	Derived from conductivity and temperature measurements
Dissolved Oxygen	Saturation concentration based on water temperature
Dissolved Organic Carbon	3.5 mg/L
Particulate Organic Carbon	3% of TSS
Particulate Organic Nitrogen	0.3% of TSS
Particulate Organic Phosphorus	0.1% of TSS
Total Suspended Sediments (TSS)	5 + 0.005 Q^2 mg/L
Orthophosphate	0.005 + 0.01% of TSS mg/L
Oxidised Nitrogen	0.3 + 0.024% of TSS mg/L
Ammonium	0.005 + 0.24% of TSS mg/L
Dissolved Organic Nitrogen	0.005 + 0.03% of TSS mg/L
Chlorophytes	1 ug/L
Cyanophytes	1 ug/L

3.2.5 *Artificial Mixer*

The mechanical mixer was implemented in AEM3D by specifying the location, depth and draft tube diameter and length. The model applies a downward flow that displaces surface water to the tube depth in the specified model cell where the mixer is located. The displaced water then rises, entraining ambient water of a higher density until it reaches a height of neutral buoyancy. The water then propagates laterally at the height of neutral buoyancy. The rates of downward displacement of water is controlled by the power of the mixing unit and the efficiency with which that power is transferred to flow down the draft tube.

An efficiency parameter of 3% was found to best reproduce the effects of the mixer that are observed in the data. This efficiency is set as constant over the period of the simulation as there is limited information describing when the mixer is operating, to what extent of full power it is operating, and the general condition of the mixer. Temperature observations (Figure 3.7) in the reservoir indicate possible intermittent operation, or lack of full operational capabilities over some of the period considered.

3.3 Model Results

3.3.1 *Temperature and Stratification*

Figure 3.7 and Figure 3.9 illustrate comparisons between the observed and simulated temperatures. The figures demonstrate the ability of the model to reproduce the seasonal cycles of mixing and stratification that were observed in 2017 and 2018 and the impact of the mixer from 2015 to 2016. There are discrepancies between the observed and modelled impact of the mixer that are likely to relate to our limited understanding of the exact configuration, efficiency and operational regime of the mixer. During the summer months of 2017-18 the observed temperatures between 4 and 8 m deep are approximately 2-4^{o}C cooler than compared to model results and observations in other years. Testing different model configurations to account for higher turbidity and windspeeds made some improvements but did not eliminate the discrepancies.

In addition, this effect is not local to one monitoring site and does not follow through into the deeper waters. Because the temperature gradients at this depth are large, small inaccuracies in the vertical distribution of heat by the model will manifest as large temperature differences. The non-local meteorological boundary conditions and/or potential changes to the extraction configuration that are not incorporated in the model (and different to the other three years) are potential reasons for the discrepancy.

The model provides an estimate of the residence time over which water in the reservoir water remains stagnant (see Figure 3.8), showing that during stratification the hypolimnetic water reaches 300 or more days old. Large inflows (which enter with an age of zero days) re-set the retention time by partially or fully flushing out the ambient water. However, there is a lack of flushing by large events in the second two years of simulation so that water age approaches 600 days in hypolimnion in 2019. The regions of elevated retention time are consistent with the poorly flushed regions of the water column that experience elevated salinity (see Figure 2.10).

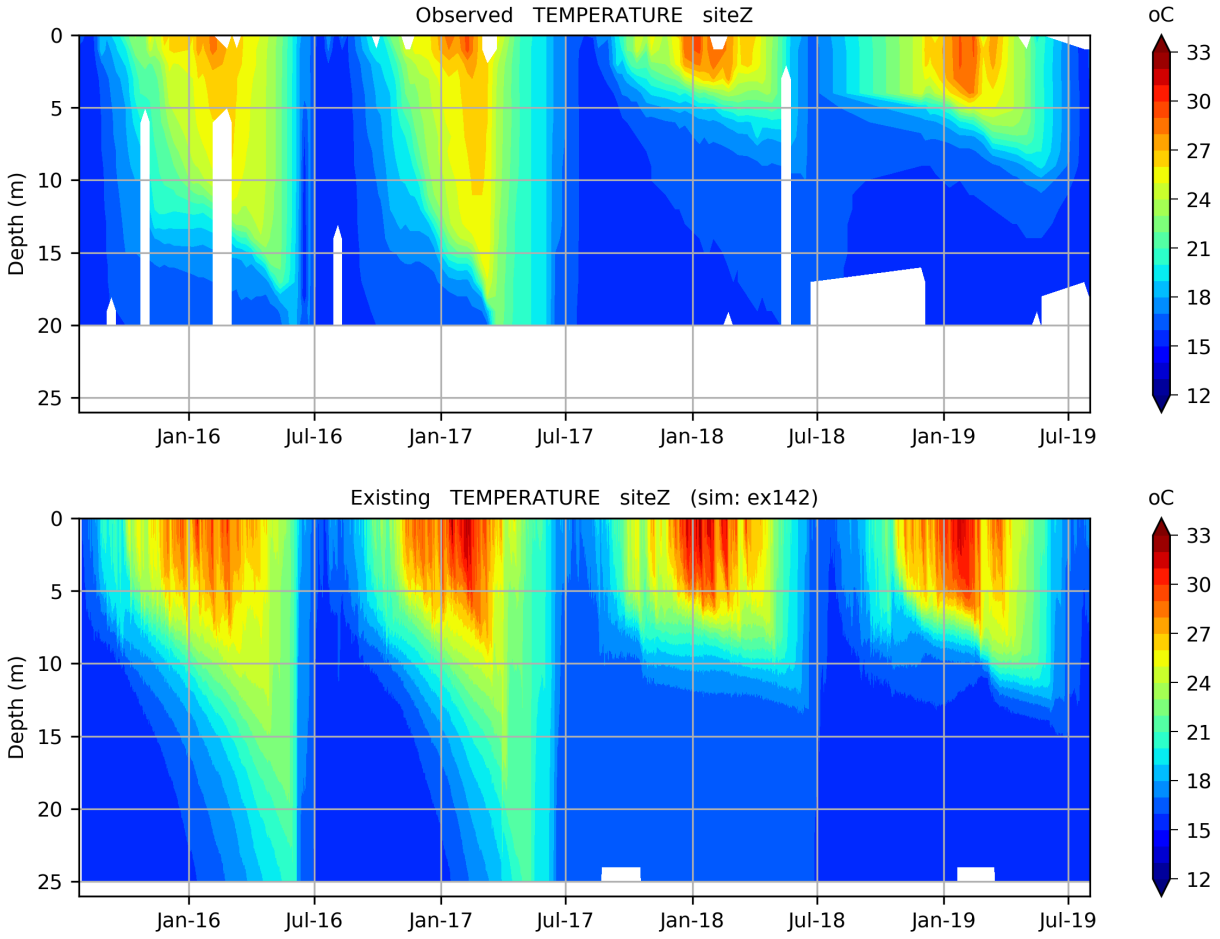


Figure 3.7 Observed (top panel) and simulated (bottom panel) temperatures at site Z.

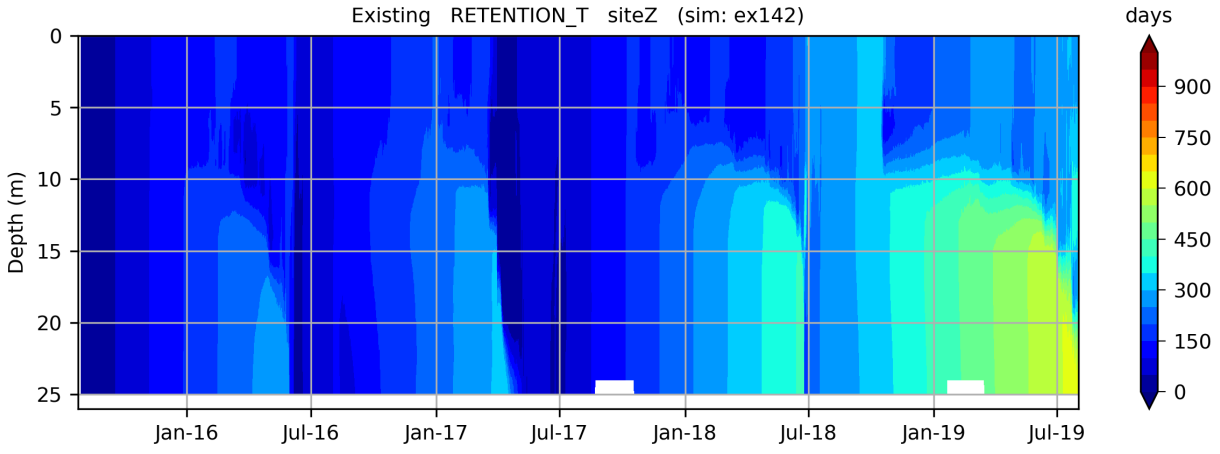


Figure 3.8 Simulated retention time at Site Z.

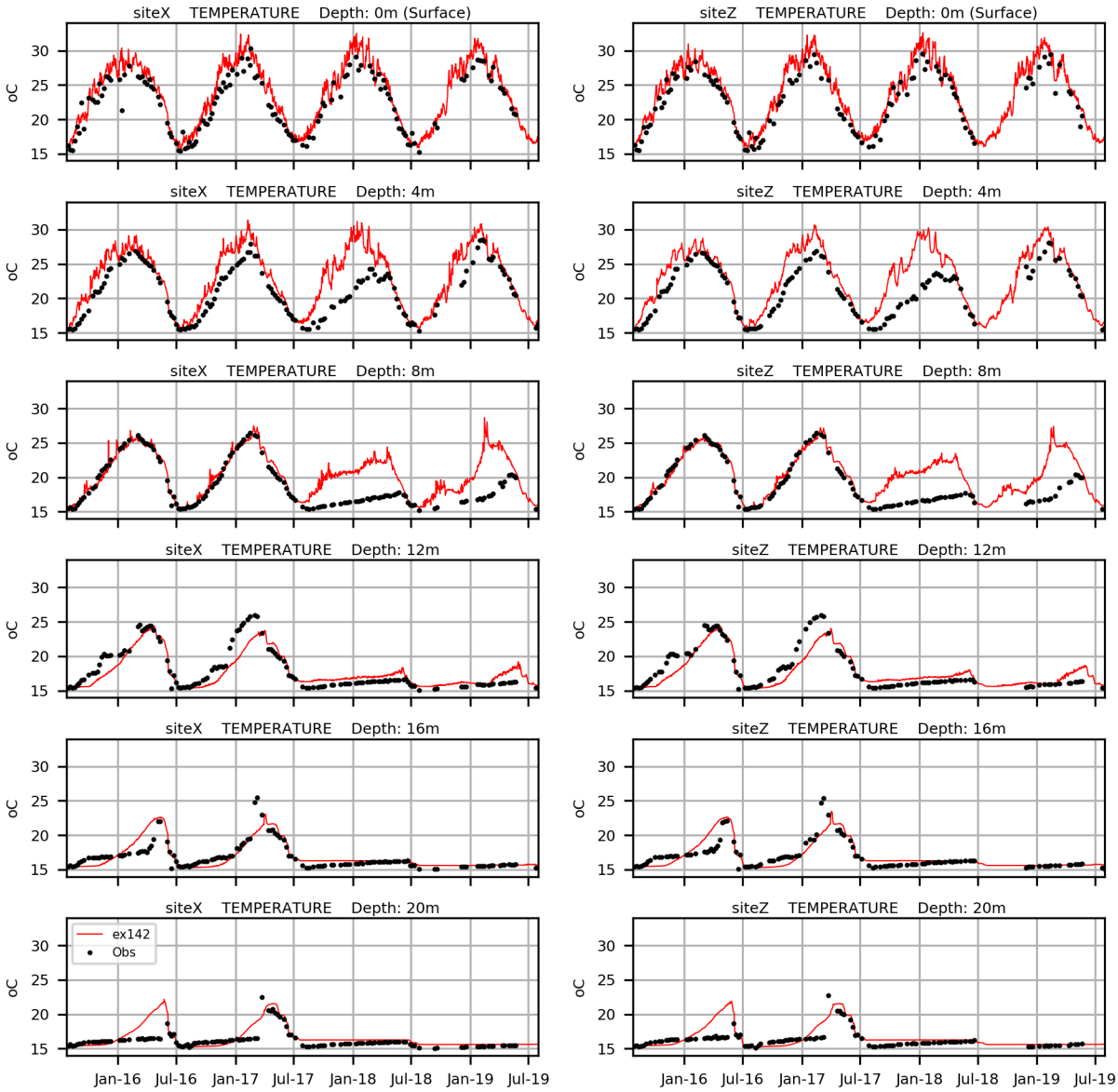


Figure 3.9 Comparison between observed (black dots) and simulated (red lines) temperatures at depths from site X (left) and site Z (right).

3.3.2 *Suspended Solids*

Simulated suspended solids (Figure 3.10) are dominated by the response to the large flow events of June 2016 and March 2017 and are consistent with turbidity observations shown in Figure 2.11. The model results illustrate the slower settling rate of the smaller fraction of particles that remain in moderate concentrations of 12-16 mg/L below 10 m and persist until winter mixing in July 2018. Comparisons between simulated TSS and observed TSS and turbidity at sites X and Z and at the tower (see Figure 3.11 and Figure 3.12) illustrate the model can reproduce the observed peak and tail of the TSS associated with the fine material delivered to the reservoir during the large inflow events.

Figure 3.13 shows time-lapse panels of the simulated underflow of June 2016 as it propagates from the headwaters to the dam wall, including the settling and dilution that occurs on passage through the reservoir. Initial concentrations near the headwaters are reduced by approximately 30% as the plume flows through the reservoir.

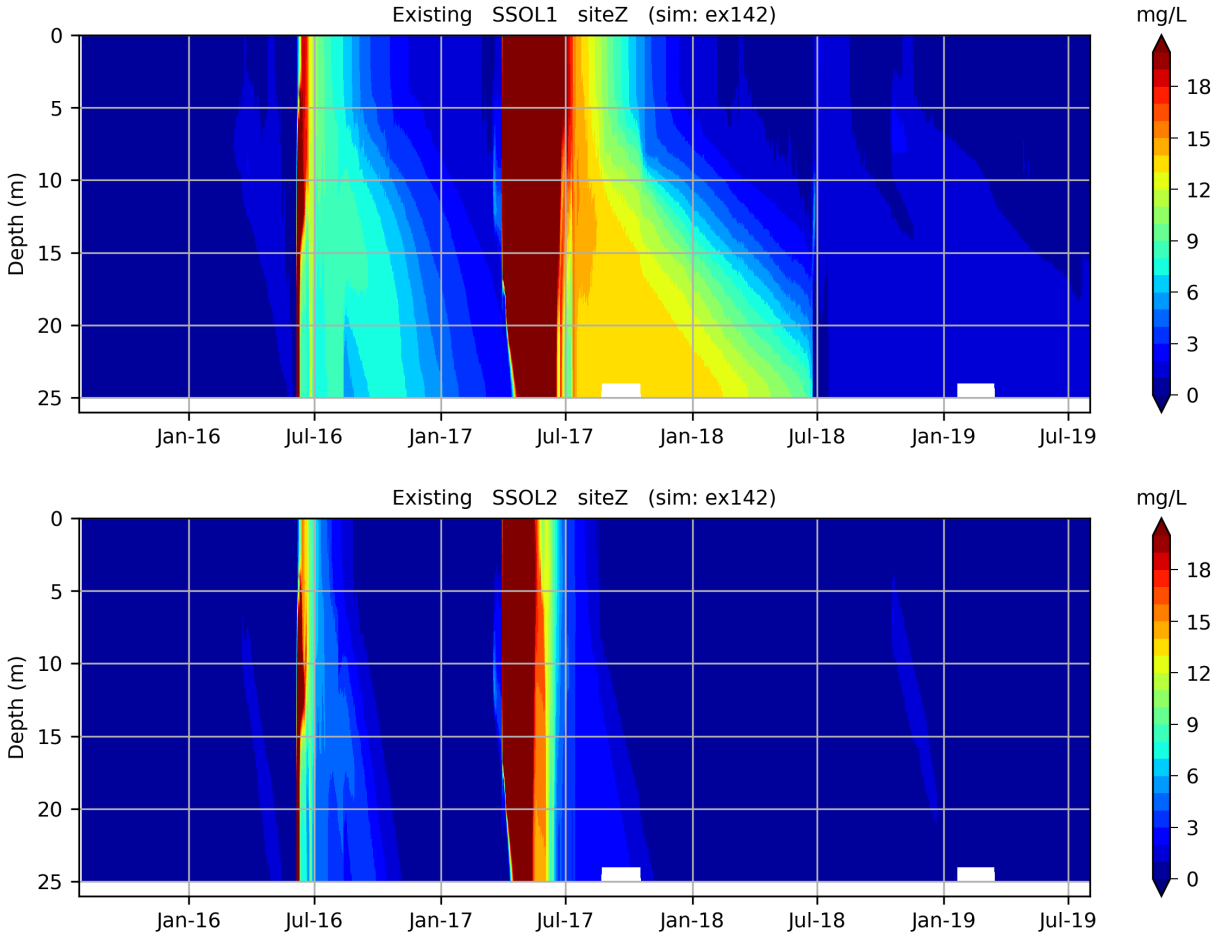


Figure 3.10 Simulated sediments with 1-micron diameter (top panel) and 2-micron diameter (bottom panel) at size Z.

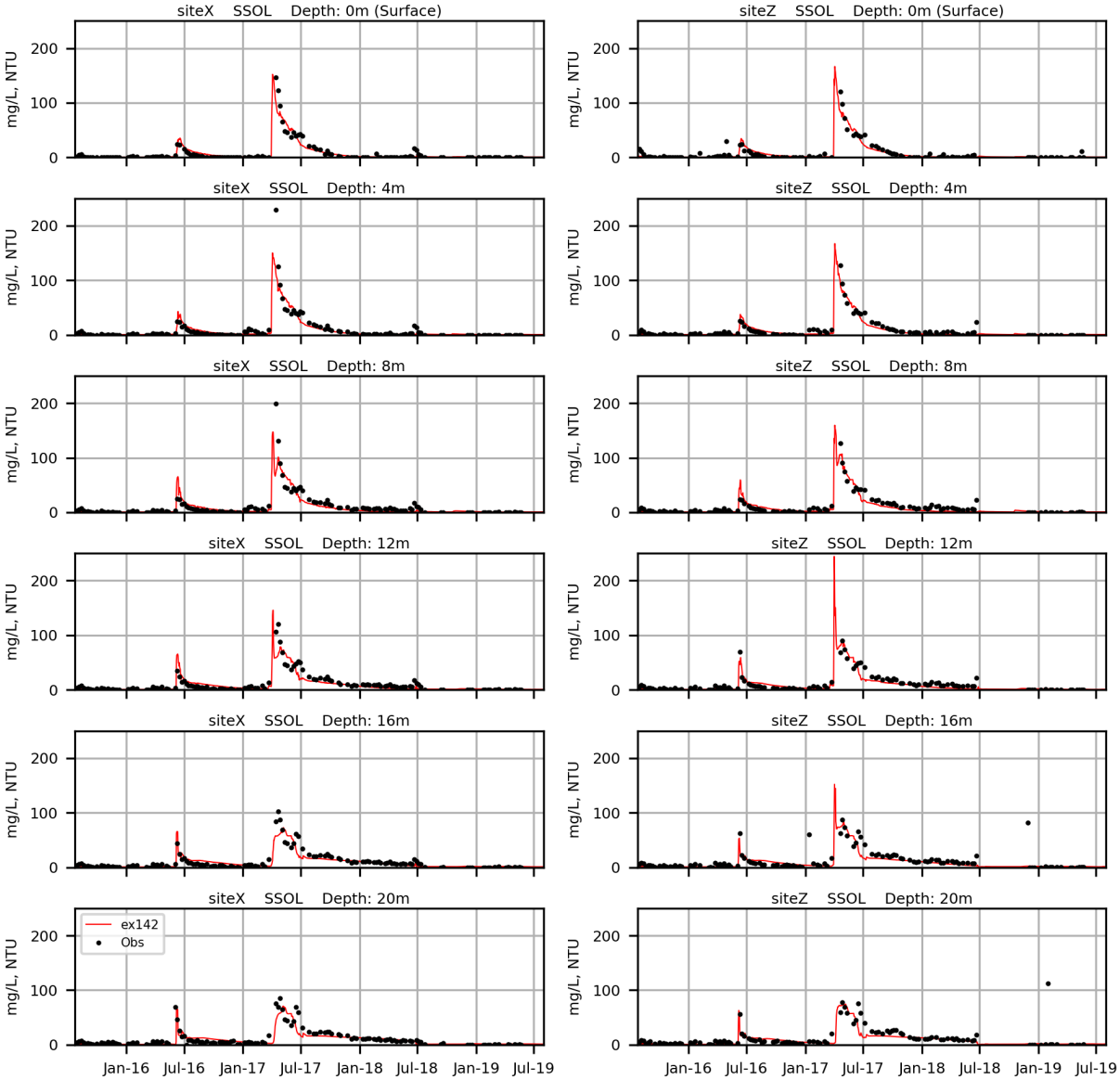


Figure 3.11 Simulated (red lines) suspended solids concentrations and observed turbidity (black dots) at depths from size X (on the left) and site Z (on the right).

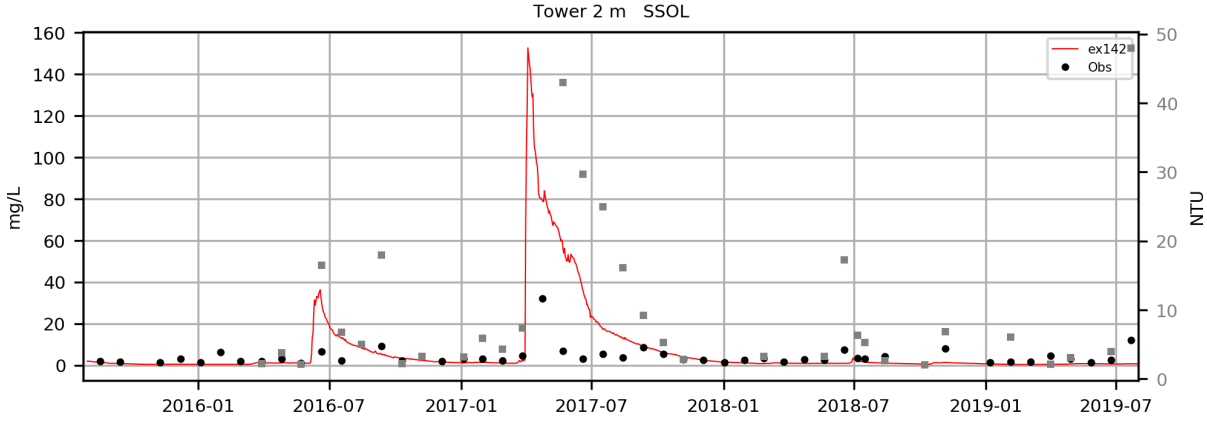


Figure 3.12 Observed (black circles) and simulated (red line) suspended solids concentrations, and observed turbidity (grey squares, right axis) at 2 m depth at intake tower.

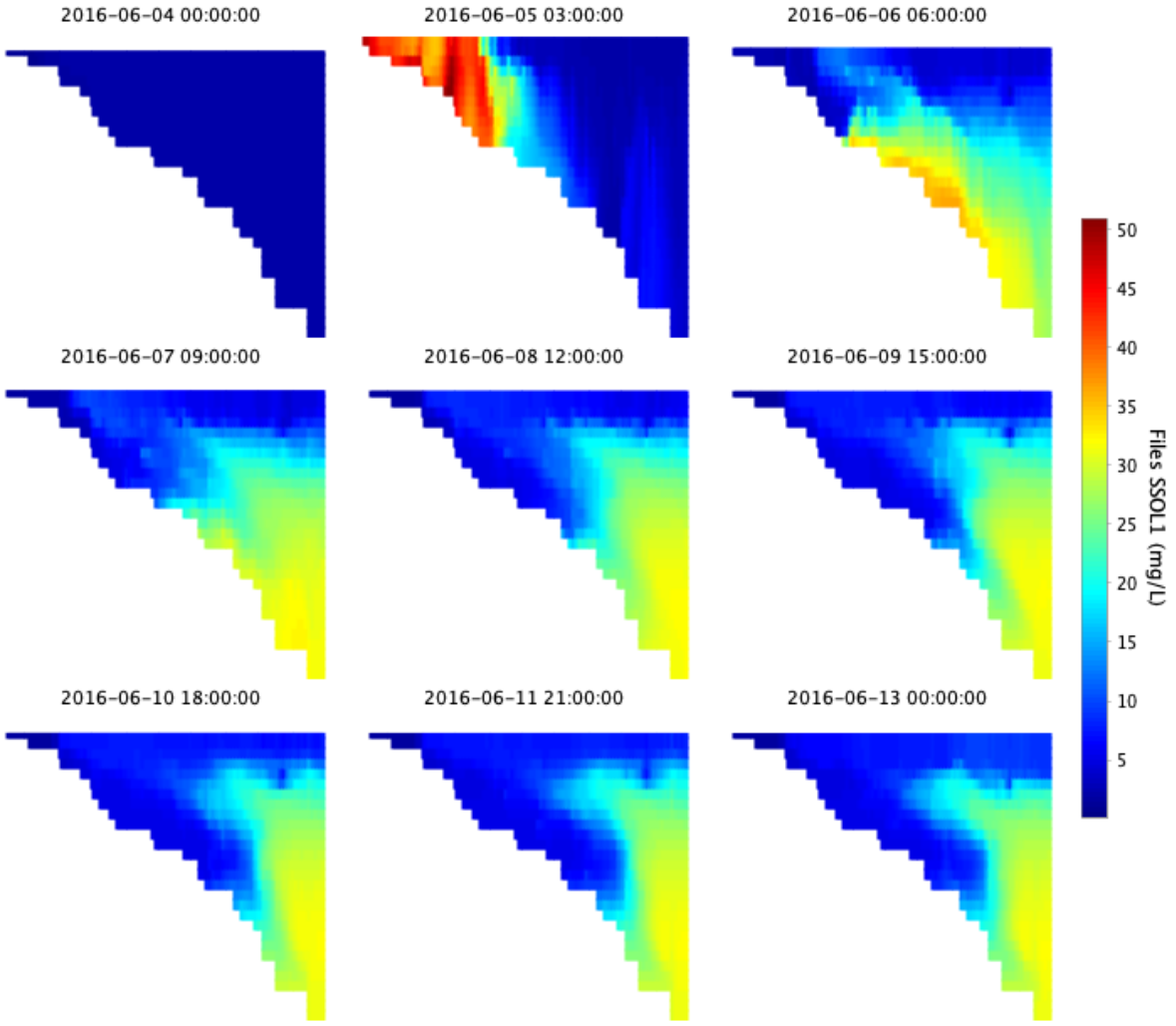


Figure 3.13 Time-lapse panels of the simulation of the June 2016 inflow event delivering fine sediments into the reservoir. The panels show the Doon Doon Creek headwaters to the left; following the reservoir thalweg to the dam wall on the right.

3.3.3 *Oxygen*

Figure 3.14 and Figure 3.15 illustrate that the model is able to reproduce the effects of stratification and mixing on the DO concentrations though the water column. The comparisons illustrate a good match between the data and the simulations through the water column, however the model overpredicts the depth of the oxycline by approximately 2 m.

The largest discrepancies occur at 4 m below the surface where there are strong vertical gradients in oxygen and temperature (Section 3.3.1) in the data. This suggests that the vertical detail in the model gradients of oxygen in the metalimnion is insufficient to reproduce the very sharp oxygen gradients seen in the field data or may be related to the mixing driven by non-local meteorological data.

Resolving these gradients would require vertical grid resolution of less than 0.5 m. Whilst physically possible, this would significantly decrease the computational efficiency. Despite this, the more critical feature of prolonged hypolimnetic anoxia that is broken by brief periods of oxygenation during winter mixing is accurately reproduced by the model.

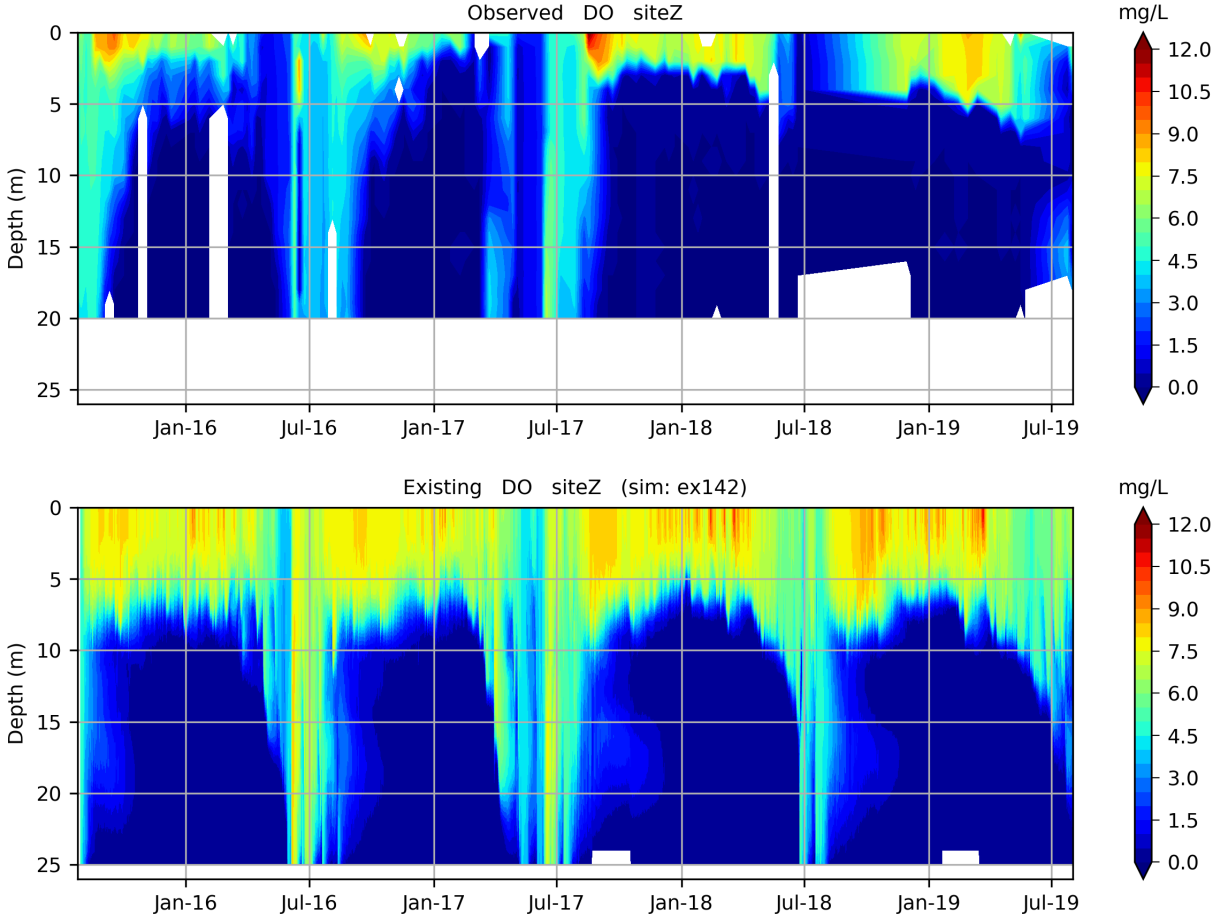


Figure 3.14 Observed (top panel) and simulated (bottom panel) dissolved oxygen (DO) concentraions at site Z.

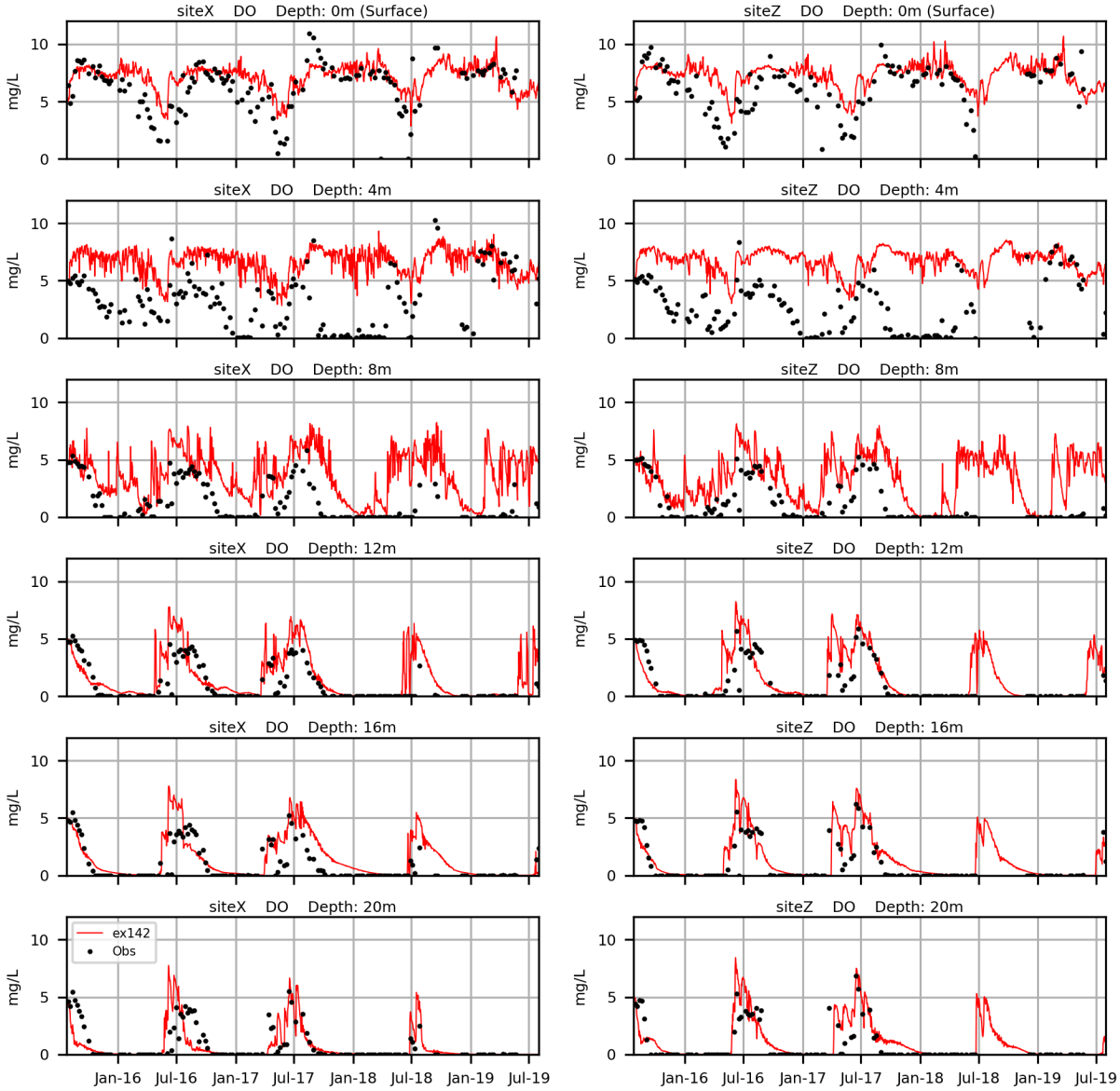


Figure 3.15 Comparison between observed (black dots) and simulated (red lines) dissolved oxygen (DO) concentrations at depths from size X (on the left) and site Z (on the right).

3.3.4 *Nutrients*

Comparisons between observed and simulated total nitrogen (TN) in the surface 20 m illustrate that the model reasonably reproduces the higher concentrations seen during large inflow events in June 2016 and April 2017 (Figure 3.16 and Figure 3.17). The origin of intermittent and vertically localised peaks that occur outside of the inflow events in the top 10 m is uncertain and not replicated by the model. Because these peaks are highest when algae growth is lowest (see Figure 2.17) and in the months after the large inflow events, the elevated TN may be related to remnant particulate organics that settle at rates slower than assigned in the model.

At the depth extent (20 m) of the observation profiles, TN is elevated during the stratified summer months. The model indicates that this is due to a build-up of NH_4-N in the hypolimnion, released from the sediments and through mineralisation of organic matter that falls out into the hypolimnion (see Figure 3.18). The results indicate that there is less simulated NH_4 accumulation in the hypolimnion in the years prior to the large flow event of April 2016, which provides an additional source of nitrogen beyond just sediment release.

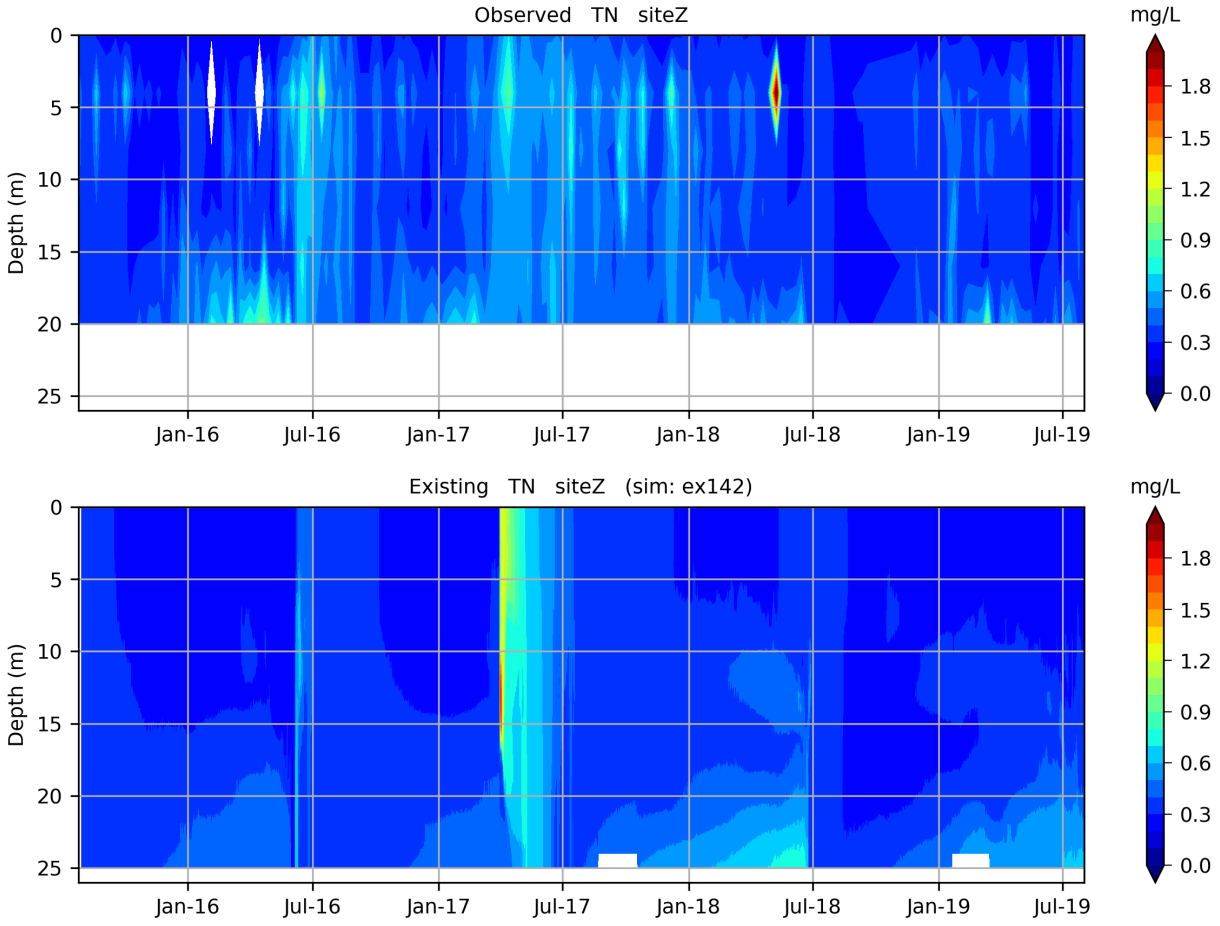


Figure 3.16 Observed (top panel) and simulated (bottom panel) total nitrogen (TN) concentrations at site Z.

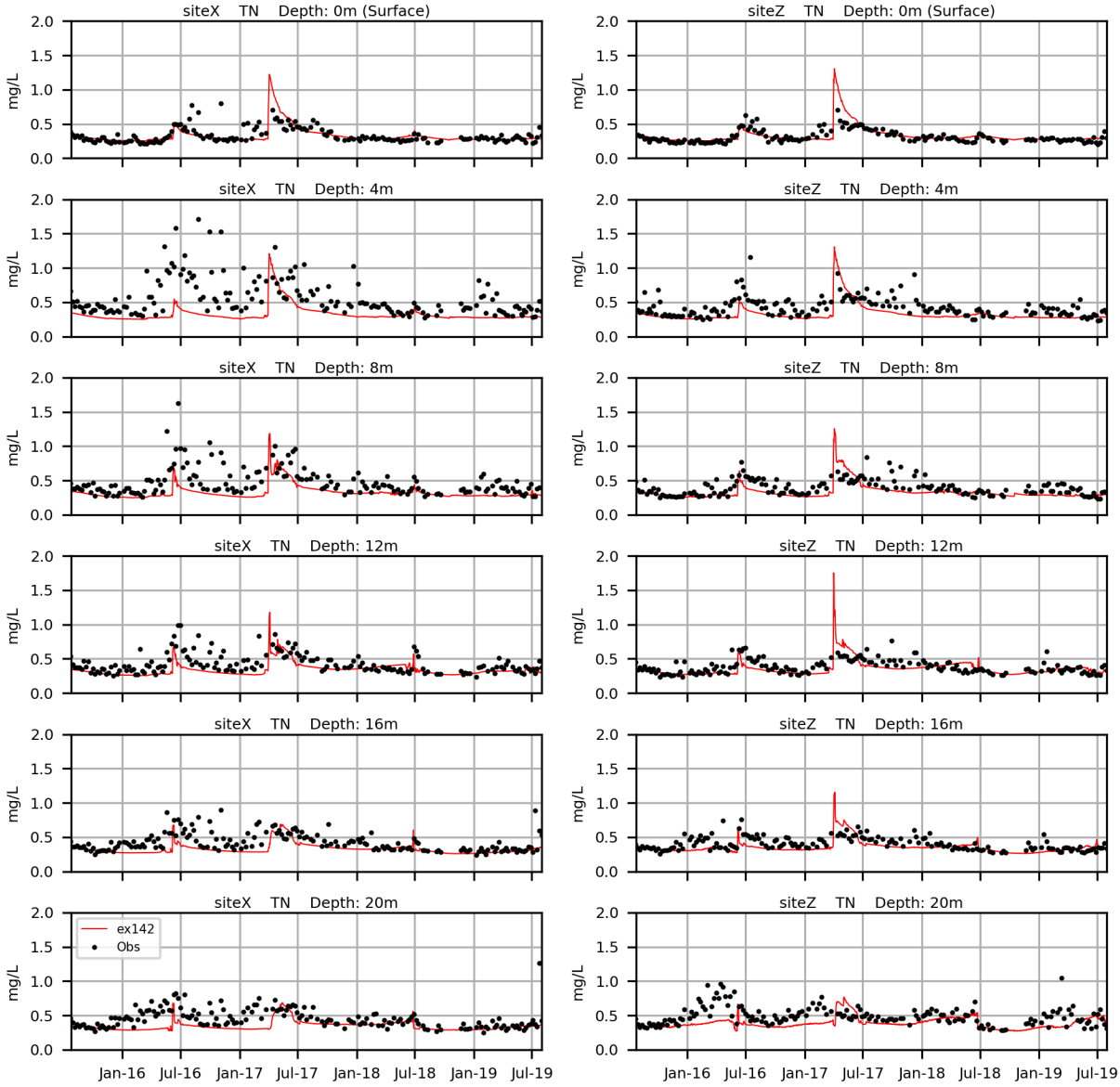


Figure 3.17 Comparison between observed (black dots) and simulated (red lines) total nitrogen (TN) concentrations at depths from site X (on the left) and site Z (on the right).

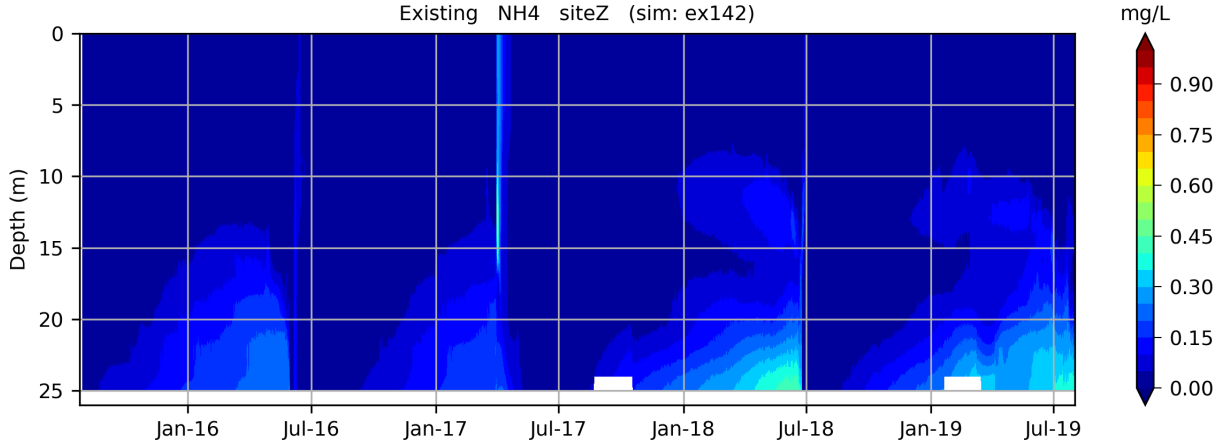


Figure 3.18 Simulated NH_4 concentrations at site Z.

The legacy effects from the inflow of organic matter coupled with the lack of data at depth (and hence inability to assign a more appropriate initial condition) may contribute to insufficient model spin-up time that would be required to replicate this internal process. It is therefore possible that the TN concentrations below 20 m in the first two years are actually comparable to the last years, but there is insufficient data at depth to more accurately assess the internal nutrient loading processes.

Simulated total phosphorus (TP) and PO_4-P concentrations (Figure 3.19 to Figure 3.20) follow the pattern of simulated TN and NH_4 with concentrations that match well against the observations. The PO_4-P concentration increases in the hypolimnion, due to sediment release and mineralisation of the accumulated organic material that occurs in the anoxic waters.

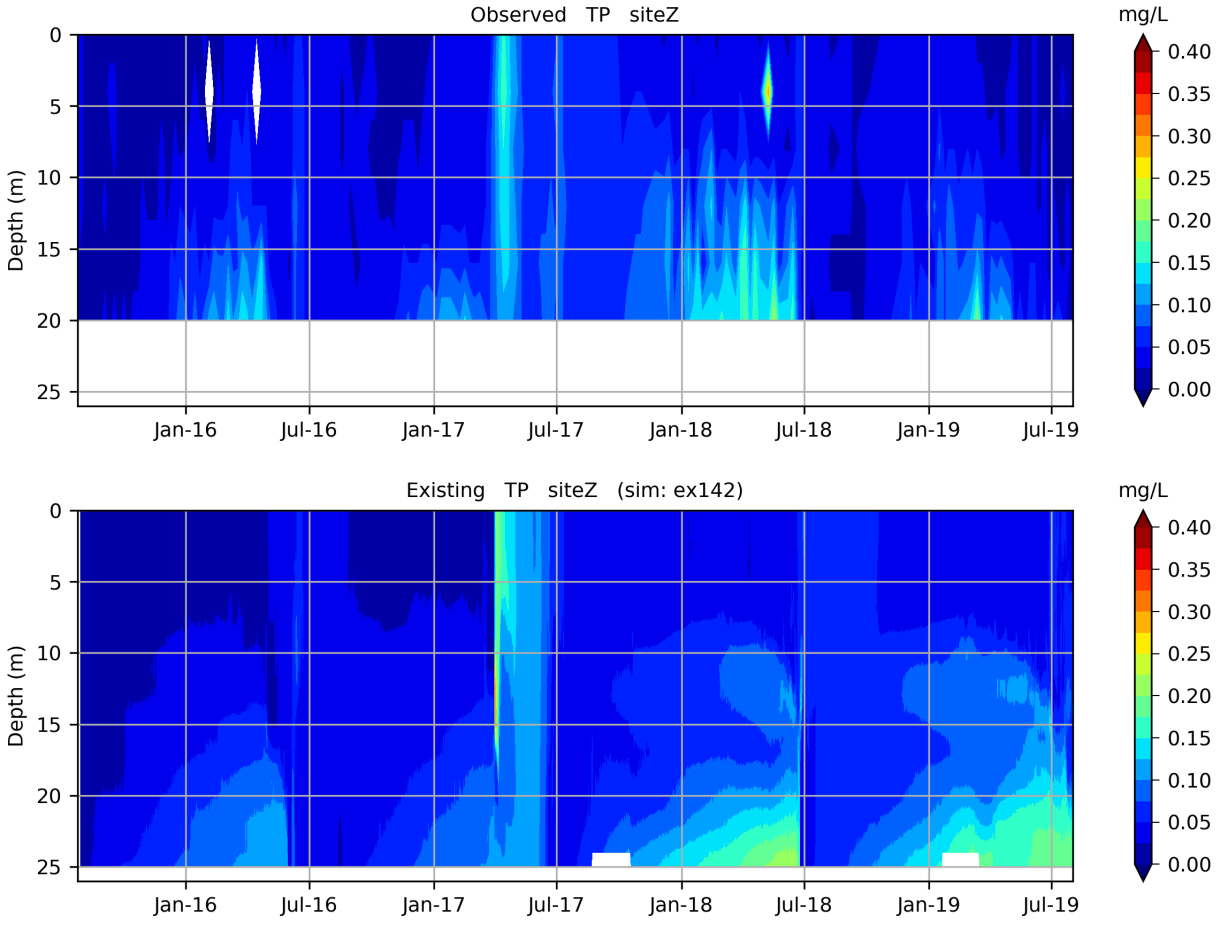


Figure 3.19 Observed (top panel) and simulated (bottom panel) total phosphorus (TP) concentrations at site Z.

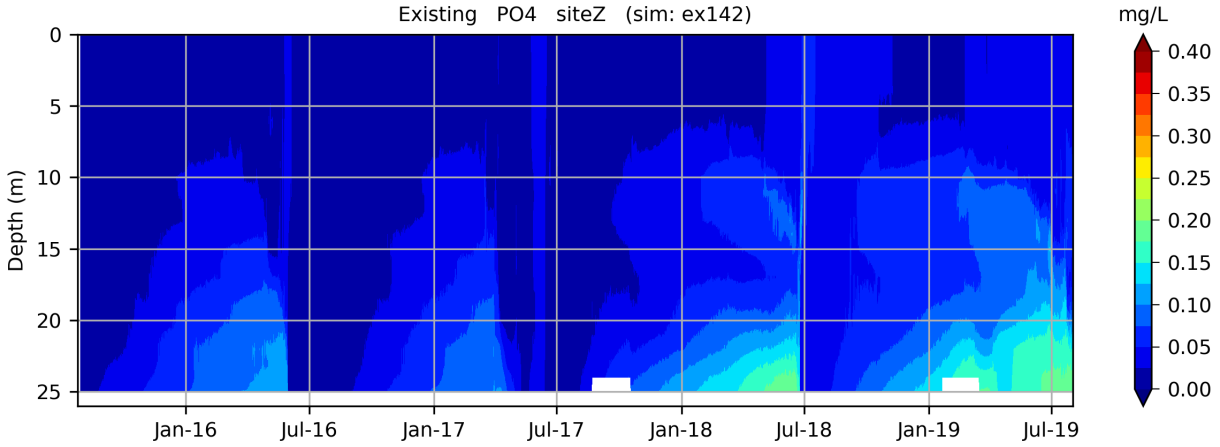


Figure 3.20 Simulated PO_4 concentrations at site Z.

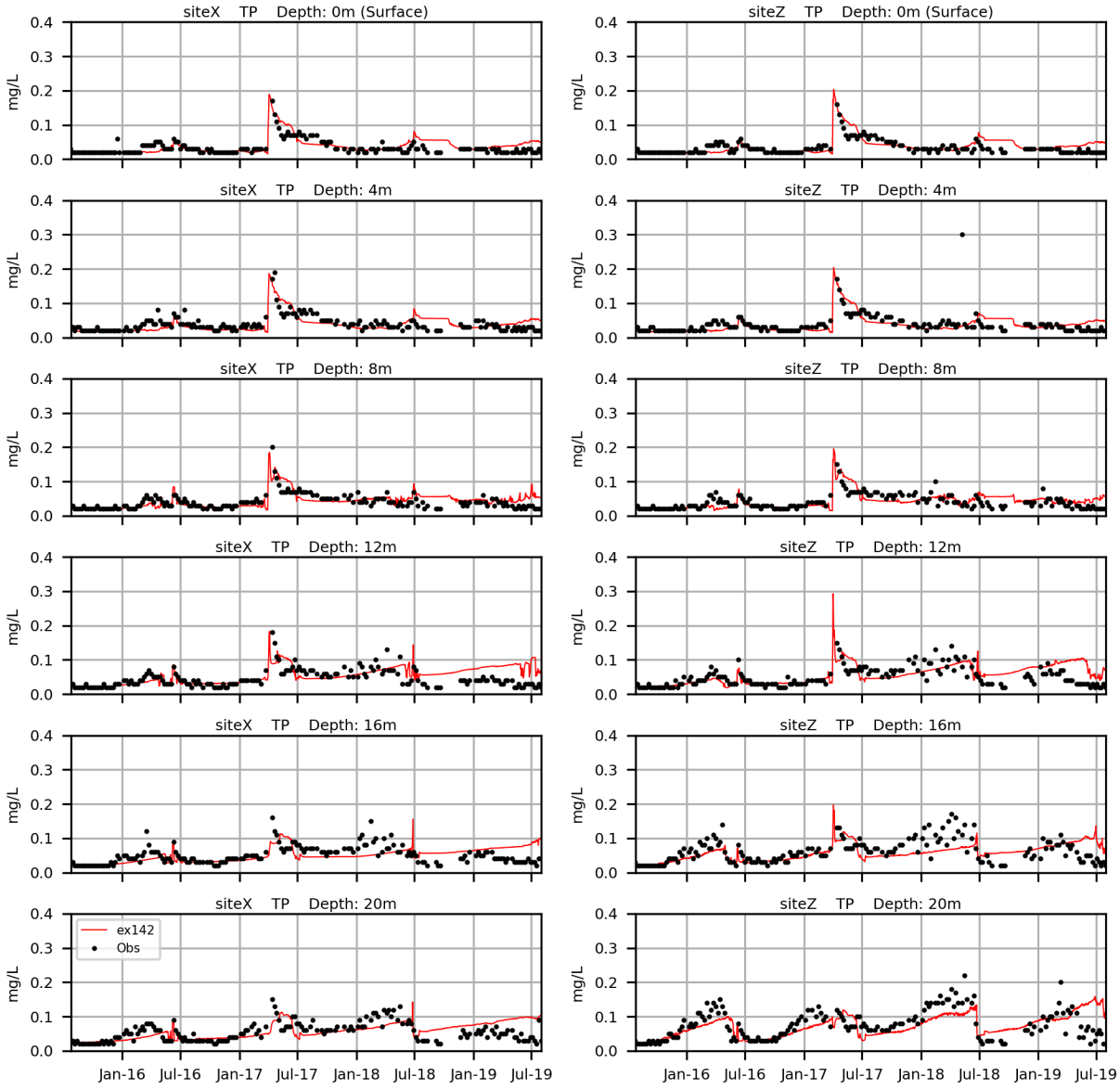


Figure 3.21 Comparison between observed (black dots) and simulated (red lines) total phosphorus (TP) concentrations at depths from site X (on the left) and site Z (on the right).

3.3.5 *Algae*

Simulated chlorophyte and cyanophyte growth (each output as chlorophyll a (Chl-a) concentrations) is illustrated in Figure 3.22. Growth of the cyanophytes occurs in the warmer summer months in the epilimnion reaching approximately 20-40 μg/L Chl-a. Simulated chlorophytes, which favour cooler waters, grow predominantly in spring when nutrients are available after winter mixing, with the highest concentrations simulated in the spring of 2018 (reaching 30+ μg/L) after the inorganic nutrients accumulated in the hypolimnion were mixed into the water column. Growth limitation functions derived by the model (see Section 3.1.4 for a description; see Figure 3.23) illustrate that for much of the simulation the growth rates of both algae groups are limited by the cool water temperatures and/or the availability of phosphorus.

The lack of simulated growth during the cooler months, as compared to the observations, occurs because the simulated phytoplankton assemblage only includes the two algae groups with modelled parameters that both favour growth in the spring and summer periods and thus are in competition with each other. It is likely that the complex assemblage of algae in CHD includes phytoplankton that undergo background levels of growth in the cooler seasons, thus maintaining Chl-a levels throughout the year. This modelling exercise focussed on the growth cycles of the dominant summer cyanophytes and therefore did not introduce the additional complexity of modelling more than two algae groups.

