
Appendix J

Geomorphology assessment report

Billabong Creek Regulators Geomorphology Assessment

Document no: DE19-823-YCM2-DE-GE-RPT-0002
Version: 3

NSW Department of Climate Change, Energy, the Environment and Water

Billabong Creek EIS



Billabong Creek Regulators Geomorphology Assessment

Client name: NSW Department of Climate Change, Energy, the Environment and Water
Project name: Billabong Creek EIS
Client reference: **Project no:** IW238424-SDLAM-19-823 RfS 063
Document no: DE19-823-YCM2-DE-GE-RPT-0002
Version: 3 **Prepared by:** Peter Sandercock
Date: 14 August 2024 **File name:** Rev-C-Billabong Creek-EIS-Geomorphology

Document history and status

Version	Date	Description	Author	Checked	Reviewed	Approved
1	18 June 24	Report	P. Sandercock	B. Plowman	B. Plowman M. Luger	
2	26 July 24	Report	P. Sandercock	M. Luger	M. Luger	
3	14 August 24	Report	P. Sandercock	M. Luger	M. Luger	D Chubb

Distribution of copies

Version	Issue approved	Date issued	Issued to
3	Final	14 August 24	NSW Department of Climate Change, Energy, the Environment and Water

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Executive summary

The NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW) proposes to replace two existing weirs along Billabong Creek with new regulators immediately downstream. The weirs to be demolished and replaced with new regulators are Hartwood Weir and Wanganella Weir (“the proposal”). DCCEEW is seeking approval from the NSW Minister for Planning and Public Spaces under the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act) for the proposal. This report has been prepared on behalf of DCCEEW for the proposal to support the environmental impact statement (EIS) and responds to the Secretary’s Environmental Assessment Requirements (SEARs) for geomorphology.

Methodology

The geomorphology impact assessment for the construction and operation of the proposal has been prepared based on a review and analysis of relevant literature and database searches, management plans and background reports, concept and detailed design documentation, applicable legislation, policies and guidelines and a site visit. The outcomes of the hydraulic modelling for existing and proposed conditions were used to assess geomorphic effects. The assessment focused on changes in velocity, shear stress, water depth and inundation extents across the channel and floodplain areas.

Existing environment

The proposal is located on Billabong Creek, which is part of the Yanco Creek system in south-west New South Wales and forms part of the Murray-Darling Basin (MDB). The Yanco-Billabong Creek System is a complex braided system of interconnecting creeks and anabranches with the main branches of the system being Yanco, Colombo, Billabong and Forest Creeks.

The River Style of the reach of Billabong Creek with the proposed Hartwood and Wanganella Regulators is described as low sinuosity/meandering fine grained, although anabranches and meandering sections are visible on the floodplain. The sediment transport regime of the reach is characterised by moderate suspended load and low bed load transport.

Irrigation works in the last century have significantly altered the flow regime of the Yanco Creek system. Billabong Creek now essentially forms a series of weir pools, and as a result the channel is largely considered to be stable, with some localised erosion noted within the immediate vicinity of structures, generally extending a distance of around 25-50 m downstream of existing weirs.

Construction impacts

Construction of the proposal would involve a range of activities adjacent to the existing and proposed weir sites including vegetation clearing, earthworks, and establishment of construction compounds. In addition the proposal would involve instream works including the construction and dewatering of cofferdams, stream bank and streambed excavation, concrete works, and demolition of existing structures. It was determined that without management, that impacts to geomorphology could occur through several impact pathways. Potential direct and indirect impacts that were identified were:

- Potential changes to fluvial processes during construction leading to adverse impacts on environmental values:
 - Construction works and structures potentially could result in bed and bank erosion or instability.
 - Potential effects to important wetlands and wetland habitat.
- Potential changes to water quality during construction leading to adverse impacts on environmental values:

- Erosion and loss of topsoil causing water quality degradation (e.g., due to clearing of vegetation and ground disturbance during construction activities).
- Discharging/dewatering poor quality water into receiving environments results in reduction in water quality.

With the implementation of safeguards and management measures it was determined that the risk of these impacts occurring changed from medium to low in the study area. As such it is expected that geomorphology values in the study area would be protected during construction.

Operational impacts

Given that it is proposed that the new replacement regulators will be located immediately downstream of the existing structures and effectively maintain existing weir pools, it is not expected that there will be any significant change in potential for scour/erosion or sedimentation of the weir pools.

A review of hydraulic modelling results shows that there is generally no appreciable change in velocity and shear stress values for existing and proposed conditions for the majority of Billabong Creek. Potential erosion predicted is within the natural geomorphic response of the river channel, where some localised erosion and deposition is part of the natural adjustment of the river channel in response to medium and high flood flow events. The results show small overall relative differences between the existing and proposed velocities and shear stresses, and that for the most part values are well below thresholds considered to represent a geomorphic risk.

It is possible that in response to the new flow regime, the bed and banks could undergo some minor geomorphic adjustment. Localised erosion risks are expected in association with these waterways and regulator structures. It is expected that erosion effects would be localised and manageable. The design of the regulator structures include energy dissipation measures to manage erosion immediately downstream including concrete aprons and rock armouring of the bed and channel banks. Periodic assessment of the condition of the structures is recommended to identify and assess any erosion, so that it can be addressed if required.

Cumulative impacts

Other projects planned in the study area were reviewed to determine if the proposal has the potential to result in significant cumulative impacts. No potential cumulative impacts relevant to geomorphology were identified. As such, no further cumulative assessment was conducted.

Summary

Overall, on the basis of the assessment of the existing geomorphology, the design of the proposal and the assumption that recommended safeguards and management measures are implemented, the assessment concluded that geomorphology values within the study area would be adequately protected during both construction and operation of the proposal.

Important note about this report

The 3Rivers Joint Venture (3Rivers), a joint venture between Jacobs Group (Australia) Pty Limited and GHD Pty Ltd has been engaged to provide certain Engineering and Approvals Services for the NSW Sustainable Diversion Limit Adjustment Mechanism (SDLAM) program in accordance with the Agreement between 3Rivers and the NSW Department of Climate Change, Energy, the Environment and Water (DCCEEW) (the client).

The sole purpose of this report and the associated services performed by Jacobs is to review the potential environmental effects associated with the construction and operation of the Billabong Creek Regulators in accordance with the scope of services set out in the contract between 3Rivers and the Client. That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

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This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This assessment has been prepared in the timeframe and on the basis of the project description prepared by the client and within the limits of the budget approved for the work.

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Glossary

Term	Description
Anabran	A section of a river or stream that diverts from the main channel of the watercourse and rejoins downstream.
Clearing area	This is the area required to construct the proposed infrastructure. Within this area it is assumed that all vegetation would be removed, including trees and ground cover vegetation. Borrow pits also include a clearing area. However this is a conservative assumption and contractors would be encouraged to avoid removal where they can (through proposed mitigation measures).
Commonwealth Environmental Water Holder	The Commonwealth Environmental Water Holder is a statutory position established under the <i>Water Act 2007</i> (Cth) responsible for managing the Commonwealth's environmental water holdings. These water holdings are used to protect or restore environmental assets of the Murray-Darling Basin.
Construction activity zone	The area surrounding and including the 'clearing area' that would be used for construction purposes e.g., laydown, site sheds, parking. It is assumed topsoil will need to be removed / cleared, with some re-grading to create level areas with grubbing and clearing of small shrubs/grasses. Trimming of trees may be required. Tree removal would not occur in portions of the CAZ outside of a clearing area.
Cumulative impacts	The combined impacts of the proposal on a matter with other relevant future projects (see NSW's Cumulative Impact Assessment Guidelines for State Significant Projects).
Disturbance area	The disturbance area includes all locations where the proposal directly impacts the land surface or water body. This includes clearing areas, construction activity zones, access tracks and power supply routes.
Efficiency measure	Provide more water for the environment by making water delivery systems for irrigation more efficient. This can include replacing or upgrading on-farm irrigation, or lining channels to reduce water losses within an irrigation network.
Entitlement	The volume of water authorised to be taken and used by an irrigator or water authority; includes bulk entitlements, environmental entitlements, water rights, sales water and surface-water and groundwater licenses.
Environmental flow	Any river flow pattern provided with the intention of maintaining or improving river health.
Fish passage	The ability of fish or other aquatic species to move through an aquatic system.
Fishway	Structures placed on or around constructed barriers (such as dams or weirs) to give fish the opportunity to move past the barrier.
The proposal	The construction and operation of the two regulators and supporting infrastructure.
The proposal site	The footprint that would be directly affected by construction and the location of operational infrastructure.
Regulator	A gated structure used to actively manage or control the amount of water that flows from one location to another.
Regulated	A water system in which water is stored or flow levels are controlled through the use of structures such as dams and weirs.

Term	Description
Sustainable diversion limit adjustment mechanism	A mechanism under the Murray-Darling Basin Plan that allows the sustainable diversion limit to be adjusted under certain circumstances.
Study area	The area investigated for this assessment which includes the proposal site and surrounding area, with the potential to be directly or indirectly affected by the proposal.
Weir	A low barrier or dam that is built across a watercourse and is designed to store water, control or alter the flow of water in a creek.

Abbreviations

Abbreviations	Definitions
AHD	Australian height datum
CEWO	Commonwealth Environment Water Office
NSW DCCEEW	NSW Department of Climate Change, Energy, the Environment and Water, formerly Water Infrastructure NSW.
EIS	Environmental impact statement
EP&A Act	<i>Environmental Planning and Assessment Act 1979 (NSW)</i>
EPBC Act	<i>Environment Protection and Biodiversity Conservation Act 1999 (Cth)</i>
FM Act	<i>Fisheries Management Act 1994 (NSW)</i>
GL	Gigalitre
ka	kilo annum. One-thousand years is represented by the abbreviation "ka"
km ²	Square kilometres
LEP	Local environmental plan
LGA	Local government area
SDLAM	Sustainable diversion limit adjustment mechanism
SEARs	Secretary's environmental assessment requirements
SEPP	State environmental planning policy

1. Introduction

1.1 Overview

NSW Department of Climate Change, Energy, the Environment and Water (NSW DCCEE) is proposing to replace two existing weirs along Billabong Creek with new regulators (the proposal). The two existing weirs to be demolished are Hartwood Weir and Wanganella Weir. These structures are situated on Billabong Creek within the Yanco Creek system in south-west NSW (refer Figure 1-1).

These weirs were built in the early 20th century and have been used to regulate flows through Billabong Creek, to create weir pools for irrigation and, in the case of Wanganella Weir, to provide town water supply. The weirs are currently in states of declining condition and functionality, and are barriers to the movement of fish through the creek. Their condition limits their ability to regulate flows through the Yanco Creek system and leads to inefficiencies in how water is delivered to the environment and irrigators.

The two proposed new regulators would be fully automated and remotely operated meaning that operators can control the delivery of water more efficiently. The proposal is needed to improve the operator's ability to deliver the right amount of water to the right place at the right time. The new regulators would also feature fishways to support fish movement past the new structures. WaterNSW would own and operate the new regulators once constructed

The proposal is subject to environmental and planning approvals in accordance with the *NSW Environmental Planning and Assessment Act 1979* (EP&A Act) and the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Under the EP&A Act, the proposal is State significant infrastructure (SSI), and the NSW Minister for Planning and Public Spaces is the approval authority. An environmental impact statement (EIS) is required to accompany the application for approval of the proposal.

1.2 Purpose and scope of this report

This report has been prepared by Jacobs as part of the EIS for the proposal. The EIS has been prepared to accompany the application for approval of the proposal and addresses the Secretary's Environmental Assessment Requirements (the SEARs), issued on 17 October 2024.

The purpose of this report is to assess potential geomorphology impacts arising from the construction and operation of the proposal, and where required, identify feasible and reasonable mitigation and management measures. This report:

- Provides a baseline assessment of the existing geomorphic environment.
- Identifies and assesses construction impacts on channel geomorphology.
- Identifies and assesses potential operational impacts on channel geomorphology.
- Identifies mitigation measures for channel geomorphology.

The geomorphology assessment has been undertaken with reference to the geomorphic characteristics of the existing environment of the creek within weir pool backwater areas, and downstream for an appropriate distance that is within the realm of significant influence of the proposal.

1.3 Structure of the proposal

The report is structured as follows:

- Section 1 – provides an introduction to the proposal and the assessment.
- Section 2 – describes the methodology for the assessment.

- Section 3 – describes the existing conditions.
- Section 4 – assesses the impacts of the construction and operation of the proposal.
- Section 5 – provides mitigation measures for the impacts identified.
- Section 6 – conclusion.

1.4 Summary of the proposal

1.4.1 Location

The proposal is located on Billabong Creek, which is part of the Yanco Creek system in south-west New South Wales (NSW). The Yanco Creek system forms a part of the Murray-Darling Basin. An overview of the location of the proposal is shown in Figure 1-1.

The proposal is located within the local government area (LGA) of Edward River.

1.4.2 Key features of the proposal

As discussed in section 1.1, the proposal involves replacing two existing weirs along Billabong Creek with new regulators including fishways.

The design of the two proposed regulators is similar and would include:

- concrete piers with maintenance bulkhead slots.
- automated layflat gates across the crest of the structure to assist with flow management and downstream fish passage.
- a low turbulence 'keyhole' type vertical slot fishway with allowances for variable headwater to provide upstream fish passage.
- automated sidewinder gates within the vertical slot fishway to allow for variable headwater conditions.
- fixed concrete crests on the opposite side of the gates to the vertical slot fishway.
- concrete apron downstream of the structure.
- concrete wingwalls upstream and downstream of the structure.
- access from a trafficable deck for maintenance (Hartwood Regulator only).
- pedestrian walkway access part way across Wanganella Regulator structure to facilitate housing of gate actuators and for maintenance.
- walkway grating over gates to facilitate operations and maintenance.
- crushed rock maintenance pads, access and turnaround areas adjacent to the structure.
- rip rap and rock beaching upstream and downstream of structure for erosion protection.
- control house.
- sheet pile cut-off walls beneath the structure.
- fencing of the structures to prevent public access.
- SCADA control system.

An indicative layout of a regulators is shown in Figure 1-2. This example is of a five gate regulator with a fish passage and trafficable deck for maintenance vehicles.



Figure 1-2. Indicative layout of the regulators.

The proposal would also involve the following elements:

- Power supply to the regulators would be provided by a mix of underground and overhead electricity cables connecting the structures to the grid.
- Access to the regulators would require permanent tracks for maintenance and some additional tracks to support construction only. Track upgrades include a new drainage culvert at Hartwood
- The existing Forest Creek block bank, associated with the Hartwood Regulator, would be upgraded to include a spillway structure with two reinforced concrete sills infilled with rock beaching and crushed rock.
- A flood bypass channel would be constructed to reduce potential upstream flooding impacts from the Wanganella Regulator. The channel would enable flood waters to drain between the billabongs in the Wanganella Reserve during flood events. It would be 85 metres long, around 40 metres wide and 1.7 metres deep and located north of the Wanganella landfill. Once completed, the channel sides and base would be naturalised and vegetated with appropriate local native species.
- An existing borrow pit on private land at lot 56 / DP756322 near Hartwood Weir would be extended to provide material for the construction of Hartwood Regulator and Forest Creek block bank.

The location of the existing weirs, proposed infrastructure, and the indicative proposal footprints are shown on Figure 1-3 and Figure 1-4.

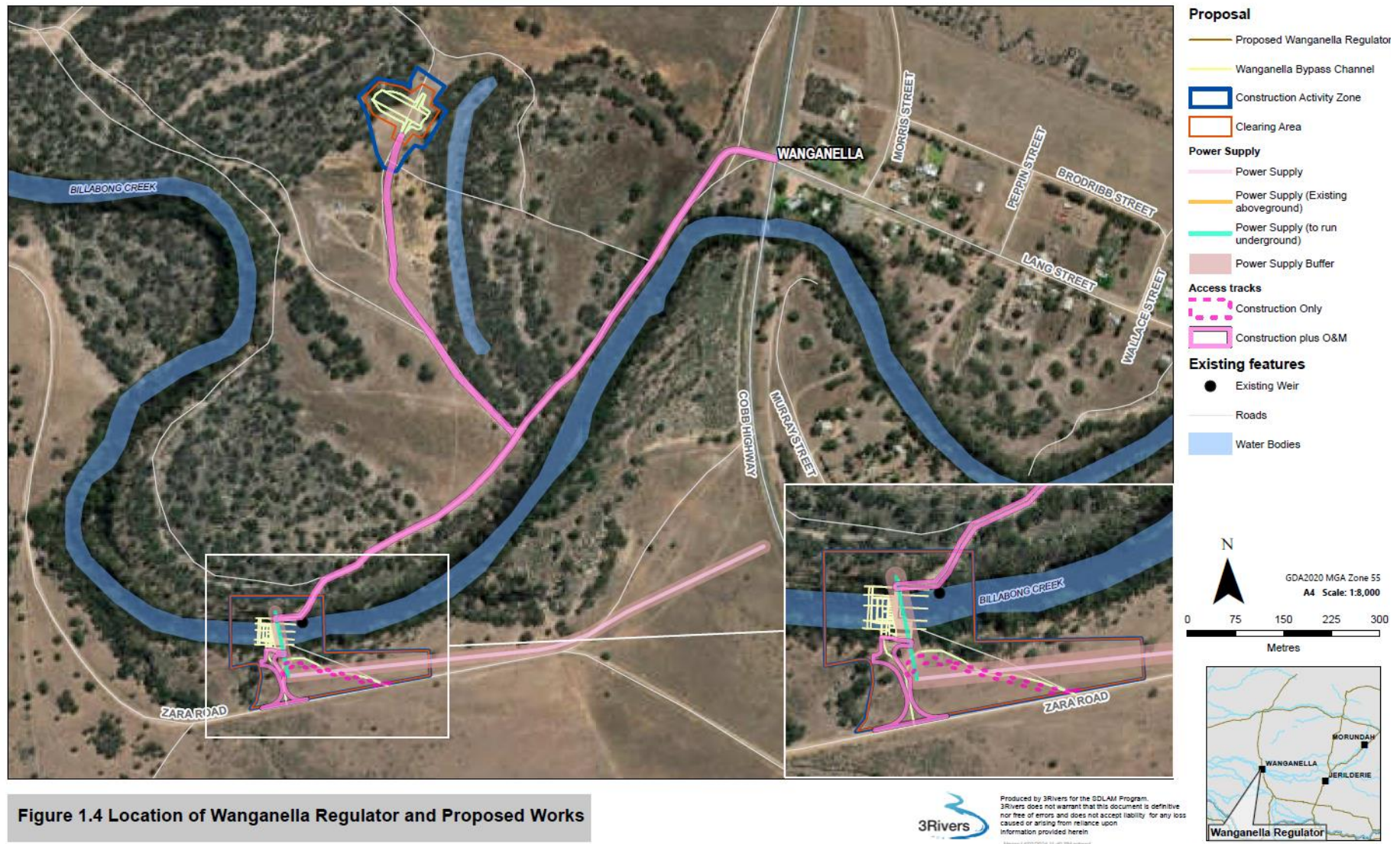


Figure 1.4 Location of Wanganella Regulator and Proposed Works

Figure 1-4. Location of Wanganella Regulator and proposed works.

1.4.3 Key features of existing proposal site

1.4.3.1 Hartwood

The existing Hartwood Weir, completed in 1916, is downstream of the Billabong Creek and Forest Creek junction and can share the regulated flows between the two creeks by creating a weir pool to divert water to Forest Creek (Alluvium, 2013).

Hartwood Weir, shown in Figure 1-5, now largely operates as a fixed crest weir with a concrete apron and abutments. The weir contains manual drop boards that would have been used historically to regulate flows past the weir and are now only removed in high flows.

The extent of the existing weir pool at full supply level, upstream of the structure, is around 16.5 kilometres.

WaterNSW owns the land on which Hartwood Weir is located. Downstream of this land includes both private and Crown land. Land on the right bank (eastern side) of the creek is privately-owned agricultural land. Billabong Creek around the weir is a Crown waterway. The land on the left bank (western side) is Crown land and includes a Travelling Stock Reserve.

The existing Forest Creek block bank was constructed of clay and rock in an excavated channel between Billabong Creek and Forest Creek. The structure is trafficable and connects access tracks on both sides of the creek, but is currently in poor condition. The structure controls flow into Forest Creek from Billabong Creek, used for irrigation and other uses. It is located within Crown land and is used as a Travelling Stock Reserve.



Figure 1-5. Hartwood Weir.

1.4.3.2 Wanganella

Wanganella Weir shown in Figure 1-6, is located on Billabong Creek and contains eleven drop board bays to regulate flows, however the drop boards are no longer in place having been removed in the 1980s. It now operates as a fixed crest weir with a concrete apron and abutments. The weir was constructed for the Wanganella village water supply. The extent of the weir pool at full supply level upstream of the structure is around 13 kilometres.

Wanganella village is located around 1 km north of the site. The site is part of the Wanganella Recreation Reserve, known to local residents as Wanganella Common. It is a Crown land reserved for the preservation of fauna and for public recreation. It is managed by Edward River Council. Billabong Creek at this location is a Crown waterway. Existing access to the site is from the Cobb Highway on the western side of the Creek. Zara Road is located on the eastern side of the creek but there is no formed access track on this side. Zara Road also intersects with another portion of Crown land used as a Travelling Stock Reserve.



