Environmental Flows Assessment

Proposed Dunoon Dam

Prepared for
Rous Water

9 November 2012

DOCUMENT TRACKING

ITEM	DETAIL
Project Name	Environmental and Aquatic Flows Assessment – Dunoon Dam
Project Number	09ARMENV-0005
File location	S:\Synergy\projects\09ARMENV\09ARMENV-0005 Dunoon Dam Environmental Flows & Aquatic Assessment\Report\Enviro Flow Reports
Prepared by	Emma Garraway, Nathalie van der Veer, Hamish Mackinnon, Ian Dixon
Internal project team review by	Dr Darren Ryder, Dr Paul Frazier
External Review by	Prof Martin Thoms, Prof Terry Hillman
Approved by	Dr Paul Frazier
Status	FINAL
Version Number	1
Last saved on	9 November 2012
Cover photo	Clockwise from top left: Rocky Creek downstream of the proposed Dunoon Dam site; typical riparian vegetation along Rocky Creek in the confined gorge zones; Rocky Creek upstream of its confluence with Terania Creek.

This report should be cited as 'Eco Logical Australia, November 2012. Environmental Flows Assessment for the proposed Dunoon Dam. Prepared for Rous Water.'

ACKNOWLEDGEMENTS

This document has been prepared by Eco Logical Australia Pty Ltd with support from Rous Water. The input and comment from the Future Water Strategy Project Reference Group is also recognised.

Professor Martin Thoms, Professor Terry Hillman and Dr Keith Bishop are also gratefully acknowledged for their assistance in the preparation of this assessment.

Contents

List of Figures

List of Tables

Abbreviations

ABBREVIATION	DESCRIPTION
ANZECC	Australian & New Zealand Environmental & Conservation Council
AUSRIVAS	Australian River Assessment Scheme
CMA	Catchment Management Authority
DIPNR	Department of Infrastructure, Planning & Natural Resources
DPI	Department of Primary Industries (of which NoW is part)
DRIFT	Downstream Response to Imposed Flow Transformations
DWE	Department of Water & Energy
ECA	Environmental contingency allowance
EHMP	Ecosystem Health Monitoring Program
ELA	Eco Logical Australia
EoS	End-of-system
FSL	Full supply level
IFIM	Instream Flow Incremental Methodology
IMEF	Integrated Monitoring of Environmental Flows
MDBA	Murray Darling Basin Authority
MER	NSW Natural Resources: Monitoring, Evaluation & Reporting Strategy
NoW	New South Wales Office of Water (in the Department of Primary Industries)
NWI	National Water Initiative
OEH	NSW Office of Environment and Heritage
PBH	Pressure –Biota-Habitat
PHABSIM	Physical Habitat Simulation
RFO	River Flow Objectives
SLU	Soil Landscape Unit
WSP	Water Sharing Plan

Executive Summary

Rous Water is assessing the viability of a new water storage dam to augment the water supply for four local council areas in the Northern Rivers region of NSW. The proposed Dunoon Dam is an in-stream storage located on Rocky Creek within the Richmond River catchment, with a proposed full storage capacity of 50,000 ML.

Eco Logical Australia (ELA) was commissioned to undertake an environmental flow assessment as part of a number of technical studies being undertaken to determine the viability of the proposed storage. The broad aim of this investigation was to determine if an environmental flow regime within the Rocky Creek system could be developed that would maintain and/or improve the downstream environment, in consideration of ecological needs and the current legislative framework.

A holistic study was undertaken to examine the environmental flow requirements of the current system. This approach integrated information from a range of disciplines including ecology, hydrology, water quality and geomorphology. A combination of desktop review, hydrological and geomorphic modelling and field studies was undertaken to determine the key flow requirements of the system.

NSW Water Solutions was engaged by Rous Water to undertake all hydrological modelling of the natural, current (i.e. with Rocky Creek dam online) and proposed system. Modelled flows were produced at a daily time-step for a 114 year period at several points along Rocky Creek, Terania Creek and Leycester Creek using the Integrated Quantity Quality Model (IQQM). Flow data for the natural and current (with Rocky Creek Dam online and current system operating rules) were compared to determine the nature of the hydrological regime in the creek system. Assessment and comparison of data was undertaken via: examination of hydrographs for different periods; key flow statistics such as mean, maximum and minimum; flow duration analysis; flood frequency analysis; and determination of the rates of rise and fall of flood events.

Field investigations included detailed survey of the physical stream environment including channel morphology and the relationship between flow and physical processes. Ecological and environmental surveys were undertaken to detail key species (flora and fauna), water quality and habitat at three time periods from October 2010 to June 2011 to capture seasonal variations. Field surveys were conducted at a range of locations to facilitate comparison between different potential impact zones and an unimpacted control area.

Hydrological assessment showed that both the natural and current Rocky Creek flow regimes are highly variable with extended periods of low flows and floods occurring at any time of the year. Rocky Creek Dam has reduced flows downstream of the Dam from the base flow to moderate flow range, but larger flood events are largely unaffected as they tend to fill and spill the dam. Data for natural flows show key flow components of base flows (2-6 MLd^{-1}), low flows (6-30 MLd^{-1}) and moderate flows (30-200 MLd^{-1}) are responsible for maintaining key ecological, water quality and channel functions. High flows (>200 MLd^{-1}) including floods greater than 17,000 MLd^{-1} provide for channel disruption and formation processes through movement of large cobbles and high energy flows.

Geomorphic assessments showed that Rocky Creek below Rocky Creek Dam is largely confined, with limited potential for erosion. The main unarmoured zone of Rocky Creek will be inundated by the proposed dam. Below Rocky Creek Dam, the character of the channel is dominated by boulder and bedrock structures. These channel types are predominantly controlled by large flood events.

Water quality in the system was indicative of good condition throughout the survey period. Nutrients, turbidity and chemical characteristics were all either well within the recommended ANZECC guidelines or where these guide lines were not met were in a range that is not critical to biota, ecological processes or physical function or the creek system. The large pool below the proposed dam wall remained weakly thermally stratified for the entire survey period and there were several short periods where the temperature difference between the surface and bottom temperatures was greater than 1 ºC, indicating that stratification is a normal part of the function of that pool. Flows of approximately 20 MLd^{-1} (at Rocky Creek Dam) for several days were sufficient to reduce thermal stratification to less than 1 ºC. Water quality is maintained in this system by low and even base flow levels.

The flora and fauna in Rocky Creek are adapted to a flow regime dominated by disruptive high flows that move large and small sediments, and scour in-stream and riparian vegetation. Maintenance of a flow regime that provides for irregular high flows and maintains base to moderate flow variability, including natural rates of rise and fall, should maintain and/or improve channel habitats and ecological condition in the Rocky Creek system downstream of the proposed Dunoon Dam. At the key flow level of 100 MLd^{-1} the main fish barriers downstream of the proposed Dunoon Dam infrastructure are open for migration to all potential fish species including the threatened Eastern Freshwater Cod.

Following detailed survey and assessment of the hydrology, geomorphology, water quality and aquatic ecology of the Rocky Creek system a set of environmental flow rules was established with the specific objective to maintain or improve the environmental and habitat values downstream of the proposed dam. These flow rules provide for a largely unchanged flow regime for flows up to 100 MLd^{-1} with contingency flows provided for prolonged dry periods.

The general flow rules are:

- Transparency of inflows up to 100 MLd^{-1} at Dunoon Dam
- If inflow to Dunoon Dam exceeds 100 MLd^{-1}, maintain release of 100 MLd^{-1}
- When inflow to Dunoon Dam drops below 100 MLd^{-1}, allow natural rates of fall
- If the unregulated spill exceeds 100 MLd^{-1}, no transparent release.

Further a set of contingency rules was developed to permit longitudinal channel connection in key fish migration periods during prolonged dry periods. These rules are:

- If inflow to Dunoon Dam is less than 0.7 MLd^{-1}, maintain release from Dunoon Dam of 0.7 MLd^{-1}
- If, by March 1, there has been < 3 days of inflows >= 100 MLd^{-1} (either as one or multiple events) over the preceding 60 days, release 100 MLd^{-1} for 3 consecutive days
- If, by August 1, there has been < 3 days of inflows >= 100 MLd^{-1} (either as one or multiple events) over the preceding 60 days, release 100 MLd^{-1} for consecutive 3 days.
- If, by October 1, there has been < 3 days of inflows >= 100 MLd^{-1} (either as one or multiple events) over the preceding 50 days, release 100 MLd^{-1} for consecutive 3 days.

These general environmental and contingency flow rules provide for a largely unchanged flow regime for flows up to 100 MLd^{-1}. Field assessment showed that at this level all key barriers downstream of the main proposed dam infrastructure are open to Eastern Freshwater Cod movement. In addition, flows in this range (base to moderate flows) provide for the other key environmental processes of fauna habitat provision, movement of smaller fish and other vertebrates, fine sediment flushing and water quality maintenance. Contingency flows potentially enhance the system by introducing flow pulses in periods where the current system had sustained low flows.

Detailed assessment of the potential impacts of the proposed dam on the flow regime of the Rocky Creek system considering the proposed environmental flow regime and changes to the operation of other water supply resources show that potential impacts can be considered in five (5) zones. Zone 1 extending from Rocky Creek Dam to Whian Whian Falls will be impacted by reduced spilling of Rocky Creek Dam due to alteration to the system operating rules. In this already impacted reach a reduction in the number of spilling events is considered unlikely to have any significant effect on the ecosystem or environment as dam seepage will continue to preserve base flows and dam spilling will be with sufficient frequency and magnitude to maintain flushing and channel forming flows.

Zone 2 will extend from Whian Whian Falls to the Dunoon Dam wall. In this zone the current lotic environment will be converted to a lentic or lake environment with substantial impact on the environment and ecology in the area. It is expected that in this zone a new environment with related habitat will form over time. Mitigation measures to preserve habitat features such as preserving standing and fallen timber, minimising bank erosion and maintaining water quality will also assist in the development of new habitat and prevent potentially hostile environmental features within the lake and downstream. A system of monitoring water quality and invasive species with appropriate management procedures will further help to minimise potential environmental impacts.

Zone 3 downstream of the proposed dam wall to the confluence to Terania Creek will receive regulated flows following the environmental flow rules unless the dam is spilling. Flow transparency to 100 MLd^{-1} is designed to provide unaltered base to moderate flows. Flows in this range will preserve key aspects of channel maintenance and habitat and food provision to minimise impacts on the aquatic environment and communities. Contingency flows will enhance the channel habitat in extended dry periods. High to flood flows will be largely unaltered by the operation of the dam and will continue to provide channel-forming flows. Initial flow modelling suggests that the creation of the dam upstream may increase the magnitude of some floods by as much as over 2000 MLd^{-1} due to increased runoff efficiency. This substantial increase requires further study when the final dam plans are in place as the modelling used in this study are insufficient to permit examination of detailed impacts from increased flood flows.

Zone 4 is Terania Creek downstream of the confluence. In this zone flow recovery from the larger Terania Creek catchment upstream of the confluence in addition to the transparent releases and spilling flows from Dunoon Dam will be sufficient to maintain environmental and ecological functions with minimal impacts.

Zone 5, Leycester Creek downstream of the confluence with Terania creek shows almost complete flow recovery and it is expected that the environment in this reach will be un-impacted by the construction and operation of the dam.

The environmental flow regime developed for this project provides a substantial mechanism to minimise the impacts of dam operation on the Rocky Creek system while maintaining the downstream environment. Whole-of-catchment solutions will also assist in mitigating impacts of the proposed dam. The conservation of native vegetation riparian zones, including the buffer zone surrounding the dam as well as the creeks that make up the Terania system (i.e. Rocky Creek, Tuntable Creek and Terania Creek) will help to maintain and improve water quality and habitat for aquatic species, including those identified threatened species.

The development and implementation of an Offset Strategy prior to dam construction could be considered as part of a broader catchment management program and would address other compensatory requirements for impacts of the dam, such as impacts to terrestrial biodiversity. An Offset Strategy would detail the location of suitable offset sites, restoration needs and on-going management requirements of the conservation areas.

Additional monitoring is also recommended should the Dunoon Dam proposal proceed to provide a more detailed and accurate understanding of the hydrology and ecology of the existing Rocky Creek system. In particular, continuous gauging of flow quantity and quality in Rocky Creek (i.e. real-time flow monitoring) would provide a more accurate understanding of the hydrology of the current system, enabling improved yield estimates and greater accuracy for future flow modelling. Real-time monitoring of inflows to the proposed Dunoon Dam would also be required for on-going dam operations to trigger the necessary dam releases.

Ecological monitoring, including continued survey of macroinvertebrates and fish species will provide for more detailed knowledge of temporal variability in species assemblages and distributions and habitat requirement. A separate suite of monitoring requirements has been recommended post-dam construction, including continued monitoring of channel physical form and ecological condition. This monitoring will allow for identification of environmental impacts and permit the implementation of necessary management procedures to ameliorate any impacts. On-going monitoring will also provide opportunity for ongoing improvements and refinements to the recommended flow regime.

The recommended mitigation measures provided in this assessment should be incorporated into relevant environmental management plans relating to both construction and operation. It is noted that these mitigation measures are based on the conceptual design of the dam; further measures may come to light once the detailed design has been completed. Any pre-construction monitoring undertaken should be reviewed and pertinent results incorporated into any assessments undertaken in the future and be used to inform revisions to suggested mitigation and management measures.

Should the Dunoon Dam project progress, Rous Water will be required to lodge an application with the Department of Planning and Infrastructure (DoPI). A set of the Director-General's Requirements (DGRs) for an Environmental Impact Statement (EIS) will be issued and as the proponent, Rous Water will be required to meet these requirements. Assessments undertaken as part of the EIS should be done in accordance with current legislation, publications and guidelines.

1 Introduction

1.1 BACKGROUND

Rous Water is the water supply authority providing bulk potable water for four Local Government areas in north-eastern NSW, servicing a population of around 95,000 over a 3,000 km^2 area. Rous Water is assessing the viability of a new water storage – the proposed Dunoon Dam - to augment the existing water sources.

The proposed dam is an in-stream storage located on Rocky Creek within the Richmond River Catchment, with a proposed storage capacity (at full supply level (FSL)) of 50,000 ML. Eco Logical Australia (ELA) has been commissioned by Rous Water to undertake an environmental flow assessment. This environmental flow assessment is one of a number of technical studies being undertaken to determine the viability of the proposed storage. The outcomes of this assessment will be incorporated into the conceptual design for the Dunoon Dam, and may form part of any future environmental assessment activities undertaken in association with the dam.

An holistic approach has been used to determine environmental flow requirements for the proposed Dunoon Dam which considers the flow requirements of the different yet inter-related components of the Rocky Creek system (Bunn & Arthington 2002).

1.2 ASSESSMENT OBJECTIVES

The broad aim of this investigation was to determine the environmental flow regime within the Rocky Creek system, with consideration given to the following factors:

- A review and consideration of all relevant information relating to Dunoon Dam
- Identification of the extent of influence of the dam on the downstream environment
- Identification of environmental and habitat values of the creek system including ecological and biodiversity values of water dependent ecosystems and fluvial geomorphology downstream, both at current conditions and different flow regimes
- Assessment, research and detailed analysis to identify the appropriate flow regimes for the environmental values identified
- Consultation with NSW Water Solutions regarding environmental flows for incorporation into their hydrological assessment to determine the capacity and secure yield of the dam
- Establishing the quantity, timing and release requirements of flows (e.g. on a seasonal, monthly basis etc) to maintain or enhance the environmental values downstream of the dam, taking into account environmental functions such as water quality, stream scouring, fish passage and maintenance of low- and medium-flow characteristics of the stream
- Identification of any specific requirements for environmental flows that will be required to be considered in the dam design
- Identification of any ecological monitoring requirements prior to and post commissioning of the dam.

1.3 LEGISLATIVE & POLICY FRAMEWORK

The following section identifies the statutory requirements relevant to the proposed Dunoon Dam project with reference to environmental flows.

Should the Dunoon Dam project progress, Rous Water will be required to lodge an application with the Department of Planning and Infrastructure (DoPI). A set of Director-General's Requirements (DGRs) for an Environmental Impact Statement (EIS) will be issued and as the proponent, Rous Water will be required to meet these requirements.

1.3.1 Water Management Act 2000

The *Water Management Act 2000* is the key piece legislation for the management of both surface water and groundwater in NSW. Importantly, the *Water Management Act 2000* recognises the allocation of water for environmental purposes. Under the Act, legal water sharing plans establish the 'rules' for water sharing between the different water users, including water for environmental purposes. These plans are being developed and implemented for rivers and groundwater systems across NSW and provide the framework for water licensing and trading.

It is noted that while some provisions of the *Water Act 1912* are in operation, this Act is being phased out and replaced by the *Water Management Act 2000*.

1.3.2 Richmond River Area Water Sharing Plan

The Water Sharing Plan for the Richmond River Area Unregulated, Regulated and Alluvial Water Sources commenced in December 2010. The Plan set management rules for water access licences, water allocation accounts, dealings in licensing for water allocations, the extraction of water, and the operation of dams and management of flows (NoW 2010b).

The objectives of the Plan are to:

- Protect, preserve, maintain and enhance the important river flow dependent and high priority groundwater dependent ecosystems of these water sources
- Protect, preserve, maintain and enhance the Aboriginal, cultural and heritage values of these water sources
- Protect basic landholder rights
- Manage these water sources to ensure equitable sharing between users
- Provide opportunities for market based trading of access licenses and water allocations within sustainability and system constraints
- Provide water allocation account management rules which allow sufficient flexibility to encourage responsible use of available water
- Contribute to the maintenance of water quality
- Provide recognition of the connectivity between surface water and groundwater
- Adaptively manage these water sources
- Contribute to the environmental and other public benefit outcomes identified under the Water Access Entitlements and Planning Framework in the Intergovernmental Agreement on a National Water Initiative (Water Sharing Plan for the Richmond River Area Unregulated, Regulated and Alluvial Water Sources Order 2010 under the Water Management Act 2000).
- The rules of the Water Sharing Plan have been developed based on the water quality and river flow objectives for the Richmond River Catchment (see Section 1.3.4) to protect the total volume of water for the environment as well as the natural variability of flow regimes.

1.3.3 National Water Initiative

The National Water Initiative (NWI) is a commitment between all Australian states to national water reform. The main objective of the NWI is "to achieve a nationally compatible market, regulatory and planning based system of managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes". The NWI agreement includes outcomes and commitments to specific actions across eight different inter-related elements of water management. An important element of the NWI is the Water Access Entitlements and Planning Framework.

The NSW NWI Implementation Plan was accredited by the National Water Commission in 2006. Integrated management of water for environmental and other public benefit outcomes is of particular interest for this project.

1.3.4 NSW River Flow Objectives

In 1999 the NSW Government endorsed broad river flow objectives that identify key aspects of the natural flow regime that protect river health and water quality for ecosystems and human uses. The objectives are the agreed targets for surface water flow management in NSW.

The NSW river flow objectives (RFOs) are to

- Protect natural water levels in pools of creeks and rivers and wetlands during periods of no flow
- Protect natural low flows
- Protect or restore a proportion of moderate flows, 'freshes' and high flows
- Maintain or restore the natural inundation patterns and distribution of floodwaters supporting natural wetland and floodplain ecosystems
- Mimic the natural frequency, duration and seasonal nature of drying periods in naturally temporary waterways
- Maintain or mimic natural flow variability in all rivers
- Maintain rates of rise and fall of river heights within natural bounds
- Maintain groundwater's within natural levels, and variability, critical to surface flows or ecosystems
- Minimise the impact of in-stream structures
- Minimise downstream water quality impacts of storage releases
- Ensure river flow management provides for contingencies
- Maintain or rehabilitate estuarine processes and habitats.

Similarly, the NSW Water Quality Objectives are the agreed environmental values and long-term goals for surface waters, consistent with the national framework (i.e. the ANZECC 2000 Guidelines) to provide the right water quality for the environment and the different water uses (such as recreation, visual amenity, drinking water and agricultural water).

1.3.1 Other

Should the Dunoon Dam project proceed the necessary planning approvals for a state significant infrastructure project would be required, including the preparation of an Environmental Impact Statement (EIS).

This environmental flows assessment does not take the place of an EIS; rather this report details the assessment process undertaken to determine environmental flow requirements for the proposed storage that considers the many system components of Rocky Creek, including hydrology, geomorphology, aquatic ecology and water quality as they relate to flow regime and aquatic system function.

1.4 A REVIEW OF ENVIRONMENTAL FLOWS

1.4.1 River regulation and the need for environmental flows

Healthy rivers are a longitudinal and lateral network of surface and groundwater flow paths, with the energy of flowing water constantly reshaping the physical form of these interconnected pathways (Stanford et al. 1996; Poff et al. 1997; Ward et al. 2001). The natural flow regime of rivers, including the magnitude, timing and variability of floods, largely controls channel morphology and biological productivity (Bayley 1995; Stanford et al. 1996; Poff et al. 1997). Flooding creates a constantly changing habitat mosaic of channel and floodplain structures supporting the myriad of plants and animals that make up riverine food webs (Stanford et al. 1996). Rivers of high ecological value are considered to have structures and functions similar to those observed under natural conditions (naturalness); are typical of a particular waterway type (representativeness); have high levels of taxa richness (diversity) and may be unusual or rare (rarity) (Bennett et al. 2002).

Patterns of flow in regulated rivers are affected by dam release, extent of en-route storage, weir pool regulation, groundwater recharge, and particularly by consumptive use extraction patterns. Flow regulation has changed the hydrology of rivers on three temporal scales: the flood pulse (days to weeks), flow history (weeks to years) and the long term statistical pattern of flows, or flow regime (decades or longer) (Arthington & Pusey 2003). Flood pulses provide cues that initiate biological events (e.g. migration, spawning) and drive ecological processes. Changes to the flow regime of regulated rivers have often had negative impacts on the environmental health of aquatic ecosystems, impacting on biodiversity, foodwebs, energy transport and ecosystem function (Bunn & Arthington 2002).

Managed environmental flows are one of the feasible operational options for river managers to address the deleterious impacts of river regulation (Watts et al. 2008). Pulsed flows are currently being built into some environmental flow regimes to mimic the action of natural floods, as small to medium natural fresh events have been reduced by water regulation and extraction. However, pulsed flows are not homogeneous in character as they vary in extent, duration and frequency and some types of flows may be better at achieving ecological outcomes than others. As the impacts of environmental flows may be varied, the relative benefits, costs, and trade-offs of incorporating these managed flows into water sharing plans need to be reviewed to inform water management practices in order to ensure aquatic ecosystem health and sustainable supply for extractive uses.

1.4.2 Environmental flow determination and assessment methods

Providing ‘environmental water’ has become an important tool for reducing some of the negative impacts of flow regulation. The emphasis of the many environmental water plans developed for Australian streams has been on ensuring sufficient water is available for plant and animal communities for ecosystem functions to remain viable, or on returning water to flow-stressed streams as a rehabilitation measure (Cottingham et al. 2005).

In reviewing environmental flow methodologies Tharme (2003) reported there were 207 individual methodologies recorded from 44 countries. This review proposed environmental flow determination methods can be classified under four headings:

- Hydrological methods – using historical data to establish a percentage of mean annual flow or specific hydrologic index
- Hydraulic methods
- Habitat-based models that define a relationship between discharge and suitable habitat for biota
- Holistic methods that integrate information from a range of disciplines including ecology, hydrology, water quality, geomorphology.

Hydrological methods include the Montana or Tennant method (Tennant 1976), and is the most frequently used method throughout the world (Pusey 1998). The Tennant method evaluates depth, velocity and wetted width and relates this to historical river discharge (Tennant 1976) and is suited to assessing the impacts of individual flow events. The wetted perimeter method (Stalnaker & Arnette 1976) is based on a series of transect measurements at different discharge levels, usually at riffle sites where fish passage is likely to be restricted (Gippel & Stewardson 1998). The Range of Variability Approach (RVA) (Richter et al. 1997) uses an Index of Hydrological Alteration (IHA) for setting benchmarks in river flow by identifying elements of the natural flow regime indexed by magnitude, timing, frequency and duration and identifying the deviation from 'natural'. This method is, of course, reliant on the availability of unregulated flow data for a system.

A number of habitat-based assessment methods exist to develop environmental flows to sustain populations or habitats of key fauna (Halleraker et al. 2007). Bovee and Cochnaur (1977) provide one of the earliest examples using the concept of weighted usable area defined by physical variables such as depth and velocity. This led to a computer model PHABSIM (Physical Habitat Simulation) developed by the US Fish and Wildlife Service (Bovee et al. 1988). The majority of these methods focus on maintaining or restoring critical habitats for specific life history stages or the entire life cycle of a species or multiple species, mainly salmonids (Bernardo & Alves 1999). The Instream Flow Incremental Methodology (IFIM) (Bovee et al. 1998) evaluates the effect of incremental changes in river discharge on in-stream channel structure, water quality, temperature, depth and flow velocity and relates this with known habitat preference data for key species. Similar methods to the IFIM are presented in Jowett (1989) and Cardwell et al. (1996). IFIM techniques are occasionally criticized due to the lack of consideration and maintenance of river channel processes such as flushing flow requirements (Hudson et al. 2003). The Habitat Analysis Method for determining environmental flow requirements (Burgis & Vanderbyl 1996) mirrors the IFIM by requiring knowledge of species tolerances and hydrology.