A qualitative comparison with the cell count data (Figure 3.24, top panel) demonstrates that the model does produce the distinct seasonal patterns in growth that are dominated by summer peaks in cyanophytes. The model also reproduces the differences between years. The most productive year occurred during the stratification of 2018/19 and was due to the increased availability of internally cycled phosphorus compared to earlier years. This is shown by an increase in the phosphorus limitation curve after mixing in mid-2018 (Figure 3.23).

Whilst the model reproduced a close correlation between observed cyanophyte counts and simulated cyanophyte Chl-a, the simulated (modelled) chlorophytes' peak only occurs in the spring, whereas the observed cell counts show a more persistent population over much of the year. As discussed above this is likely the result of the model being limited to only one particular chlorophyte configuration and not accounting for a more diverse assemblage that might be expected to reflect the full range of conditions experienced over the course of each year.

A further complication in modelling algae is illustrated by a comparison between the Chl-a and cell count data at the tower (Figure 3.25). The Chl-a data at the tower only shows a weak correlation, and at low concentrations only, to the growth cycles that are shown in the cell count data. The model, however, applies a constant Chl-a to biomass ratio for each of the groups, hence simulated increases in Chl-a directly represent a growth in cell numbers. The model does not take into account potential variation in the Chl-a composition that may occur between species in the same group or changes under different growth conditions. That is, the simulated Chl-a is more closely related to the measured cell counts and not the Chl-a concentration, *per se*.

By applying literature relationships between Chl-a and cell counts for cyanobacteria (Brient et al. 2008, Ahn et al. 2007, Kong et al. 2014) the modelled Chl-a can, however, be used to estimate

cell count (Figure 3.26) and can be used to show that the seasonal cycles and extent of cell counts derived from the model fall in the range of the observed counts.

Further, the slightly deeper mixing in the simulated surface layer (see Figure 3.7) indicates that the simulated algae are likely to occupy a deeper euphotic zone than observed. The timeseries of simulated Chl-a at the tower at 4 m (bottom of the surface layer) shows intermittent peaks and troughs in the Chl-a that relate to mixing periods at concentrations that are comparable to the observations (see bottom panel, Figure 3.24).

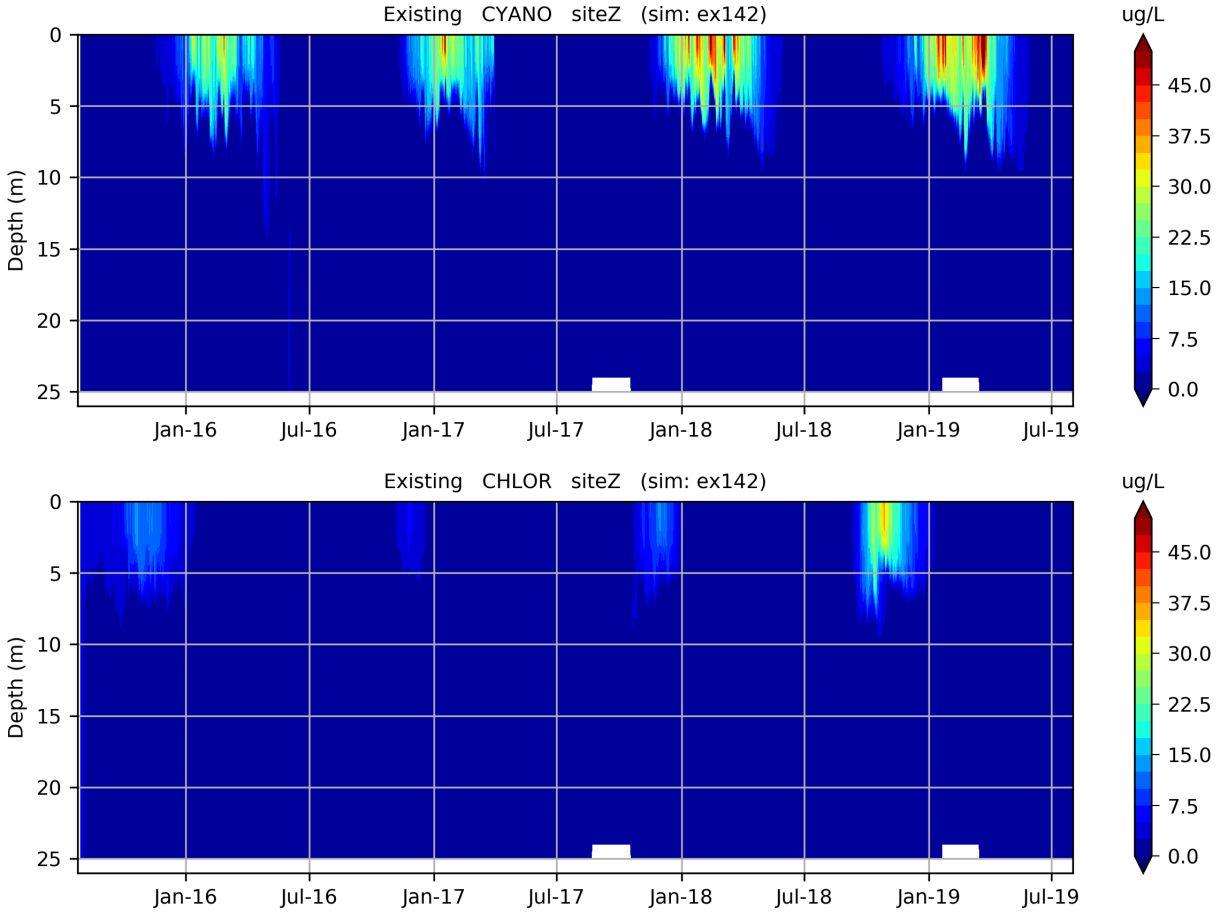


Figure 3.22 Simulated Chl-a contributions from cyanophytes (top panel) and chlorophytes (bottom panel) at site Z.

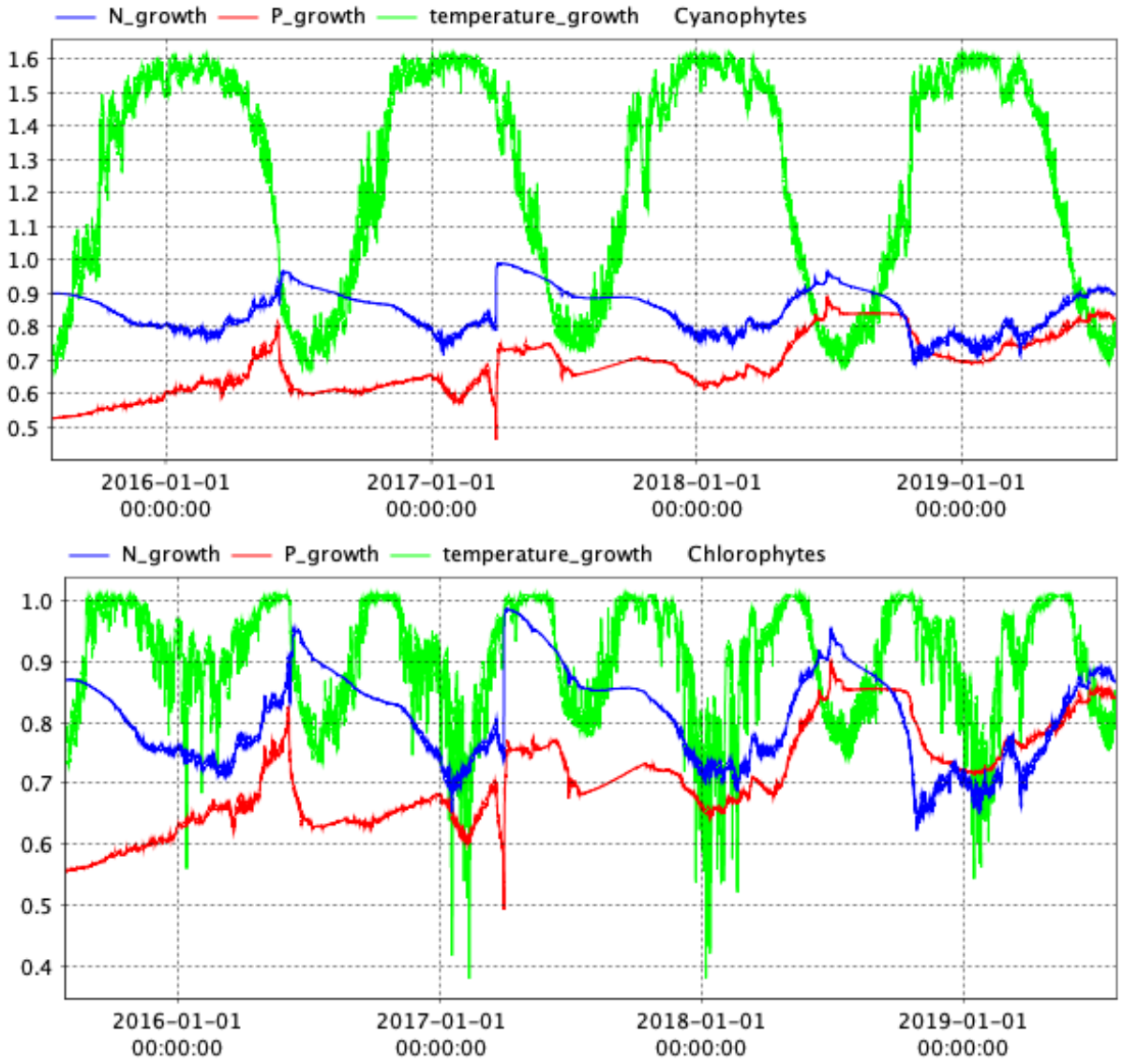


Figure 3.23 Growth limitation functions in the epilimnion for cyanophytes (top panel) and chlorophytes (bottom panel): temperature - blue, phosphorus- green, and nitrogen – red.

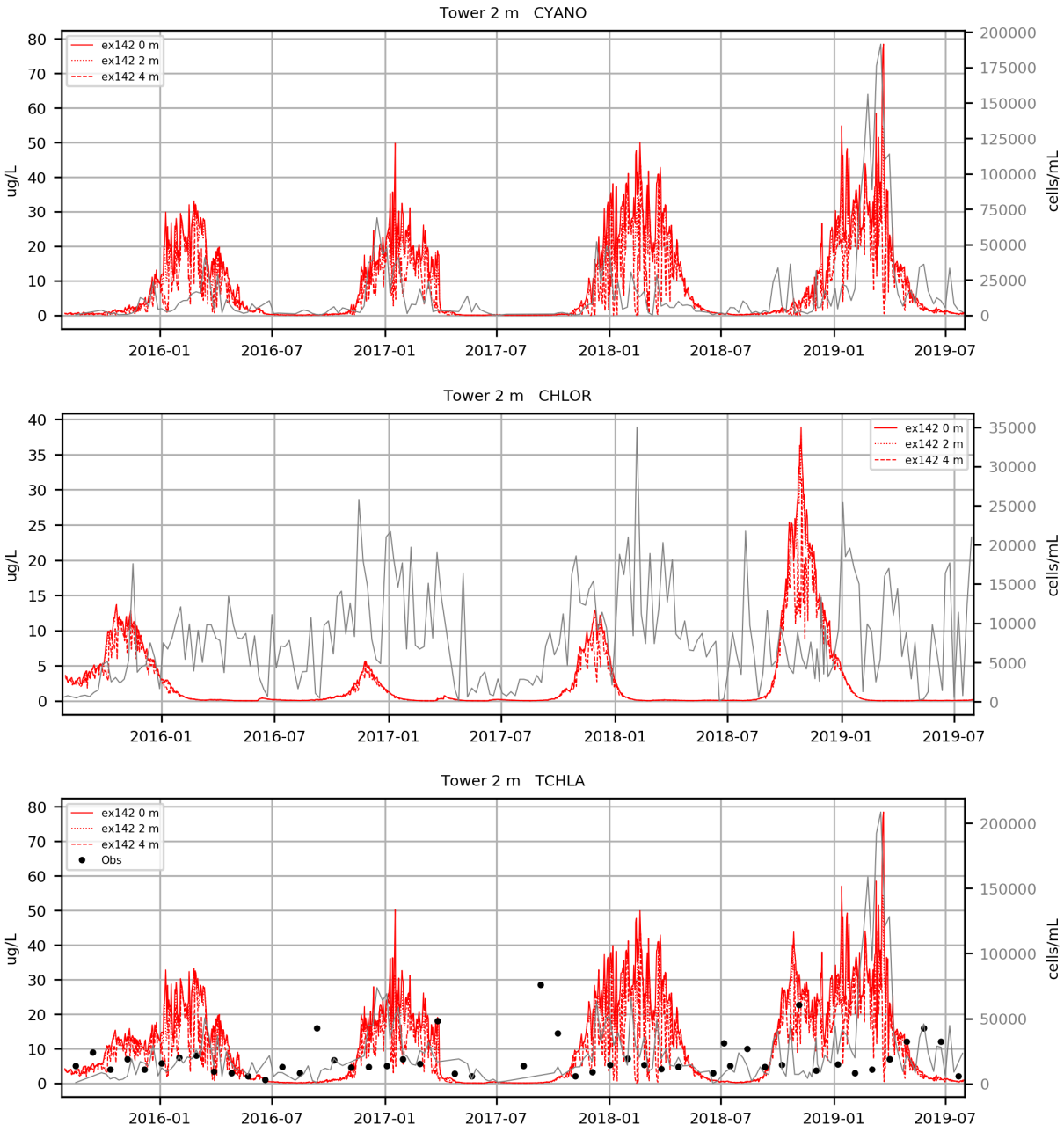


Figure 3.24 Simulated Chl-a contributions from cyanophytes (top panel, red) and chlorophytes (centre panel), total Chl-a (bottom panel, red), observed Chl-a (black symbols) and the observed cell counts (grey, right axis), at the tower at 2 m deep.

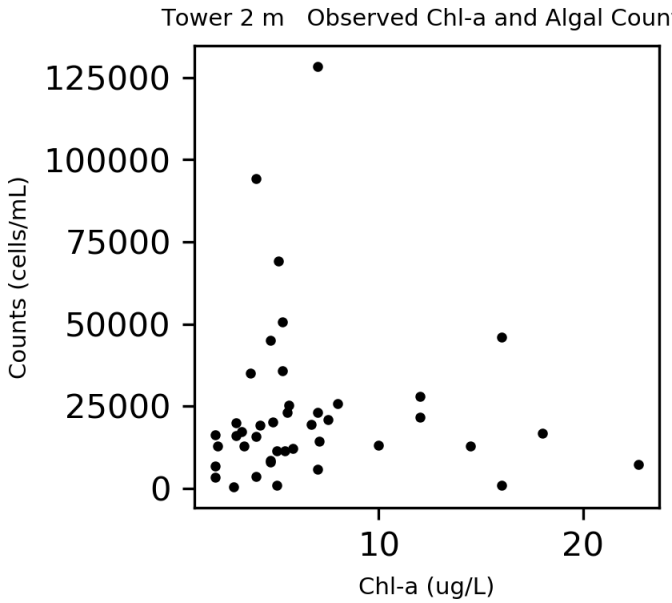


Figure 3.25 Observed Chl-a concentraions and algae cell counts at the tower at 2m deep.

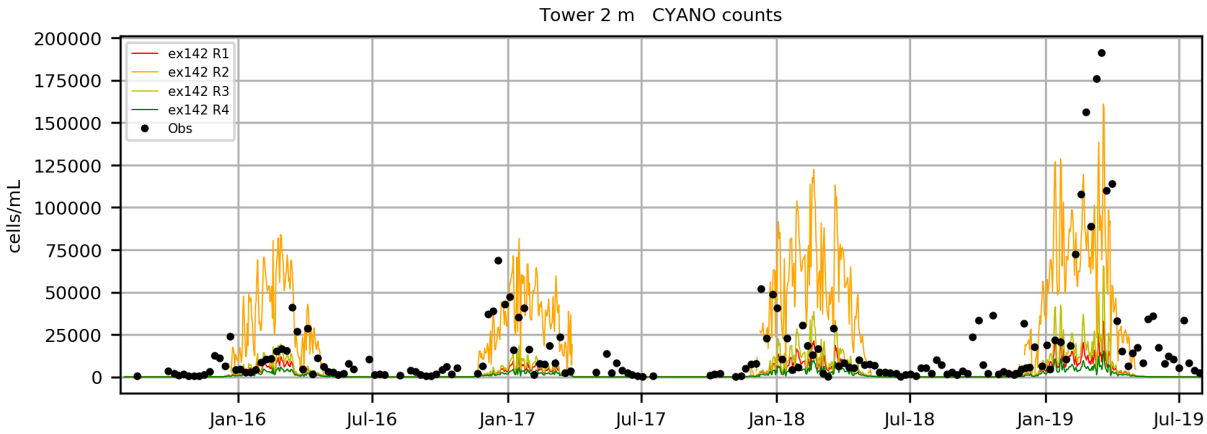


Figure 3.26 Cyanophyte cell counts (coloured lines) derived from simulated Chl-a and literature relationships (Brient et al. 2008 – R1, Ahn et al. 2007 – R2 and Kong et al 2014 – R3 + R4) compared to observed cell counts (black dots).

3.4 Model Sensitivity and Uncertainty

Where possible, default values or values from other studies (Table 3.1) have been used to assign model parameters. However, key biogeochemical parameters that specifically relate to sediment oxygen demand and phosphorus release are site-specific and these have been specifically addressed through a sensitivity assessment. Thus, increased bottom anoxia and increased sediment PO_4 release both increase the availability of P for phytoplankton growth in the euphotic zone. This in turn increases the predicted peak cyanophyte concentration, an important consideration in terms of potential Proposal outcomes.

Calibrated variables for these processes have therefore been derived using comparisons between data for DO, P and Chl-a and with consideration of the indirect effects of parameter selection.

During calibration of the model, the sensitivity of the model for these and other relevant parameters were tested for a range of input configurations and parameters. The calibrated value for each tested parameter and the range of tested values are summarised in Table 3.3 and reference is made to calibration charts presented in Appendix B.

The highest model sensitivity was related to the top-down effects of the meteorological forcing that influenced epilimnion depth and the extent of mixing. This is critical when the vertical grid resolution is sufficient to distinguish an accurate depth profile (i.e. ~ 0.5 m). This observation is important as the meteorological forcing is not locally recorded (i.e. the closest weather station is over 10 km away) and this carries uncertainty associated with how forcing may vary for the local conditions (as compared to the utilised BoM monitoring sites). In particular, the topographical setting of CHD is distinctly mountainous when compared to that at the BoM monitoring stations.

Despite these uncertainties, the calibrated results indicate that adjustments that have been made to account for this uncertainty provide results that adequately reproduce the observations.

Table 3.3 Model parameter values tested and the resultant response in the simulations.

Parameter	Calibrated Value	Values Tested	Result	Reference
Model Grid				
Horizonal spacing	90 m	30, 90	Smaller grid size increases vertical mixing but leads to excessive run times.	Appendix B Fig. 2.7 – 2.11
Vertical spacing in stratified region	0.5 m	0.5, 1.0	Larger cell heights produce weaker temperature gradients.	Appendix B Fig. 2.12
Physics				
Background PAR light extinction coefficient (K_d)	0.4 m^{-1}	0.2, 0.6, 1.0, 4.0	Lower values increase the penetration depth of PAR, heating the hypolimnion.	Appendix B Fig. 2.15 – 2.17

Parameter	Calibrated Value	Values Tested	Result	Reference
Wind speed factor	0.6	1.0, 0.8, 0.6	Decrease in wind speed reduces vertical mixing, which increases hypolimnion volume. However, lowest wind speed prevents deeper mixing.	Appendix B Fig. 2.13
Air temperature factor	0.9	1.0, 0.9	Decrease in air temperature reduces surface water temperature.	Appendix B Fig. 2.14
Biogeochemical				
Sediment release rate (PO_4-P) (P_{sed})	0.008 $g/m^2/day$	0.005, 0.01	Higher values increase TP in hypolimnion and orthophosphate at 2 m depth.	Appendix B Fig. 2.18-2.20
Sediment oxygen demand (DO_{sed})	1.5 $g/m^2/day$	1, 2	Higher values increase period of anoxia increasing phosphorus in water as above.	Appendix B Fig. 2.21-2.23

4 Scenarios

4.1 Overview

A series of scenario simulations were undertaken to assess the effect on temperature, dissolved oxygen, nutrients and algae for the raised dam and under different climate change conditions. The scenarios assume that the mixer is not operating. Scenario descriptions are as follows:

Current (CU)

This scenario incorporates the existing dam height, meteorology and inflow but incorporates a steady offtake rate of 40 ML/day for the duration of the simulation.

Raised Dam (RD)

The dam wall height is increased by 8.5 m (FSL at 70 m AHD) so the supply capacity is increased by an estimated 26,300 ML. The model bathymetry for the enlarged reservoir was created using GIS data provided by Eco Logical and is illustrated in Figure 4.1. Inflow boundary conditions were provided by the Eco Logical SOURCE model and calculations from Table 3.2 and included the creation of 3 new sub-catchments (by splitting an existing sub-catchment).

Climate Change (CC)

The climate change scenarios included the configuration of the raised dam with the addition of hydrological changes determined from the SOURCE model (Eco Logical, 2021) and meteorological changes that were applied based on meteorological climate change predictions (Table 4.1 and Eco Logical, 2021). The climate change scenarios were divided into the following set:

- **Climate Change Hydrology – High Flow (CCH High)** that incorporated high rainfall and flow predictions and current meteorological conditions;
- **Climate Change Hydrology – Low Flow (CCH Low)** that incorporated low rainfall and flow predictions and current meteorological conditions;
- **Climate Change Hydrology – High Flow and Met (CCHM High)** that incorporated high rainfall and flow predictions and meteorological conditions for the high flow predictions (see Table 4.1); and
- **Climate Change Hydrology – Low Flow and Met (CCHM Low)** that incorporated low rainfall and flow predictions and meteorological conditions for the low flow predictions (see Table 4.1).

Section 4.2 below describes some of the key processes that are predicted to change for the Raised Dam (RD) scenario. Section 4.3 describes the predicted changes for all the scenarios and highlights the key changes when compared to the current condition (CU).

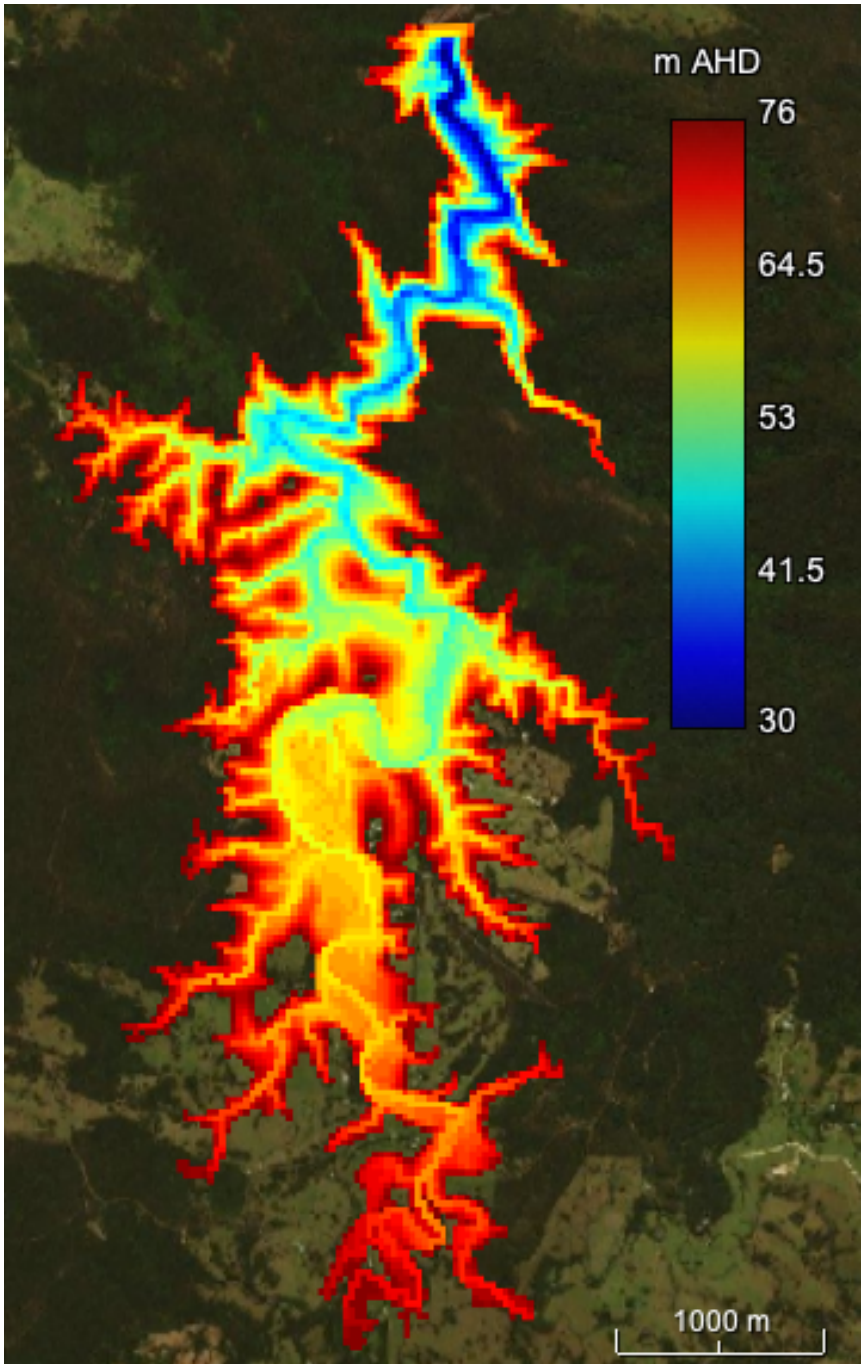


Figure 4.1 Model bathymetry of raised dam reservoir.

Table 4.1 Climate change factors for Low and High Rainfall cases.

	Low Rainfall Case				**High Rainfall Case**			
Season	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Air Temp.	11.3%	10.9%	16.0%	12.4%	8.1%	12.9%	21.1%	9.0%
Specific Humidity	14.1%	14.2%	9.4%	14.8%	15.9%	18.4%	24.7%	21.6%
Wind Speed	1.5%	-3.0%	0.9%	-2.0%	-0.4%	-0.6%	-7.9%	-6.3%

4.2 Raised Dam Scenario

The simulated raised dam scenario (RD) is compared to the current condition simulation (CU) in the section headers below.

4.2.1 *Temperature and Stratification*

Figure 4.2 shows that the raised (and hence enlarged) dam simulation follows similar cycles of stratification that exist in the current dam. The model suggests that the metalimnion deepens by 2-3 m which is likely to be the result of the significantly larger surface area exposed to convective and wind mixing processes.

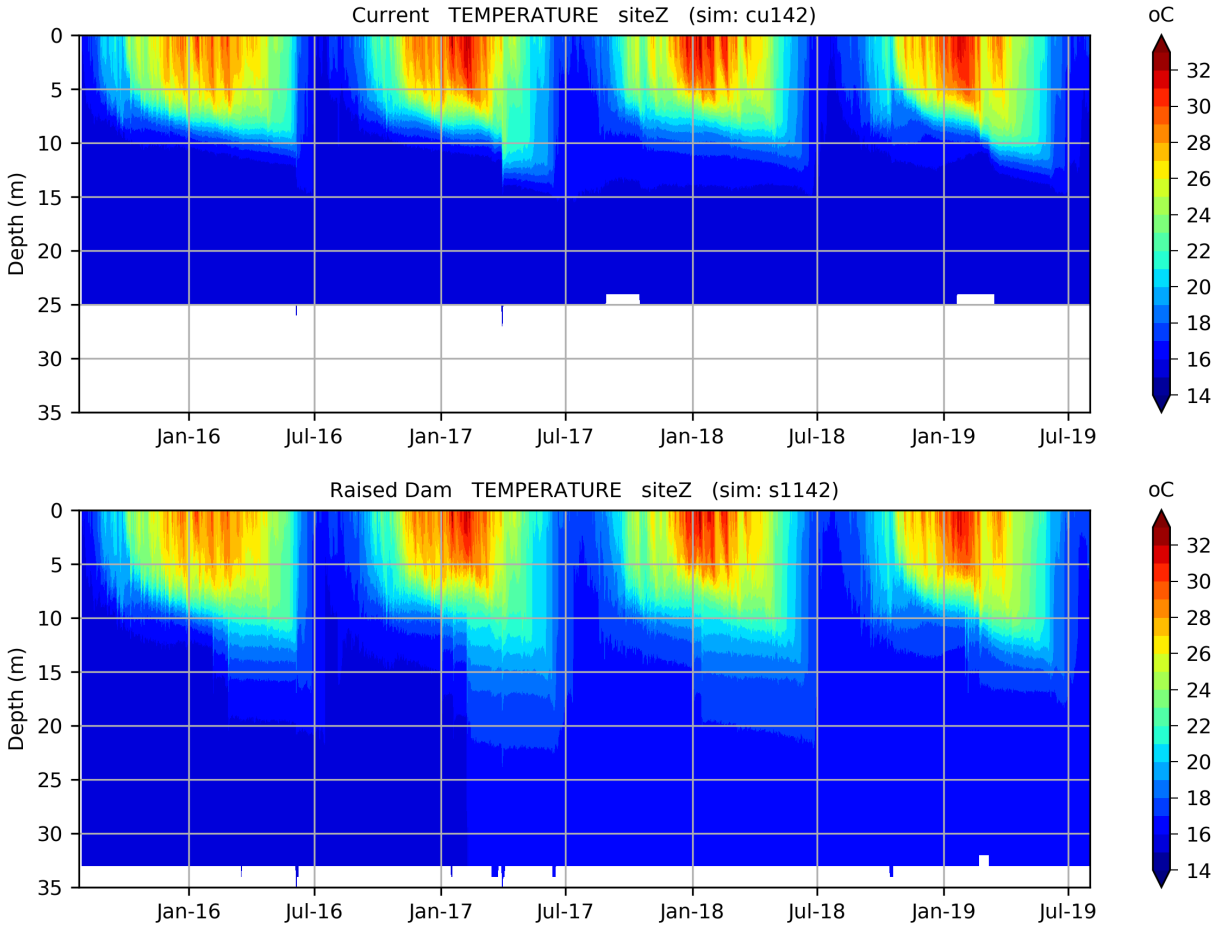


Figure 4.2 Simulated temperature for the Current scenario (top panel) and Raised Dam scenario (bottom panel).

The simulated retention time (Figure 4.3) demonstrates that the larger reservoir provides a buffer against flushing by inflows (see in particular March 2017) as large inflows become a smaller fraction of the total reservoir volume. The effect is that water age continues to rise over the duration of the simulation, indicating that the internal cycling of water quality parameters becomes increasingly important as the impact of the inflows diminishes.

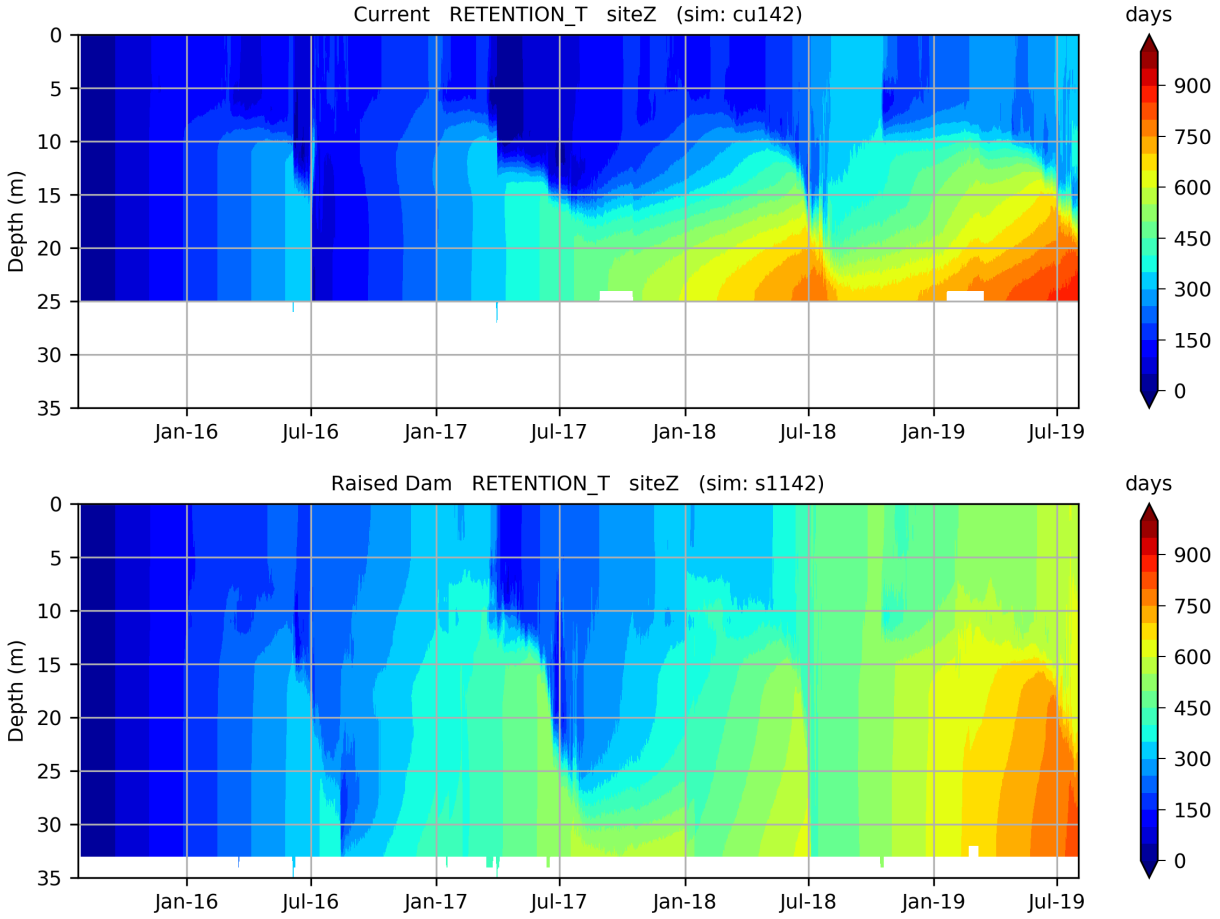


Figure 4.3 Simulated retention time for the Current scenario (top panel) and Raised Dam scenario (bottom panel).

4.2.2 *Suspended Solids*

Figure 4.4 illustrates that peak concentrations of suspended solids near the surface are likely to be greatly attenuated in the raised dam due to the increased dilution and travel time of the flows through the reservoir, which allows for greater settling out of particles. The results also demonstrate that peak concentrations are likely to be more localised within the vertical extent of the water column, as the sediment-laden plume mixes with a larger body of warmer water and adjusts to a height of neutral buoyancy as it propagates through the reservoir as an intrusion. Model results for the raised dam scenario indicate that these intrusion zones form in the metalimnion where the density gradients are highest.

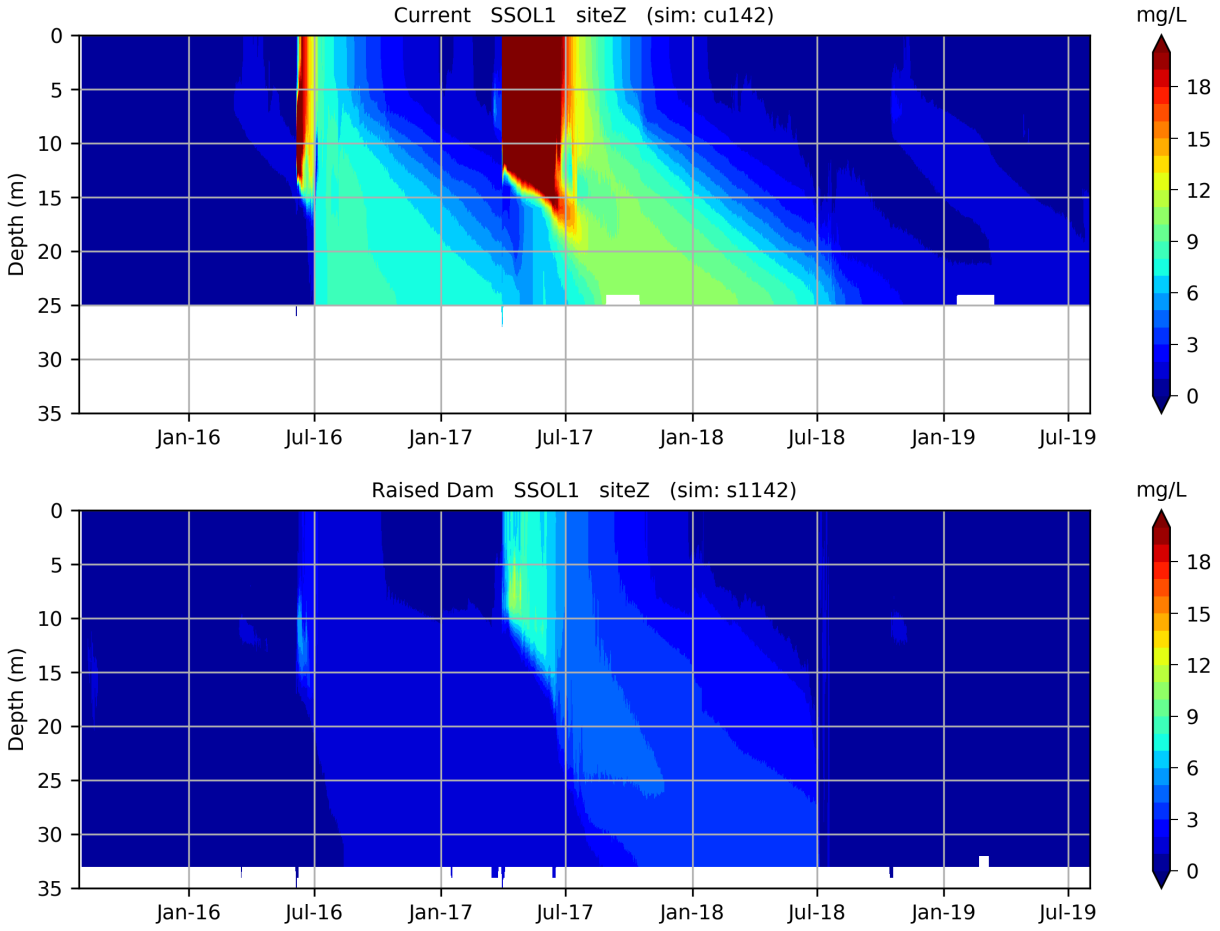


Figure 4.4 Simulated fine clay for the Current scenario (top panel) and Raised Dam scenario (bottom panel).

4.2.3 *Dissolved Oxygen*

Simulated DO concentrations (Figure 4.5) indicate that the oxycline may deepen slightly in the raised dam, as it adjusts with the deepening thermocline discussed above. However, these results need be considered with caution because of the potential for additional oxygen demand in the surface 5-10 m that arises from the decomposition of organic matter in the soil and vegetation following initial inundation. This process is not captured in the model and may decrease the oxygen concentrations in the surface waters, at least for an initial period until the increased oxygen demand of the newly inundated regions subsides.

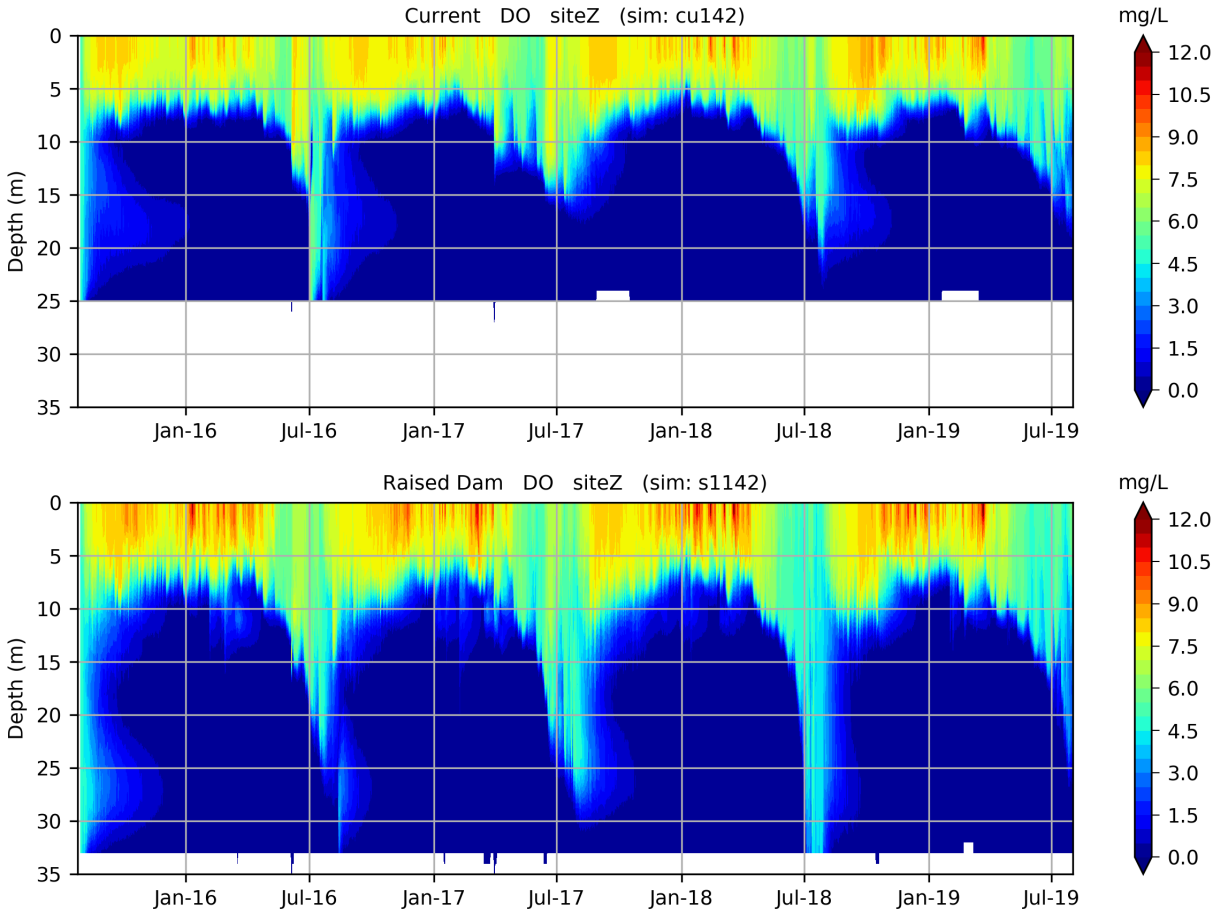


Figure 4.5 Simulated DO concentrations for the Current scenario (top panel) and Raised Dam scenario (bottom panel).

4.2.4 *Nutrients*

The current and raised dam scenarios indicate that despite the significant increase in the vertical extent of the hypolimnion in the raised dam, the hypolimnetic concentrations of TP and TN are predicted to decrease compared to the existing dam (see Figure 4.6 and Figure 4.7).

The rate of release of nutrients from the sediments is dependent on the sediment area that is exposed to low-oxygen or anoxic conditions. Whilst the sediment area exposed to low-oxygen or anoxic conditions is greatly increased in the raised dam scenario, the hypolimnetic volume is also increased so that the concentrations apparent in the raised dam hypolimnion are slightly lower. However, the overall internal loads are higher and during the mixing events that entrain nutrients into the epilimnion (the largest in July 2018) the simulated concentrations of phosphorus, in particular in the surface waters, are higher in the raised dam scenario.

A hypolimnion from 15 m deep to the bottom of the existing reservoir accounts for approximately 11% of the total volume of the reservoir. In contrast, a hypolimnion from 15 m deep to the bottom of the raised dam reservoir contains approximately 16% of the total reservoir volume. As a consequence, mixing of the hypolimnion with the remaining waters during winter in the raised dam results in higher hypolimnion-derived nutrient concentrations after mixing, as compared to the existing reservoir.

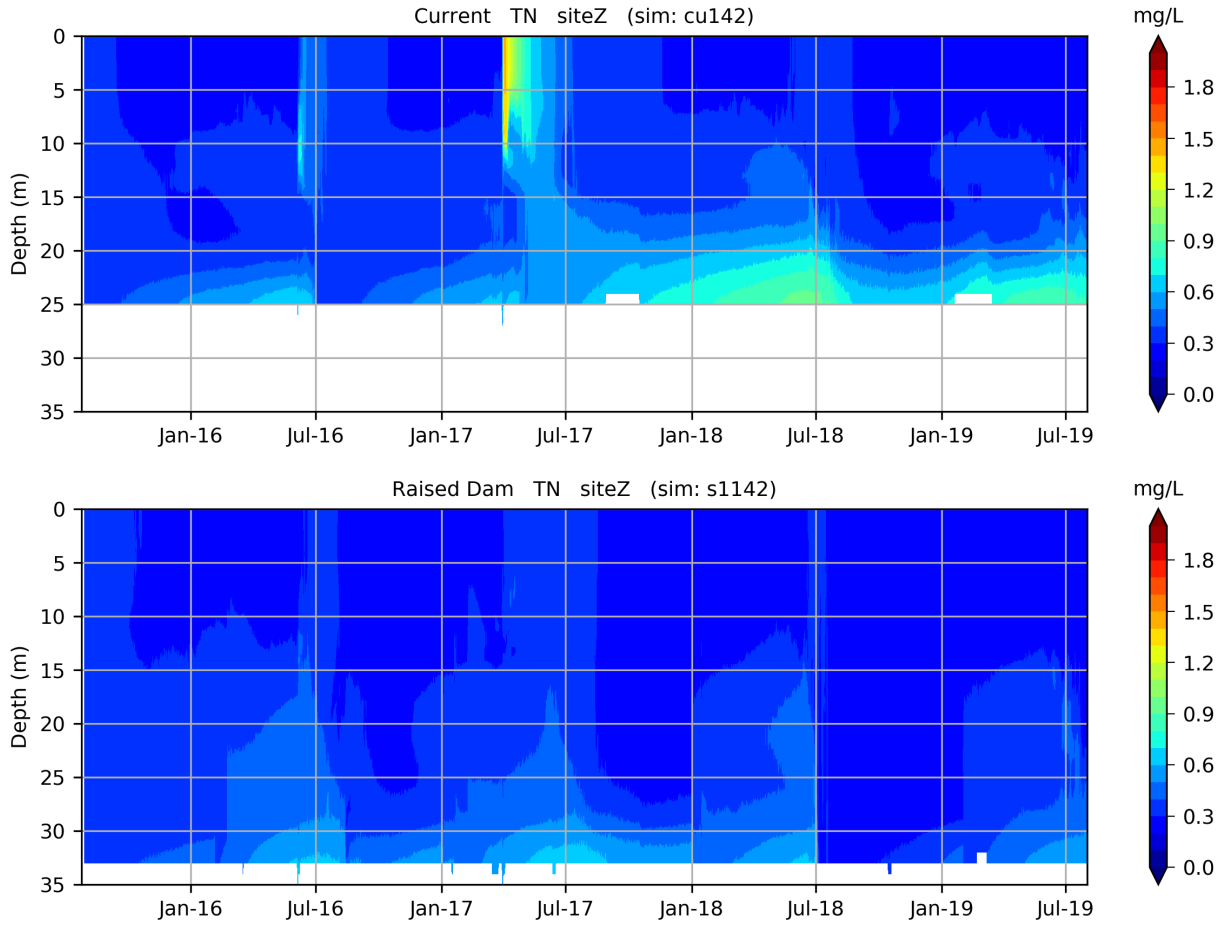


Figure 4.6 Simulated TN concentrations for the Current scenario (top panel) and Raised Dam scenario (bottom panel).

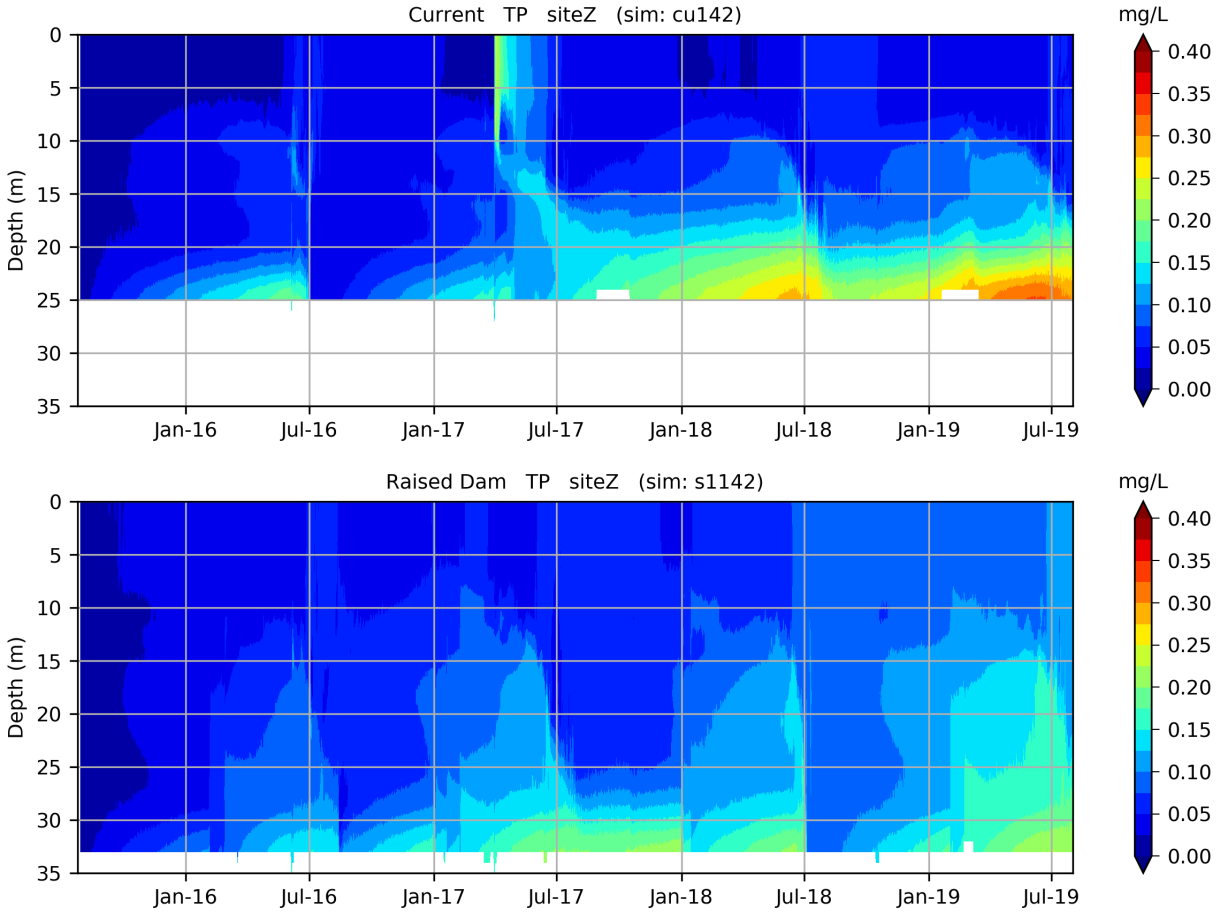


Figure 4.7 Simulated TP concentrations for the Current scenario (top panel) and Raised Dam scenario (bottom panel).

4.2.5 *Algae*

Simulated Chl-a concentrations for cyanophytes and chlorophytes (see Figure 4.8 and Figure 4.9) indicate that for the raised dam there is a predicted increase in the growth of algae. The increase is driven by the elevated availability of internal loads of phosphorus (see nutrient discussion above) in the surface waters, which alleviates phosphorus limitation on growth.

The simulated surface concentrations of PO_4 and the derived phosphorus limitation function (see Section 3.1.4, Figure 4.10) illustrate that over the duration of the simulation the algae growth is less inhibited by the availability of phosphorus in the raised dam scenario when compared to the current dam.

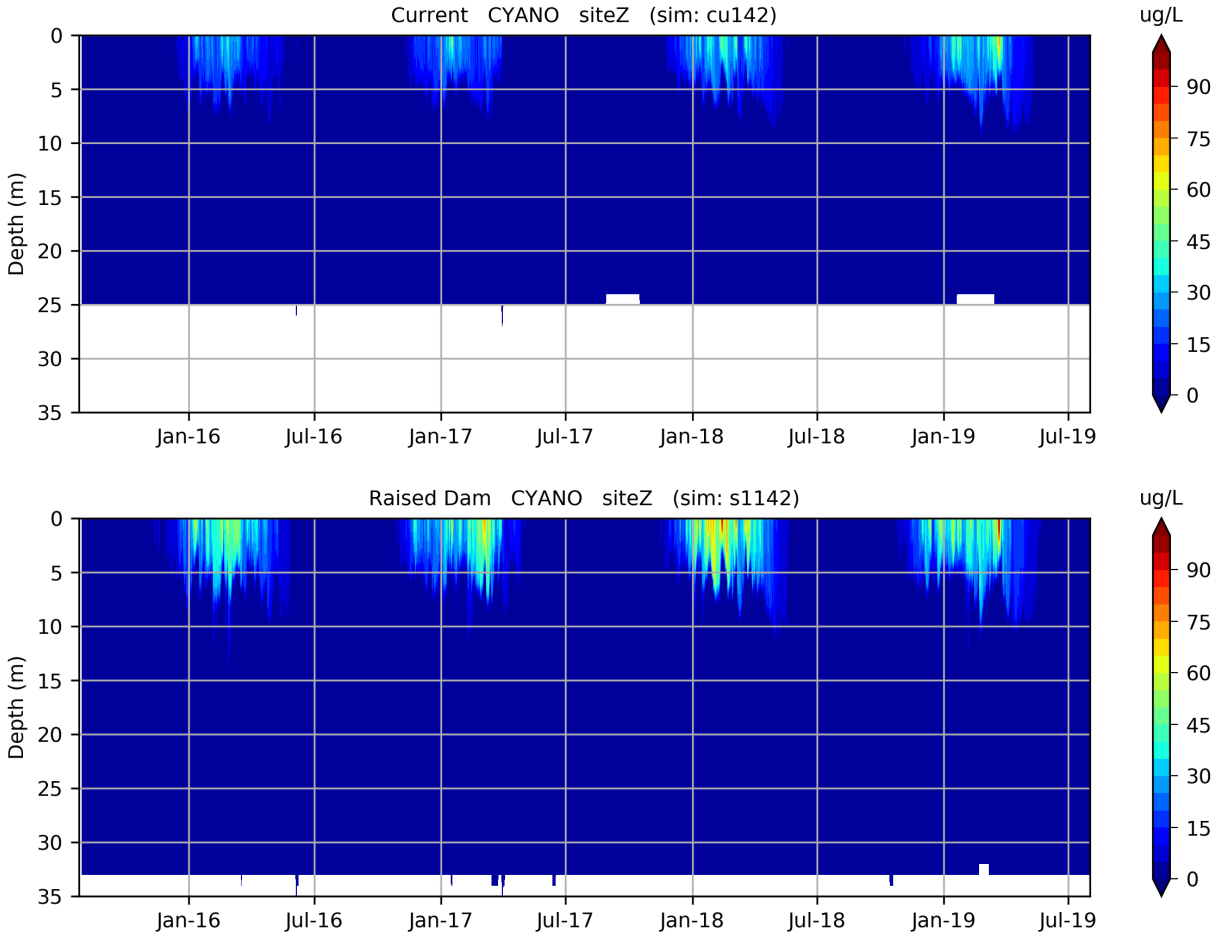


Figure 4.8 Simulated Cyanophytes Chl-a concentrations from for the Current scenario (top panel) and Raised Dam scenario (bottom panel).