Figure 1-6. Wanganella Weir.

1.4.4 Timing

Construction of the proposal is anticipated to start in 2025 and be completed by 2026. The construction period is anticipated to be around 18 months. Construction would pause during periods of high flow.

1.4.5 Operation

The proposal would be operated in accordance with the operating requirements established with NSW DCCEEW and developed in consultation with the asset owner and other agency stakeholders. These operating requirements are known as the Yanco Creek System Operations Plan. The plan would consider the regulation requirements at each regulator, as well as constraints such as limits to rates of rise and fall to accommodate fish breeding requirements.

The proposed regulators would provide greater control of weir pool water levels and would be operated to meet environmental and water supply objectives. WaterNSW would own and operate the new regulators.

1.5 Secretary’s environmental assessment requirements

This geomorphology assessment has been prepared to address the Secretary’s Environmental Assessment Requirements (SEARs). Table 1-1 outlines the requirements relevant to this assessment. The assessment also considers matters raised by the NSW DCCEEW and Department of Primary Industries (Fisheries) as part of ongoing agency consultation.

Table 1-1. Relevant SEARs

Requirements	Where addressed in this report
Water	
3. Include a thorough description of the existing environmental conditions and hydrological regime to the extent of project influence up and down stream, including:	<p>A description of the existing geomorphology conditions has been prepared.</p> <p>This assessment is based on a desktop review of available information (Section 3.1) and site assessments (Section 3.2). Inferences have been made as to the geomorphological stability of the creek and potential erosion/sedimentation within the vicinity of existing weirs based on a visual site assessment and review of available survey information (Section 3.2). Section 0 provides modelling of existing flow conditions 50% and 2% AEP events. The 50% AEP event approximates bankfull discharge, the maximum discharge that the channel can convey without overflowing onto the floodplain. The 2% AEP event represents a much larger flow that exceed the capacity of the channel, inundates the broader floodplain and engages network of connecting anabranches and paleochannels.</p>
d. River channel form, relevant river styles, geomorphic processes including sediment transmission rates, storage and reworking, and in-channel sediment features.	
g. Relationships between the channel and adjacent floodplains, including a description of the frequency and duration of overbank flows, sediment trapping and sediment features on the floodplain and any river levees.	
4. Include a thorough assessment of the hydrological impacts of the project in comparison with existing hydrological conditions, to the extent of project influence up and down stream, including:	<p>An assessment has been made of the potential impacts of the proposal on the geomorphic characteristics of the existing environment of the creek. This assessment of potential impact is outlined in Section 4. The assessment is based on a review of hydraulic modelling outputs, in particular comparison of velocity and shear stress for existing and proposed conditions.</p>
g. Proposed surface and groundwater monitoring activities and methodologies.	
i. Design criteria relating to flow hydrographs, release rules, any proposed translucency measures and other alteration of riverine hydrology, flow energy and sediment transport.	
Land	
7. Include an assessment of the impacts of the project on soils and land capability of the site and surrounds, including:	<p>An assessment has been made of the potential impacts of the proposal on the geomorphic characteristics of the existing environment of the creek. This assessment of potential impact is outlined in Section 4.</p>
- Bank stability.	
- Soil erosion and sediment transport inclusive of geomorphological impacts to waterways.	
- Sediment deposition.	

Flooding	
14. The EIS must assess the impacts on the proposed development on flood behaviour, to the extent of project influence up and down stream, including:	An assessment has been made of the potential impacts of the proposal on the geomorphic characteristics of the existing environment of the creek. This assessment of potential impact is outlined in Section 4. The assessment is based on a review of hydraulic modelling outputs, in particular comparison of velocity and shear stress for existing and proposed conditions.
a. Whether there will be direct or indirect increase in erosion, siltation, destruction of riparian vegetation or a reduction in the stability of riverbanks or watercourses.	
Biodiversity Assessment	
19. Assessment of biodiversity impacts must include the following:	An assessment has been made of the potential impacts of the proposal on the geomorphic characteristics of the existing environment of the creek. This assessment of potential impact is outlined in Section 4.
j. An assessment of impacts during construction and operation of the project and associated works on river hydrology, hydraulics (lotic and lentic flow profiles), geomorphology, and water quality and associated impacts on flow-dependent ecological communities.	

1.6 Assumptions

The opinions, conclusions and any recommendations in this report are based on the assumptions described in this report. The assumptions have been made using the usual standard of care and skill to be expected of the consulting professions and disclaims liability arising from any of the assumptions being incorrect. These assumptions include:

- This report is based on desktop assessment supported by site-specific information from other sources. A visual geomorphological assessment was also undertaken by a fluvial geomorphologist.
- The impact assessment was undertaken with reference to the detailed design, the Billabong Creek Regulators Hydrology Assessment (Jacobs, 2024a), Billabong Creek Regulators Flood Impact Assessment (GHD, 2024) and the Billabong Creek Regulators Groundwater Assessment (Jacobs, 2024b).

2. Assessment approach and methodology

2.1 Methodology

2.1.1 Study area

For the purposes of the assessment the proposal footprint and study area have been defined as follows:

- proposal footprint – the area that would be directly disturbed by construction and the location of operational infrastructure. The disturbance area would include clearing areas, construction activity zones, access tracks, power supply corridors, Forest Creek block bank and Wanganella flood bypass channel. The focus of this assessment is on the regulators. The works associated with tracks, power supply, Forest Creek block bank and Wanganella flood channel are considered a low risk to the geomorphology of Billabong Creek. The scale of these works is small, with low potential for impact on geomorphic conditions and processes, relative to the regulators.
- study area – the area covered by this geomorphology assessment which includes the proposal footprint and surrounding area, with the potential to be directly or indirectly affected by the proposal (including changes to weir pool inundation) as shown in Figure 1-3 and Figure 1-4.

2.1.2 Existing conditions

2.1.2.1 Desktop assessment

The following reports and information associated with the proposal were reviewed to inform the desktop assessment:

- Alluvium (2013) Yanco Creek system environmental flow study (final report), report prepared by Alluvium Consulting Australia for State Water, Leeton NSW.
- Bewsher (2002) Billabong Creek Floodplain Management Plan. Phase A – Data Review and Flood Behaviour. Report prepared by Bewsher Consulting for Department of Land and Water Conservation.
- Bewsher (2002) Billabong Creek Floodplain Management Plan. Phase A & B – GIS Description & Compendium of Data. Report prepared by Bewsher Consulting for Department of Land and Water Conservation.
- Butler, B. E., Blackburn, G., Bowler, J. M., Lawrence, C. R., & Pels, S. (1973). A geomorphic map of the riverine plain of south-eastern Australia. Australian National University Press.
- Cooling, M.P. and Gippel, C.J. (2018). Integrated Hydrological Operations Plan for the Billabong, Yanco and Colombo Creeks – Literature Review and Stakeholder Consultation. Ecological Associates report FL001-1-F prepared for Murray Local Land Services, Albury.
- DPE NSW, 2024. River Styles Spatial Database¹.
- Streamology (2022) Geomorphic Assessment for the NSW Reconnecting River Country Program in the Murray and Murrumbidgee Rivers. Report prepared by Streamology for Water Infrastructure NSW, Department of Planning and Environment.
- Information relating to existing weirs and future proposed regulator structures as outlined in Yanco Creek Modernisation Project (YCMP) Concept Design Report (3RJV, 2022), YCMP Yanco Creek System Operations Plan (NSWDPIE, 2022), Survey for Existing Structures and Channel Environment, Design Drawings and Constructability Reports.

¹ <https://trade.maps.arcgis.com/apps/webappviewer/index.html?id=25d05de7453d4b0eb54783f84d319f0c>

2.1.2.2 Site visits

Site visits were undertaken by a geomorphologist on 27 April 2022 and 4 May 2022. These visits provided the opportunity to confirm the current geomorphic conditions and processes at the sites of proposed regulators, existing weir structures and sections of channel upstream and downstream of existing weirs. Site visits included the proposal site of Hartwood Weir and Wanganella Weir. In addition the areas around two other weirs, Picaninny Weir and Caroonboon Weir were also surveyed as this assisted in providing a broader understanding of existing geomorphologic conditions and processes along Billabong Creek. The geomorphic condition of the channel banks at these locations and any structures were inspected and assessed, and any obvious instabilities (i.e. undercutting, slumping, evidence of ongoing erosion) were identified.

2.1.3 Risk assessment

A risk-based approach was adopted to understand the key risks and impact pathways with the potential to lead to significant geomorphological impacts. The risk assessment included:

- 1) Assessing impact pathways identified as relevant to the proposal.
- 2) Evaluating the significance of any potential adverse effects.
- 3) Developing measures to avoid, minimise or manage adverse effects to acceptable levels.

2.1.4 Assessment of effects

Potential effects were assessed using a risk-based approach. The assessment of effects involved:

- Identifying key issues or risks.
- Characterising the existing environment.
- Identifying the potential effects of the proposal on current geomorphic conditions and processes (pre-mitigation), including likely extent, magnitude and duration of effects to geomorphic conditions and processes.
- Identifying design and mitigation measures and, where relevant, design alternatives, to reduce or mitigate the likelihood, magnitude, extent and duration of potential effects.
- Assessing cumulative effects by identifying likely residual effects rated as medium or above, reviewing the potential for these effects to accumulate across the study area, and based on this review assessing the significance of any identified potential cumulative effects.

The specific steps followed are outlined below.

2.1.4.1 Effects pathways

Effects on geomorphology from construction and operation of the proposal have been determined using the source → pathway → receptor model of effects. Pathways that could pose a risk to geomorphology are linked to proposed changes in surface water hydrology, hydraulics or quality. Without the presence of a pathway to a receptor there is no possibility of an effect from a source. Impact pathways are identified for both construction and operation.

2.1.4.2 Design and operating scenarios

The proposed regulators would provide greater control of water levels to meet environmental and water supply objectives. With an understanding of the existing conditions and the proposed works and potential operational scenarios, an assessment of potential geomorphology effects associated with construction and operation was undertaken based on an understanding of potential impact pathways. Design and operational

scenarios are described in the proposal descriptions (Section 1.4) and discussed in further details in the EIS and Yanco Creek System operations plan (NSWDPIE, 2022).

2.1.4.3 Evaluation

Construction, commissioning and operation effects have been analysed and evaluated both qualitatively based on geomorphology understanding, specialist’s experience, and quantitatively using tools such as hydraulic modelling, which are described further in the Billabong Creek Regulators Flood Impact Assessment (GHD, 2024).

Effects pathways have been determined for fluvial processes (surface water flow) and separately for surface water quality. The impact pathways for the surface water assessment are:

- Fluvial processes – Potential changes to fluvial processes leading to adverse impacts on environmental values including channel form and habitat.
 - Fluvial processes comprised changes in hydrology and hydraulics, as well as associated changes to geomorphic condition.
- Surface water quality – Potential changes to water quality leading to adverse impacts on environmental values including waterway health.
 - Potential changes to water quality included change to general water quality parameters, for example turbidity.

Potential adverse effects to surface water values were assessed using a combination of likelihood (Table 2-1) and consequence (Table 2-2). The significance of effect was defined using the matrix in Table 2-3.

Table 2-1. Project proposal likelihood criteria.

Likelihood of an effect	Description
Almost certain	The event is expected to occur in most circumstances
Likely	The event will probably occur in most circumstances
Possible	The event could occur
Unlikely	The event could occur but not expected
Rare	The event may occur only in exceptional circumstances

Table 2-2. Project proposal consequence criteria.

Consequence Criteria rating	Surface water specific description
Severe	<ul style="list-style-type: none"> ▪ Changes to surface water as a result of the proposal, that are well outside the range experienced during natural inundation of the creek and floodplain. This has the potential to cause permanent loss of one or more environmental values of surface water across a large geographic area. Specific effects could include: <ul style="list-style-type: none"> - Increase in hydraulic shear stress above thresholds for very high erosion risk. Erosion may be widespread across Billabong Creek channel and floodplain areas. - Widespread and prolonged (years) degradation of general water quality parameters outside of ambient conditions within the Billabong Creek channel and creeks and wetlands on the floodplain. - May have state-wide effects that would involve permanent significant impacts on values of state or national significance

Major	<p>Changes to surface water as a result of the proposal, that are outside the range experienced during natural inundation of the creek and floodplain. This may cause long-term impairment of one or more environmental values of surface water within channel and floodplain areas. Specific effects could include:</p> <ul style="list-style-type: none"> ▪ Increase in hydraulic shear stress above thresholds for high erosion risk. Erosion may occur around regulators and across the broader floodplain (floodplain creeks and wetlands). ▪ Widespread and prolonged (months) degradation of general water quality parameters outside of ambient conditions within the Billabong Creek channel and creeks and wetlands on the floodplain. ▪ May have long-term regional effects with impacts on values of regional or state significance, limited impacts on values of national significance.
Medium	<p>Changes to surface water as a result of the proposal, that are at the extremes of the range that could occur during natural inundation of the creek and floodplain. This may cause short-term impairment of one or more environmental values of surface water within channel and floodplain areas. Specific effects could include:</p> <ul style="list-style-type: none"> ▪ Increase in hydraulic shear stress above thresholds for medium erosion risk. Erosion may occur around regulators and within creeks along the flow path of the inundation event. ▪ Short-term (weeks) degradation of general water quality parameters outside of ambient conditions within the Billabong Creek channel and creeks and wetlands on the floodplain.
Minor	<p>Changes to surface water as a result of the proposal, that are outside the typical range that occurs during natural inundation but is within the range that may be experienced during natural inundation of the creek and floodplain under some circumstances. This may cause some localised and/or transient impairment of one or more environmental values of surface water for a short duration of time and from which there is rapid recovery. Specific effects could include:</p> <ul style="list-style-type: none"> ▪ Increase in hydraulic shear stress above thresholds for low erosion risk. Erosion may occur around regulators. ▪ Localised and transient (days) degradation of general water quality parameters outside of ambient conditions within some parts of Billabong Creek channel and creeks and wetlands on the floodplain. Other parts of the creek and floodplain, including floodplain creeks, are unlikely to experience degraded water quality outside of the range experienced under natural conditions.
Insignificant	<p>Changes to surface water as a result of the proposal, that is within the typical range experienced during natural inundation of the creek and floodplain. There is no practicable measurable effect on environmental values, including:</p> <ul style="list-style-type: none"> ▪ No notable increase in hydraulic shear stress (or associated erosion) above levels currently experienced during natural flood events ▪ No notable change from current water quality for general water quality parameters compared to natural flood events.

Notes:

Inundation of the channel and floodplain during natural flooding events can lead to significant environmental impacts. The criteria in this assessment relate to the extent that changes to surface waters fall within or outside the natural range.

Table 2-3. Significance of effect.

		Consequence of an effect				
Likelihood of an effect	Rating	Insignificant	Minor	Moderate	Major	Severe
	Almost certain	Low	Medium	High	Extreme	Extreme
	Likely	Low	Medium	High	High	Extreme
	Possible	Insignificant	Low	Medium	High	High
	Unlikely	Insignificant	Low	Medium	Medium	High
	Rare	Insignificant	Insignificant	Low	Medium	High

In evaluating effects, this assessment has considered the interdependencies and linkages between surface water and geomorphic characteristics. Changes in surface water characteristics can affect fluvial geomorphology with consequences for waterways stability, for example through changes in hydraulic characteristics (e.g., flow velocity and shear stress) that causes unacceptable erosion. This Geomorphology Assessment documents the potential effects of the proposal on geomorphic characteristics.

2.1.4.4 Assessment methods

2.1.4.4.1 Hydraulic modelling

Hydraulic modelling at Hartwood and Wanganella has included the assessment of several flow conditions and flood events ranging from operational flow (minimum environmental base flow requirements as stipulated by DCCEEW and/or Water NSW) to flood flows (ranging from 50% AEP up to the probable maximum flood (PMF)) for both existing and proposed conditions.

Results from hydraulic modelling include:

- Flood extents (provided in the form of inundation maps and GIS layers).
- Flood characteristic grids (water level, depth, velocity, hazard and bed shear stress).
- Difference grids (showing afflux or change in water level between proposed and existing scenarios) and long-section plots.
- Processed results to assist understanding of impacts associated with the proposed works to inform the EIS process.

2.1.4.4.2 Geomorphic assessment

The outcomes of the hydraulic modelling were used to assess geomorphic effects. The assessment focused on changes in velocity, shear stress, water depth and inundation extents across the floodplain areas. Specifically, the assessment considered whether the proposals construction or operation was likely to result in changes in velocity or shear stresses that were outside the range experienced during a natural inundation event or that would exceed critical erosion thresholds. Velocity and shear stresses under natural and proposed conditions were modelled using hydraulic modelling.

Critical shear stress thresholds were identified with reference to tables of maximum permissible shear stress for different soils as documented in the literature (Chang, 1988; Chow, 1981; Gippel et. al. 2008; Water Technology, 2009). Ground conditions and thresholds for assessment of erosion were verified in the field through site inspections. Shear stress patterns were compared between natural and proposed across each project area.

2.1.4.4.3 Cumulative impacts

The other projects planned in the study area were reviewed to determine if the proposal has the potential to result in significant cumulative impacts. The assessment of cumulative effects is reported in Section 4.5.

3. Existing Environment

3.1 Desktop review

The geomorphology of Billabong Creek has been described in a number of reports. These reports are reviewed here as they provide the existing state of knowledge on the geomorphology of Billabong Creek. The region has previously been described by Butler *et. al* (1973) as part of the development of a geomorphic map of the river plain of South-eastern Australia. The majority of the Billabong Creek region is described as a plain or as a plain with channels and depressions. Scattered across the plains are small areas classified as channelled plain, lunettes, indistinct dune fields on aeolian sediments and swamps (Butler *et. al* 1973).

Alluvium (2013) as part of an Environmental Flows Study for the Yanco Creek system describe the geomorphology of Billabong Creek. The Yanco Creek system is an effluent of the Murrumbidgee River downstream of Narrandera which flows south-west, discharging into the Edward River (part of the Murray River basin) at Moulamein. The Yanco Creek system includes the floodplains of the Yanco Creek, the regulated portion of Billabong Creek, Colombo Creek, and the regulated and unregulated portions of Forest Creek (Figure 3-1). The system receives most inflow from the Murrumbidgee River, and also catchment inflows from the unregulated Billabong Creek.



Figure 3-1. Yanco Creek system showing environmental flow study reaches (Alluvium 2013).

Building further upon the mapping work of Butler *et. al.* (1973) the Yanco Creek system is described as lying within the lower tract of riverine plains of NSW, which include the alluvial fans of the Lachlan, Murrumbidgee and Murray rivers west of the Great Dividing Range and extends down the Murray River. Discharge from past and present streams control patterns of sediment deposition, soils, landscapes and vegetation.

Yanco Creek is part of a complex distributary system of paleochannels that emanates from the confined upstream valley at Narrandera (Page *at al.* 2009). Four phases of paleochannel have been recognised, commencing with the Coleambally phase between 105 kilo annum (ka) (105 000 years ago) and 80 ka and progressing through the Kerarbury (55 to 35 ka), Gum Creek (35 to 25 ka) and Yanco (20 to 12 ka) phases until the establishment of channels similar to those of the present regime by about 10 ka (Page *et. al.* 2009).

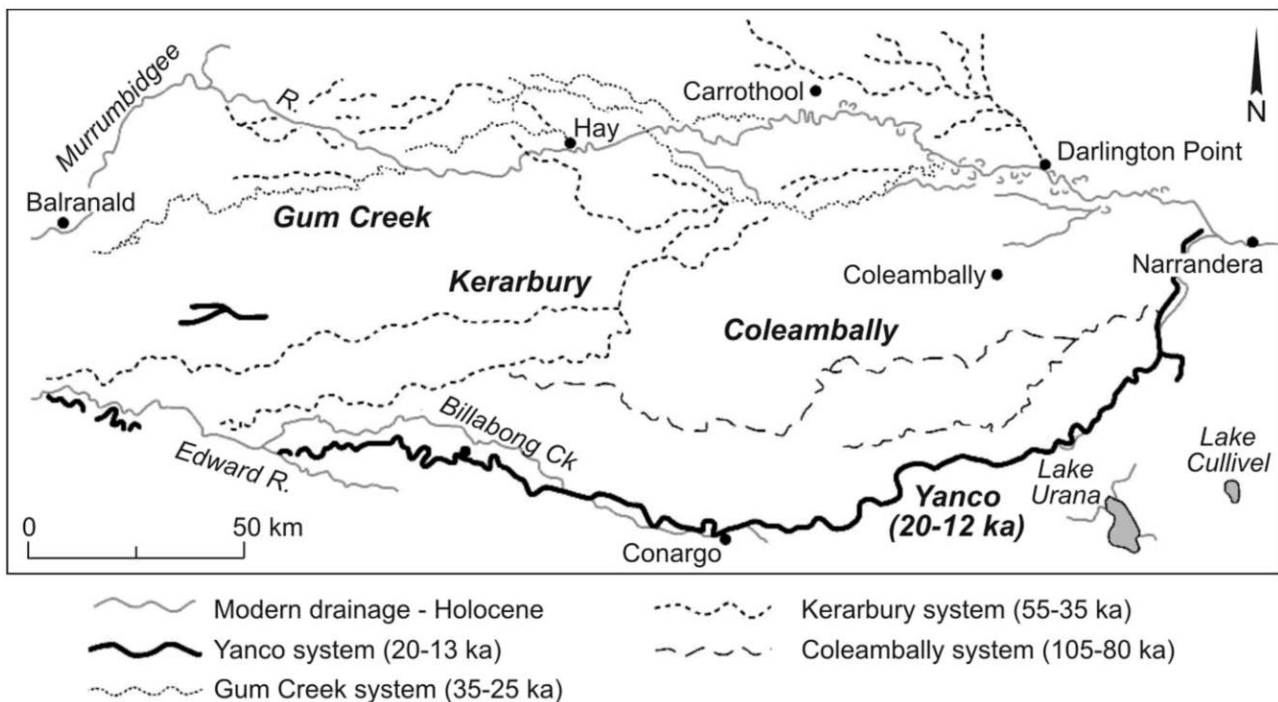


Figure 3-2. Map of Late Quaternary paleochannels of Murrumbidgee River west of Narrandera (Page *et. al* 2009).