There has been a move away from hydrological or habitat-based models towards holistic models, as current evidence about river ecosystems function in relation to flow regime still largely exists as a series of untested hypotheses, it is crucial that future research focuses on experimentally evaluating the success of flow restoration on river ecosystems (Bunn & Arthington 2002). The Building Block Method is based on the premise that riverine species are reliant on basic elements of the flow regime (Tharme & King 1998). It uses a team of experts across a diversity of disciplines to assess available and modeled data to develop the building blocks (flows) required for a system. In Australia, several holistic methods have been developed including the Expert Panel Assessment Method (Swales & Harris, 1995), the Scientific Panel Approach (Thoms et al 1996; Cottingham et al 2001) and the Benchmarking Methodology (Brizga et al 2002). A progression from the combination of numerous holistic methodologies is the Downstream Response to Imposed Flow Transformations (DRIFT) process. DRIFT is a structured process for combining data and knowledge from a range of disciplines to produce flow-related scenarios for water managers to consider. DRIFT's basic philosophy is that all major abiotic and biotic components constitute the ecosystem to be managed; and within that, the full spectrum of flows and their temporal and spatial variability, constitute the flows to be managed (King et al. 2003).

Each method has advantages and disadvantages which make it suitable for a particular set of circumstances. Criteria for method selection include the type of issue (abstraction, dam release, hydropower), the management objective (pristine or 'working river'), expertise, time and money available, and the legislative framework within which flow management must be set.

Application of methods to environmental flows in North Coast NSW

A review of global environmental flow assessment methodologies by Tharme (2003) identified holistic assessment methods as those most appropriate for where environmental flow research is in its infancy and water allocations for ecosystems at present are based on scant data and best professional judgement and risk assessment need to be applied. In light of the ongoing development of WSPs and the current lack of detailed biophysical information on the impacts of flow delivery in coastal regulated rivers in Northern NSW, a risk-based expert panel approach may facilitate immediate demands for knowledge, with habitat and hydrologic assessment programs established to inform management in the longer term.

1.4.3 Current environmental flow assessment programs

There are a number of long-term programs that have been developed for the assessment of environmental flows or ecological condition of coastal system in eastern Australia. The Integrated Monitoring of Environmental Flows (IMEF) is a systematic scientific program to assess the ecological benefits of the environmental flow rules in the regulated Gwydir, Namoi, Macquarie, Lachlan, Murrumbidgee and Hunter River Valleys; and the Barwon-Darling and Severn Rivers. The program was established in 2000 and sets to test hypotheses on the response of algae, biofilms, low flow habitat, terrestrial organic matter, wetlands, fish and estuarine nutrient supply. Studies of algal blooms, biofilm scouring and fish surveys have been implemented in the Hunter Catchment (including Glennies Creek) with preliminary results reported in the State Summary Report 1998-2000 (DIPNR 2003). More recently, the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy (MER) for riverine systems has been implemented. The Riverine MER strategy acknowledges the dearth of information on coastal streams relative to the Murray-Darling Basin, and has current programs to enhance hydrologic, temperature and water quality monitoring, apply the Sustainable Rivers Audit fish component, develop methods for aquatic and riparian plant assessment, and a trial on the use of frogs as indicators of ecosystem change in NSW coastal streams. The Estuaries MER strategy and Wetlands MER strategy are under development by the NSW Office of Environment and Heritage (OEH). The Wetlands MER includes both coastal and inland wetlands, and is focused on monitoring the condition and extent of ‘important’ wetlands such as Ramsar sites and wetlands listed in the *Directory of Important Wetlands in Australia*. The NSW Algal Management Strategy includes Algal Contingency Plans aimed to minimise the effects of algal blooms, as well as develop short to medium term measures to control the factors leading to algal bloom development and nutrient and water management measures to minimise nutrient inputs to waterways. The Strategy involves Catchment Management Authorities, state government agencies, local government, communities, industry, researchers and landholders (NoW 2011).

The Pressure-Biota-Habitat (PBH) program for assessing stream condition is a general framework for the assessment of ecological conservation values and ecosystem stress in small and medium size coastal streams in NSW and southern Queensland; however, it is not designed to explicitly assess biotic responses to short-term changes in flow regime. The PBH approach uses three kinds of variables: human generated pressure on rivers, components of the biota and aspects of bio-physical habitat. These variables are used to generate indicators of richness, rarity, native abundance, alien biota, sensitivity, physical structure, water extraction and water quality (Chessman 2003). The PBH approach has been trialed on a number of coastal streams in NSW, with the most detailed study on the Bega River in southern NSW (Chessman et al. 2006). A similar study was undertaken in coastal streams of south-east Queensland to develop an Ecosystem Health Monitoring Program (EHMP) (Smith et al. 2003), and recommended the use of physical and chemical variables, invertebrates, fish, ecosystem processes and nutrients as key indicators to assess stream condition.

NSW Primary Industries have a number of projects relevant to environmental flow implementation and assessment currently underway including:

- Coastal river rehabilitation monitoring and evaluation in the Broadwater region

- Fish community monitoring in the upper Hunter River including responses to habitat rehabilitation
- NSW Integrated Fish Monitoring Program
- NSW Threatened Freshwater Fish Monitoring Program
- Developing a long-term monitoring program of freshwater fish in the Clarence River System – including the Eastern Cod
- Analysis of the impacts of freshwater flow on estuarine fisheries production
- Monitoring that contributes to the NSW Fisheries freshwater sampling database and Fish Files but is not directly linked to assessment of environmental flow allocation or delivery.

The State of the Rivers approach has been applied to a number of catchments in NSW under the theme of 'Inland Waters' and has been reported for 1996, 2001 and 2006 (DSEWPC 2011). The attributes measured include: reach environment condition; channel habitat diversity; aquatic and riparian vegetation; aquatic habitat; and scenic, recreational and conservation values. These data contribute to datasets that may be useful in evaluating the long-term impacts of environmental flow allocation and delivery on biophysical attributes.

The AUSRIVAS State-Wide Assessment commenced in 1994 under the name of the Monitoring River Health Initiative as a part of the National River Health Program. The NSW EPA was selected as the lead agency for this program in NSW. Macroinvertebrates and a wide range of environmental data were collected from 1064 river sites throughout NSW between September 1994 and May 2000. Of these sites 329 are reference sites representing the best available condition of a river type in NSW. The data from the reference sites were used by the EPA to develop predictive models that allowed the assessment of the ecological health of river sites in NSW using macroinvertebrates (Turak & Waddell 2001). The predictive models were then used to obtain assessments of the ecological health each of the sampling sites. (Full list of AUSRIVAS data are available from AUSRIVAS.canberra.edu.au.) Additional research by Turak and others (e.g. Turak & Koop 2007) has predicted the condition of sub-catchments in the Hunter-Central Rivers catchment management authority (CMA) region based on fish and macroinvertebrate assemblages. This research has the potential to identify specific regulated reaches that are important for biodiversity conservation, and subsequently, be used to inform environmental flow management.

1.4.4 **Potential costs and benefits of environmental flow delivery**

Geomorphology

The potential geomorphic benefits of mimicking natural flow patterns from baseflow levels to moderate flows (freshes) include the ability to 'reset' stream environments: activate bedload transport (Batalla et al. 2006), maintain channel dimensions (Batalla et al. 2006) and remove silt and fine sand from gravel bars (Vericat et al. 2006). The potential costs of flow pulses include erosion of the stream bed (incision) and banks (Kondolf 1997). The majority of environmental flow methods and assessments have focussed on large bankfull flushing and channel maintenance flows, resulting in a lack of information on the implications of environmental flows for small flows that may result in sediment mobilisation and substrate flushing as well as deposition (Brizga 1998).

Increased sedimentation is often a consequence of low or reduced flow in regulated rivers. Because slower velocities enable more sediment to settle out of suspension, sediment can accumulate and remain in the stream for longer time periods in the absence of high or flushing flows (Wood & Petts 1999). The filling of gaps in the substratum with fine sediments especially in areas of the channel not usually subject to persistent sedimentation may reduce habitat diversity and dissolved oxygen in the lower substratum, isolating the hyporheic zone from the surface stream (Wood & Armitage 1999).

Flows that are confined to the stream bed have the potential to scour fine grained sediment deposited previously on the stream bed and low-lying bars. Larger flow pulses have the potential to cause bed and bank erosion because of their relatively high velocity, depth and duration of flow. Where prolonged bank wetting is then followed by rapid drawdown bank slumping can occur, and has been reported in the Hunter River (Gippel & Blackham 2002). Little quantitative information exists on the relative importance of drawdown-induced slumping compared to bank slumping resulting from other fluvial processes (e.g. exposure to prolonged high water levels and bank undercutting by high velocity flows) and the critical rates of drawdown causing slumping.

The release of a large flow pulse from a reservoir can also result in clear-water erosion when the flow has sufficient energy to move sediment on the stream bed but carries a negligible sediment load because of retention in the reservoir (Kondolf 1997). Erosion continues until the bed becomes armoured with material too coarse to be moved. This effect persists downstream until the stream is able to entrain sufficient sediment to compensate for the deficit caused by the dam (Brizga 1998). Clear-water erosion in Australia has been reported on the Hunter River downstream of Glenbawn Dam (Erskine 1985).

Increased armouring of the stream bed can occur with altered stream hydrology (for example, decreased low flows and a reduced frequency of flushing); with subsequent ecosystems responses including a reduction in habitat availability and quality for macroinvertebrates and small fish (Cottingham et al. 2005).

In certain situations, where flow release capacity is large relative to channel dimensions, flow pulses of up to and sometimes above bankfull stage can be achieved. These have the capacity to connect with floodplain wetlands (Frazier & Page 2006) and result in ecological benefits similar to those achieved in natural flood pulses (Junk et al. 1989). The geomorphic effects of overbank flows are similar to those associated with large pulses but include the potential for floodplain deposition, particularly at the channel margins (Page et al. 2003) and in major overbank flows, channel realignment, floodplain scouring and damage to crops and infrastructure (fences, roads and other structures). In addition, floodplain inundation can have severe water quality implications (acid sulphate soils, blackwater events) in floodplain sections of many streams in North Coast NSW, but these impacts are mitigated by relatively small environmental flow allocations and the very large discharge volumes required for floodplain inundation in coastal streams of NSW.

Water quality

The main cause of poor water quality in regulated rivers is not necessarily the flow regulation itself, but may be from altered land-use practices and channel management. The use of environmental flows to flush or dilute contaminants such as nutrients, salt, and suspended sediment is merely addressing the symptom and not the cause. In other cases, environmental flows can be used to break persistent thermal or chemical stratification, or regulate the movement of the salt wedge under drought conditions (Pierson et al. 2001). More recently, environmental flows as pulsed releases from dams in Victoria and the ACT have been used to improve water quality and benthic habitats in streams impacted by bushfires (EPA 2007, Peat & Norris 2007).

The relationship between flow regime and the sources, sinks and transport of contaminants is poorly understood, making it a difficult task to predict the outcome of managed flow releases for river rehabilitation initiatives. Constructing reservoirs modifies biogeochemical cycles, such as interrupting the flow of organic carbon, changing the nutrient balance, and altering oxygen and thermal conditions. The consequences of altered processes may not be immediately apparent and may become obvious only after a long period of time or only in combination with other anthropogenic alterations (Friedl & Wüest 2002).

The prevalence of low flow conditions and a reduction of flushing flows in many coastal river systems associated with regulation and climate change can lead to gradual increases in the concentration of salt over time. Biota that would have survived short-term rises in salinity or dispersed to less saline systems are being permanently lost from aquatic systems leading to a substantial decline in aquatic biodiversity. In addition, rising salinity levels are associated with increased water volumes, longer periods of inundation and more widespread acidity, each of which is also likely to be detrimental to aquatic biota. Nielson et al. (2003) suggest adverse direct effects of salinization in most Australian stream systems will occur when salinity increases to around 1 500 mg/L, although this research was largely undertaken in the Murray-Darling Basin.

Environmental flow releases are often used by water resource managers to specifically address the ecological needs for the inundation of river-floodplain environments (Arthington & Pusey 2003; Schofield et al. 2003). However, there are potential environmental costs resulting from the inundation of floodplain wetlands that are well documented. Sulfidic sediments are common in coastal floodplain regions of NSW (White et al. 1997) and the negative environmental effects of acidification have been well-documented in these systems (e.g., White et al. 1997, Wilson et al. 1999, Corfield 2000, Lin et al. 2004). Similarly, the impact of inundating highly modified floodplain habitats that contain high loadings of organic matter has been demonstrated to cause deoxygenation, nutrient enrichment and algal blooms in regulated reaches of the Richmond River, NSW (Eyre 1997, Eyre et al. 2006). In 2001 and 2008, floodplain inundation in the lower Richmond River resulted in severe fish kills from deoxygenated floodplain water re-entering the channel with receding flows (C. Copeland pers. comm. (NSW Fisheries). It may be possible to use environmental flow releases to dilute blackwater events and sulfidic materials as they re-enter streams following large floods.

Algae and riparian plants

Several studies have shown that flow is the controlling factor for the development of cyanobacterial blooms in Australian rivers (e.g. see review in Davis & Koop 2006). Low flows contribute to the stabilization of the water environment, increased light availability, longer retention times and allow the release of nutrients from sediments (Davis & Koop 2006), as do the creation of in-stream storages. In addition, the impact of climate change on hydrology and water resources management may result in the conditions conducive to cyanobacterial blooms becoming more prevalent (Viney et al. 2007). As a consequence, flow management strategies such as pulsed and flushing flows, weir drawdown and artificial de-stratification have been used to control cyanobacterial blooms in regulated rivers (Herath 1997). The major limitation with using pulsed releases to disperse algal blooms is the lack of available water for an effective flushing flow or operational capacity to deliver water to the affected reach and often the bloom is merely transported downstream. The original source of the algal bloom may be the reservoir from which flow pulses are released.

Disturbance by flood events is one of the most important regulators of spatial and temporal variability in stream communities (Davis & Barmuta 1989). Very few studies in Australian systems have examined the effects of flow velocity from floods or managed flow pulses on biofilm scouring or productivity. In response to this lack of knowledge, programs such as the NSW IMEF have initiated long-term research to examine biofilm scour and resetting in cobble and snag (large woody debris) in the Hunter River catchment. Results to date have not demonstrated an effect of environmental flows on biofilm attributes, but have shown that biofilms in regulated rivers were consistently different from those in the unregulated rivers, related to differences in catchment development and consequently water quality, as well as to differences in flow regime. As such, water quality factors and high-volume summer irrigation flows may constrain the capacity of environmental releases to engender natural biofilm characteristics, making it difficult to assign value to trajectories of change in biofilm attribute (NSW IMEF 2003). Similar research on the response of biofilms to environmental flow releases relevant to coastal streams in northern NSW has also been undertaken in the regulated Cotter River in the ACT (Reid et al. 2006, Chester & Norris 2006) and in the Mitta Mitta River Victoria (Sutherland et al. 2002, Watts et al. 2004, 2006, 2008). These studies have demonstrated that environmental flows of the same magnitude, duration and timing in the same system can yield incredibly different ecological outcomes, highlighting the importance of antecedent flow conditions in regulating biofilm growth and therefore their resilience to disturbance. Further research to better understand the mechanisms regulating benthic algal resilience and resistance to flow velocity is required for designing experimental floods that aim to effectively scour biofilms. For example, Ryder et al. (2006) provides the only example of experimentally derived thresholds for biofilm scouring in Australia rivers and these are not transferable to coastal cobble-based streams.

Riparian vegetation plays an important role in regulating light and temperature within the stream zone, as well as providing food resources to aquatic and terrestrial biota, a source of large woody debris, regulating the flow of water and nutrients and maintaining biodiversity by providing a variety of habitats and ecological services (Naiman et al. 1993; Tabacchi et al. 1998). Within catchments, flood history and groundwater levels are considered to be the main determinants of the type and productivity of riparian vegetation (McCosker 1998; Richter & Richter 2000). Flooding is the primary agent of disturbance in riparian plant communities and disturbance is an important factor in riparian zone ecology as it maintains plant diversity through increasing environmental heterogeneity (Stromberg 2001; Hughes & Rood 2003; King et al. 2003). However, large floods are also capable of causing temporary reductions in heterogeneity of the river bed by dumping fine sediments within the channel and destroying vegetation through scouring or inundation (Friedman & Auble 1999; Hughes et al. 2001; Stevens et al. 2001). Reviewers of Australian literature observe that there is often little published information available about the water regime requirements of plant species that commonly occur in the riparian zone (e.g. McCosker 1998). Howell and Benson (2000) examined the likely effects of frequency, season, depth and duration of inundation on riparian vegetation in relation to habitat, dispersal season and tolerance to waterlogging. They found environmental flows could benefit native water-edge plants by maintaining continuous low-level flow in the river, and higher level environmental flows restricted to the river-edge habitat in autumn (the season in which a greater proportion of native species than weed species are known to disperse propagules).

Invertebrates

Invertebrate communities in many river systems are highly mobile, reproduce rapidly and recolonise quickly making them well-adapted to the disturbances of floods (Boulton and Brock 1999; Bunn & Arthington 2002; Jakob et al. 2003). Although significant decreases in invertebrate abundance have been recorded after large flood pulses, these taxa are generally very resilient and usually recover to pre-flood densities within a few weeks or months (Scrimgeour et al. 1988; Collier 2002; Robinson et al. 2004). Without the flood pulses of natural water regimes, species with life stages that are sensitive to sedimentation, such as the eggs and larvae of many invertebrates, can suffer high mortality (Poff et al. 1997). Potential impacts of sedimentation on invertebrate communities include alteration of substrate composition causing changes to the suitability of the substrate for some taxa; increases in drift due to sediment deposition or substrate instability; reduced respiration due to the deposition of silt on respiration structures (e.g. gills) and impairment of filter feeding (Growns 1998; Owens et al. 2005).

Generally a disturbance causing a reduction in flow is expected to decrease aquatic invertebrate density and diversity downstream from the point of the disturbance such as a weir (Bunn & Arthington, 2002; Richter et al. 2006). However, benthic invertebrates can be highly resilient to the effects of reduced flows (Gunderson, 2000) because of their evolution within a highly variable and dynamic aquatic environment. This inherent capacity of many benthic invertebrates to recover from disturbance suggests recolonisation from the hyporheic zone (Fowler 2004), refugia within the substrate (Lancaster & Hildrew, 1993) and by drifting from upstream (Svendsen et al. 2004), could enable the recovery of invertebrates in response to environmental flows.

Although these studies identify the mechanisms likely to regulate macroinvertebrate responses to changes in flow, there are limited studies of macroinvertebrate community dynamics in response to an environmental flow release in northern NSW. Growns (1998) concluded that only a small proportion of the information necessary to develop environmental flow methods for invertebrates was available. Recent research in coastal streams of NSW has improved the knowledge of the relationships between hydraulic microhabitats and the distribution of macroinvertebrate assemblages in riffles (Brookes et al. 2005).

Fish

A considerable body of work has been done examining the consequences of the direct (e.g. barriers to dispersal) and indirect effects (e.g. reduced inundation of floodplain habitat for spawning or larval recruitment) of flow regulation on fish assemblages and aquatic ecosystems in south-eastern Australia. Gehrke et al. (2002) identified Tallowa Dam on the Shoalhaven River, south coast NSW, as a migration barrier for fish and observed accumulations of diadromous fish downstream of the dam and believed up to 10 migratory species to be extinct upstream of the dam. Alteration of the natural hydrograph has associations with direct and indirect effects of flow regulation (Growns & James 2005), with reduced variability of flow influencing aquatic habitat diversity (Merigoux & Ponton 1999), thereby affecting the flora and fauna and the ecosystem processes that support fish populations. In the Hawkesbury-Nepean River system, Gehrke et al. (1999) observed greater abundances of some fish species in unregulated reaches when compared to regulated reaches, and larger abundances of other species in regulated reaches as opposed to unregulated. In the same river system, the percentage (range between 0.43-6.65%) of young-of-the-year (YOY) and total number of Australian bass (*Macquaria novemaculeata*) caught during recreational fishing events was correlated with the number and duration of high flow events in the previous year (Growns & James 2005). The impacts of flow regulation on flow regime are also likely to extend beyond the reach where a dam is present (Growns & James 2005), including downstream to estuaries where fishery production (catch) is often associated to total annual river flow (Kimmerer 2002).

Flow regulation is often correlated to changes in temperature and water quality downstream of dams and weirs, with effects noticeable for large distances (>100 km) (Halleraker et al. 2007). Many species of freshwater fish require critical minimum temperatures before spawning occurs, including Murray Cod (*Maccullochella peelii peelii*) (Humphries 2005), Australian smelt (*Retropinna semoni*) (Milton & Arthington 1985) and freshwater catfish (*Tandanus tandanus*) (Lake 1967). Changes to river temperature patterns as a consequence of damming is therefore likely to alter spawning periods for fish species with critical minimum spawning temperatures by reducing the duration of the spawning season. Management of environmental flow releases must consider the potential negative impacts associated with thermal pollution, often resulting in the ‘piggy-backing’ or ‘shandying’ of environmental flow releases with unregulated tributary flows.

While a number of experimental studies in conjunction with habitat suitability modelling have been used to predict the response to environmental flows and develop environmental flow regimes (Gibbins & Acornley 2000), no research has been conducted to assess the response of fish populations to the change in habitat distribution associated with increased discharge during environmental flow releases.

Other aquatic vertebrates

Coastal streams are also important habitats for other aquatic vertebrates. Platypus are still common in coastal streams of northern NSW, but are locally vulnerable to habitat changes, particularly water pollution and degradation of their aquatic homes (Grant & Temple-Smith 2003). The effects of dam operations on platypus have not been studied, however, Rohweder & Baverstock (1999) reported their presence in dams and weirs suggesting environmental flow releases (and concomitant dam drawdown) might negatively influence platypus habitat availability. Several studies have reported fragmentation of platypus distribution within individual river systems. This has been attributed to poor land management practices associated with stream bank erosion, loss of riparian vegetation and channel sedimentation. There is currently also evidence for adverse effects of river regulation and impoundments, introduced species, poor water quality, fisheries by-catch mortality and disease on platypus populations, but none of these has been well studied (Grant & Temple-Smith 2003).

The earliest formal use of environmental water within Australia was for the Kerang Lakes in 1968 to maintain habitat for avifauna (Wettin et al. 1994). Since then, environmental water has been used to inundate or prolong the inundation of wetlands where bird-breeding events have been initiated in response to natural floods. Allocations have been used in this manner for the Macquarie Marshes (Wettin et al. 1994; Kingsford & Auld 2005), the Barmah-Millewa Forest (Baldwin et al. 2001) and the Narran Lakes (MDBA n.d.). The strong community interests in waterbirds (as visible, charismatic vertebrates) also means that the success of environmental flow pulses in floodplain systems may always be partly assessed by the abundance and diversity of birds. No studies were found on the assessment of waterbird communities to environmental flow releases in coastal streams of northern NSW. However, some doubt exists over the sensitivity of birds to hydrological change in the short-term (Roshier 2002). The great mobility of birds means that many species can exploit resources from both local and distant water bodies. The presence or absence of birds within a given wetland may, therefore, depend upon conditions hundreds of kilometres away, rather than the condition of the wetland under consideration. Moreover, birds possess a high degree of behavioural complexity, which may further confound responses to changing hydrological conditions (Reid & Brooks 2000). However they might still be susceptible to “death by a thousand cuts if changes occur in an increasing number of coastal streams.

Frogs are integral components of river and floodplain ecosystems. They are an important food source for birds, reptiles and fish and are predators of large variety of small aquatic animals. Diverse and healthy frog populations are important to maintain ecosystem services provided by wetlands. Frogs can also be indicators of overall catchment health as they are sensitive to alterations in natural water regimes. Riverine wetlands play a vital role in the persistence of many frog species. Seasonally flooded or temporary wetlands can provide breeding habitat and permanent wetlands with fringing vegetation provide habitat for long-term refuge. For the temporary habitats to be beneficial to frogs they need to persist for periods longer than the time it takes for tadpoles to develop into adult frogs (generally greater than 3 months). The delivery of environmental flows for wetland watering has traditionally focused on meeting the needs of vegetation, waterbirds and fish. Unlike waterbirds, frogs are limited in their capacity to disperse between wetlands (Wassens et al. 2007, 2008) and their responses to the flooding of a wetland may be influenced by its proximity or hydrological connection to other occupied wetlands. Many frog species have highly specialised requirements in terms of the timing of inundation, frequency of inundation and wetland hydroperiod, but the influence of environmental flows on these attributes are poorly understood for coastal systems.