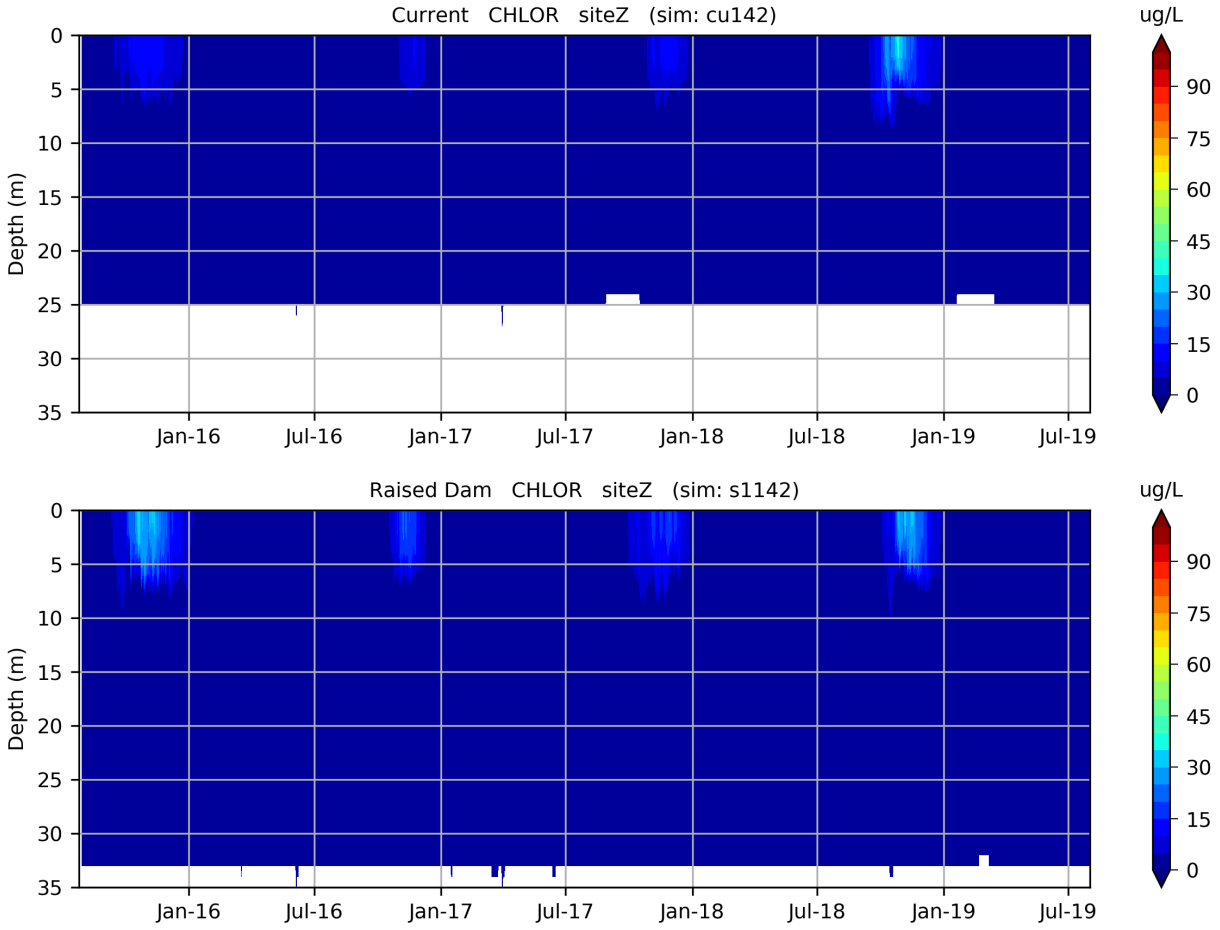


Figure 4.9 Simulated Chloropytes Chl-a concentrations from for the Current scenario (top panel) and Raised Dam scenario (bottom panel).

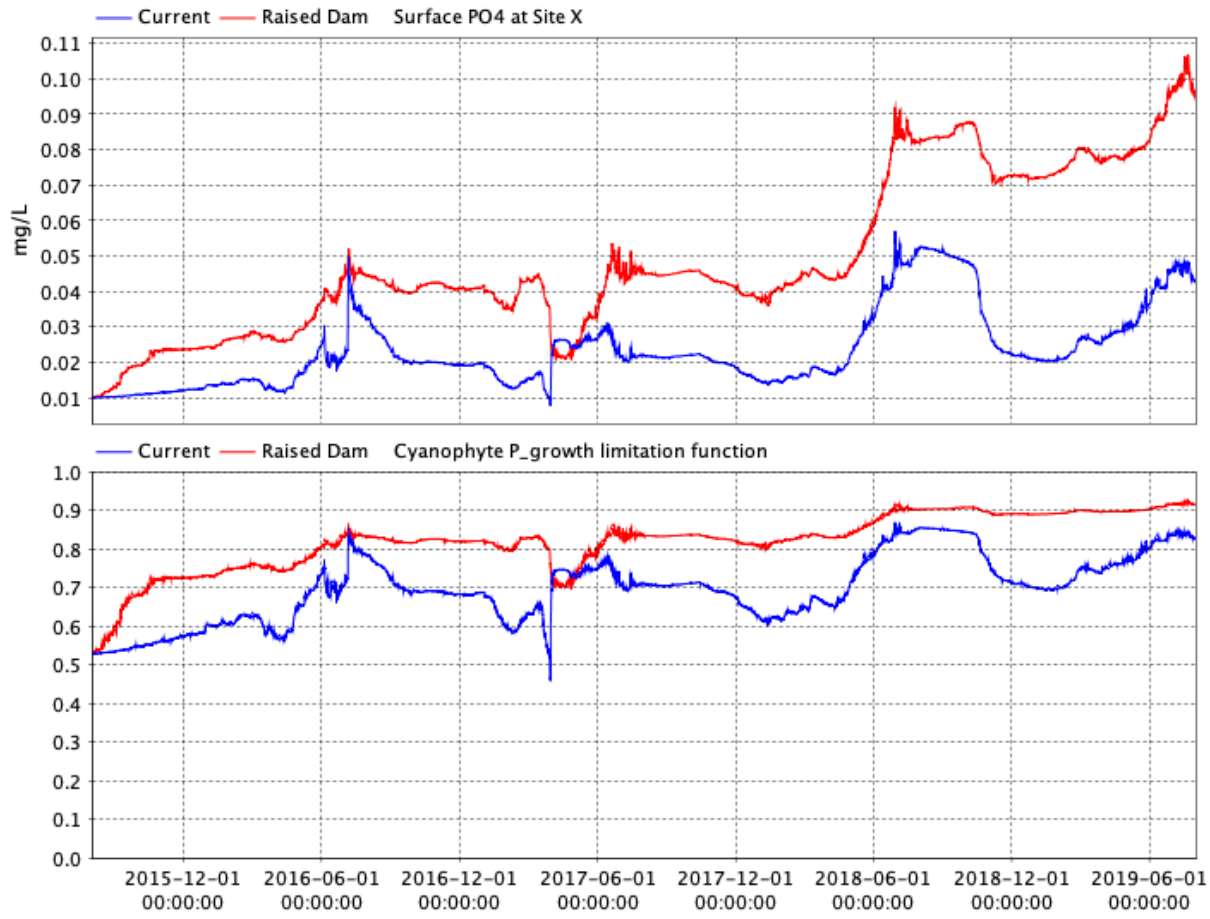


Figure 4.10 Simulated PO_4 and Cyanophytes growth limitation curves for biologically available phosphorus in the surface for the current (blue) and raised dam (red) scenarios.

4.3 Climate Change Scenarios

4.3.1 *Presentation of Results*

The scenario results are depicted below in terms of 5th percentile, mean and 95th percentile of the 4-year simulation results at the tower in approximately the surface of the epilimnion (2 m deep), the metalimnion (12 m deep), the hypolimnion (20 m deep) and near the bottom (30 m deep) for the raised dam scenarios. The 5th and 95th percentiles have been used to approximate the minimum and maximum values in the model timeseries, whilst removing potential outliers. The results compare the existing (EX) simulation (i.e. calibrated simulation with mixer operating in the first 2 years) to the six scenarios described in Section 4.1.

For some of the variables the results can be compared to derived water quality ANZECC trigger values for no significant adverse impact on freshwater lakes and reservoirs as applied to CHD (Hunter H_2O, 2018). The relevant values are:

- Chl-a concentration of 5 μg/L
- Dissolved Oxygen concentrations of 5 mg/
- Ammonium concentration of 0.01 mg-N/L
- NO_x concentration of 0.01 mg-N/L
- Total Nitrogen concentration of 0.35 mg-N/L
- Total Phosphorus concentration of 0.01 mg-P/
- Orthophosphate (PO_4) concentration of 0.005 mg-P/L
- Turbidity of 20 NTU.

Further analysis of the relationship between scenario outcomes and ANZECC trigger values are discussed in Section 5.1.

4.3.2 *Temperature*

Modelled temperature results (Figure 4.11) indicate minor increases in minimum, mean and maximum surface temperatures when the climate change meteorology is applied (i.e. simulations CCHMH and CCHML).

There is a significant decrease in mid-depth temperatures when comparing the existing to the current case which relates to the absence of the mixer in the current (CU) scenario. When compared to the current condition the raised dam (RD) scenario temperatures are higher at depth due to the deeper distribution of heat and increase further when the climate change meteorology is applied, in particular the mean and peak values at 20 and 30 m deep.

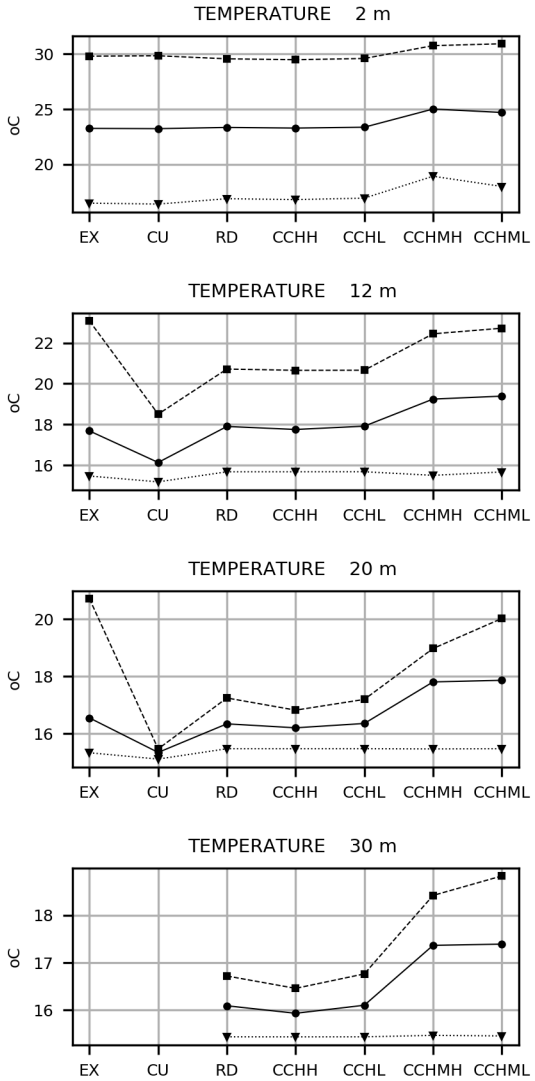


Figure 4.11 Scenario results for temperature at 2, 12, 20 and 30 m deep. Squares, circles and triangles indicate 5th percentile, mean and 95th percentile of the simulated value over the 4-year simulation period.

4.3.3 *Suspended Solids*

The suspended solids simulation results (Figure 4.12) indicate a significant decrease in peak and mean suspended solids concentrations as a consequence of raising the dam and increased dilution of inflow events that transport suspended solids through the reservoir. Peak values, and to a lesser extent mean values, increase for the high-flow climate change scenarios (CCHH and CCHMH) due to the increased size of the inflow events under these scenarios.

Using a TSS:NTU ratio of 0.85 (Grinham et al., 2012; Section 2.6.9) the simulated peaks in the surface of over 40 mg/L TSS in the existing and current scenarios equate to a turbidity values of over 47 NTU, which is consistent with previous records (Hunter H_2O, 2018) and above the ANZECC trigger value of 20 NTU. In the raised dam scenarios, these peak values drop below the trigger values of 20 NTU.

The mean values remain significantly lower for all the scenario simulations which is consistent with the low background levels and event-based nature of the suspended solids increases.

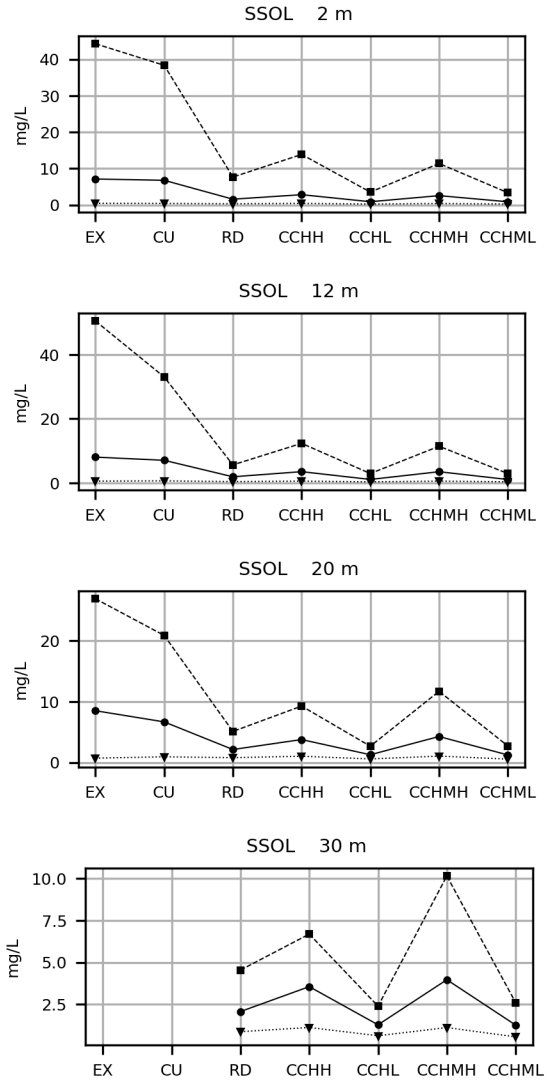


Figure 4.12 Scenario results for suspended solids concentrations at 2, 12, 20 and 30 m deep. Squares, circles and triangles indicate 5th percentile, mean and 95th percentile of the simulated value over the 4 year simulation period.

4.3.4 *Dissolved Oxygen*

Modelled dissolved oxygen concentrations (Figure 4.13) in the surface and metalimnion are relatively consistent for the scenario simulations. The largest differences occur at 20 m and below, with DO peaks in the current (CU) simulation supressed at 20 m compared to the existing and raised dam scenarios. This is due to reduced mixing to depth under the current scenario compared to the existing case (with mixer) and the raised dam scenario.

All simulations indicate that at the surface DO concentrations are consistently at or above the 5 mg/L trigger value, with mean values of approximately 7 mg/L. At 12 m deep only the peak DO concentrations (during winter mixing) are above the trigger value. At 20m and deeper (for the raised dam scenarios) the mean concentrations approach zero, but due to regular winter mixing generally remain slightly above zero.

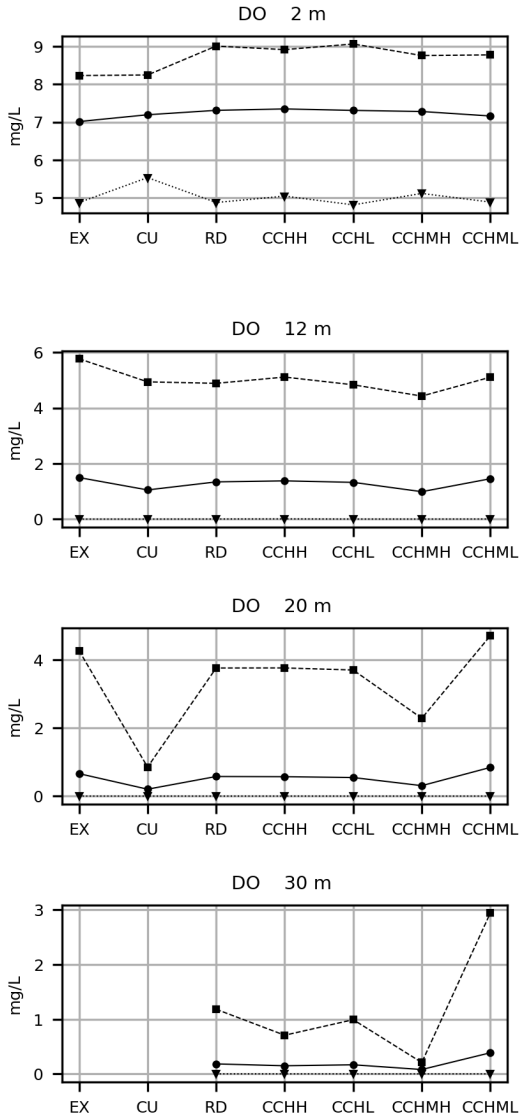


Figure 4.13 Scenario results for dissolved oxygen concentrations at 2, 12, 20 and 30 m deep. Squares, circles and triangles indicate 5th percentile, mean and 95th percentile of the simulated value over the 4 year simulation period.

4.3.5 *Nutrients*

Scenario simulations show that total nitrogen concentrations (Figure 4.14) decrease when the dam is raised, due to the dilution of the large inflow events that typically lead to peaks in total nitrogen. The higher-flow climate change scenarios slightly increase the total nitrogen, due to the larger inflow loads.

Peak total nitrogen values are predicted to be in excess of 0.5 mg/L near the surface for the existing (EX) scenario, which is above the trigger value of 0.35 mg/L, but this may reduce such that peak concentrations are similar to the trigger value under all other scenarios. Reductions are less below 12 m with mean values around the trigger concentration.

The model results indicate less change in the nitrate and ammonium concentrations between the scenarios (Figure 4.15). Whilst the peak values near the surface are consistently above the trigger values of 0.01 mg/L for both forms of nitrogen, the mean values of ammonium are approximately at the trigger value, whereas the mean nitrate value are sustained above the trigger value. At 12 m and below the nitrate concentrations decrease and the ammonium concentrations increase.

Total phosphorus (TP) and orthophosphate (PO_4) scenario simulation results are shown in Figure 4.16. Whilst peaks in TP remain similar for all the simulations and above the trigger values of 0.01 mg/L, the mean values increase in the raised dam scenarios as a result of the increase in internal loading (see Section 4.2.4) and are increased further for the low-flow climate change scenario because of the increased role of internal loading in the lower flow periods. This trend is evident at 12 m but below this the TP concentrations across the scenarios remain similar with the exception of the existing case, presumably indicating that the mixers may play a role in reducing TP concentrations in the deeper waters. Orthophosphate concentrations increase in the surface and mid-depth when the dam is raised and in all other scenarios the mean and peaks exceed the trigger value of 0.005 mg/L, which is consistent with observed values (Hunter H_2O, 2018).

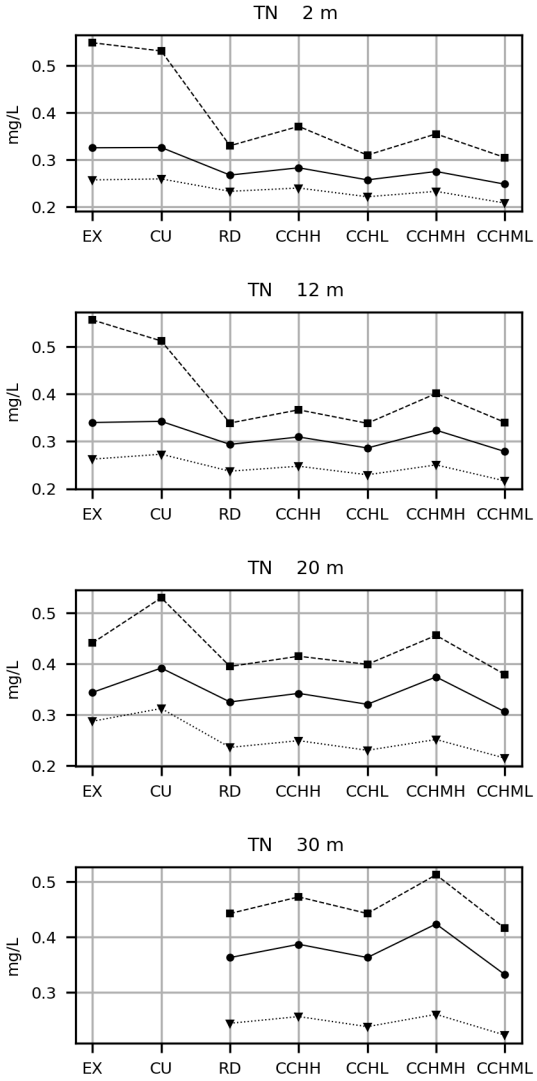


Figure 4.14 Scenario results for total nitrogen concentrations at 2, 12, 20 and 30 m deep. Squares, circles and triangles indicate 5th percentile, mean and 95th percentile of the simulated value over the 4 year simulation period.

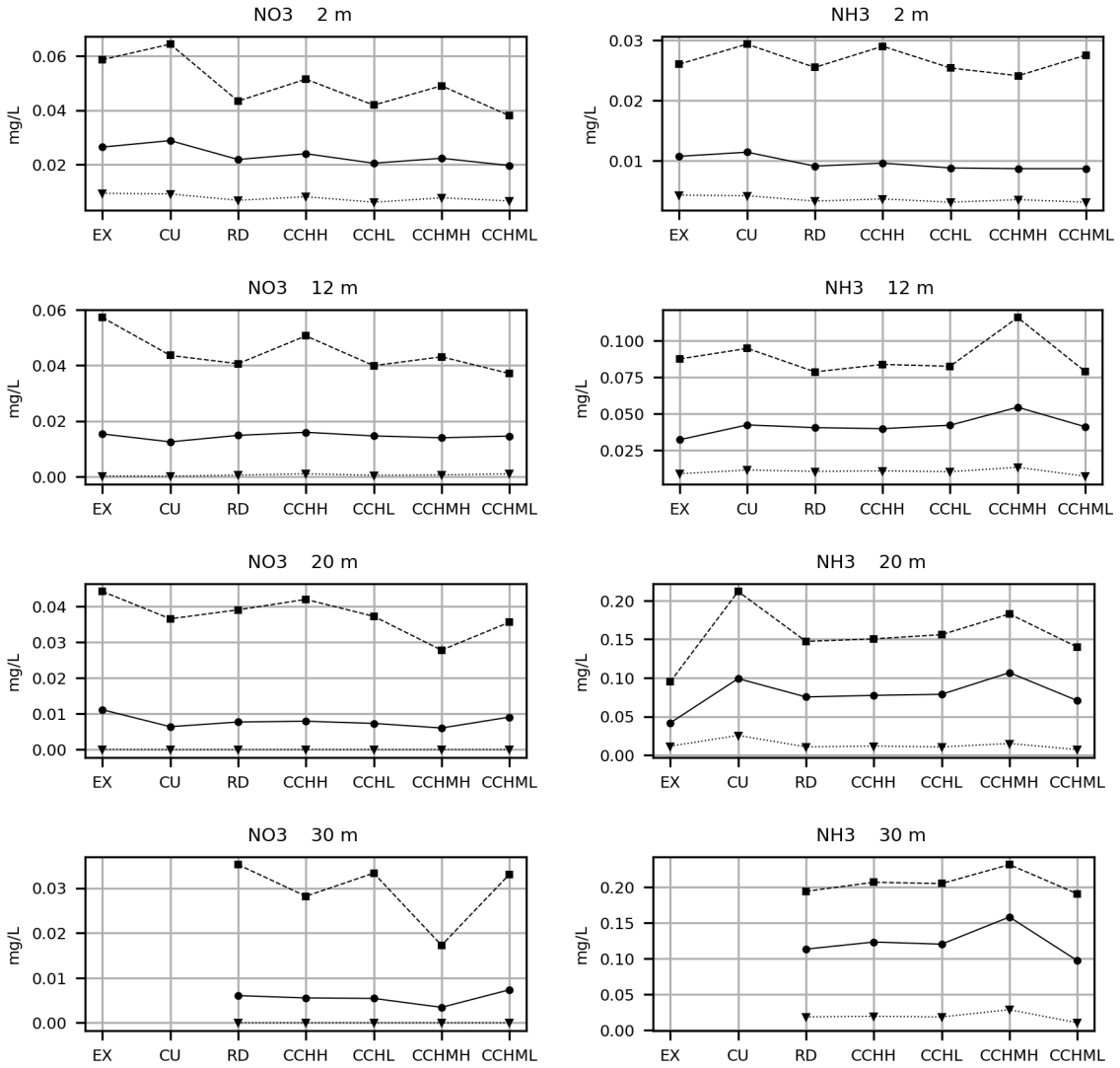


Figure 4.15 Scenario results for nitrate (left) and ammonium (right) concentrations at 2, 12, 20 and 30 m deep. Squares, circles and triangles indicate 5th percentile, mean and 95th percentile of the simulated value over the 4-year simulation period.

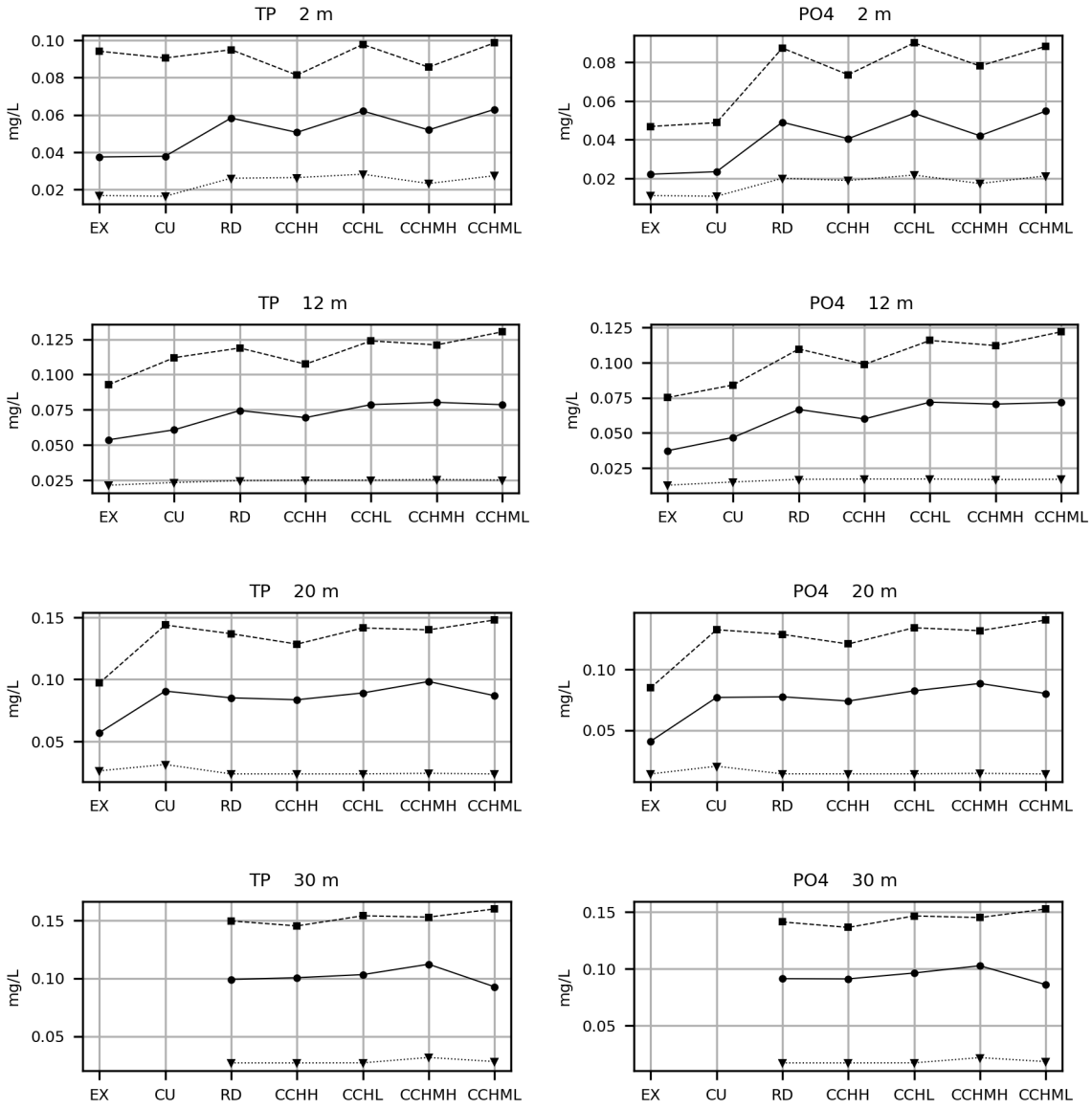


Figure 4.16 Scenario results for total phosphorus (left) and orthophosphate (right) concentrations at 2, 12, 20 and 30 m deep. Squares, circles and triangles indicate 5th percentile, mean and 95th percentile of the simulated value over the 4-year simulation period.

4.3.6 *Algae*

Figure 4.17 illustrates the Chl-a concentration contributions from cyanophytes at chlorophytes for the different scenario simulations at the surface and at the offtake.

The results at the surface indicate a significant increase in peak values for both groups as a result of the increased dam height. Peak cyanophyte concentrations increased by approximately 50% and chlorophytes by 60%. Mean values changed only marginally owing to the highly seasonal growth periods over the warmer months. Climate change scenarios indicated higher peaks for the lower flow scenarios, which is consistent with the higher availability of orthophosphate. The combined mean values are consistently higher than the trigger value of 5 µg/L and the peaks are considerably higher, which is consistent with current observations (Hunter H_2O, 2018).

Chl-a concentrations in the offtake are much reduced compared to near the surface with mean values less than the trigger value and peak values slightly higher than the trigger value.

The simulated chlorophyte Chl-a concentrations show a large reduction in peak values (and smaller reduction in mean values) for the meteorological climate change scenarios. This reduction is correlated with increased water temperatures (see Figure 4.11) and indicates that the changing reservoir conditions are reducing the simulated chlorophyte concentrations by limiting the period over which growth rates are optimised.

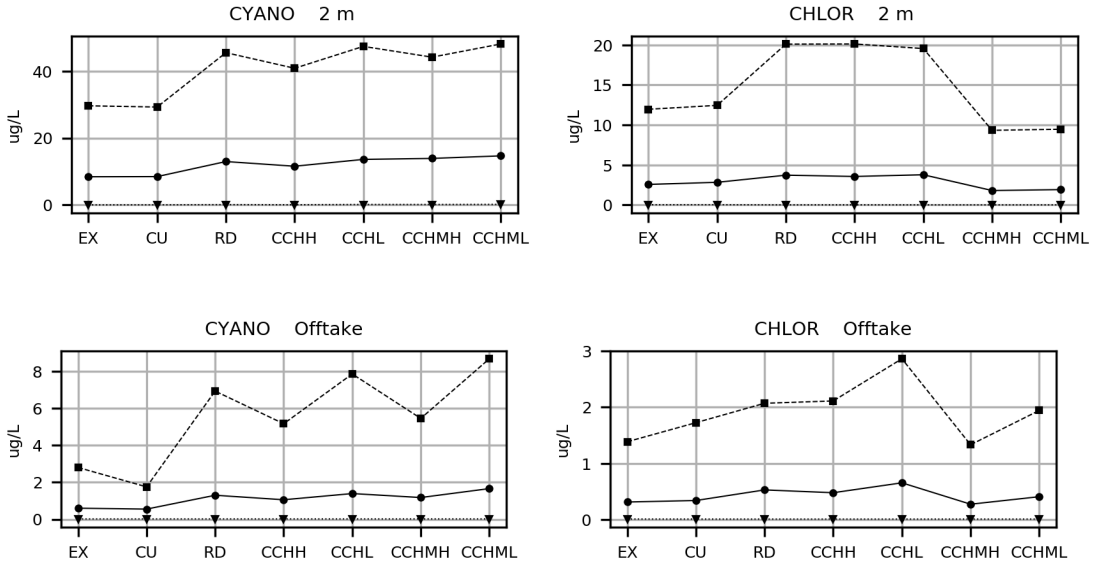


Figure 4.17 Scenario results for cyanophytes (left) and chlorophytes (right) Chl-a concentrations at 2m deep and at the offtake. Squares, circles and triangles indicate 5th percentile, mean and 95th percentile of the simulated value over the 4-year simulation period.

5 Impact on Water Quality

5.1 Comparison with ANZECC Trigger Values

Table 5.1 provides a summary of the predicted WQ parameter values for the raised dam scenarios which are compared to the observations that have been recorded between March 2013 and December 2019 and to the ANZECC Guidelines Trigger Values (following the previous assessment of CHD water quality documented by Hunter H_2O, 2018). The trigger values referred to are those documented for Freshwater Lakes and Reservoirs (ANZECC & ARMCANZ, 2000).

Observed and simulated mean and 95th percentile (5th percentile for DO) values are shown for 2 m, 8 m and 20 m deep. The 2 m observed values are those from the tower and the 8 and 20 m deep observations are from nearby Site X. The simulated values are from Site X. Both the mean values and the 95th percentile values (5th percentile for DO) are tabulated to indicate the average water quality and the poorest 5th percent of water quality condition. The simulated worst-case values (i.e. highest concentrations of nutrients, chlorophyll-a and turbidity and the lowest DO concentrations; see the final 3 columns on the right) have been extracted as the poorest water quality outcome for each metric (variable, statistic and depth) from the different scenario results described in Section 4.3. This provides a measure of the full range of outcomes and is not biased by the selection of one scenario to represent all variables.

Amber coloured entries in Table 5.1 denote values that are above the ANZECC trigger value, or in the case of DO, below the trigger value. These values indicate that the observed water quality in the reservoir is on average above the trigger values (below for DO) with the exceptions of TN at 2 m deep and turbidity (at 2, 8 and 20 m deep). The 95th percentile (5th percentile for DO) are above (below for DO) the trigger values for all variables with the exception of turbidity at 2 m deep, which is just below the trigger value of 20 NTU.

The results illustrate that the average predicted DO concentrations for the raised dam is likely to be below (for DO, 'below' the trigger value is a poor outcome) the trigger value of 5 mg/L at 8 and 20 m deep, which is consistent with observations. The 5th percentile concentration scenario simulation results indicate that there are likely to be events during which the concentrations at 2 m are also below the trigger value.

The observed average turbidity at 2, 8 and 20 m and 95th percentile turbidity at 2 m deep are below the trigger value of 20 NTU. However, the 95th percentile of observed values at 8 and 20 m exceed the trigger value. The increased dilution of inflow water in the raised dam scenarios suggest the turbidity associated with terrestrial inputs from inflows will on average, and for the 95th percentile, be below the 20 NTU trigger value. However, it is important to note that high algae concentrations will likely elevate the observed turbidity in the raised dam, particularly near the surface. This is because predicted turbidity is derived only from the simulated sediment concentrations and does not include the contribution from algae and organic debris.

The raised dam scenario results indicate that whilst there is a predicted decrease in the average and 95th percentiles of simulated concentrations of NH_4 and NO_x near the surface the simulated concentrations remain at or above the trigger values, with the exception of simulated NO_x at 20 m, which is below the trigger value. However, the predictions for the average and 95th percentile

of TN concentrations drop below the trigger value of 0.35 mg-N/L with the exception of concentrations at 20 m deep and 95th percentiles of the worst-case simulation concentrations at 2, 8 and 20 m. Based on the comparison with observations of NH_4 and NO_x at 2 m deep (there are no deeper observations) the scenario results indicate a potential reduction in concentrations as a result of raised dam.

Observed TP and PO_4 concentrations are also greater than the trigger values of 0.01 and 0.005 mg-P/L, respectively, and the scenario results indicate that these concentrations are likely to increase further. This occurs because of the increased contribution from internal loading of P from the sediments for the raised dam and the lack of artificial mixing imposed in the scenario simulations (as discussed in Section 4.3.5).

Observed chlorophyll-a concentrations are on average above the trigger value of 5 (μg/L) near the surface (2 m deep). The scenario predictions indicate an approximate two-fold increase in mean chlorophyll-a concentrations at 2 m deep. At 8 and 20 m deep, however, the predicted mean concentrations are below the trigger value. The 95th percentile concentrations at both 2 m and 8 m exceed the trigger values. As discussed in Section 4.2.5 the predicted increase in the availability of PO_4 in the raised dam is the driving factor for increased growth, with some variation introduced in the scenarios by the different climate change predictions (see Section 4.3.6).

Table 5.1 Summary of observations and scenario outputs with reference to the ANZECC trigger values. See table notes on following page.

WQ Variable (units)	**ANZECC Trigger Value**		**Observed (Mar 2013- Dec 2019)** [1]			**Raised Dam Scenario**[2]			**Worst Case**[2,3]		
		Depth (m)	2	8	20	2	8	20	2	8	20
Chl-a (μg/L)	5	mean	6.93	N/A	N/A	16.4	1.89	0.08	17.1	2.07	0.17
		95th%	16.8	N/A	N/A	48.1	8.19	0.20	49.1	9.1	0.74
Dissolved Oxygen (DO)[4] (mg/L)	5	mean	5.31	1.54	0.88	7.29	4.15	0.58	7.14	3.34	0.31
		5th%	0.9	0	0	4.84	1.24	0	4.80	0.55	0
Ammonium (NH_4) (mg-N/L)	0.01	mean	0.04	N/A	N/A	0.01	0.014	0.075	0.01	0.018	0.107
		95th%	0.102	N/A	N/A	0.026	0.034	0.147	0.029	0.049	0.183
Oxidised Nitrogen (NO_x) (mg-N/L)	0.01	mean	0.035	N/A	N/A	0.022	0.022	0.008	0.024	0.024	0.009
		95th%	0.092	N/A	N/A	0.043	0.043	0.039	0.052	0.051	0.042
Total Nitrogen (TN) (mg-N/L)	0.35	mean	0.338	0.48	0.491	0.267	0.269	0.325	0.283	0.285	0.375
		95th%	0.462	0.852	0.73	0.329	0.331	0.395	0.37	0.366	0.457
Orthophosphate (PO_4) (mg-P/L)	0.005	mean	0.022	N/A	N/A	0.049	0.053	0.077	0.055	0.06	0.088
		95th%	0.02	N/A	N/A	0.087	0.088	0.129	0.09	0.096	0.141
Total Phosphorus (TP) (mg-P/L)	0.01	mean	0.037	0.035	0.048	0.058	0.062	0.085	0.063	0.067	0.098
		95th%	0.07	0.07	0.09	0.095	0.097	0.137	0.098	0.105	0.148
Turbidity[5] (NTU)	20	mean	5.49	9.35	11.9	1.85	2.06	2.51	3.31	3.75	5.01
		95th%	19.4	43.4	46.4	9.01	8.67	5.99	16.4	17.2	13.7

Table 5.1 Notes:

[1] Observed values are shown in the following order: 2 m deep at the tower, 8 m deep at Site X and 20 m deep at site X. Records indicated below detection limit are considered at detection limit for purpose of generating statistics.

[2] Simulation results are shown in the following order: 2 m deep at Site X, 8 m deep at Site X and 20 m deep at site X.

[3] Each worst-case statistic is identified from one of simulations RD, CCHH, CCHL, CCHMH and CCHML independently at each depth.

[4] Observed DO concentrations at 2 m are taken from Site X (DO data was not available at the tower).

[5] Simulated turbidity is estimated from relationship Turbidity (NTU) = 1.18 x TSS (mg/L) following Grinham et al. (2012).

5.2 Key Potential Risks

The observational data presented in Table 5.1 illustrates that current water quality conditions in CHD (with the exception of turbidity) generally do not comply with ANZECC Guidelines and exceed Trigger Values. Consideration of these existing water quality conditions and their commensurate potential risks were not investigated for this study. Consideration below is made of the potential risks that relate directly to the predicted changes to the existing water quality as a result of raising the dam wall.

The key potential risk associated with the raising of the dam wall that has been identified through the scenario modelling results is an increase in primary production. Modelling results illustrate that the increase in primary production is supported by an increase in the availability of PO_4 through sediment release in the enlarged hypolimnion of the raised dam. In terms of trigger values this means a predicted increase in concentrations of TP, PO_4 and Chl-a, compared to the currently observed values.

Compounding this risk is the prediction that cyanophytes (blue-green algae), which are currently dominant during the summer months, may become more dominant throughout the year as a result of climate change impacts (in particular the direct and indirect impacts of increased air temperature).

Whilst metal species iron and manganese were not modelled in this study (as there is insufficient observational data to provide realistic calibration) the increased hypolimnion size and likely sustained anoxia of the hypolimnion suggests that, like PO_4, there is the potential risk that the dissolution of sediment-bound metals into the reservoir waters may increase for the raised dam.

In addition, but also not included in the modelling assessment, there is the risk that for at least some period immediately after filling the raised dam, there may be depleted dissolved oxygen in the surface waters due to the decomposition of organic matter from inundated vegetation and soils. This is likely to have short-term implications for establishing the desired raised-dam ecology and the period over which this impact may be experienced has not been assessed.

5.3 Potential Risk Mitigation Strategies

5.3.1 *Artificial Mixing*

Observations show (Section 2.6.2) that previously installed mixing devices in CHD have been somewhat effective in redistributing temperature gradients and have weakened, but not eliminated, thermal stratification. The overall performance of the mixers, however, has proven unsatisfactory and Hunter H_2O (2018) conclude from the monitoring data that:

- Complete thermally destratified conditions cannot be maintained by the mechanical mixer
- Stable and sufficient dissolved oxygen concentrations throughout the water column cannot be maintained
- Low and stable iron and manganese concentrations cannot be maintained
- Low and stable cyanobacterial populations cannot be maintained.

Given the increased depth of the raised dam and the predicted increase in internal loading of nutrients from the hypolimnion under anoxic conditions is it considered unlikely that a destratification system with the specifications of the previous system will effectively mitigate the water quality risks that have been identified.

Alternative destratification systems should be investigated for application in the raised dam with the objectives of breaking down the thermal stratification (through complete mixing if feasible) and reducing, or eliminating, hypolimnetic anoxia. This, in turn, will decrease internal loading of nutrients (and potentially metals) and aim to decrease primary productivity or, more importantly, the prevalence of cyanophyte populations. Importantly, the mixing needs to be sufficiently vigorous to sustain a supply of oxygen to depth that can overcome the rate of dissolved oxygen loss to the sediments and organic matter and reduce, or eliminate, stratification near the surface. This will in turn disrupt the euphotic layer and counteract stable warm surface waters that are typically advantageous to cyanophytes over other algae.

The details of design of an effective system would need to be carefully investigated in terms of the air flow rates, diffuser location and type (line or point) and the operational processes such as full year or seasonal operation.

Because of the multiple objectives for the measure of effectiveness of the mixer and previous observations in CHD with the mechanical type mixer, focus should be placed on implementation of a bubble diffuser type destratification system.

5.3.2 *Tower Offtake Selection*

The risk of extraction of poor-quality water can potentially be managed with the adaptive use of tower gates to extract water with fit-for-use water quality from different depths. Alternatively, poor-quality water might be removed from the reservoir via controlled extraction from selected depths.

The proposed intake tower has the flexibility to allow selection of off-take water at 3 m depth intervals, providing the means to adaptively alter the off-take depths to account for seasonal changes in water quality, or in response to adverse events. High concentrations of algae in waters near the surface during summer, for example, might require extraction from below the epilimnion, or avoiding extraction of low dissolved oxygen, high nutrient and high metal concentration water by extracting water from above the hypolimnion.

As the seasons change, or in the event of large inflows or prolonged low-flow drought, the depth of the layer of most suitable water quality for extraction may vary and would depend on whether destratification systems are operating or not.

The modelling results for the raised dam scenarios suggest that extraction depths between 7 and 9 m below the surface can, on average, avoid the high concentrations of algae, but typically have low to very low DO concentrations and elevated phosphorus (see Table 5.1, indicated by 8 m deep data points).

Optimal extraction depth will differ with the introduction of a destratification system and with seasonal changes. Further, there may be continuous changes to water quality during the early months to years after filling that are induced by the decomposition of organic matter from inundated vegetation and soils. High-frequency and potentially automated monitoring is recommended to be introduced as part of the ongoing management of the raised dam. This data would provide a basis for ongoing assessment of water quality changes, efficacy of destratification systems and adaptive selection of offtake depth (see Section 5.4 below).

5.4 Instrumentation and Monitoring

Additional monitoring is recommended to assess the changes in water quality that arise in the raised dam and to support an assessment of the efficacy of destratification and adaptive selection of offtake gate heights. For the purpose of water quality in terms of the variables considered in this report, specific additions include remote instrumentation and additional sample analysis as described below.

1. Remote telemetered instrumentation (either a chain or profiler) should be deployed to measure at high frequency (sub-daily) the temperature, turbidity, dissolved oxygen, pH, conductivity and Chl-a at the deepest point in the reservoir nearest to the offtake tower. This provides an ongoing up-to-date picture of the stratification and basic water quality in response to seasons and to events and can assist with the selection of offtake gates to avoid poor quality water.
2. Additional water quality analysis should be undertaken for PO_4, NO_x, NH_4 and metals at multiple depths through the water column to the full depth of the reservoir, at or near the same site as the remote instrumentation, with samples taken at least on a monthly basis. This provides a means to understand the nutrient processes occurring through the water column and different water quality changes between the epilimnion, metalimnion and hypolimnion that respond to DO concentrations. Coupled with the instrumentation data this additional sample data provides a means to better assess the success of (and optimize the operation of) a destratification system targeted at modifying these DO dependent water quality variables.

6 SEARS Outcomes

Table 6.1 and Table 6.2 provide a tabulated reference to the key SEARS and Departmental issues that relate to water quality in CHD reservoir and are addressed in this report.

Table 6.1 Relevant Key Issue SEARs for CHD reservoir assessment

SEARs Desired Performance Outcome	Relevant Requirements	Result
6. Climate Change Risk	2. The Proponent must quantify specific climate change risks with reference to the NSW Government's climate projections and incorporate specific adaptation actions in the design.	Climate change projections applied to climate inputs and incorporated into CHD reservoir scenarios. Refer to Section 4.3
9. Hydrology, Flooding and Water Quality	6. The Proponent must describe background conditions for current operations and any water resource likely to be affected by the proposal, including:	
	(a) existing surface and groundwater quality	Potential increase in phosphorus, iron, manganese and chlorophyll-a concentrations in Clarrie Hall Dam. Refer to Section 5.1 and 5.2.
	(b) frequency and quality of dam discharges including for environmental flows	Potential increase in phosphorus, iron, manganese and chlorophyll-a concentrations in water released downstream. Refer to Section 5.1.
	(e) water quality monitoring programs and indicators and trigger values/criteria.	Recommendations for additional instrumentation and monitoring. Refer to Section 5.4
	7. The EIS must assess the impacts of the proposal on water quality, including the nature and degree of impact on receiving waters for both surface and groundwater	Potential increase in phosphorus, iron, manganese and chlorophyll-a concentrations in Clarrie Hall Dam. Refer to Section 5.1 and 5.2.

Table 6.2 Relevant Key Department Issues for CHD reservoir assessment

Department of Industry (NSW) comments on SEARs	**Relevant Requirements**	**Result**
Management of Environmental Flows and Dam Releases	Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.	Potential increase in phosphorus, iron, manganese and chlorophyll-a concentrations in Clarrie Hall Dam. Recommendations for destratification system and variable tower offtake. Refer to Section 5.1, 5.2 and 5.3.
OEH standard environmental assessment	**Relevant Requirements**	**Result**
Water and soils	11. The EIS must describe background conditions for any water resource likely to be affected by the Clarrie Hall dam raising project, including:	
	a. Existing surface and groundwater.	Background conditions assessment and comparison to trigger values. Refer to Section 2.6 and 5.1.
	c. Water Quality Objectives (as endorsed by the NSW Government including groundwater as appropriate that represent the community's uses and values for the receiving waters.	Comparison of modelling outcomes against ANZECC trigger values for CHD waters. Refer to Section 5.1.
	d. Indicators and trigger values/criteria for the environmental values identified at (c) in accordance with the ANZECC (2000) Guidelines for Fresh and Marine Water Quality and/or local objectives, criteria or targets endorsed by the NSW Government.	Comparison of modelling outcomes against ANZECC trigger values for CHD waters. Refer to Section 5.1.
Transport for NSW standard environmental assessment requirements	**Relevant Requirements**	**Result**
Water - Quality	(a) state the ambient NSW Water Quality Objectives (NSW WQO) and environmental	Comparison of existing conditions against ANZECC trigger values for CHD waters.

	values for the receiving waters relevant to the proposal, including the indicators and associated trigger values or criteria for the identified environmental values;	Refer to Section 5.1.
	(d) assess the significance of any identified impacts including consideration of the relevant ambient water quality outcomes;	Potential increase in phosphorus, iron, manganese and chlorophyll-a concentrations in Clarrie Hall Dam and associated risk. Refer to Section 5.2
	(i) identify proposed monitoring locations, monitoring frequency and indicators of surface and groundwater quality.	Recommendations for additional monitoring. Refer to Section 5.4

7 References

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Appendix A: Observational Data

A.1. Water Quality Data

A.1.1. Temperature

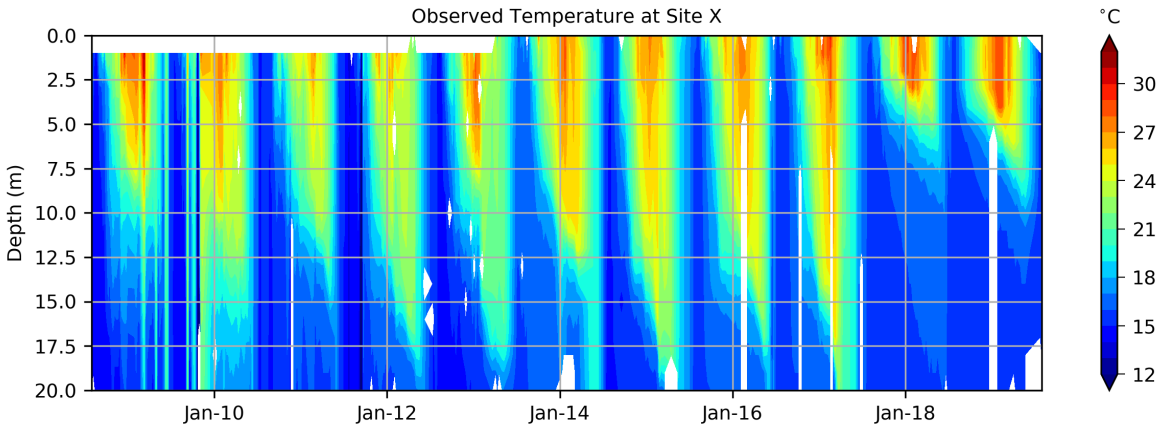


Figure A.1 Water temperature measurements from profiling in CHD at Site X during August 2008 to August 2019.

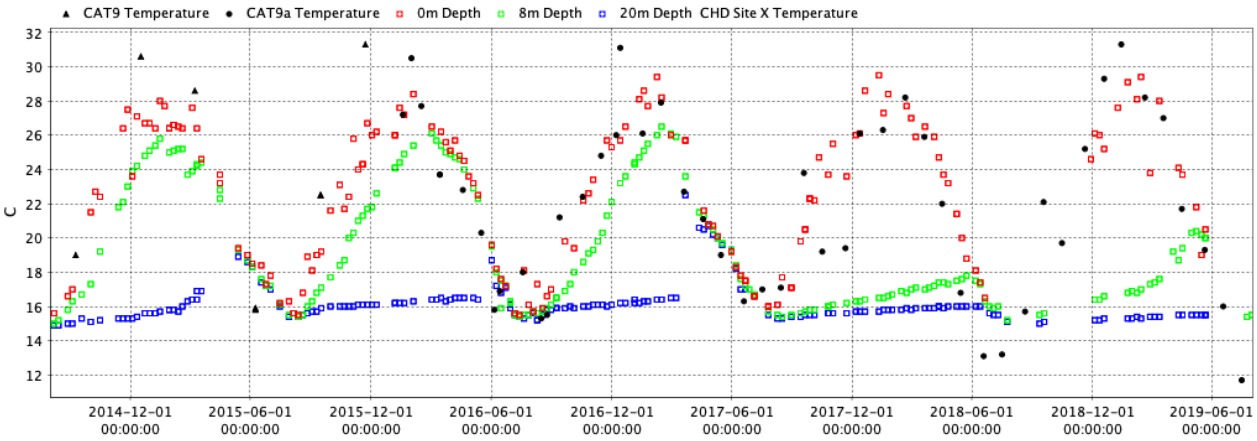


Figure A.2 Water temperature measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

A.1.2. Salinity

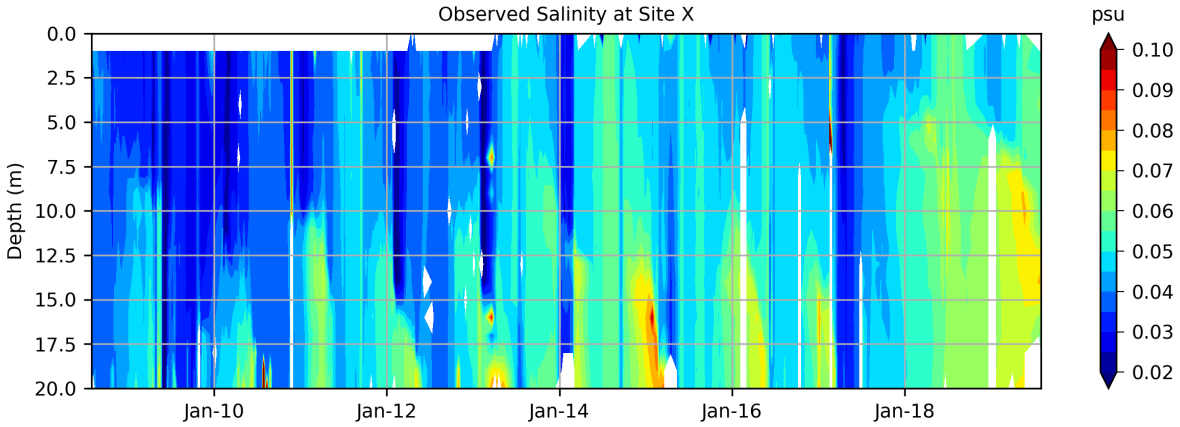


Figure A.3 Salinity calculated from temperature and conductivity measurements from profiling in CHD at Site X during August 2008 to August 2019.

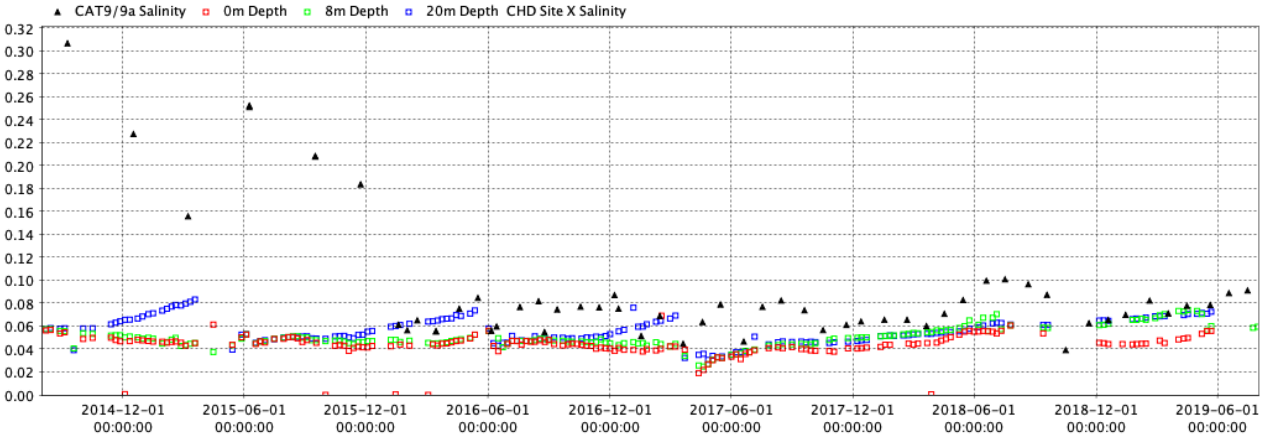


Figure A.4 Salinity (psu) calculated from temperature and conductivity measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

A.1.3. Dissolved Oxygen

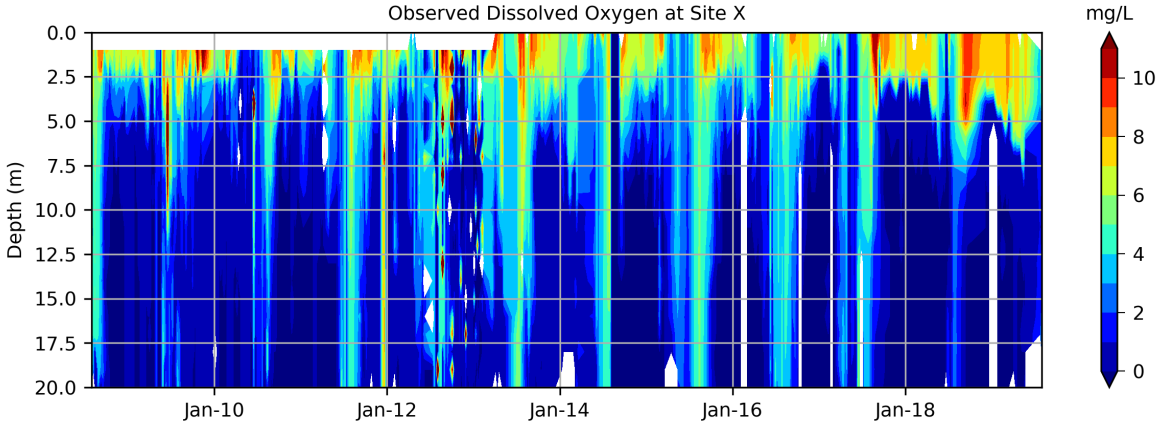


Figure A.5 Dissolved oxygen measurements from profiling in CHD at Site X during August 2008 to August 2019.