The present geomorphology of the Yanco system reflects its evolution through the Late Quaternary, with a number of (relatively) small, highly sinuous channels dominated by suspended sediment load (i.e. low bedload) within a large, very flat floodplain formed by the Yanco paleochannel that operated between 20,000 to 12,000 years ago (Alluvium, 2013).

The formation of the present geomorphology of the Yanco Creek is strongly influenced by the drier climate of the Holocene, which has resulted in the smaller, more sinuous pattern of the channels. In the lower section of the system there is a general floodplain gradient to the north so the floodplain flows generally towards Billabong Creek. Eight Mile Creek appears to be in active aggradation phase, which exacerbates the tendency for flows to move towards Billabong Creek, and reduces the effectiveness of this channel as a delivery route to Wanganella Swamp (Alluvium, 2013).

Streamology (2022) as part of the geomorphic assessment for the NSW Reconnecting River Country Program in the Murray and Murrumbidgee Rivers describe the geomorphological characteristics of Yanco Creek/Billabong Creek. Their assessment is also based on the information available in the River Styles dataset (DPE NSW, 2024). The River Style of the reach is described as low sinuosity/meandering fine grained, although anabranches and meandering sections are visible in floodplain. The sediment transport regime of the reach is characterised by moderate suspended load and low bed load transport.

Cooling and Gippel (2018) describe the physical form of the Billabong Creek. The channel has deep pools separated by shallower runs and benches at a variety of elevations in the channel. Large woody debris is present on the banks and in the channel. Reed beds are present on benches in the channel.

Irrigation works in the last century have significantly altered the Yanco Creek system flow regime. Prior to irrigation development, the system would have flowed only when flooding was occurring in the Murrumbidgee River and/or when there was substantial runoff and flows in the upper catchment of Billabong Creek. Demand for water in the area led to the construction of a significant number of structures, both publicly and privately owned, that impact on flows along the system. These include the off-take from the Murrumbidgee River, and weirs, regulators, block dams and by-wash dams throughout the creek system (Alluvium, 2013).

3.2 Site assessments

Site assessments were carried out by Dr Peter Sandercock along Billabong Creek, the focus being on completing an assessment of channel conditions within the vicinity of four existing weirs on Billabong Creek including two associated with the proposed regulators. Site assessment included the proposal site of Hartwood Weir and Wanganella Weir. In addition the areas around two other weirs, Picaninny Weir and Caroonboon Weir were also surveyed. The site assessments for all four weirs are documented in this report as it this assisted in providing a broader understanding of existing geomorphologic conditions and processes along Billabong Creek. A summary of site assessments and the existing condition of Billabong Creek at each of these locations is documented in the following sections. This also includes a review of survey data, including creek cross-sections, within the vicinity of each weir, as this is useful in informing an understanding of bed conditions in particular whether erosion/sedimentation is likely to be an issue.

Billabong Creek essentially forms a series of weir pools, the channel is largely considered to be stable, with some localised erosion noted within the immediate vicinity of structures, generally extending a distance of around 25-50 m downstream of existing weirs. This is accentuated in instances where there has been structural deterioration/failure of concrete side walls (Hartwood, Piccaninny and Caroonboon). High flows are outflanking these areas and there are also some seepage/flows through cracks. Reviewing survey of bed levels upstream and downstream of existing weirs reveals very little difference in bed levels which suggests there is unlikely to be significant sedimentation upstream of existing weirs, or erosion of bed downstream of the existing weirs. Existing concrete sill levels are also generally 2 m higher than bed levels upstream. Bank slumping/erosion with current operations is considered a low risk. The banks themselves are comprised of cohesive clays, and combined with vegetation this provides strength to bank materials.

3.2.1 Hartwood Weir

Figure 3-3 and Figure 3-4 show some photographs of existing Hartwood Weir and channel conditions upstream and downstream. A concrete side wall has failed on left hand side of channel (Figure 3-3). Otherwise, it would appear that the remaining structure is intact. Channel upstream appears to be stable. There has been some erosion of channel banks evident downstream of weir over distance of about 50 m. There is little difference in bed invert levels upstream and downstream of weir (Table 3-1). It is considered unlikely that there is significant sedimentation in channel upstream of the weir. It is considered possible that erosion of banks downstream and associated channel widening, there has been some build-up of sediments on the channel bed downstream of the weir (bed invert levels 0.5 to 0.8 m higher downstream of weir).



Looking upstream at weir at failure of concrete side wall on left hand side of channel.



Looking downstream at erosion of channel bank on left hand side of channel.

Figure 3-3. Hartwood Weir – Selected photographs of existing structure and channel.



Looking at channel upstream of existing weir. Stable channel banks with reeds at margins.

Looking downstream of weir, evidence of ongoing erosion of banks and channel widening.

Figure 3-4. Hartwood Weir – Selected photographs of existing structure and channel.

Table 3-1. Hartwood Weir – Comparison of weir invert/sill levels with bed invert levels.

Weir Invert/Sill Level (m AHD)	Bed Invert Level Upstream (m AHD)	Bed Invert Level Downstream (m AHD)
94.69 to 94.96	92.48	92.95 to 93.30

3.2.2 Piccaninny Weir

Figure 3-5 and Figure 3-6 shows some photographs of existing Piccaninny Weir structure and channel conditions upstream and downstream. Cracking of concrete side wall was noted on the left hand side of the channel (Figure 3-5). Otherwise it would appear that the remaining structure is intact. Channel upstream appears to be stable. There has been some erosion of banks downstream of the weir over a distance of about 50 m, particularly on the left hand side of the channel.



Looking across channel at Piccaninny Weir from left hand bank.

Looking downstream at erosion of channel bank on left hand side of channel.

Figure 3-5. Piccaninny Weir – Selected photographs of existing structure and channel.



Looking at channel upstream of existing weir. Stable channel banks with reeds at margins.



Photo taken about 100 m downstream from Piccaninny Weir looking upstream at stable banks.

Figure 3-6. Piccaninny Weir – Selected photographs of existing structure and channel.

There is little difference in bed invert levels upstream and downstream of weir (Table 3-2). It is considered unlikely that there is significant sedimentation in channel upstream of weir.

Table 3-2. Piccaninny Weir – Comparison of weir invert/sill levels with bed invert levels.

Weir Invert/Sill Level (m AHD)	Bed Invert Level Upstream (m AHD)	Bed Invert Level Downstream (m AHD)
89.64 to 89.78	87.30	87.15 to 87.35

3.2.3 Wanganella Weir

Figure 3-7 and Figure 3-8 shows selected photographs of existing Wanganella Weir structure and channel conditions upstream and downstream. Weir structure generally appear to be intact, although some cracking of concrete noted.



Looking across channel at Wanganella Weir from right hand bank.



Looking upstream at bank erosion that has occurred immediately downstream of Wanganella Weir.

Figure 3-7. Wanganella Weir – Selected photographs of existing structure and channel.



Looking at channel upstream of Wanganella Weir. Minor erosion/notching of banks in weir pool.



Photo taken about 100 m downstream of Wanganella Weir. Stable channel banks, and clear high water mark is apparent on opposite bank.

Figure 3-8. Wanganella Weir – Selected photographs of existing structure and channel.

Channel upstream of weir appears to be stable, with some minor erosion/notching of banks. Some erosion is evident of banks downstream of the weir over a distance of about 50 m, particularly on the right hand side of the channel. There is little difference in bed invert levels upstream and downstream of weir (Table 3-3). It is considered unlikely that there is significant sedimentation in channel upstream of weir.

Table 3-3. Wanganella Weir – Comparison of weir invert/sill levels with bed invert levels.

Weir Invert/Sill Level (m AHD)	Bed Invert Level Upstream (m AHD)	Bed Invert Level Downstream (m AHD)
Unknown	78.73	78.84 to 79.41

3.2.4 Caroonboon Weir

Figure 3-9 shows some photographs of existing Caroonboon Weir and channel conditions upstream and downstream. A concrete side wall has failed on left hand side of channel. Otherwise, it would appear that remaining structure is intact. Channel upstream of weir appears to be stable, with some minor erosion/notching of banks. Some erosion is evident of banks downstream of the weir over a distance of about 50 m, particularly on the left hand side of the channel.

There is little difference in bed invert levels upstream and downstream of weir (Table 3-4). It is considered unlikely that there is significant sedimentation in channel upstream of weir.



Looking upstream at Caroonboon Weir



Looking downstream at erosion of channel bank on left hand side of channel.



Looking at channel upstream of existing weir. Minor erosion/notching of banks in weir pool.



Photo taken about 100 m downstream of existing weir. Stable channel banks.

Figure 3-9. Caroonboon Weir – Selected photographs of existing structure and channel.

Table 3-4. Caroonboon Weir – Comparison of weir invert/sill levels with bed invert levels.

Weir Invert/Sill Level (m AHD)	Bed Invert Level Upstream (m AHD)	Bed Invert Level Downstream (m AHD)
75.94	73.54	73.62 to 73.84

4. Impact assessment

4.1 Overview

An environmental risk assessment process was undertaken. Worst case scenario risk pathways were initially assessed without controls to mitigate impacts in place (initial risk rating) and then assuming effective mitigation and management measures were in place (residual risk rating).

Key risks and proposed mitigation measures for the Billabong Creek Regulators project are summarised in Table 4-1 below. None of these key risks were assessed to pose a high or extreme risk to geomorphology prior to implementation of the proposed mitigation and management measures. Following the effective implementation of the proposed mitigation and management measures, the residual risk rating for all key risks assessed was low.

Table 4-1. Key risks and proposed mitigation and management measures for the Billabong Creek Regulators Project.

Risk number	Activity	Impact pathway	Initial risk rating	Proposed mitigation and management measures	Residual risk rating
A	Construction - Surface water - Flow	Potential changes to fluvial processes leading to adverse impacts on environmental values	Medium	GE01, GE02, GE03, GE04	Low
B	Construction - Surface water - Quality	Potential changes to water quality leading to adverse impacts on environmental values	Medium	GE01, GE02, GE03, GE04	Low
C	Operation - Surface water - Flow	Potential changes to fluvial processes leading to adverse impacts on environmental values	Medium	GE05	Low

4.2 Assessment of impacts

A number of potential impact pathways are plausible within each of the risks identified in Section 4.1, and each of these are considered as part of the assessment of effects for the Billabong Creek Regulator project. A list of impact pathways identified for each risk is provided below. These pathways are discussed in Section 4.3 for construction and Section 4.4 for operations.

Construction phase risks, Risks A and B from Table 4-1, and effects are assessed in Section 4.3 and include:

- Risk A: Potential changes to fluvial processes leading to adverse impacts on environmental values.
 - Construction works and structures potentially result in bed and bank erosion or instability.
 - Potential effects to important wetlands and wetland habitat as a result of changes in fluvial processes during construction.
- Risk B: Potential changes to water quality leading to adverse impacts on environmental values.
 - Erosion and loss of topsoil during construction causing water quality degradation (e.g., due to clearing of vegetation and ground disturbance, inundation during construction activities).
 - Discharging/dewatering poor quality water into receiving environments results in reduction in water quality.

Operation phase risks, Risks C Table 4-1, and effects are assessed in Section 4.4 and include:

- Risk C: Potential changes to fluvial processes leading to adverse impacts on environmental values
 - Potential changes in hydraulic characteristics (e.g., velocity and shear stress) that result in changes in patterns of erosion, sediment transport and deposition potentially resulting in bed and bank erosion or deposition in pools. In extreme cases this can result in bank slumping and loss of riparian vegetation or cultural heritage values on river banks, infilling of pools, loss of aquatic habitat, and increased sediment load and turbidity.
 - Potential changes in hydraulic characteristics (e.g. velocity and shear stress) that result in changes in the types and distribution of hydraulic habitat (e.g. still, slow and fast moving water). This has the potential to affect the suitability of habitat for different species, such as fish that may prefer/require certain hydraulic conditions.

4.3 Construction impacts

Potential fluvial and water quality impact pathways (Risks A and B from Table 4-1) are assessed together in this section as these two impact pathways would not occur in isolation. For the effects to surface water quality to occur, there must be a fluvial process to complete the impact pathway – i.e., the fluvial process connects the source of the water quality impact to the receptor or environmental value effected.

The following specific effects are addressed by mitigation and management measures:

- Appropriate design and construction methodology, which aims to minimise erosion and sediment risks, including upstream and downstream during both demolition of existing regulators and construction of the new replacement regulators (GEO1).
- Preparation and implementation of a Construction Environmental Management Plan (CEMP) (GEO2), which will include:
 - Avoidance of disturbance to areas of channels and instream or riparian vegetation/habitat where possible beyond the construction area (GEO3) and requirements for rehabilitation and recovery of disturbed areas (GEO4)
 - Management of sediment and erosion during construction including instream and riparian areas including measures to contain, monitor and if necessary, treat, surface water runoff (GEO3)
 - Contingency measures for managing construction sites during a high flow event to minimise any adverse effects (GEO3)
 - The establishment of a monitoring program to determine current conditions and during construction, monitor for adverse effects, trigger contingency measures, assess effectiveness of recovery and enable reporting (GEO3)

Effective implementation of the mitigation and management measures minimises changes in flow or water quality during construction, which in turn results in insignificant or low effects (Table 4-2 and see Table 4-1 for consequence effect criteria). Specifically, any residual effects are expected to be temporary and localised in nature, are common to similar types of construction activities and standard control mechanisms for these types of impacts are well established.

There is high confidence that construction related impacts to surface waters will be mitigated by the controls proposed in the relevant mitigation and management measures. The residual effect after implementation of mitigation and management measures is assessed as low.

Table 4-2. Types and causes of water quality degradation and the potential for adverse effects to water quality during construction of the Billabong Creek Regulators and the significance of the effect.

Source of water quality degradation	Key causes (pathways) of water quality degradation	Receptors that could be adversely affected by construction related impact pathways at Billabong Creek and specific control measures required to mitigate adverse effects	Relevant mitigation measures and residual effect ratings after implementation
Elevated levels of suspended matter	Poor soil conservation practices	Un-mitigated runoff from exposed soils during rainfall or flow events (including inundation of the construction site during a high flow event) has the potential to entrain sediments and elevate turbidity in Billabong Creek. Implementation of erosion control measures and consideration of areas at high risk of water erosion in the design and construction methodology as part of GEO1 and GEO2 would reduce the likelihood and consequence of the effect by limiting the potential for erosion to occur during construction. This would limit the potential for downstream receptors to be exposed to sediment runoff as a result of erosion. Moreover, if erosion did occur, the occurrences would most likely be associated with periods of higher river flow, which also correspond to higher levels of background turbidity, so the specific effects of runoff from construction sites would be difficult to distinguish from effects associated with elevated turbidity from catchment sources.	<p>GEO2 and GEO3 specify controls for on-site water and sediment management.</p> <p>Structures designed to avoid erosion around and downstream of structures as per GEO1 (erosion and sediment control through design)</p> <p>Vegetation management to minimise disturbance and ensure rehabilitation as per GEO3 and GEO4.</p> <p><u>Likelihood:</u> Unlikely</p>
	Practices that over the long-term cause decline of stream morphology, leading to bed and bank erosion	Although unlikely, poor regulator design and construction quality could result in structure failure and consequent effects such as erosion of waterway banks (loss of habitat for water dependent species, reduced amenity) and increased turbidity. The risk of structure failure is not limited to the construction period. GEO1 specifies erosion and sediment control through design to mitigate this potential adverse effect.	<p><u>Consequence:</u> Minor</p> <p><u>Effect:</u> Low</p>
	Rapid drawdown of water within a surface water resource	Although unlikely to be realised, rapid de-watering of coffer dams during construction could lead to erosion. The rate of drawdown and groundwater intrusion should be managed to avoid bank slumping.	

4.4 Operational impacts

4.4.1 Review of changes in operation levels

Given that it is proposed that the new replacement regulators will be located immediately downstream of the existing structures and effectively maintain existing weir pools, it is not expected that there will be any significant change in potential for scour/erosion or sedimentation of the weir pools.

There may be some sedimentation in channel immediately upstream of the new regulator structures, but given this does not appear to be happening at present in relation to existing structures (little difference in bed invert levels upstream and downstream), this is unlikely to be significant. It may be that higher flows are effective in flushing suspended sediments through the existing weir pools or there just isn't as much sediment moving through the system (banks widely noted as stable along creek).

The regulator structures have been designed so as to include sufficient energy dissipation of flows immediately downstream, i.e. stilling pools/armouring of channel banks.

Bank slumping/erosion as a result of operation of the proposed regulators is considered a low risk. The banks themselves are comprised of cohesive clays, and combined with vegetation this provides strength to bank materials. It is understood that rates of rise/fall are yet to be confirmed. Rates of rise are less of a concern (up to and exceeding 300 mm/day). Rates of fall that are more of an issue, as if banks are saturated and water levels drop rapidly, banks may slump as a result of additional mass and positive water pressures. It is recommended that rates of fall are kept to less than 100-200 mm/day. It is noted that the proposed operation of both weirs specifies a rate of fall not exceeding 100 mm/day.

Rising of water levels has the potential to cause death of treed vegetation at the channel margins. This will be an issue if there are new areas of bank that will be permanently inundated (i.e. as is the case with Hartwood and Wanganella Regulator in the 73 m and 150 m sections of channel respectively between the existing regulators and the proposed new regulators).

4.4.1.1 Hartwood Regulator

Table 4-3 provides a summary of key levels for the proposed replacement Hartwood Regulator and weir pool operating range. The proposed replacement regulator will have a concrete crest with a level of 95.84 m AHD with layflat gates. The bed of the creek upstream of the weir will be 2.74 m below the concrete crest (93.1 m AHD). The water level operating range for the regulator is 0.46 m with a maximum controlled level of 95.74 m AHD and a lower controlled level of 95.28 m AHD. The maximum daily rate of rise/fall is 0.30/0.10 m day. The controlled water level at the existing Hartwood Weir is approximately 95.3 m but this does vary with flow rate.

Table 4-3. Hartwood Regulator – Proposed regulator levels relevant to assessing potential geomorphological impacts. For further information on weir pool operating zones, refer to YCMP Yanco Creek System Operations Plan (NSWDPIE, 2022).

Concrete Crest ¹ (m AHD)	Channel RL Upstream (m AHD)	Normal Regulated Flow Operational Limits					
		Full Supply Level (m)	Top of Green Zone (m)	Bottom of Green Zone (m)	Operating Range (m)	Max Daily Rate of Fall (m)	Max Daily Rate of Rise (m)
95.84	93.1	95.74	95.44	95.28	0.46	0.10	0.30

¹Crest levels may be revised with future updates to design.

Based on a review of site conditions (Section 3.2.1), survey levels for bed upstream and downstream of existing weir (92.5 to 93.3 m AHD, refer to Table 3-1) and design information provided (Table 4-3), the proposed replacement regulator is not likely to have a significant impact on the geomorphological stability of

the creek. As the new regulator is proposed immediately downstream of the existing structure and will maintain existing weir pool, it is not expected there will be any change in the potential for scour/erosion or sedimentation of the weir pool. The regulator structure has been designed so as to include sufficient energy dissipation of flows immediately downstream, i.e. stilling pools/armouring of channel banks.

The hydrological modelling results presented in the Hydrology Assessment report (Jacobs 2024a) show that there would be very little change to the hydrological nature of the study area. Furthermore, hydraulic modelling in the Hartwood weir pool presented in the hydrology assessment indicated very minor increases in the area flooded by the pool under any of the operating scenarios and as such no significant geomorphological impacts are expected. The mapped area of newly wetted channel areas during normal operating levels at maximum and minimum operating flows are presented in Figure 4-1 and Figure 4-2 as an example.