1.5 ENVIRONMENTAL FLOW REGIMES

1.5.1 **Water Sharing Plans**

Water Sharing Plans (WSP) balance the needs of the environment and other water users including town water supplies, basic landholder rights and commercial uses.

Under a WSP, all water extraction requires a water access licence (or some form of exemption), with the exception for basic landholder rights. Access licence categories include local water utility, domestic and stock, unregulated river, aquifer, regulated river, Aboriginal cultural and Aboriginal community development. Available water determinations are made to define how much of the total component under each category of licence will be available for extraction (NoW 2010b).

A licence holder's annual access to water is managed in the WSP firstly through the long-term annual extraction limit which sets out how much water licence holders can extract annually and then through daily access rules (NoW 2010b). Daily access rules consider not only the quantity of water extraction but also the timing and rate of extraction. Daily access rules manage water extraction of a day-to-day basis.

Some water sources are divided into flow classes to manage extractions across a range of stream flows. These flow classes can range from the very low flow class (low flow that is exceeded on 95 percent of days) up to C class (moderate to high flows that are exceeded on 50% of days) (NoW 2010b).

The WSP protects flows for environmental purposes by limiting extractions on a local and river basin scale and implementing environmental flow protection rules (cease to pump rules).

The allocation and use of environmental water under the WSP will require negotiations and consultations between the various government agencies.

1.5.2 **Environmental flow types**

Specific strategies for the allocation and use of environmental water are:

- Planned environmental water such as:
    - Environmental Contingency Allowances (ECA) where a specific volume of water is set aside as an environmental contingency
    - Transparency / translucency rules that require dams to pass predetermined discharge under certain inflow conditions
- First flush rules (restricted extraction during natural spill events to protect flushing flows)
- End of System Flow Targets (EoS) (to ensure low flow entry to estuaries)
- Adaptive Environmental Water (water purchased and committed to environmental purposes).

Identifying the specific environmental requirements of unregulated and regulated water sources and the estuary is critical for determining whether the environmental flow rules are sufficient to protect riverine processes, maintain fresh water inflows to estuaries, maintain biodiversity and mitigate water quality threats. Scientific knowledge on the thresholds for key species, biological communities and ecosystem processes is also critical for providing decision-makers with clear guidance on when and how to activate an ECA or when developing other environmental flow provisions.

Coastal regions of northern NSW include temperate through to sub-tropical climates with variation from summer to winter dominated rainfall. As such, transferring knowledge of environmental flow requirements for rivers from inland systems or other biogeographical regions may be problematic, and require system or region specific information to guide policy development and management of environmental water.

1.5.3 Current practice in pulsing flows

Many agencies are involved in the policy, regulation and operation of rivers and the supply of water in the different states of Australia. In addition, there is a diversity of different types of water and variation in the nomenclature of water licensing. Statutory operating rules provide both opportunities and barriers to environmental flow practice. For water managers to make use of opportunities for pulsing flows they need to consider implications for consumptive and environmental users of the licence conditions attached to different types of water.

Pulsed flows are delivered under different management contexts including:

1. Delivery of environmental water by pulsing
    - Translucent flows
    - Environmental health water
    - Environmental quality water
    - Water for the environment that has been leased or purchased

2. Supply of consumptive water by pulsing during conveyance
    - Bulk water transfer or inter-valley transfer between storages
    - Bulk delivery of stock and domestic water

3. Safeguarding natural pulses
4. Hydropower pulsing
5. Release of pulsed flows for recreational purposes.

1.5.4 Examples of environmental flows regimes in NSW

Emigrant Creek

Emigrant Creek Dam (completed in 1968) supplements the Rous Water regional water supply from Rocky Creek Dam and the Wilsons River Source. It has a capacity of 820 ML with an annual yield of around 1,600 $MLyr^{-1}$ (based on existing system operation rules). Water is released via an integrated spillway.

Environmental flow releases from the dam are also provided via a 600 mm diameter scour valve in the base of the dam. Environmental flows for the downstream system were designed to provide for the following:

- Variability of natural flows
- Seasonality of natural flows
- Ecosystem baseflow requirements
- Freshes (or moderate in-channel rises in water levels)
- Natural rates of rise and fall.

The environmental flow release program for Emigrant Creek provides a calendar of months where transparent releases between 5-30 MLd^{-1} are set for protection of key environmental and ecological functions (**Figure 1-1**).

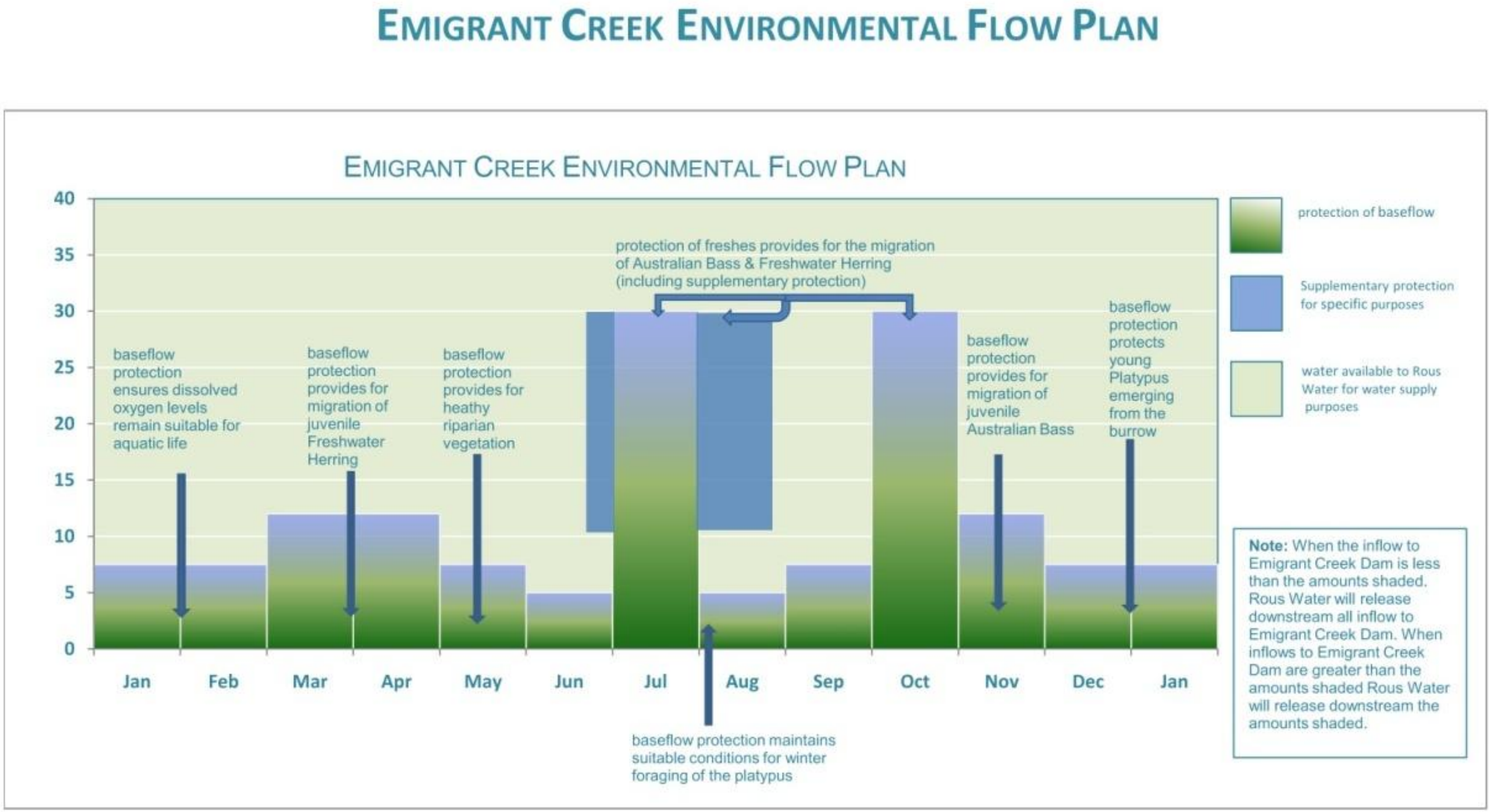


Figure 1-1: Emigrant Creek Environmental Flow Plan (Rous Water 2007)

Shannon Creek Dam

The recently constructed Shannon Creek Dam (30,000 ML capacity) is an off-river storage reservoir and part of the Clarence Valley and Coffs Harbour Regional Water Supply Scheme. Water is gravity fed from the Nymboida River under certain conditions (including only extracting water from the weir pool when flow exceeds 225 MLd^{-1}).

Environmental flow requirements for downstream of Shannon Creek dam are provided in the licence, these include:

- All control devices (including pipes fitted with stop valves) are to have a discharge capacity of no less than a flow equivalent to the one in two year flood frequency of Shannon Creek at the dam site
- Compensatory flow: when a natural flow is entering the storage, these pipe/s shall be operated as to maintain a flow in the creek immediately downstream of the dam that is equivalent to the flow entering the storage of the dam or the capacity of the pipe/s, whichever is the lesser (i.e. transparent to the one in two year flood frequency flow magnitude)
- Passage of high flows (translucent dam): notwithstanding the above, any natural flow retained in the storage of the dam due to the pipes inability to maintain releases equal to the instantaneous rate of inflow, shall be released as soon as possible
- Retention of high flows during initial filling period: notwithstanding the above during the initial filling period and prior to the dam attaining a volume of 15,000 ML for the first time (and commissioning of the storage) any flow that is in excess of a flow equivalent to the one in two year flood frequency of Shannon Creek at the dam site may be retained in the storage.

Burrendong and Windamere Dams

Two storages in the upper catchment regulate flows in the Macquarie River. Windamere Dam on the Cudgegong River is upstream of Burrendong Dam. Environmental provisions are provided in the Water Sharing Plan for the Macquarie and Cudgegong Regulated Rivers Water Source. Key environmental provisions include:

The major environmental provisions for the regulated Macquarie water source are (Green et al. 2011):

1. All flows above the plan extraction limit are reserved for the environment
   On a long-term average basis, approximately 73% of yearly flows in the river are protected for environmental health
2. Provide more natural flows in the upper reaches of the Cudgegong River
   This is achieved by releasing a portion of inflows to Windamere Dam to attain, in combination with downstream tributary contributions, a flow of 150-1,500 ML/day at Rocky Water Hole. No releases occur when the capacity of Windamere Dam is less than 110,000 ML, and releases are subject to an annual limit of 10,000 ML
3. Establish an environmental water allowance for the Macquarie River.

The WSP allows for up to 160,000 ML to be credited to an environmental water allowance in any water year. Part of this allowance is used to provide more natural flows downstream of Burrendong Dam with releases made during June to November and March to May. The other part of the environmental water allowance is released when needed for special environmental purposes, such as enhancing native fish recruitment, ensuring completion of water bird breeding events and alleviating severe, unnaturally prolonged drought conditions in the Macquarie Marshes (Green et al. 2011). An Environmental Flow Reference Group provides advice on when the water should be released for environmental purposes.

The Plan also contains rules for the release of a portion of inflows to Windamere Dam (which are protected from extraction until they have entered the Burrendong Dam storage). These flows are aimed at ensuring connectivity throughout the Cudgegong River system and reintroducing a more natural flow pattern in the upper reaches below Windamere Dam.

1.6 OUR APPROACH – HOLISTIC

To determine the key elements of flows required to maintain or improve the environment downstream of the proposed Dunoon Dam an holistic approach that combines assessment of hydrology, geomorphology, water quality and ecology was used.

The environmental flow requirements of hydrology, geomorphology, aquatic ecology and water quality functions and processes were integrated, based on a review of available data and field survey data. Outcomes of the separate *Aquatic Ecology Assessment for the proposed Dunoon Dam* (ELA 2012) have been integrated into this assessment.

1.7 PROJECT DESIGN AND REPORTING QUALITY ASSURANCE

The project overall project approach and specific project design including field survey program, data analysis and reporting was designed by a Technical Expert Team including Dr Paul Frazier, Assoc. Prof. Darren Ryder and Dr Keith Bishop (**Figure 1-2**). The project design was then reviewed and approved by Prof. Martin Thoms and Prof. Terry Hillman, and presented to Rous Water and the Project Reference Group (PRG) for acceptance.

Following acceptance of the project design, ELA environmental scientists and ecologists conducted a program for desktop research and field survey to assess key environmental aspects of the project and prepare the initial draft report. During this data collection period project progress reports were presented to Rous Water and the PRG.

Consultation with government agencies was undertaken during the initial stages of the project. This consultation involved an invitation to comment on the proposed assessment methodologies (for both environmental flows and aquatic ecology). The following agencies were contacted:

- Department of Industry and Investment (Fisheries) (now part of the NSW Department of Primary Industries)
- Department of Environment, Climate Change and Water (now NSW Office of Environment and Heritage)
- NSW Office of Water (within the Department of Primary Industries)
- Department of Environment, Water, Heritage and the Arts (now the Department of Sustainability, Environment, Water, Population and Communities - SEWPC).

As the project has not yet been submitted or referred to any of the agencies, little feedback was received.

The NSW Office of Water provided the following comments:

- The proposed geomorphic assessment (sediment transport, stream power etc using HEC-RAS modeling) will provide a rough reach scale assessment and would provide only limited information for a detailed assessment of wetted perimeter and fish passage.

SEWPC referred to the necessary survey guidelines for EPBC listed threatened species, in particular threatened bats, birds and frogs.

Final reporting was reviewed and approved by Dr Paul Frazier and Associate Professor Darren Ryder and by the independent expert team of Professors Martin Thoms and Terry Hillman. Final reporting was approved and accepted by Rous Water.

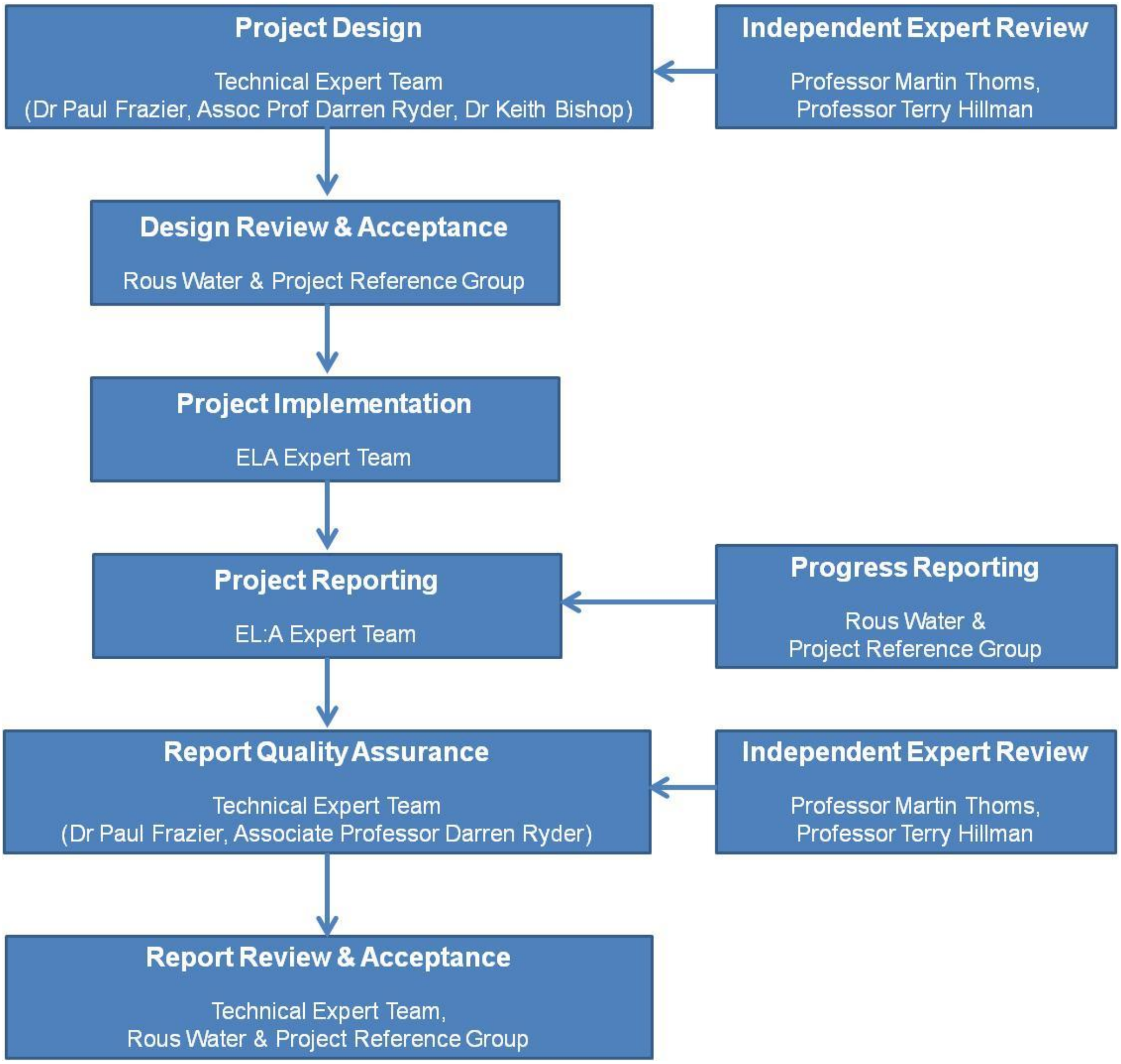


Figure 1-2: Project design, review and quality assurance process

1.8 REPORT STRUCTURE

This assessment is structured according to **Table 1-1**.

Table 1-1: Report structure

SECTION	CONTENT
Section 1	Provides important background information to the project and the approach used for this assessment
Section 2	Provides information on the Rocky Creek system and characteristics of the catchment
Section 3	Outlines the field study sites selected for the assessment
Section 4	Characterises natural and existing hydrological patterns and flow components of the system
Section 5	Characterises natural and existing geomorphological characteristics of the system
Section 6	Characterises natural and existing water quality characteristics of the system
Section 7	Characterises natural and existing aquatic ecology characteristics of the system
Section 8	Considers key aspects of the creek flow, ecology, process and function to identify environmental flow requirements for the Rocky Creek system
Section 9	Considers the impacts of the proposed flow regime for Dunoon Dam on the key aspects of the creek flow, ecology, process and function along the system
Section 10	Identifies mitigation measures to manage potential impacts from the proposed flow regime and provides monitoring recommendations both prior to construction and during operation of the dam
Section 11	Provides a conclusion to this assessment
Section 12	Lists references cited during this assessment

2 Site Background & Physical Setting

2.1 INTRODUCTION

The proposed Dunoon Dam is located on Rocky Creek within the Richmond River catchment in north-eastern NSW (**Figure 2-1**). Rocky Creek drains the Nightcap Range and is a sub-catchment of the Wilsons River, one of the main arms of the Richmond River. Rocky Creek forms part of the Terania Creek sub-catchment that drains to Leycester Creek, Wilsons River and the Richmond River, entering the Pacific Ocean at Ballina. The system is influenced by tidal effects up to a point 20 km downstream of the Rocky Creek and Terania Creek confluence (DIPNR 2004) although the water in Terania Creek is entirely fresh.

Flows in Rocky Creek have been altered due to the construction of Rocky Creek Dam in the 1940s. The section of creek downstream of Rocky Creek Dam to the confluence with Terania Creek (approximately 17.5 km) has formed a naturalised environment and ecology downstream. The proposed Dunoon Dam wall will be located approximately 15 km downstream of the existing Rocky Creek Dam **(Figure 2-2)**.

With a storage capacity of 14,000 ML, Rocky Creek Dam is the primary water source for Rous Water. The secure yield of the dam (under the existing operating rules) is 9,600 $MLyr^{-1}$.

The Terania Creek sub-catchment (which includes Rocky Creek) was identified as being of high conservation value by NPWS and NSW Fisheries due to the presence of significant aquatic fauna and/or flora and significant native fish species or habitat (NSW DLWC 1998). The Terania Creek sub-catchment was given an overall low stress classification based on indicators that suggested the medium levels of environmental stress in the system were likely to be from factors other than water extraction. However, water extraction is likely to contribute further to environmental stress and was identified as a high priority for river management planning.

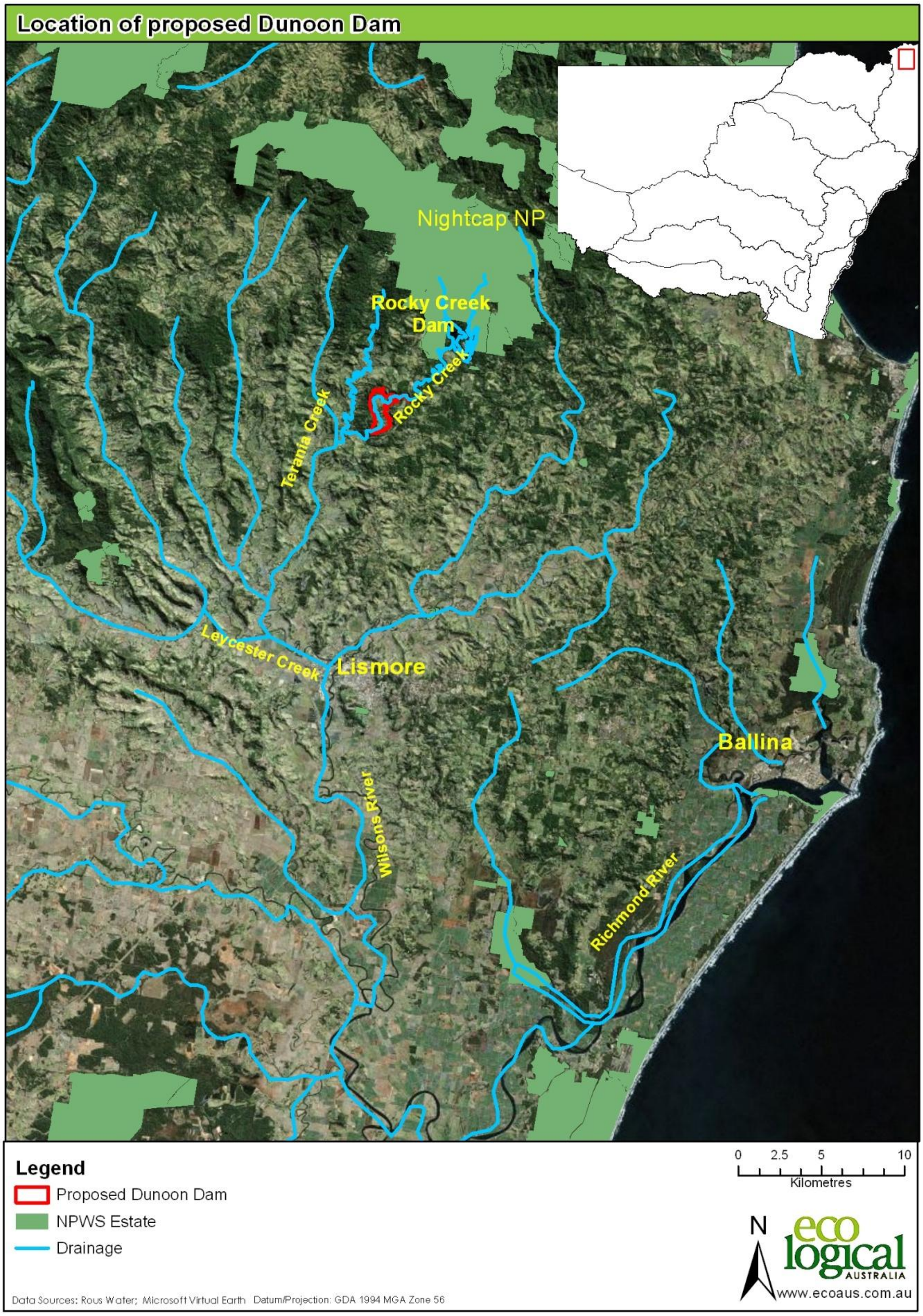


Figure 2-1: Location of the proposed Dunoon Dam in relation to the Richmond River Catchment

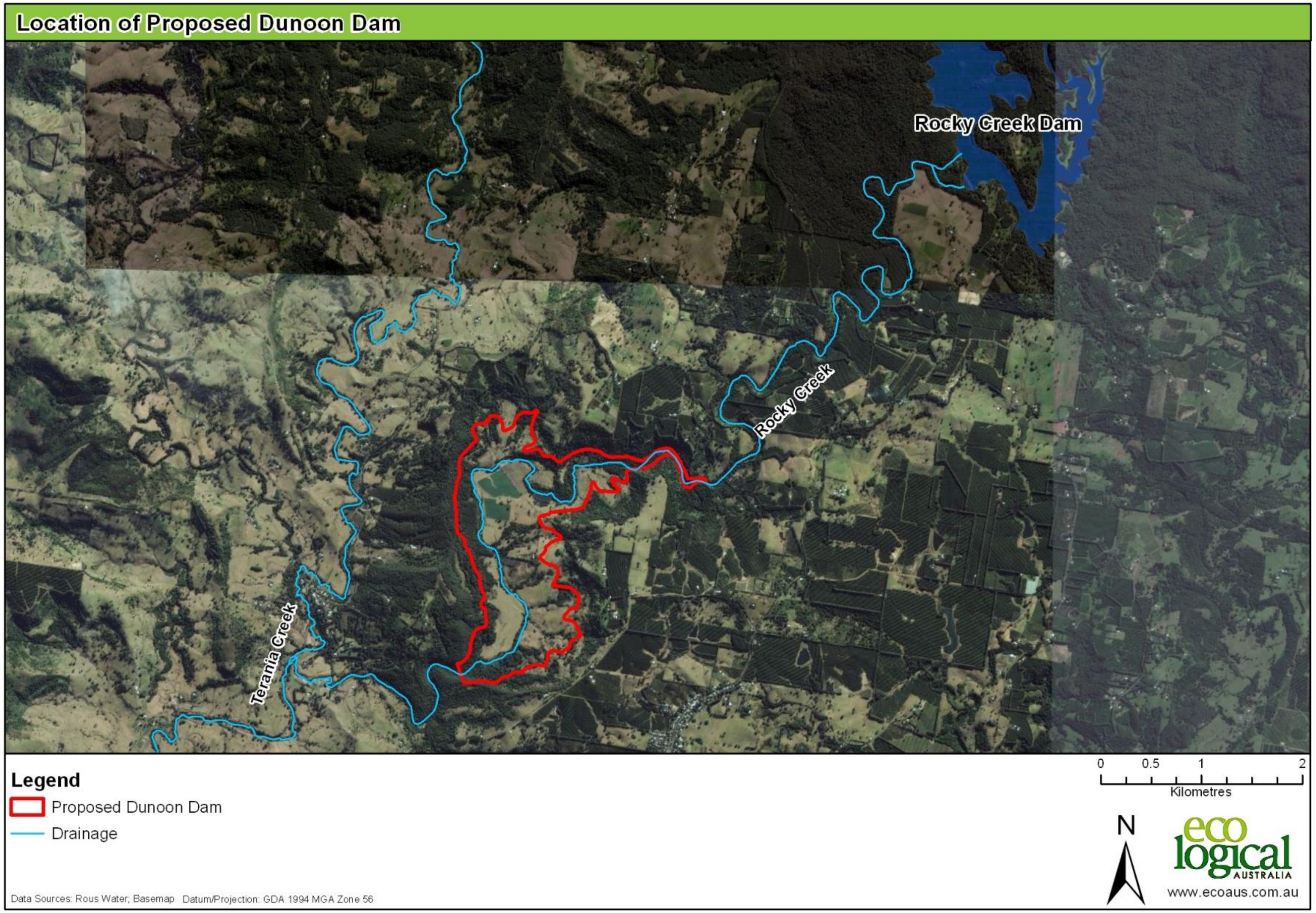


Figure 2-2: Location of the proposed Dunoon Dam in relation to Rocky Creek Dam

2.2 CLIMATE

The nearest long term Bureau of Meteorology station to the project site is Lismore (11 m AHD). Evaporation data were sourced from Altsonville approximately 10 km to the east of Lismore. Lismore experiences subtropical conditions year round with warmer summer months and colder winter months. Average annual rainfall exceeds 1300 mm with a dominant rainy period in summer and early autumn (**Table 2-1**).