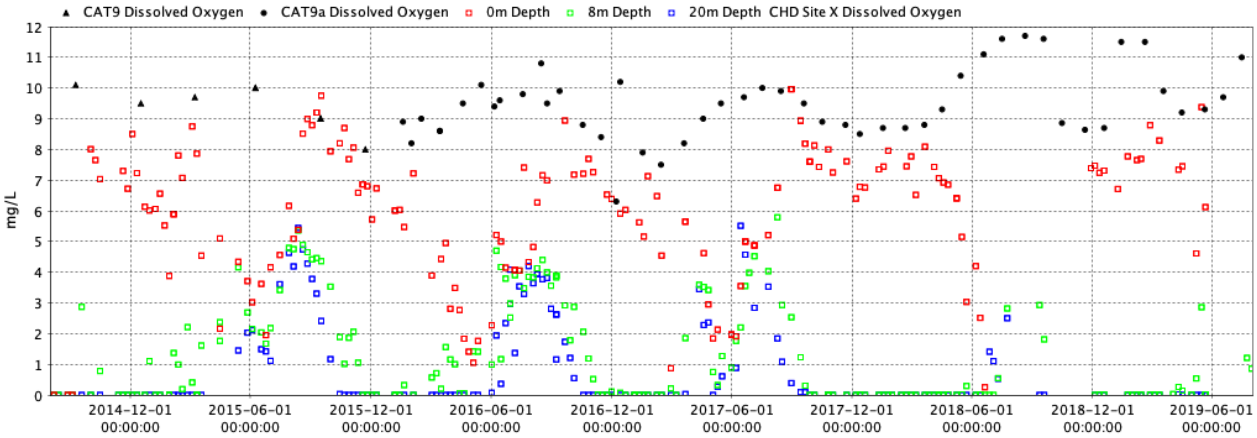


Figure A.6 Dissolved oxygen measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

A.1.4. Turbidity

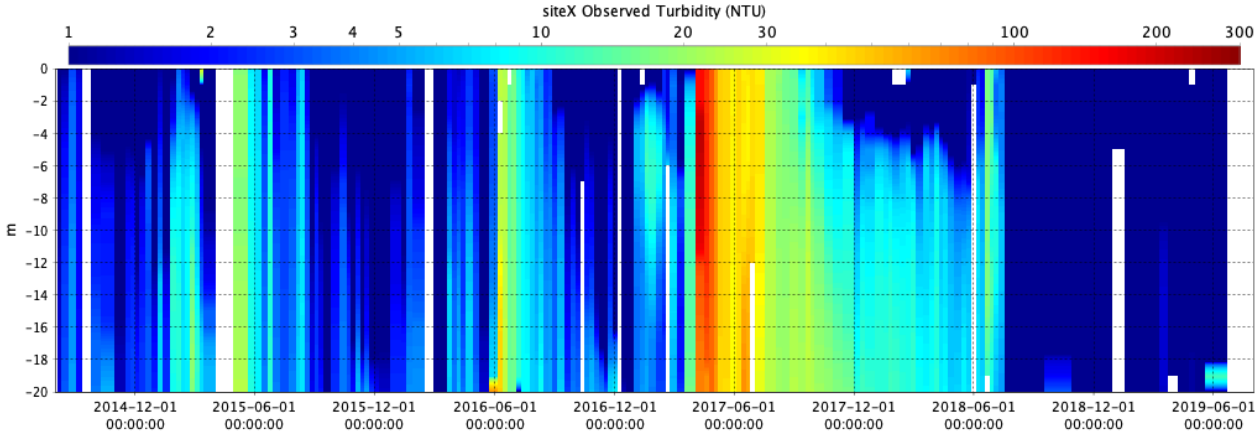


Figure A.7 Turbidity measurements from profiling in CHD at Site X during August 2014 to August 2019.

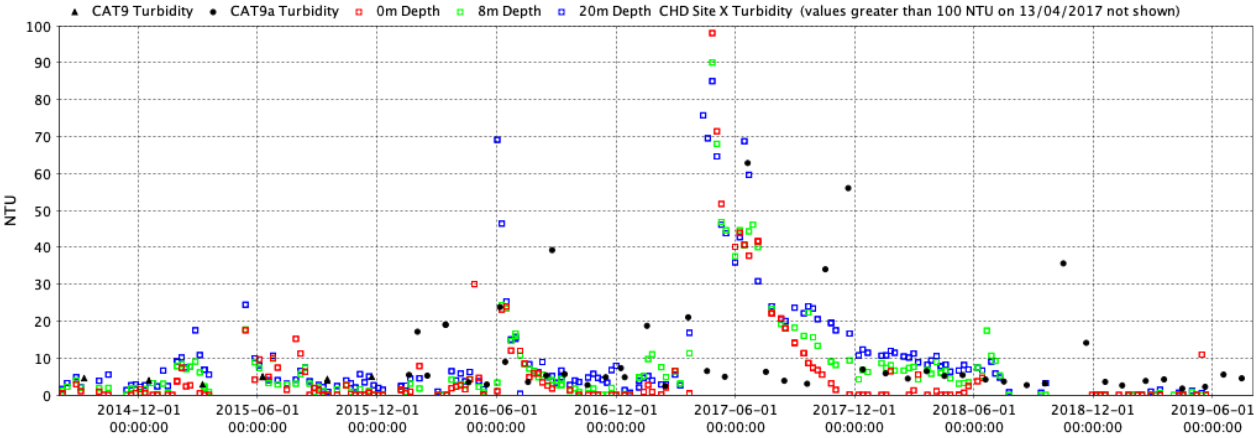


Figure A.8 Turbidity measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

A.1.5. pH

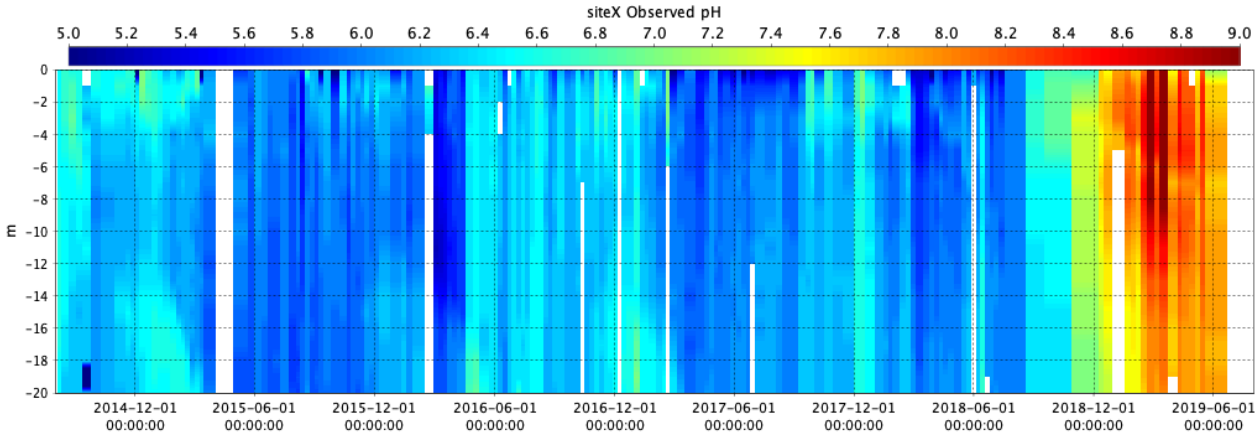


Figure A.9 pH measurements from profiling in CHD at Site X during August 2014 to August 2019.

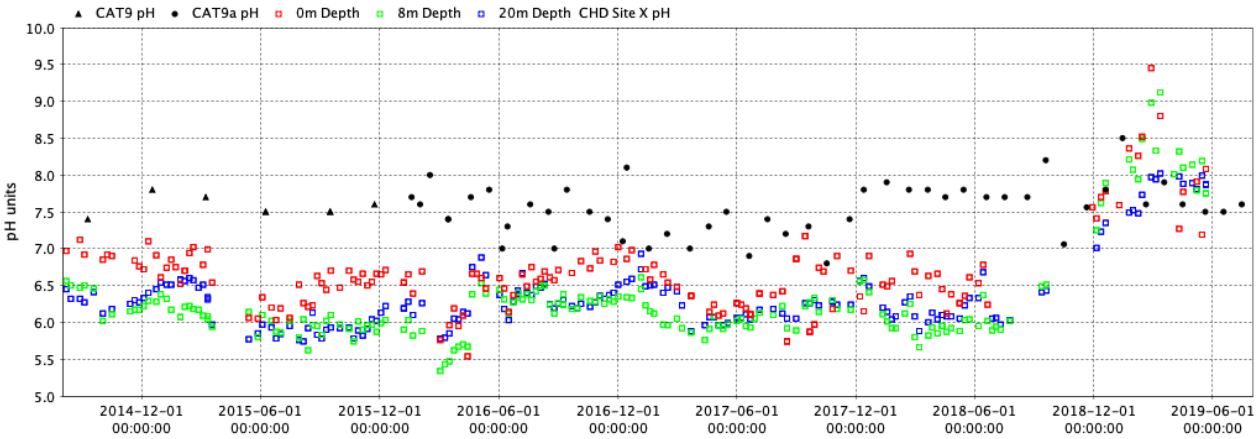


Figure A.10 pH measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

A.1.6. Metals

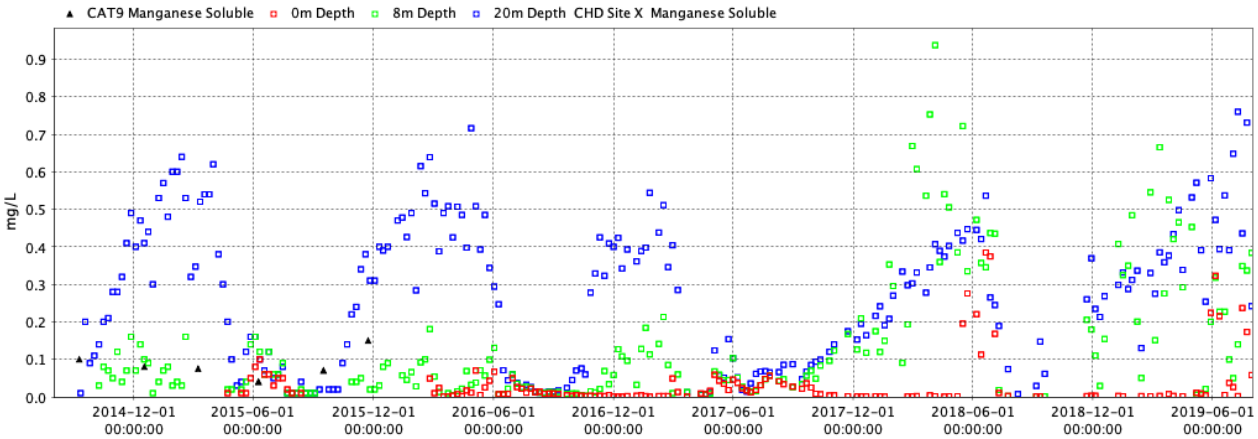


Figure A.11 Manganese ion concentration measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

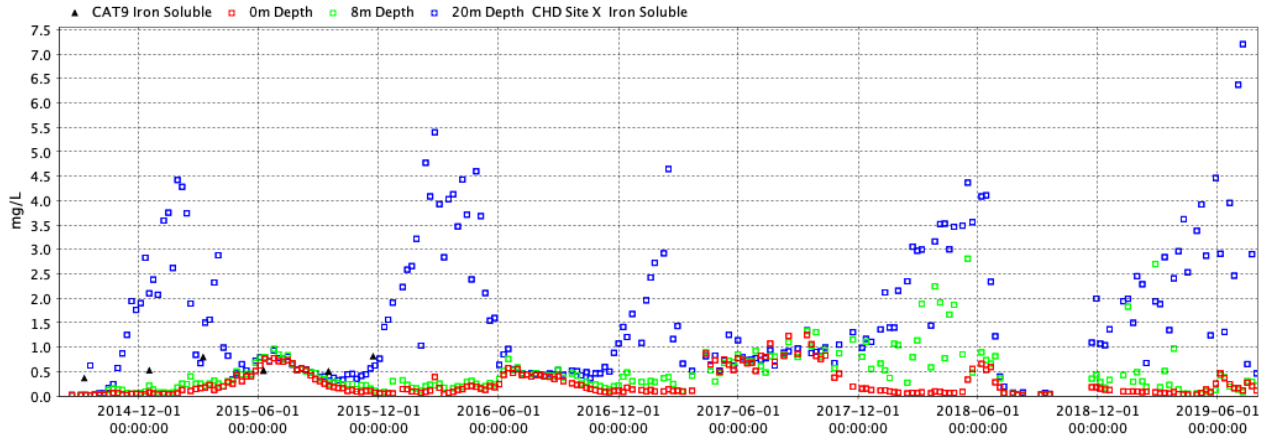


Figure A.12 Iron ion concentration measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

A.1.7. Nitrogen

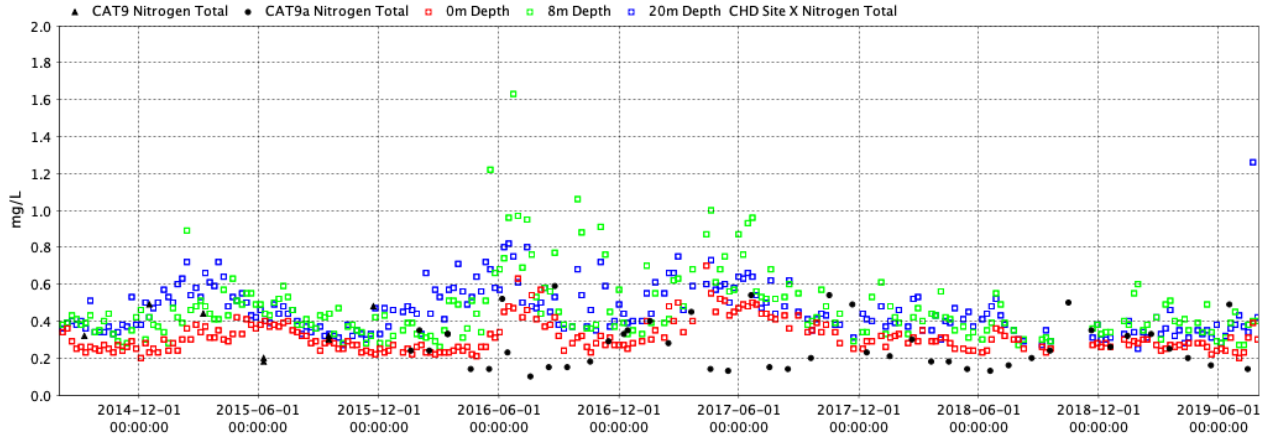


Figure A.13 Total nitrogen measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

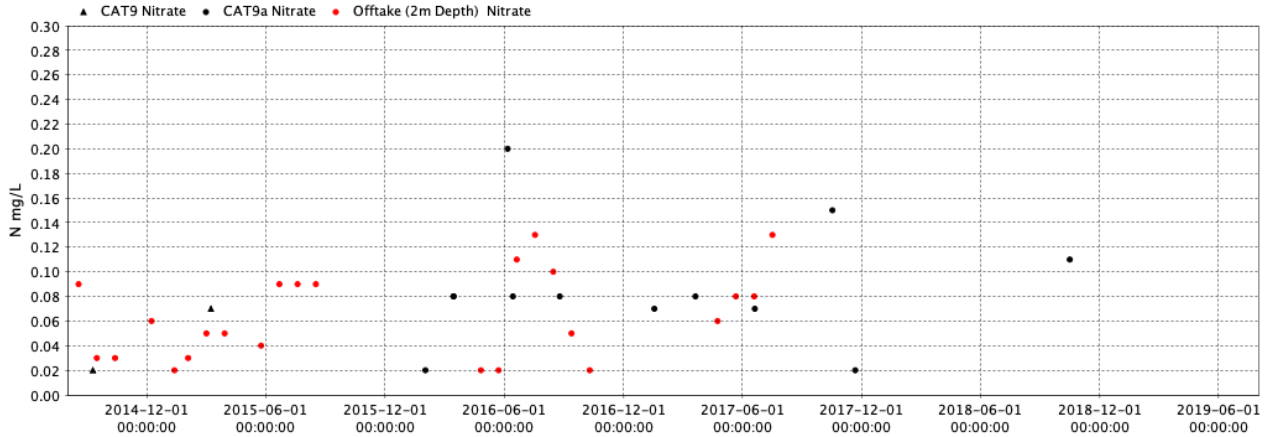


Figure A.14 Nitrate measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD offtake at 2 m depth (red) during August 2014 to August 2019.

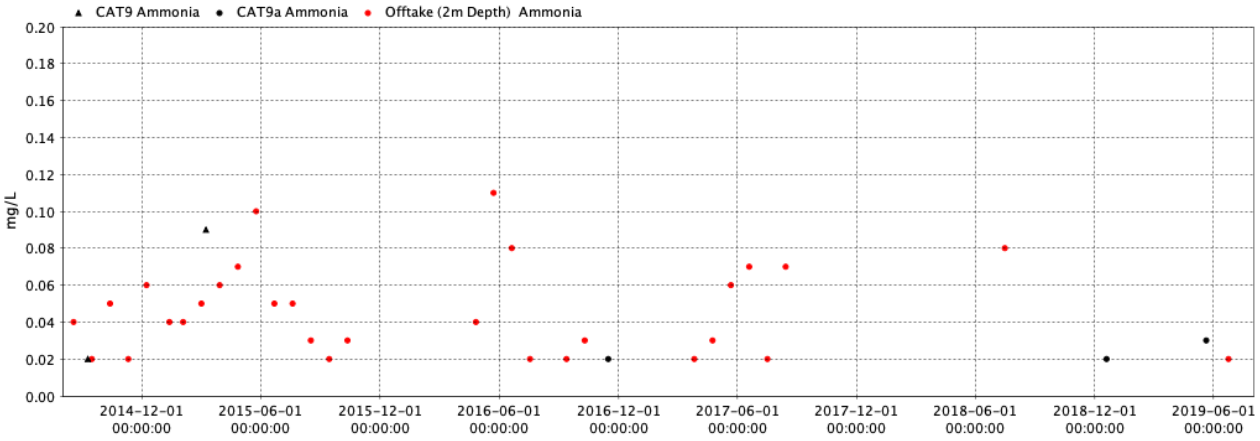


Figure A.15 Ammonia measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD offtake at 2 m depth (red) during August 2014 to August 2019.

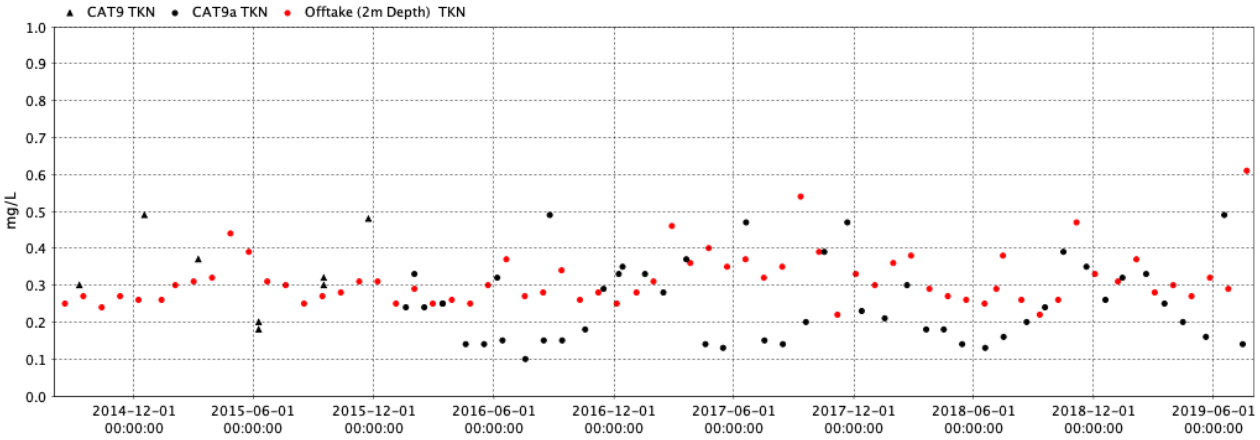


Figure A.16 TKN measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD offtake at 2 m depth (red) during August 2014 to August 2019.

A.1.8. Phosphorus

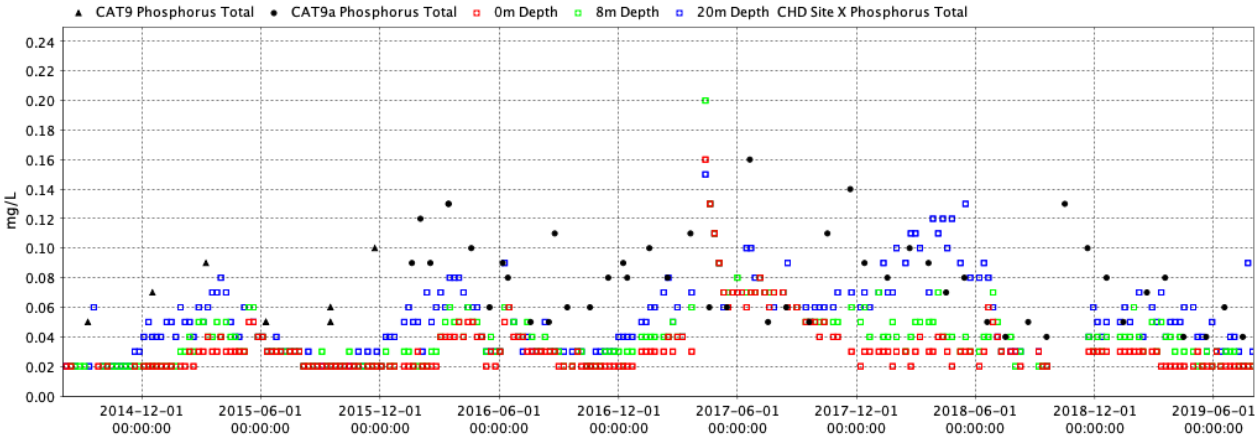


Figure A.17 Total phosphorus measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

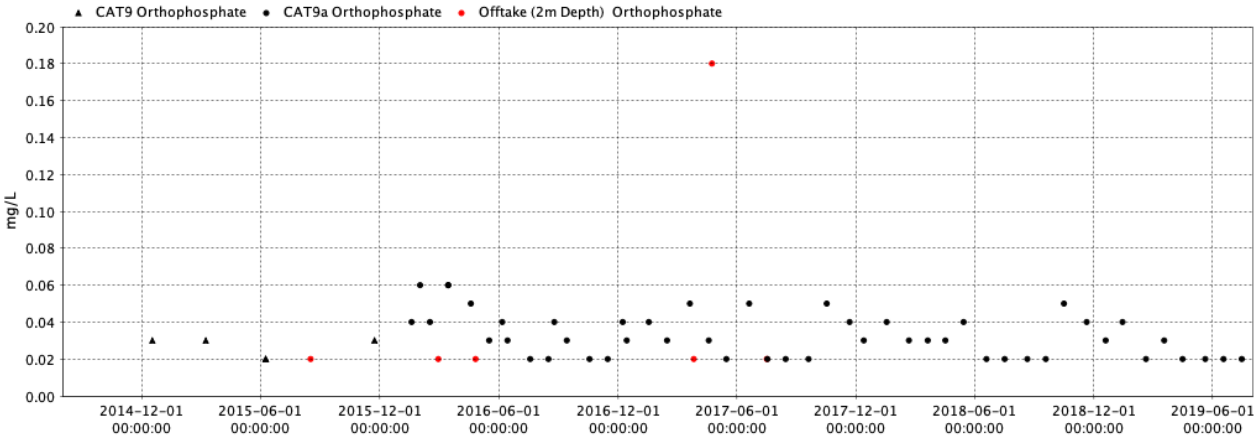


Figure A.18 Orthophosphate measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD offtake at 2 m depth (red) during August 2014 to August 2019.

A.1.9. Carbon

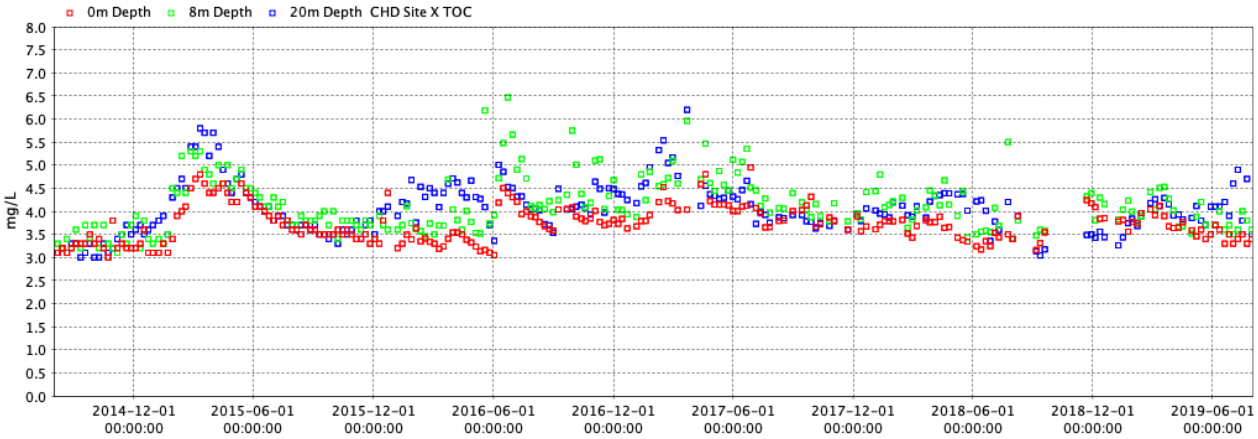


Figure A.19 Total organic carbon measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

A.1.10. Algae

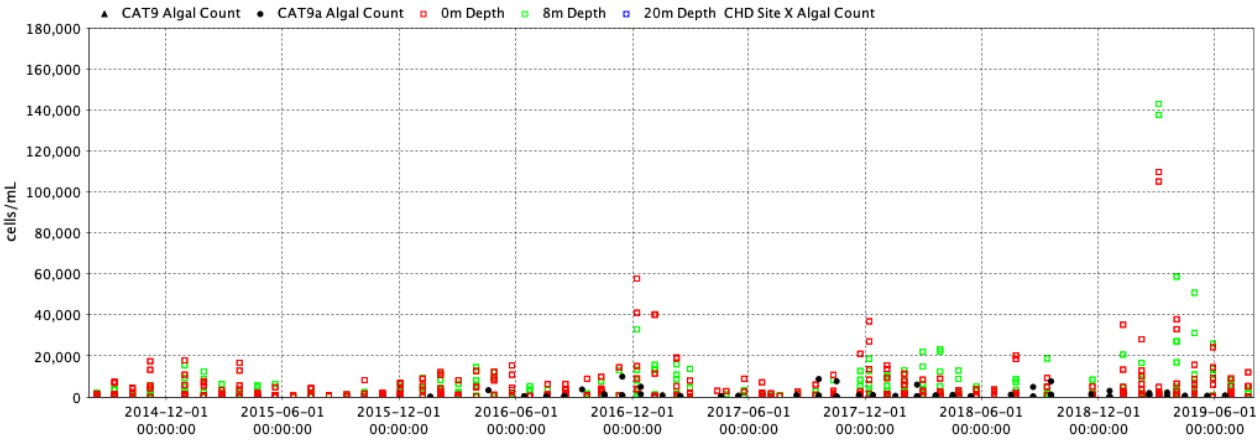


Figure A.20 Algal count measurements from Doon Doon Creek upstream of CHD (black symbols) and measurements from CHD at Site X at depths of 0 m (red), 8 m (green) and 20 m (blue) during August 2014 to August 2019.

A.2. Meteorological Data

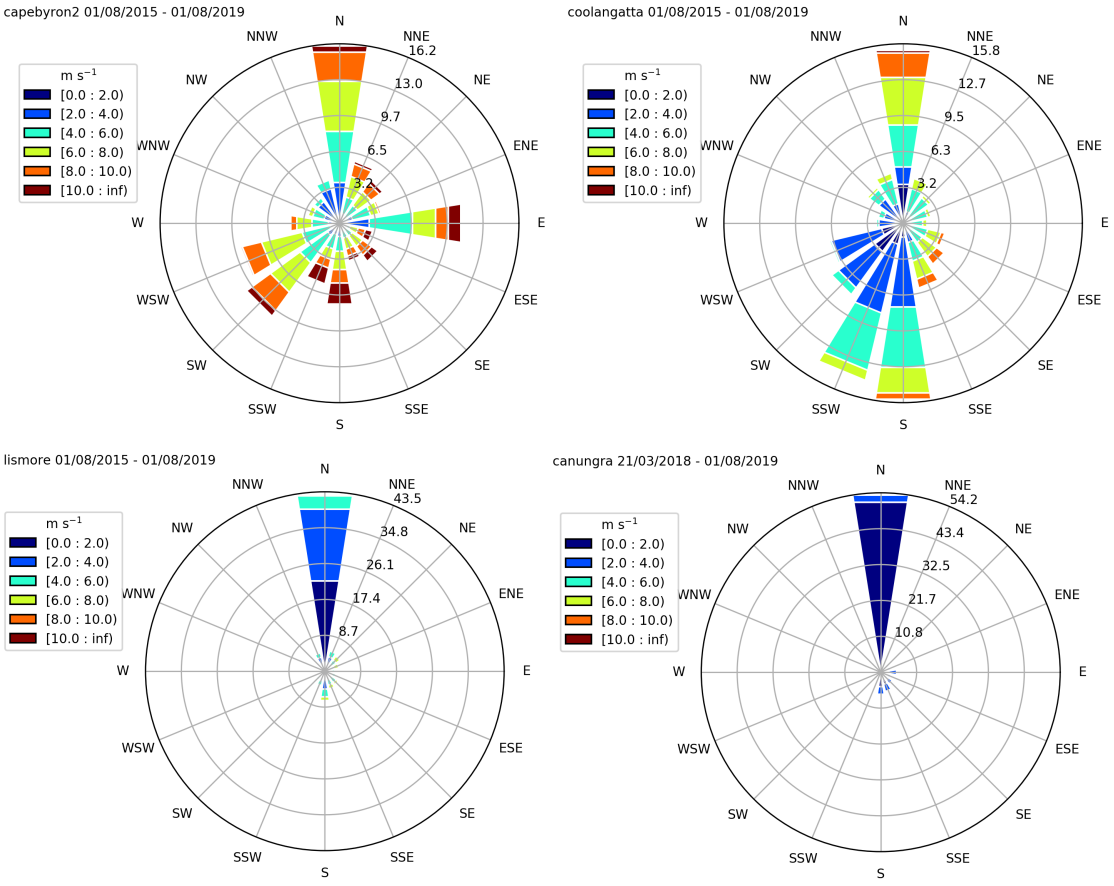


Figure A.21 Wind roses showing data from BoM weather stations at Byron, Coolangatta, Lismore and Canungra.

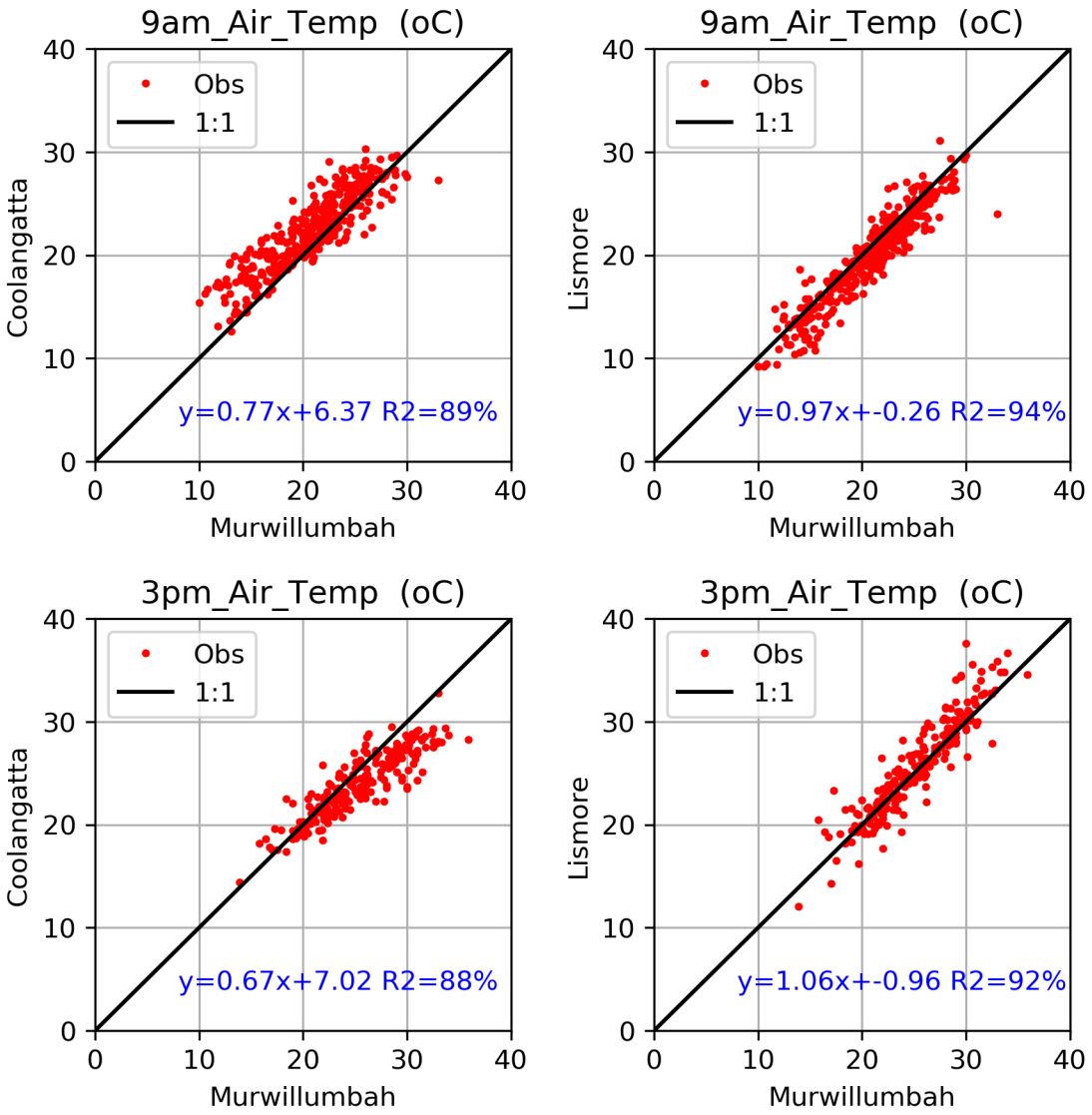


Figure A.22 Comparison of 9 am (top row) and 3 pm (bottom row) air temperature observations at Murwillumbah (Bray Park) with observations at Coolangatta (left column) and Lismore (right column) during March 2019 to March 2020.

Table A.1 Seasonal averages of wind speed and air temperature records from BoM weather stations at Byron, Coolangatta and Lismore from 2009 to 2019. Only the period Apr 2018 to Apr 2020 is available for the BoM station at Canungra; seasonal averages for this period are shown in brackets.

Season	Byron	Coolangatta (CO)	Lismore (LI)	Canungra
Daily Mean Wind Speed (m s^{-1})				
DJF	6.5 (6.3)	4.7 (4.6)	3.2 (3.3)	(1.2)
MAM	6.0 (6.3)	3.9 (4.0)	2.5 (2.4)	(0.8)
JJA	5.9 (5.7)	3.5 (3.4)	2.9 (2.8)	(0.8)
SON	6.3 (6.5)	4.6 (4.7)	3.4 (3.5)	(1.1)
Daily Mean Air Temperature (°C)				
DJF	23.7 (24.3)	24.2 (24.6)	23.4 (24.3)	(23.7)
MAM	20.8 (21.1)	20.9 (21.1)	19.1 (19.3)	(18.6)
JJA	16.0 (16.4)	15.7 (15.9)	13.6 (13.6)	(12.2)
SON	20.0 (19.8)	20.3 (20.2)	19.4 (19.6)	(18.6)
Daily Max Air Temperature (°C)				
DJF	27.2 (28.2)	28.0 (28.3)	29.4 (30.8)	(29.8)
MAM	24.0 (24.3)	25.3 (25.6)	25.4 (25.7)	(25.8)
JJA	19.3 (19.7)	21.1 (21.6)	21.1 (21.8)	(22.1)
SON	23.5 (23.3)	24.7 (24.6)	26.8 (27.3)	(26.7)
Daily Min Air Temperature (°C)				
DJF	20.9 (21.4)	20.6 (21.0)	18.1 (18.3)	(18.3)
MAM	17.9 (18.1)	17.1 (17.3)	14.1 (14.1)	(12.6)
JJA	13.1 (13.2)	10.7 (10.4)	7.3 (6.5)	(4.2)
SON	17.0 (16.9)	15.7 (15.8)	12.6 (12.4)	(11.2)

Appendix B: Model Data

B.1. Model Input Data

B.1.1. Inflow Water Quality

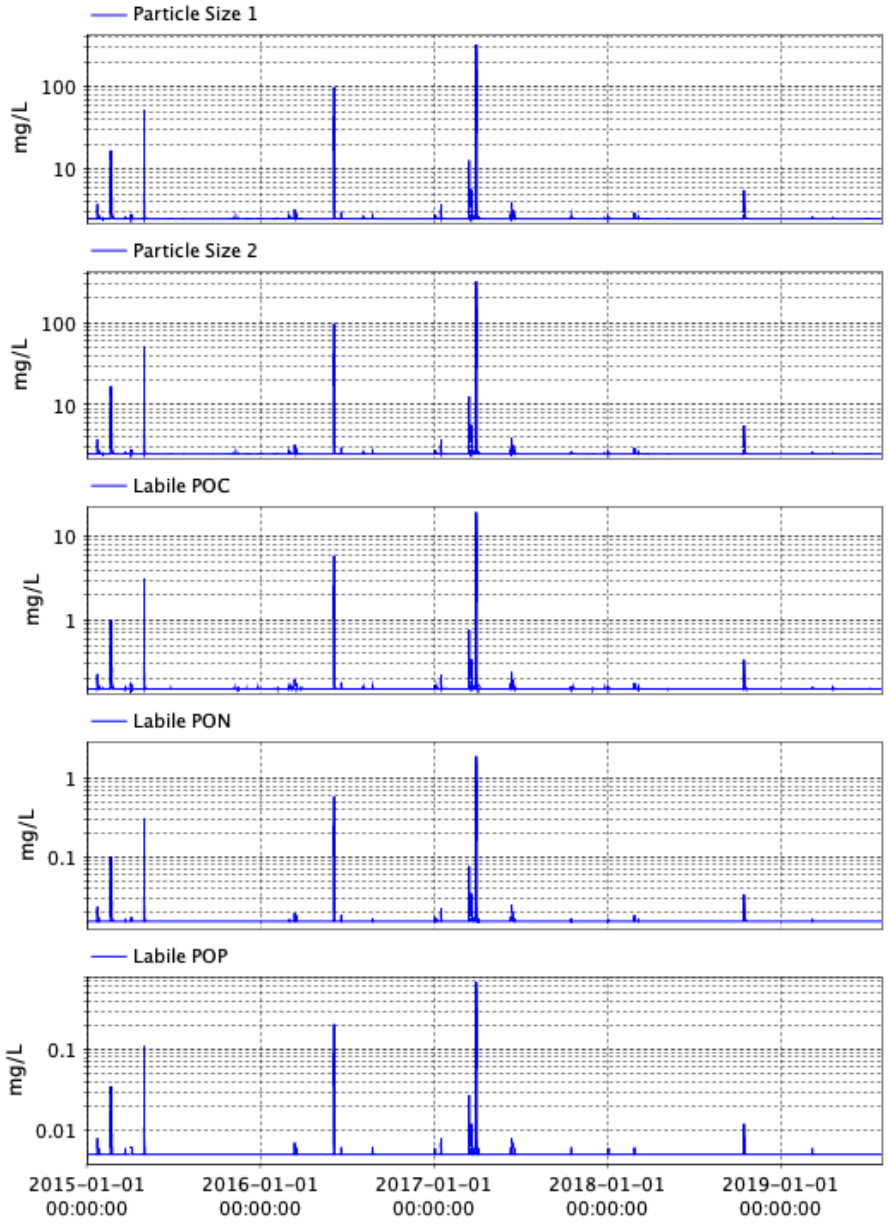


Figure B.1 Model hourly timeseries inflow concentrations of suspended solids and particulate organic carbon (POC), nitrogen (PON) and phosphorus (POP).

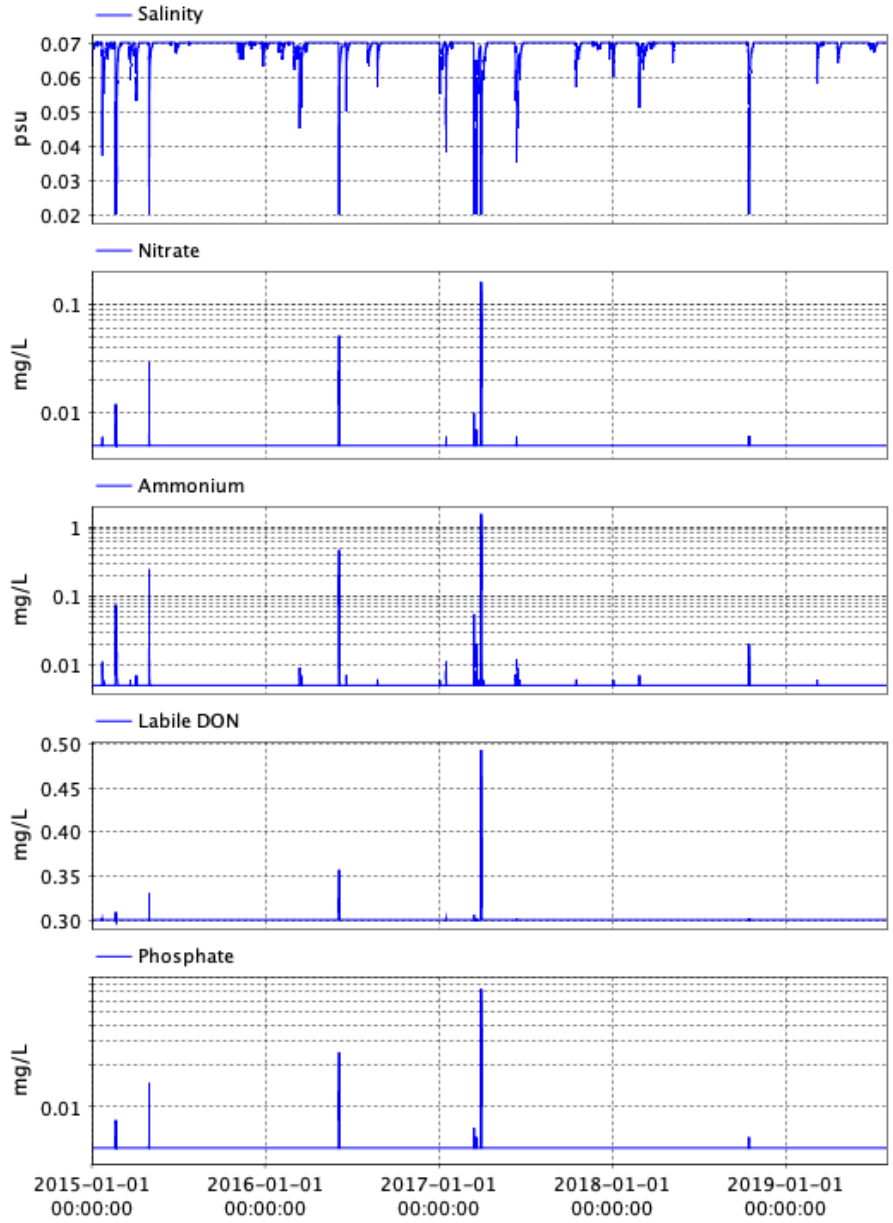


Figure B.2 Model hourly timeseries inflow concentrations of dissolved constituents.

B.1.2. Meteorology

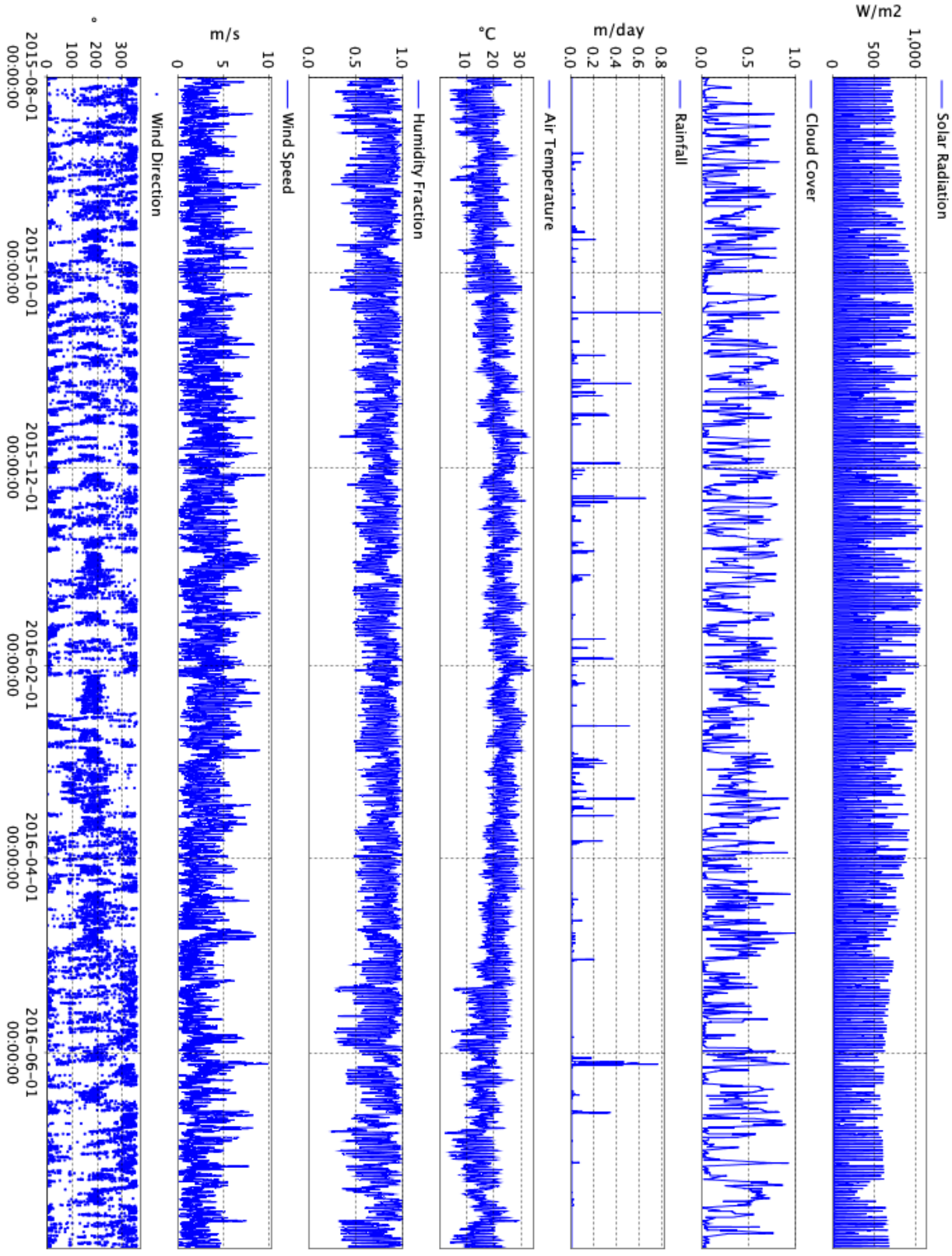


Figure B.3 Model hourly timeseries surface boundary condition data for August 2015 to August 2016.

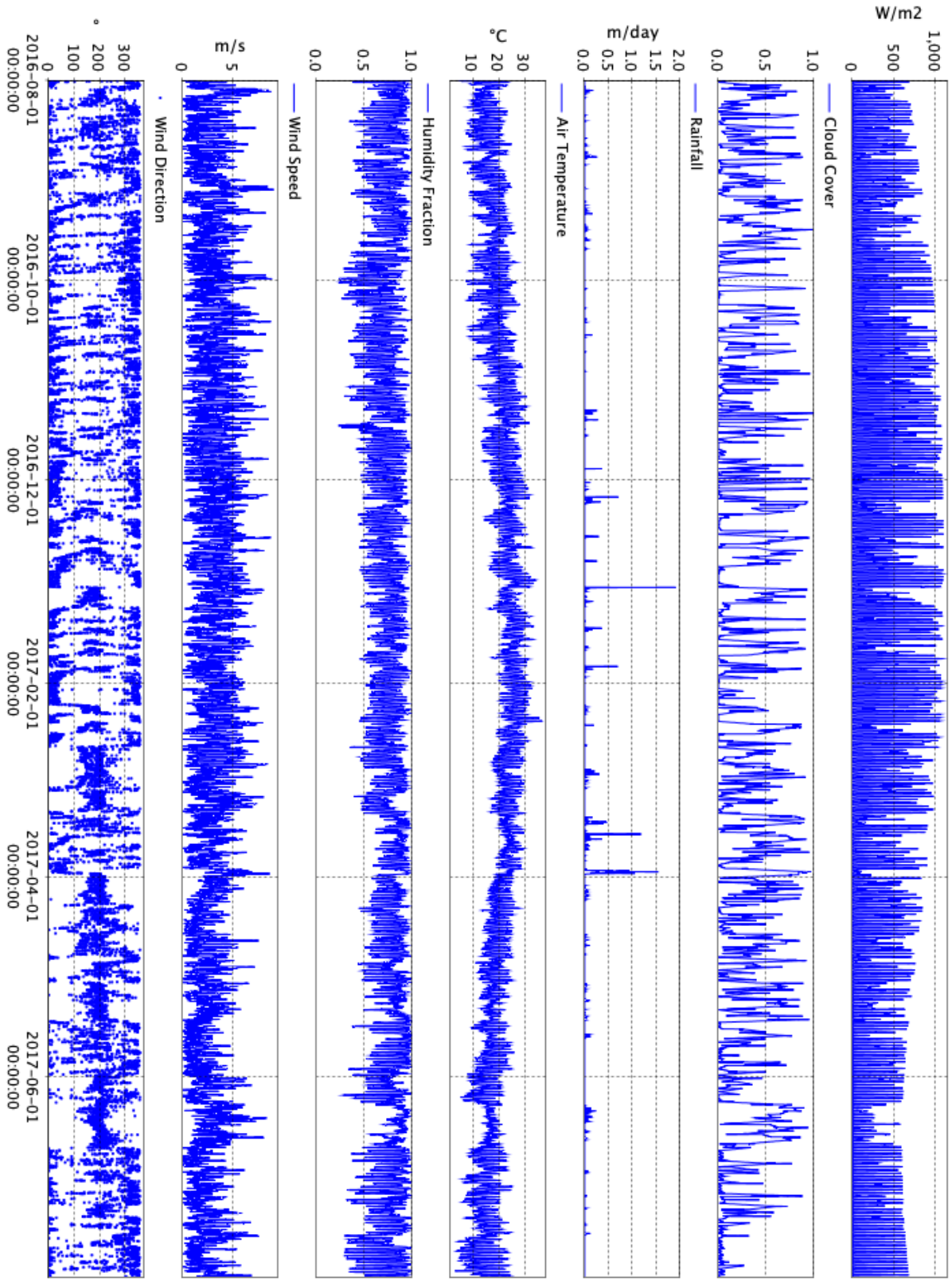


Figure B.4 Model hourly timeseries surface boundary condition data for August 2016 to August 2017.

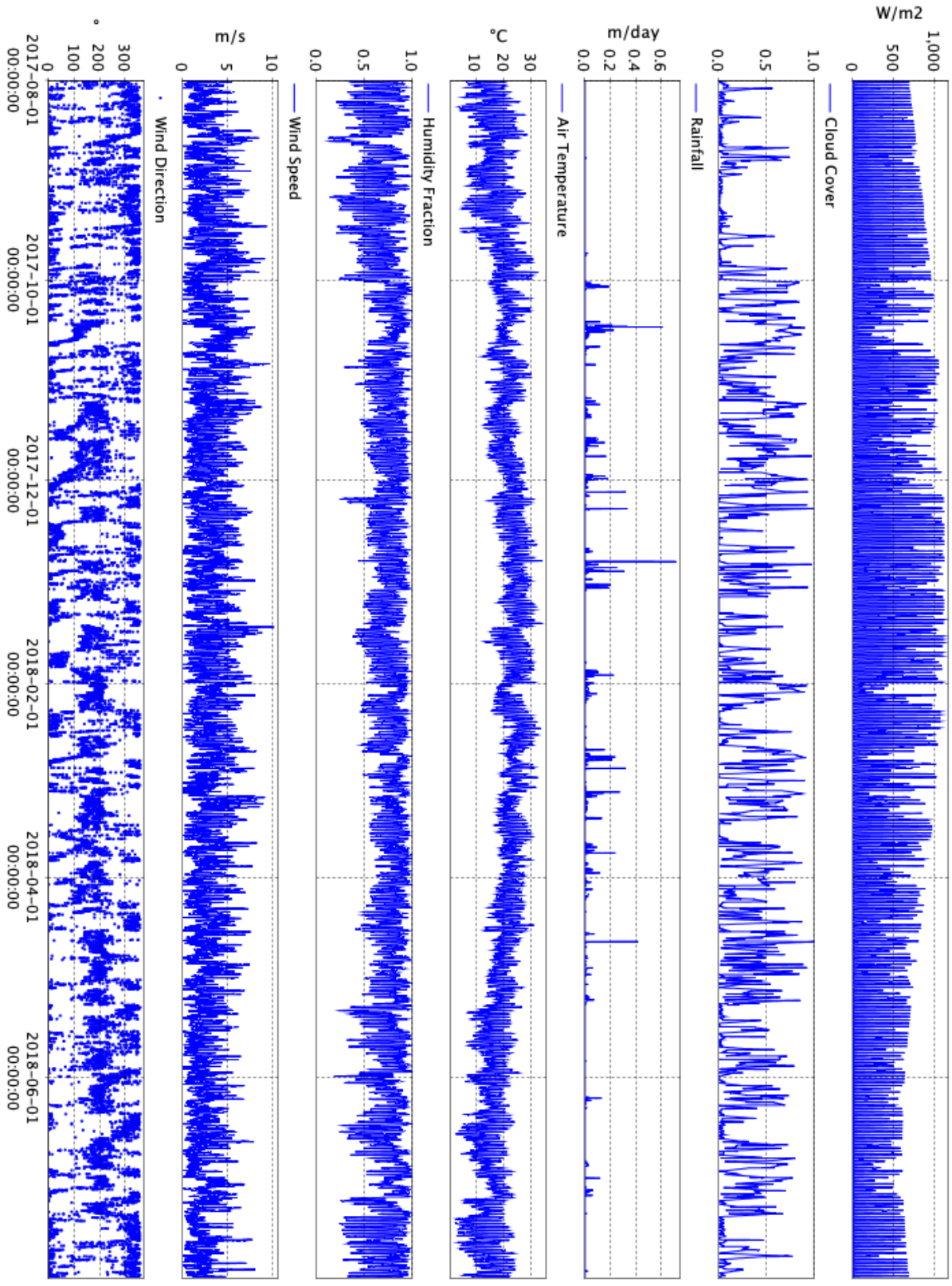


Figure B.5 Model hourly timeseries surface boundary condition data for August 2017 to August 2018.

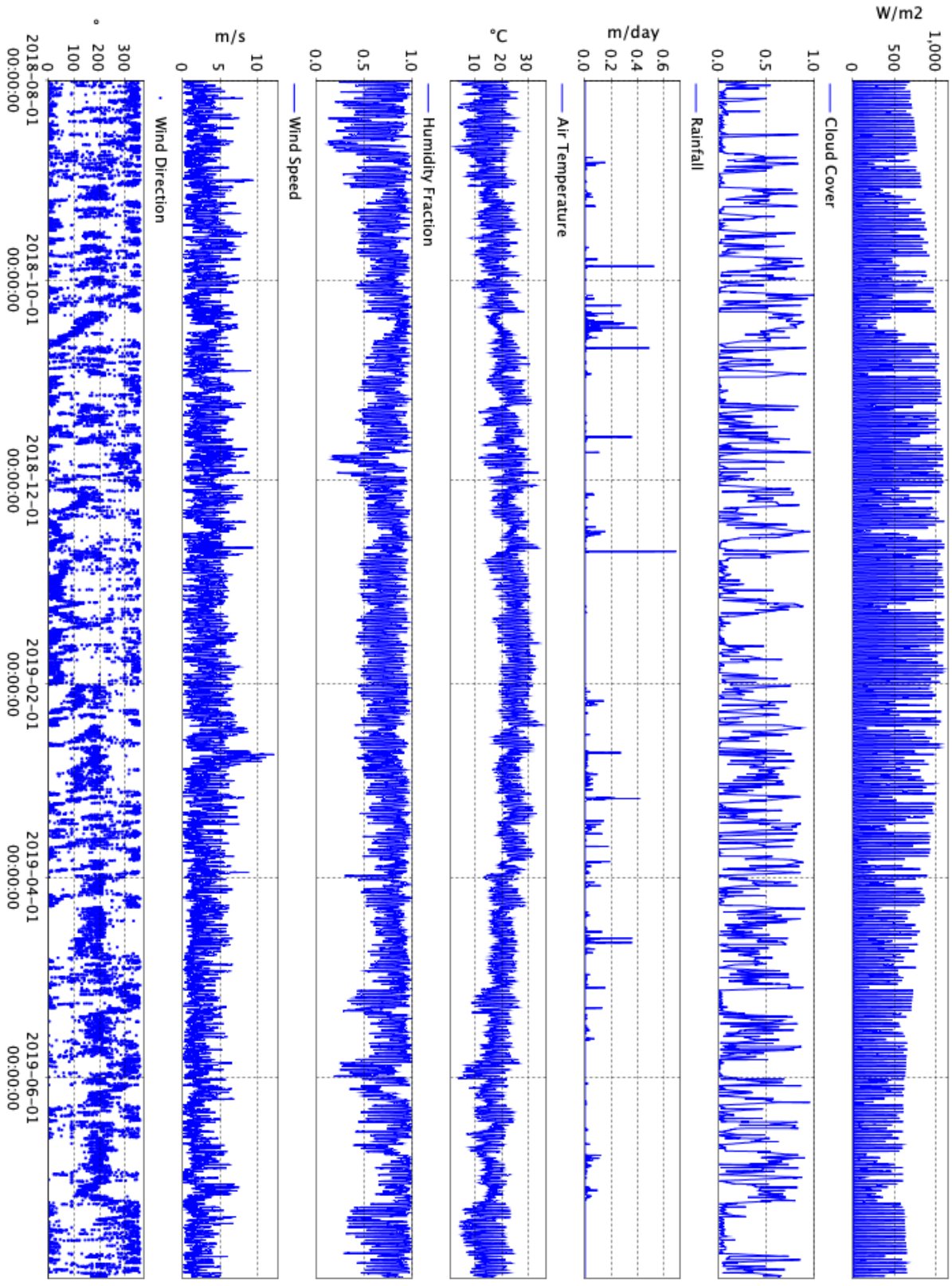


Figure B.6 Model hourly timeseries surface boundary condition data for August 2018 to August 2019.