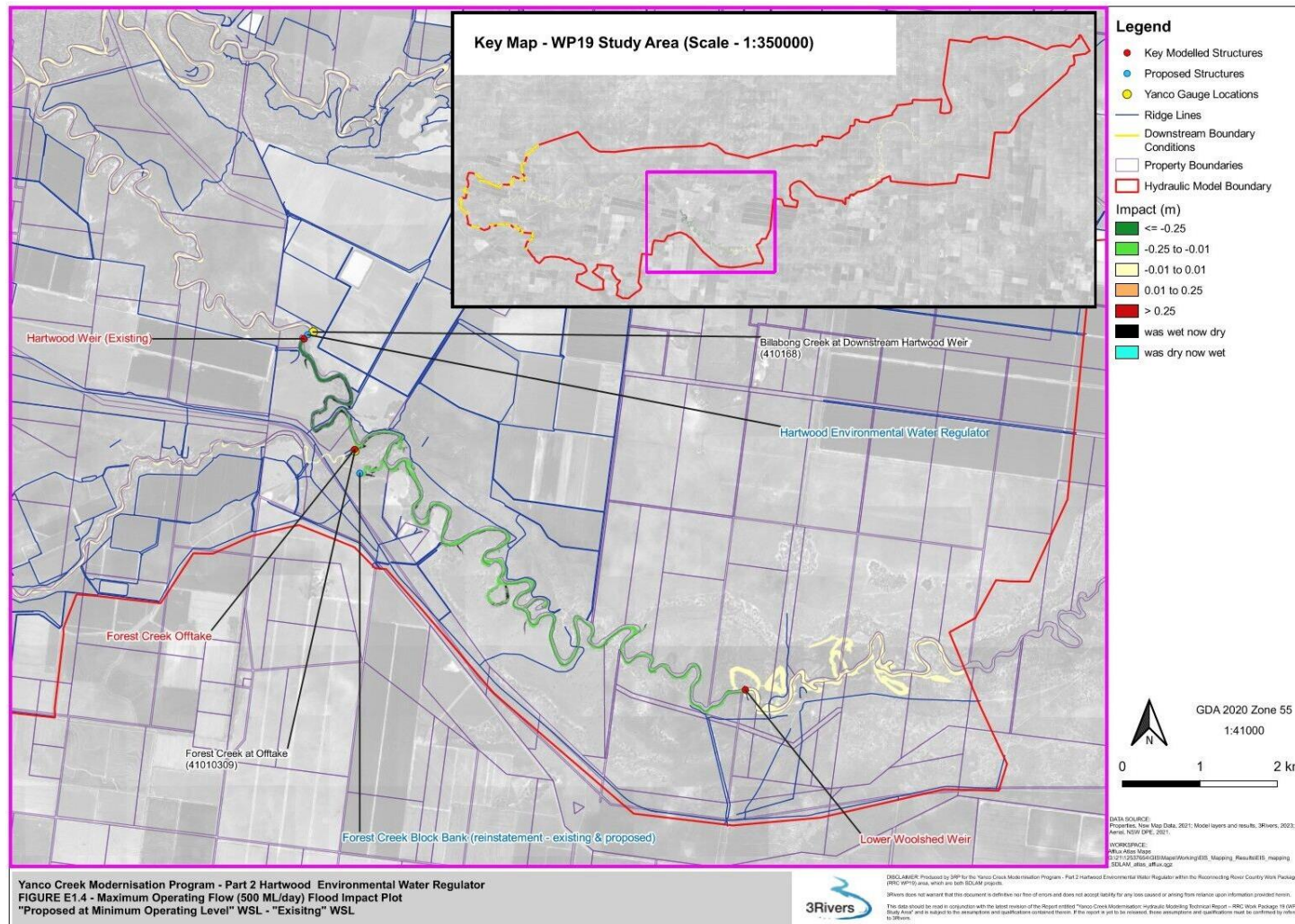


Figure 4-1. Afflux (i.e. change in Water Surface Level) results upstream of the existing Hartwood Weir during maximum operating flows (500 ML/day) when control is set to normal operating level (taken from the Billabong Creek Regulators Flood Impact Assessment Report). This map is presented as an example of commonly experienced conditions under the proposed operating plan (see the Billabong Creek Regulators Flood Impact Assessment Report for full results).

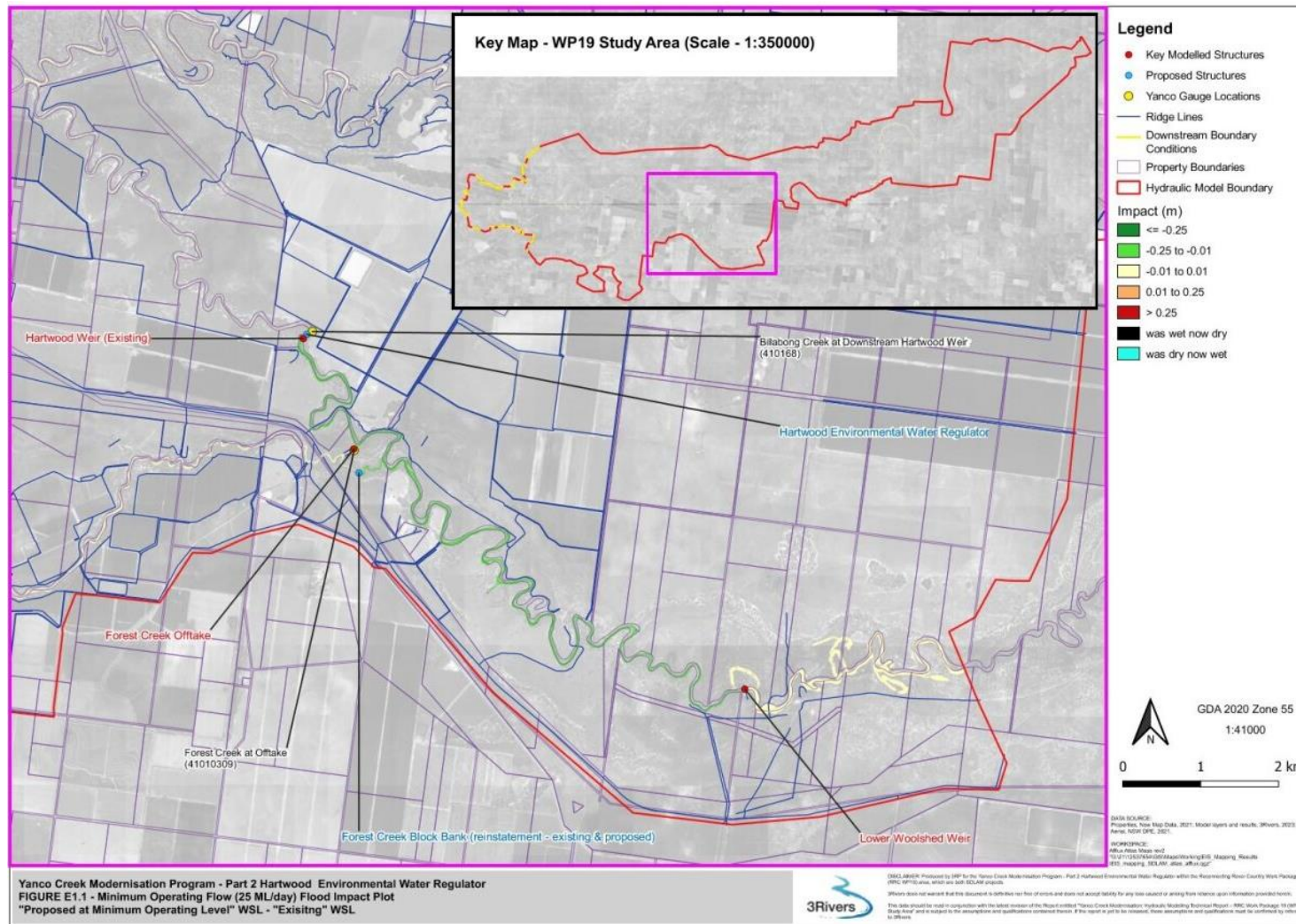


Figure 4-2. Afflux results upstream of the existing Hartwood Weir during minimum operating flows (25ML/day) when control is set to normal operating level (taken from the Billabong Creek Regulators Flood Impact Assessment Report). This map is presented as an example of commonly experienced conditions under the proposed operating plan (see the Billabong Creek Regulators Flood Impact Assessment Report for full results).

4.4.1.2 Wanganella Regulator

Table 4-4 provides a summary of key levels for the proposed replacement Wanganella Regulator and weir pool operating range. The proposed regulator will have a concrete crest with a level of 82.20 m AHD with layflat gates. The bed of the creek upstream of the weir will be 1.85 m below the concrete crest (80.35 m AHD). The water level operating range of the regulator is 1.35 m with a maximum controlled level of 82.10 m AHD and a lower controlled level of 80.75 m AHD. The maximum daily rate of rise/fall is 0.30/0.10 m day.

Table 4-4. Wanganella Regulator – Proposed regulator levels relevant to assessing potential geomorphological impacts. For further information on weir pool operating zones, refer to YCMP Yanco Creek System Operations Plan (NSWDPIE, 2022).

Concrete Crest ¹ (m AHD)	Channel RL Upstream (m AHD)	Normal Regulated Flow Operational Limits					
		Full Supply Level (m)	Top of Green Zone (m)	Bottom of Green Zone (m)	Operating Range (m)	Max Daily Rate of Fall (m)	Max Daily Rate of Rise (m)
82.20	80.35	82.10	80.99	80.75	1.35	0.10	0.30

¹Crest levels may be revised with future updates to design.

Based on a review of site conditions (Section 3.2.3), survey levels for bed upstream and downstream of existing weir (78.73 to 79.41 m AHD, refer to Table 3-3) and design information provided (Table 4-4), the proposed replacement regulator is not likely to have a significant impact on the geomorphological stability of the creek. As the new regulator is proposed immediately downstream of the existing structure and will maintain existing weir pool, it is not expected there will be any change in the potential for scour/erosion or sedimentation of the weir pool. The regulator structure has been designed so as to include sufficient energy dissipation of flows immediately downstream, i.e. stilling pools/armouring of channel banks.

The hydrological modelling results presented in the Hydrology Assessment report (Jacobs 2024a) show that there would be very little change to the hydrological nature of the study area. Furthermore, hydraulic modelling in the Wanganella weir pool presented in the hydrology assessment indicated very minor increases in the area flooded by the pool under any of the operating scenarios and as such no significant geomorphological impacts are expected. The mapped area of newly wetted channel areas at maximum and minimum operating flows are presented in Figure 4-3 and Figure 4-4 as an example.

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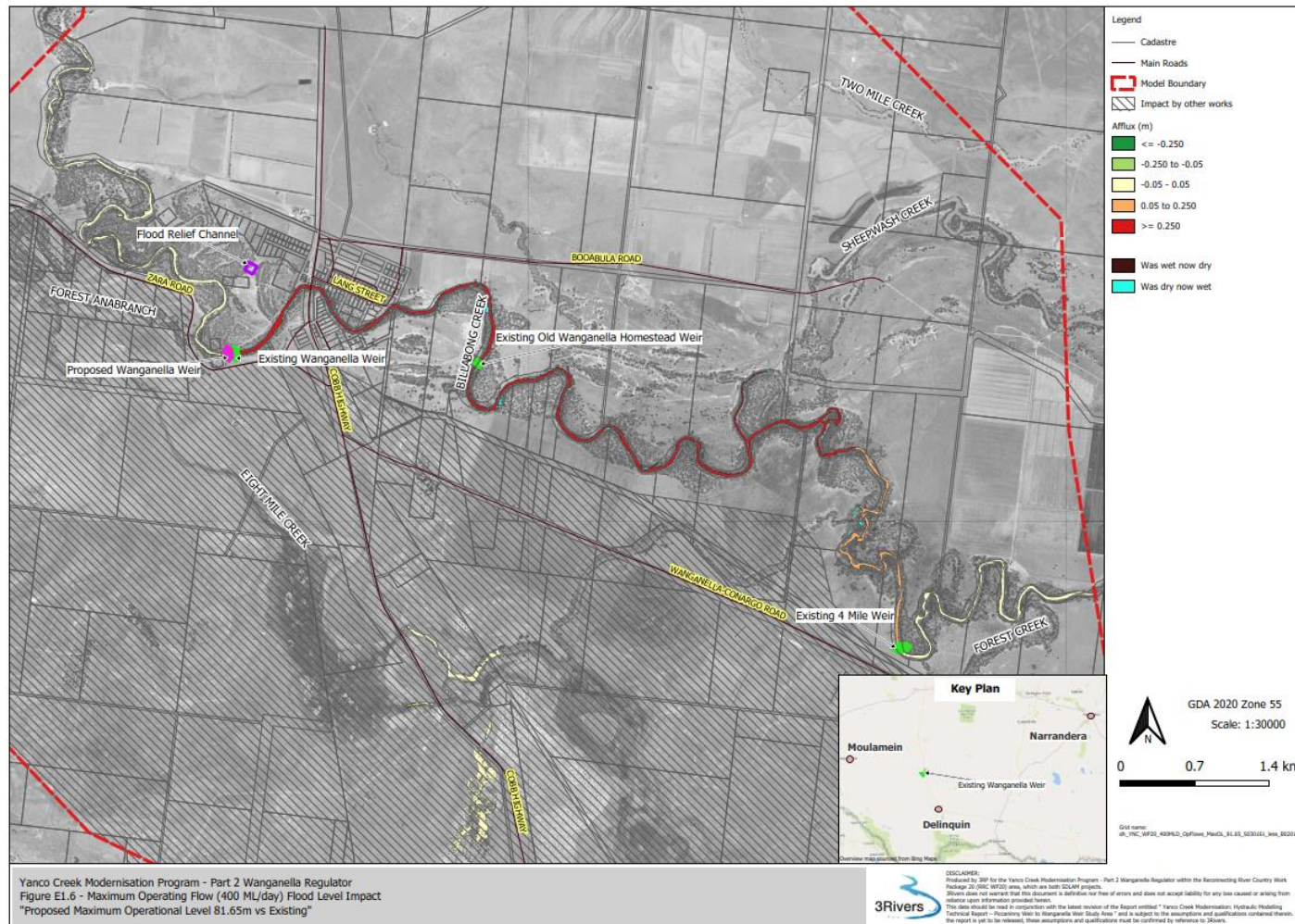


Figure 4-3. Afflux (i.e. change in Water Surface Level) results upstream of the existing Wanganella Weir during maximum operating flows (400 ML/day) when control is set to maximum operational level 81.65 m (taken from the Billabong Creek Regulators Flood Impact Assessment Report). This map is presented as an example of commonly experienced conditions under the proposed operating plan (see the Billabong Creek Regulators Flood Impact Assessment Report for full results).

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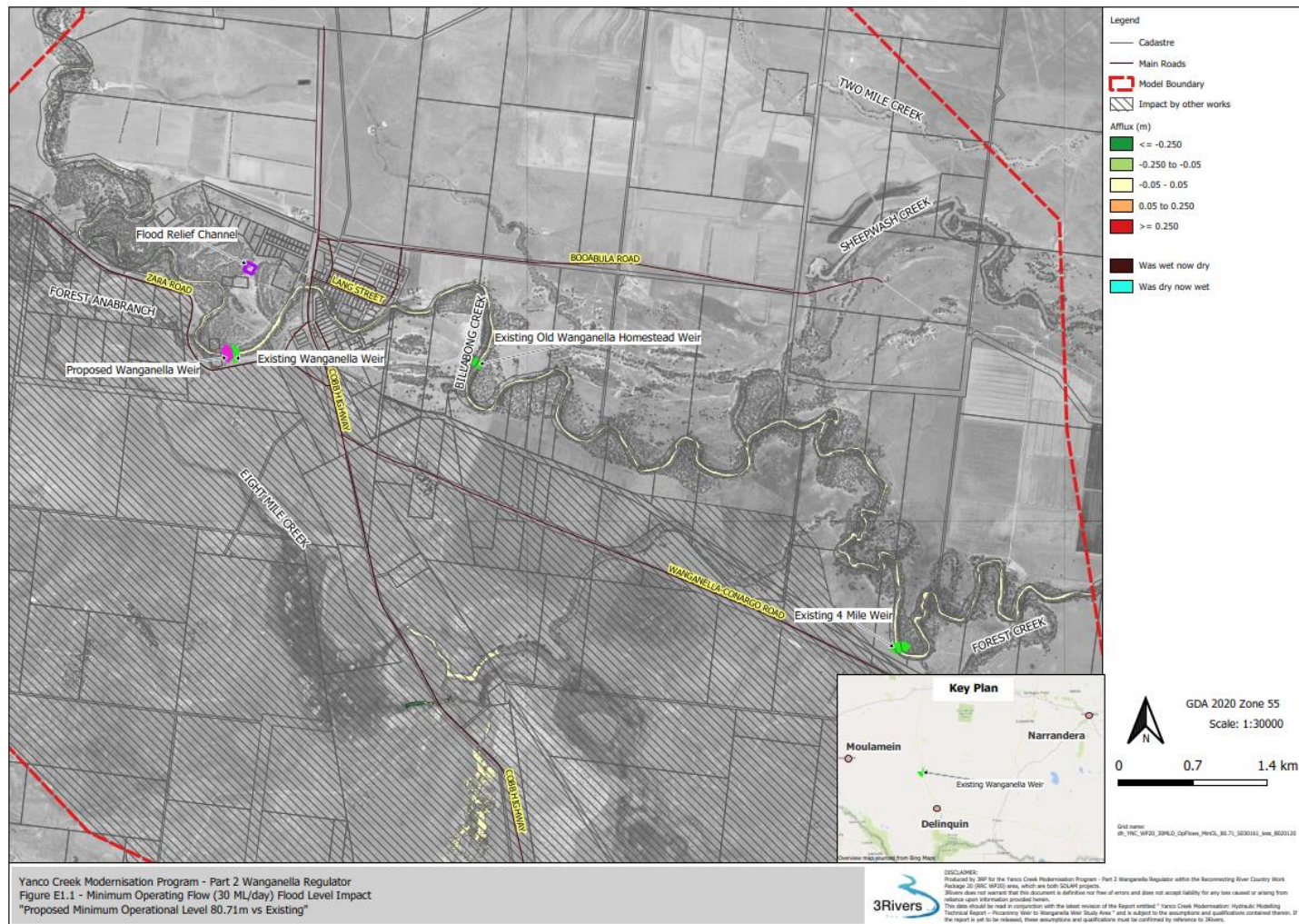


Figure 4-4. Afflux (i.e. change in Water Surface Level) results upstream of the existing Wanganella Weir during minimum operating flows (30 ML/day) when control is set to minimum operational level 80.71 m (taken from the Billabong Creek Regulators Flood Impact Assessment Report). This map is presented as an example of commonly experienced conditions under the proposed operating plan (see the Billabong Creek Regulators Flood Impact Assessment Report for full results).

4.4.2 Review of channel hydraulics

An assessment has been made of hydraulics for both existing and proposed flows to inform an assessment of potential geomorphic effects. This assessment is based upon a review of velocity and shear stress values as described below:

- Velocity – Water velocity was classified into six bands, based on fish habitat categorisation in Table 4-5. A higher propensity for erosion is expected to occur with higher velocity waters. Broadly speaking, in sections experiencing fast flowing and very fast velocity it may be expected that these flows will be effective in eroding channel and floodplain surfaces.
- Shear stress – Shear stress, and in particular maximum bed shear stress, acting on the surface of the channel or floodplain is the primary variable used to assess erosion risk. For clay-rich bank materials a maximum shear stress of 9 to 13 N/m² is considered appropriate for assessing erosion risks. This is also consistent with tables of maximum permissible shear stress (Carter, 1953; Chow, 1981; Chang, 1988; Lane, 1952), which provide values for stiff clay and alluvial soils of 12.5 N/m² (with no vegetation). Maximum permissible shear stress values for vegetated surface indicate that vegetation significantly enhances resistance to scour. A critical shear stress in the range of 100-200 N/m² is a reasonable guide to the shear stress required to remove vegetation.

Taking into account soil conditions observed in the field and literature on shear stresses for similar soils, threshold values for erosion risk were assigned for Billabong Creek. These values and class ranges are shown in Table 4-6. The values and ranges chosen are very conservative, as they assume bare sediments. It is expected that critical shear stresses will be considerably higher, due to above and below ground biomass and leaf/litter layers that form a cover on top of the sediments.

Table 4-5. Billabong Creek velocity classes based on fish habitat.

Fish habitat	Backwaters	Weir pools	Slow flowing	Moderate flowing	Fast Flowing	Very Fast
Water Velocity (m/s)	0.00 to 0.03	0.03 to 0.10	0.10 to 0.17	0.17 to 0.30	0.30 to 0.50	>0.50

Table 4-6. Billabong Creek classes of erosion risk assigned for critical shear stress.

Erosion risk	None	Low	Medium	High	V. High
Shear Stress (N/m ²)	<9	9-13	13-18	18-26	>26

It is the change from existing to proposed conditions that is of particular interest for this assessment. The change in velocity and bed shear stress was calculated as a percentage, with reference to existing conditions. These % change values and categories are shown in Table 4-7. To provide some relativity if existing velocity was 0.4 m/s (Fast Flowing), a +50% change (+0.2 m/s) would take the flow up to 0.6 m/s which pushes it into the highest category (Very Fast). A +/- 2% to 10% change for existing velocity of 0.4 m/s would result in a proposed flow ranging from 0.36 to 0.44 m/s, hence there is no change in velocity category (remains Fast Flowing).