Table 2-1: Monthly rainfall and temperature statistics

MONTH	MEAN MAX TEMP (°C) (1907-2003)	MEAN MIN TEMP (°C) (1907-2003)	MEAN RAINFALL (mm) (1884-2003)	MEAN NUMBER OF DAYS OF RAIN >1 mm (1884-2003)	MEAN DAILY EVAP (mm) (1971-2011)
Jan	29.1	18.8	155.4	10.4	5.7
Feb	29.1	18.8	183.6	11.7	5
Mar	27.9	17.4	188.4	13	4.3
Apr	25.7	14.2	129.2	10	3.5
May	22.6	10.9	115.3	9.3	2.7
Jun	20.2	8.2	97	7.4	2.4
Jul	19.9	6.5	80.3	6.4	2.7
Aug	21.5	7.2	54.9	5.8	3.5
Sep	24.4	9.9	50.4	5.7	4.4
Oct	26.6	13.2	73.2	7.1	5
Nov	28.2	15.8	94.1	8.2	5.4
Dec	29.7	17.8	121.3	9.4	5.9
Annual	**25.5**	**13.2**	**1343.1**	**104.4**	**4.2**

Source: Bureau of Meteorology 2009 (Lismore Centre Street Station 58037; Alstonville Research Station 58131)

2.3 LANDFORM & TOPOGRAPHY

The topography of the Rocky Creek catchment consists of High Rolling Hills (McDonald et al 1990) with average local relief between 90-300 m and a modal slope of between 10% and 32% (**Figure 2-3**). Bishop (1998a) estimated that 11% of the catchment had slopes steeper than 30%.

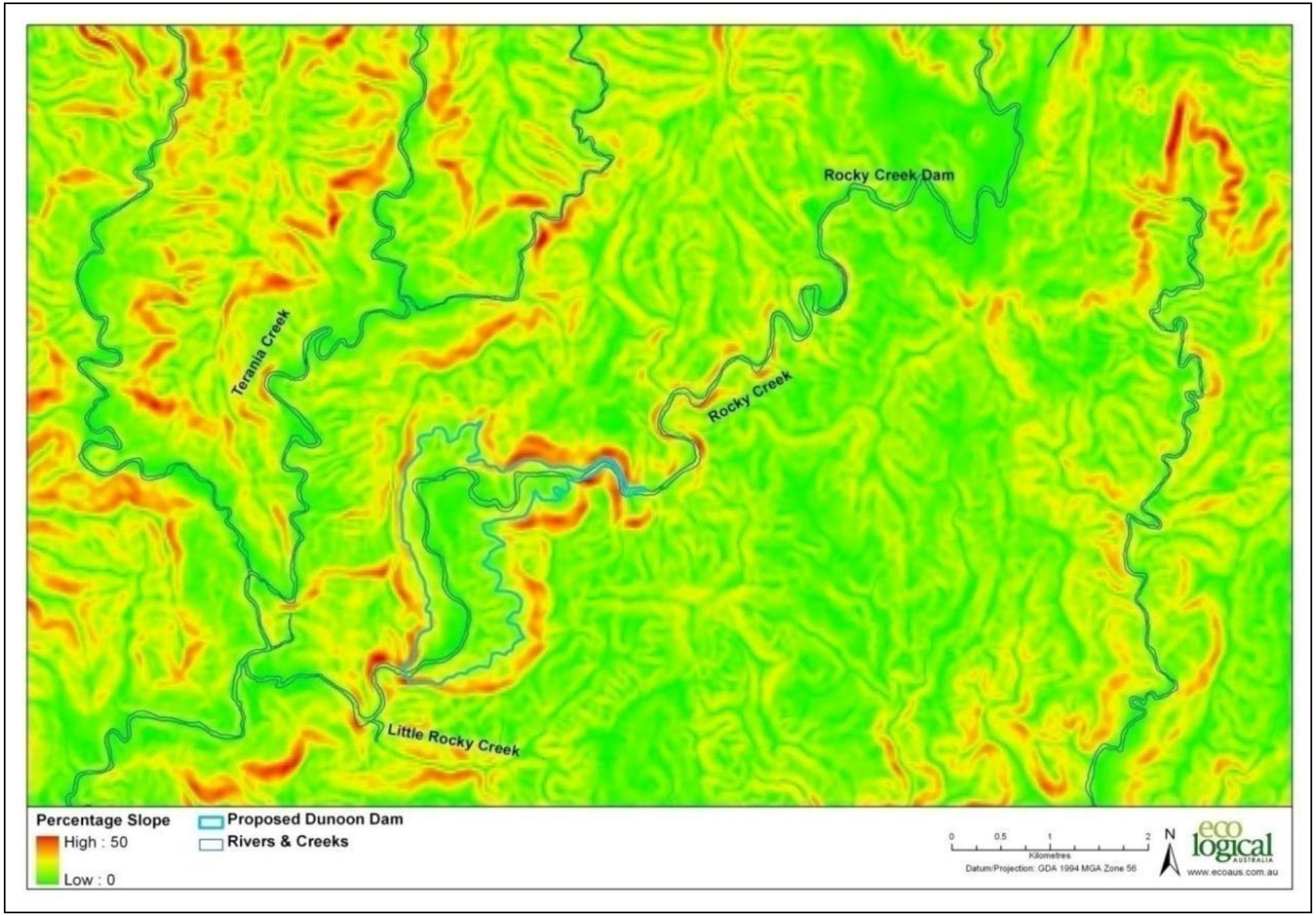


Figure 2-3: Catchment slope

2.4 GEOLOGY & SOILS

The area consists of a range of sedimentary and volcanic geological units **(Figure 2-4)** (DMR 2002) including:

- Lismore Basalt
- Kangaroo Creek Sandstone
- Walloon Coal Measures
- Nimbin Rhyolite.

The Lismore Basalt covers the largest area in the Rocky Creek catchment and has produced relatively neutral and highly fertile red loamy soils (Allen & Bainbridge 2006). Within the study area the Lismore Basalt is likely to be found in the undulating higher ground and outcropping on the valley sides.

The area within the proposed inundation area, upstream from the dam site, is underlain by the Kangaroo Creek Sandstone (quartz sandstone and conglomerate) while the upper portion is underlain by the Walloon Coal Measures (shales, sandstone and coal).

The Nimbin Rhyolite is found in the upper portions of the Rocky Creek catchment that are elevated and heavily vegetated to the north-east and east of Nimbin.

Soil landscapes were described and mapped by Morand (1994b). The soils landscapes along Rocky Creek from Rocky Creek Dam to the upstream extent of the inundation area are the Wollongbar and Rosebank units **(Figure 2-5)**. These units are characterised by Ferrosols that range in depth (up to 2 m) depending on their position in the landscape. Shallower and stonier soils typically occur on crests and upper slopes. Self-mulching dark reddish/reddish brown clay loams are generally found in the top horizons of the soil profile. These soils are susceptible to erosion, and slumping has been known to occur.

Soil landscapes within the proposed inundation area include the Terania unit along the creek line and the Calico, Coolamon and Georgica units occurring higher on the slopes. Soil types within the Terania unit are varied and typically deep (> 3 m) and well-drained, with heavier poorly-drained clays found on more recent floodplains. Soils in the Calico and Georgica unit include moderately deep (<1.5 m) Chromosols, Sodosols and Dermosols, with Vertosols occurring on the lower slopes. Alluvial soils occur along drainage lines. The soils of the Coolamon landscape are shallower (<1 m) Dermosols and Ferrosols.

Table 2-2: Soil landscape units

SLUs	SOIL DESCRIPTION	SOIL CHARACTERISTICS
Rosebank (ro)	Well drained Ferrosols ranging from shallow (<1 m) on crest margins to moderately deep to deep (1 m) on slopes The dominant soil materials include self-mulching clay loam topsoils overlying strongly structured clay subsoils	• Highly acidic, including induced acidity from agriculture • High aluminium toxicity potential • Mass movement and localised rock outcropping may occur on steep slopes
Wollongbar (wo)	Soils are predominantly deep (>2 m) and well drained Ferrosols with shallower stonier soils occurring on crests and upper slopes. Wet alluvial Krasnozems are present in drainage lines Dominant soil materials consist of self-mulching dark reddish brown clay loam/light medium clay topsoils and dark red strongly structured light medium clay subsoils	• Extremely acidic • Moderately erodible soils • High aluminium toxicity potential • Low water holding capacity • Mass movement hazard
Calico (cl)*	Moderately deep (1-1.5 m) Chromosols, and Chromosol/Sodosol intergrades overlying sandstone/shale parent material Deeper poorly drained Sodosols occur on the lower slopes and in drainage depressions with alluvial soils in drainage lines Dominant soil materials include clay loam/sandy clay loam/medium clay topsoils overlying medium clays	• Hard setting soils • Dispersible/sodic soils that are highly erodible • Low fertility • Localised water logging • Steep slope and mass excessive mass movement hazard. • High foundation hazard on slopes
Terania (te)*	Characterised by deep (>3 m), well-drained soils and Alluvial clays with poorly drained Black Vertosols occurring in recent floodplains. Deep, rapidly drained Orthic Tenosols occur in drainage channels Dominant soil materials include dark brown clay loam/sandy clay/sandy loam topsoils overlying sandy clays	• Highly erodible • Seasonally waterlogged • Stony soils of low fertility • Low available water holding capacity • High flood foundation hazard • Drainage lines susceptible to bank erosion
Georgica (ge)*	Brown and Black Dermosols ranging from shallow (0.5-1 m) to deep (>1.5 m) on crests and upper – mid slopes. Poorly drained Black vertosols occur on the lower slopes and footslopes Dominant soil materials include clay loam and friable cracking clay topsoils transitioning to brown clay/sandy clay loam and “massive” cracking clay subsoils	• Erodible soils • Surface movement potential • Localised low wet bearing strength and waterlogging • Extensive mass movement and localised rock outcropping (with moderate erosion hazard) on steep slopes • High foundation hazard on steep slopes
Coolamon (co)*	Shallow (<1 m), moderately well drained Brown Dermosols and shallow (<1 m), well drained Ferrosols Dominant soil materials include clay loam topsoils overlying basalt *in situ* parent material	• Steep slopes • Mass movement hazard • Shallow and stony soils • Waterlogging • Moderate to high erosion hazard • High foundation hazard

Morand (1994b)

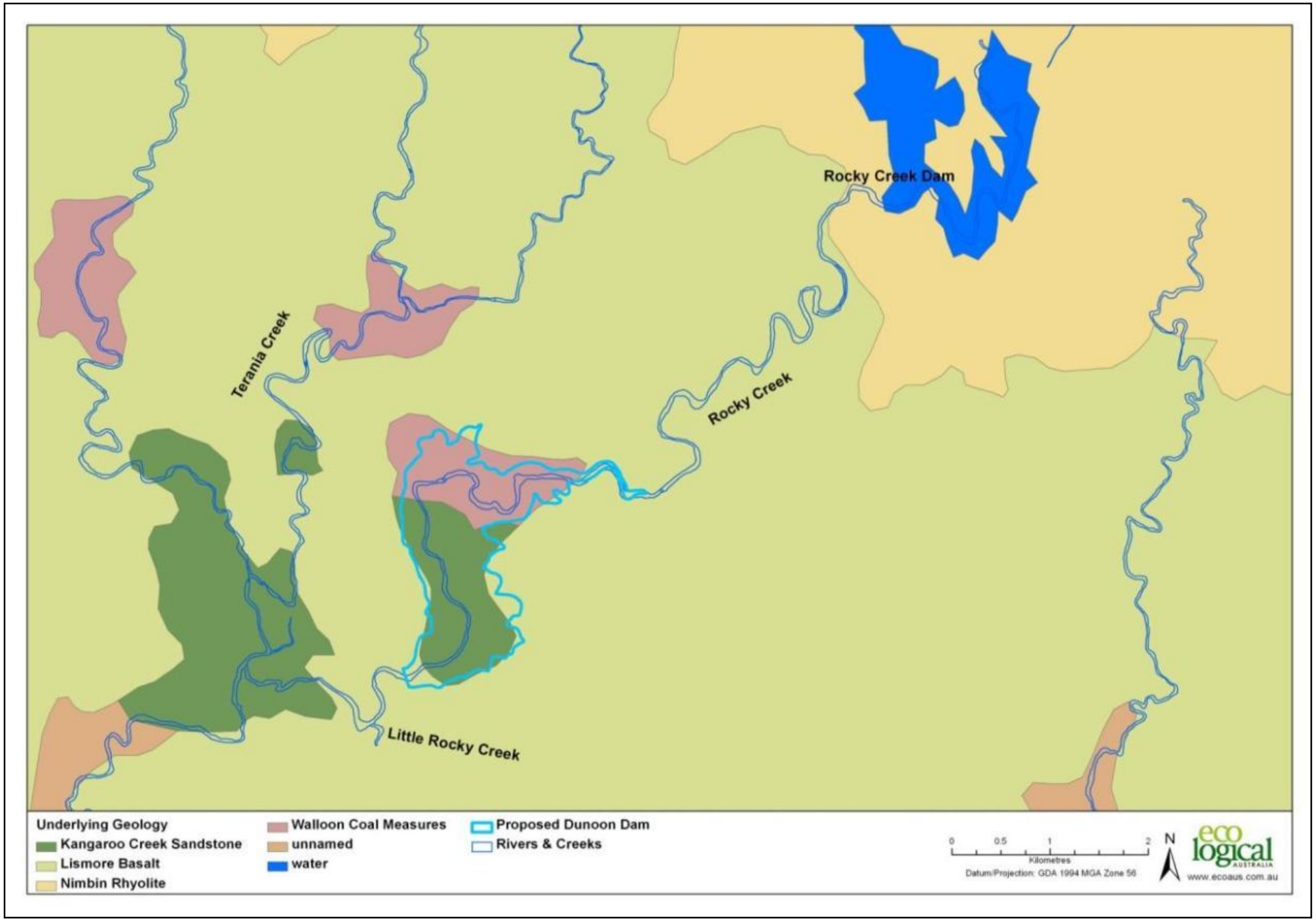


Figure 2-4: Geology (DMR 2002)

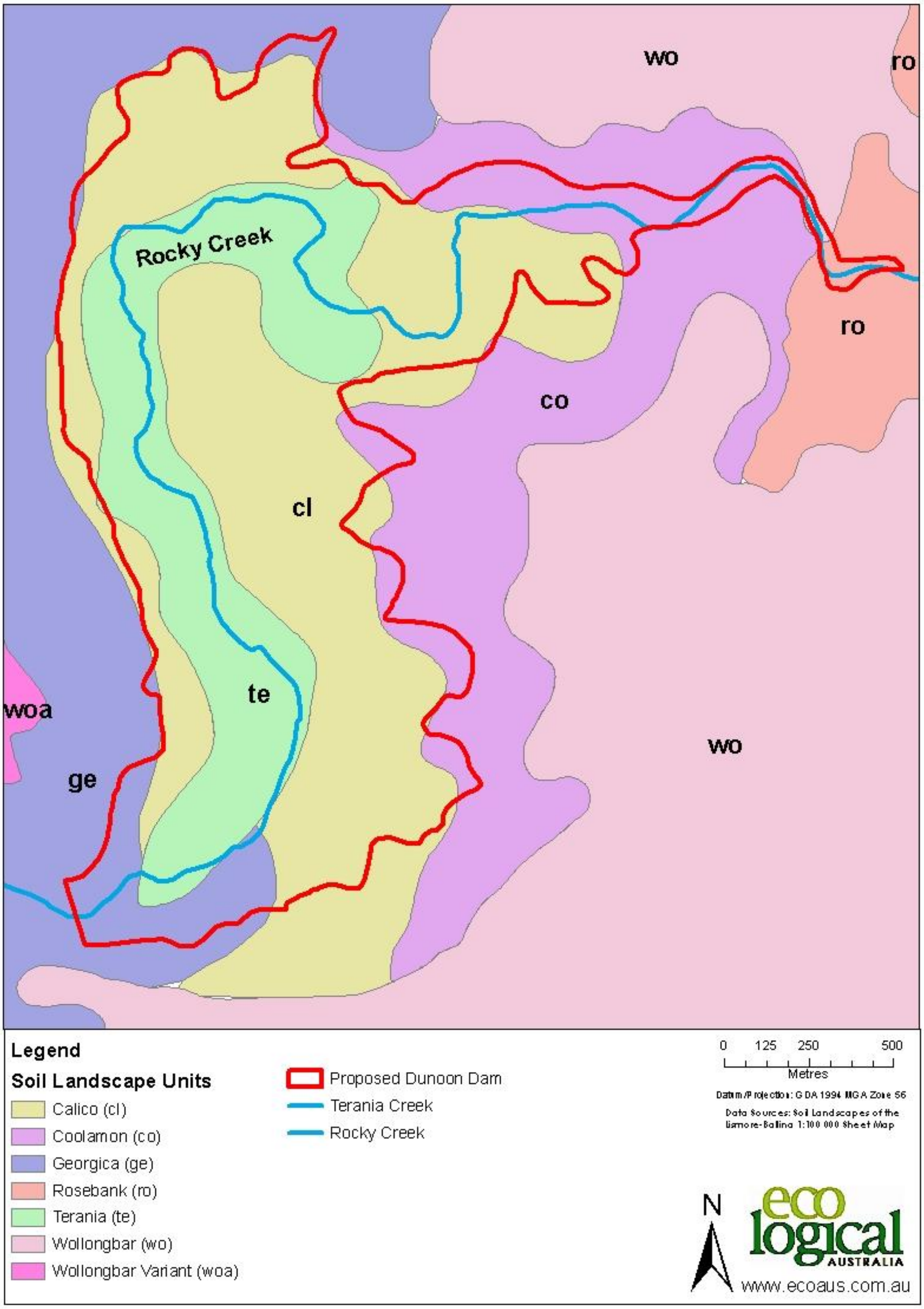


Figure 2-5: Soil landscape units (Morand 1994b)

2.5 VEGETATION

The catchment downstream of Rocky Creek Dam has largely been cleared with typical land uses including cattle grazing and horticulture and macadamia nut plantations. Bishop (1998a) estimated that up to 80% of the catchment has been cleared.

Remnants of native vegetation and other woodland/forest areas (**Figure 2-6**) are composed of:

- Northern Ranges Dry Tallowwood - tall to very tall forest with a highly mixed canopy containing Tallowwood (*Eucalyptus microcorys*) in association with one or several other species and often with a Forest Oak (*Allocasuarina torulosa*) midstorey (NPWS 1999)
- Camphor Laurel (*Cinnamomum camphora)* - Introduced scrub
- Forestry Plantations – largely relatively recent plantations (< 12 years old) of mostly hardwood plantations (various eucalypt species)
- Sub-tropical & Warm Temperate Rainforests. Basalt soils support sub-tropical rainforests with a well-developed multi layered canopy. Warm temperate rainforests are found on areas with a rhyolitic base (and typically higher in elevation). Species include Coachwood (*Ceratopetalum apetalum*), Soft Corkwood (*Caldcluvia paniculosa*), Crabapple (*Schizomeria ovata*), Yellow Carabeen (*Sloanea woollsii*), Cryptocarya spp., Booyongs (*Argyrodendron* spp.) and Rosewood (*Dysoxylum fraseranum*).

Outside of Nightcap National Park, these remnants typically occur on the steeper slopes.

2.6 AQUATIC HABITAT

Bishop (1998b) surveyed the physical habitats (pool, riffle, run, cascade, and backwater) of Rocky Creek from Rocky Creek Dam to the Terania Creek confluence. This survey identified the creek as a high-energy system with pool-riffle-run sequences, several cascades and two subterranean structures (**Table 2-3**).