B.2. Sensitivity Tests

- Sensitivity to model parameters, as shown in Table B.1
- Changes to inflow WQ (see section B.2.4)

Table B.1 Model parameter values tested and the resultant response in the simulations.

Parameter	Value	Values Tested	Result	Reference
Model Grid				
Horizonal spacing	90 m	30, 90	Smaller grid size increases vertical mixing but leads to excessive run times.	Fig. 2.7 – 2.11
Vertical spacing in stratified region	0.5 m	0.5, 1.0	Larger cell heights produce weaker temperature gradients.	Fig. 2.12
Physics				
Background PAR light extinction coeff. (K_d)	0.4 m^{-1}	0.2, 0.6, 1.0, 4.0	Lower values increase penetration depth of PAR, heating the hypolimnion.	Fig. 2.15 – 2.17
Wind speed factor	0.6	1.0, 0.8, 0.6	Decrease in wind speed reduces vertical mixing, which increases hypolimnion volume. However lowest wind speed prevents deeper mixing.	Fig. 2.13
Air temperature factor	0.9	1.0, 0.9	Decrease in air temperature reduces surface water temperature.	Fig. 2.14
Biogeochemical				
Sediment release rate (PO_4-P) (P_{sed})	0.008 $g/m^2/day$	0.005, 0.01	Higher values increase TP in hypolimnion and orthophosphate at 2 m depth.	Fig. 2.18-2.20
Sediment oxygen demand (DO_{sed})	1.5 $g/m^2/day$	1, 2	Higher values increase period of anoxia increasing phosphorus in water as above.	Fig. 2.21-2.23

B.2.1. Model Grid

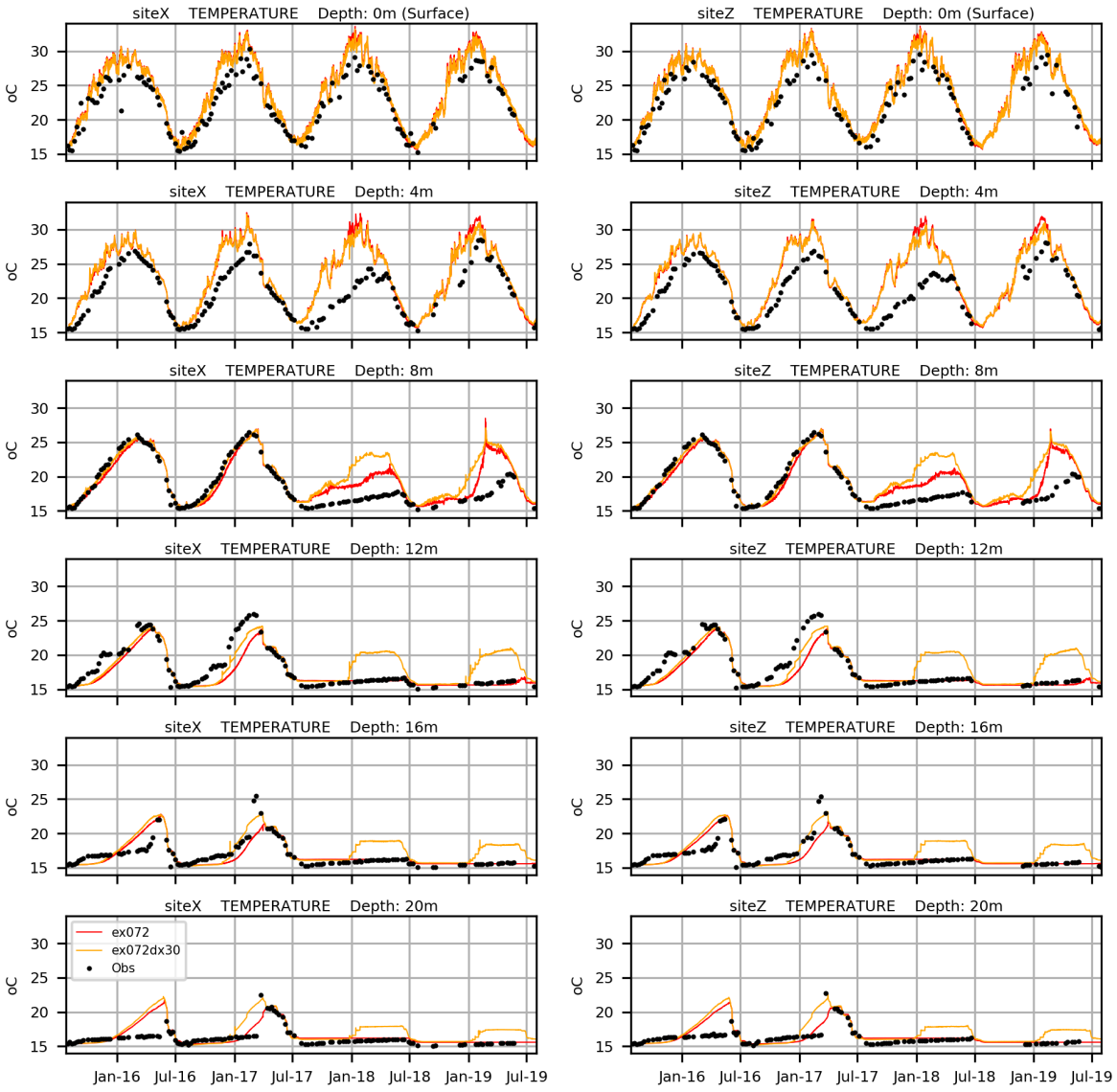


Figure B.7 Comparison between observed (black dots) and simulated (lines) temperatures at depths from size X (on the left) and site Z (on the right), from simulations with horizontal grid sizes of 90 m (red) and 30 m (orange).

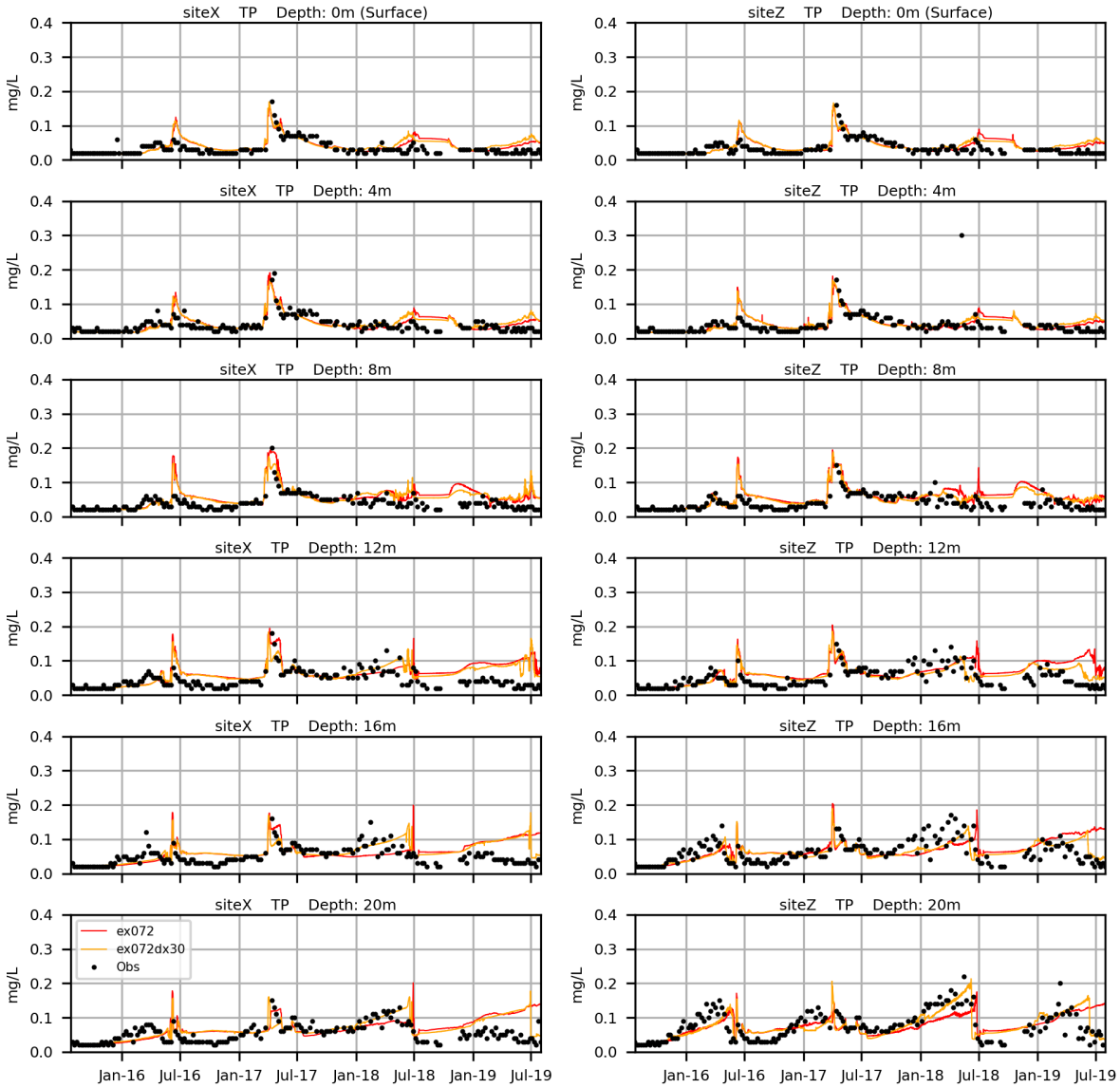


Figure B.8 Comparison between observed (black dots) and simulated (lines) total phosphorus (TP) concentrations at depths from size X (on the left) and site Z (on the right), from simulations with horizontal grid sizes of 90 m (red) and 30 m (orange).

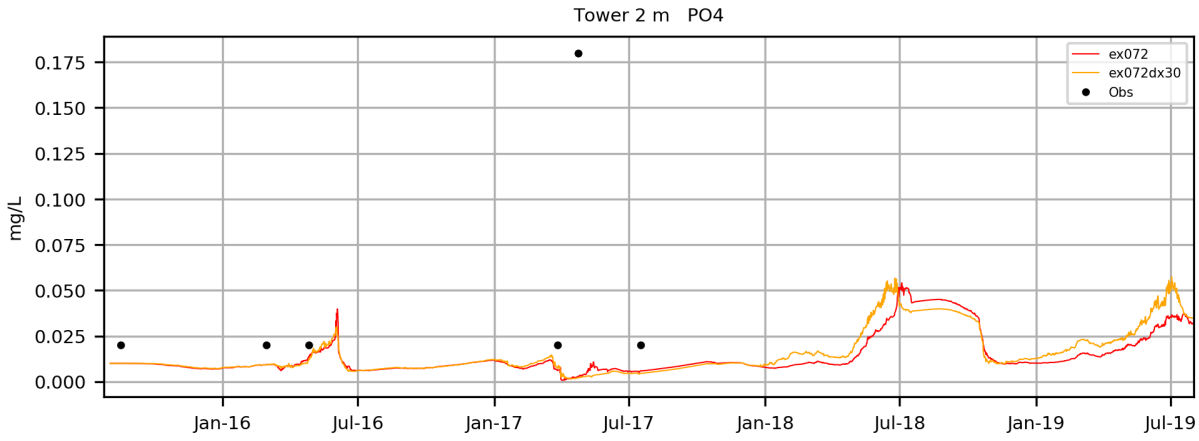


Figure B.9 Comparison between (black dots) and simulated (lines) orthophosphate concentration at the

tower at 2 m deep, from simulations with horizontal grid sizes of 90 m (red) and 30 m (orange).

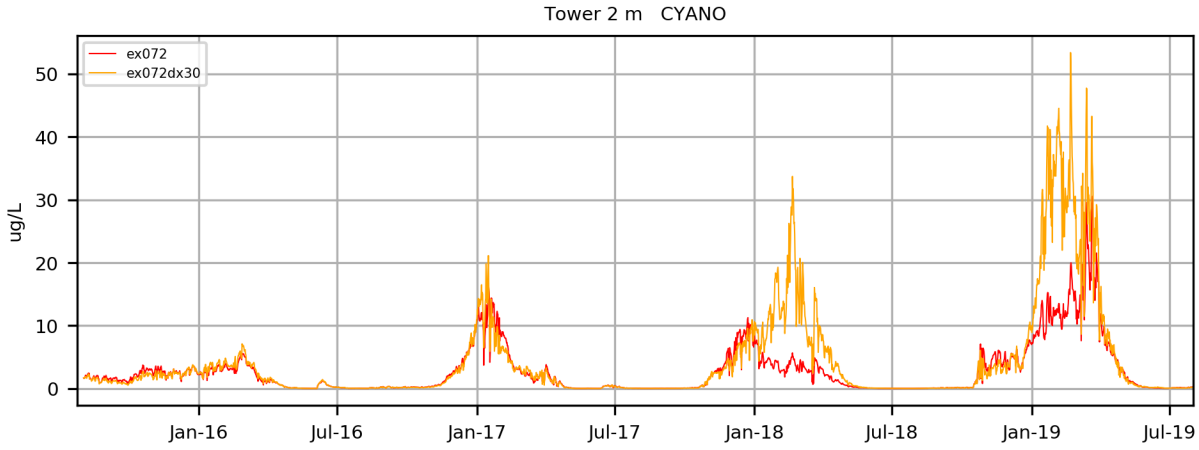


Figure B.10 Comparison between (black dots) and simulated (lines) cyanophyte Chl-a at the tower at 2 m deep, from “Existing” simulations with horizontal grid sizes of 90 m (red) and 30 m (orange).

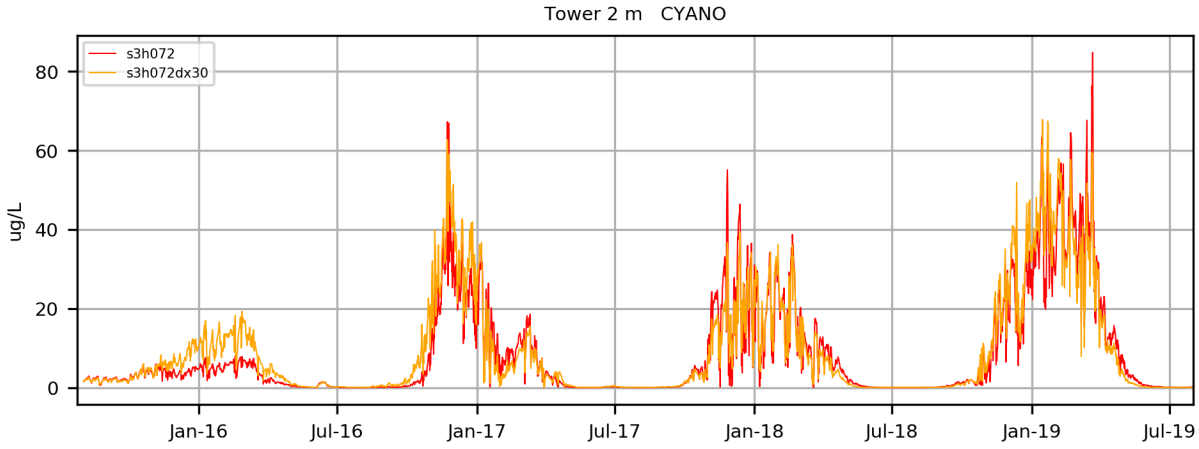


Figure B.11 Comparison simulated cyanophyte Chl-a at the tower at 2 m deep from “CCHM Low” simulations with horizontal grid sizes of 90 m (red) and 30 m (orange).

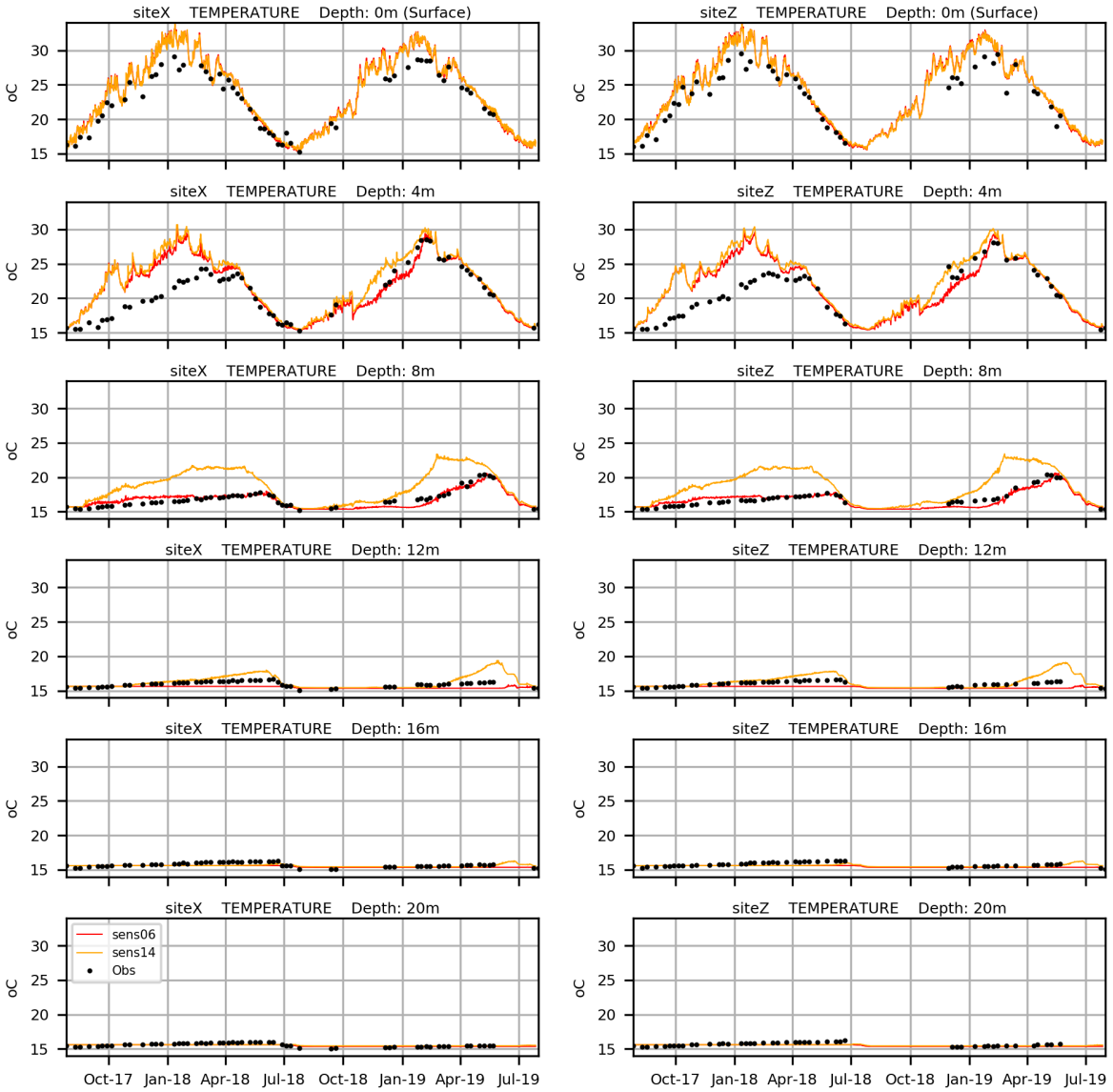


Figure B.12 Comparison between observed (black dots) and simulated (lines) temperatures at depths from size X (on the left) and site Z (on the right), from simulations with grid heights in the stratified region of 0.5 m (red) and 1.0 m (orange).

B.2.2. Physics

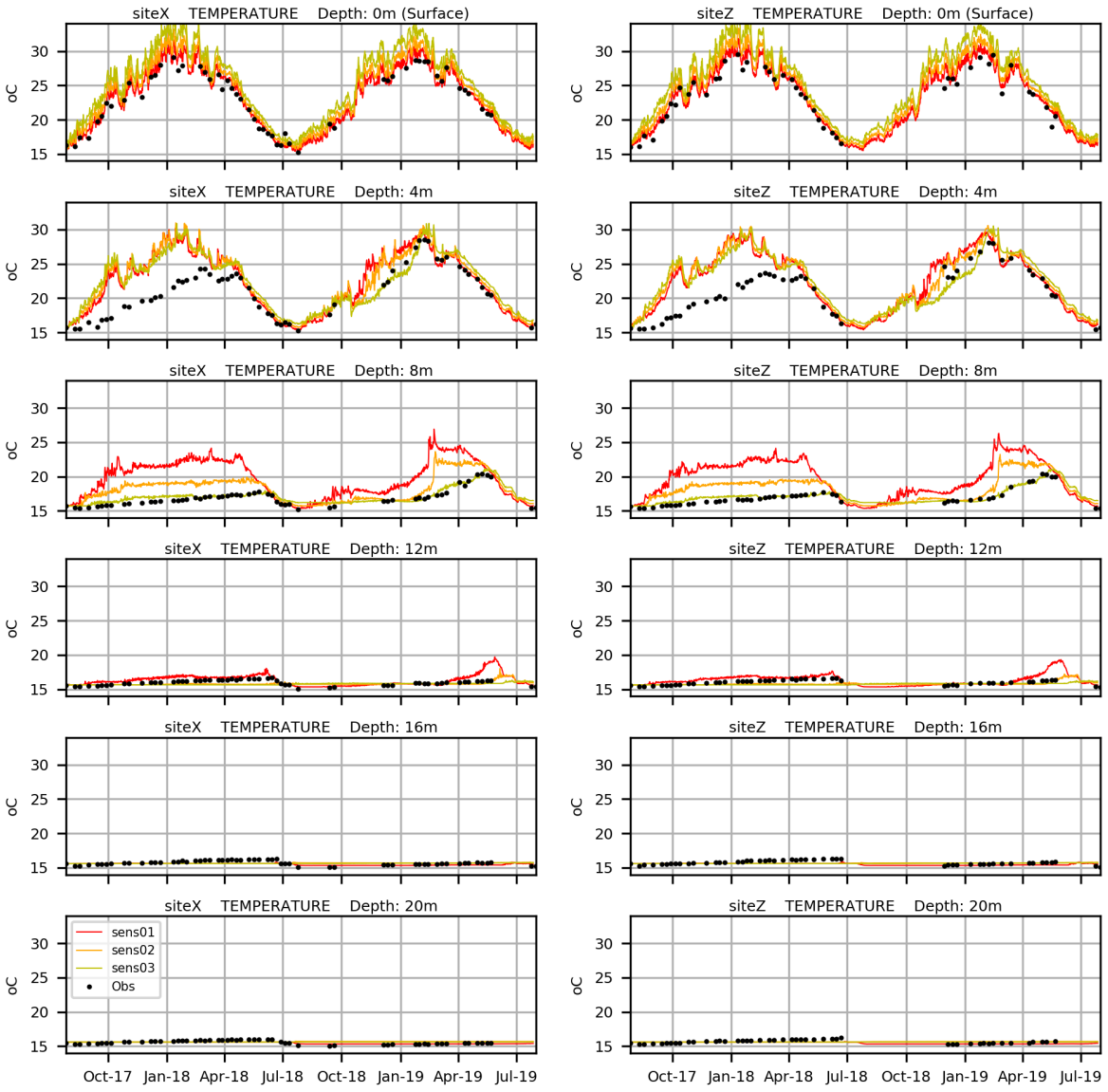


Figure B.13 Comparison between observed (black dots) and simulated (lines) temperatures at depths from size X (on the left) and site Z (on the right), from simulations with wind speed factors of 1.0 (red), 0.8 (orange) and 0.6 (yellow).

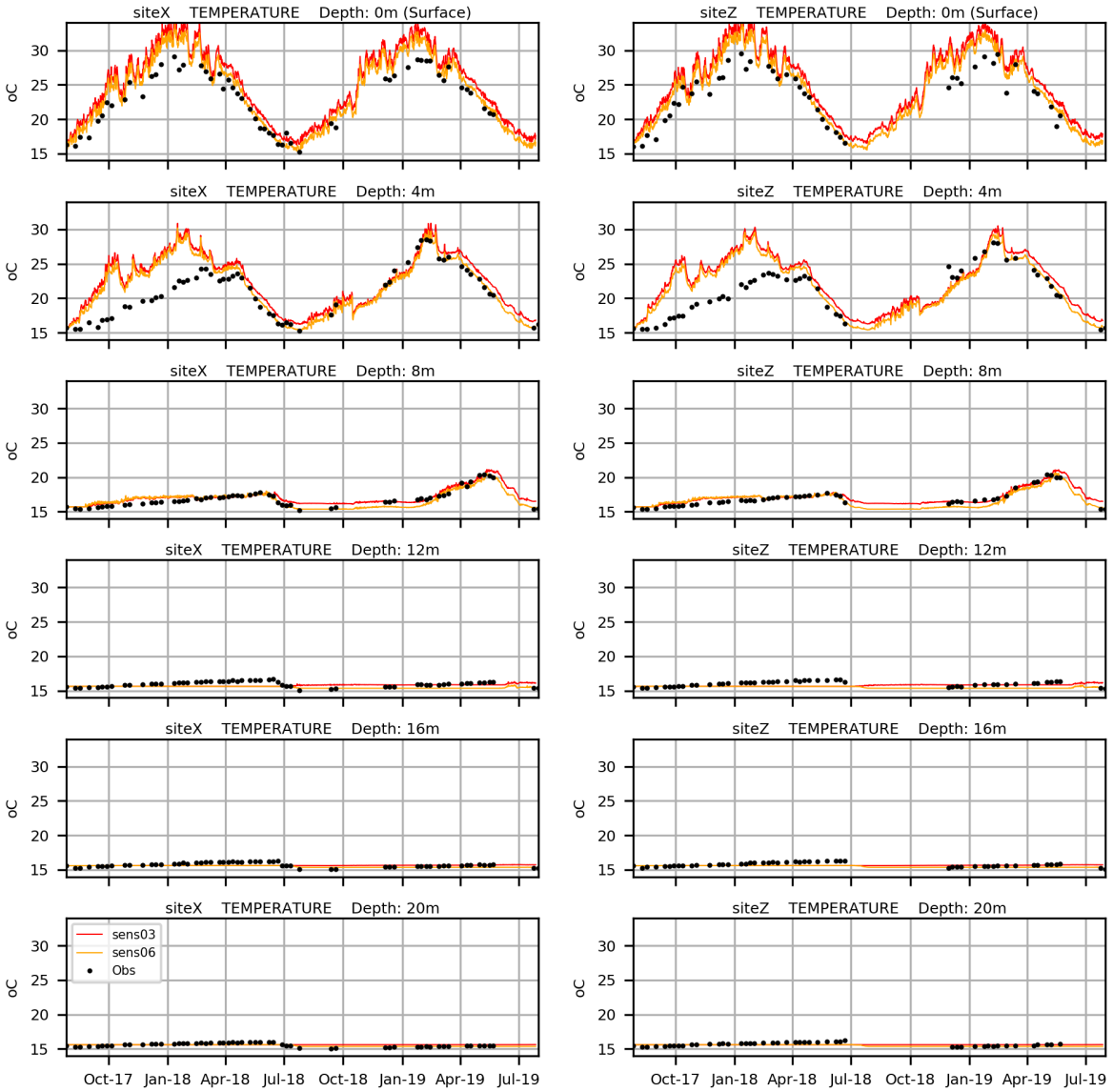


Figure B.14 Comparison between observed (black dots) and simulated (lines) temperatures at depths from size X (on the left) and site Z (on the right), from simulations with air temperature factors of 1.0 (red) and 0.9 (orange).

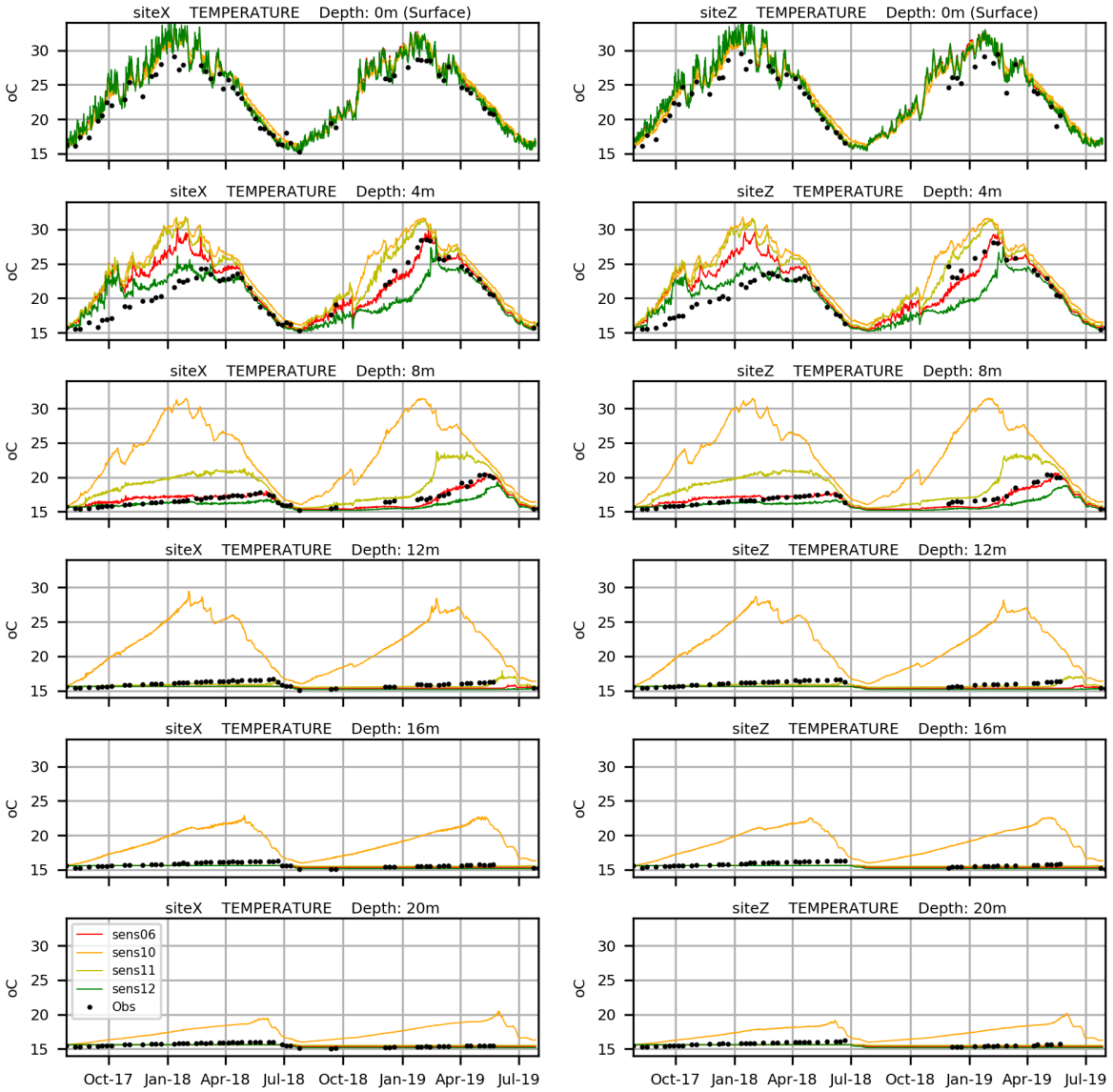


Figure B.15 Comparison between observed (black dots) and simulated (lines) temperatures at depths from size X (on the left) and site Z (on the right), from simulations with light extinction coefficients of 1.0 (red), 0.2 (orange), 0.6 (yellow) and 4.0 (green).

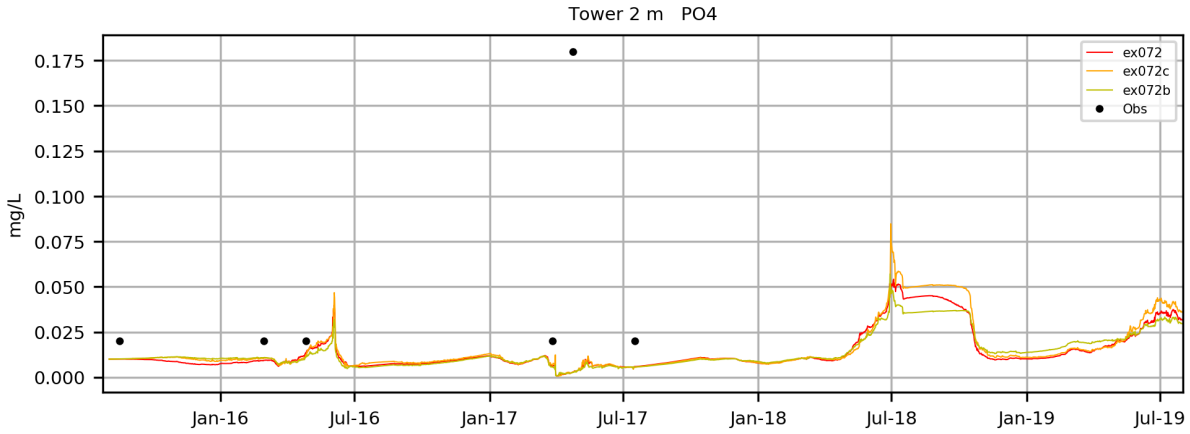


Figure B.16 Comparison between observed (black dots) and simulated (lines) orthophosphate concentration at the tower at 2 m deep, from simulations with wind speed factor of 0.6 and light extinction coefficients of 0.4 (red) and 1.0 (orange), and a simulation with wind speed factor of 0.8 and light extinction coefficients of 1.0 (yellow).

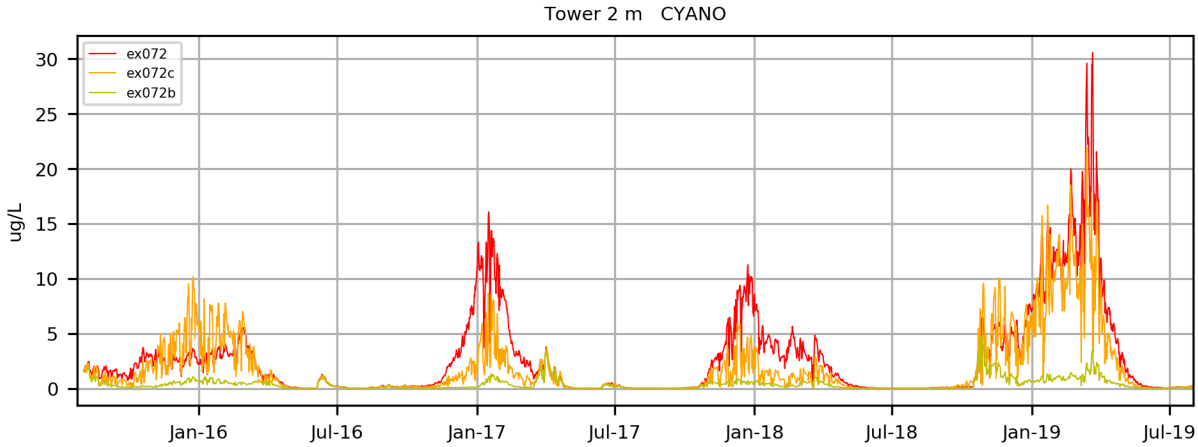


Figure B.17 Comparison between observed (black dots) and simulated (lines) total Chl-a concentration at the tower at 2 m deep, from simulations with wind speed factor of 0.6 and light extinction coefficients of 0.4 (red) and 1.0 (orange), and a simulation with wind speed factor of 0.8 and light extinction coefficients of 1.0 (yellow).

B.2.3. Biogeochemical

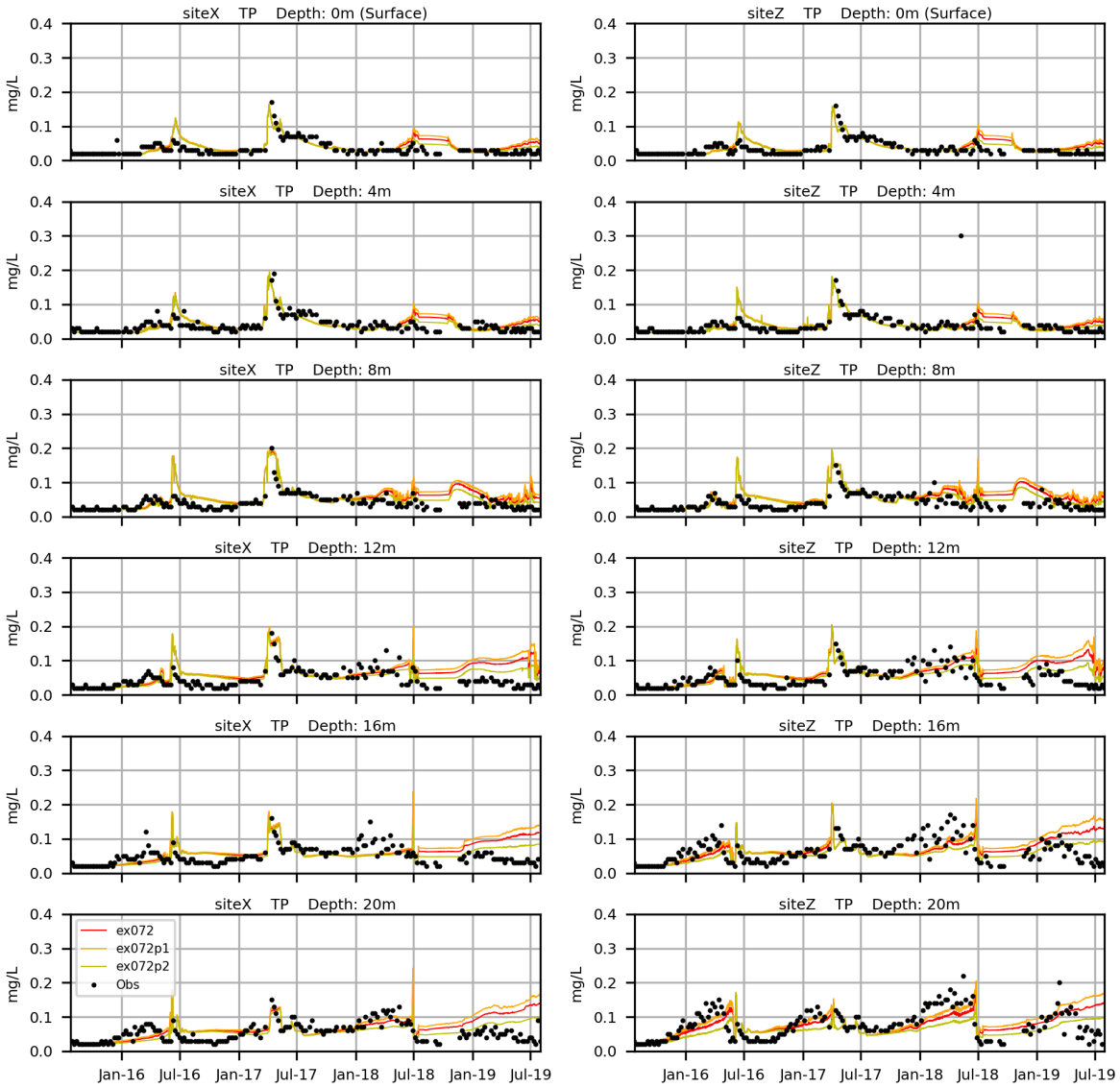


Figure B.18 Comparison between observed (black dots) and simulated (lines) total phosphorus concentration at depths from size X (on the left) and site Z (on the right), from simulations with sediment release rates of phosphorus of 0.008 (red), 0.01 (orange) and 0.005 (yellow) g/m^2/day.

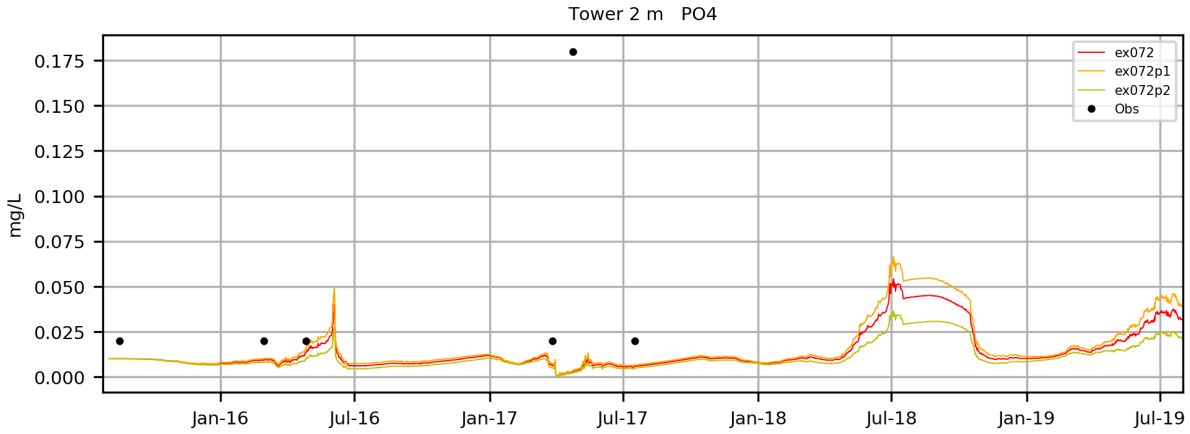


Figure B.19 Comparison between observed (black dots) and simulated (lines) orthophosphate concentration at the tower at 2 m deep, from simulations with sediment release rates of phosphorus of 0.008 (red), 0.01 (orange) and 0.005 (yellow) g/m^2/day.

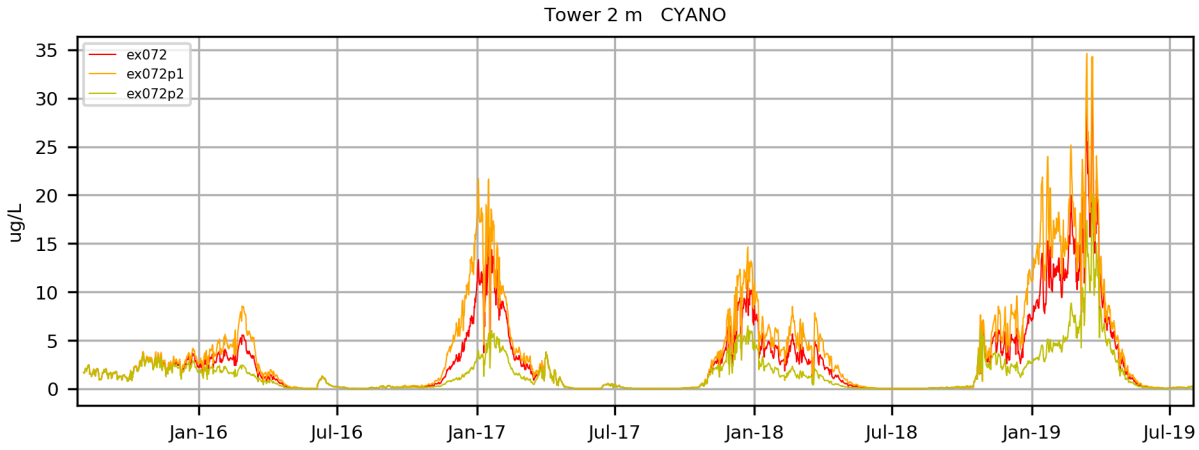


Figure B.20 Comparison between simulated cyanophyte Chl-a at the tower at 2 m deep, from simulations with sediment release rates of phosphorus of 0.008 (red), 0.01 (orange) and 0.005 (yellow) g/m^2/day.

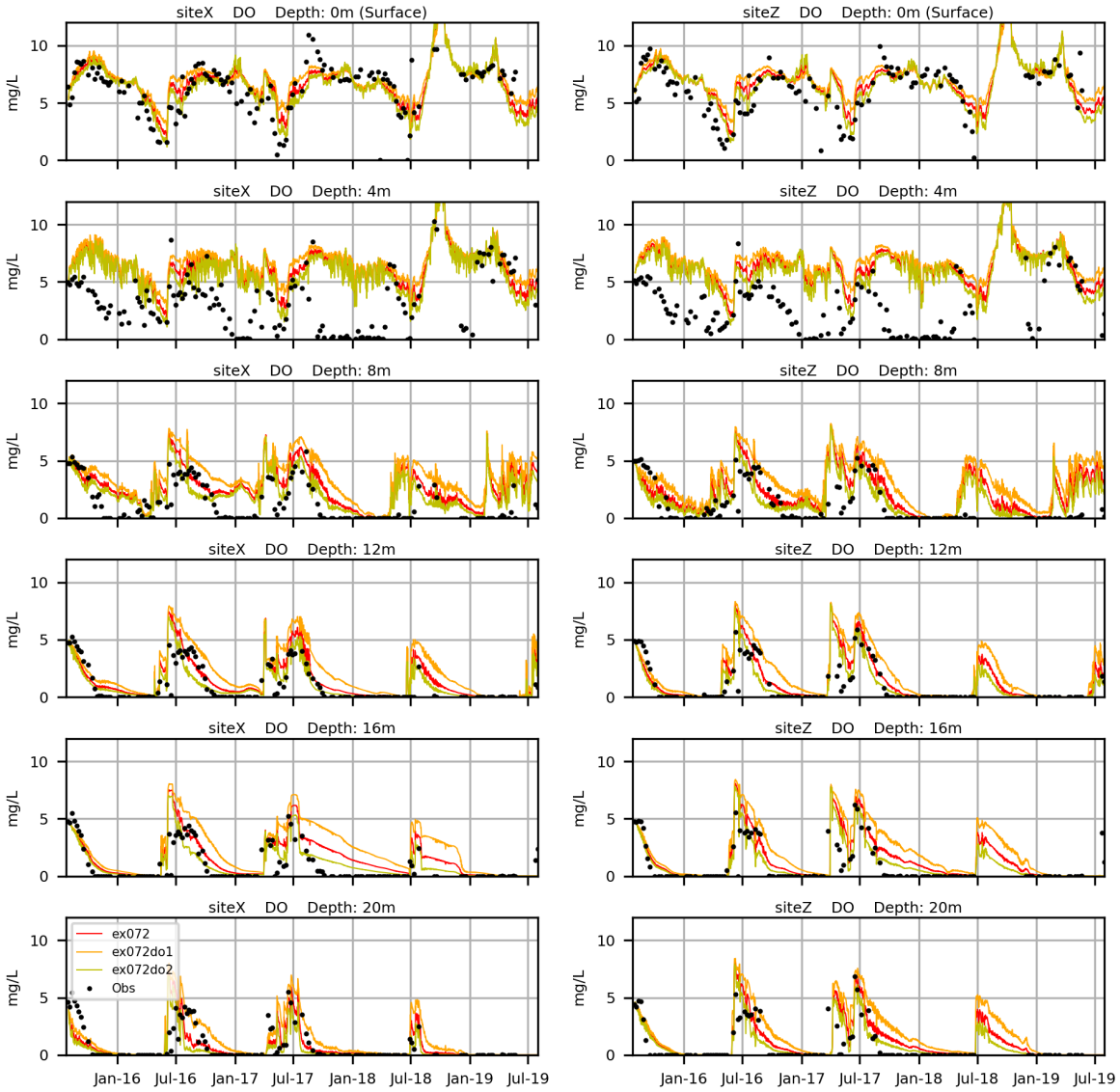


Figure B.21 Comparison between observed (black dots) and simulated (lines) dissolved oxygen concentration at depths from size X (on the left) and site Z (on the right), from simulations with sediment oxygen demand of 1.5 (red), 1.0 (orange) and 2.0 (yellow) g/m^2/day.

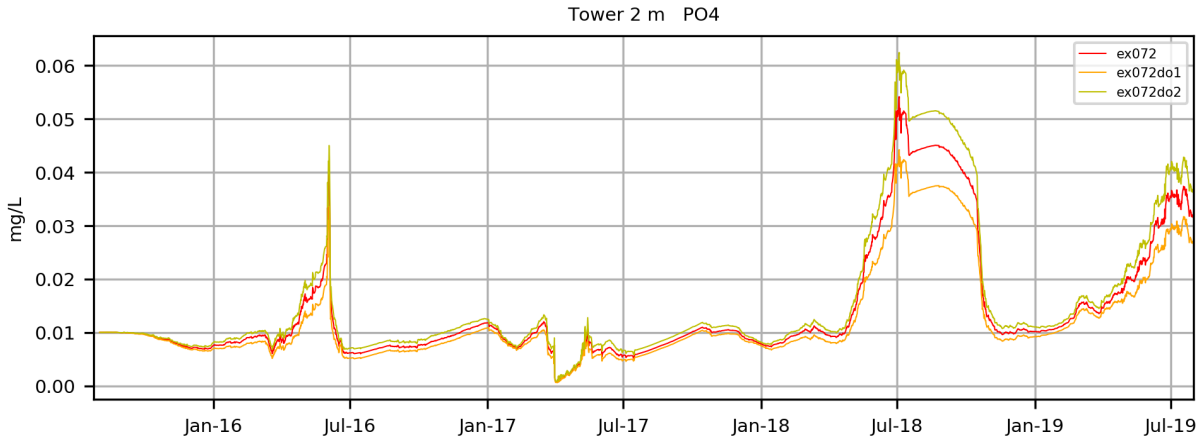


Figure B.22 Comparison between simulated orthophosphate concentration at the tower at 2 m deep, from simulations with sediment oxygen demand of 1.5 (red), 1.0 (orange) and 2.0 (yellow)

g/m^2/day.

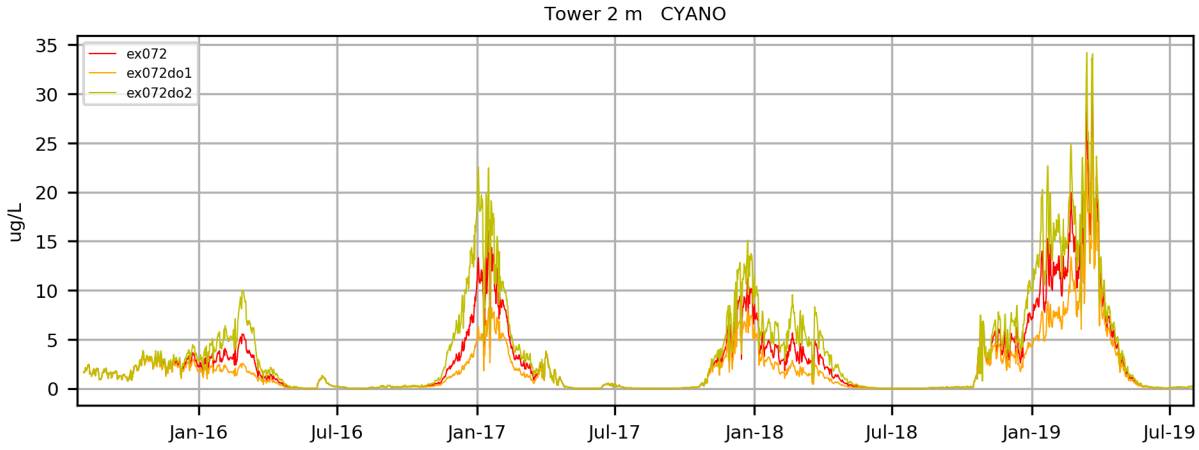


Figure B.23 Comparison between simulated cyanophyte Chl-a at the tower at 2 m deep, from simulations with sediment oxygen demand of 1.5 (red), 1.0 (orange) and 2.0 (yellow) g/m^2/day.

B.2.4. Inflow WQ

Table B.2 Boundary condition data used for model inflows in three simulations. Blank entries indicate no change to inflow variable compared to simulation on the left.

Inflow Variable	**AEM3D Inflows**		
	Cal083b	*Cal089b*	*Cal088b*
Flow	Direct from SOURCE		
Temperature	Direct from SOURCE		
Total Suspended Sediments	Direct from SOURCE	15 x SOURCE when above 4 mg/L	
Salinity	Derived from SOURCE 0.5 x TDS	Derived from conductivity and temperature measurements	
Dissolved Oxygen	Direct from SOURCE	Saturation concentration based on water temperature	
Orthophosphate	Direct from SOURCE (baseline concentration ~0.02 mg/L)	0.05 x SOURCE TP (reduces baseline concentration to ~0.003 mg/L)	0.20 x SOURCE TP (reduces baseline concentration to ~0.01 mg/L)
Dissolved Organic Phosphorus	0.0 mg/L		
Particulate Organic Phosphorus	0.0 mg/L	0.1% of TSS	
Oxidised Nitrogen	Direct from SOURCE		
Ammonia	Direct from SOURCE		
Dissolved Organic Nitrogen	Derived from SOURCE TKN – NH3		
Particulate Organic Nitrogen	0.0 mg/L	0.4% of TSS	
Dissolved Organic Carbon	0.0 mg/L		
Particulate Organic Carbon	0.0 mg/L	4% of suspended solids	
Cyanophyte Chl-a	0.5 x SOURCE TCHLA	1 ug/L	
Chlorophyte Chl-a	0.5 x SOURCE TCHLA	1 ug/L	

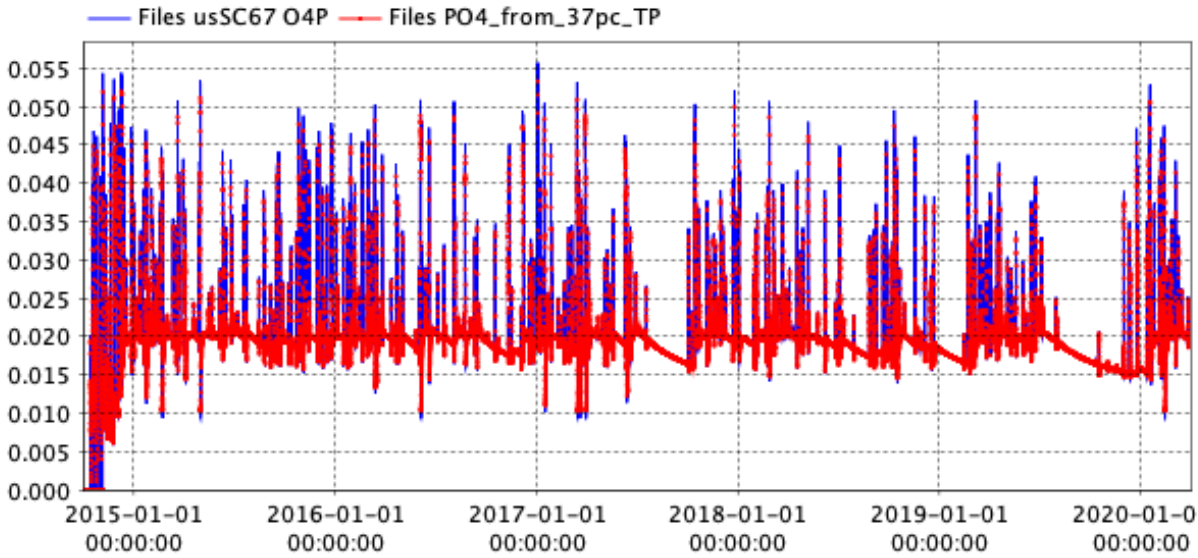


Figure B.24 Inflow orthophosphate concentrations based on 37% of TP from SOURCE output produces very similar time series to orthophosphate from SOURCE output.