Similarly for shear stress, if existing bed shear stress was 13 N/m² a +20% increase in shear stress (Existing 13 N/m², Proposed 15.6 N/m²) would change erosion risk from Low to Medium. This falls in the category of Medium % change. It represents a moderate increase under proposed conditions with erosion risk class shifting upwards one category. A +50% change in shear stress (Existing 13 N/m², Proposed 19.5 N/m²) would change erosion risk with respect to shear stress from Low to High range. This would represent a high increase under proposed conditions, the erosion risk class shifting upward by two categories.

Table 4-7. Categorisation of % change and description with respect to velocity and erosion risk classes.

% Change	Category	Description
< -50%	High	High reduction under proposed conditions, velocity and erosion risk classes expected to shift downwards one or more categories
-50 % to -10%	Medium	Moderate reduction under proposed conditions, velocity and erosion risk class expected to remain unchanged or shift downwards one category
-10 % to -2%	Low	Minor reduction under proposed conditions, however velocity and erosion risk class expected to remain unchanged
+/- 2%	No change	No change from existing to proposed conditions
2% to 10%	Low	Minor increase under proposed conditions, however velocity and erosion risk class expected to remain unchanged
10% to 50%	Medium	Moderate increase under proposed conditions, velocity and erosion risk class expected to shift upwards one category
>50%	High	High increase under proposed conditions, velocity and erosion risk classes expected to shift upward by one or more categories

One challenge with using % Change is that there will be some low velocity and bed shear stress values that show a very high % increases just because the existing value is very low. For example, a flow velocity of 0.01 m/s increases to 0.03 m/s which is a 300% increase, however it still remains a very low flow velocity under existing or proposed conditions. The decision was made to filter the % change results to manage high % increases associated with low velocity and bed shear stresses. The following filters were applied with justification outlined:

- If velocity is < 0.1 m/s for existing and proposed conditions assume no change. Velocities remain very low, this being equivalent to backwater (0.00 to 0.03 m/s) and weir pool (0.03 to 0.1 m/s) velocity classes.
- If bed shear stress is < 9 N/m² for existing and proposed conditions assume no change. Bed shear stresses remain very low, below the erosion threshold for stiff clay and alluvial soils. The Erosion risk for existing and proposed conditions stays categorised as None (< 9 N/m²).

Including these filters helps to separate out changes in velocity and bed shear stress for existing and proposed conditions that are inconsequential and would not contribute to a change in geomorphological processes and channel stability.

The upper threshold of bed shear stress for channel stability was set at 13 N/m² based on the composition of the bed and bank materials. This value can be used as a guide to assess erosion risk, but values less than the threshold do not imply that erosion will not occur. With sufficiently long duration of flow, alluvial banks will erode regardless of the bed shear stress or velocity. The most stable channels have naturally variable water levels and dense riparian vegetation. Stream channels naturally adjust in form over time, and this process should be expected to occur in Billabong Creek. The creek has a reasonably wide riparian zone within which geomorphic adjustment might be acceptable. The channel stability threshold was used to identify areas of the creek most prone to erosion for the design events.

In particular for this environmental impact assessment, the purpose is to identify whether the proposal results in a significant change in flow conditions (velocity/shear stress) that contribute to a change in erosion risk in Billabong Creek. Plotted on the following pages are selected hydraulic model outputs for existing and proposed conditions. Velocity and bed shear stress values and % change for 50% and 2% AEP events are presented as long profiles. Maps are also presented showing % change in velocity and bed shear stress values between existing and proposed conditions.

We have chosen the 50% and 2% AEP events for the following reasons. The 50% AEP event approximates bankfull discharge, the maximum discharge that the channel can convey without overflowing onto the floodplain. This discharge is considered to have morphological significance because it represents the breakpoint between the processes of channel formation and floodplain formation (Bridge, 2003). The 2% AEP event represents a much larger flow that exceed the capacity of the channel, inundates the broader floodplain and engages network of connecting anabranches and paleochannels.

A review of modelling results shows that there is generally no appreciable change in velocity and shear stress values between existing and proposed conditions for the majority of Billabong Creek. Sections of the river exceed the low erosion risk shear stress range of 9 to 13 N/m² for both the existing and proposed conditions. Potential erosion predicted is within the natural geomorphic response of the river channel, where some localised erosion and deposition is part of the natural adjustment of the river channel in response to medium and high flood flow events.

The results show small overall relative differences between the existing and proposed velocities and shear stresses, and that for the most part values are well below thresholds considered to represent a geomorphic risk. It is possible that in response to the new flow regime, the bed and banks could undergo some minor geomorphic adjustment. Localised erosion risks are expected in association with these waterways and regulator structures. It is expected that erosion effects would be localised and manageable (GEO5).

The bed shear stress profiles and maps indicate that the zone of the creek likely to be most prone to channel instability and higher erosion risk (relative to existing conditions) are the sections of creek immediately downstream from the proposed regulators. The design of the regulator structures include energy dissipation measures to manage erosion immediately downstream including concrete aprons and rock armouring of the bed and channel banks (GEO1). Periodic assessment of the condition of the structures is recommended to identify and assess any erosion, so that it can be addressed if required.

4.4.2.1 Hartwood

Presented on following pages are a series of long profiles that show velocity and bed shear stress values for existing and proposed conditions for the 50% and 2% AEP. Also shown on these plots is the change from existing to proposed conditions presented as % change. Maps are also presented that show % change.

A review of velocity values for existing and proposed 50% AEP shows that the section of creek from chainage 8000 to 22000 is where there are increases in velocity under proposed conditions (Figure 4-5 to Figure 4-7). These increases are greatest downstream of the proposed Hartwood Regulator (10000 to 16300 m chainage), rising from 0.2-0.25 m/s under existing conditions (moderately flowing, 0.17 to 0.3 m/s) to 0.4-0.9 m/s under proposed conditions (fast to very fast, 0.3 to >0.5 m/s). These changes are a result of the operations of the proposed regulator for the 50% AEP, all five gates will be fully open which will result in an additional 85 ML/day passing the regulator. By comparison a review of the 2% AEP shows that the length of channel downstream of the proposed Hartwood Regulator that experiences velocity change is further reduced to between 14000 m and 16300 m chainage (Figure 4-8 to Figure 4-10).

A review of bed shear stresses shows that upstream of the proposed Hartwood Regulator there is very little to no change in values between existing and proposed conditions (Figure 4-11 to Figure 4-16). Erosion risk varies from Low (9-13 N/m²) to Very High (>26 N/m²) under both scenarios. Shear stresses remain below the 100-200 N/m² range that is required to remove vegetation. There is a notable shift in shear stress downstream of existing Hartwood Weir and Proposed Regulator. Under existing conditions, erosion risk is generally assessed as None (<9 N/m²). Under proposed conditions, the 2km section of channel downstream of Hartwood Regulator (14000 m to 16300 m chainage) erosion risk rises to Medium (13-18 N/m²) to Very High (>26 N/m²).

The results indicate that there is potential for elevated erosion of sediment from bed and banks downstream of Hartwood Regulator (14000 m to 16300 m chainage), however these values are not dissimilar to that which is already experienced along the creek upstream of Hartwood Weir. The variability and range of bed

shear stresses under proposed conditions falls within that which forms part of the existing conditions and are to be expected in a river channel, with localised erosion and deposition in response to medium and high flow events.

In summary, based on a review of channel hydraulics there are no significant changes from existing and proposed flow conditions that would result in a change to the geomorphology of the creek. The section of creek downstream of the proposed Hartwood Regulator (14000 m to 16300 m chainage) will experience higher shear stresses and erosion risk. However, the range of shear stresses that will be experienced in this section is not dissimilar to areas upstream of the proposed regulator under existing conditions.

The regulator structure has been designed so as to include energy dissipation of flows immediately downstream including concrete aprons and rock armouring of bed and channel banks.

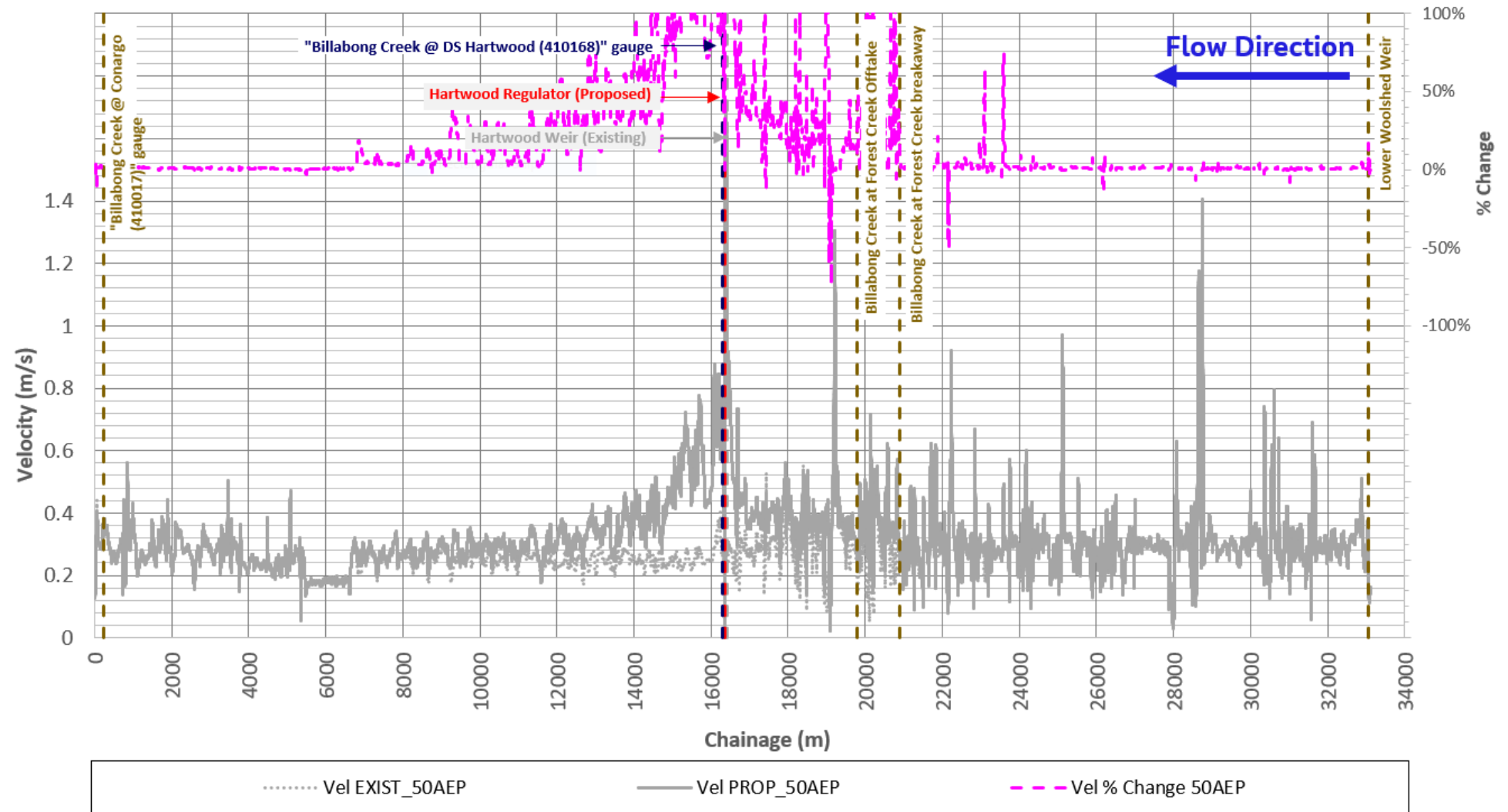


Figure 4-5. Hartwood Regulator: Long profile with velocity values for existing and proposed 50% AEP. Change in velocity from existing to proposed are also presented as % change. Refer to Figure 4-6 for more detail on section of creek from 8000 m to 22000 m chainage.

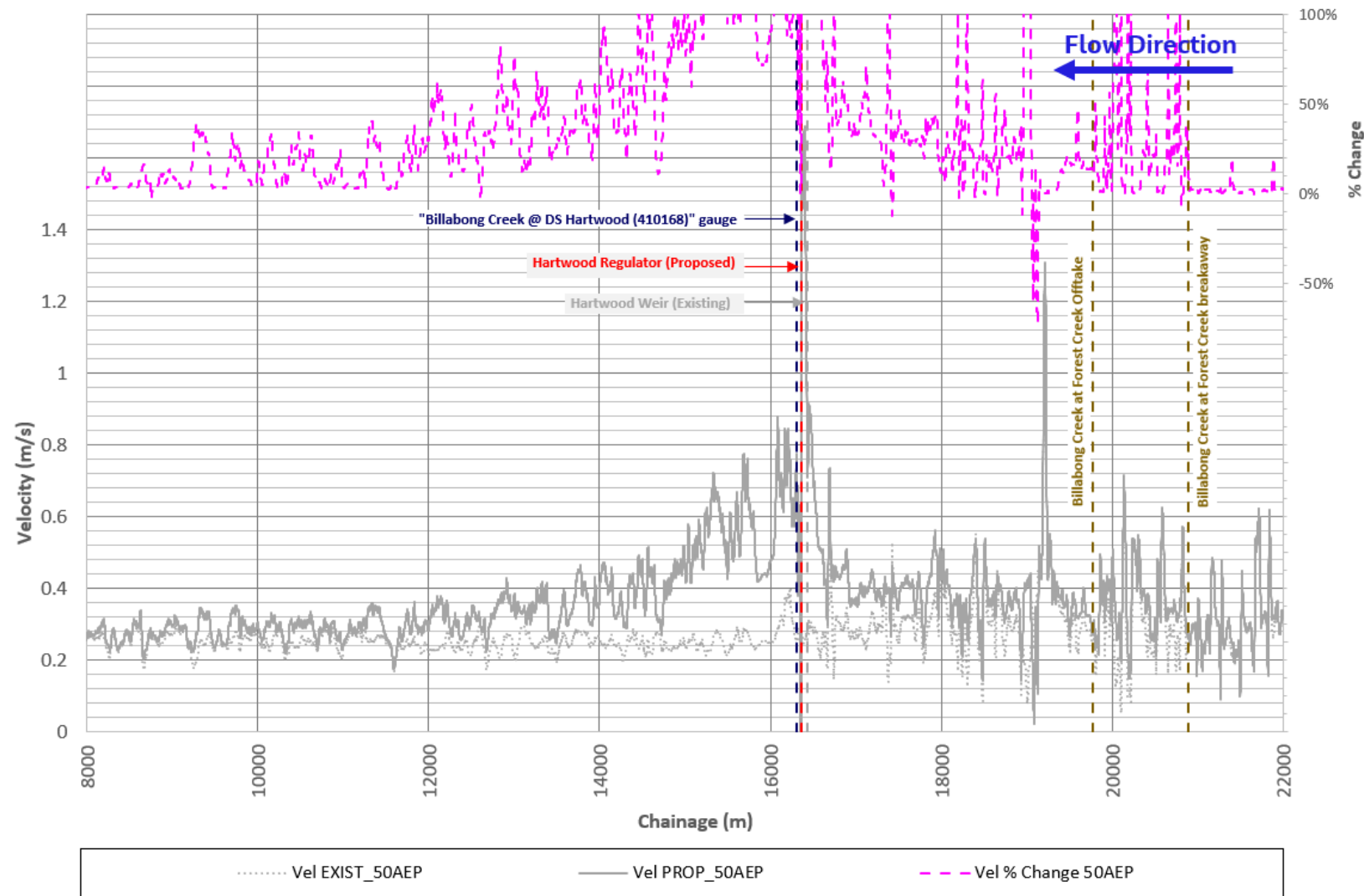


Figure 4-6. Hartwood Regulator: Long profile with velocity values for existing and proposed 50% AEP. Change in velocity from existing to proposed are also presented as % change. Plot shows in more detail section of creek from 8000 m to 22000 m chainage.

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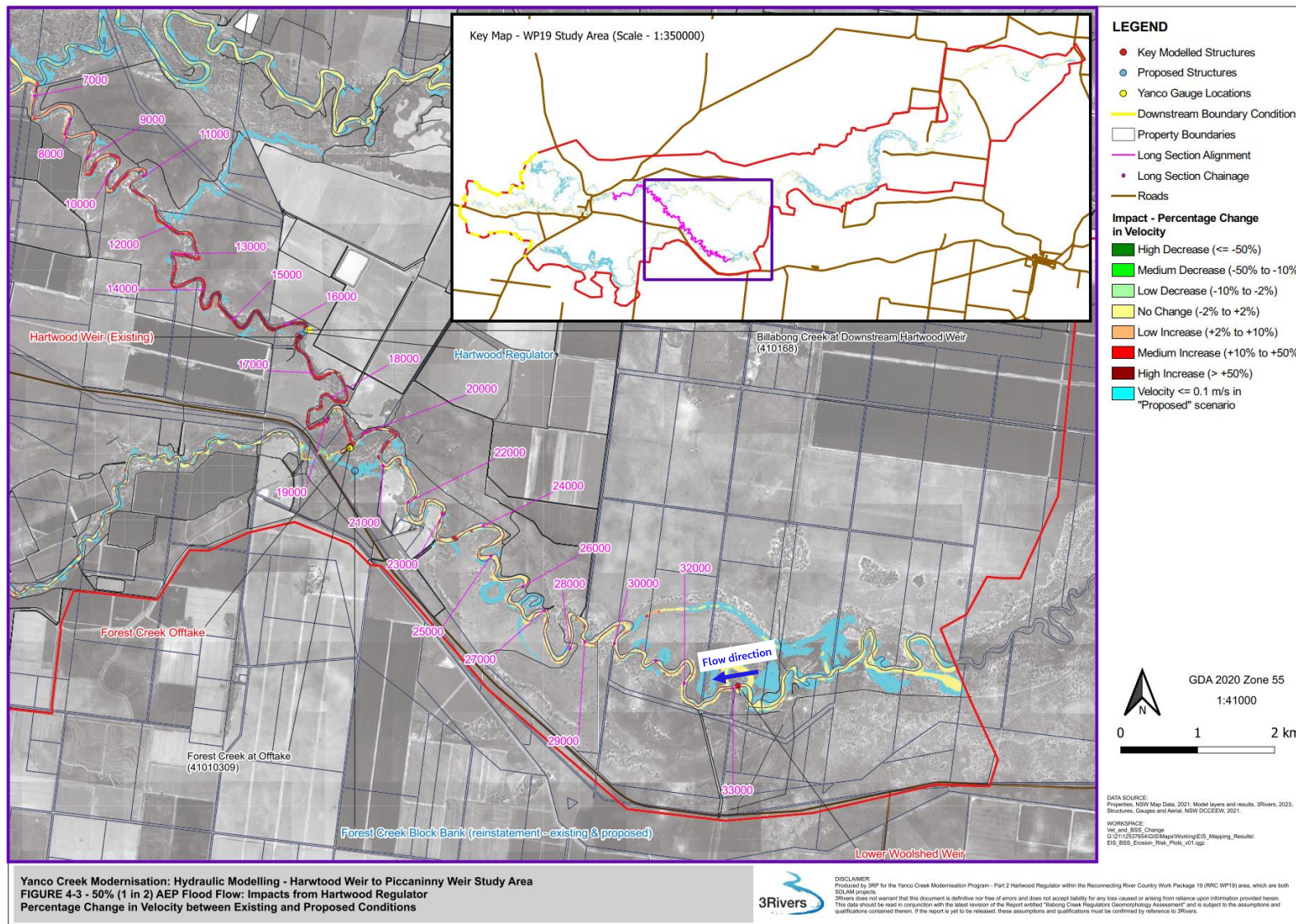


Figure 4-7. Hartwood Regulator: Map showing % change in velocity between existing and proposed conditions for 50% AEP.