Table 2-3: Physical habitat of Rocky Creek (Bishop 1998b)

HABITAT FEATURE	% OF CREEK LENGTH	FIGURE EXAMPLE
Pool	51.1	Figure 2-7
Run	30.7	Figure 2-8
Cascade	0.9	Figure 2-9
Riffle	14.8	Figure 2-10
Backwater	2.1	-
Subterranean structures	0.4	Figure 2-11

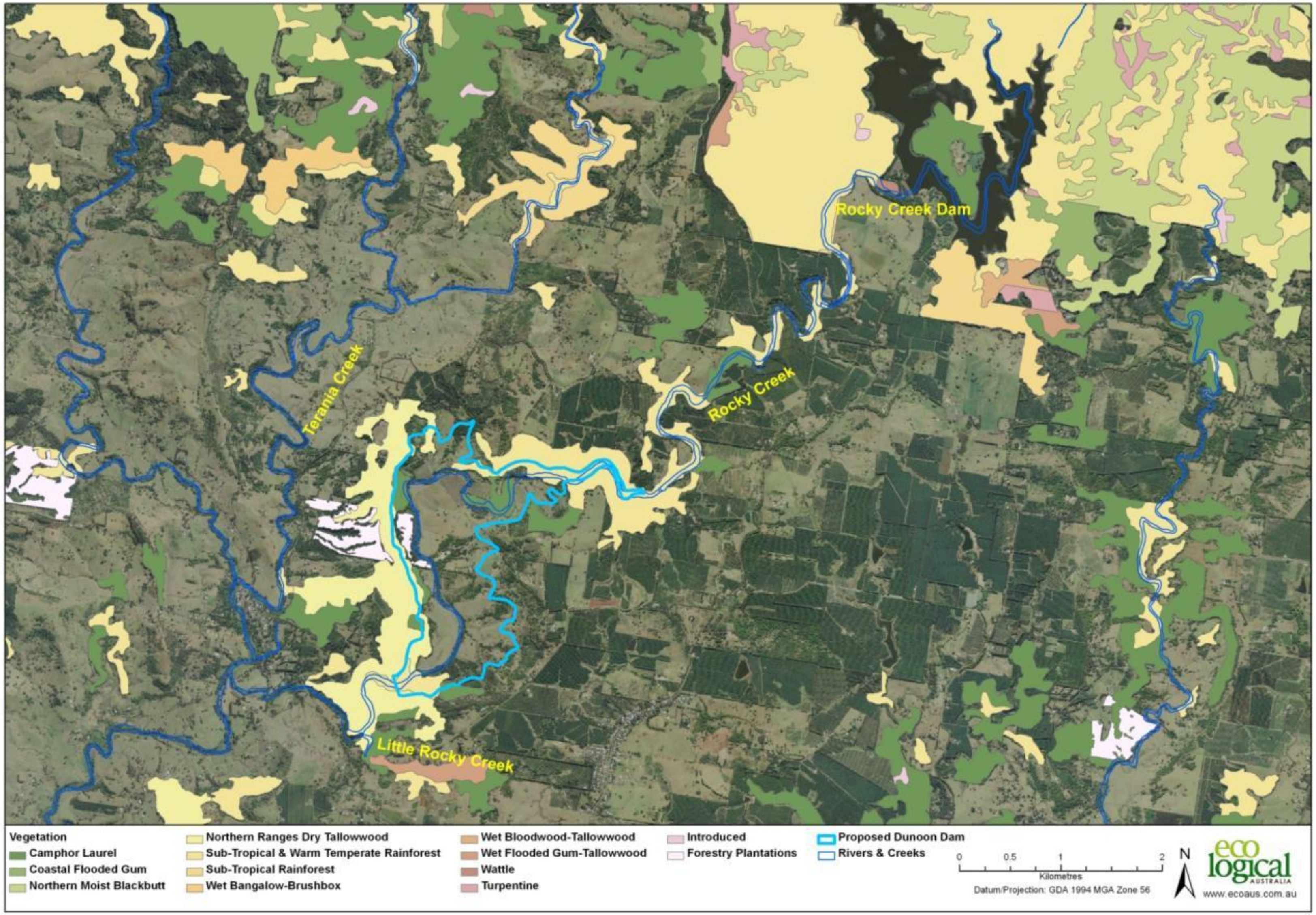


Figure 2-6: Native vegetation communities (ELA 2005)

a) Site 6 – deep pool

b) Pool downstream of dam wall

c) Pool of Terania Creek downstream of Rocky Creek confluence

d) Site 9 – long pool near Munro Road

Figure 2-7: Typical physical habitat along Rocky Creek - pools

a) Upstream of Frasers Road crossing

b) Downstream of Robertson Bridge

Figure 2-8: Typical physical habitat along Rocky Creek – runs

a) Upstream of Robertson Bridge   b) Whian Whian Falls

Figure 2-9: Typical physical habitat along Rocky Creek – cascades

a) Simes Bridge   b) Little Rocky Creek

Figure 2-10: Typical physical habitat along Rocky Creek – riffle

a) Upstream of Frasers Road crossing   b) Downstream of Robertson Bridge

Figure 2-11: Typical physical habitat along Rocky Creek – subterranean features

2.7 HYDROLOGY

2.7.1 Catchment contributions

The catchment of Rocky Creek is approximately 59 km^2 with 34 km^2 (60%) of the catchment captured by Rocky Creek Dam (Bishop 1998a). The combined catchment area of Rocky Creek Dam and the proposed Dunoon Dam is estimated to be around 51 km^2. Little Rocky Creek, the major Rocky Creek tributary below the proposed dam site, contributes 4.7 km^2 to the Rocky Creek catchment.

The Terania Creek catchment immediately upstream of the confluence with Rocky Creek is approximately 90 km^2 (Bishop 1998a). Under natural conditions the Rocky Creek system contributes around 45% of the total discharge in Terania Creek below the confluence at low flows which decreases to around 40% during high flow periods.

Below the confluence with Rocky Creek the gradient of Terania Creek decreases markedly and there are no significant inflows until the confluence with Leycester Creek. The relative flow contribution from Rocky Creek to the total Leycester Creek catchment (downstream of its confluence with Terania Creek) is between 12% (low flows) and 7% (high flows).

At the confluence of Rocky Creek and Terania Creek, flow from 23% of the combined catchment area is captured and modified via Rocky Creek Dam. The relative flow contribution by Rocky Creek at the confluence is reduced to about 22% due to Rocky Creek Dam, based on long-term modelled flows and existing operating rules. This reduction in flow contribution continues up until around the first percentile of flows **(Table 2-4)**. This proportion increases at around the 20th percentile flow. Similarly, while the flow contribution at the Leycester Creek confluence from Rocky Creek is reduce to 4% during low flows, for the 1-10th percentile flows (i.e. the higher flows) the flow contribution from Rocky Creek (with Rocky Creek Dam online) is the same as the flows under a natural system.

Table 2-4: Contributions to system flows by Rocky Creek (at site of Dunoon Dam)

	NATURAL FLOWS			NATURALISED FLOWS (ROCKY CREEK DAM ON-LINE)		
FLOW %	DUNOON DAM SITE (MLd^{-1})	TERANIA CK BELOW CONFLUENCE (MLd^{-1})	LEYCESTER CK BELOW CONFLUENCE (MLd^{-1})	DUNOON DAM SITE (MLd^{-1})	TERANIA CK BELOW CONFLUENCE (MLd^{-1})	LEYCESTER CK BELOW CONFLUENCE (MLd^{-1})
95th	8.43	18	72.4	2.61	11.8	65.5
90th	11.5	25	104	3.85	17.5	95.8
80th	17.1	39	166	6.23	27.8	155
50th	43.1	101	523	16.8	74.7	496
20th	129	310	1,647	82.7	265	1,602
10th	219	547	3,050	171	501	3,002
5th	400	1049	5,603	338	987	5,565
1st	2,112	5,150	25,184	2,063	5,069	24,726
Mean	141	345	1,736	113	317	1,707

2.7.2 Current operating rules

With a storage capacity of 14,000 ML, Rocky Creek Dam is the primary water source for Rous Water. The secure yield of Rocky Creek Dam under the existing operating rules is 9,600 ML/y. Currently there is no capacity for controlled release of water from Rocky Creek Dam and as such no existing environmental release regime from Rocky Creek Dam is in place. Records indicate that Rocky Creek Dam generally spills from February through to April. Rocky Creek Dam has a surface water licence entitlement of 12,358 ML/y (NoW 2009). This volume is 80% of the total entitlement of the water source (Terania Creek).

Rous Water's other water supply sources include Emigrant Creek Dam (secure yield 1,600ML) and the Lismore Source. The Lismore Source supplements water supply from Rocky Creek Dam and Emigrant Creek Dam under a licence that allows for upper extraction limits based on daily flow in the Wilsons River (i.e. extraction up to 25% of available flow above a nominated 'cease to flow' pump rate).

The current water management strategy (**Table 2-5**) is underpinned by hydrological modelling developed by NSW Water Solutions and estimates secure yield of water sources using the 5/10/20 rule (the industry standard for the adoption of water restrictions).

1. Restrictions should not be in place > 5% of the time
2. Restrictions should not be introduced (on average) more than once in 10 years during analysis period (which must be at least 100 years)
3. System is to supply 80% of normal demand (i.e. 20% reduction in capacity) through a repeat of worst drought on record, starting with the storage drawn down to a level at which restrictions would be applied to satisfy the 5% and 10% rules).

Table 2-5: Rous Water – Regional Water Management Strategy (Rous Water 2009)

WHEN ROCKY CREEK DAM REACHES (%)	SUPPLY STATUS	SOURCE
100	Normal Operation	Rocky Creek Dam only
95		Start Wilson's River Source and Emigrant Creek Dam
60	Dry Period Operation	Start Woodburn Bores, Convery's Lane Bore
50		
40		
30		Start Ballina Council's Plateau Bores
20	Emergency Operation	Start Wilson's River Emergency Extraction
15		
10		

It is noted that the Terania Creek Water Source is one of the unregulated water sources covered by the Richmond WSP that is classified as being of high economic significance to local communities due to their dependence on commercial water extraction (NoW 2009).

2.7.3 Overview of flows in Rocky Creek

Long-term modelled natural flows in Rocky Creek range from 8 MLd^{-1} (95^{th} percentile flow) at the site of the proposed Dunoon Dam up to a maximum flood peak of 17,280 MLd^{-1}. Flow is highly variable with the flow regime dominated by rapidly rising and falling flood events. Flows less than 43 MLd^{-1} occur more than 50% of the time and flows greater than 1,000 MLd^{-1} occur less than 2% of the time.

Under existing flow conditions (i.e. with Rocky Creek Dam operating under current flow rules), flows at the site of the proposed dam range from 3 MLd^{-1} (95th percentile flow) up to 17, 378 MLd^{-1}. Flows less than 17 MLd^{-1} occur more than 50% of the time and flows greater than 1000 MLd^{-1} occur less than 2% of the time.

Anecdotal evidence provided by Rous Water suggests that seepage from Rocky Creek Dam is relatively constant at 0.7 MLd^{-1} (Rous Water pers. comms. 21 December 2010).

The highly seasonal pattern of natural flows in Rocky Creek reflects the rainfall patterns of the catchment, with peak flows in later summer early autumn, and lowest flows in August – October.

Due to model limitations the minimum daily flows have not been reported.

The impact of Rocky Creek Dam on low flows can be seen when flow duration curves for the natural and altered system are compared (**Figure 2-12**). The magnitude of key percentiles is reduced up until around the 5th percentile flows.

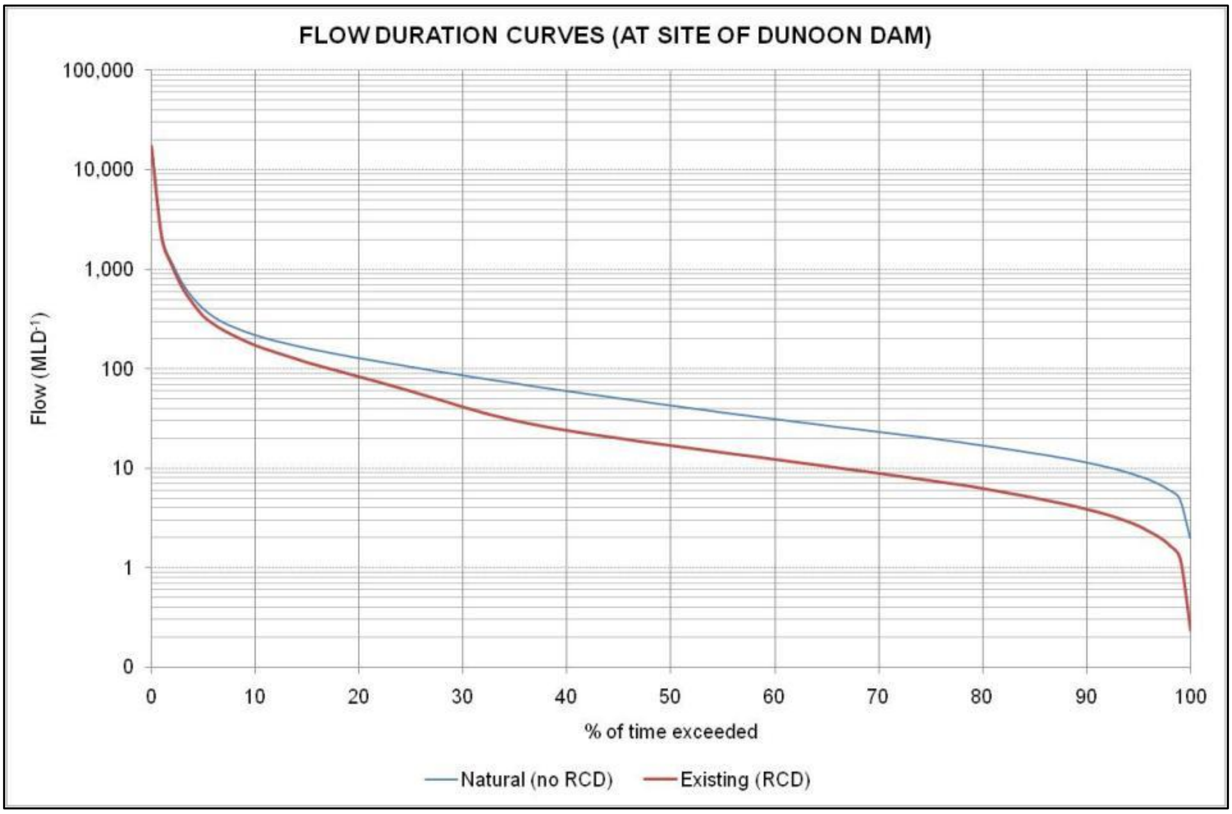


Figure 2-12: Flow duration curve (annual series) immediately downstream of Dunoon Dam site

Flows in Rocky Creek have been regulated via Rocky Creek Dam since the 1940s and the section of creek downstream of Rocky Creek Dam has formed a naturalised environment and ecology in response to the associated flow regime change.

In 1998, a preliminary assessment of the impact of Rocky Creek Dam on the downstream environment was undertaken (Bishop 1998). This study concluded that the dam has a gross hydrological impact on the system which has implications for geomorphology, water quality, aquatic and riparian vegetation, macroinvertebrates, platypus and fish fauna.

2.8 GEOMORPHOLOGY

Rocky Creek is predominantly a valley confined creek system although some floodplain features do occur. Thoms (1998) identified three functional process zones between Rocky Creek Dam and the Terania Creek confluence. These zones include two gorge zones, an armoured zone and two mobile zones (**Table 2-6**; **Figure 2-12**).

The proposed dam wall will be located in the gorge/constrained zone located upstream of Robertson Bridge.

Table 2-6: Function process zones in Rocky Creek (Rocky Creek Dam to Terania Creek confluence)

FUNCTION PROCESS ZONES	LOCATION	KEY CHARACTERISTICS
Gorge / constrained zone	1. Immediately downstream of Whian Whian Falls for approximately 1.5km 2. Lower gorge upstream of Roberston Bridge	- High energy zones - Steep bed slopes - Bedrock, large boulder/cobbles and scour pools dominate - Sediment source zone
Armoured zone	Rocky Creek Dam to Simes Bridge	- High energy zone - High bed slopes - Highly armoured bed sediments (cobble and gravel) - Sediment source area - Some floodplain formations
Mobile zone	1. 2km downstream of Simes Bridge to 5km downstream of Frasers Road 2. Robertson Bridge to Terania confluence	- Relatively mobile bed sediment - Large sediment (silt and sand) storage areas within the channel - Relatively active channel - Floodplain features

Source: Thoms 1998

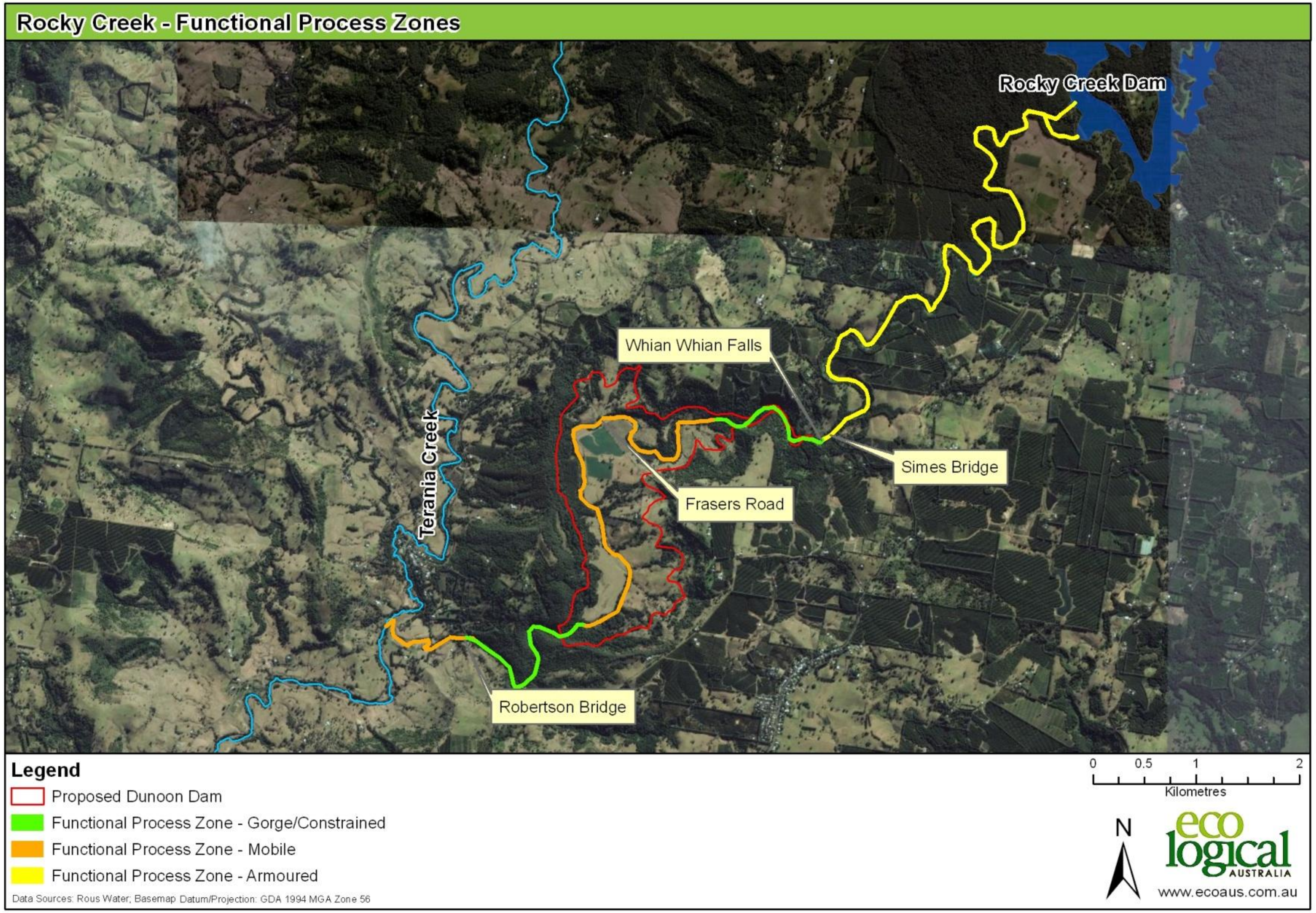


Figure 2-13: Rocky Creek functional process zones

3 Field Site Selection

Field survey sites were selected for a range of assessments based on information obtained from literature review, GIS analysis and extensive field reconnaissance. These sites were selected to provide in-field data regarding geomorphology, water quality and aquatic ecology prior to any dam construction and to provide potential monitoring sites for future evaluation if required.

Sites were selected above, within and below the reaches of Rocky Creek to be inundated from Dunoon Dam to identify existing impacts from Rocky Creek Dam, to provide reference or control conditions and to assess potential impacts resulting from an altered flow regime (**Table 3-1**; **Table 3-2; Figure 3-1**). Reaches were selected to cover the range of typical habitat features (pool, riffle, run) and were used for a variety of assessments including: geomorphic assessment and modelling; habitat/flow/inundation relationships; water quality; aquatic ecology and fish barrier assessment. Detailed descriptions of the field survey sites are provided in **Chapter 5**.

Table 3-1: Summary field survey sites selected for environmental flows assessment

SITE NO.	LOCATION	JUSTIFICATION	SURVEY PURPOSE
1	Rocky Creek: upstream of proposed Dunoon Dam inundation area	Existing impact condition; direct impacts of Rocky Creek Dam and potential impacts of changes to Rocky Creek Dam operations	Aquatic ecology Water quality
2	Rocky Creek: within proposed inundation area	Inundation impacts on aquatic flora, fauna and landscape	Aquatic ecology Water quality
3	Rocky Creek: downstream of proposed dam wall	Future impacts from the proposed dam condition: reach of likely largest direct impacts of altered flow regime from proposed dam	Aquatic ecology Water quality Geomorphology
4	Terania Creek: upstream of Rocky Creek confluence	Terania Creek control condition: no direct impacts from Rocky Creek Dam and the proposed dam	Aquatic ecology Water quality
5	Terania Creek: downstream of Rocky Creek confluence	Terania Creek impacted condition: direct impacts from Rocky Creek Dam and the proposed dam	Aquatic ecology Water quality Geomorphology
6	Rocky Creek: deep pool downstream of proposed dam wall	Local impacts on water quality in key habitat feature	Water quality Aquatic ecology (fish)
7	Rocky Creek: downstream of proposed dam wall	Future impacts from the proposed dam condition	Geomorphology Habitat/inundation relationships
8	Terania Creek; deep pool downstream of Rocky Creek confluence	Impacts on water quality in key downstream habitat feature	Water quality
9	Rocky Creek: long pool in proposed inundation area	Inundation impacts on aquatic flora	Aquatic ecology (fish)

Table 3-2: Field survey site coordinates

SITE NO.	LOCATION	COORDINATES (GDA94 ZONE 55)	
		UPSTREAM	DOWNSTREAM
1	Rocky Creek: upstream of proposed Dunoon Dam inundation area	E 532746 N 6831812	E 532835 N 6831733
2	Rocky Creek: within proposed inundation area	E 529199 N 6829529	E 529100 N 6829517
3	Rocky Creek: downstream of proposed dam wall	E 528346 N 6826987	E 528261 N 6826928
4	Terania Creek: upstream of Rocky Creek confluence	E 527135 N 6828016	E 527178 N 6827932
5	Terania Creek: downstream of Rocky Creek confluence	E 526971 N 6826882	E 526995 N 6826793
6	Rocky Creek: deep pool downstream of proposed dam wall	E 528206 N 6826901	
7	Rocky Creek: downstream of proposed dam wall	E 527967 N 6827257	E 527419 N 6827306
8	Terania Creek: deep pool downstream of Rocky Creek confluence	E 525129 N 6821504	
9	Rocky Creek: long pool in proposed inundation area	E 529288 N 6827912	E 528874 N 6827505

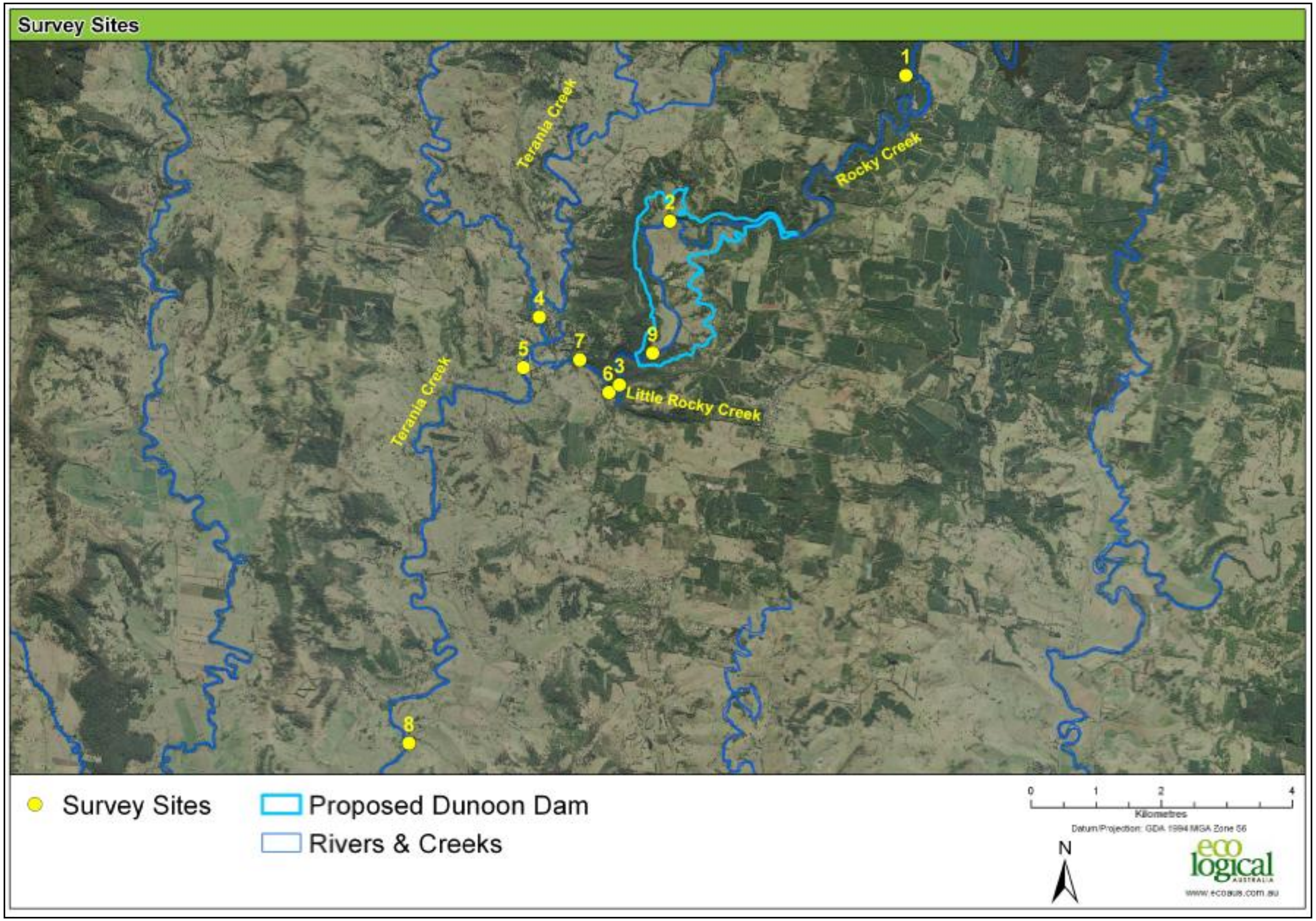


Figure 3-1: Field survey sites selected for environmental flows assessments

4 Hydrology

4.1 INTRODUCTION & AIMS

Stream character including physical form and habitat potential is largely determined by the hydrological regime. Environmental flows generally try to mimic aspects of the natural flow regime, demanding a prior understanding of the natural flow regime. This chapter aims to:

- Characterise the natural flow pattern of the Rocky Creek system and identify critical flow components of the natural flow regime
- Characterise the existing Rocky Creek flow system and identify hydrological impacts of Rocky Creek Dam on the natural flow regime
- Consider flow scenarios to determine if critical flow components and objectives are met, to ultimately establish the quantity, timing and release requirements of flows to maintain or enhance the environmental values downstream of Dunoon Dam.