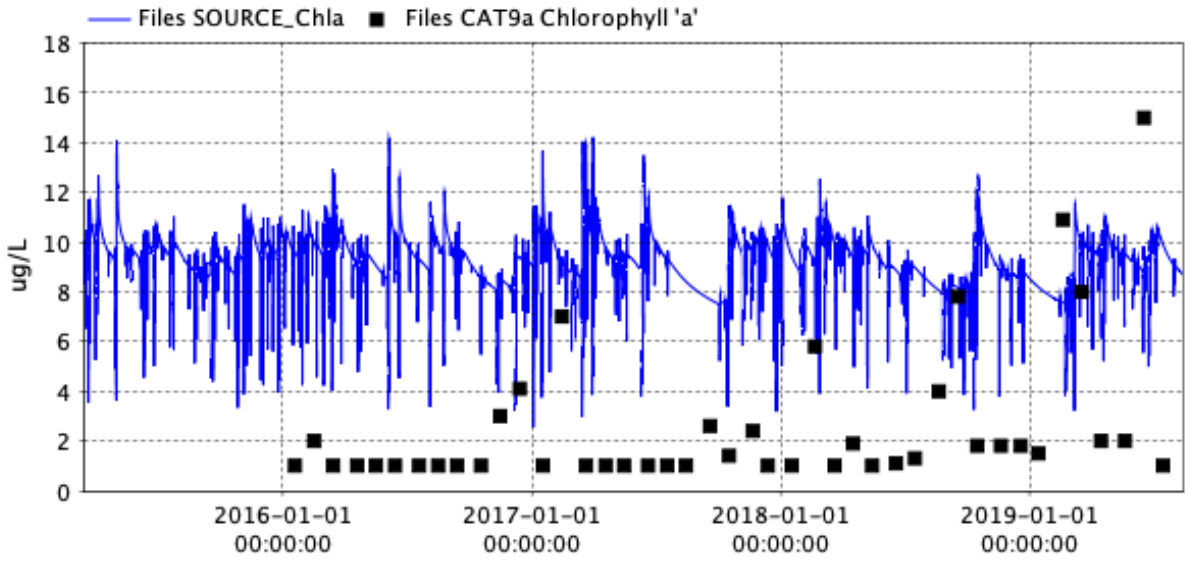


Figure B.25 Chl-a from SOURCE output and observations at CAT9a.

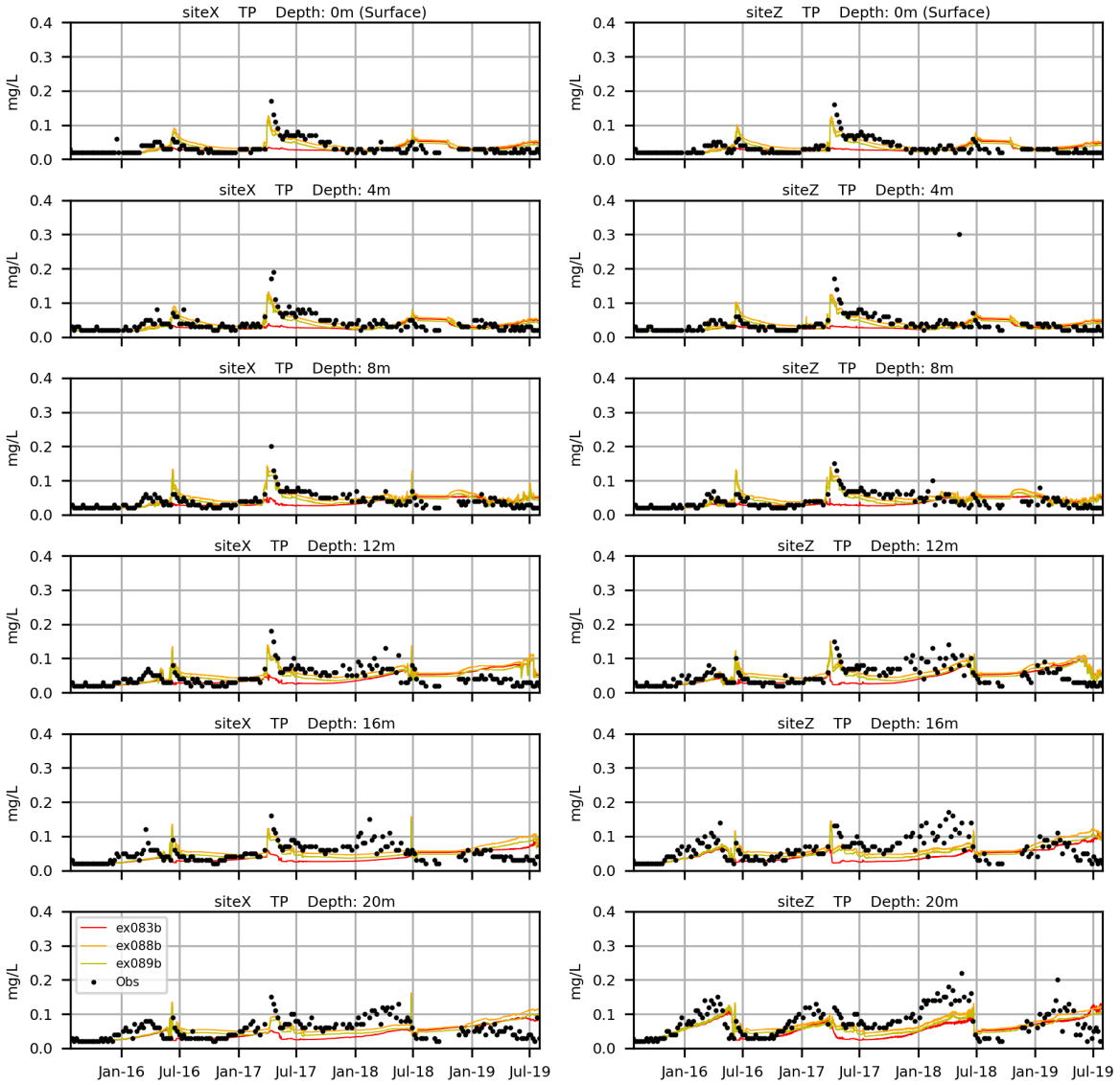


Figure B.26 Comparison between observed (black dots) and simulated (lines) total phosphorus concentration at depths from size X (on the left) and site Z (on the right), from simulations with different inflow WQ.

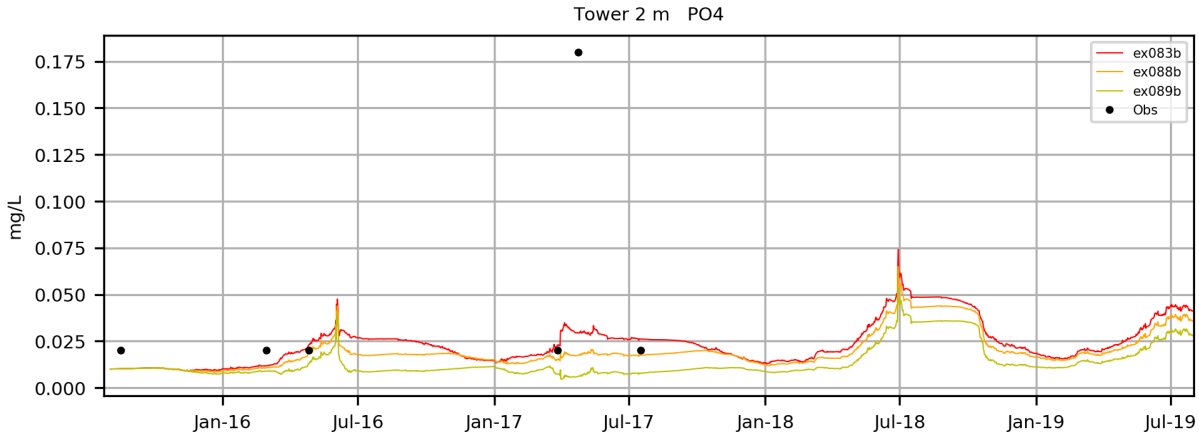


Figure B.27 Comparison between observed (black dots) and simulated (lines) orthophosphate concentration at the tower at 2 m deep, from simulations with different inflow WQ.

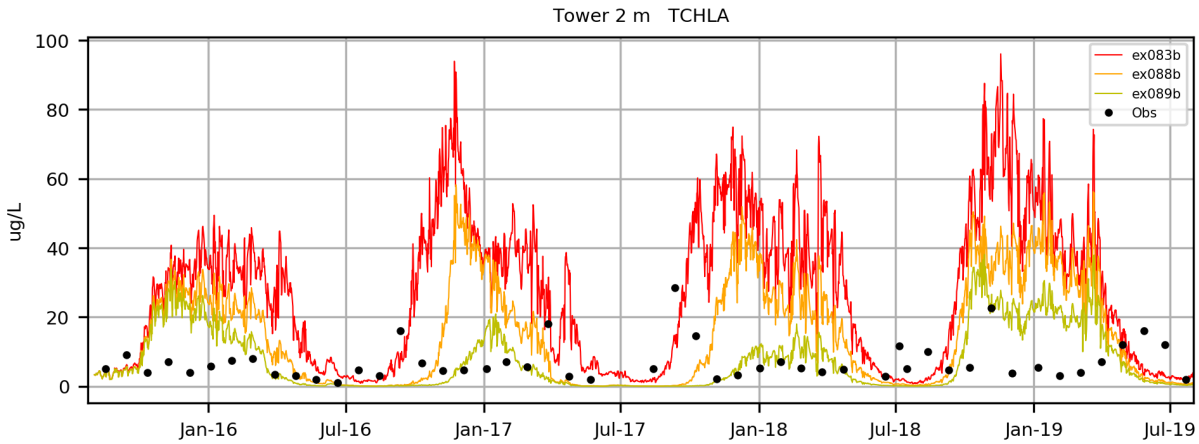


Figure B.28 Comparison of simulated total Chl-a at the tower at 2 m deep from “Existing” simulations with different inflow WQ.

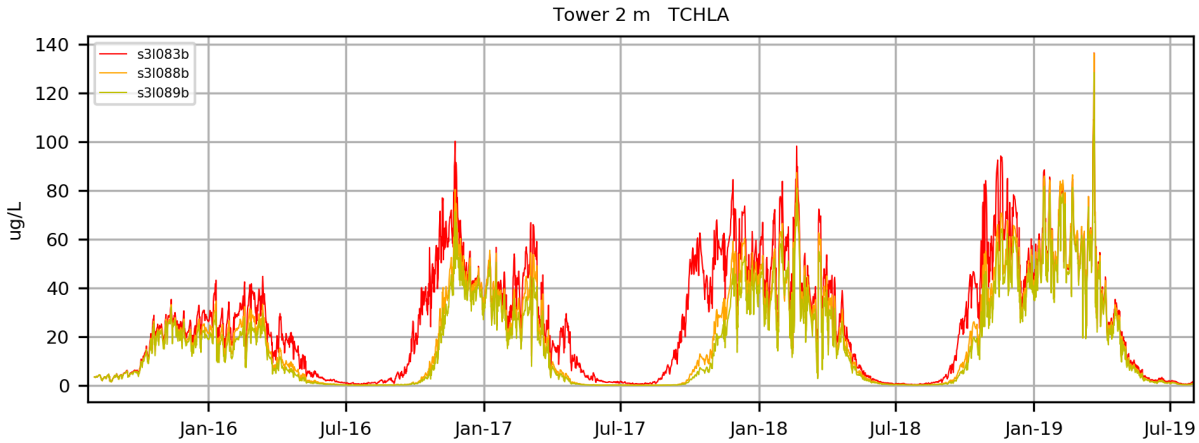


Figure B.29 Comparison of simulated total Chl-a at the tower at 2 m deep from “CCHM Low Rain” simulations with different inflow WQ.

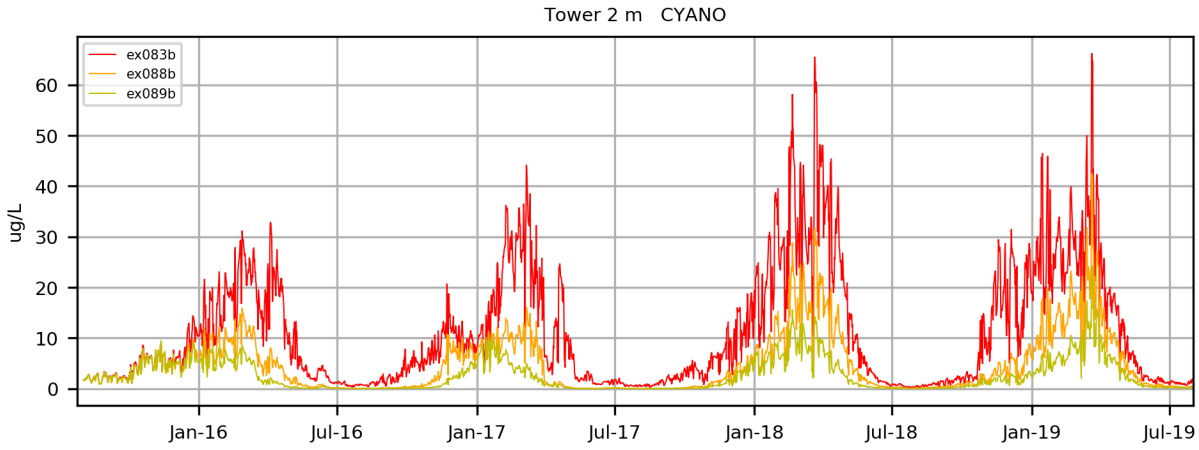


Figure B.30 Comparison of simulated cyanophyte Chl-a at the tower at 2 m deep from "Existing" simulations with different inflow WQ.

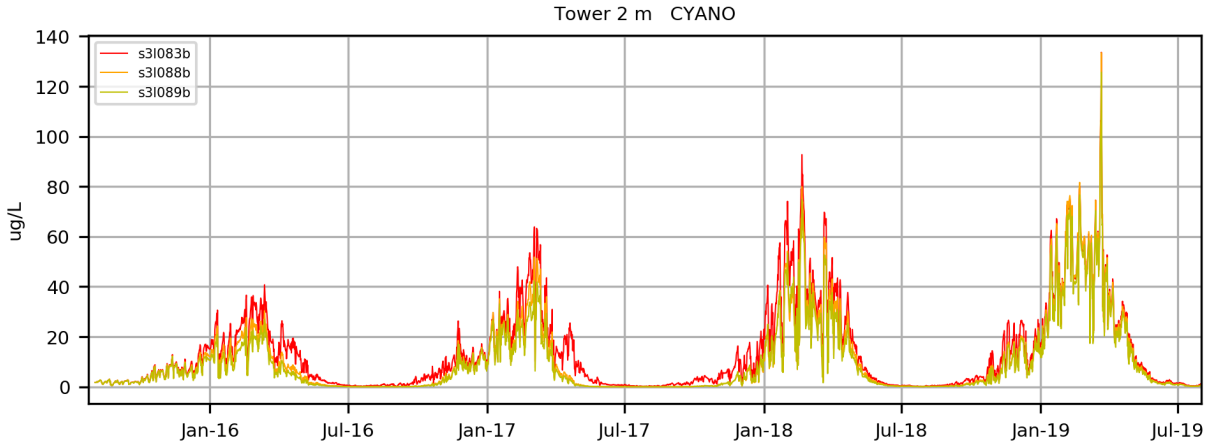


Figure B.31 Comparison of simulated cyanophyte Chl-a at the tower at 2 m deep from "CCHM Low Rain" simulations with different inflow WQ.

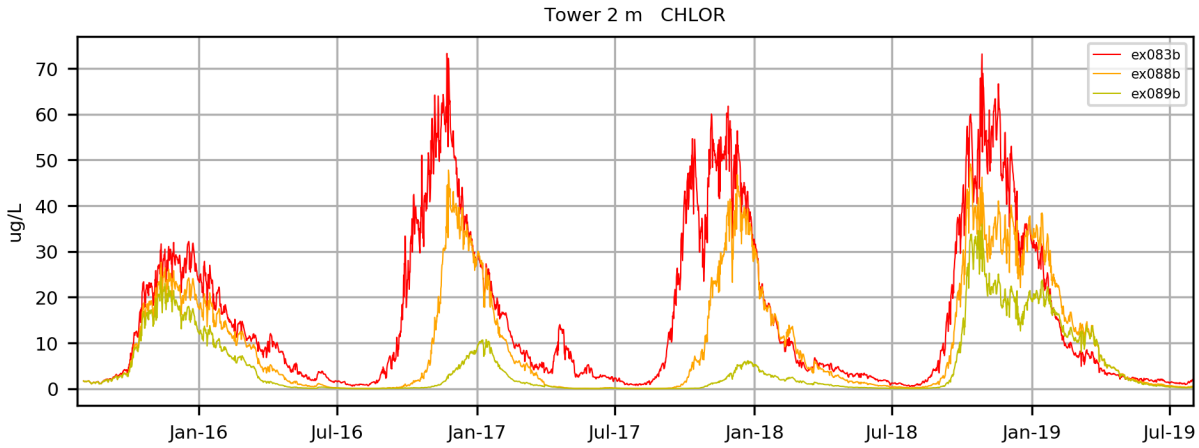


Figure B.32 Comparison of simulated chlorophyte Chl-a at the tower at 2 m deep from "Existing" simulations with different inflow WQ.

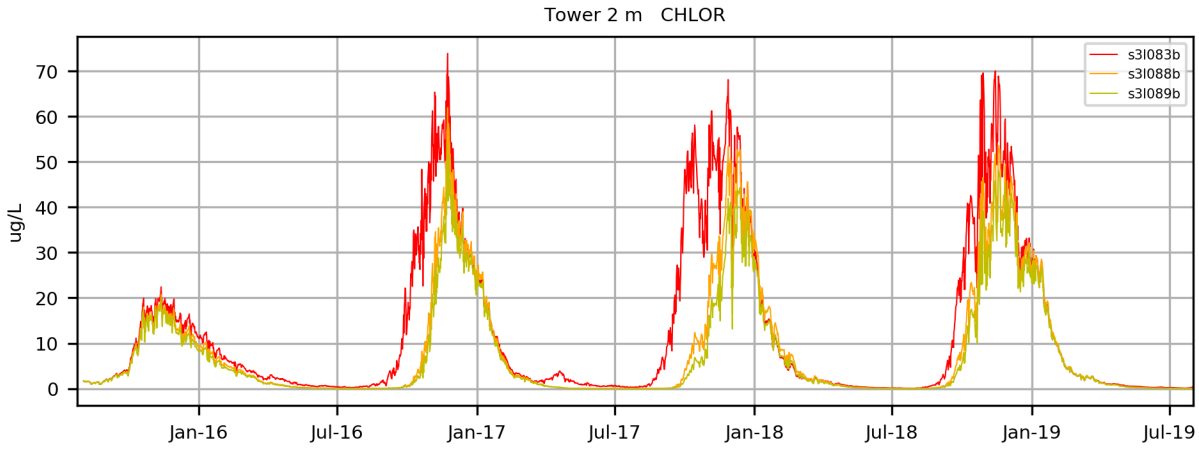


Figure B.33 Comparison of simulated chlorophyte Chl-a at the tower at 2 m deep from "CCHM Low Rain" simulations with different inflow WQ.

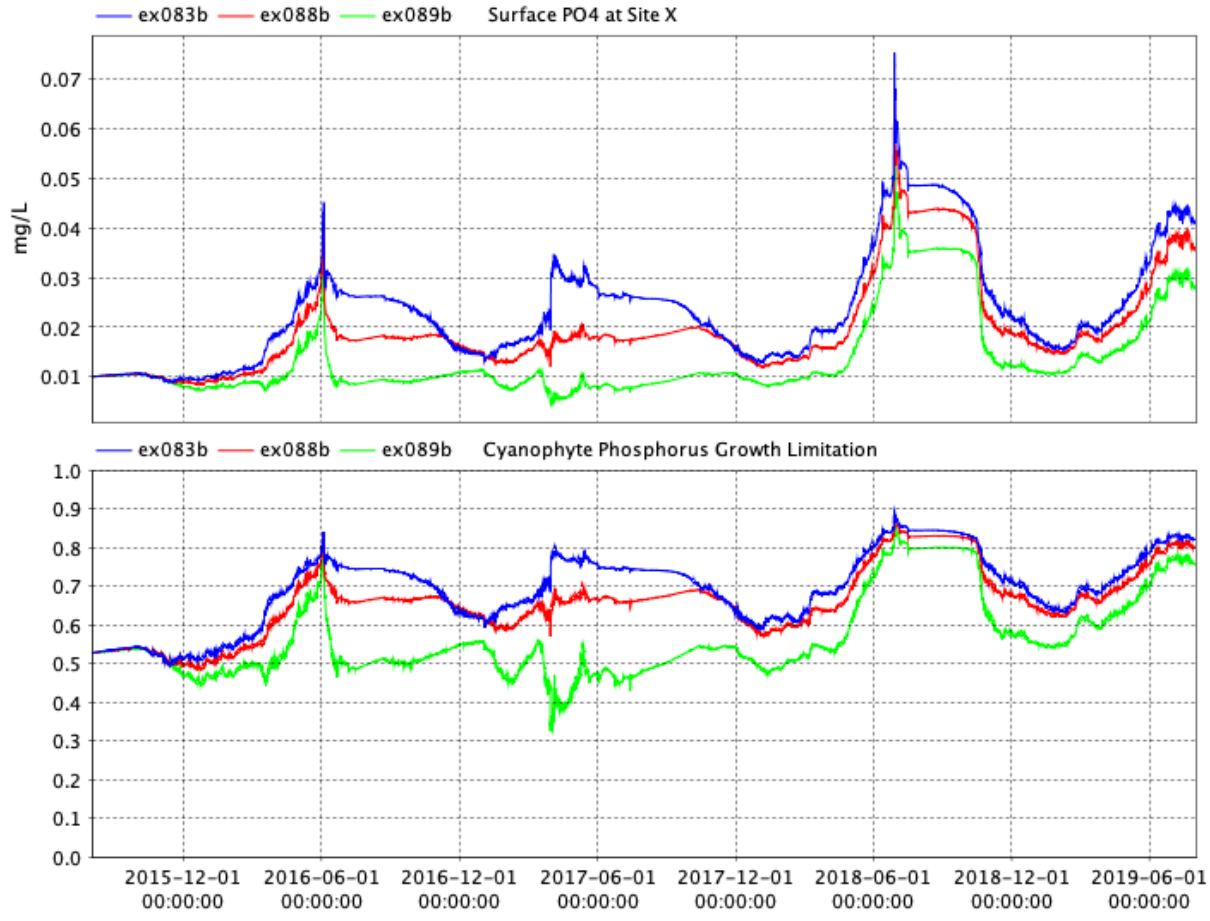


Figure B.34 Simulated PO_4 and Cyanophytes growth limitation curves for biologically available phosphorus in the surface for simulations with different inflow WQ.

Annexure C

Downstream temperature modelling

EMM
creating opportunities

Doon Doon Creek and Tweed River Temperature Model

Surface Water Assessment

Prepared for Tweed Shire Council

August 2024

Doon Doon Creek and Tweed River Temperature Model

Surface Water Assessment

Tweed Shire Council

E230039 Annexure C

August 2024

Version	Date	Prepared by	Reviewed by	Comments
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This report has been prepared in accordance with the brief provided by Tweed Shire Council/KBR and has relied upon the information collected at the time and under the conditions specified in the report. All findings, conclusions or recommendations contained in the report are based on the aforementioned circumstances. The report is for the use of Tweed Shire Council/KBR and no responsibility will be taken for its use by other parties. Tweed Shire Council/KBR may, at its discretion, use the report to inform regulators and the public.

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1 Introduction

A HEC-RAS model was created to describe the hydraulic and thermal behaviour of Doon Doon Creek and the Tweed River between Clarrie Hall Dam and Bray Park Weir to support and inform the assessment of the proposed raising of Clarrie Hall Dam (the Proposal). This report specifically deals with the thermal characteristics of the watercourses and predicted changes to temperature that may occur as a result of the Proposal, to inform assessment of potential cold water pollution (CWP) risks associated with dam releases.

2 Model choice and purpose

HEC-RAS is an industry standard hydraulic modelling software package developed by the US Army Corps of Engineers for modelling rivers and creeks. HEC-RAS is widely used for water management assessments and can be applied to a variety of ecological and environmental assessment related applications, including water quality modelling and simulation of water temperature.

The one-dimensional (1D) formulation of HEC-RAS solves the hydraulic Manning's equation using channel sections developed from cross section data in order to resolve the hydraulic conditions within all watercourses represented in a model.

The HEC-RAS water temperature model requires inputs of sub daily air temperature and humidity, air pressure, wind speed, temperature of inflowing water, and solar radiation, and applies these to the resolved hydraulic model. The temperature model does not consider detailed local effects such as shading from trees or banks at certain times of the day depending on sun height and the creek geographical orientation. The level of detail included in the HEC-RAS temperature model is commensurate with the level of detail presented in the results. This means that the actual temperature at any point in a watercourse is likely to be a little different to the modelled temperature due to site specific conditions not accounted for, but the overall picture developed by the model of changes in temperature over time towards a mean value is expected to be robust.

3 Hydraulic model construction

3.1 Geometry

Elevation data for exposed land areas was sourced from the ELVIS (Elevation Information System) database managed by Geoscience Australia (ICSM 2023). In the region of the Proposal, ELVIS contains LiDAR derived digital elevation models (DEM) with 1–2 m resolution which were combined to create a single DEM over the model domain.

A field survey was undertaken by Austral in May 2023 to collect bathymetry data for Doon Doon Creek and the Tweed River. Surveyed bathymetry cross sections of Doon Doon Creek and the Tweed River provided a series of cross sections illustrating the pool and riffle nature of the system.

The cross section geometry for the model domain (Figure 3.1) was developed using HEC-RAS and QGIS. The creek centreline, flow paths, bank lines, and cross sections were digitised by hand using the DEM and aerial photography as a guide for the position of the stream centreline. Cross sections were digitized at a spacing of approximately 200–300 m.

The creek grade extracted from the LiDAR data was relatively constant at around 0.002 m/m from Byangum to Bray Park.

The modelled river length was slightly over 16 km, from below Clarrie Hall Dam to Bray Park Weir.

Bridges were not included in the model as they have only local effects and were not the focus of the study.

Bray Park Weir was included in the model as it regulates water surface elevation and flow. The weir is situated at the downstream end of the model domain with a crest of 1 m AHD.

3.2 Boundary conditions

Downstream from Bray Park Weir the river is influenced by tides, and can exceed 1 m AHD infrequently during king tide events. The magnitude of these events can be slightly increased due to storm surges. For this study it was assumed that the water level in the tidal portion of the river was below the weir crest in all scenarios, such that the weir hydraulics controlled the water level at the downstream end of the model.

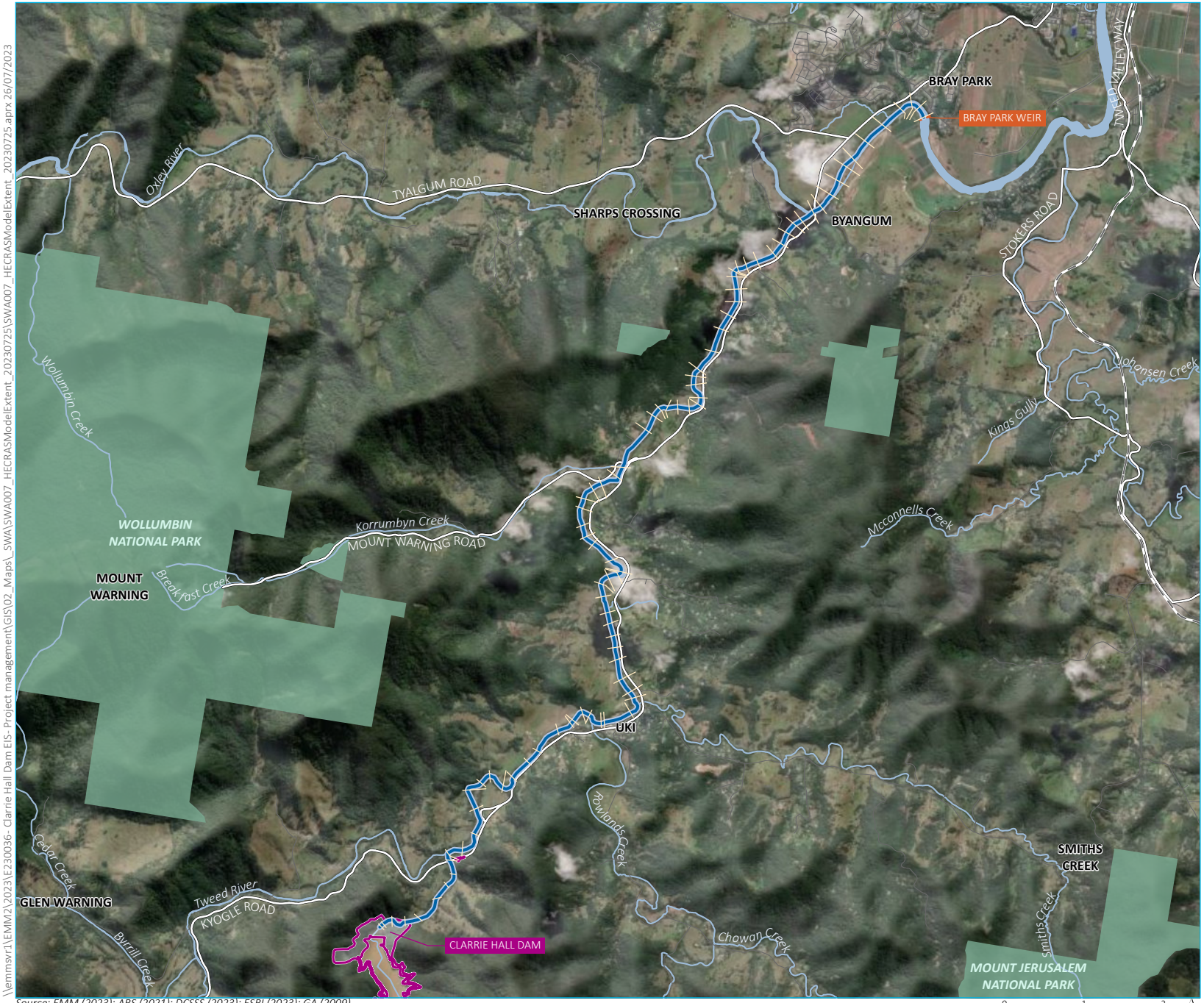
The downstream model boundary was located below Bray Park Weir as normal depth with a slope of 0.002 m/m, representing the average bed slope. This parameter had no influence on model results as the weir geometry became the controlling factor for water levels within the model domain.

Flow rates introduced into the model were dependent on the scenario being investigated, with flows introduced within ranges identified through investigation of stream flow data reported by Water NSW stream gauges.

3.3 Parameters

HEC-RAS requires few parameters as the hydraulic flow equations are primarily described through the geometric shape of the channel, the flow rate, and gravity.

A Manning's roughness *n* of 0.06 was selected initially for the channel based on calibration to gauge rating curves but was adjusted during calibration (see Section 3.4). This value is generally suitable for 'clean, winding streams with some pools and shoals, some weeds, and many stones' (Chow 1959).



\\emmsvr1\EMM2\2023\E230036- Clarrie Hall Dam EIS- Project management\GIS\02_Maps_SWA\SWA007_HECRASModelExtent_20230725\SWA007_HECRASModelExtent_20230725.aprx 26/07/2023

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

HEC-RAS model extent, thalweg and cross sections

Clarrie Hall Dam EIS
Groundwater Impact Assessment
Figure 3.1

EMM
creating opportunities

3.4 Model calibration

Calibration of the model was undertaken by adjusting Manning's *n* channel roughness. This calibration process only applies to the hydraulic calculations of the model near Uki and does not relate to the water quality aspect of the model.

A rating curve was downloaded for the Tweed River at Uki gauge (201900) from BOM's Water Data online database (BOM 2023) to calibrate flow against water surface elevation in the model. The hydraulic model was run with steady state flows from 0.001 m^3/s to 500 m^3/s. HEC-RAS generated a rating curve for the cross section situated near the Tweed River at Uki gauge, which was then extracted from the model and plotted against the rating curve from the BOM database (Figure 3.2). It was found that a Manning's *n* value of 0.03 was most suitable for the model as it had the best fit to the rating curve for the Tweed River at Uki gauge.

Channel roughness may vary up- and downstream from Uki, and so results contain increasing uncertainty with increased distance from that location.

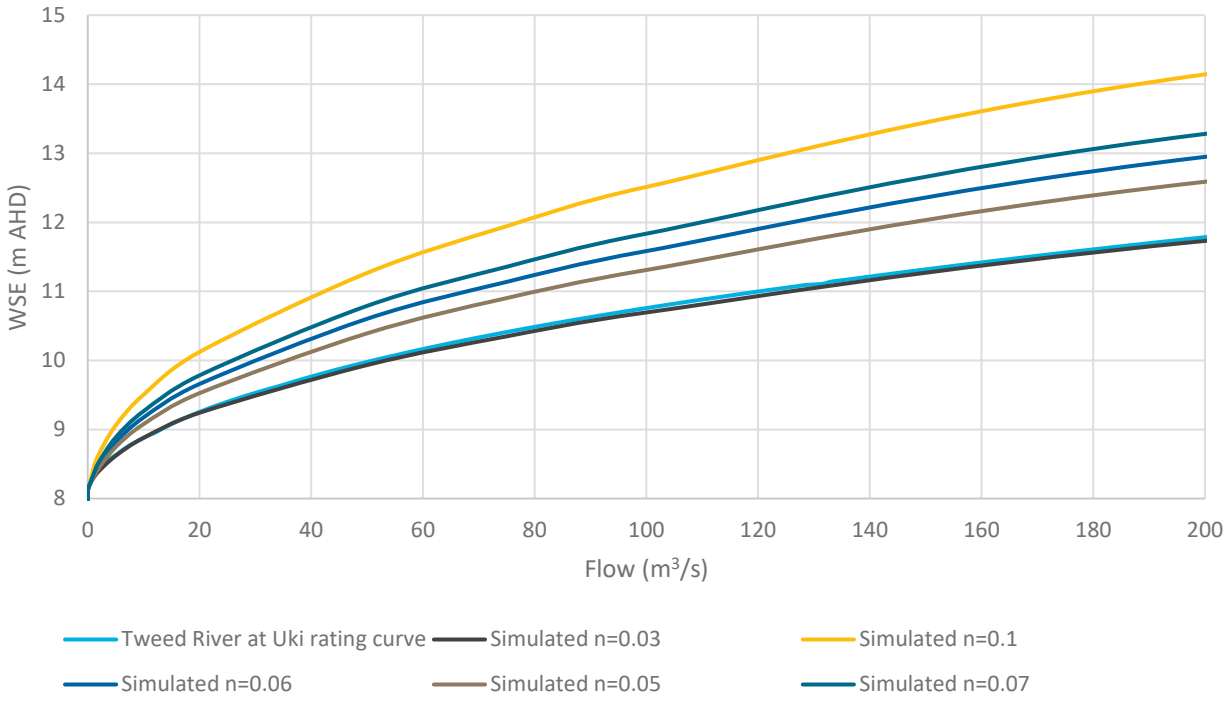


Figure 3.2 Rating curve analysis at Uki

4 Temperature model construction

4.1 Module description

The water quality simulation module in HEC-RAS uses the QUICKEST-ULTIMATE numerical scheme (Leonard 1979; Leonard 1991) to solve the 1D advection-dispersion equation. The module simulates the fate and transport of water temperature, dissolved nitrogen species, dissolved phosphorus, algae, oxygen, and biological oxygen demand (Brunner, 2016). Only the temperature components of the water quality module were applied.

The model was run only with steady state hydraulic solutions as the pool and riffle sequences created a mixture of super- and sub-critical flow conditions and resulted in a model that was not unconditionally stable for all flow rates when running with transient flows. Stable hydraulic solutions are required for the basis of water quality simulations.

As HEC-RAS is a 1D model, temperature results are averaged across the waterway and averaged with depth.

4.2 Data sources

The temperature of water discharged from the dam was selected based on typical values in summer conditions as described in the Hydronumerics (2023).

Minimum and maximum daily air temperature and humidity data and daily solar energy data were obtained from the SILO database (DES 2023) at one point close to the centre of the model domain near Uki. Daily average solar radiation data were disaggregated to hourly data between the hours of sunrise and sunset using a cubic spline pattern peaking at around mid-day. While incoming solar radiation above the cloud layer can be determined by the day of the year and latitude using geometric relationships, the SILO daily solar radiation varies in response to weather patterns and provides an estimate of solar energy at ground level, beneath any cloud cover.

Daily wind speed data were obtained from CSIRO, interpolated from Bureau of Meteorology wind speed gauges (McVicar, et al. 2008).

Example data selections are illustrated below.

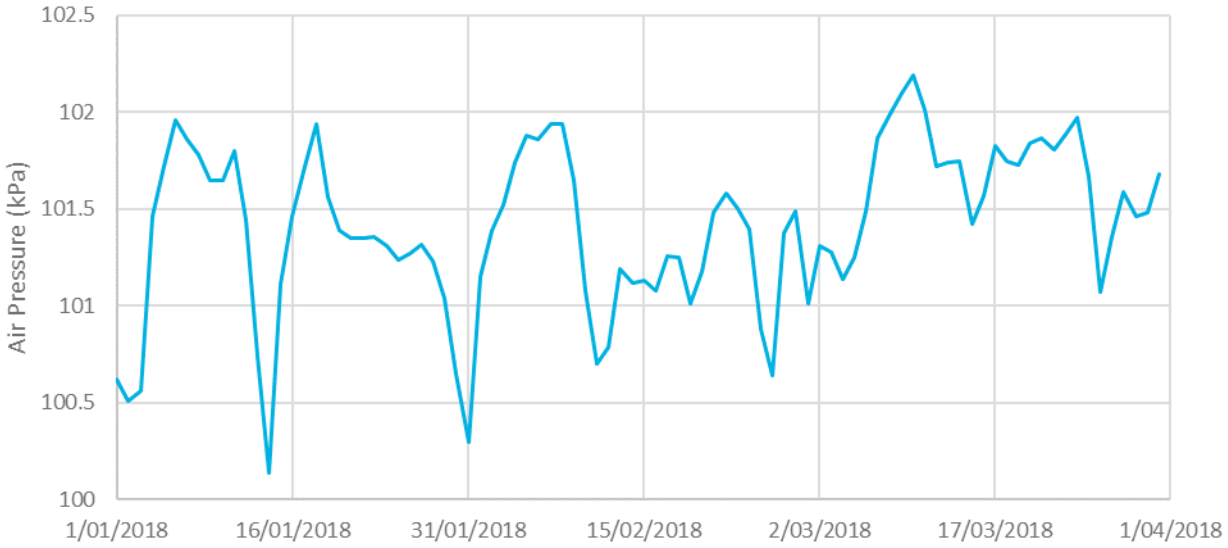


Figure 4.1 Uki air pressure (SILO) (Summer–Autumn 2018)

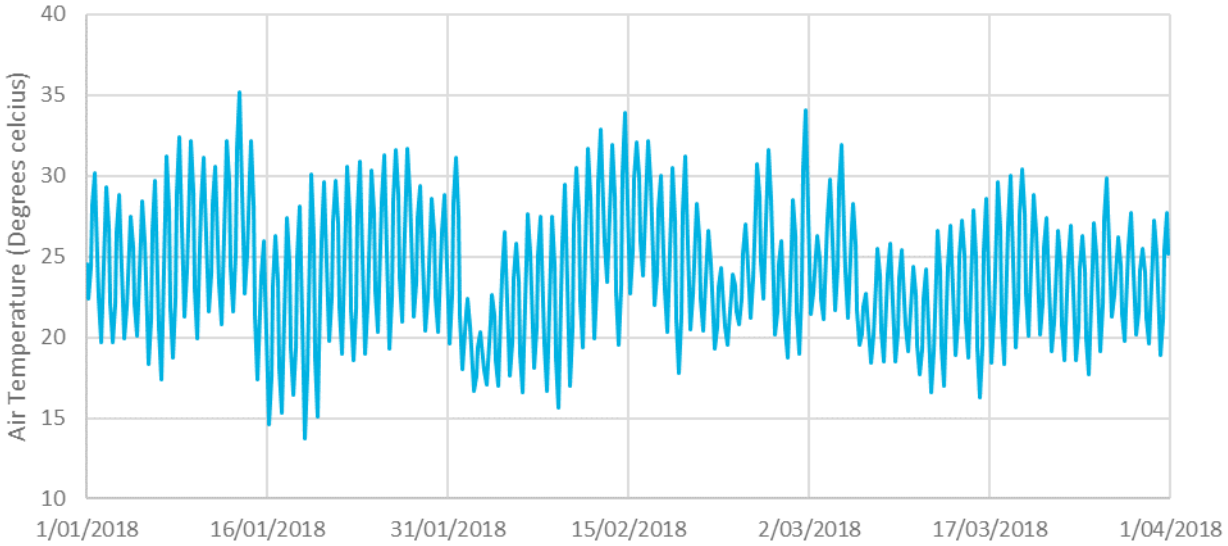


Figure 4.2 **Uki air temperature (SILO) (Summer–Autumn 2018)**

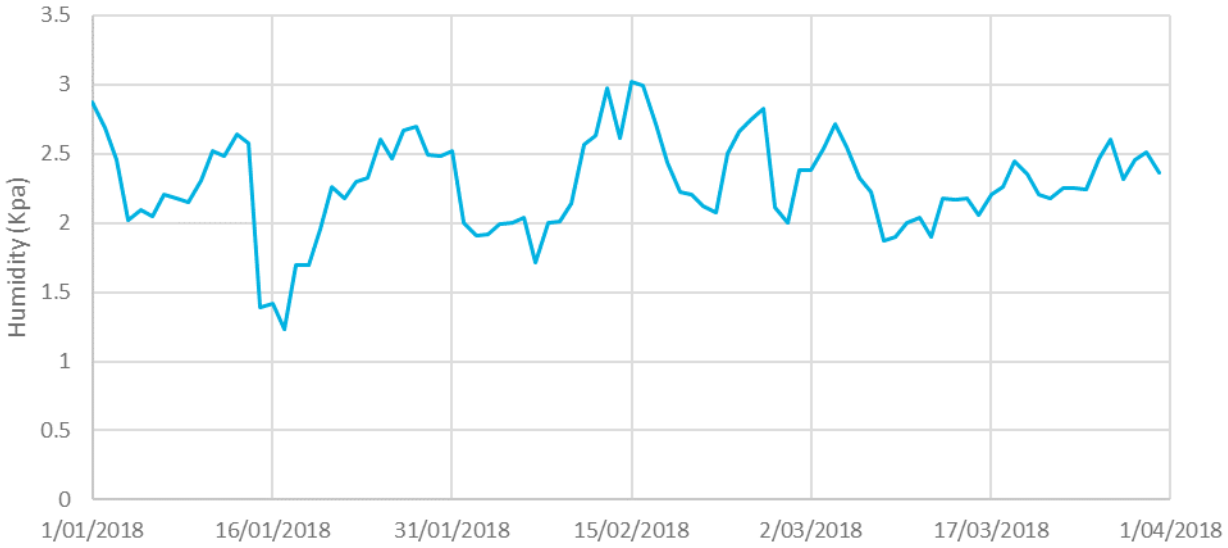


Figure 4.3 **Uki air humidity (SILO) (Summer–Autumn 2018)**

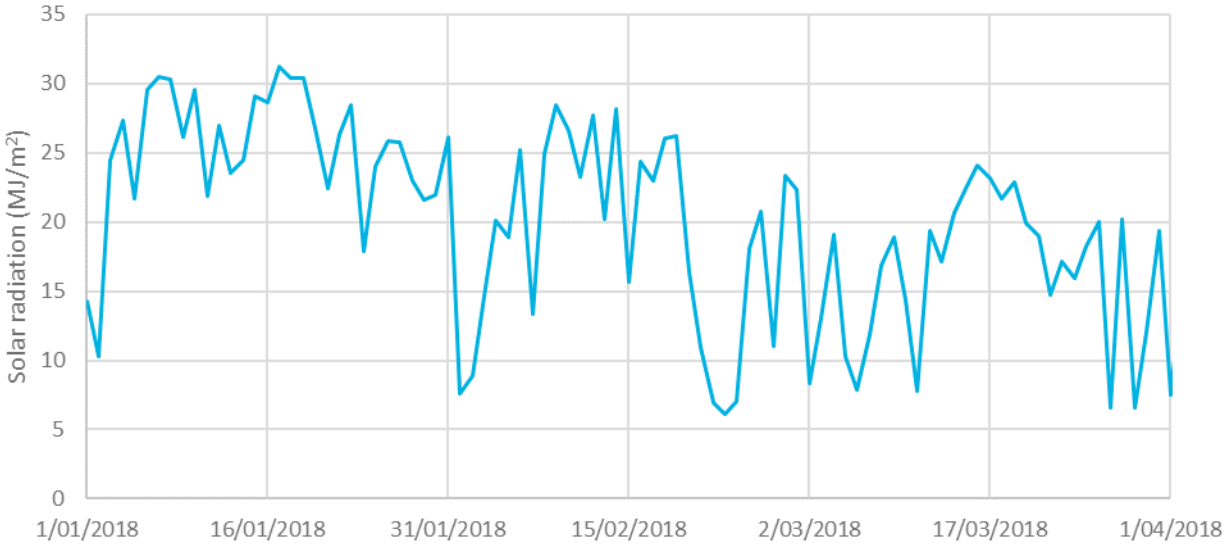


Figure 4.4 Uki solar radiation (SILO) (Summer–Autumn 2018) (daily data prior to disaggregation)

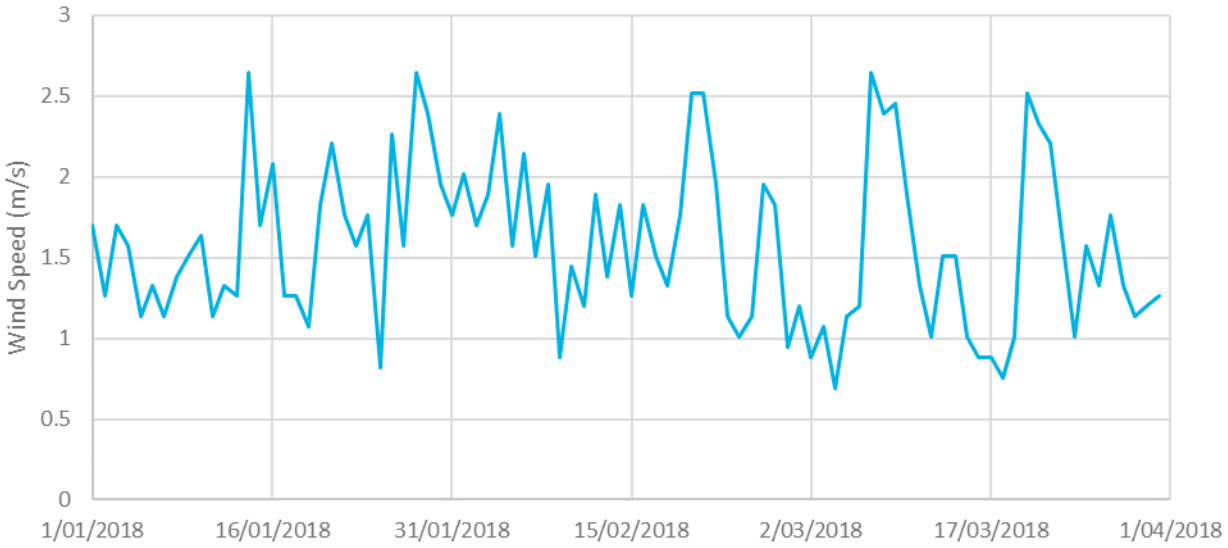


Figure 4.5 Uki wind speed (CSIRO) (Summer–Autumn 2018)

4.3 Model validation

4.3.1 Background and approach

There are few parameters which may be adjusted to calibrate a HEC-RAS temperature model, with the calculation based on the energy balance developed from the entered climate data. Published studies (Stonewall and Buccola 2015) indicate that the parameters which most significantly affect the solution are:

- Manning's *n*, as the hydraulic roughness affects travel time and water depth
- short-wave radiation inputs.

Hydraulic roughness was calibrated as part of the hydraulic model construction as detailed in Section 3.4, and there is not a strong basis to alter this for the temperature model.

As the HEC-RAS energy balance model does not include energy gain or loss due to interaction with groundwater, or from bed materials, and does not include shading effects, some studies have applied scaling factors for solar radiation inputs to account for unmodelled processes.

Johnson (2004) describes experiments in small streams in which the diurnal temperature range was found to be larger in reaches with bedrock stream beds, and lower in reaches with alluvial stream beds. It was proposed that in alluvial reaches water contained in the hyporheic zone (near surface groundwater, and water within stream gravel beds) adds additional thermal mass, and mixing with this water through the day and night will reduce both day and night temperature extremes.

Rutherford et al (1997) describes interactions with bank vegetation, whereby vegetation shades the creek and absorbs energy during the day, reducing peak stream temperatures. At night the vegetation releases some energy, and also provides a micro-climate with lower wind speed which reduces the extent of overnight temperature falls.

HEC-RAS has no built-in method for adding hyporheic influences or night time heat sources, but wind speed parameters can be used for adjusting the local effect of wind such as due to bank vegetation, and disaggregated solar energy inputs can be adjusted prior to modelling to account for shading and thermal inertia.

No investigations have been undertaken for the current study to determine whether the processes described by Johnson (2004) and Rutherford et al (1997) occur within the Tweed valley. However, Doon Doon Creek below Clarrie Hall Dam flows though sandstone and quartzite valley, while the Tweed River flows through an alluvial valley with a granite section. Doon Doon Creek is incised with significant bank vegetation, so it would be reasonable to expect that these processes are occurring to some degree.

On this basis model parameters were adjusted to refine the model to produce temperatures in the range of available observed data and with warming over the observed duration/distance. The following changes were made to adjust the model results:

- Solar radiation was reduced by 30% to account for shading of Doon Doon Creek and the Tweed River reducing total solar input into the system. This reduced average modelled water temperature to align with observations.

- 30% of the remaining solar energy was subtracted from daylight hours and applied at night, simulating the assumed potential effect of the hyporheic zone in absorbing daytime solar energy and releasing at night. This reduced the modelled diurnal temperature range to align with observations more closely.

- The daily gridded wind speed data from CSIRO were benchmarked (adjusted) to BOM observations at Lismore as the average wind speed from in the CSIRO data set was lower than the local recorded data.

4.3.2 Observed water temperature data

Stream temperature was monitored by Council from late February 2023. In April 2023 Council made a cold water release of 30 ML/d for a 12 hour period (i.e. approx. 15 ML released) to monitor how far downstream CWP might travel. Monitoring points included up- and downstream of Clarrie Hall Dam (i.e. in the reservoir and in Doon Doon Creek), Palmers Road bridge (Tweed River upstream from Doon Doon Creek), Tarcoola crossing (Tweed River), Uki water treatment plant (Tweed River), Bray Park Weir (Tweed River), Old Lismore Road (Oxley River) and Mount Warning Road (Tweed River).

4.3.3 Model validation – March 2023

For the period 1 March 2023 to 25 March 2023 flow past Uki was in the range 22 – 66 ML/day, with an average flow of 38 ML/day (Figure 4.6). With relatively constant flows and no large flow peaks occurring, this period was appropriate for use for temperature model validation using a stable steady state flow solution. Figure 4.7 to Figure 4.9 illustrate observed and modelled temperature results at three locations within the Tweed River.

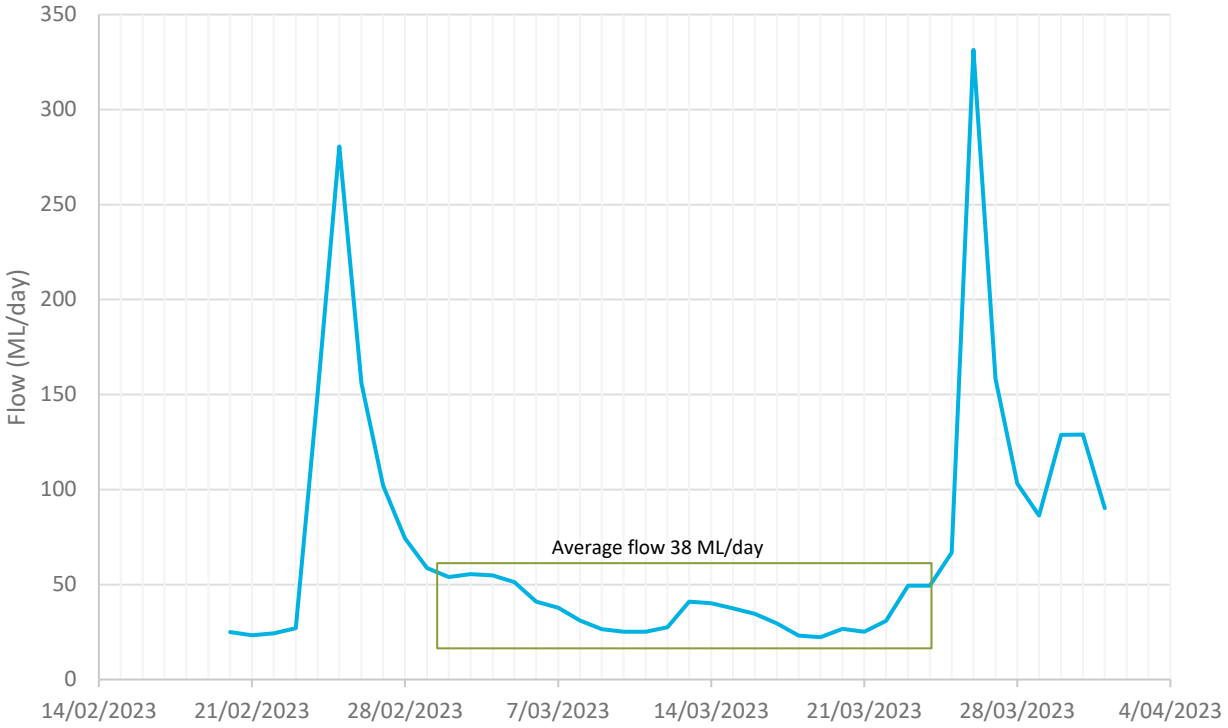


Figure 4.6 Tweed River flow past Uki (March 2023)

Average observed temperatures at all three sites were around 26°C. These were approximately replicated by the model, indicating that the overall energy balance is appropriate.

At Tarcoola and Byangum the observed water temperature had a relatively muted diurnal signal, with temperature fluctuations in the order of <1°C. In contrast, the diurnal signal at Uki was 2–3°C. The model did not predict the damped signal at Tarcoola Lane bridge, but did predict an appropriate diurnal range at Uki and a damped response at Byangum that were consistent with observations.