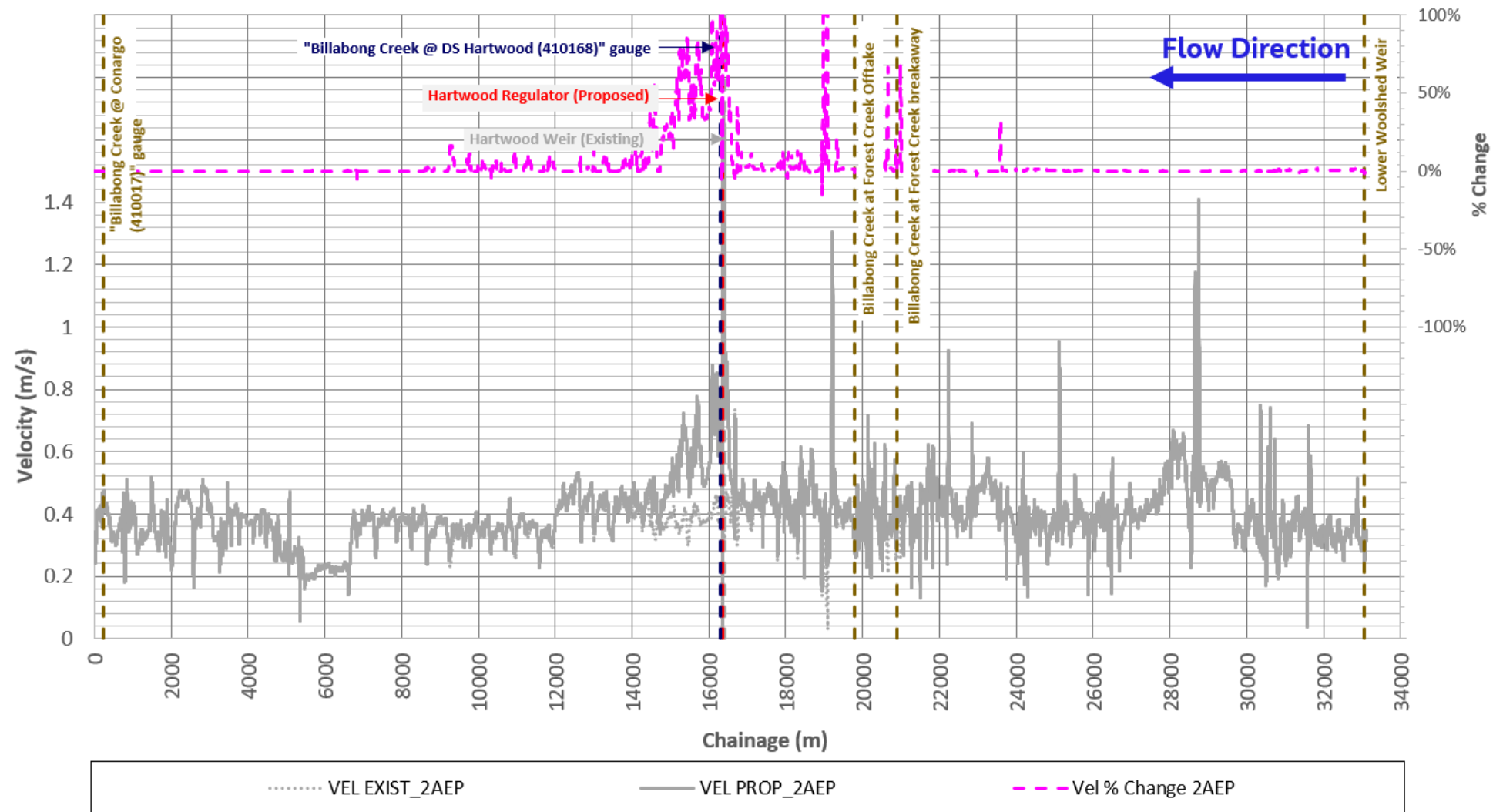


Figure 4-8. Hartwood Regulator: Long profile with velocity values for existing and proposed 2% AEP. Change in velocity from existing to proposed are also presented as % change. Refer to Figure 4-9 for more detail section of creek from 8000 m to 22000 m chainage.

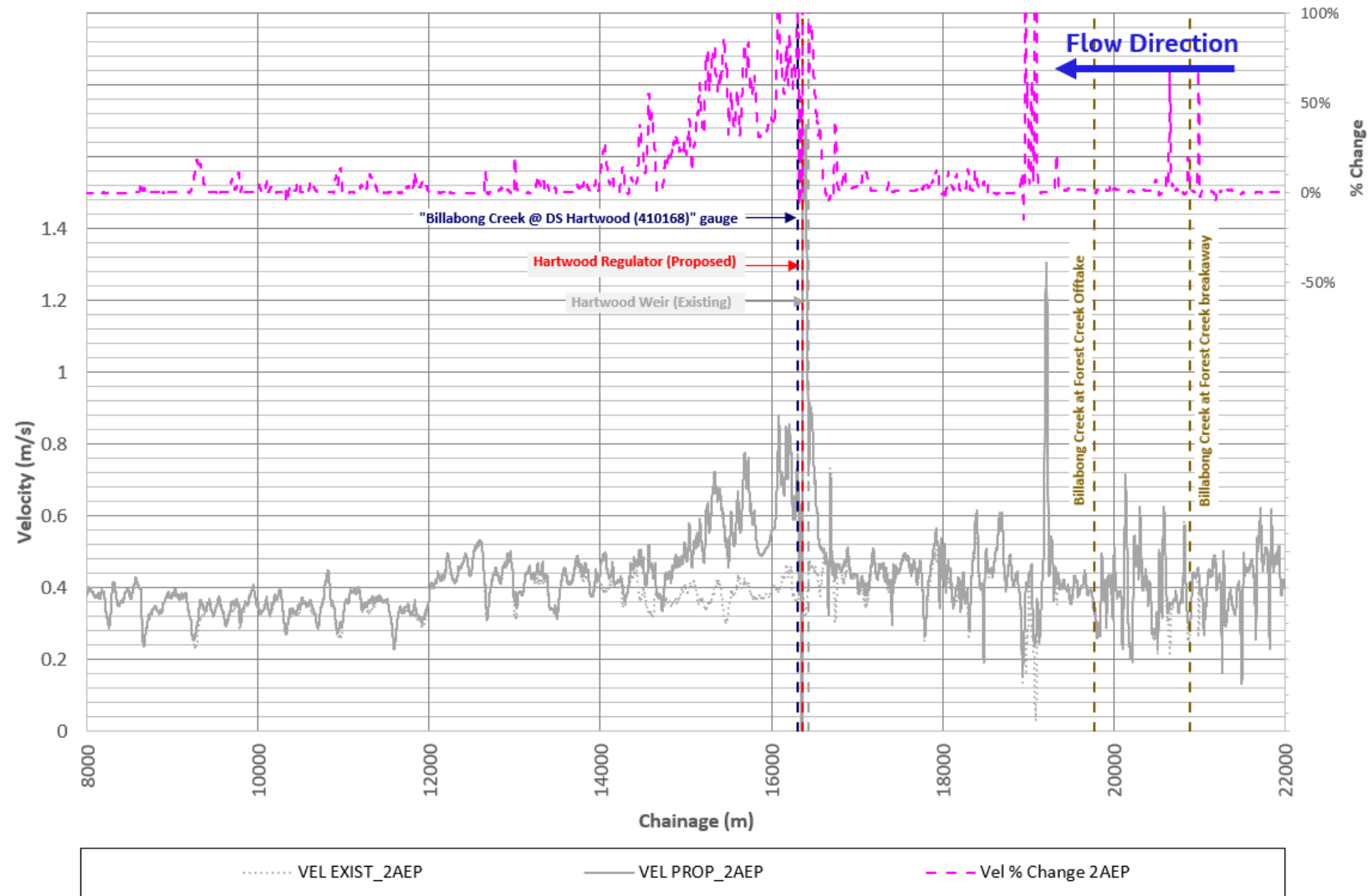


Figure 4-9. Hartwood Regulator: Long profile with velocity values for existing and proposed 2% AEP. Change in velocity from existing to proposed are also presented as % change. Plot shows in more detail section of creek from 8000 m to 22000 m chainage.

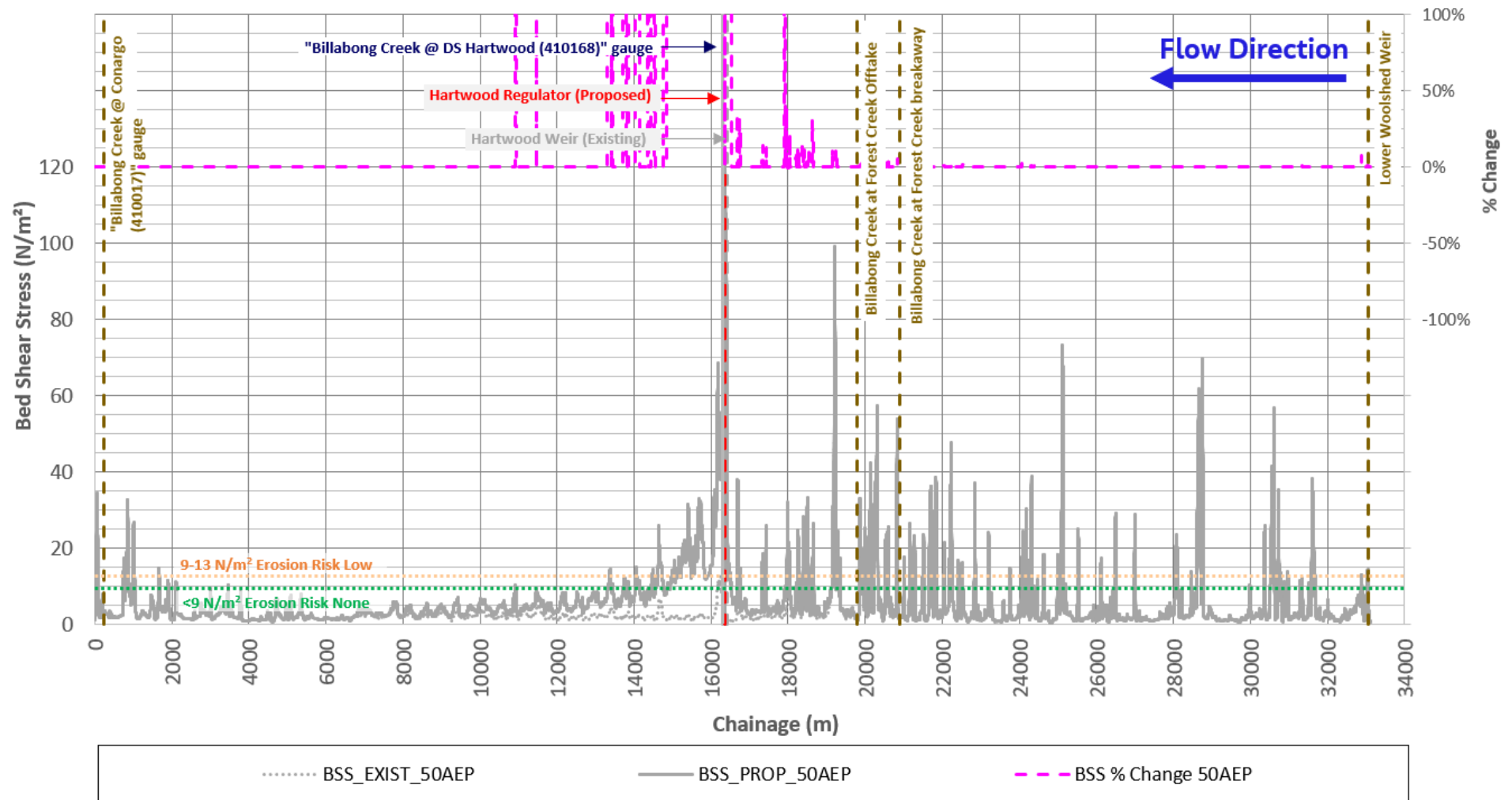


Figure 4-11. Hartwood Regulator: Long profile with bed shear stress values for existing and proposed 50% AEP. Change in values from existing to proposed are also presented as % change. Refer to Figure 4-12 for more detail section of creek from 8000 m to 22000 m chainage.

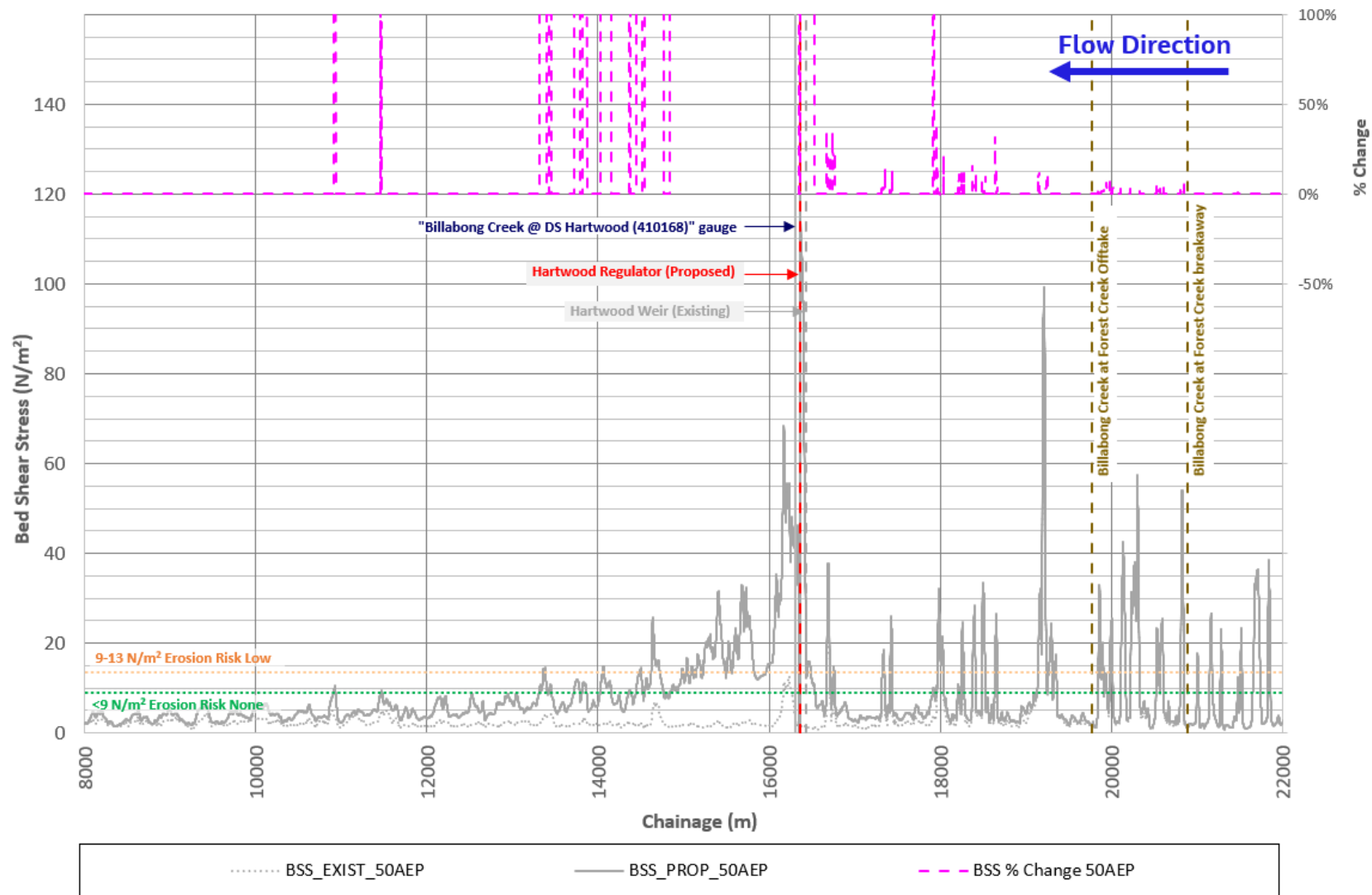


Figure 4-12. Hartwood Regulator: Long profile with bed shear stress values for existing and proposed 50% AEP. Change in values from existing to proposed are also presented as % change. Plot shows in more detail section of creek from 8000 m to 22000 m chainage.

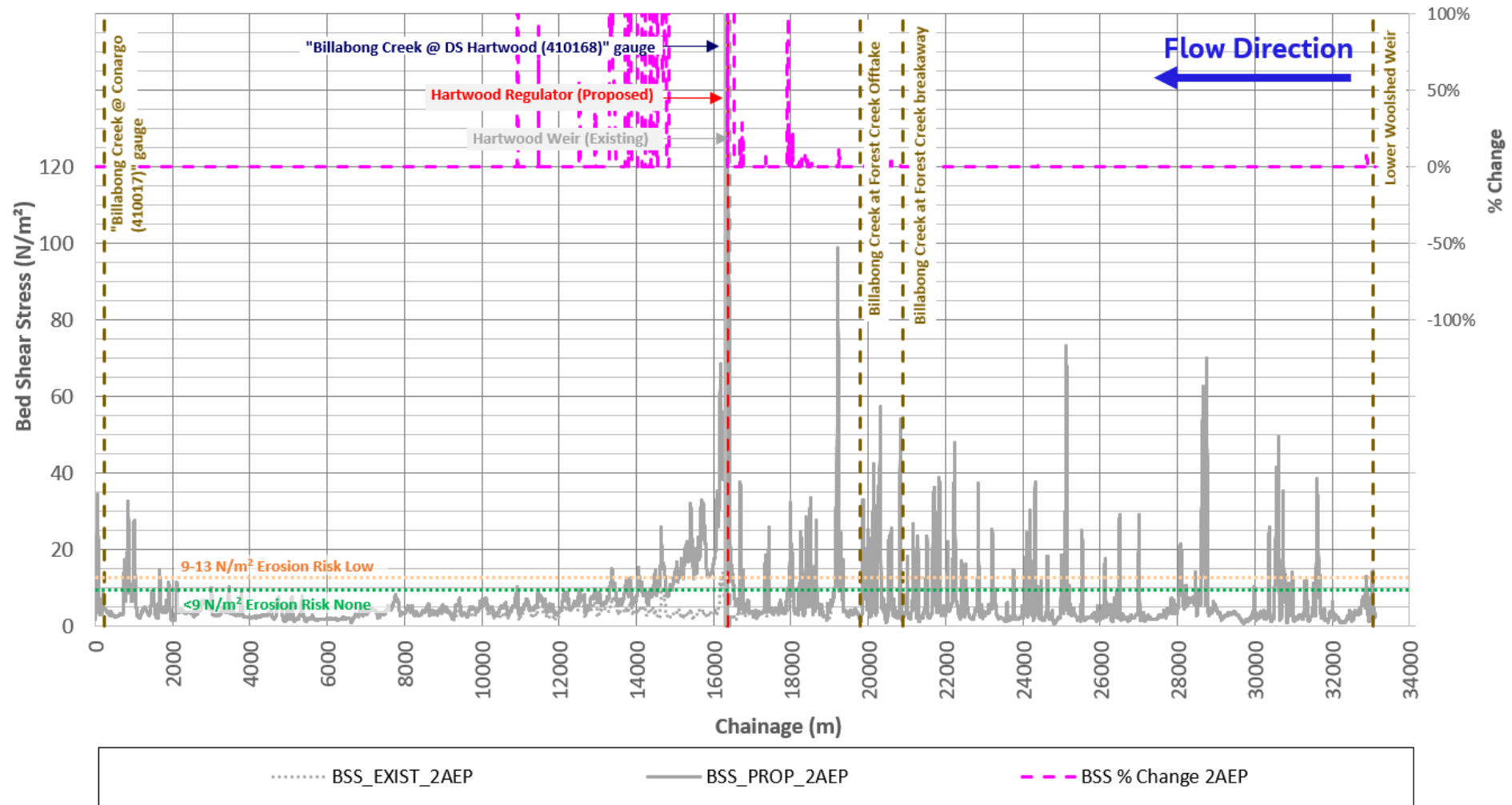


Figure 4-14. Hartwood Regulator: Long profile with boundary shear stress values for existing and proposed 2% AEP. Change in values from existing to proposed are also presented as % change. Refer to Figure 4-12 for more detail section of creek from 8000 m to 22000 m chainage.

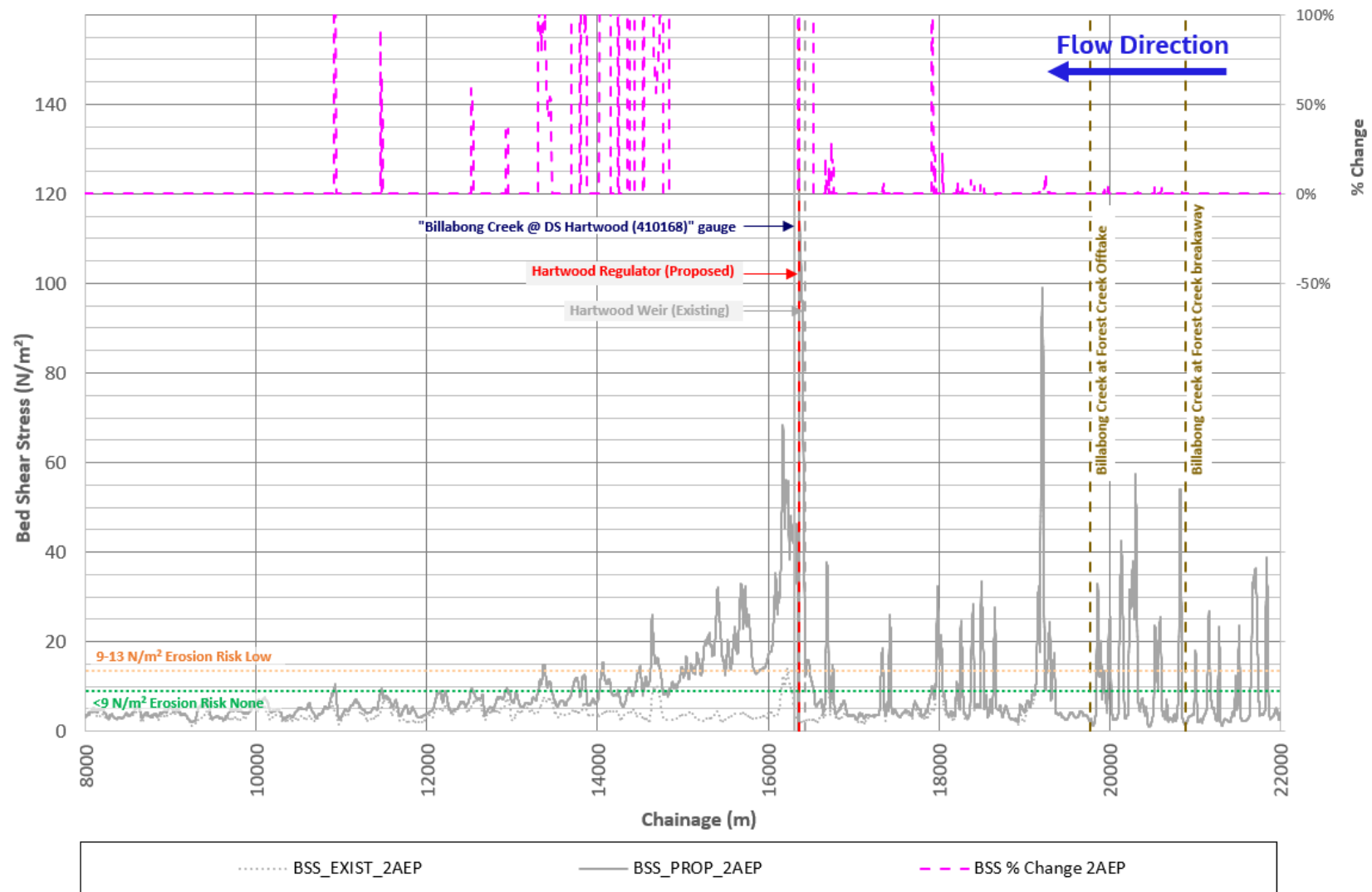


Figure 4-15. Hartwood Regulator: Long profile with boundary shear stress values for existing and proposed 2% AEP. Change in values from existing to proposed are also presented as % change. Plot shows in more detail section of creek from 8000 m to 22000 m chainage.