4.2 METHODS

4.2.1 Literature review

A review of key literature was undertaken to assess earlier studies. Bishop (1998a), which specifically examined the effect of Rocky Creek Dam on Rocky Creek was examined in detail.

4.2.2 Hydrological analysis

IQQM Modelling

As no gauged flow data exist for Rocky Creek, modelled flows were produced for the system using an Integrated Quantity and Quality Model (IQQM) developed by the then Department of Land and Water Conservation. The IQQM is a generic simulation model for catchment scale water management planning (Simons et al. 1996) that uses a series of nodes and links to simulate a river system. The IQQM simulated different management scenarios to provide flow conditions with a daily time step.

In 2002, the then Department of Land and Water Conservation developed an IQQM for the Wilsons River and Emigrant Creek components of the Richmond River system for Rous Water. Modelling undertaken for this project was based on this previously developed IQQM (NSW Department of Natural Resources 2007). It is noted that the Wilsons River IQQM does not simulate the impacts of the tidal influence in the Wilsons River below Lismore.

Rainfall data utilised in the model were sourced from a number of Bureau of Meteorology (BoM) daily-read rainfall gauges and from the SILO database (DIPNR 2004) and interpolated to produce a long-term rainfall data set (1892-2003). Rainfall data were required to generate catchment inflows which were produced using the Sacramento rainfall-runoff model. All flow outputs were derived using rainfall-runoff modules within IQQM. Long-term evaporation data were generated using the evaporation generation module using short-term evaporation and rainfall data at the BoM Alstonville station and long-term rainfall data at Lismore.

Two scenarios were developed for the initial hydrological analysis to consider a “natural” flow regime (i.e. modelled unregulated flow with no Rocky Creek Dam) and the current flow regime of the system (with Rocky Creek Dam operating as per operating rules, including extraction, outlined in **Section 2.7.2**).

While the IQQM can predict average flows reliably it has been found that modelled data are not as reliable for the prediction of extreme flows (i.e. very small or very large flows). Hence minimum and maximum flows are not reported.

Discharge Analysis

Daily time step flow data were simulated to represent the flows at the site of the proposed Dunoon Dam wall.

Hydrographs were created by plotting simulated flow data for a number of years to examine the variability of the system, then more closely examined by creating typical hydrographs over a 10 year, two year, one year and four month period. These hydrographs were used to identify key flow components to help determine environmental water requirements.

Mean daily discharge was calculated by dividing the sum of the daily records by the number of records for each dataset. Statistical analysis of daily flows was also undertaken by ranking the daily flows and determining the percentage of time each was equalled or exceeded. These data were plotted on semi-log axes to generate flow duration curves.

Flood-frequency analysis was undertaken on the 112 years of data. More than 100 years of data allows the estimate of the 50 and 100 year floods within an error of about 10% (Gordon et al 2004). Given the ‘flashy’ periods of flow where flow rate exceeds the median, the annual exceedence series was used to determine the flood-frequency analysis. The 112 highest peaks occurring within the entire data set (of 112 years) were selected (i.e. irrespective of when they occurred) and ranked in decreasing order. Data were Log transformed and used to calculate the Log Pearson III distribution (Pilgrim & Doran 1987). The annual exceedence probability (AEP) for each discharge was calculated using Cunnane’s (1979) distribution free formula (**Figure 4-1**). The fit of the data was checked by plotted the individual floods using log-normal probability axes together with the Log Pearson III distribution curve.

$$P(m) = \frac{m - 0.4}{N + 0.2}$$

P(m)	=	Annual exceedence probability of a flood of rank m
m	=	Rank of flood in the series
N	=	number of years on record

Figure 4-1: Cunnane’s distribution free formula

Rates of rise and fall were calculated by expressing daily flow as a proportion of the previous day’s flow and separating rates of rise (i.e. where proportion exceeds 1) and rates of fall (i.e. where proportion is less than 1). Key percentiles were then calculated for both rates of rise and fall (Earth Tech 2006; Wealands et al. 2007).

Flow components of the naturalised flow regime at the site of Dunoon Dam were described, based on the magnitude, duration, frequency and timing of flows (SKM 2002). Annual hydrographs were examined for a number of scenarios including an average rainfall year, above-average and below-average rainfall. The years 1994-1996 were also considered as they provided hydrographs reflective of normal rainfall patterns (summer/early autumn dominance and a drier period in late winter/early spring).

4.3 RESULTS

Daily flow data were extracted from the IQQM for two scenarios to consider the "natural" (i.e. unregulated) flow regime and the current flow regime of the system with Rocky Creek Dam online using the current system flow rules.

Long-term modelled natural flows in Rocky Creek range from 8 MLd^{-1} (95th percentile flow) at the site of the proposed Dunoon Dam to flows greater than 2112 MLd^{-1} (1st percentile flow). Flows smaller than 43 MLd^{-1} occur more than 50% of the time and the mean daily flow was 141 MLd^{-1}.

Under existing flow conditions (i.e. with Rocky Creek Dam operating under current flow rules), flows at the site of the proposed dam range from 3 MLd^{-1} (95th percentile flow) at the site of the proposed Dunoon Dam to flows greater than 2000 MLd^{-1} (1st percentile flow). Flows less than 17 MLd^{-1} occur more than 50% of the time and the mean daily flow was 131 MLd^{-1}.

Anecdotal evidence provided by Rous Water suggests that seepage from Rocky Creek Dam during dry weather is relatively constant at 0.7 MLd^{-1} (Rous Water pers. comms. 21 December 2010).

Table 4-1: Daily flow data at the proposed site of Dunoon Dam

STATISTIC	NATURAL[1] (MLd^{-1})	EXISTING[2] (MLd^{-1})
95th percentile exceedence	8.43	2.61
90th percentile exceedence	11.5	3.85
80th percentile exceedence	17.1	6.23
50th percentile exceedence	43.1	16.84
20th percentile exceedence	129	82.8
10th percentile exceedence	219	172
5th percentile exceedence	400	338
4th percentile exceedence	512	453
3rd percentile exceedence	713	646
2nd percentile exceedence	1137	1075
1st percentile exceedence	2112	2063
Mean	141	113

[1] natural flow (i.e. unregulated)

[2] Existing flow (i.e. Rocky Creek Dam online)

Flow duration curves plot the percentage of time a flow of a certain magnitude has been exceeded during a period of flow record (in this instance 112 years of modelled flow data). The lowest flow is plotted at the right (i.e. flow is exceeded by 100% of other flows in the record) and the largest flow is plotted at the left (i.e. flow was exceed by 0% of the other flows).

The impact of Rocky Creek Dam on low end flows can be seen when flow duration curves for the natural and altered system are compared (**Figure 4-2**). The magnitude of key percentiles is reduced to approximately the 3rd percentile flow level.

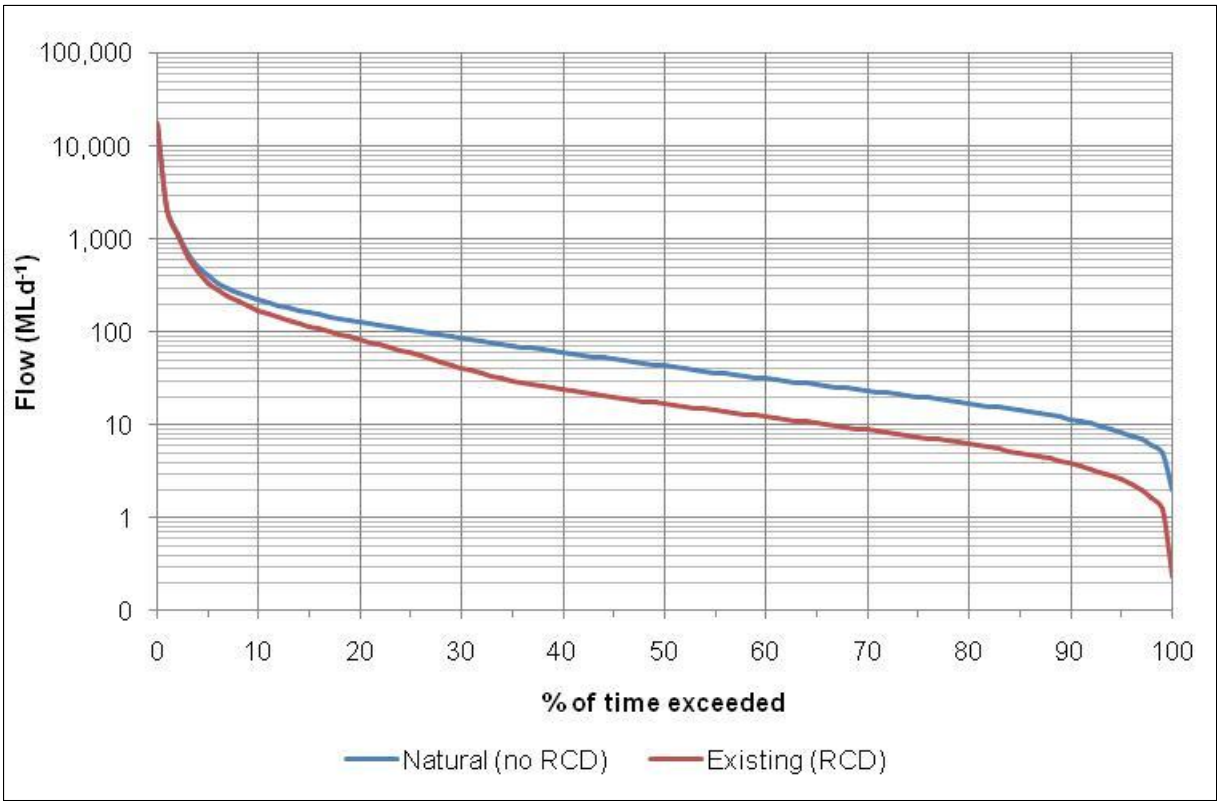


Figure 4-2: Flow duration curve (annual series) at the site of the proposed Dunoon Dam

The highly seasonal pattern of natural flows in Rocky Creek reflects the rainfall patterns of the catchment, with peak flows in later summer early autumn, and lowest flows in August – October. Hydrographs of the system show highly variable flows with fast moving flood peaks (**Figure 4-3**).

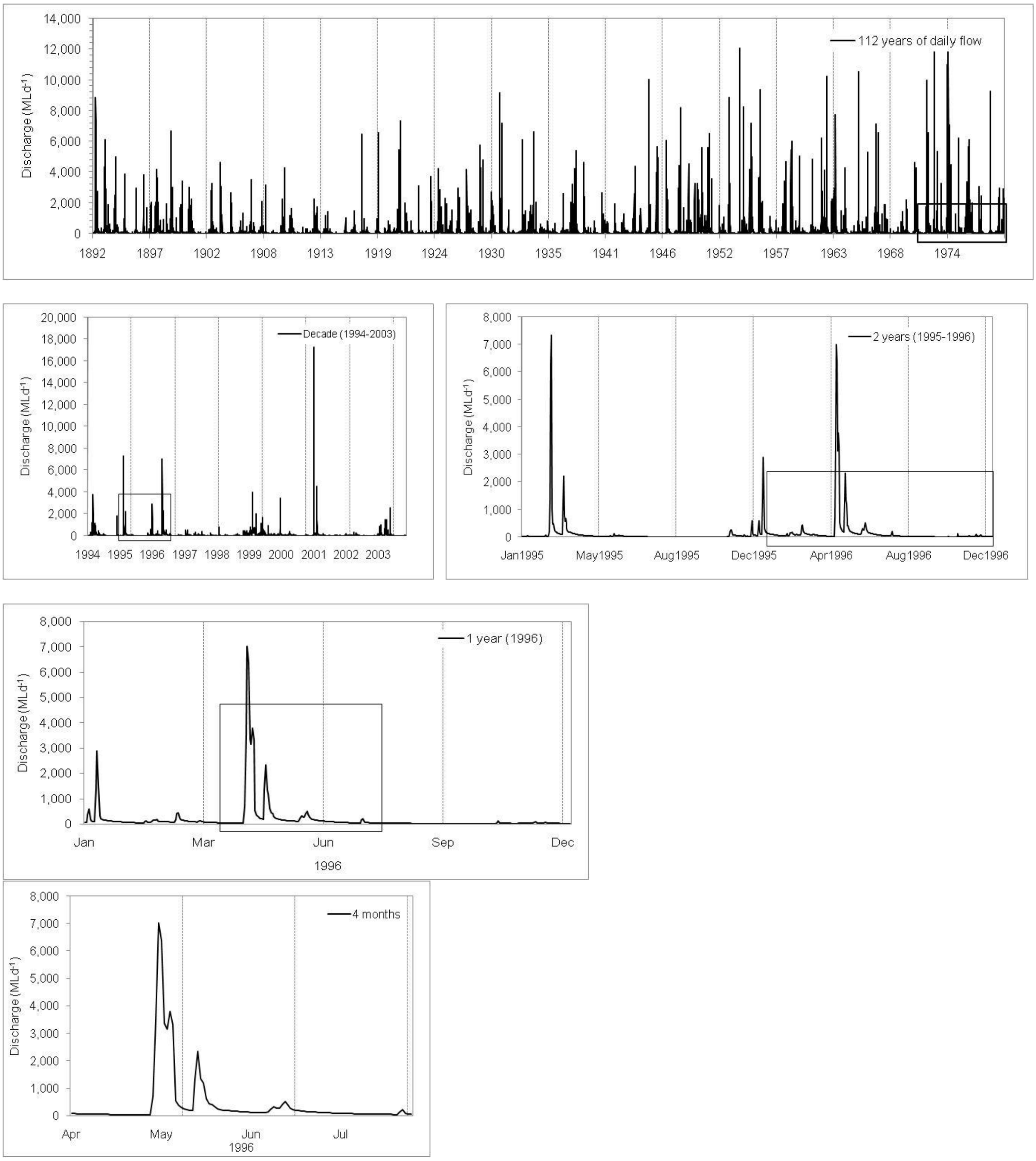


Figure 4-3: Historic daily flows at the site of the proposed Dunoon Dam (with Rocky Creek Dam online)

Flow components can assist in providing a conceptual link between hydrology and ecosystem processes (SKM 2002) with the timing, duration, frequency and magnitude driving ecosystem and channel forming processes. Typical flow components of larger river systems can include cease to flow, low flow, freshes, high (in-channel) flows, bankfull flows and overbank flows. The confined valley/gorge system of Rocky Creek (particularly immediately downstream of the proposed dam site) means that there is no clearly defined bankfull flow. Consequently flow components cannot be broken down into the 'standard' components.

IQQM modelling indicated that there were no periods of cease-to-flow in Rocky Creek at the site of the Dunoon Dam for the natural system. A minimum flow of 2 MLd^{-1} was modelled. Flow exceeded 6 MLd^{-1} for more than 98 percent of the time and flows within this range were defined as base flows. Base flows were most likely in spring/summer, on average occurring at least once a year and could last for months at a time. Partial drying of the channel and associated habitat and substrate occurs during base flows.

Low flow is generally described as the flow that provides a continuous flow through the channel for a particular reach (SKM 2002) and may be limited to a narrow area of the channel. These flows support a range of functions, including linking habitats, sustaining aquatic habitat and recruiting of native fish. A low flow event was defined as an event that last for five or more days where daily flow was between 6 and 30 ML. Substantial periods (weeks to months) of low flow were common during August-November (corresponding with months of low rainfall).

A moderate flow range of between 30 to 200 MLd^{-1} was defined. Several periods of flows of moderate magnitude occurred throughout a year, particularly during autumn and winter. Flows in this range typically lasted for periods of weeks.

High flows are defined by the persistent increase in the seasonal base flow (SKM 2002). Typically, high flows remain ‘in-channel’ covering the stream bed and effectively connecting most habitats within the main channel. Due to the absence of a well defined ‘bankfull flow’, flows greater than 200 MLd^{-1} have been defined as a high flow or flooding event. Freshes or pulses of flow between 200-400 MLd^{-1} occur most commonly over summer and autumn and can last from a single day to weeks. Floods greater than 400 MLd^{-1} can occur at any time of the year but are more likely in summer/autumn.

The magnitude, duration, frequency and timing of key flow components that make up a flow regime all contribute to the ecological and geomorphic processes that maintain a healthy and functioning natural system. The flow components summarised in the table below provide a simplified understanding of the highly variable natural flow regime of Rocky Creek (**Table 4-2**).

Table 4-2: Flow Components of the natural Rocky Creek system

FLOW COMPONENT	DESCRIPTION	TIMING	FREQUENCY	DURATION	"NATURAL" % EXCEED	"NATURAL" FLOW (MLd^{-1})	KEY FUNCTION (AS PER SKM 2002)
Base flow	Partial drying of channel	Spring Summer	At least once annually	Months	>98 %	2 - 6	Drying of habitat and substrate Facilitates decomposition and processing of organic matter
Low flow	Minimum (continuous) flow in channel	Late Winter Early Summer	Several annually (~3)	Weeks to months	60 - 98 %	6 - 30	Connects in-stream habitats System maintenance
Moderate Flow	Prolonged period of higher flow	Summer Autumn Winter	Can be several annually (~10)	Weeks	60 - 12 %	30 - 200	Biological triggers Physico-chemical maintenance and changes
High Flow / Flood	Flashy periods of flow that exceed the median	Summer Autumn Early Winter	Several annually (~13)	Single day to a week	12 - 5 %	200 - 400	Channel forming processes
		Summer Autumn	Several annually (~5)	Single day to several days	< 5 %	> 400	

As identified by Bishop (1998) flow characteristics influence both the physical and chemical characteristics of the ecosystem. Alterations to low-end and medium- to high-end flows drive changes in creek parameters such as water quality, vegetation, connectivity, depth of runs and riffles and substrate, which in turn influence environmental assets such as fish, platypus and riparian fauna via a number of complex pathways.

Channel forming geomorphic processes predominantly occur during the high magnitude but infrequent events. The frequency of these high flow or ‘flood’ events is determined via flood frequency analysis using an annual exceedence series. Plotting the annual flood frequency analysis shows the AEP against the flood magnitude. AEPs and average flood recurrence intervals (ARIs) are shown in **Table 4-3**. It is noted that flood frequency analysis is ideally completed on peak instantaneous daily discharge rather than mean daily discharge. The latter was used for this assessment using the daily time-step series provided by the IQQM.

Table 4-3: Annual exceedence probabilities for flood events on Rocky Creek

AEP	ARI	NATURAL FLOOD[1] (MLd^{-1})	EXISTING FLOOD[2] (MLd^{-1})
99 %	1.01	4251	4337
95 %	1.055	4663	4752
90 %	1.11	4951	5042
80 %	1.25	5381	5475
50 %	2	6537	6637
20 %	5	8354	8458
10 %	10	9701	9805
5 %	20	11106	11208
2 %	50	13099	13195
1 %	100	14736	14824
45 %	2.22	6680	6780

[1] Natural flow (i.e. unregulated)

[2] Existing flow (i.e. Rocky Creek Dam online)

The mean annual flood (i.e. the mean of the annual maximum series) can be estimated from the 45% AEP (or 2.22 ARI). The mean annual flood of the natural system was calculated to be 6680 MLd^{-1} and 6780 MLd^{-1} for the existing flow regime.

In addition to flow components, rates of rise and fall are also important considerations for ecological and geomorphic reasons. Unnaturally rapid fluctuations in flow can strand biota and cause bank slump from rapid wetting/drying events.

The maximum rate of rise was selected as the 90th percentile value of all recorded rates of rise for the natural system. The maximum rate of fall was selected as the 10th percentile value of all recorded rates of fall for the natural system (the rate of fall being a more critical value) (Earth Tech 2006; Wealands et al. 2007). The rates of rise and fall can be expressed as a proportion of flow of the previous day (i.e. rate of rise >1.0) (**Table 4-4**). The rates of rise and fall for the existing system have also been calculated for comparative purposes.

Table 4-4: Maximum rates of rise and fall (expressed as a proportion of flow of the previous day)

	NATURAL[1]		EXISTING[2]	
	RISE	FALL	RISE	FALL
Mean	1.97	0.92	2.40	0.90
SD	4.26	0.13	7.15	0.15
10th %	-	0.82	-	0.74
90th %	2.72	-	3.40	-

[1] natural flow (i.e. unregulated)

[2] Existing flow (i.e. Rocky Creek Dam online)

Bishop (1998) also identified the duration of flows as being an important consideration for environmental flows. A summary of duration of key flows (on an annual basis) is provided in **Table 4-5**, comparing duration of certain flow heights for natural and the existing (altered) flow regime in Rocky Creek. One of impacts of Rocky Creek Dam has been the increase in the number of days of flows less than around 100 MLd^{-1} occurred each year. The greatest changes to flow duration are for flows between 5 MLd^{-1} and around 150 MLd^{-1} where the average time of these flow events increases by more than five percent.

Table 4-5: Duration of time flow threshold is achieved

FLOW THRESHOLD (MLd^{-1})	DAYS/YR THAT FLOW THRESHOLD ACHIEVED*		
	NATURAL[1]	EXISTING[2]	SHIFT IN DURATION (i.e. BETWEEN EXISTING AND NATURAL)
≤ 1	0	2	2
≤ 5	4	55	51
≤ 10	27	123	96
≤ 15	60	170	110
≤ 20	90	201	111
≤ 50	199	265	66
≤ 100	270	303	33
≤ 200	324	334	10
≤ 250	334	341	6
≤ 300	341	345	4
≤ 400	347	349	2

FLOW THRESHOLD (MLd^{-1})	DAYS/YR THAT FLOW THRESHOLD ACHIEVED*		
	NATURAL[1]	EXISTING[2]	SHIFT IN DURATION (i.e. BETWEEN EXISTING AND NATURAL)
≤ 500	350	352	1
≤ 1000	357	358	0
≤ 2000	361	361	0
≤ 10000	365	365	

* Averaged across 112 years of modelled data

[1] natural flow (i.e. unregulated)

[2] Existing flow (i.e. Rocky Creek Dam online)

4.4 HYDROLOGY FLOW REQUIREMENTS

Both the natural and existing Rocky Creek flow regimes are highly variable with extended periods of low flows and floods occurring at any time of the year. Rocky Creek Dam has reduced flows in the base flow to moderate flow range but larger flood events are largely unaffected as they tend to fill and spill the dam.

Using the modelled natural data the key flow components of base flows, low flows and moderate flows have been identified as flows between 2-200 MLd^{-1} (**Table 4-2**). Flows in these ranges are responsible for key ecological, water quality and channel forming functions.

5 Geomorphology

5.1 INTRODUCTION & AIMS

The physical nature of a stream system helps to determine environmental character and habitat complexity. Key elements such as channel planform, bank and bed sediment character and the presence of floodplain features assist in the determination of critical flow stages required to maintain the channel character and inundate key features.