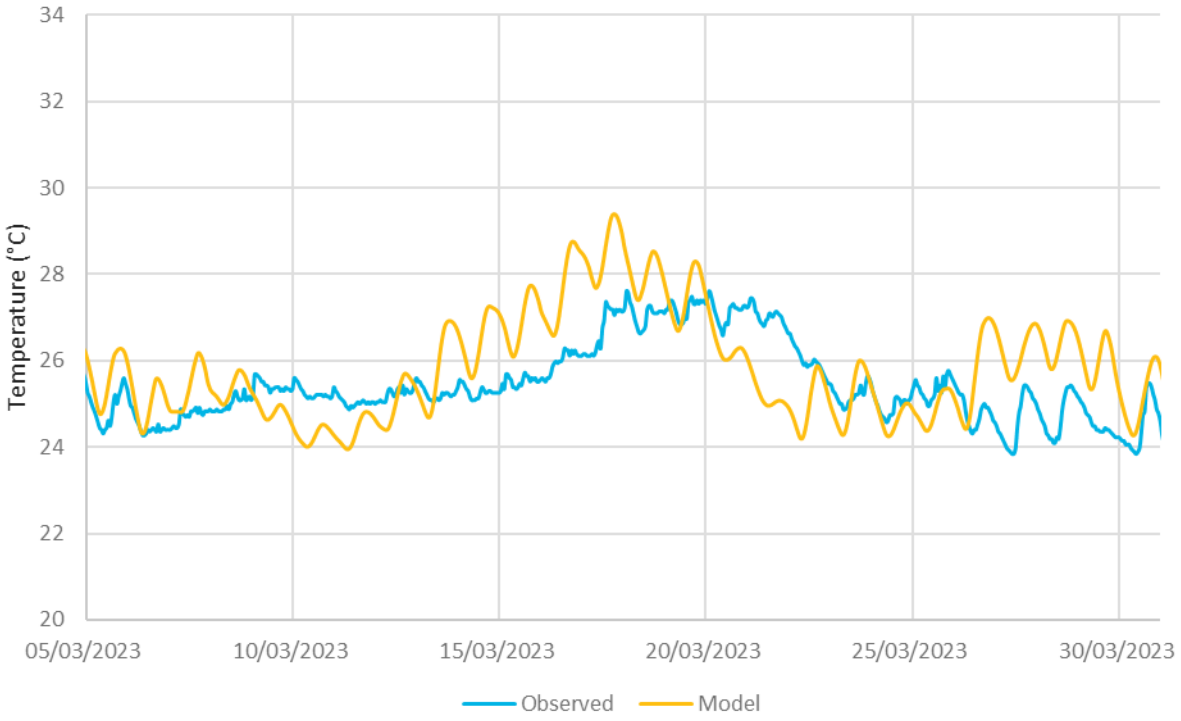


Figure 4.7 Temperature comparison at Tarcoola Lane bridge (approximately 3 km from Clarrie Hall Dam)

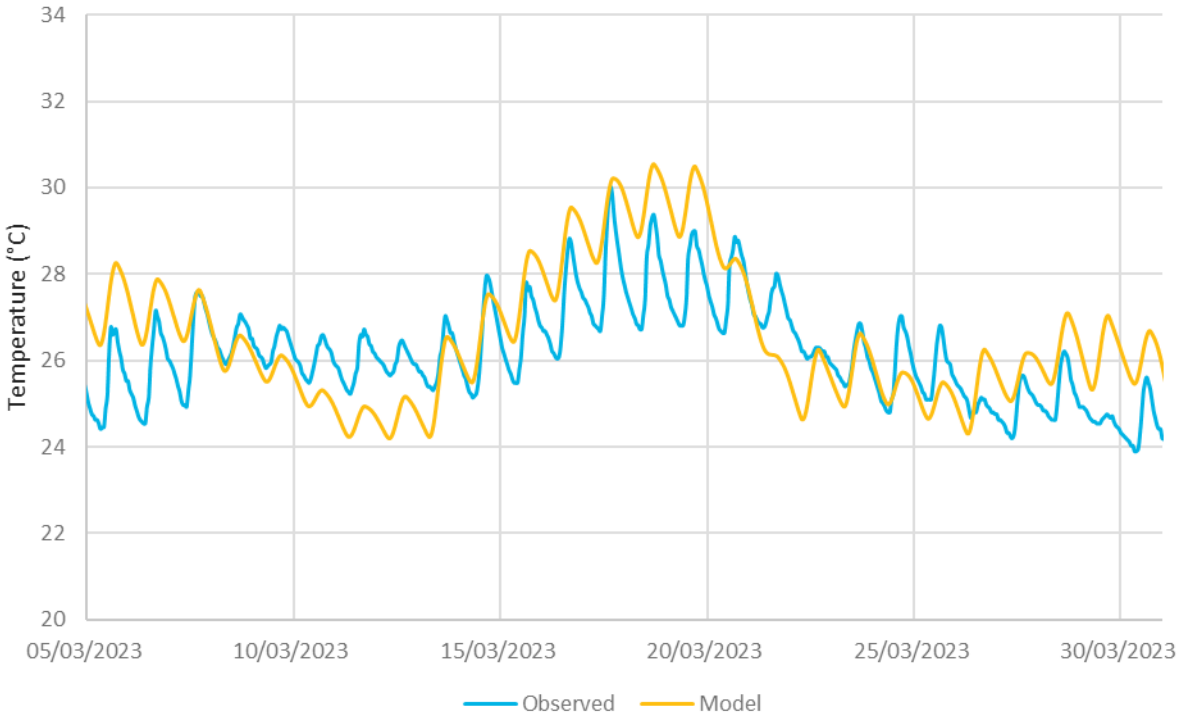


Figure 4.8 Temperature comparison at Uki water treatment plant (approximately 5 km from Clarrie Hall Dam)

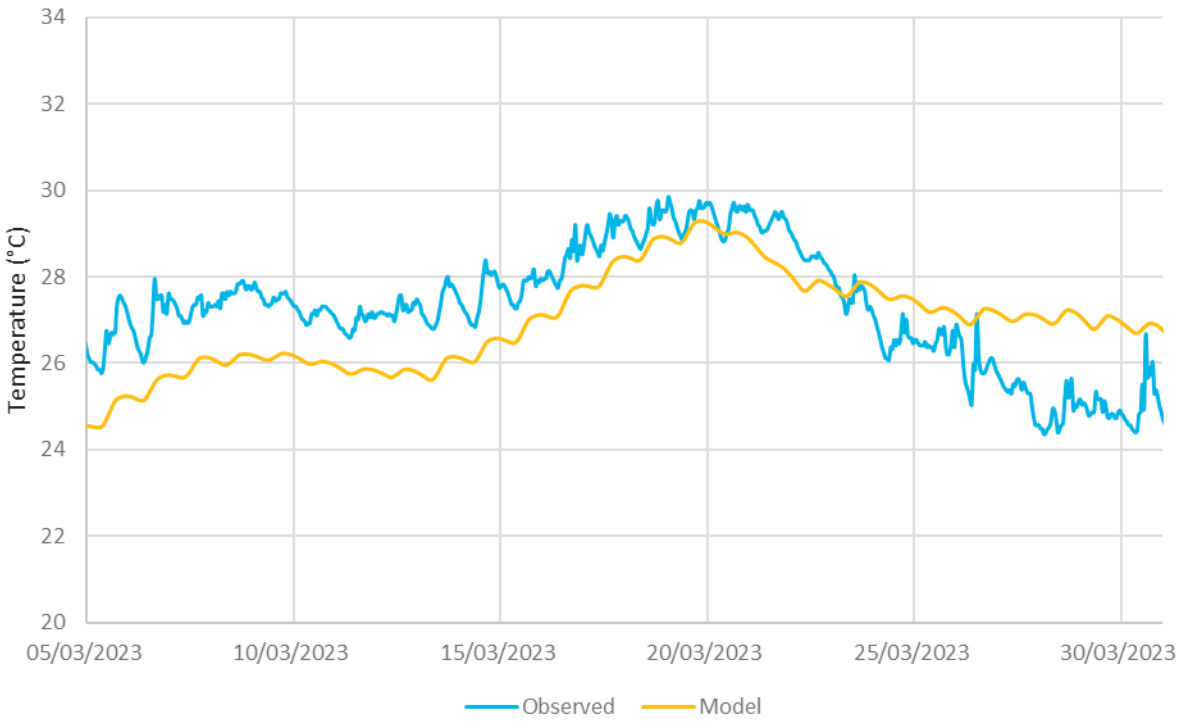


Figure 4.9 Temperature comparison at Byangum Bridge (approximately 14 km from Clarrie Hall Dam)

4.3.4 Model validation – April 2023 cold water release

A controlled discharge from Clarrie Hall Dam was undertaken in April 2003 to support empirical understanding of the fate of a cold water release along Doon Doon Creek and the Tweed River and its influence on receiving water temperature, and allow collection of data to support development of the temperature model that could be used to predict impacts of cold water releases for a broader range of scenarios. The discharge commenced at 8:00 pm on 5 April and continued until about 8:00 am on 6 April 2023, at a rate of 34 ML/day (i.e. 17 ML released).

Flow in the Tweed River at the time was approximately 20 ML/day, therefore the release would have resulted in about 2:3 mixing at the confluence of the Tweed River and Doon Doon Creek. Within the dam spillway pool there was an immediate 6°C drop in temperature when the release started (Figure 4.10). At the downstream end of Doon Doon Creek the temperature dropped 3.5°C. No changes to temperature were seen in the Tweed River at Tarcoola Lane bridge or Uki, with temperatures matching those measured upstream at Palmers Road (Figure 4.10).

A model simulation of the release was developed using quasi-unsteady flows (a series of steady flow steps), with flows and temperatures as per Table 4.1.

Table 4.1 Simulated flow and temperature conditions – April 2023 cold water release

Flow period	Dam release (ML/d)	Release temperature (°C)	Upstream Tweed River flow (ML/d)	Upstream Tweed River temperature (°C)
Pre release	10	Variable as per reservoir temperature transducer. Approximately 24°C	20	Variable as per 'Palmers Road' series in Figure 4.10. Approximately 22°C
Release	30	18	20	
Post release	5	Variable as per reservoir temperature transducer. Approximately 22°C	20	

A comparison of the modelled results with observed data is provided in Table 4.2. The modelled temperature results are similar to observations, with the following divergence from observed data:

- the modelled cold water release travelled further before warming than was observed
- reaches of Doon Doon Creek remained colder for longer after the cold release had passed
- it took approximately 2 hours in the model before water temperature began to drop at the end of Doon Doon Creek, while observations were that it took 6 hours.

Possible explanations for these effects are:

- Doon Doon Creek contains large rocks and boulders which may have contained more latent heat that was allowed for in the model. As discussed in Section 4.3, HEC-RAS does not include a native method to account for this effect, and it has been partially accounted for by time shifting part of the solar energy inputs from the day into following nights. This adjustment is applied globally to the model and cannot be adjusted for specific cross sections. Adjusting this parameter for Doon Doon Creek would dampen diurnal temperature fluctuations throughout the model.
- It is likely that following the cold water release, cold water settled to the base of pools, and did not mix with warmer water flowing down the Tweed River, or with warmer water released over the spillway following the cold water release. The weir pool thermistor could have thus recorded colder temperatures even while warmer water could have flowed above, resulting in an appearance of a longer period for the weir pool temperature to warm up. This would also have had the effect of reducing cold slug transmission and could account for the difference in distance the cold slug was detected. As a 1D model, HEC-RAS assumes complete vertical mixing at each cross section and cannot simulate differences in water temperature between the top and bottom of pools, or simulate warmer water flowing over the top of unmoving cold water.
- It is possible that a high permeability hyporheic zone exists within rocks that form the bed and banks, and that the total volume of water that can be stored in the creek is larger than the surveyed cross section dimensions imply. However, it is unlikely the volume stored in this zone his would explain the difference in released water residence time in Doon Doon Creek, as part of the released volume would have filled voids between rocks rather than flowing downstream. The volume of water required to fill these voids is insignificant compared to release rate and wouldn't result in the observed longer duration before cold water arrived at the downstream end of the creek. It is most likely that the lag in cold water experienced is from latent heat in the system that was unable to be quantified.

Table 4.2 Comparison of observations and model response – April 2023 cold water release

Aspect	Observation	Model response
Release temperature.	Temperatures in the weir pool began falling at 8:00 pm 5 April 2023 from 23°C. The lowest temperature in the weir pool was 17.8°C at 7:00 am on 6 April 2023, 11 hours after the release commenced.	The observed temperature was applied as a model boundary condition for 12 hours.
Temperature change along Doon Doon Creek during the release.	Approximately 1.5 °C warming along Doon Doon Creek.	Approximately 0.5°C warming along Doon Doon Creek.
	Arrival of cold water after 6 hours.	Arrival of cold water after 2 hours.
Temperature change at Tarcoola.	No change.	Approximately 4°C drop in temperature for around 24 hours.
Temperature change at Uki.	No change.	No change.
Rate of warming within Doon Doon Creek.	Approximately 48 hours to warm following the cold pulse.	Approximately 12 hours to warm following the cold pulse.

The above comparisons imply:

- For short duration releases, the model may overestimate the distance which cold water travels. This overestimate is likely to reduce with longer duration releases as deeper pools and the bank portion of the hyporheic zone would trap only the 'first flush' of cold water. The distances predicted for the 3 day pulse releases documented in Chapter 5 are likely to have only a minor overestimate of travel distance.
- The base of deeper pools may experience longer duration cooling than the model results imply, as the model assumes vertically mixed conditions.

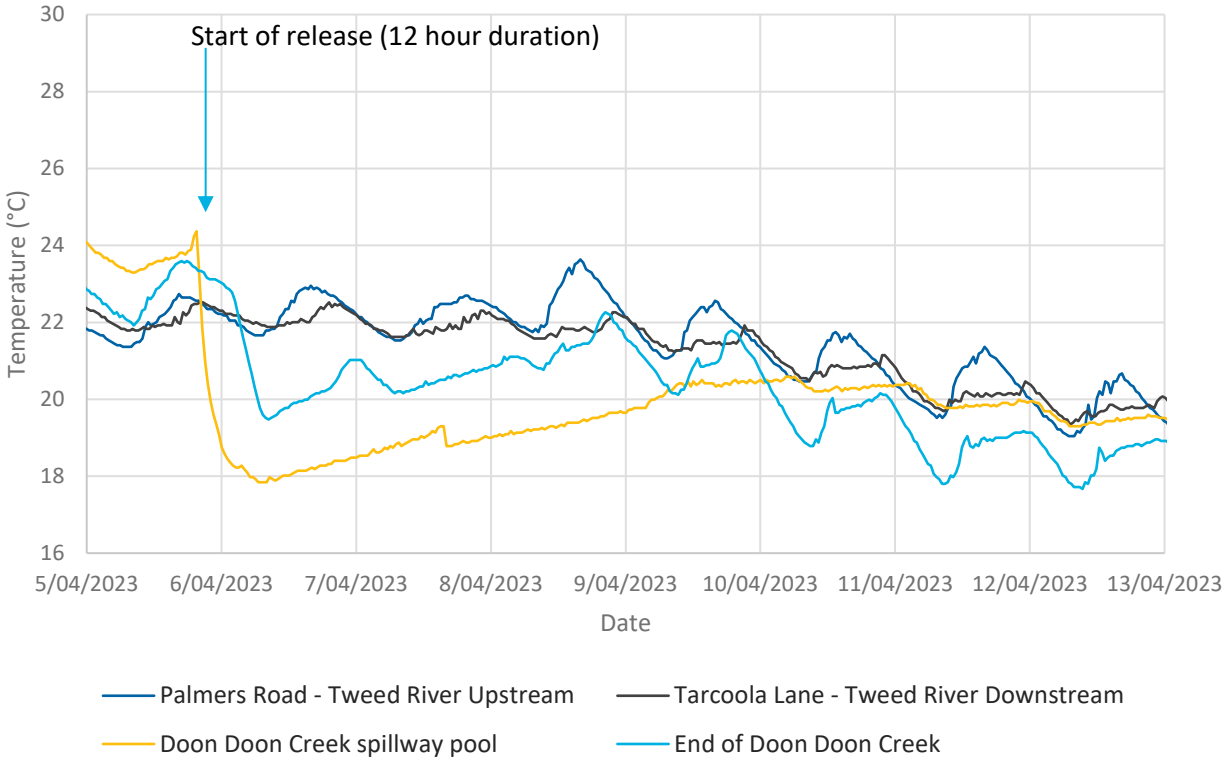


Figure 4.10 Observed water temperatures – April 2023 cold water release

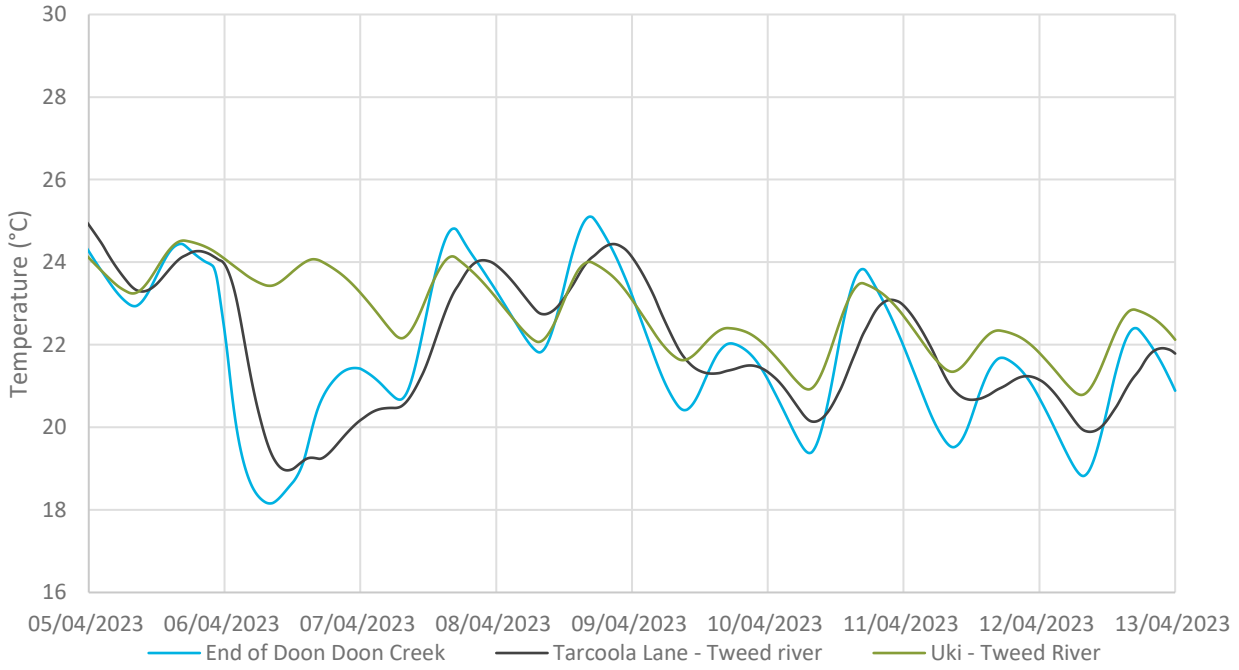


Figure 4.11 Modelled water temperatures – April 2023 cold water release

5 Cold water release scenarios

Several CWP scenarios were developed to investigate the response of Doon Doon Creek and the Tweed River to release of cold water from Clarrie Hall Dam using the temperature model described in Chapter 4. These scenarios were developed with consideration of limnology modelling presented by Hydrosphere (2023) which illustrated that:

- With the current dam, a common summer water temperature within the hypolimnion is around 16°C.
- With the proposed dam, the water temperature in the hypolimnion at the same time of year may increase to 17°C.
- In each case, water near the dam surface is typically around 25°C in summer.

For the purposes of this report, CWP was defined as the difference between:

1. A 'base case' defined as the temperature of water in the watercourses downstream from the dam following a release of 25°C water over the spillway.
2. The temperature of watercourses downstream from the dam if the same volume of water was released from the hypolimnion.

Modelling scenarios were run using climate data for summer months only, as CWP is a problem primarily in summer months when dam stratification leads to a colder water temperature below the reservoir thermocline than the natural stream temperature at that time of year. This aligns with the recommendations of the NSW Cold Water Pollution Inter Agency Group (2017), who recommend targeting summer months only for CWP management measures, as NSW reservoirs tend to become fully mixed in winter and temperature management measures become impractical outside summer months.

A 'worst case' scenario was modelled in which no tributaries contributed water to the Tweed River downstream from Doon Doon Creek. In reality, runoff from catchments downstream of the dam wall could enter the creek and mix with flows influenced by cold water releases, reducing the effect of CWP. Another scenario was built to assess the impact of existing flow in the Tweed River on CWP.

Modelling scenarios were set with five different flowrates being constantly released from the dam. Modelled flowrates included:

- 10 ML/d for 3 days, representing a small release
- 30 ML/d for 3 days, representing a below average release currently made
- 50 ML/d for 3 days, representing a common type of release currently made
- 70 ML/d for 3 days, representing a possible future release with larger population
- 450 ML/d for 3 days, as an emergency/high volume release close to the maximum possible with the current outlet arrangement, such as could occur if very high tide conditions threatened to cause saline water to flow up the Tweed River and over Bray Park Weir.

To assess the impact of inflow to the model from the Tweed River a scenario was developed where a constant inflow of 25 ML/d was applied at the junction of the Tweed River and Doon Doon Creek at the baseline temperature to assess how an average low flow in the river affects the magnitude of CWP for each modelled flowrate. Higher flowrates were not assessed in the river as release from the dam would not normally be required when the river has significant flow.

Table 5.1 summarises the CWP scenarios that were analysed. Events from different years were reported to increase the potential range of results under different climatic conditions.

Table 5.1 CWP simulations

Scenario	Date	Duration (Days)	Daily peak air temperature (°C)	Cold release temperature (°C)	Baseline release temperature (°C)
1	1 January 2002	31	41	16	25
2	1 January 2006	31	36	16	25
3	1 January 2010	31	35	16	25
4	1 January 2014	31	39	16	25
5	1 January 2018	31	37	16	25
6	1 January 2018	31	37	17	25
7	1 January 2018	31	37	16	28

Each scenario included two model runs, the first was a month duration with the subject flow rate discharged though the model at the baseline temperature. The second included the baseline temperature discharged at the subject flow rate for 21 days followed by a three day cold release discharge. Discharge was then returned to the baseline temperature for the last seven days of the modelling period and the cold pulse was monitored moving though the model. The 21 day warmup period was important to include at the beginning of both runs as it enabled the model to establish natural temperature variations within Doon Doon Creek and the Tweed River. From the two model runs for each scenario and subject flow rate, CWP was quantified as per Equation 5.2.

Equation 5.2 Cold Water Pollution

$$CWP = Cold\ temperature - Baseline\ temperature$$

Parameter	Description	Value
$Cold\ temperature$	The calculated water quality (WQ) cell temperature at a given timestep and chainage for the cold water impacted scenario.	°C
$Baseline\ temperature$	The calculated WQ cell temperature at a given timestep and chainage for the baseline scenario.	°C

This calculation was performed for every timestep and WQ cell for the last day of the cold release and the following week after. The minimum CWP was taken from each WQ cell timeseries to display the largest temperature difference through the model and thus greatest effect of CWP. Any temperature differential below -2 °C was classed as CWP as per the NSW Cold Water Pollution Inter Agency Group (2017).

6 Cold water release results

It was found that the temperature in the creek was not a constant throughout modelled reaches even for the null scenario with no CWP effects modelled. The modelled water temperature varied along the watercourses depending on water age, bathymetry, and local climate each reach of water had been exposed to.

Figure 6.1 to Figure 6.5 illustrate the effect of varying flowrate and climate conditions. In summary:

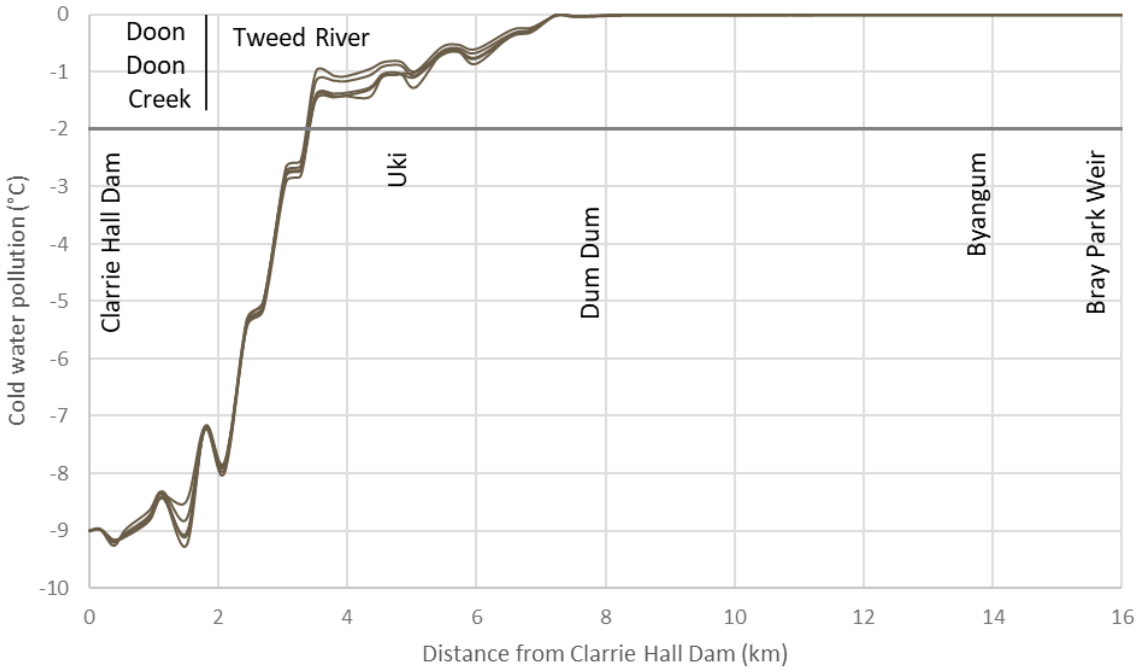
- there was minimal variability in the effect of climate condition on temperature within the model, with a maximum of 1°C difference in CWP between years of assessment
- the distance that CWP travelled downstream increased with flow rate.

The distance for the temperature differential to reduce to -2°C for the 10 ML/d and 30 ML/d modelled releases was approximately 3.5 km and 7.2 km from the base of the dam wall, respectively. For these flows larger temperature change occurs when the cold release meets larger pools containing warmer water, where increased mixing can occur.

The distance required for the 50 ML/d modelled release ranged between 8 km to 10 km from base of the dam wall. Between 8 km and 10 km the Tweed River has shallow sections where there is greater influence of climate conditions which vary between the modelled years.

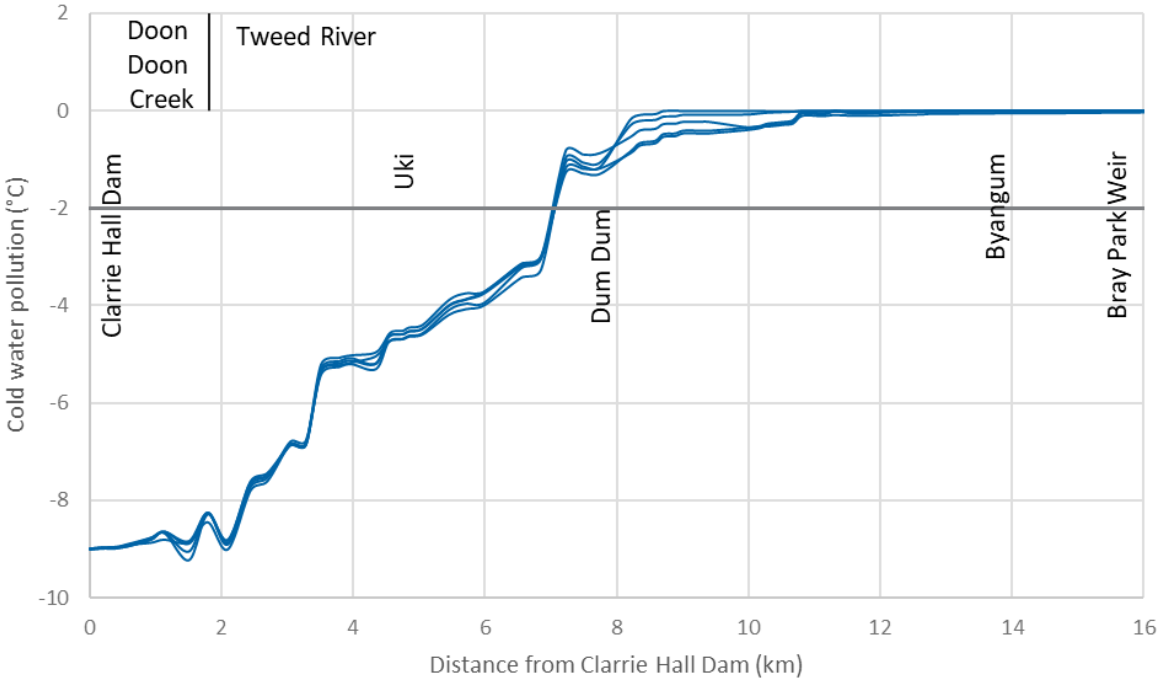
The 70 ML/d scenario takes approximately 11 km from the base of the dam wall to reach -2°C. At this point the Tweed River enters a large pool where mixing has significant effect, and the influence of climate conditions decreases.

The 450 ML/d scenario results showed CWP occurring though the entire model. With the larger flowrate the impact of climate conditions variability was minimal as residence time decreased and there was less opportunity for transfer of energy into the water.



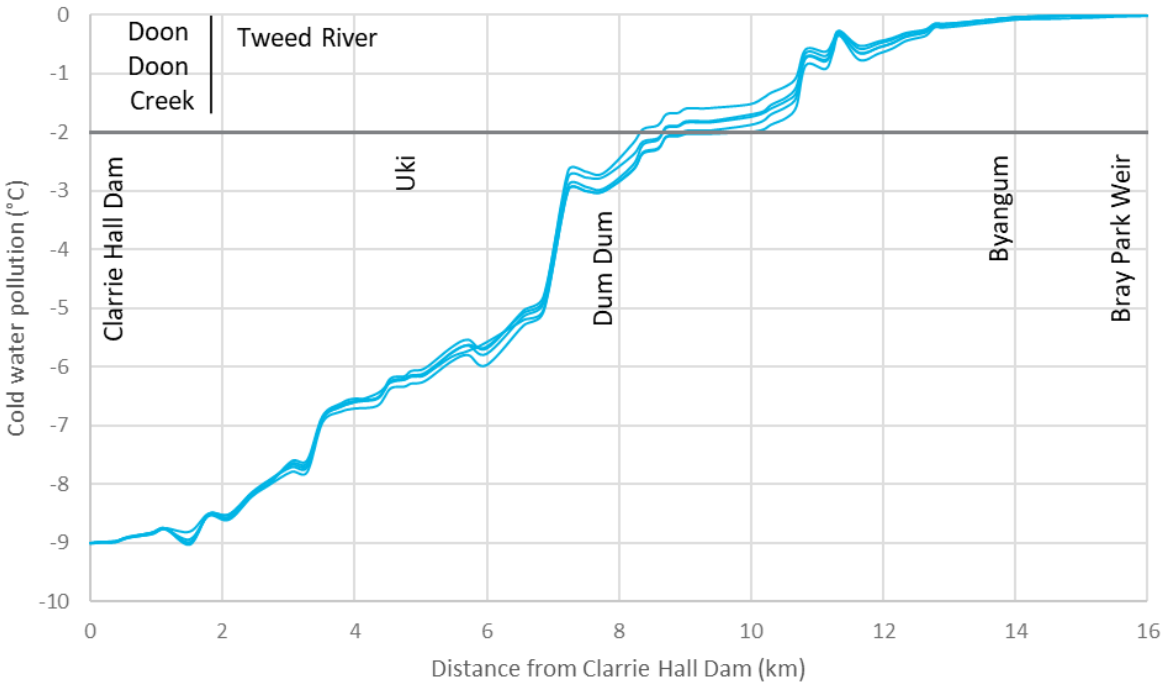
Note – Each trace represents one of climate scenarios 1 to 5 per Table 5.1 for the subject dam release.

Figure 6.1 Modelled cold water pollution travel distance with 10 ML/d releases of 16°C water into 25°C water



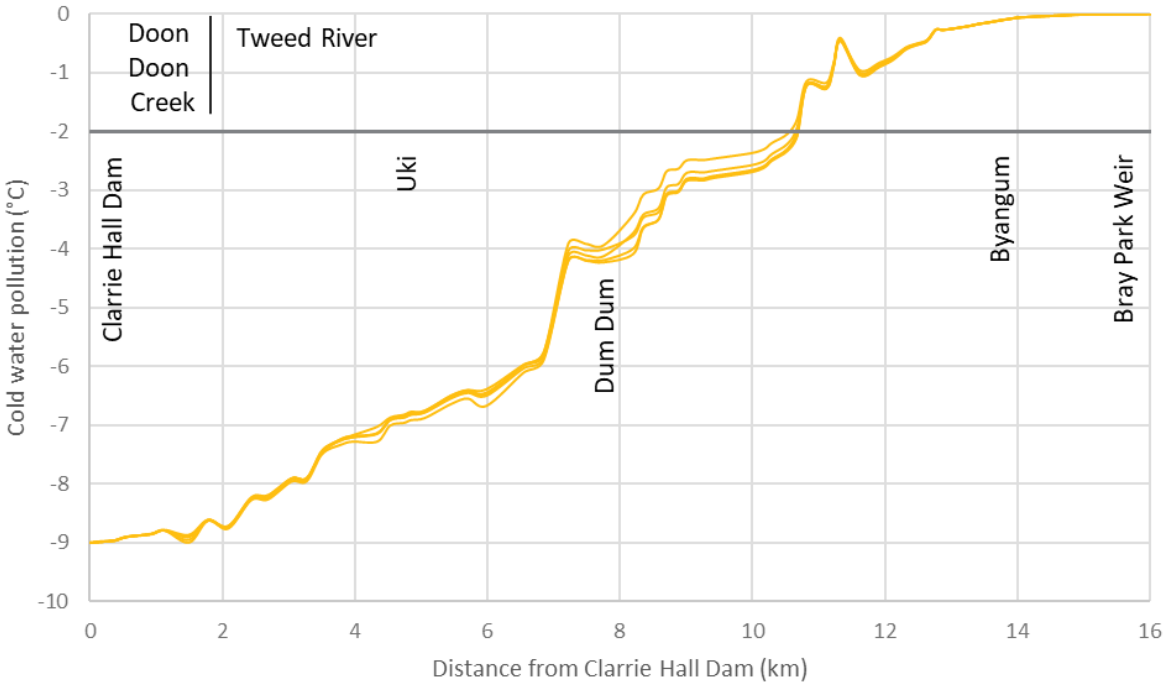
Note – Each trace represents one of climate scenarios 1 to 5 per Table 5.1 for the subject dam release.

Figure 6.2 Modelled cold water pollution travel distance with 30 ML/d releases of 16°C water into 25°C water



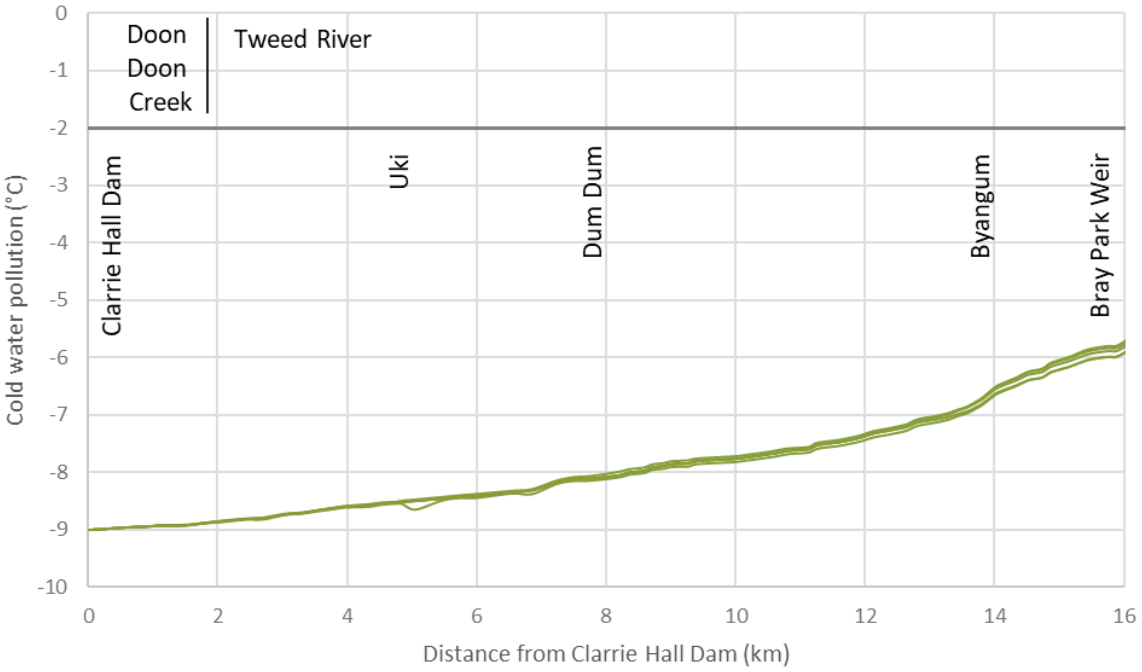
Note – Each trace represents one of climate scenarios 1 to 5 per Table 5.1 for the subject dam release.

Figure 6.3 Modelled cold water pollution travel distance with 50 ML/d releases of 16°C water into 25°C water



Note – Each trace represents one of climate scenarios 1 to 5 per Table 5.1 for the subject dam release.

Figure 6.4 Cold water pollution travel distance with 70 ML/d releases of 16°C water into 25°C water



Note – Each trace represents one of climate scenarios 1 to 5 per Table 5.1 for the subject dam release.

Figure 6.5 Cold water pollution travel distance with 450 ML/d releases of 16°C water into 25°C water

Hydronumerics (2023) illustrated that with the larger dam the cold portion of a stratified water column in the reservoir may be between 0 to 1°C warmer than occurs with the existing dam. This difference in starting temperature would create a minor reduction to the magnitude of CWP and negligible reduction to the extent of CWP (Figure 6.6).

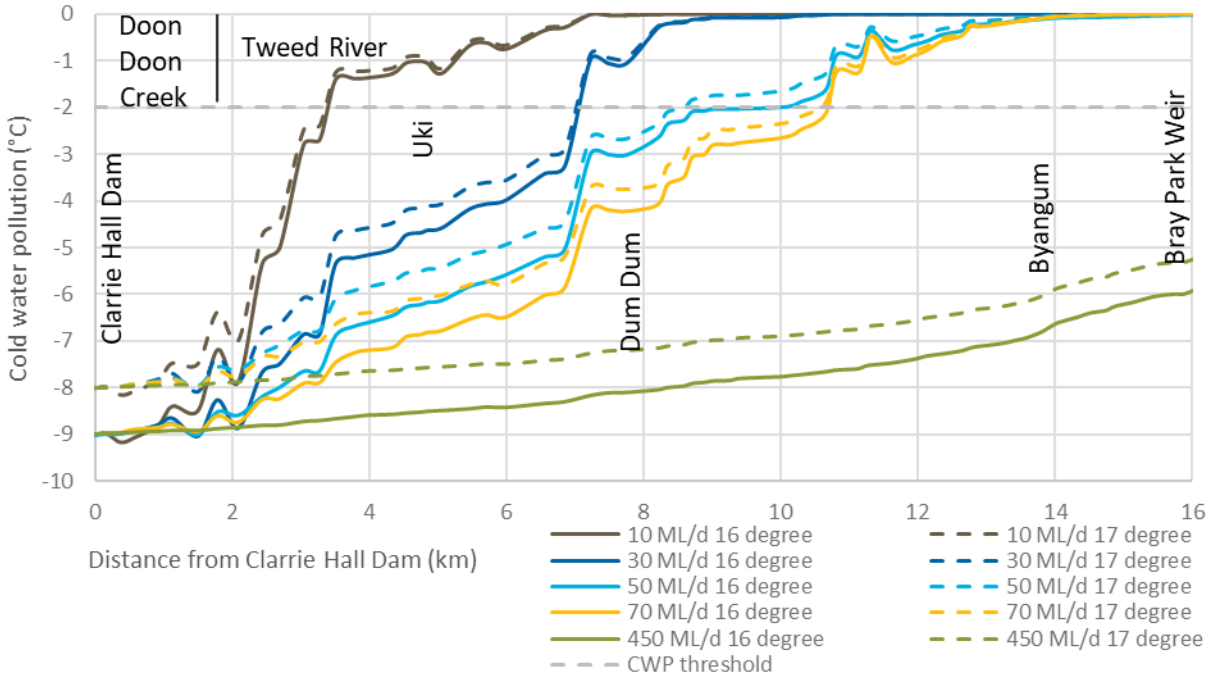


Figure 6.6 Existing (16°C) and post dam wall raising (17°C) release scenarios (2018 climate scenario)

If the Tweed River is flowing at the time a release is made from the dam, the cold water would mix with Tweed River water at the junction of Doon Doon Creek and the river, altering the temperature profile, and the total flow would also travel downstream more rapidly. These effects were investigated by modelling a 16°C release with the 2018 summer climate and a 30 ML/day flow in the Tweed River (Figure 6.7). The additional warm water in the river caused a moderate reduction to the magnitude of CWP, and a negligible change to the extent of CWP.

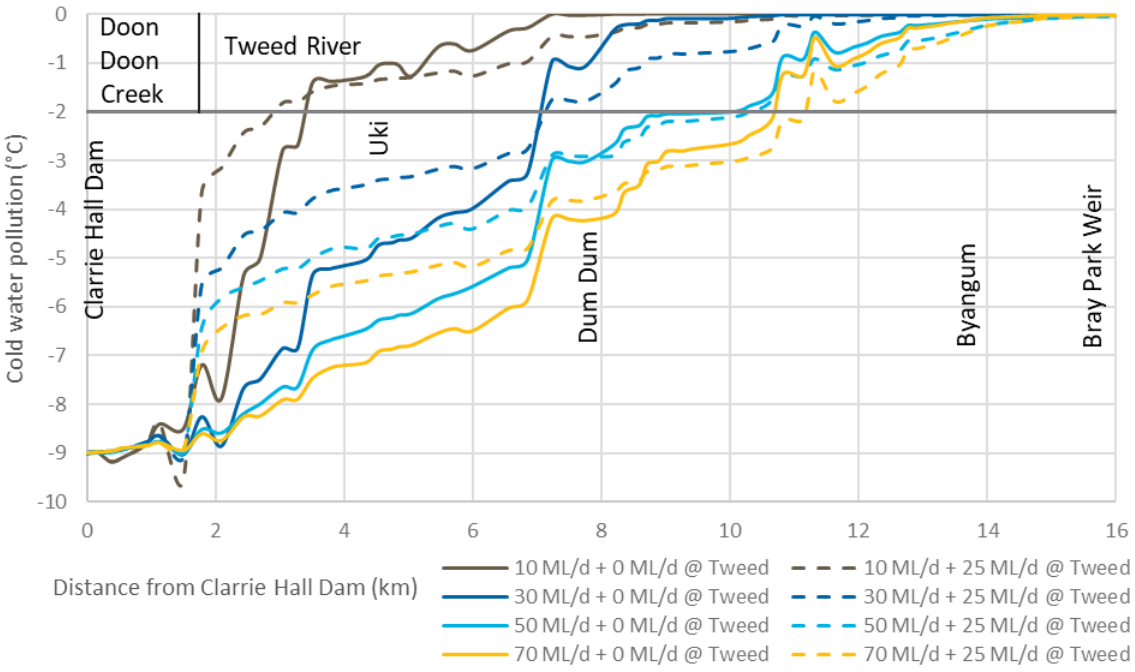


Figure 6.7 **Modelled cold water pollution travel distances with 0 ML/d and 25 ML/d inflow at the Tweed River, releases of 16°C water into 25°C water for the 2018 scenario**

7 Discussion

7.1 Summary

The CWP modelling results showed that if cold water releases of up to 70 ML/day were made from Clarrie Hall Dam, for example for town water during a period of algal management, CWP effects could reach up to 11 km downstream of the dam before the released water warmed due to interaction with the climate and receiving environment. With smaller release rates, the distance CWP would travel is reduced. The approximate modelled distance for cold releases to reach within 2°C of natural temperature is illustrated in Figure 7.1.

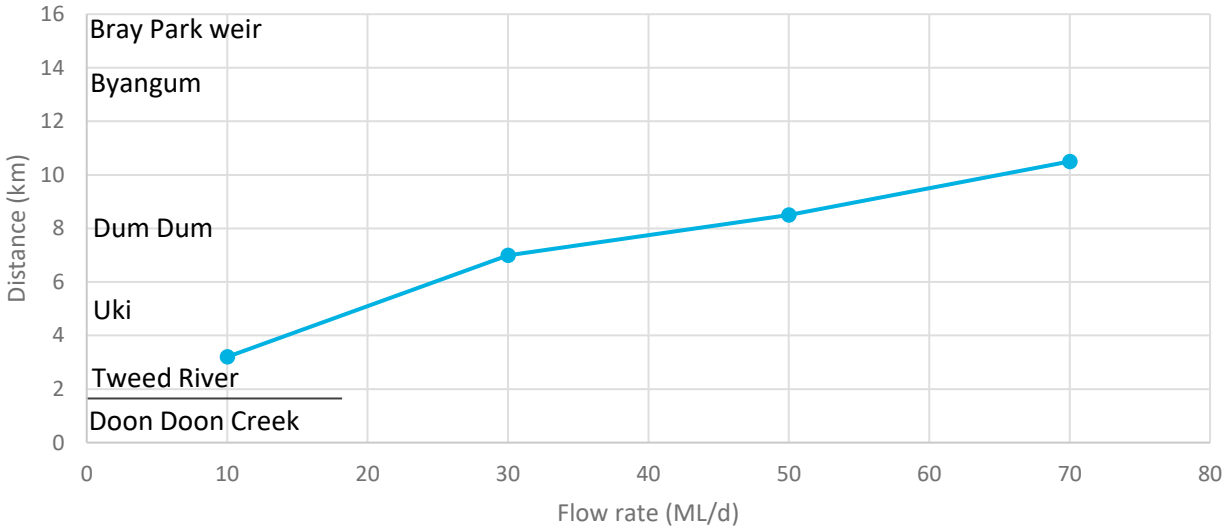


Figure 7.1 Distance before water warms to within 2°C of 'natural'

7.2 Discussion of higher flow release rates

If higher flows were released, these flows would likely be released either:

- via the spillway, in response to natural flood flows into the dam when at capacity
- via the outlet pipe to draw the dam water level down for dam maintenance.

In the case of spillway activation, water will not be discharged from deep within the dam, and CWP is not expected to occur.

In the case of planned dam maintenance, it may be possible to schedule the maintenance during periods when CWP is not a problem (i.e. avoiding fish breeding times), or when the multi-level outlet may be used to take water from the upper part of the water column, and so reduce the likelihood or severity of CWP.

The case of emergency dam maintenance causing CWP would be extremely rare. In emergency situations, short duration release of warm water containing algae or colder water may be equally acceptable.

7.3 Modelling caveats

For short duration releases, the model may overestimate the distance which cold water travels as deeper pools and the hyporheic zone are able to trap the 'first flush' of cold water. This overestimate is likely to reduce with longer duration releases as the system equilibrates.

The base of deeper pools may experience longer duration cooling than the model results imply following the cessation of releases, as the model assumes vertically mixed conditions.

8 Model sensitivity

A standardised qualitative set of descriptors of model uncertainty and sensitivity, as summarised in Table 8.1, has been applied to the models described in this report to allow readers unfamiliar with the modelling software and methods to contextualise the statements made regarding data sources, methods, and reliability of outputs.

Table 8.1 Standardised model sensitivity descriptors

Ranking	Descriptor
Input uncertainty	
A	• Extensive data. • Field verified. • Limited use of assumptions.
B	• Limited data. • Use of industry recognised or benchmarked data. • Some assumptions.
C	• Numerous assumptions. • Limited (if any) verification.
Software/methodology uncertainty	
A	• Recognised method and application. • Industry standard approach.
B	• New method or new application of existing method. • Not industry recognised.
C	• *ad hoc* methodology. • Informal approach.
Results sensitivity	
A	• Predictions not sensitive to input variation.
B	• Some sensitivity of input variations.
C	• Predictions highly sensitive to input variations. • Sensitivity not studied/unknown.

The uncertainty and sensitivity of creek hydraulic and temperature modelling inputs and results are described below and summarised in Table 8.2.

Table 8.2 Doon Doon Creek and Tweed River hydraulic and temperature model uncertainty and sensitivity

Item	Ranking
Inputs	
Topographic information	B
Wind speed	B
Solar radiation	C

Air temperature	B
Humidity	B
Dam release water temperature	B
Flow rates	A
Interaction with tributaries, groundwater, irrigation offtakes	C
Method	
Solar disaggregation and shading adjustment	B
Wind adjustment to observed data	C
HEC-RAS water quality module	A
Results Sensitivity	
Absolute temperature predictions at each model location (not used for assessment)	C
Distance to reach ΔT 2 °C	A

While the topographic data includes some site survey, and climate data were sourced from recognised and trusted Australian sources (i.e. ELVIS, SILO and CSIRO), a ranking of 'B' has been assigned to these inputs as the elevation data was somewhat coarse for creek definition, and the climate data was interpolated from sparse gauges.

Solar radiation was downgraded from a 'B' ranking to a 'C' due to the model not incorporating local shading effects due to bank vegetation. Interaction with tributaries, groundwater and irrigation offtakes were likewise not included in the model.

The method of solar disaggregation from daily to hourly values was necessary for modelling. The method used made appropriate assumptions regarding daylight hours of each day of the year, but no verification could be undertaken, and it is recognised that the curves developed are simplifications, and that cloud cover would vary in different ways on different days.

Regardless of the uncertainties of methods and inputs, the model results showed a very short distance over which CWP effects might be seen during typical flow rates. This result was insensitive to tested parameter ranges.

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Annexure D
Geomorphic parameters

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Doon Doon Creek and Tweed River

Geomorphology parameters

Prepared for Prepared for Tweed Shire Council / KBR

August 2024

Doon Doon Creek and Tweed River

Geomorphology parameters

Prepared for Tweed Shire Council / KBR

E230036 Annexure D

August 2024

Version	Date	Prepared by	Reviewed by	Comments
1	2 August 2024	J Muller	N Bartho	Issue for publication

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1 Introduction

A HEC-RAS model was used to describe the hydraulic behaviour of Doon Doon Creek and the Tweed River between Clarrie Hall Dam and Bray Park Weir to support and inform the assessment of the proposed raising of Clarrie Hall Dam (the Proposal). This report describes the hydraulic changes in representative reaches of these two watercourses that may occur due to predicted changes to the streamflow regime as a result of the Proposal.

HEC-RAS is an industry standard hydraulic modelling software package developed by the US Army Corps of Engineers for modelling rivers and creeks. HEC-RAS is widely used for water management assessments and can be used to describe hydraulic parameters resulting from flow in waterways. The one-dimensional (1D) formulation of HEC-RAS solves the hydraulic Manning's equation using channel sections developed from cross section data in order to resolve the hydraulic conditions within all watercourses represented in a model.

Development of the HEC-RAS model is described in Annexure C of the surface water assessment.

The Doon Doon Creek and Tweed River streamflow regime was simulated using a catchment model, described in Annexure A of the surface water assessment.

The flow regimes described by the Source model for Doon Doon Creek and the Tweed River at Uki with the existing dam and proposed larger dam were applied to the HEC-RAS hydraulic model to describe depth, velocity, and shear stress regimes. The hydraulic regime of the Tweed River downstream from Uki was not assessed as the hydrologic changes at Uki due to the Proposal were found to be negligible.

The HEC-RAS model was run with flows from 4 ML/d up to 30,000 ML/d to develop curves describing how hydraulic parameters within Doon Doon Creek and the Tweed River (near Uki) relate to flow. These curves were then used to transform the flow regime predicted by the Source modelling.

2 Bed material mobilisation theory

The initiation of particle movement on the bed depends on the hydraulics of the near bed region. As determination of velocity near the bed is difficult, bed shear stress is a commonly used method of determining incipient motion. In 1D (cross-sectional) space, mean bed shear stress (N/m^2) (τ_b) is conventionally calculated as per Equation 2-1 (Gordon, McMahon, Finlayson, Gippel, & Nathan, 2004).

Equation 2-1 Bed shear stress

$$\tau_b = \rho g R S$$

Parameter	Description	Value
R	hydraulic radius of the channel (m)	equal to A/P where A is the cross-sectional area of the flow, and P is the length of the wetted perimeter
S	energy slope of the water (m/m)	equal to the bed and water surface slopes in uniform reaches
ρ	water density (kg/m^3)	1,000
g	acceleration due to gravity (m/s^2)	9.8

The critical shear stress (τ_c) is the shear stress required to set the bed particles in motion, represented by the Shields equation (Equation 2-2).

Equation 2-2 Critical shear stress

$$\tau_c = \theta_c g d (\rho_s - \rho)$$

Parameter	Description	Value
θ_c	dimensionless critical Shields stress	typically 0.6-0.75
g	acceleration due to gravity (m/s^2)	9.8
d	representative particle size (d_{50}) (m)	See Table 2.1
ρ_s	particle density(kg/m^3)	2,650
ρ	water density (kg/m^3)	1,000

For particles to move, the actual shear stress (τ_b) (estimated through modelling) must exceed the critical shear stress (τ_c) (Table 2.1).

Table 2.1 Critical shear stress for selected bed materials

Bed material	Representative particle size d_{50} (m)	Critical shear stress (N/m^2)
Silt	0.00001	0.1
Sand	0.001	10
Gravel	0.01	100
Boulder	0.5	5,000

3 Watercourse hydraulic properties

Curves describing watercourse hydraulics (Figure 3.1) were developed for pool and riffle sequences in Doon Doon Creek and the Tweed River near Uki (Figure 3.2).

From the results it is noted that the Tweed River riffle section turns into a pool at higher flows due to backwater effects. This is evident in the drop in bed shear stress and velocity when flow is over approximately 7,500 ML/d.

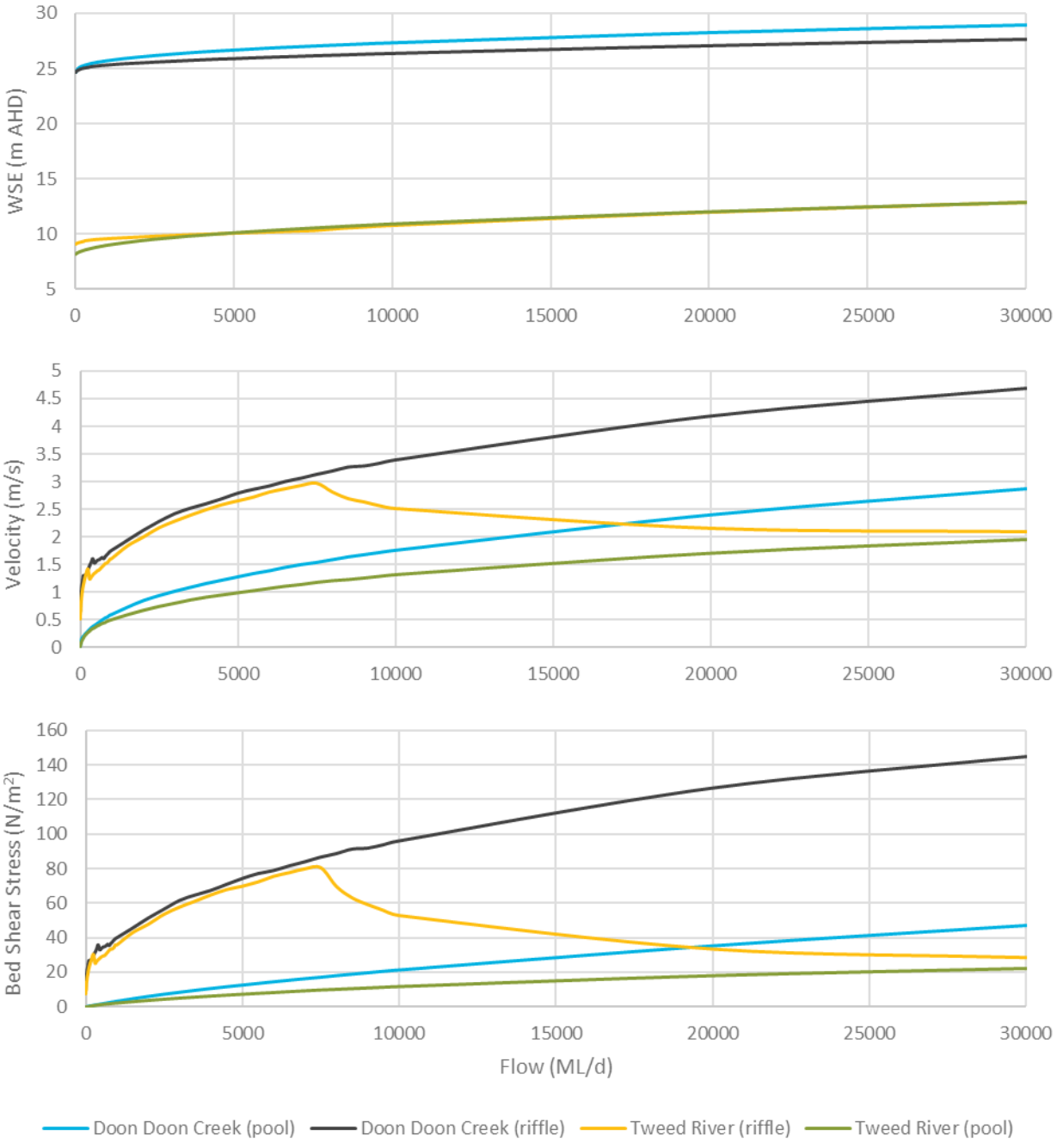
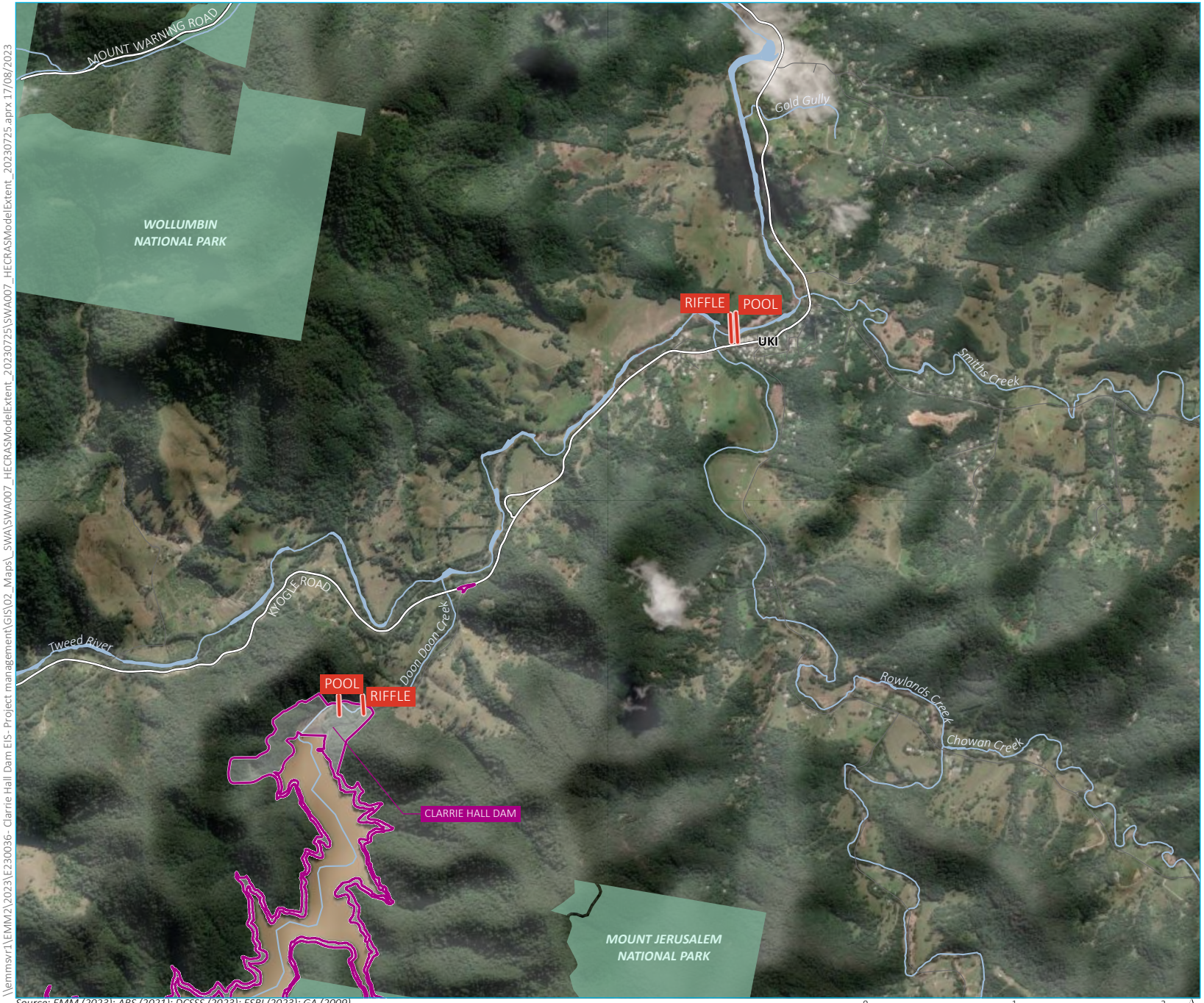
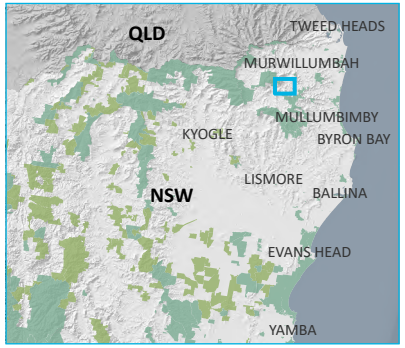


Figure 3.1 **Water surface elevation, velocity and bd shear stress descriptive curves**





KEY

- Development site
- Cross section
- Major road
- Minor road
- Named watercourse
- Named waterbody
- NPWS reserve

INSET KEY

- NPWS reserve
- State forest

Reporting locations

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

0 1 2 km

GDA2020 MGA Zone 56

N

Clarrie Hall Dam EIS
Surface Water Assessment
Figure 3.2

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4 Impact assessment

4.1 Overview

The flow regimes described by the Source model (see SWA Annexure A) were transformed using the hydraulic properties presented in Chapter 3, producing the results presented in Attachment A.