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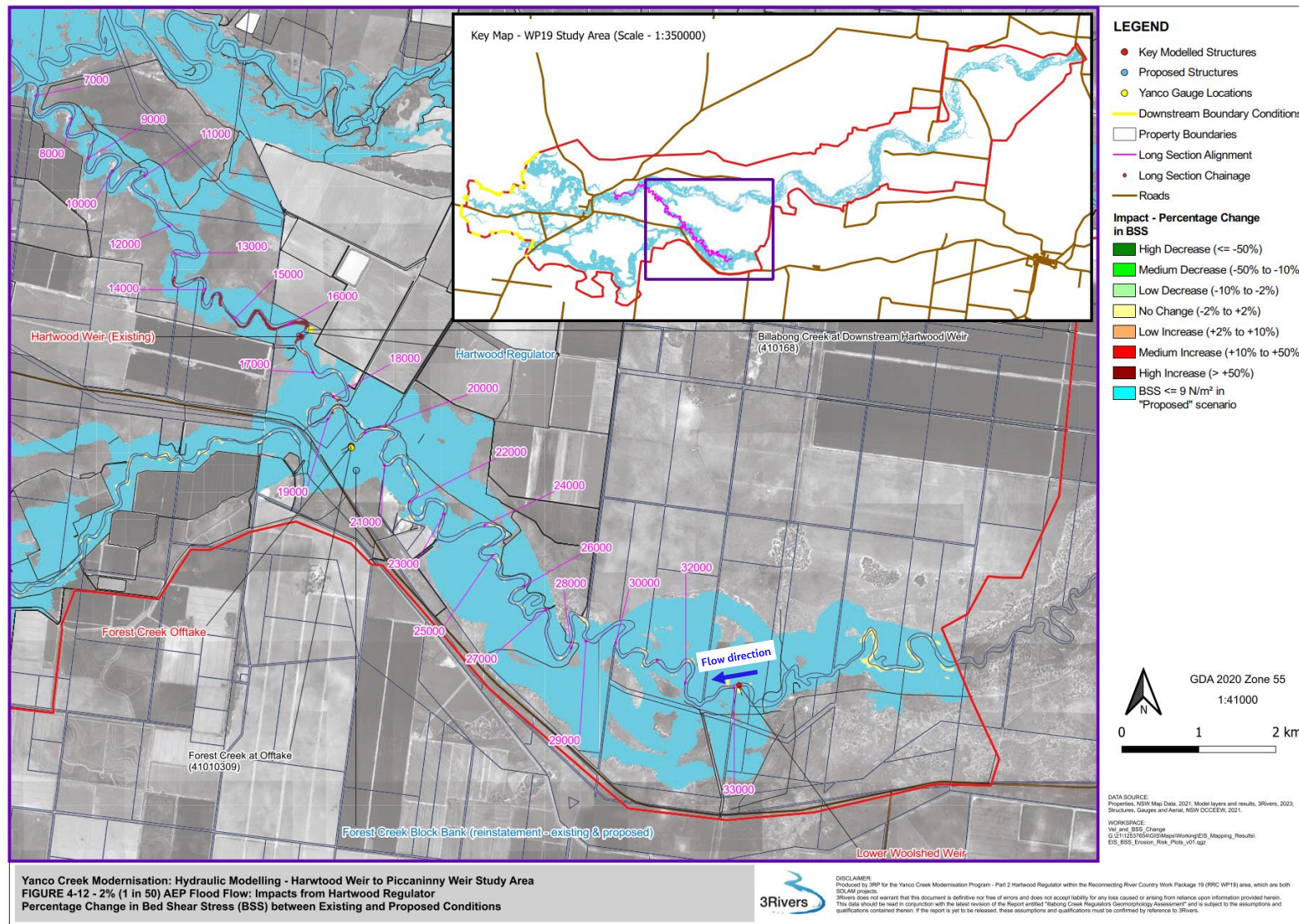


Figure 4-16. Hartwood Regulator: Map showing % change in bed shear stress between existing and proposed conditions for 2% AEP.

4.4.2.2 Wanganella

Presented on following pages are a series of long profiles that show velocity and bed shear stress values for existing and proposed conditions for the 50% and 2% AEP events. Also shown on these plots is the change from existing to proposed conditions presented as % change. Below each long profile is a map that shows % change.

There is a general reduction in velocity values between existing and proposed conditions for both the 50% AEP (Figure 4-17, Figure 4-18) and 2% AEP (Figure 4-19, Figure 4-20). The % changes in flow from existing to proposed conditions overall are relatively minor (no change or low % change). The velocity classes for the majority of the creek would remain unchanged, with flow type ranging from moderate flowing (0.17 to 0.3 m/s) to very fast (>0.5 m/s). The section of channel between the proposed Wanganella Regulator and where Forest Creek breaks away from Billabong Creek experiences a greater reduction in velocity, dropping from very fast flow (>0.5m/s) to moderate flowing (0.17 to 0.3 m/s) in one 100m section of creek (Chainage 1350-1450).

A review of bed shear stresses shows that the majority of the creek channel and floodplain areas upstream and downstream of the proposed Wanganella regulator has values < 9 N/m², which fall within the no erosion risk category for both the 50% AEP (Figure 4-21, Figure 4-22) and 2% AEP (Figure 4-23, Figure 4-24). Comparing existing with proposed conditions, there is generally a reduction in shear stress under proposed conditions (low to medium % change), however as shear stresses are generally < 9 N/m² the no erosion risk categorisation remains unchanged. Some elevated shear stresses are evident within the vicinity of the proposed Wanganella Regulator (Chainage 1150-1350).

In summary, based on a review of channel hydraulics there are no significant changes from existing and proposed flow conditions that would result in a change to the geomorphology of the creek. The section of creek immediately downstream of the proposed Wanganella regulator would experience higher shear stress relative to existing conditions. The regulator structure has been designed so as to include energy dissipation of flows immediately downstream including concrete aprons and rock armouring of bed and channel banks.

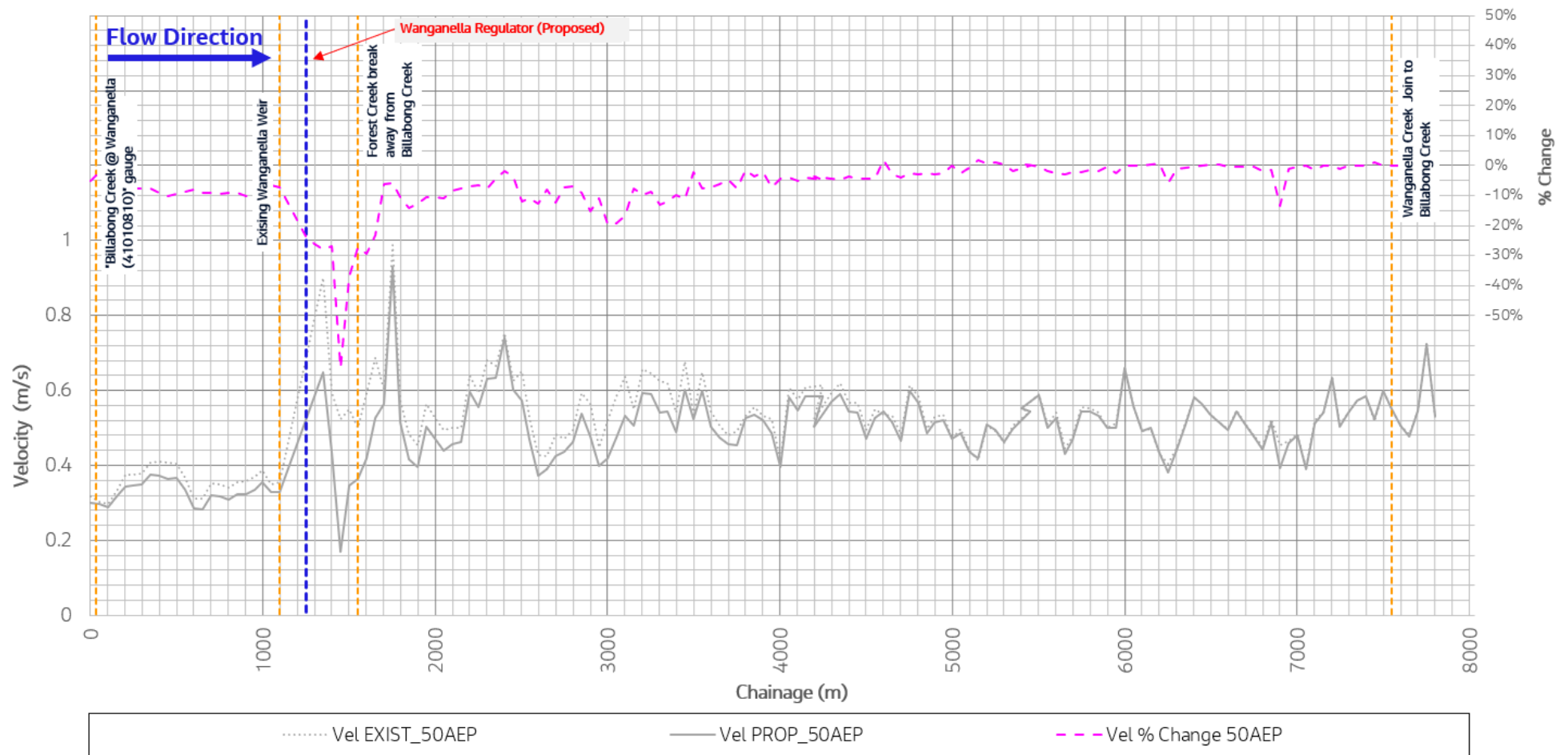


Figure 4-17. Wanganella Regulator: Long profile with velocity values for existing and proposed 50% AEP. Change in velocity from existing to proposed are also presented as % change.

Billabong Creek Regulators Geomorphology Assessment

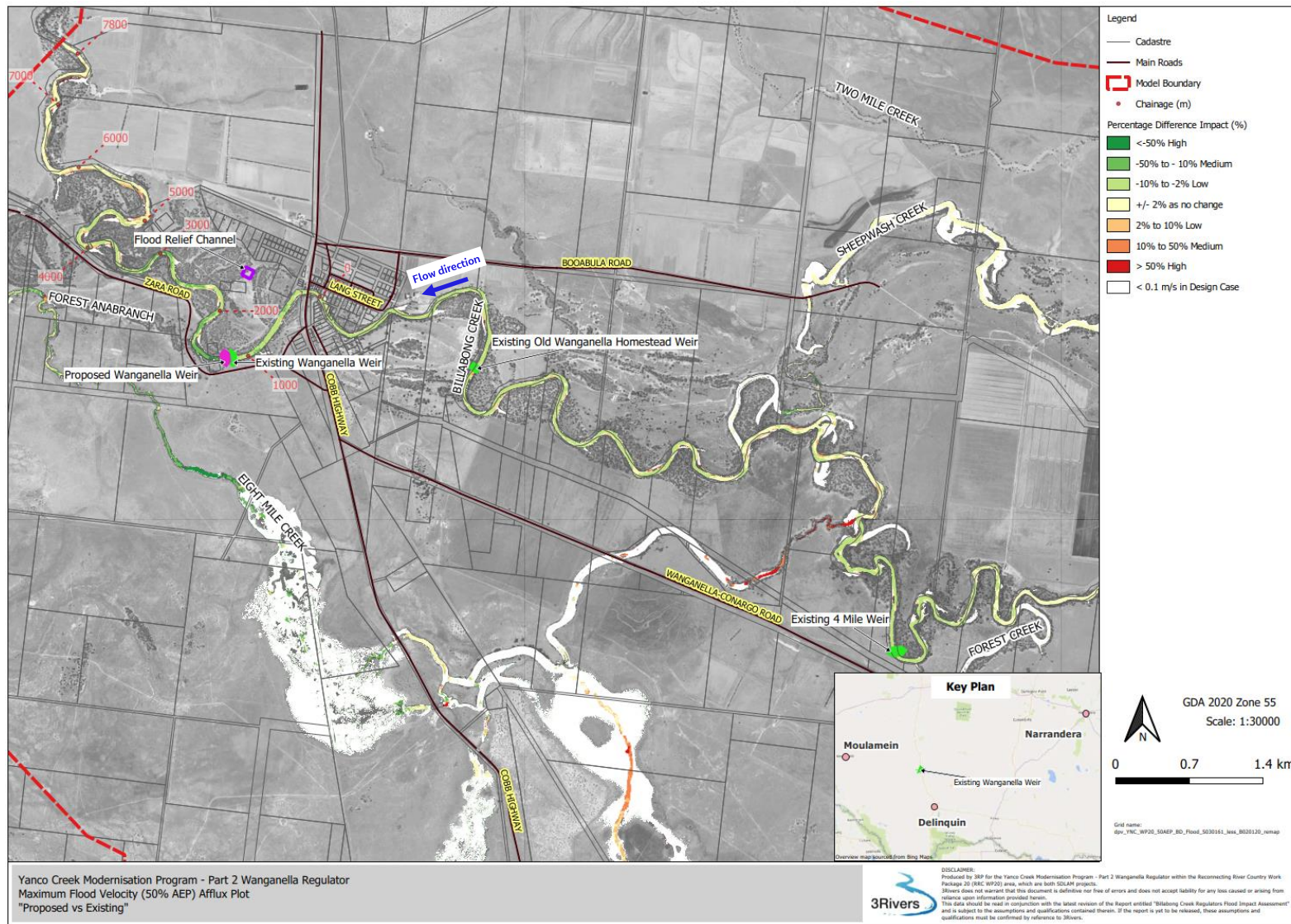


Figure 4-18. Wanganella Regulator: Map showing % change in velocity between existing and proposed conditions for 50% AEP.

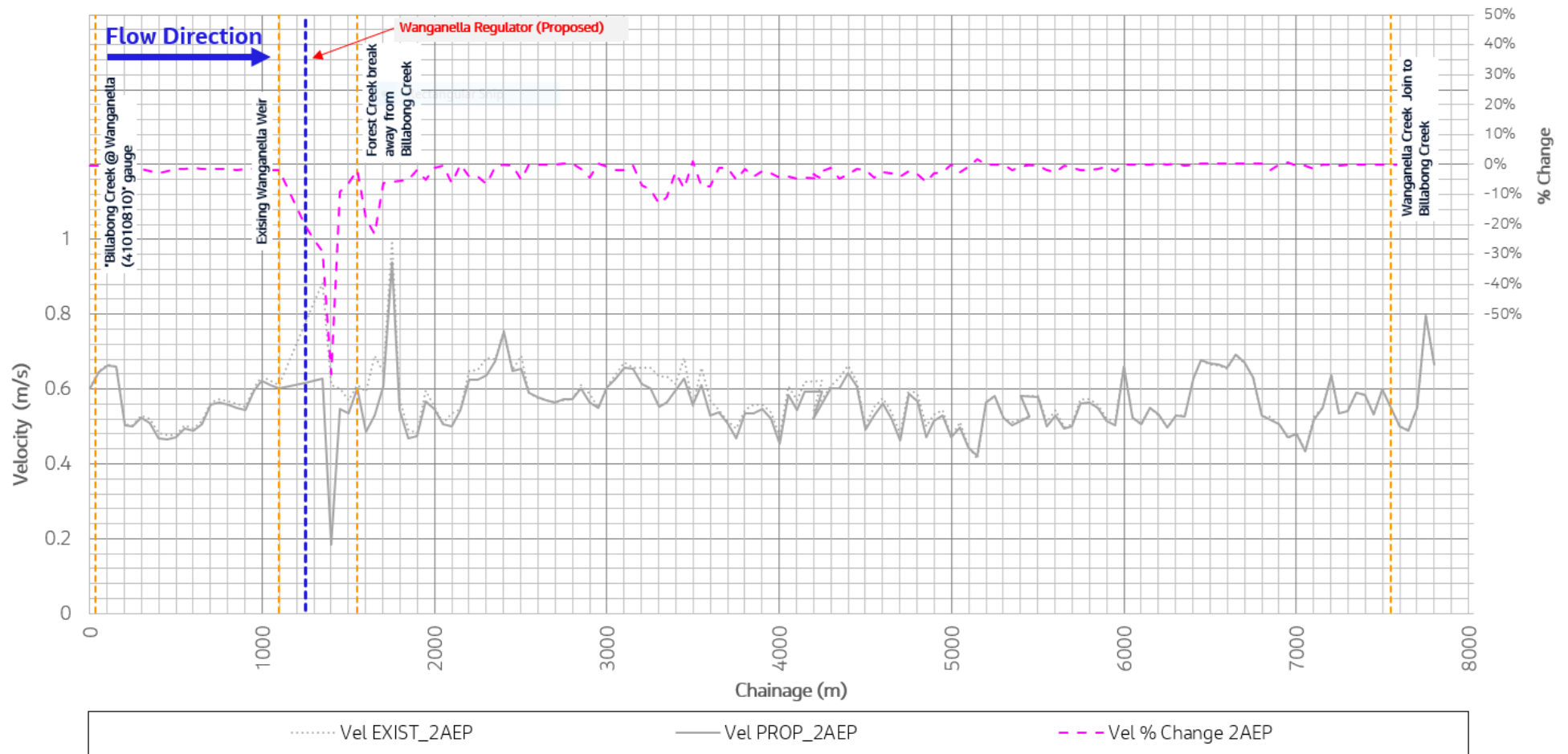


Figure 4-19. Wanganella Regulator: Long profile with velocity values for existing and proposed 2% AEP. Change in velocity from existing to proposed are also presented as % change.