This geomorphic assessment was undertaken to support the overall environmental flow assessment process. The specific aims of this assessment were to:

- Identify key geomorphic features, including:
  - Sediment and substrate type and mobility
  - Presence and form of existing habitat features (e.g. cascades, pools, riffles, floodplains)
  - Channel shape and dimensions
  - Presence of woody debris and aquatic vegetation
- Identify geomorphic aspects and functions (including flow thresholds) to maintain (or improve) channel form and processes which maintain the environmental values of Rocky Creek downstream of Dunoon Dam.

Results of this geomorphic study complement and have implications for the hydrology, water quality and aquatic ecology requirements of the creek system.

5.2 METHODS

5.2.1 Catchment scale assessment

Existing maps, data and reports were reviewed and analysed to determine the character of Rocky Creek and surrounding areas. Mapping including geology, topography (at two scales) and soils were reviewed to assist in describing the overall creek system. Thoms (1998) included a detailed discussion of the geomorphic nature of Rocky Creek downstream of Rocky Creek Dam. These data were used to define distinct geomorphic zones along Rocky Creek and assist with field site selection.

5.2.2 Field survey

The geomorphic character of field sites 1 to 5 and site 7 (**Figure 3-1**) was described in detail using a suite of field measurements. At each site an approximate 100 m reach was characterised, the reach length was selected to cover greater than ten (10) times the channel width and contain a range of physical habitat features (pool/riffle/run or cascade). Prior to collection of field data each reach was traversed to gain understanding of the variability within each reach. Follow this initial traverse a suite of standard parameters were recorded at each site:

- Channel cross-section to include:
  - Bank top level
  - Channel width and depth
  - Bank angle and bank form
  - Water depth (at time of survey)
  - Estimate of ‘bankfull” level

- Channel bed slope
- Reach morphology and habitat composition
- Discharge (at time of survey)
- Field texture of bank material
- Presence of bank erosion
- Presence of secondary bed material (including presence and description of sediment slugs)
- Roughness estimates (Manning's n)
- Large woody debris (pieces > 0.1m diameter and >1m length)
- In-channel and bank vegetation structure and abundance.

Direct measurement of bed material particle size was undertaken using the "pebble count" method developed by Wolman (see Gordon et al. 2004). The crest or cascade of each reach was waded in a zigzag pattern. At a consistent interval (i.e. each pace), a rod was placed next to the toe to locate the rock to be measured. The b-axis of 100 bed material samples was measured per reach. Where bedrock was encountered it was noted.

Sites 6, 8 and 9 were briefly described in the field in terms of geomorphic and riparian characteristics.

5.2.3 **Hydraulic modelling**

Three key sites (Sites 3, 5 and 7) were selected for one-dimensional hydraulic modelling. At these sites detailed cross-sectional surveys were undertaken at 25 m intervals or less along the 100 m reach. Where possible, cross-sections were captured using a dumpy level; alternatively a rangefinder was used. The centreline of the reach was also surveyed including a distance of 100 m upstream and downstream of the reach (or until the nearest significant hydraulic control e.g. pool, cascade etc) to improve the model estimates.

Key channel features were identified during the cross section survey, including water surface and an estimate of the high flow water mark. As noted previously, the predominantly confined valley/gorge system of Rocky Creek means there is generally no clearly defined 'bankfull' stage. An estimate was made of the 'high flow' water level based on in-field observations of lichen limits and vegetation (as described in Gordon et al. 2004).

The cross sectional surveys were used to create one dimensional hydraulic models using HEC-RAS (U.S. Army Corps of Engineers 2010) for reaches at Sites 3, 5 and 7. A minimum of five cross-sections were used to define the modelled reach for each site.

Key flow levels were simulated to estimate data to calculate geomorphic thresholds, including:

- Energy slope (S)
- Top width of flow
- Average velocity
- Water surface level
- Mean shear stress.

Given the limited number of cross sections developed for each site, data from the downstream extent of each reach only was used in any analysis.

5.2.4 **Geomorphic processes**

Fluvial geomorphology examines the relationship between river channel forms and processes (i.e. how landforms are created, maintained and altered by moving water) (Gordon et al. 2004; Charlton 2007). The erosion, transport and deposition of sediments are key aspects of river geomorphology, driving the shaping and forming of channels. A balance exists between the erosive capacity of flow and the ability of the channel bed and bank to resist erosion with flow discharge (i.e. the volume of flow passing through a point at a given time) influencing the erosive power of flow.

The processes of sediment erosion, transport and deposition are influenced by the volume of sediment (both upstream and locally eroded material) and the size of the sediment. Fine materials such as clays, silts and fine sands are generally carried as suspended load while coarse sediments are entrained as bedload. The estimate of sediment entrainment is usually based on a 'critical' state or threshold.

Key geomorphic process discharge thresholds considered during this assessment include:

- Coarse bed material mobilisation / critical discharge
- Fine bed surface material flushing
- Macrophyte disruption
- Grass and shrub disturbance.

5.2.5 **Dam shoreline erosion**

Sediments from the erosion of a dam shoreline can contribute to sedimentation of the water storage if erosion rates are sufficiently high, with the potential to increase turbidity, increase the risk of algal blooms (from nutrients bonded to eroded soil particles) and loss of land and vegetation.

Shoreline erosion of water storages is generally caused by:

- Slumping of saturated banks during (rapid) drawdown
- Wind attack from generated waves.

Bank slumping or slip failure is usually associated with rapid drawdown when banks do not have enough time to drain adequately. The proposed operating rules are based on natural rates of rise and fall and therefore bank slumping as a result of rapid drawdown is not considered significant for this proposed dam.

Erosion from waves is potentially a problem as it is expected that any existing (or remaining) vegetation beneath the full supply level would die leaving an exposed shoreline. The 'worst-case' scenario for shoreline erosion is that the entire circumference of the dam shoreline would be eroded to the underlying (weathered) parent material and the eroded material is deposited within the storage. The maximum potential volume of material that could be lost via shoreline erosion is assumed to be the product of soil depth, variation of storage water level (between 95% and 100% of full supply level (FSL)) and the slope of the shoreline. Based on the proposed operating rules for the system, it has also been assumed that Dunoon Dam will generally be operated within 95-100 % of capacity, concentrating erosion on the top two metres of the storage (based on conceptual design only).

5.3 RESULTS

5.3.1 **Catchment scale assessment**

The Rocky Creek catchment covers an area of approximately 59 km^2 with a landform of high steep hills (**Chapter 2**). The upper catchment is underlain by rhylolitic geological units while the mid and lower catchment has largely basalt geology with smaller areas of sedimentary units within the proposed inundation area. The upper catchment above Rocky Creek Dam has largely intact native vegetation, including the Nightcap National Park. The basalt areas generally have gentler slopes and have largely been cleared for agricultural and horticultural land use. Cliff-lined outcrops are common in the lower catchment areas underlain by the Kangaroo Creek Sandstone. These lower catchment areas comprised of sedimentary geology generally have mostly intact pockets of native vegetation.

Below Rocky Creek Dam, Rocky Creek is predominantly a valley confined creek system although some floodplain features do occur (Thoms 1998). Thoms (1998) identified three function process zones between Rocky Creek Dam and the Terania Creek confluence. These zones include an armoured zone, two mobile zones and two gorge zones (**Table 2.6**).

A topographic long-section of Rocky Creek from the headwaters to the confluence with Terania Creek shows a generally steep creek bed with a relatively flat reach between Whian Whian Falls and the approximate site of the proposed Dunoon Dam wall (**Figure 5-1**). The average slope of the creek bed is 0.01 m/m.

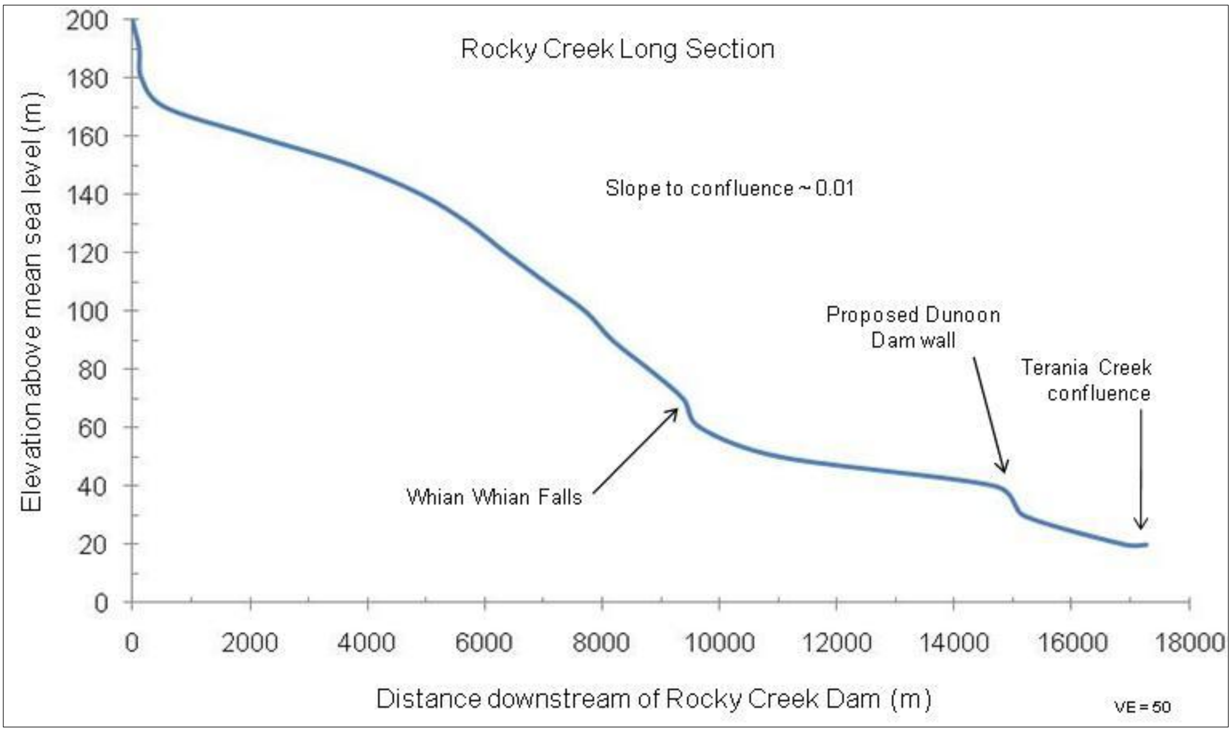


Figure 5-1: Rocky Creek long-section

The headwaters of Terania Creek have a similar overall slope to Rocky Creek (**Figure 5-2**), however, below the confluence with Rocky Creek the systems flattens considerably with the average slope reducing from 0.01 to 0.00075 m/m.

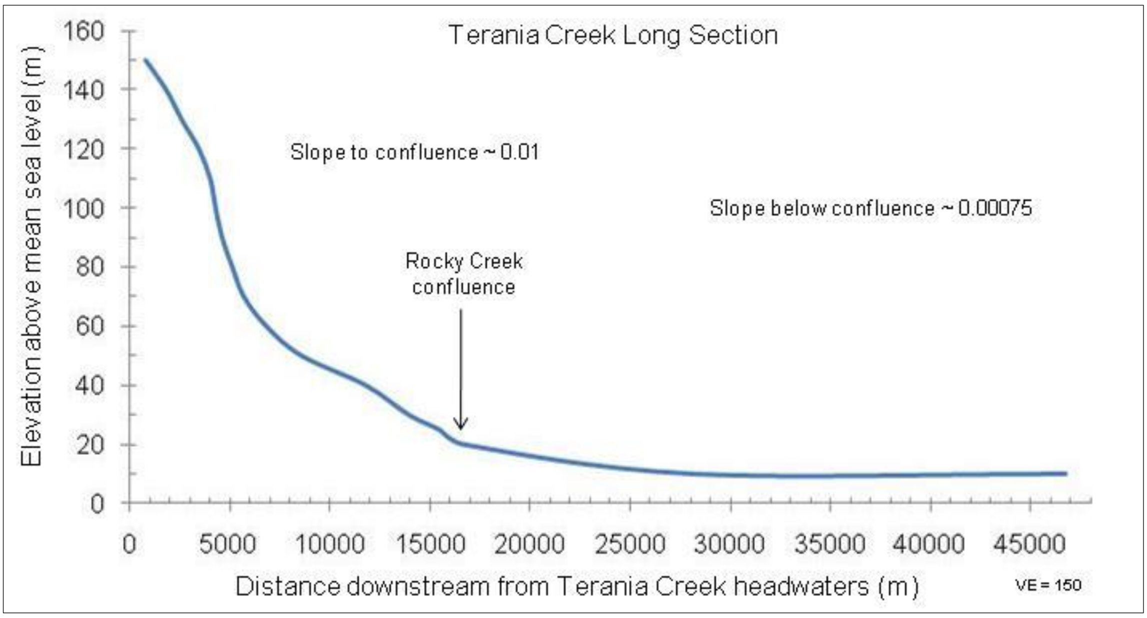


Figure 5-2: Terania Creek long-section

5.3.2 Field survey – site descriptions

Site description - Site 1

Site 1 is located approximately 2 km downstream of Rocky Creek Dam, immediately upstream of the Gibbergunjah Road crossing and on the south-eastern edge of Nightcap Range National Park. The site is located in mostly natural bushland with some horticultural land use less than 500 m downstream of the site.

Site 1 consists of a run and riffle sequence ending in a pool approximately 14 m wide (**Table 5-1**; **Figure 5-3**). The channel splits into two with a well vegetated island separating the two channels. The main channel is relatively flat with steep valley sides joining directly into the channel. The channel width at the start of the reach is around 4.5 m and widens and flattens out downstream. The average bed slope of the main channel is 2.7% (up to the start of the pool). The secondary channel is narrower and deeper than the main channel and runs parallel to the main channel for a short distance before merging prior to the downstream pool.

The riparian vegetation was largely intact and was continuous along the entire reach on both sides of the bank and along the island between the two channels. Native canopy species were dominant. The in-stream riffle sections showed some moss (less than 5%).

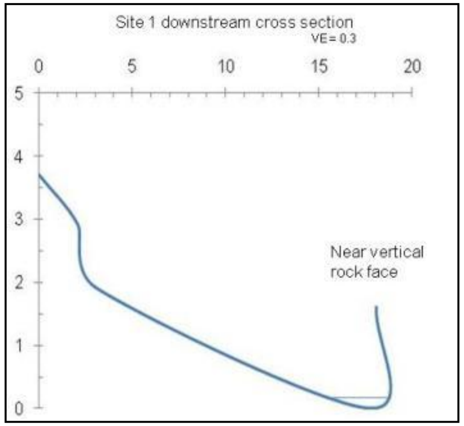
Table 5-1 Site 1 attributes

ATTRIBUTE	DESCRIPTION			
Coordinates (GDA94 Zone 55)	Upstream	E 532746 N 6831812	Downstream	E 532835 N 6831733
Elevation (m AHD)	170 m			
Process zone	Armoured zone (Thoms 1998)			
Average bed slope	2.7 %			
Valley shape	Asymmetrical relatively shallow valley (southern valley continuously steeper along reach)			
Habitat features	Riffle-run-pool sequence			
Bed material	Coarse gravel – large cobbles		d_{50} = 75 mm	
Bed stability	Stable			
Bank material	Medium – coarse gravel			
Bank stability	Stable			
Banktop form	Down sloping top (left hand bank only)			
Woody debris	Woody debris (tree roots) present towards downstream end (< 1 %)			
Longitudinal extent of riparian vegetation	Continuous			
Flow	0.2 MLd^{-1} (20th September 2010)			

a) Site 1 – upstream extent of reach (run)

b) Site 1 – downstream extent of reach (run)

c) Site 1 – aerial view



d) Site 1 – typical cross-section (downstream extent of reach)

Figure 5-3: Rocky Creek downstream of Rocky Creek Dam - Site 1

Site description - Site 2

Site 2 is located within the proposed inundation zone, approximately 12 km downstream of Rocky Creek Dam and immediately upstream of the Frasers Road crossing. Land adjacent to the site (outside of the riparian zone) has been largely cleared for agricultural and horticultural use.

The reach consists of a large pool at the upstream extent, approximately 20 m wide (**Table 5-2; Figure 5-4**). A silt and organic layer exists in the pool. A run and riffle sequence downstream of the pool provides faster flowing water. The channel at the downstream extent is relatively flat and 7 m wide. Pockets of thin silt layers were found in the riffle sequences. The right bank of the upstream extent abutted a relatively steep boulder wall while the left bank was characterised by alluvial material (sandy loam). Deposits of alluvium and debris have accumulated on the left bank. The downstream banks merged into a shallow valley, stepped on the right hand side and concave on the left bank. Localised bank erosion from cattle access was evident at the downstream section.

Continuous riparian vegetation occurs along the banks of the riffle sequence and opens up on the left hand bank at the start of the pool. Native canopy species were dominant, however, Camphor Laurel and *Ligustrum sinense* (Small-leaved Privet) were also present.

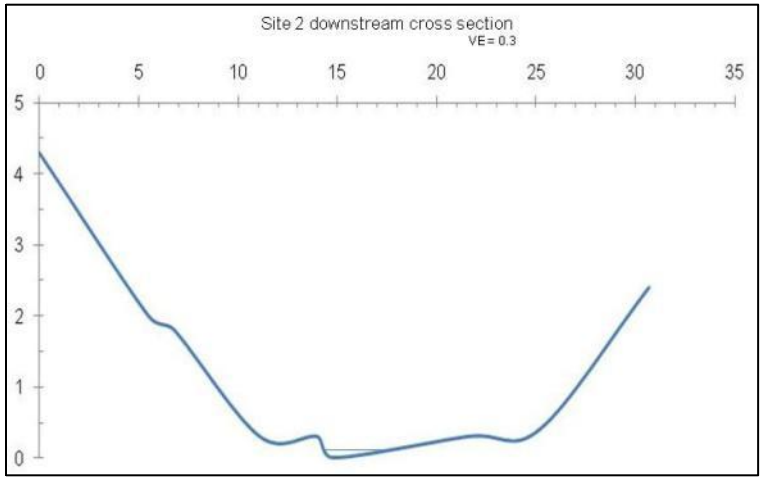
Table 5-2: Site 2 attributes

ATTRIBUTE	DESCRIPTION			
Coordinates (GDA94 Zone 55)	Upstream	E 529199 N 6829529	Downstream	E 529100 N 6829517
Elevation (m AHD)	45 m			
Process zone	Mobile zone (Thoms 1998)			
Average bed slope	1.4%			
Valley shape	Shallow valley, asymmetrical (northern side of valley steeper, particularly at upstream extent)			
Habitat features	Pool-riffle sequence			
Bed material	Coarse gravel – medium boulder		d_{50} = 100 mm	
Bed stability	Stable			
Bank material	Sandy loam (U/S LHB)		Boulders (US RHB)	
Bank stability	Localised bank erosion, exacerbated by cattle tracks			
Banktop form	Down sloping top			
Woody debris	None			
Longitudinal extent of riparian vegetation	Semi-continuous along riffle; opens to scattered riparian vegetation on the left hand bank at the upstream pool			
Flow	8 MLd^{-1} (18th August 2010)			

a) Site 2 – upstream extent of reach (pool)

b) Site 2 – downstream extent of reach (run)

c) Site 2 – aerial view



d) Site 2 – typical cross-section (downstream extent of reach)

Figure 5-4: Rocky Creek – proposed inundation area - Site 2

Site description - Site 3

Site 3 is located immediately downstream of the proposed Dunoon Dam wall, approximately 15 km downstream of the Rocky Creek Dam.

The channel is around 6 m in width, with large boulders that may act as fauna barriers and constrict flow (**Table 5-3; Figure 5-5**). The steep valley forms the channel banks. Upstream of the reach is a steep gorge section of the creek. In this reach the creek consists of pool/riffle/run suites with large boulders and exposed bedrock. Little Rocky Creek enters Rocky Creek immediately downstream of the reach.

Continuous riparian vegetation extends along the entire reach on both banks. Native canopy species are dominant.

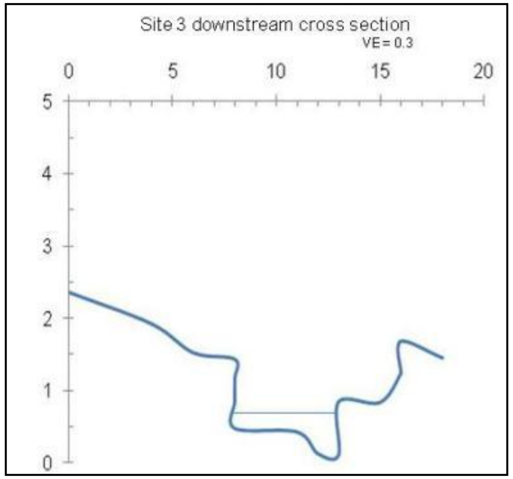
Table 5-3: Site 3 attributes

ATTRIBUTE	DESCRIPTION			
Coordinates (GDA94 Zone 55)	Upstream	E 528346 N 6826987	Downstream	E 529100 N 6829517
Elevation (m AHD)	40 m			
Process zone	Gorge zone (Thoms 1998)			
Average bed slope	1.4%			
Valley shape	Asymmetrical valley; northern valley slope significantly steeper particularly at the downstream extent			
Habitat features	Pool-cascade-pool sequence			
Bed material	Fine gravel - bedrock		d_{50} = 150 mm	
Bed stability	Stable			
Bank material	Sandy loam (U/S RBH); transitions to large cobbles/small boulders towards the downstream extent of the reach			
Bank stability	Stable			
Banktop form	Down sloping top			
Woody debris	Woody debris present at upstream end (< 5 %)			
Longitudinal extent of riparian vegetation	Continuous			
Flow	20 MLd^{-1} (23rd September 2010)			

a) Site 3 – upstream extent of reach (pool)

b) Site 3 – middle of reach (cascade)

c) Site 3 – aerial view



d) Site 3 – typical cross-section (downstream extent of reach)

Figure 5-5: Rocky Creek – downstream of proposed Dunoon Dam - Site 3

Site description - Site 4

Site 4 is located on Terania Creek downstream of the Tuntable Creek confluence and upstream of the Rocky Creek confluence, adjacent to the The Channon township. The western (right hand) side of the catchment has been cleared for grazing. The left hand bank has been altered by a constructed pathway that runs along the creek creating a benched slope. The right hand is a steep almost vertical valley wall. The bank material is generally clayey sand with pockets of fine gravels.

The reach consists of a pool/riffle/run sequence with a width of 8-12 m in width (**Table 5-4; Figure 5-6**). The channel bed consists of coarse sand to small cobbles.

Semi-continuous riparian vegetation occurs along both banks. The upper canopy was dominated by native species with some exotic species including Small-leaved Privet. The ground cover was dominated by exotic species.

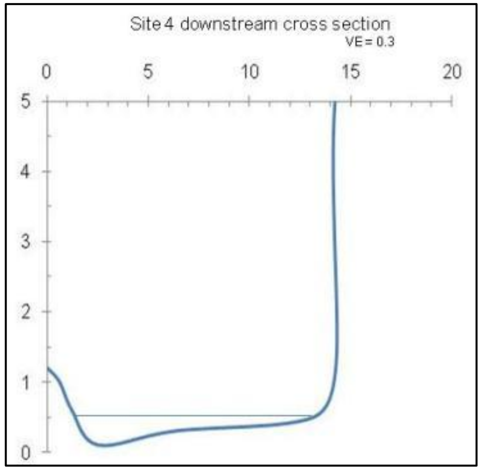
Table 5-4: Site 4 attributes

ATTRIBUTE	DESCRIPTION			
Coordinates (GDA94 Zone 55)	Upstream	E 527135 N 6828016	Downstream	E 527178 N 6827932
Elevation (m AHD)	20 m			
Process zone	Mobile zone			
Average bed slope	0.5 %			
Valley shape	Shallow valley, asymmetrical (northern side of valley steeper, particularly at upstream extent)			
Habitat features	Pool riffle sequence			
Bed material	Fine gravel - small cobbles		d_{50} = 15 mm	
Bed stability	Stable			
Bank material	Clayey sand with some (fine) gravels			
Bank stability	Localised bank erosion (eastern bank) due to cattle access			
Banktop form	Down-sloping top			
Woody debris	None			
Longitudinal extent of riparian vegetation	Semi-continuous (LHB); continuous (RHB)			
Flow	79 MLd^{-1} (21st September 2010)			

a) Site 4 – upstream extent of reach (pool)

b) Site 4 – downstream extent of reach (run)

c) Site 4 – aerial view



d) Site 4 – typical cross-section (downstream extent of reach)

Figure 5-6: Terania Creek – upstream of confluence with Rocky Creek - Site 4

Site description - Site 5

Site 5 is located approximately 2 km downstream of the confluence of Rocky Creek with Terania Creek. The site is upstream of the tidal limit. Land adjacent to the site (outside of the riparian zone) has been largely cleared for agricultural use and there is evidence of cattle access to the creek, particularly on the left hand bank (eastern side).