Results presented in this report are targeted at the assessment of surface water interactions with groundwater and soils over extended periods, and do not consider seasonality.

4.2 Doon Doon Creek

The Proposal may increase the frequency of minimum releases from the dam, and subsequently increase the frequency of minimum flow depth over riffles within Doon Doon Creek (Figure A.1) from 38% of the time to 47% of the time. There may also be an increase in depth of up to 0.1 m for about 20% of the time, when the riffle depth is around 0.5–0.6 m.

The flow velocity in Doon Doon Creek riffles is expected to be below 1.5 m/s for 90% of the time, but could increase to around 3 m/s during high flows (Figure A.2). The velocity and depth data influence the calculation of bed shear stress, which in the assessed Doon Doon Creek riffle is expected to be below 100 N/m^2 close to 100% of the time (Figure A.3). The Proposal is not predicted to substantially alter these thresholds or frequencies. Under these conditions, gravel sized rocks (i.e. 10 mm and larger) are not expected to be particularly mobile with either the current or future flow regime.

The minimum release of 4 ML/day is expected to cause bed shear of 10 N/m^2, sufficient to mobilise particles 1 mm diameter and smaller.

From these results, the morphology of rocky Doon Doon Creek riffles are not expected to be affected by changes in the shear stress regime.

Depth of water in pools within Doon Doon Creek may vary by ± 0.1 m due to alterations of the flow regime as a result of the Proposal (Figure A.4). Average flow velocities are expected to remain below 1 m/s almost 100% of the time (Figure A.5). Bed shear stress within pools is expected to remain low and not be materially affected by the Proposal (Figure A.6).

4.3 Tweed River

Water levels, velocities and bed shear stress in the Tweed River are not expected to be materially affected by the Proposal (Figure A.7 to Figure A.12).

References

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Attachment A

Waterway hydraulics plots

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A.1 Doon Doon Creek riffle

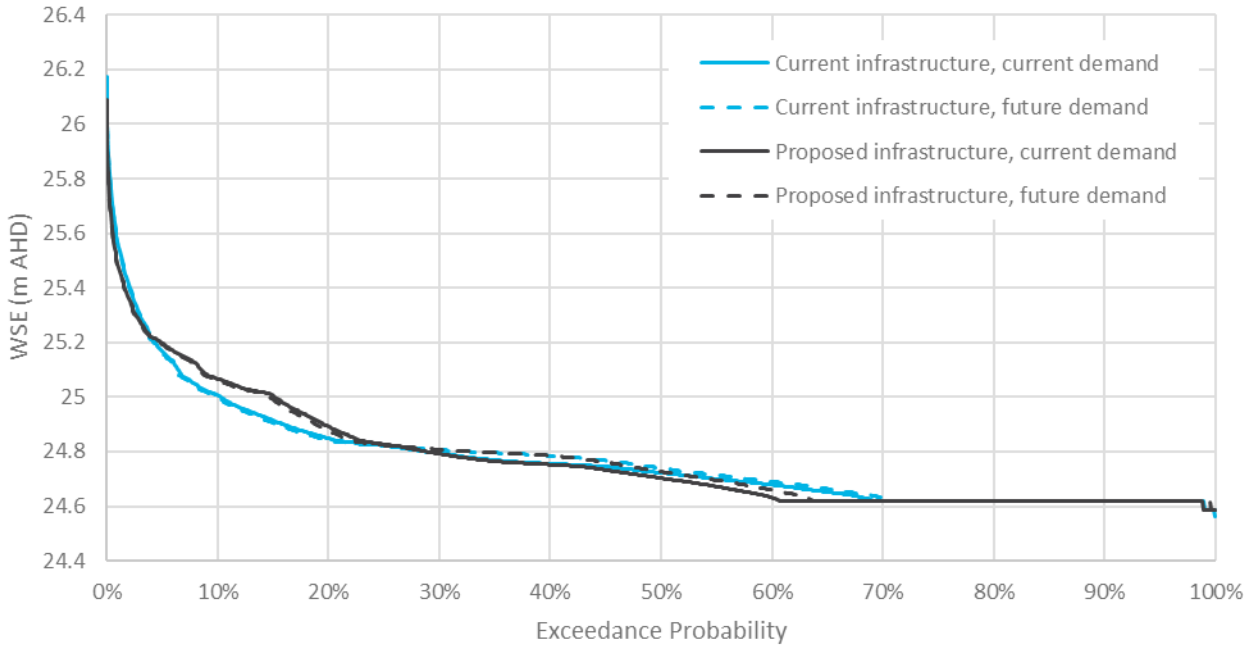


Figure A.1 Water surface elevation, Doon Doon Creek riffle

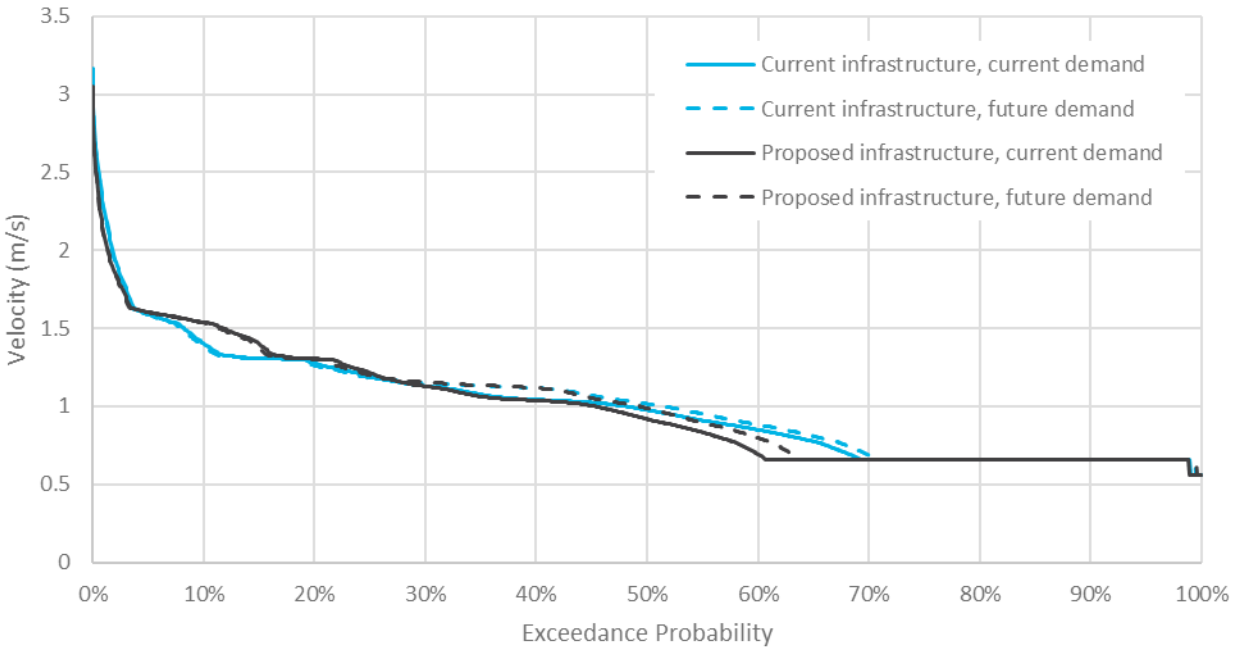


Figure A.2 Velocity, Doon Doon Creek riffle

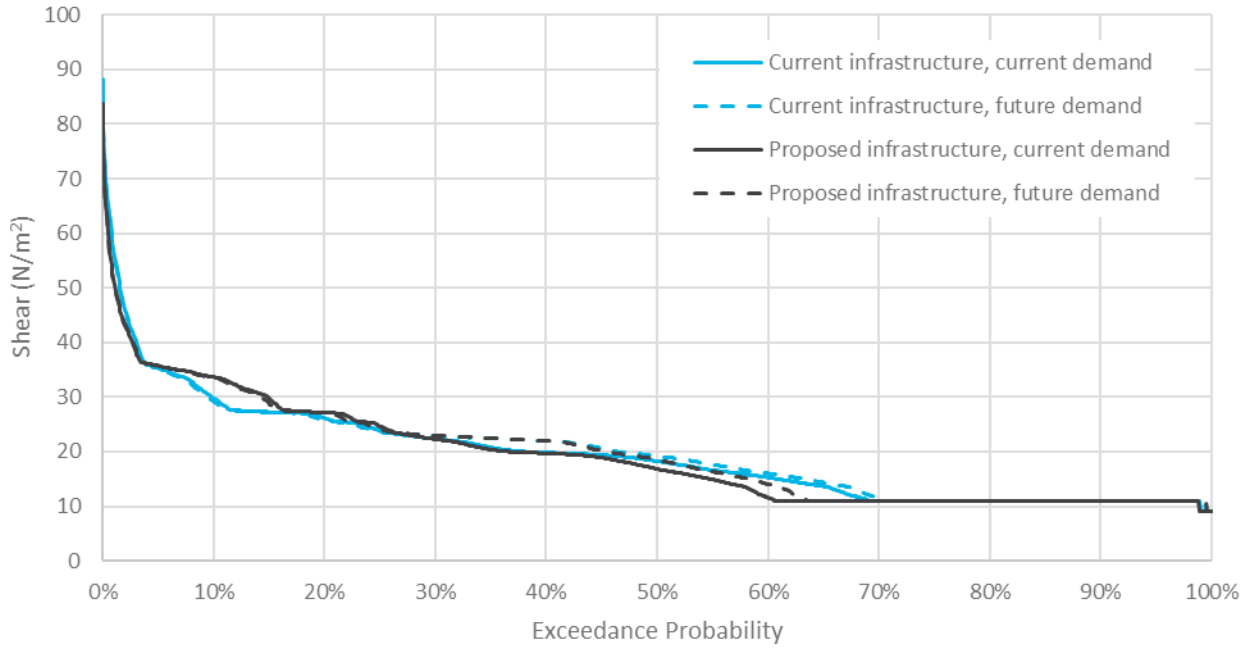


Figure A.3 Bed shear stress, Doon Doon Creek riffle

A.2 Doon Doon Creek pool

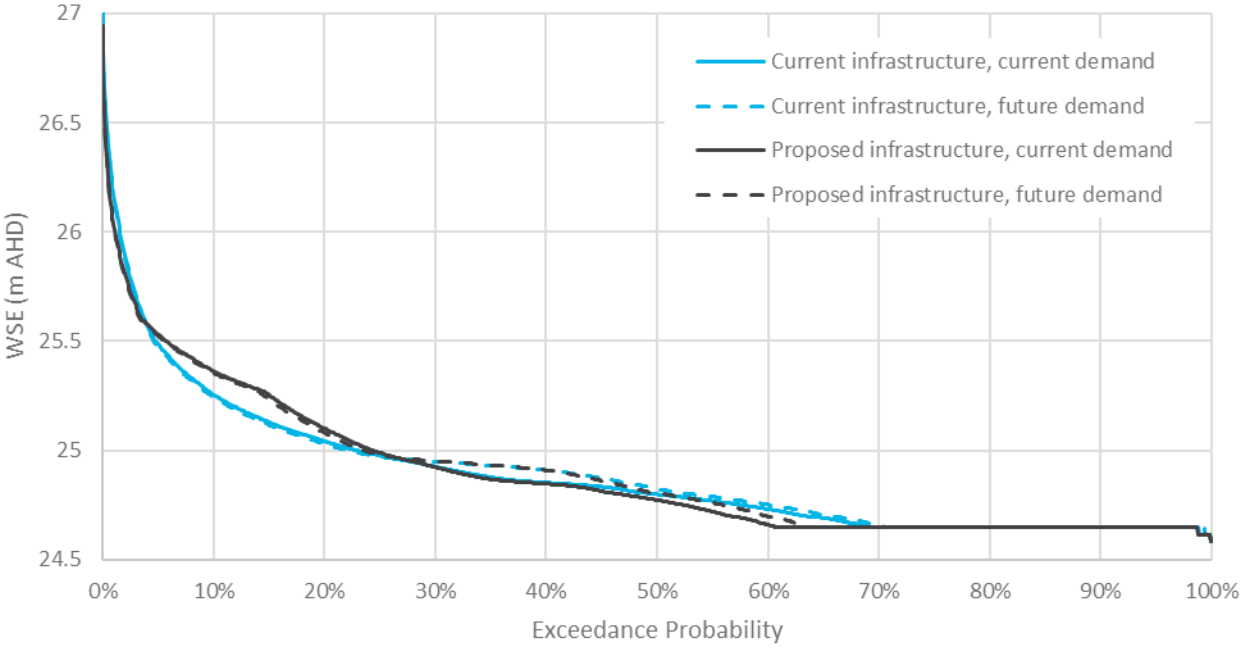


Figure A.4 Water surface elevation, Doon Doon Creek pool

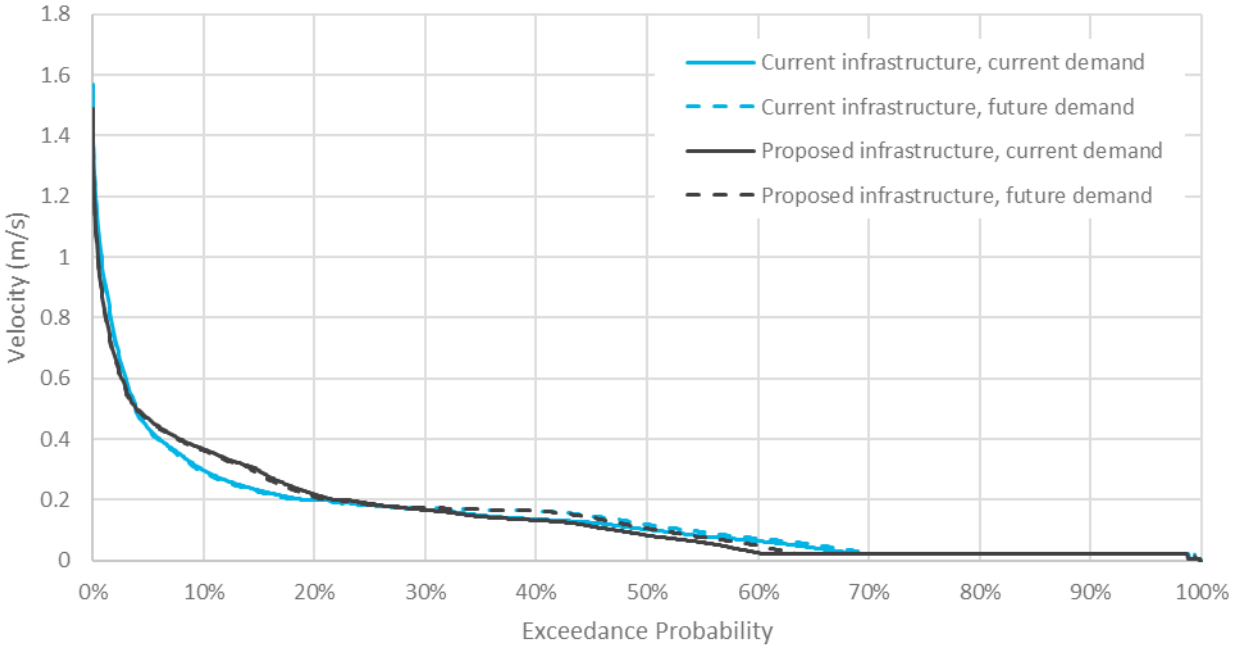


Figure A.5 Velocity, Doon Doon Creek pool

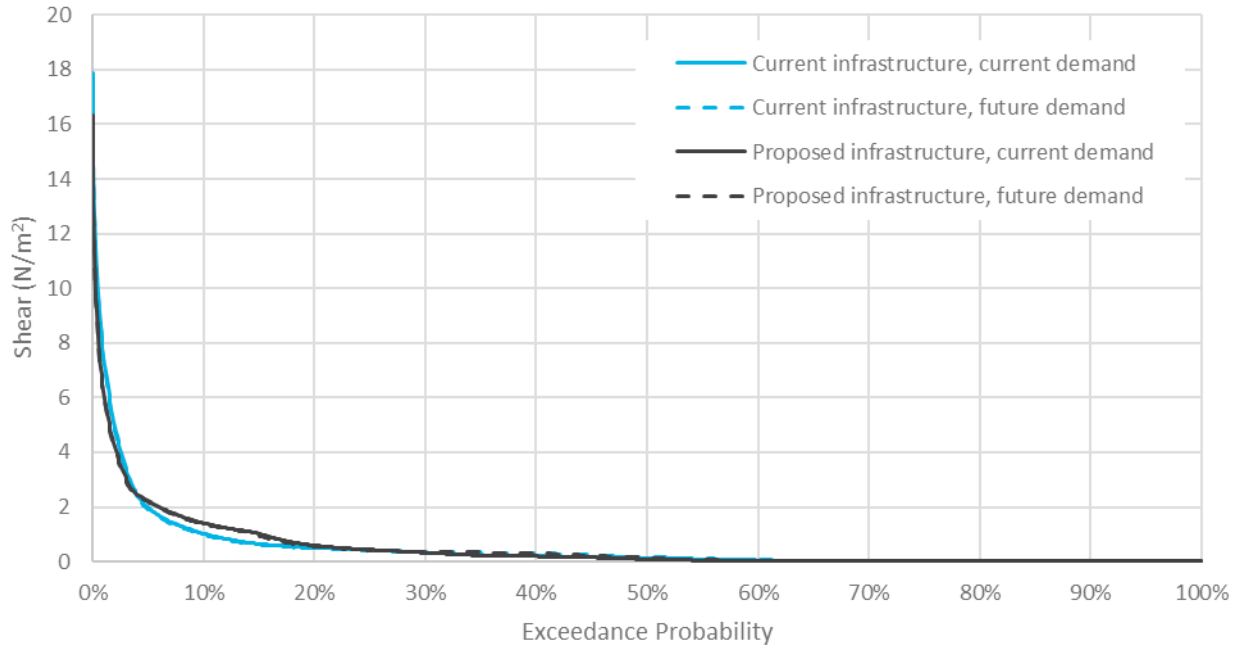


Figure A.6 Bed shear stress, Doon Doon Creek pool

A.3 Tweed River riffle

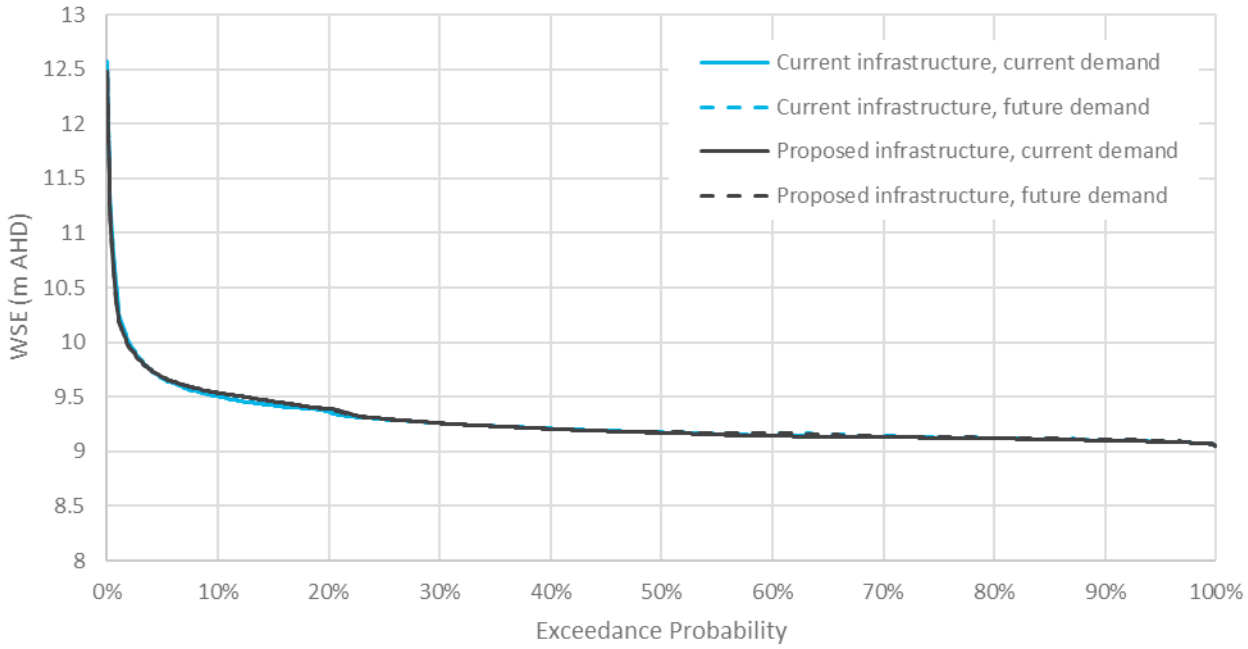


Figure A.7 Water surface elevation, Tweed River riffle

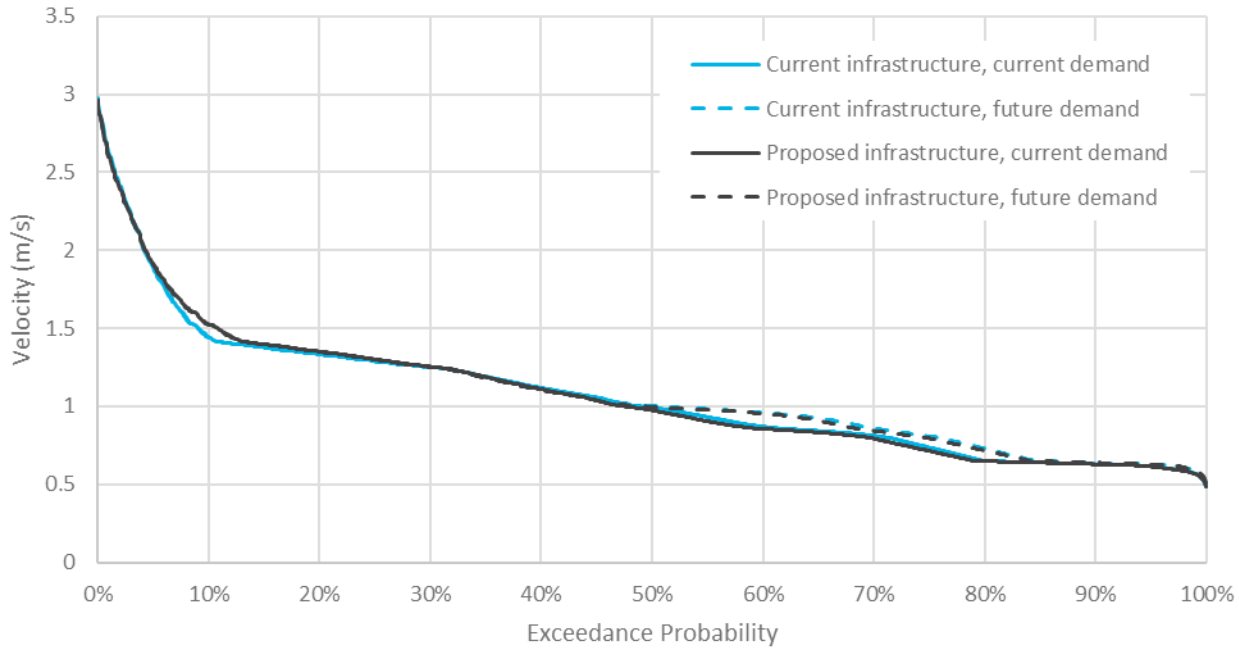


Figure A.8 Velocity, Tweed River riffle

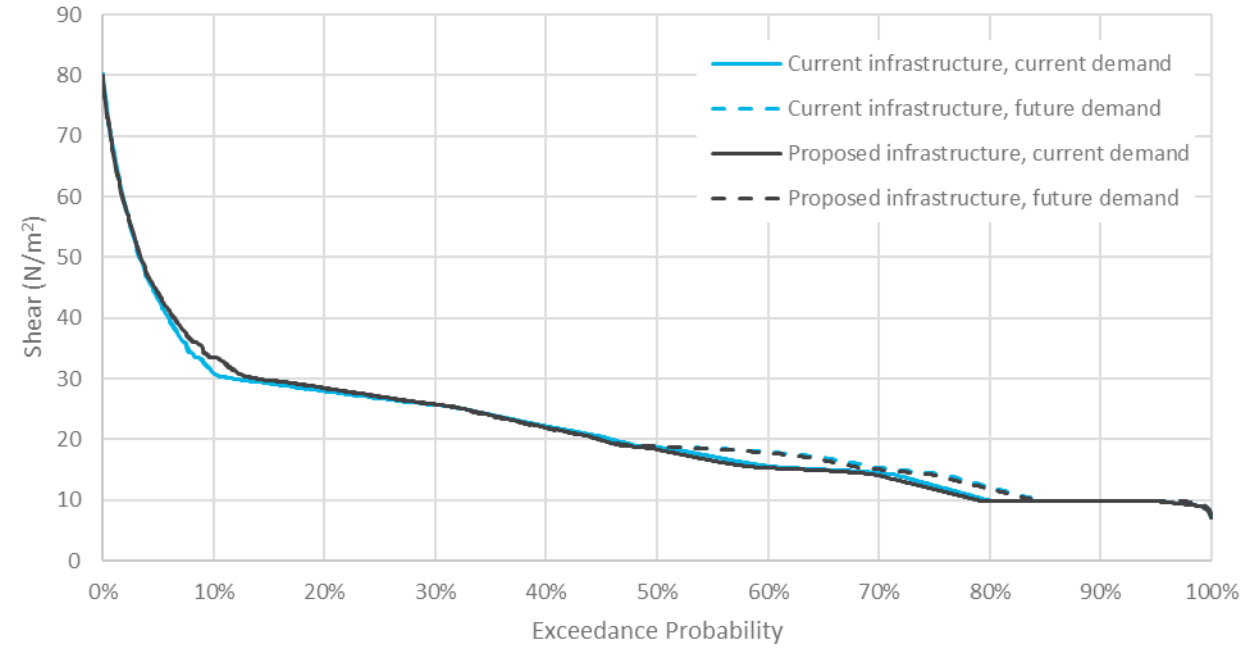


Figure A.9 Bed shear stress, Tweed River riffle

A.4 Tween River pool

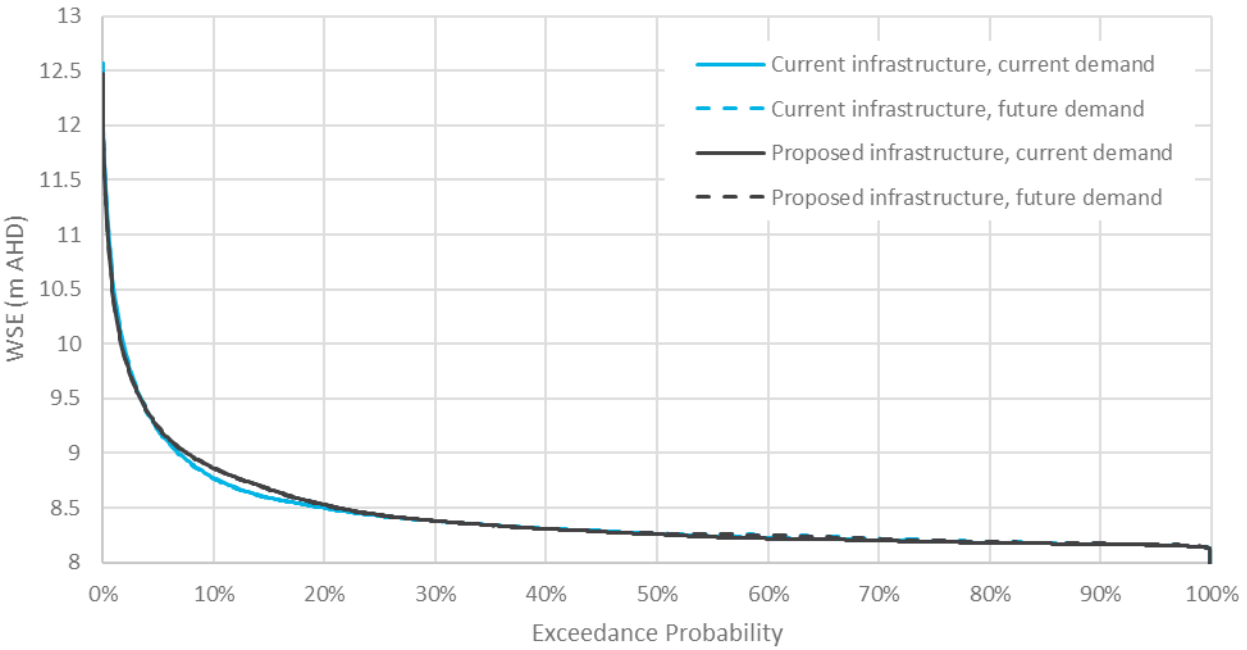


Figure A.10 Water surface elevation, Tweed River pool

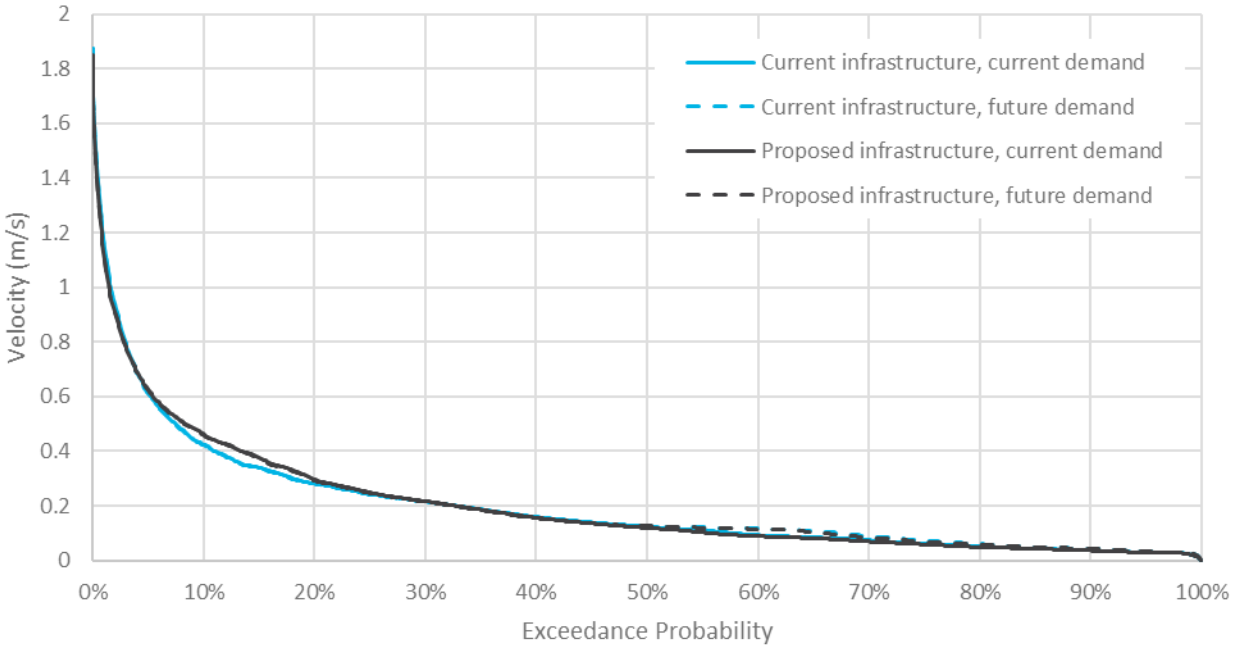


Figure A.11 Velocity, Tweed River pool

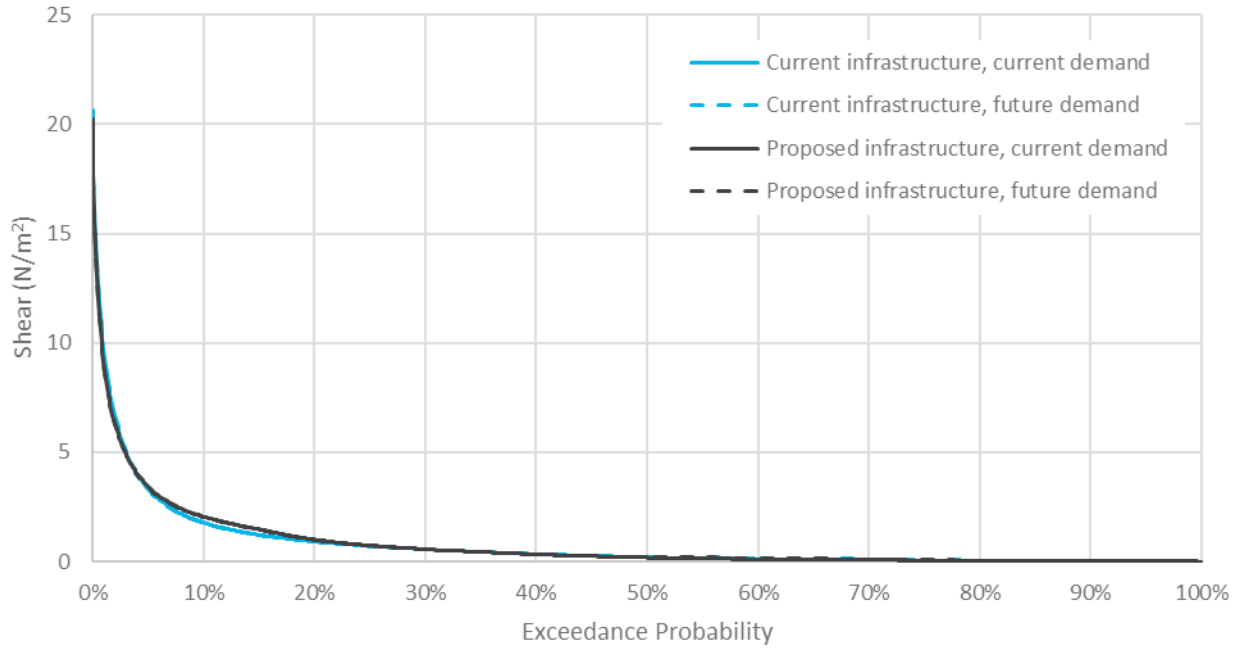


Figure A.12 Bed shear stress, Tweed River pool

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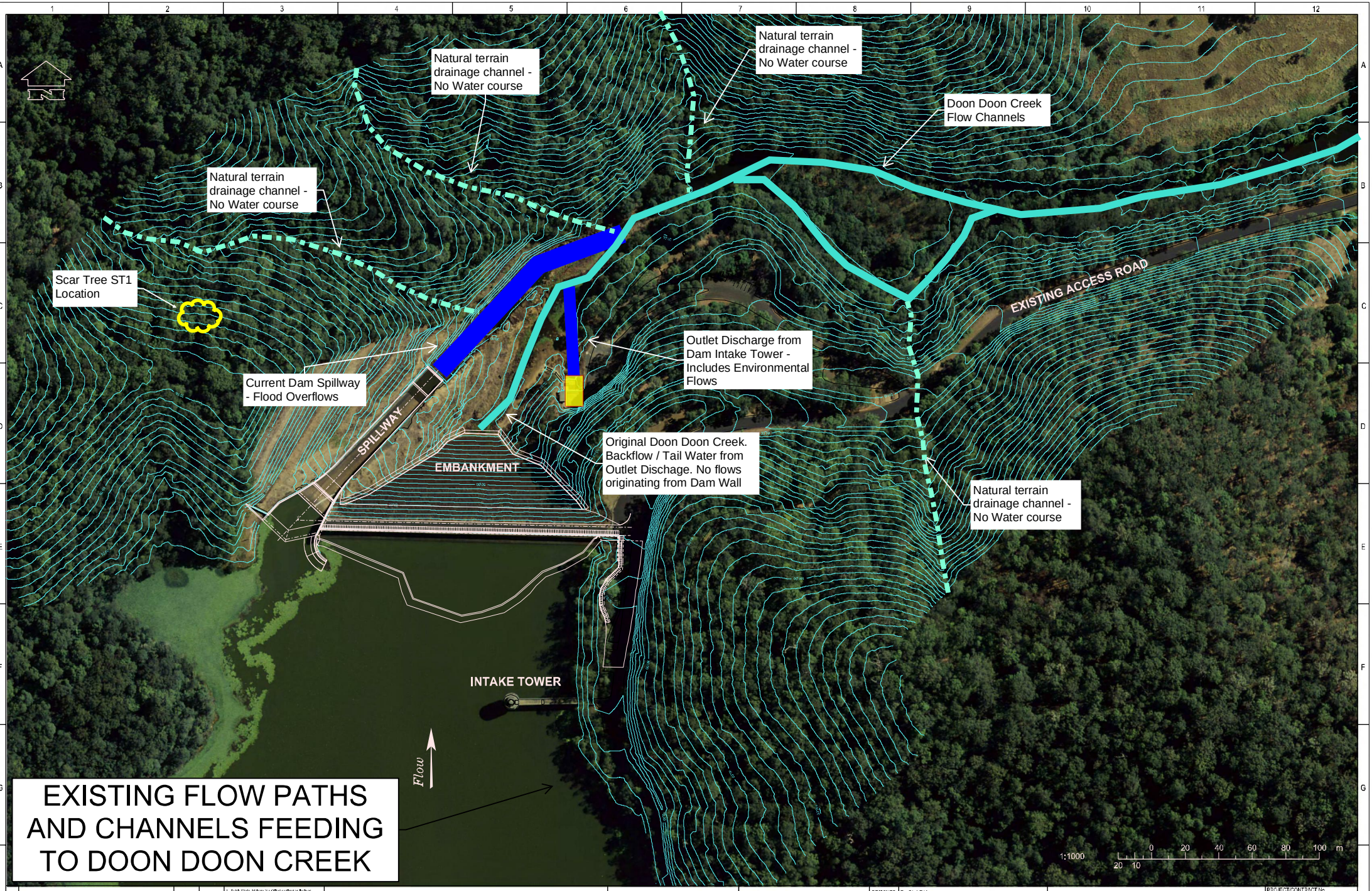


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Annexure E

Draft construction phase spillway and dam wall access arrangements

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EXISTING FLOW PATHS AND CHANNELS FEEDING TO DOON DOON CREEK

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CLARRIE HALL DAM
RAISING OPTIONS

EXISTING SITE PLAN

PROJECT/CONTRACT No. ?

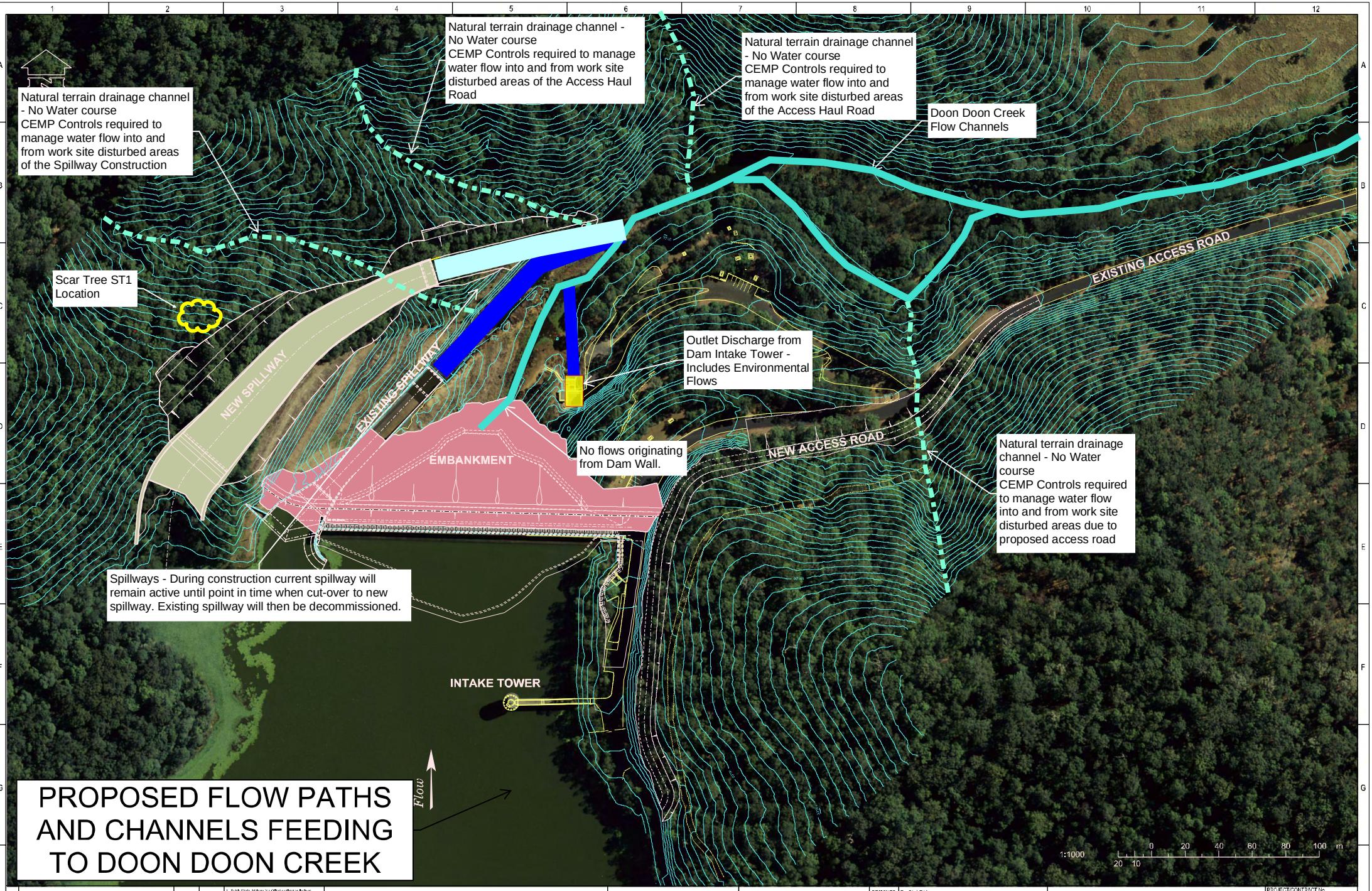
A1 | SCALE @ A1 1:1000

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CONFIRM SCALE — 100mm ON A1 ORIGINAL

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PROPOSED FLOW PATHS AND CHANNELS FEEDING TO DOON DOON CREEK

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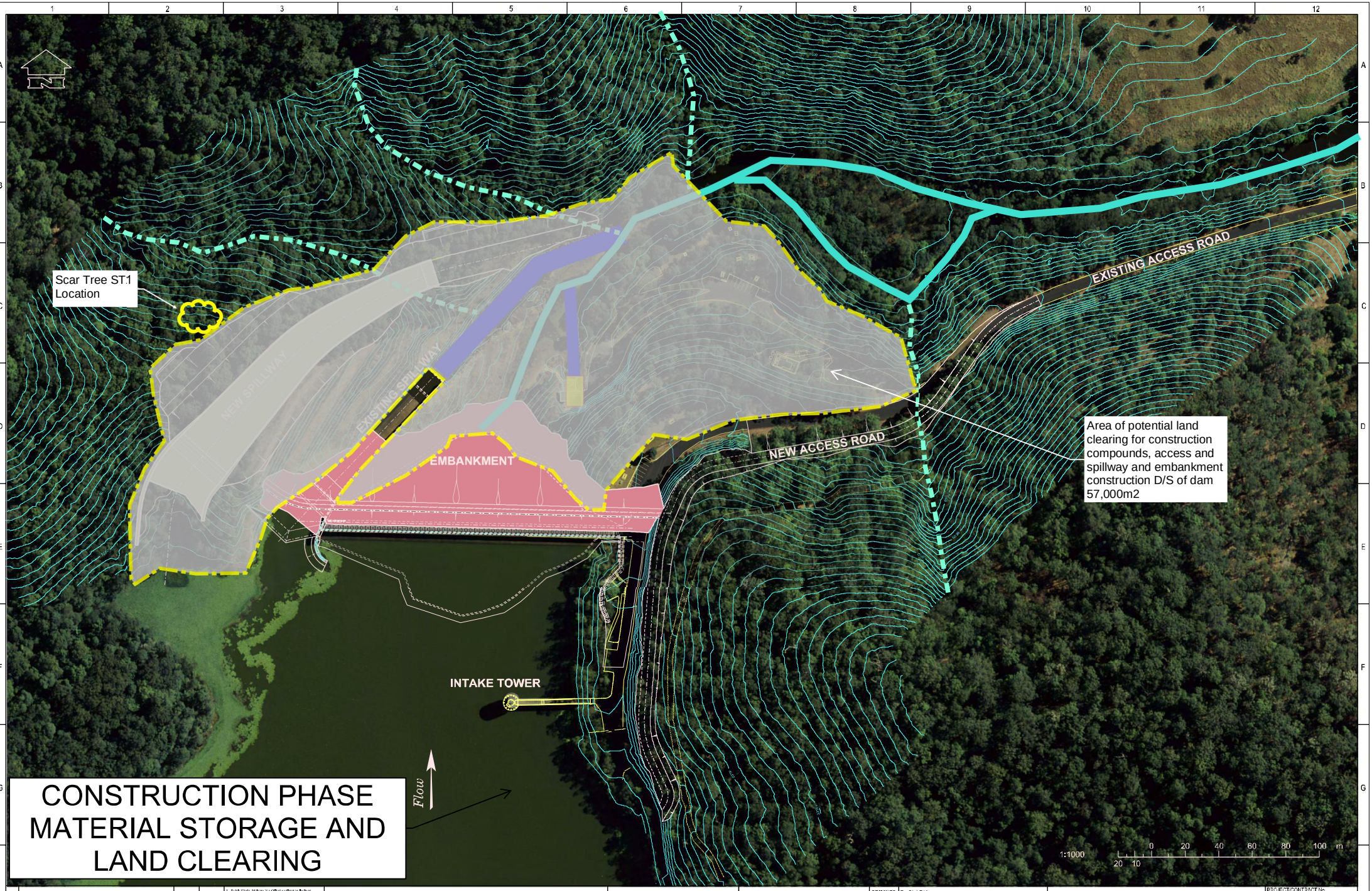
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RAISING OPTIONS
OPTION 1b
GENERAL ARRANGEMENT

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A1 SCALE @ A1 1:1000
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CONSTRUCTION PHASE MATERIAL STORAGE AND LAND CLEARING

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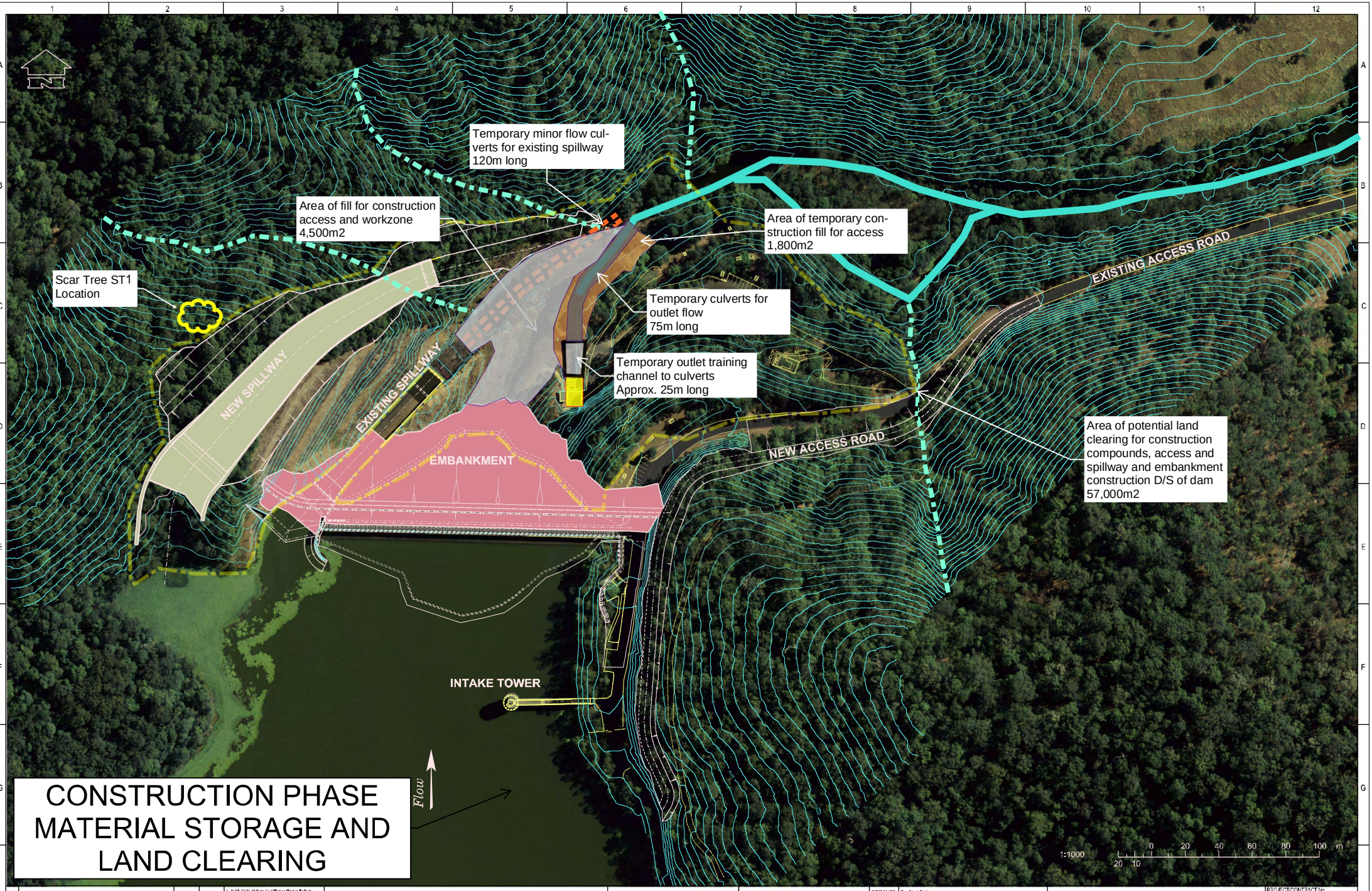
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RAISING OPTIONS
OPTION 1b
GENERAL ARRANGEMENT

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A1 SCALE @ A1 1:1000
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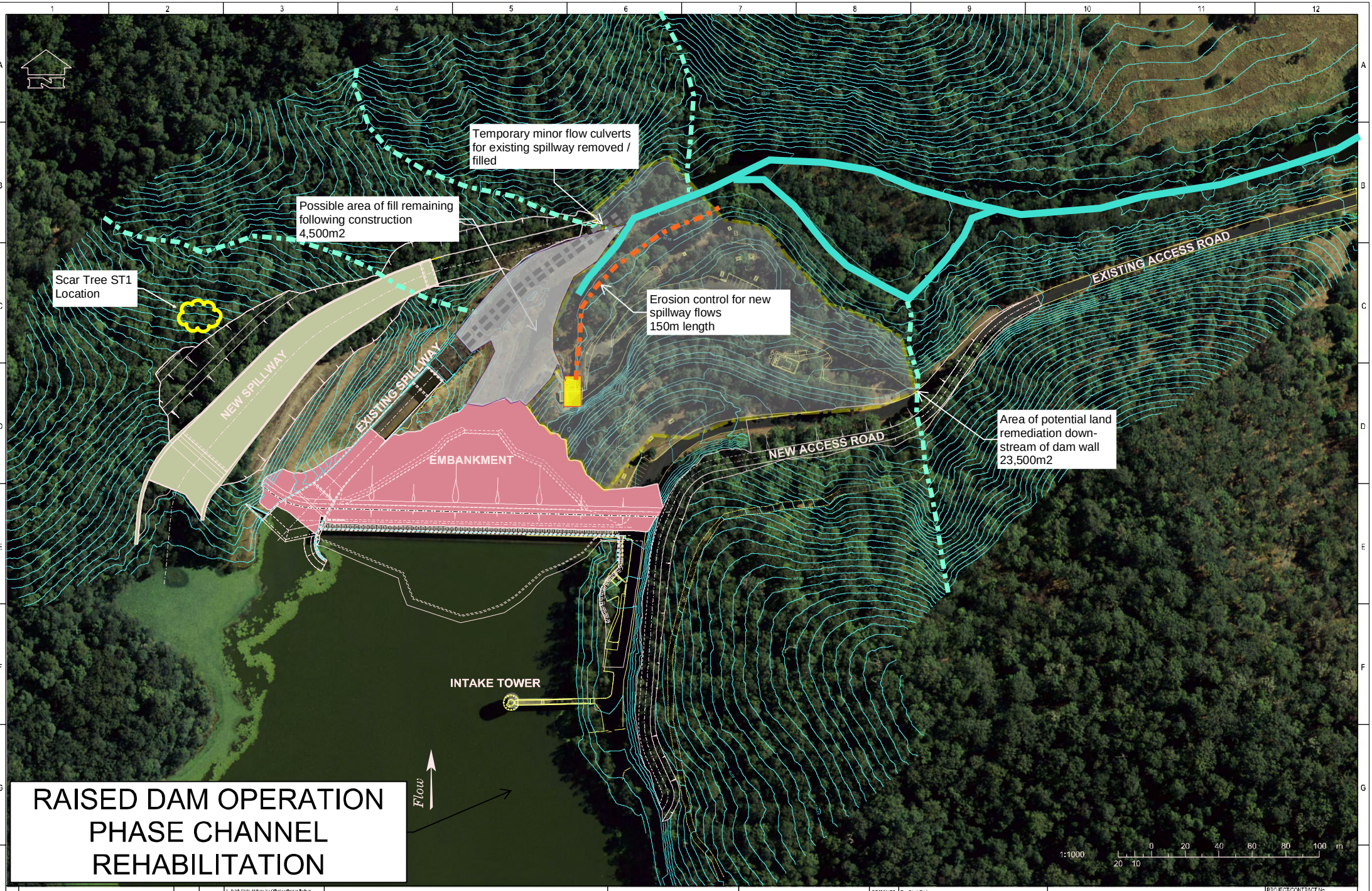
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RAISED DAM OPERATION PHASE CHANNEL REHABILITATION

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RAISING OPTIONS
OPTION 1b
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