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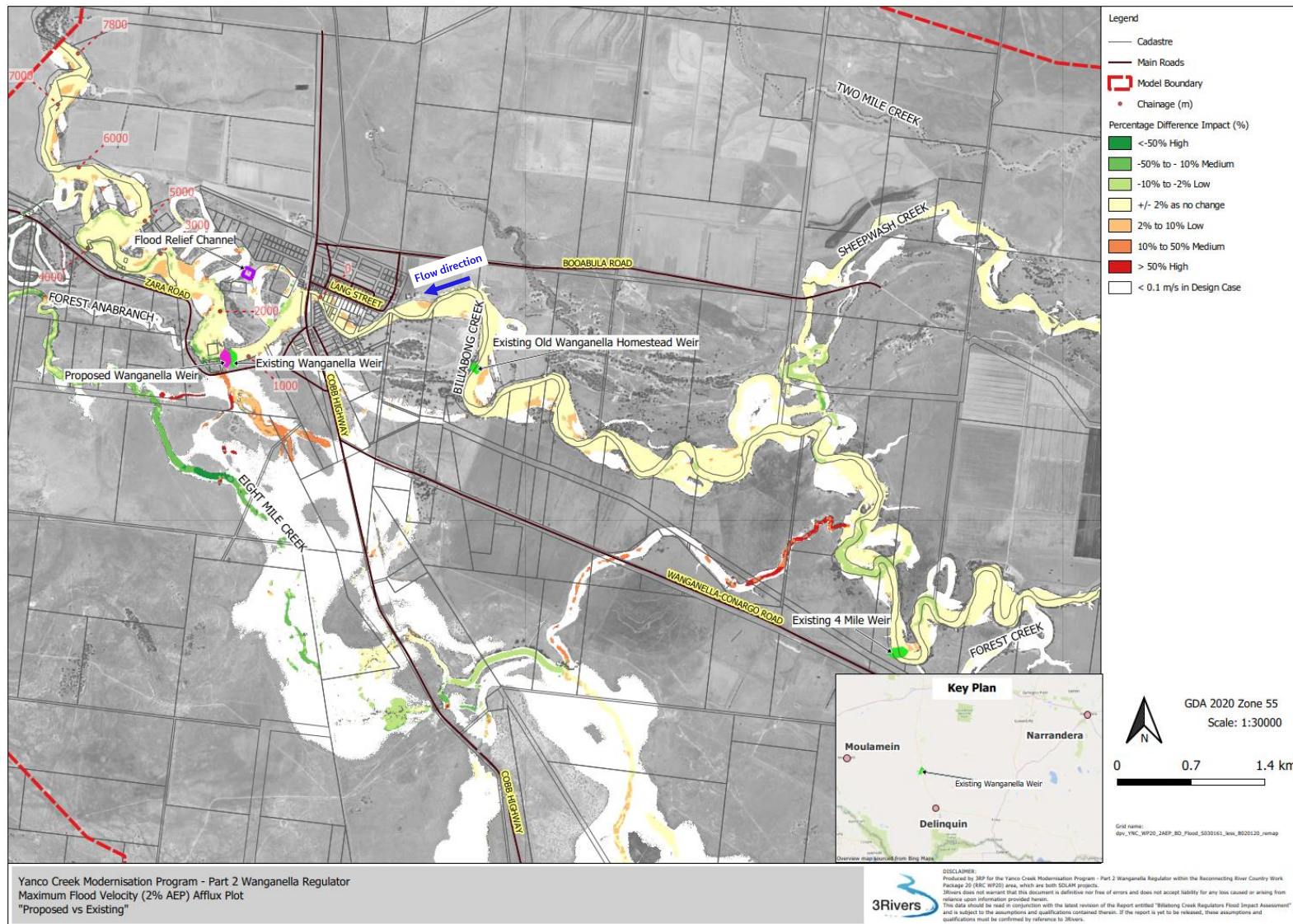


Figure 4-20. Wanganella Regulator: Map showing % change in velocity between existing and proposed conditions for 2% AEP.

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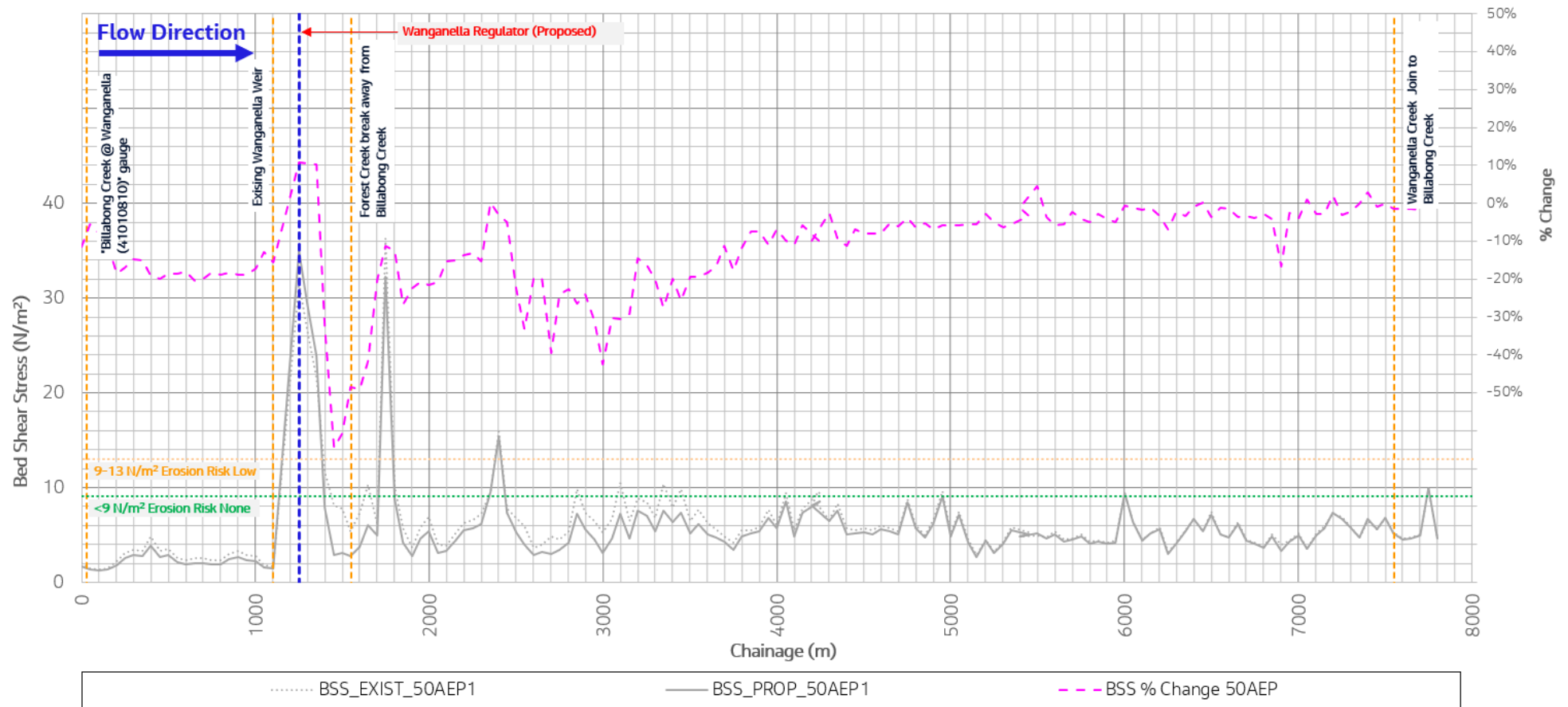


Figure 4-21. Wanganella Regulator: Long profile with bed shear stress values for existing and proposed 50% AEP. Change in values from existing to proposed are also presented as % change.

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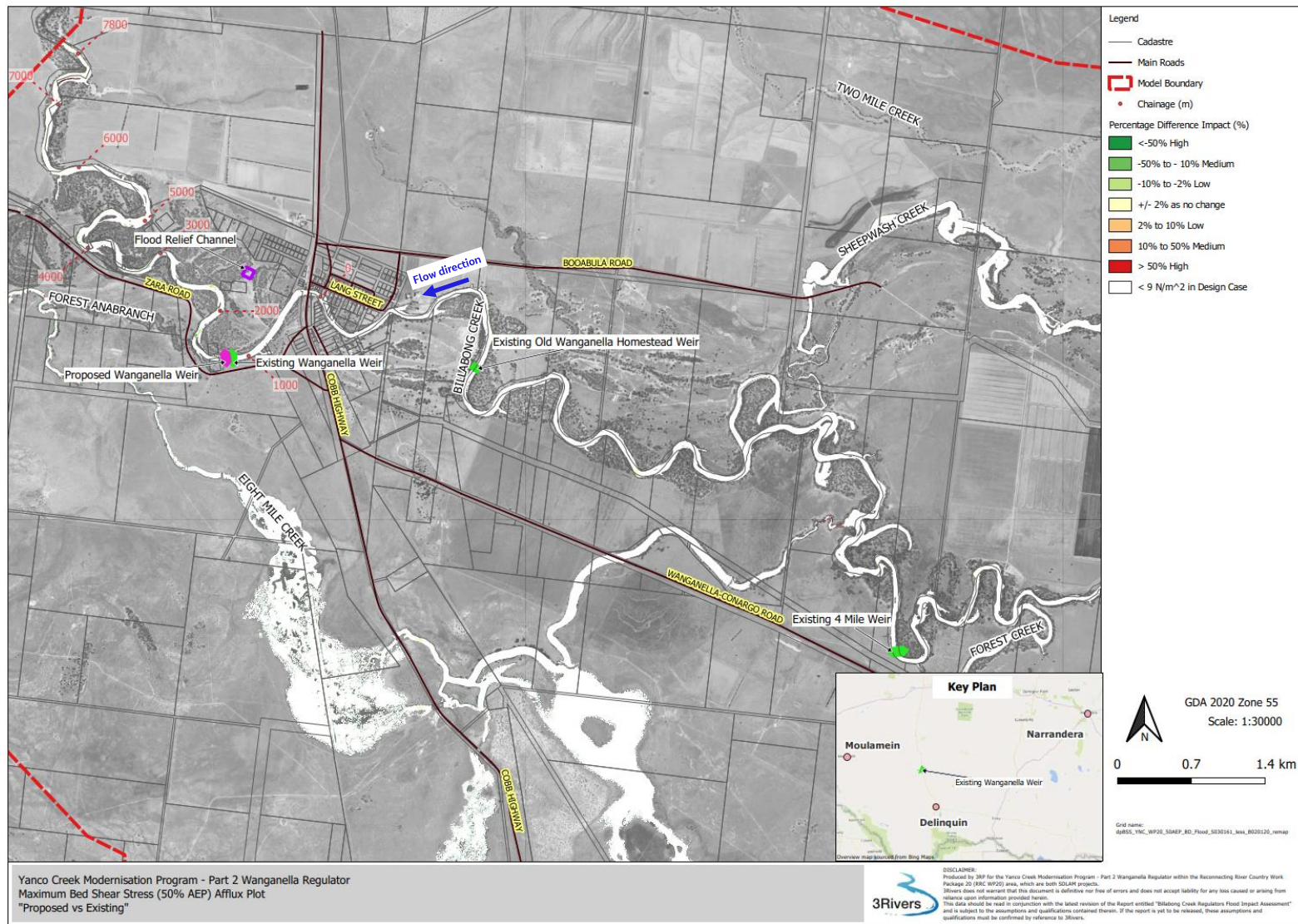


Figure 4-22. Wanganella Regulator: Map showing % change in bed shear stress between existing and proposed conditions for 50% AEP.

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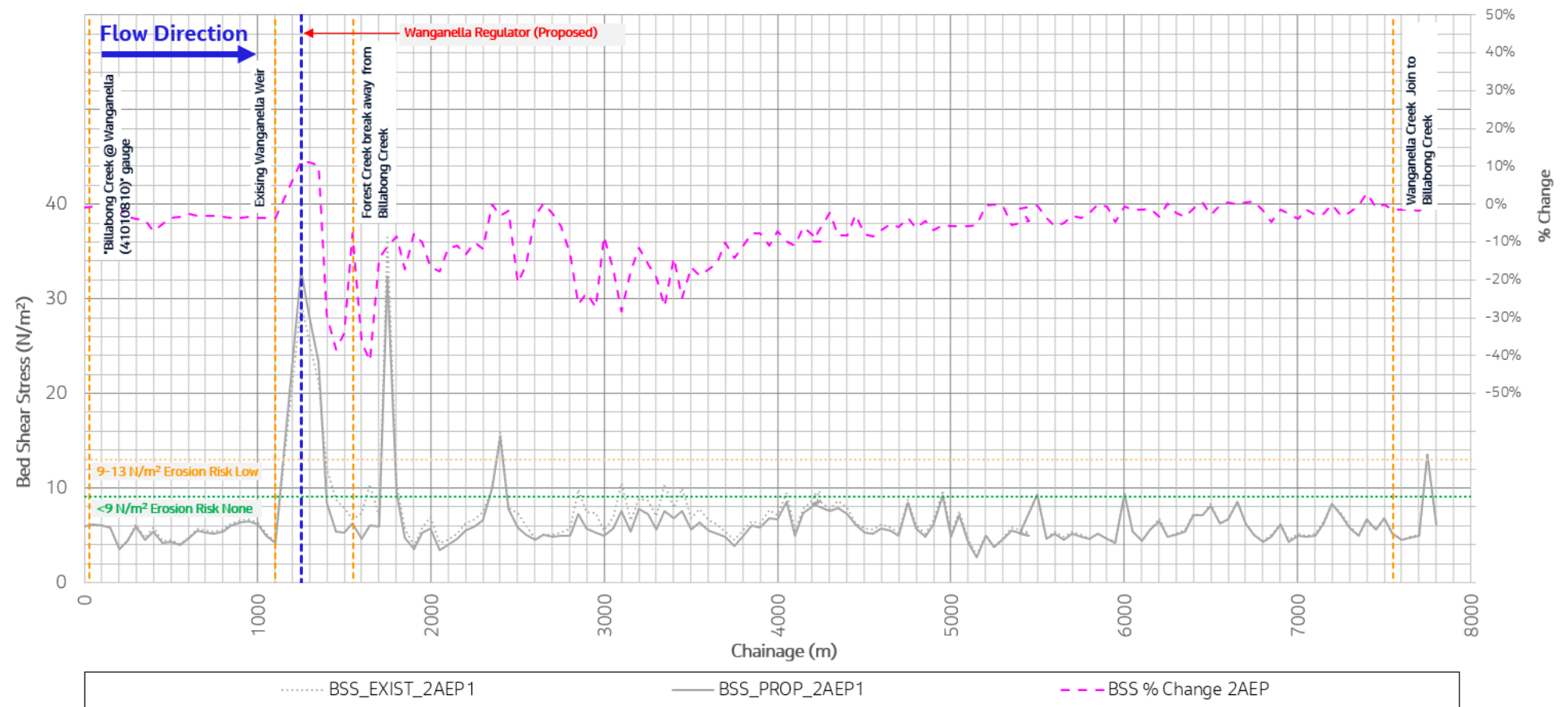


Figure 4-23. Wanganella Regulator: Long profile with boundary shear stress values for existing and proposed 2% AEP. Change in values from existing to proposed are also presented as % change.

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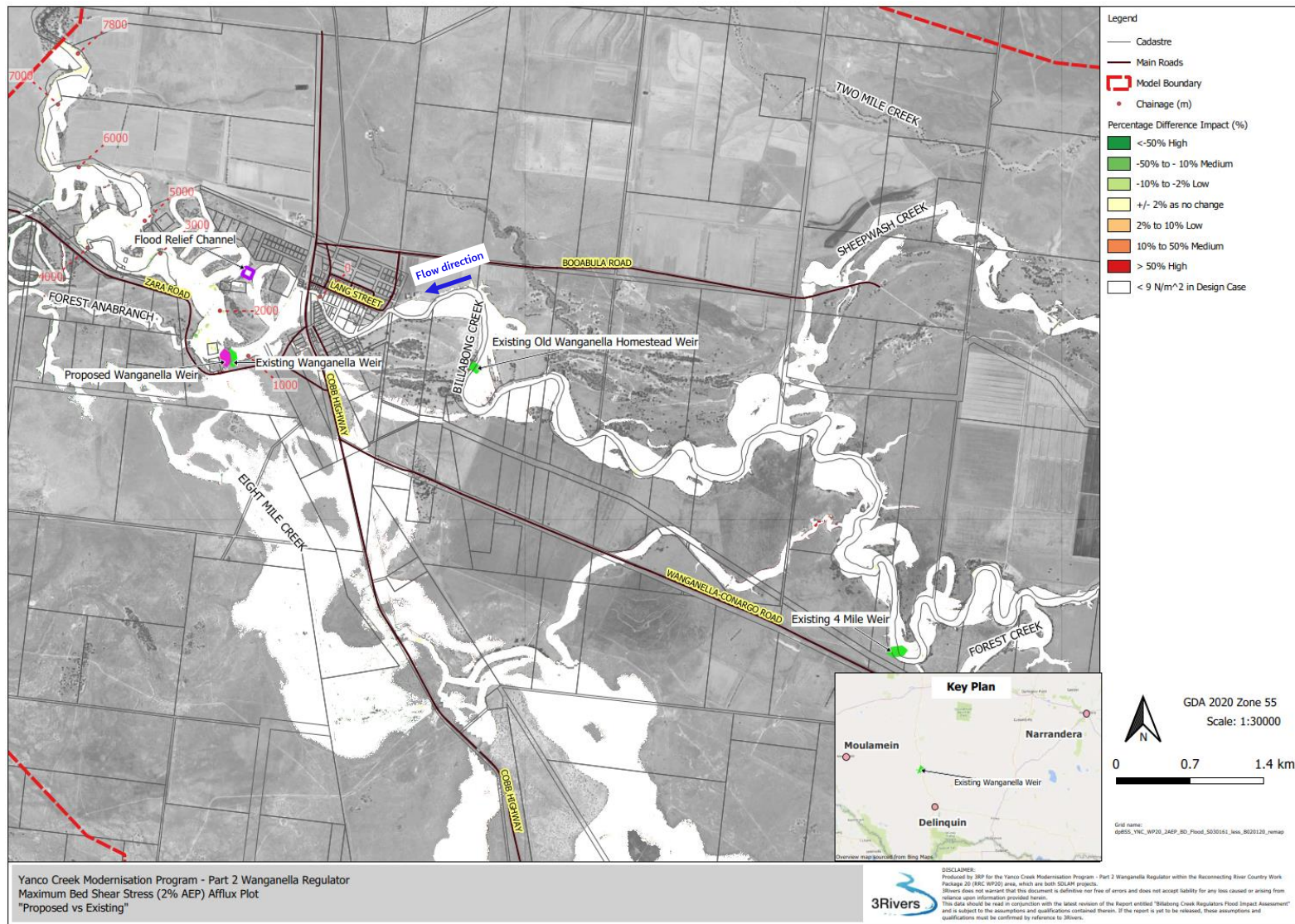


Figure 4-24. Wanganella Regulator: Map showing % change in boundary shear stress between existing and proposed conditions for 2% AEP.

4.5 Cumulative impacts

The other projects planned in the study area were reviewed to determine if the proposal has the potential to result in significant cumulative impacts. No potential cumulative impacts relevant to geomorphology were identified. As such, no further cumulative assessment was conducted.

5. Mitigation and management of impacts

Table 5-1 lists the mitigation and management measures that would be implemented to manage potential impacts to geomorphology identified in section 4.

Table 5-1. Geomorphology mitigation and management measures

ID	Impact	Mitigation and management measure	Responsibility	Timing
GEO1	Erosion and sedimentation	<ul style="list-style-type: none"> ▪ Regulator structures designed to avoid erosion around and downstream of structures through erosion protection. ▪ Regulator structure include energy dissipation measures to manage erosion immediately downstream including concrete aprons and rock armouring of bed and channel banks. 	NSW DCCEEW	Detailed design
GEO2	General	<ul style="list-style-type: none"> ▪ A Construction Environment Management Plan (CEMP) will be prepared to include side specific control measures to manage potential erosion or sedimentation impacts from instream works as set out below. 	Construction contractor	Prior to construction
GEO3	Erosion and sediment	<ul style="list-style-type: none"> ▪ Implement site specific control measures to manage potential erosion or sedimentation impacts from instream works including but not be limited to: <ul style="list-style-type: none"> - Instream control measures <ul style="list-style-type: none"> ▪ Floating silt fences for instream works. ▪ Undertaking work when flows are low/dry and minimise the duration of works within the watercourse as far as practicable ▪ Weir removal and new regulator construction to be undertaken in two phases; half of the creek needs to remain unobstructed to maintain continuous flow of water while construction is undertaken on the other side. Cofferdams, sumps and pumps would be used to separate and dewater the half of the creek undergoing construction. ▪ Minimise clearance of vegetation and retain existing vegetation as much as possible ▪ Contingencies are in place for moderate to high flows, particularly during instream construction works. ▪ Wherever possible, prefabricate instream structural elements prior to instream installation - Terrestrial control measures 	Construction contractor	Construction

		<ul style="list-style-type: none"> ▪ Install sediment controls around stockpiles and borrow areas to contain coarse soil and sediment, as applicable to prevent sedimentation of watercourses ▪ Placement of stockpiles away from the watercourse (at least 20 m of creek channels) and be covered when not in use to prevent sediment runoff, and consider whether covering of stockpiles containing coarse soil and sediment is also required ▪ Stabilise exposed soil where applicable with the appropriate structural materials and media for the construction activities (e.g., stabilisation matting, rock armour or vegetation) ▪ Regular, at least daily, visual water quality monitoring of waterways adjacent to the project area during construction, to assess the effectiveness of silt fences, so they can be fixed if necessary. ▪ Erosion and sediment controls established prior to commencement of vegetation clearing or earthworks where practical. 		
GE04	Reinstatement	<ul style="list-style-type: none"> ▪ Disturbed areas will be revegetated as soon as practical, progressively. ▪ Rehabilitation at construction sites to include replacing topsoil. 	Construction contractor	Construction
GE05	Erosion and sediment	<ul style="list-style-type: none"> ▪ Erosion and sediment controls, will be maintained post construction until disturbed areas are stabilised. ▪ Undertake two post-construction visual assessments of the regulator over 2 years to identify and assess any erosion, so it can be addressed if required. 	WaterNSW	Operation

6. Conclusions

This geomorphology assessment has provided a description of the geomorphology of Billabong Creek and provided a geomorphological examination of the hydraulic model outputs and possible erosion risk areas. For the majority of Billabong Creek there are no significant changes from existing flow conditions to proposed flow conditions.

The bed shear stress profiles and maps indicate that the zone of the creek likely to be most prone to channel instability and higher erosion risk (relative to existing conditions) are the sections of creek immediately downstream from the proposed regulators. The regulator structures have been designed so as to include energy dissipation of flows immediately downstream including concrete aprons and rock armouring of bed and channel banks.

7. References

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