In this reach the channel has a meandering planform and a substantial floodplain. The 14 m wide channel forms a sequence of pools, riffles and bars (**Table 5-5; Figure 5-7**). The bed material consists of fine gravel to medium cobbles and the bank material was generally sand to loamy sand with gravel lenses.

Continuous riparian vegetation occurs along the right bank; while vegetation along the left bank is semi-continuous. The upper canopy was mainly native species with some Camphor Laurel and Small-leaved Privet. The ground cover was dominated by exotic pasture species and weeds. There were significant beds of macrophytes within the channel (20% cover).

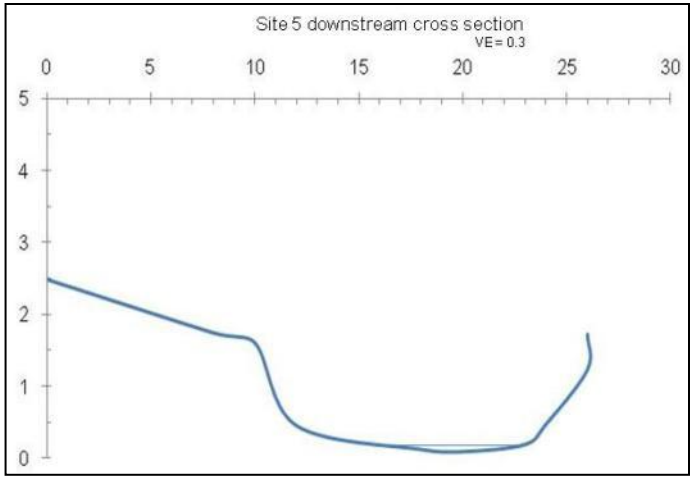
Table 5-5: Site 5 attributes

ATTRIBUTE	DESCRIPTION			
Coordinates (GDA94 Zone 55)	Upstream	E 526971 N 6826882	Downstream	E 526995 N 6826793
Elevation (m AHD)	17 m			
Process zone	Mobile zone			
Average bed slope	0.74 %			
Valley shape	Relatively steep valley, asymmetrical			
Habitat features	Pool-run sequence with a developed floodplain and in channel bars			
Bed material	Fine gravel – small cobble		d_{50} = 15 mm	
Bed stability	Stable			
Bank material	Sand/loamy sandy			
Bank stability	Stable in general, with localised bank erosion due to cattle access. Some undercutting of the embankment toe on the left-hand bend at the downstream extent of the reach. Upstream left hand bank actively eroding.			
Banktop form	Down sloping top			
Woody debris	Woody debris present (< 1 %)			
Longitudinal extent of riparian vegetation	Semi-continuous on left hand bank. Continuous on right hand bank.			
Flow	95 MLd^{-1} (22nd September 2010)			

e) Site 5 – upstream extent of reach (pool)

f) Site 5 – downstream extent of reach (run)

g) Site 5 – aerial view



h) Site 5 – typical cross-section (downstream extent of reach)

Figure 5-7: Terania Creek – downstream of confluence with Rocky Creek - Site 5

Site description - Site 6

Site 6 is a large deep pool located immediately downstream of Site 3 approximately 15 km downstream of Rocky Creek Dam (**Table 5-6; Figure 5-8**). The pool is unique in the creek system and is 55 m wide and up to 5 m in depth. The channel bank is a combination of large boulders in a matrix of clayey soil. The pool drains via a main channel (riffle/run sequence) in the north-west corner. A secondary channel runs parallel to the main channel and would become active at higher flows. A small floodplain pocket has developed on the right hand side of the channel.

Riparian vegetation is continuous around the perimeter of the pool.

Figure 5-8: Site 6 - deep pool

Table 5-6: Site 6 attributes

ATTRIBUTE	DESCRIPTION
Coordinates (GDA94 Zone 55)	E 528206 N 6826901
Elevation (m AHD)	40 m

Site description - Site 7

Site 7 is located immediately downstream of Robertson Bridge on Rocky Creek, approximately 16 km downstream of Rocky Creek Dam (**Table 5-7; Figure 5-9**). The reach confined within a shallow to steep valley with stepped bank faces. The bed material consists of large boulders and bedrock with pockets of mud and silt. Small patches of macrophytes and aquatic vegetation are present in relatively protected areas.

The bank material consists of large cobbles and boulders within a matrix of clayey sand with some fine gravel. Fibrous roots are also found in the material. Vegetative debris is especially prevalent on the benches.

Riparian vegetation is largely intact along both banks, with a mix of natives and exotic species.

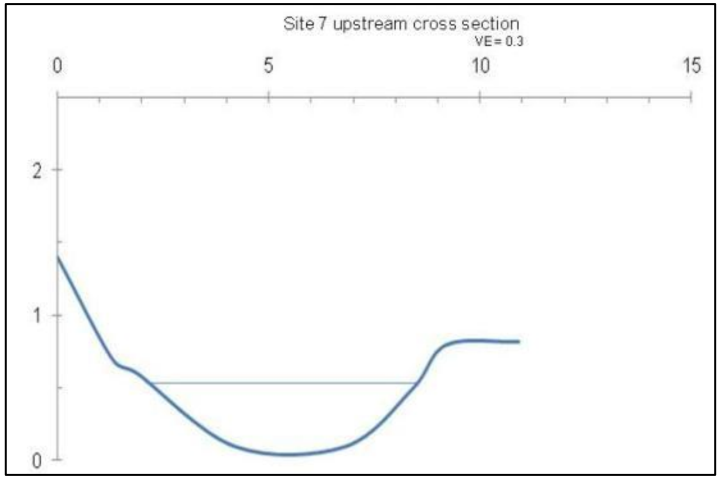
Table 5-7: Site 7 attributes

ATTRIBUTE	DESCRIPTION			
Coordinates (GDA94 Zone 55)	Upstream	E 527967 N 6827257	Downstream	E 527419 N 6827306
Elevation (m AHD)	20 m			
Process zone	Gorge / constrained zone transitioning to mobile zone at downstream extent (Thoms 1998)			
Average bed slope	1.5 %			
Valley shape	Symmetrical shallow-steep valley			
Habitat features	Pool-run sequence			
Bed material	Very coarse gravel – large cobbles		d_{50} = 90 mm	
Bed stability	Stable			
Bank material	Large cobbles and boulders; clayey sand			
Bank stability	Stable with isolated occurrences of bank erosion. Upper bank benches has layer of accumulated vegetative debris (leaf litter, twigs)			
Banktop form	Down sloping top			
Woody debris	Woody debris present (< 1 %)			
Longitudinal extent of riparian vegetation	Continuous on both banks for the extent of the reach			
Flow	29 MLd^{-1} (22nd September 2010)			

a) Site 7 – upstream extent of reach (run)

b) Site 7 – downstream extent of reach (run)

c) Site 7 – aerial view



d) Site 7 – typical cross-section (upstream extent of reach)

Figure 5-9: Rocky Creek– upstream of confluence with Terania Creek - Site 7

Site description – Site 8

Site 8 is a large deep pool on Terania Creek located approximately 12 km downstream of the confluence of Terania Creek and Rocky Creek. The surrounding land has largely been cleared. Riparian vegetation is mostly continuous around the perimeter of the pool (canopy cover and ground cover). This reach is in the flat section of Terania Creek with a meandering channel and extensive floodplain (**Figure 5-10; Table 5-8**).

Figure 5-10: Site 8 - deep pool (Terania Creek)

Table 5-8: Site 8 attributes

ATTRIBUTE	DESCRIPTION
Coordinates (GDA94 Zone 55)	E 525129 N 6821504
Elevation (m AHD)	20 m

Site description - Site 9

Site 9 is a long pool (around 350 m in length) located within the proposed inundation area just upstream of the proposed wall (**Figure 5-11; Table 5-9**). The channel width is 10-20 m with an average depth of around 2 m. The northern slope of the reach has largely been cleared, as has the upstream extent of the reach. The riparian vegetation is mostly continuous and dominated by exotic species in both the upper canopy and ground cover layers.

Figure 5-11: Site 9 - long pool

Table 5-9: Site 9 attributes

ATTRIBUTE	DESCRIPTION			
Coordinates (GDA94 Zone 55)	Upstream	E 529288 N 6827912	Downstream	E 528874 N 6827505
Elevation (m AHD)	45 m			

5.3.3 Bed material particle size analysis

Cascades and runs at Sites 3, 5 and 7 were sampled to determine dominant bed particle sizes in the reaches downstream of the proposed Dunoon Dam. Particle size was described in terms of standard percentile classes of D_{16}, D_{50} and D_{84} (Gordon et al 2004) (**Table 5-10**).

Generally the bed material at the three sites was loosely arranged. At Sites 3 and 7 large boulders would be immobile at all flow ranges. There were significant areas of bedrock at Site 3.

Substrate at all sites was largely free of algae and diatoms (<5% cover at Site 5 on Terania Creek; <1% at Sites 3 and 7).

Table 5-10: Summary of bed material sizes

SITE	RANGE OF BED MATERIAL	D_{50}	D_{16}	D_{84}
S3*	Fine gravel – bedrock	158 mm (large cobble)	40 mm	260 mm
S5	Very coarse sand – small cobbles	15 mm (medium gravel)	10 mm	30 mm
S7	Coarse gravel – large cobbles	90 mm (small cobble)	50 mm	131 mm

* bedrock excluded from bed particle size analysis at site 3

5.3.4 Hydraulic modelling

To determine relevant flows and water levels for ecological and hydrological assessment, representative cross sections at Sites 3, 5 and 7 were constructed based on cross sectional surveys collected during the initial field investigations. One-dimensional hydraulic models were created using HEC-RAS (U.S. Army Corps of Engineers 2010) to determine water level, flow velocity and shear stress at various flow magnitudes.

The results of this modelling are shown below for Site 3 (**Table 5-11; Figure 5-12**), Site 7 (**Table 5-12; Figure 5-13**) and Site 5 (**Table 5-13; Figure 5-14**).

Table 5-11: HEC-RAS modelling results for representative riffle cross section – Site 3 (Rocky Creek)

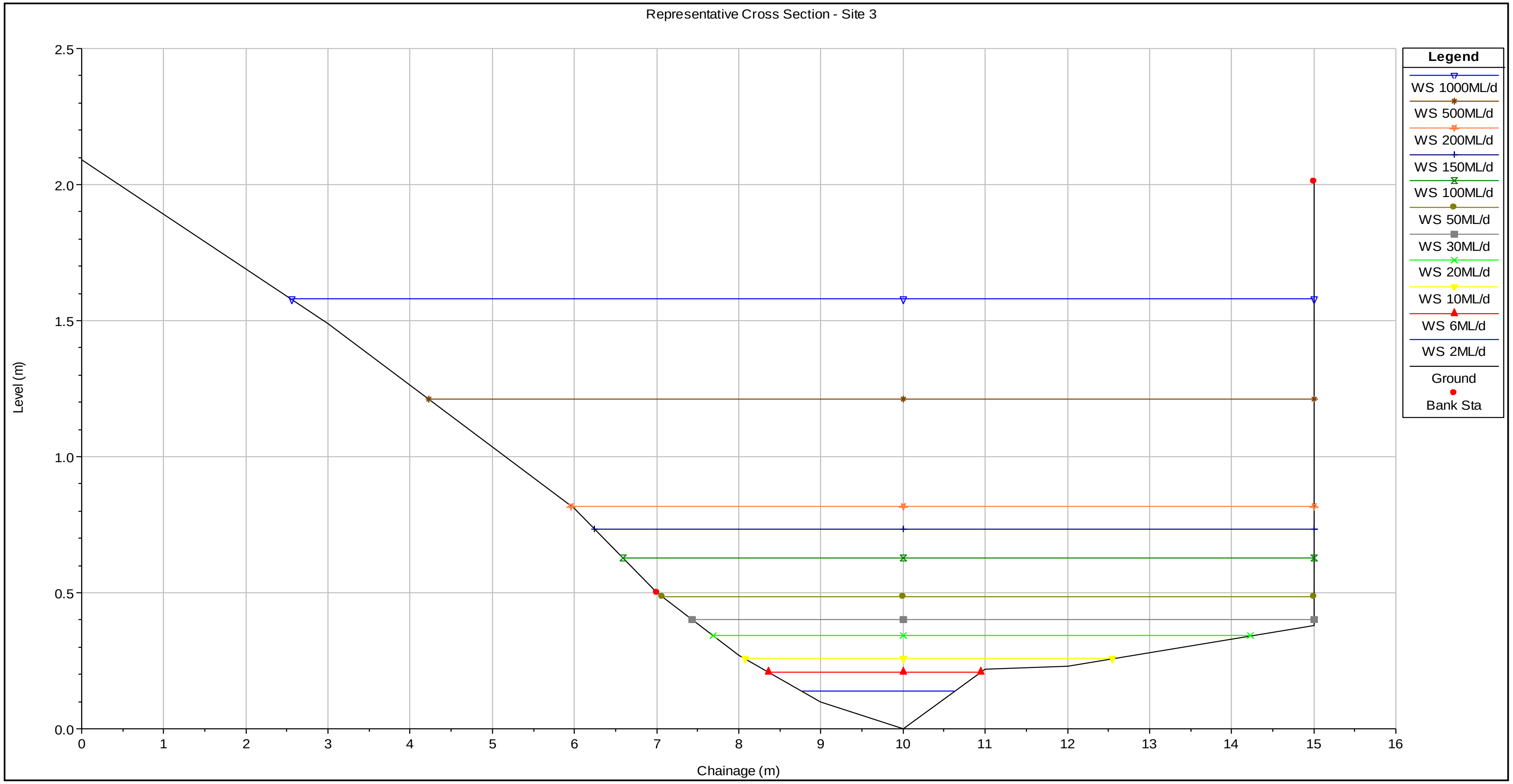
FLOW	FLOW	VELOCITY	WATER LEVEL	TOP WIDTH	SHEAR TOTAL	POWER TOTAL
(MLd^{-1})	(m^3s^{-1})	(ms^{-1})	(m)	(m)	(Nm^{-2})	(Nm^{-1} s)
2	0.02	0.14	0.06	3.91	2.38	0.33
6	0.07	0.15	0.13	5.37	2.09	0.31
10	0.12	0.16	0.17	6.39	2.13	0.34
20	0.23	0.18	0.25	7.0	2.39	0.43
30	0.35	0.21	0.31	7.0	2.87	0.59
50	0.58	0.26	0.39	7.07	3.99	1.02
100	1.16	0.35	0.54	7.5	6.53	2.29
150	1.74	0.42	0.64	8.07	8.49	3.57
200	2.31	0.48	0.73	8.53	10.33	4.93
500	5.79	0.67	1.12	10.23	18.09	12.19
1000	11.6	0.92	1.49	11.56	31.57	29.07

Table 5-12: HEC-RAS modelling results for representative riffle cross section – Site 7 (Rocky Creek)

FLOW	FLOW	VELOCITY	WATER LEVEL	TOP WIDTH	SHEAR STRESS	POWER
(MLd^{-1})	(m^{3}s^{-1})	(ms^{-1})	(m)	(m)	(Nm^{-2})	(Nm^{-1} s)
2	0.02	0.22	0.05	2.44	1.03	0.22
6	0.07	0.25	0.11	3.29	1.12	0.28
10	0.12	0.28	0.15	3.85	1.3	0.37
20	0.23	0.33	0.21	4.72	1.6	0.53
30	0.35	0.37	0.26	5.15	1.8	0.66
50	0.58	0.42	0.34	5.77	2.19	0.93
100	1.16	0.55	0.46	6.39	3.3	1.82
150	1.74	0.67	0.54	6.62	4.48	2.99
200	2.31	0.77	0.6	6.8	5.65	4.32
500	5.79	1.21	0.84	7.72	12.48	15.17
1000	11.6	1.72	1.08	8.87	23.31	40.04

Table 5-13: HEC-RAS modelling results for representative riffle cross section – Site 5 (Terania Creek)

FLOW	FLOW	VELOCITY	WATER LEVEL	TOP WIDTH	SHEAR TOTAL	POWER TOTAL
(MLd^{-1})	(m^{3}s^{-1})	(ms^{-1})	(m)	(m)	(Nm^{-2})	(Nm^{-1} s)
2	0.02	0.2	0.17	4.58	2.16	0.43
6	0.07	0.27	0.2	6.78	3.57	0.96
10	0.12	0.31	0.21	8.25	4.32	1.32
20	0.23	0.36	0.24	10.28	5.36	1.93
30	0.35	0.4	0.26	11.15	6.11	2.43
50	0.58	0.46	0.29	12.35	7.35	3.36
100	1.16	0.57	0.36	12.68	9.9	5.65
150	1.74	0.66	0.4	12.94	12.08	7.93
200	2.31	0.73	0.44	13.16	13.98	10.14
500	5.79	1.02	0.63	14.15	23.36	23.92
1000	11.6	1.33	0.83	15.38	33.18	44.05



VE = 0.30

Figure 5-12: Representative riffle cross section - Site 3 (Rocky Creek)

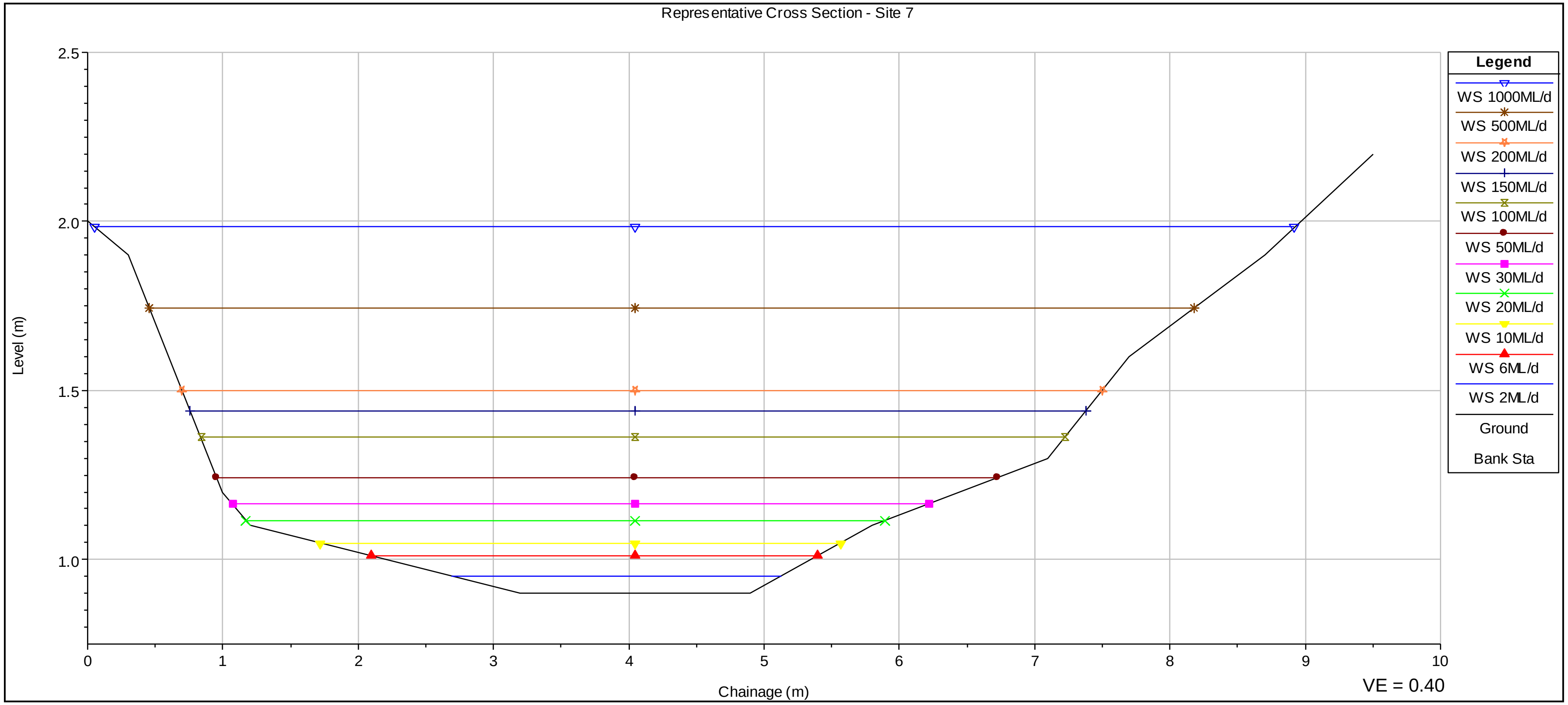


Figure 5-13: Representative riffle cross section - Site 7 (Rocky Creek)

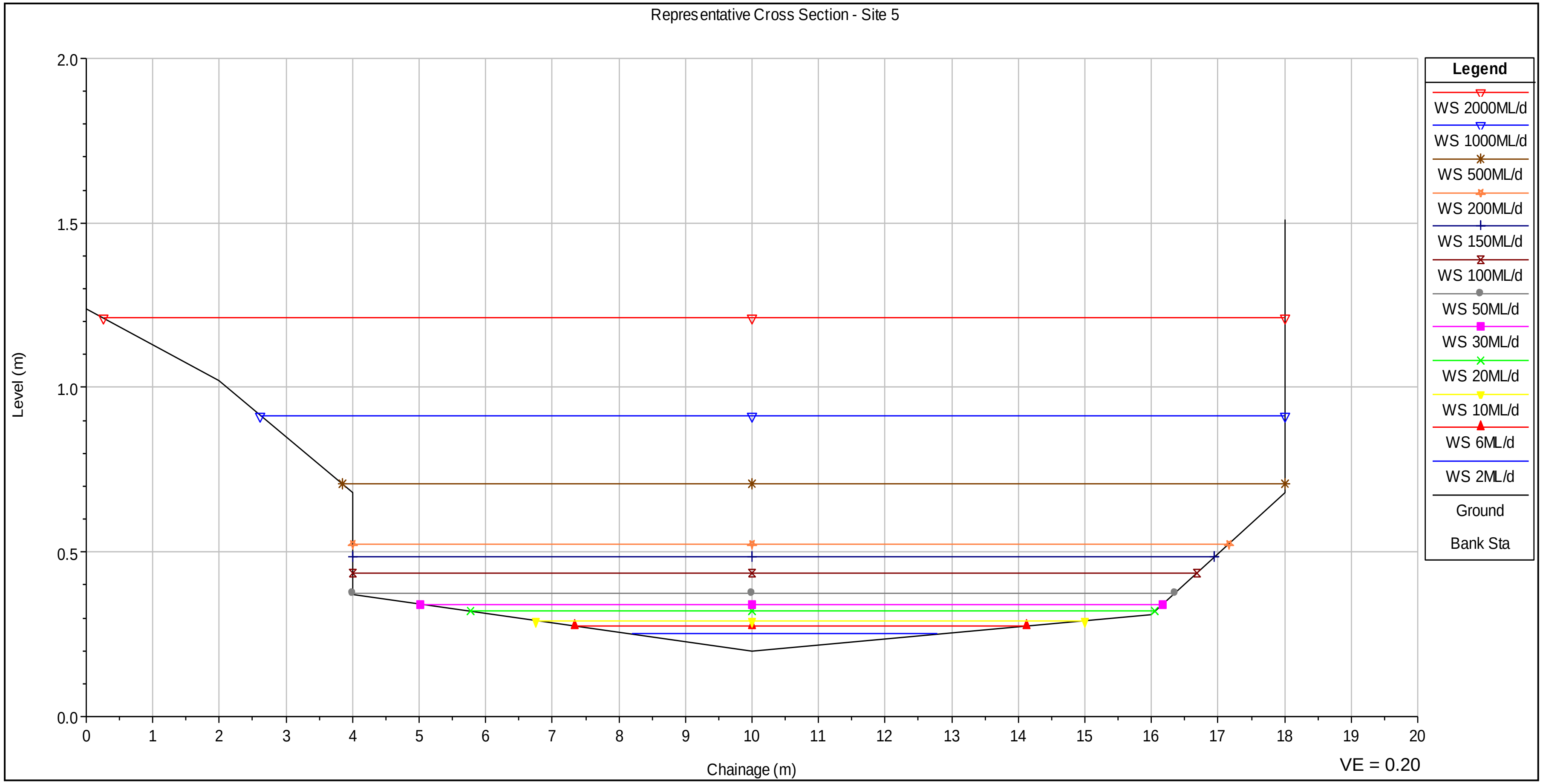


Figure 5-14: Representative riffle cross – Site 5 (Terania Creek)

Modelled flow parameters for the flow components identified for the Rocky Creek system (**Section 4**) are summarised in **Table 5-14**.

Table 5-14: Flow components and key features – Site 3

FLOW COMPONENT	PERCENTILE EXCEEDENCE ("NATURAL")	FLOW RANGE (MLd^{-1})	VELOCITY (ms^{-1})	WATER DEPTH (m)	TOP WIDTH (m)	SHEAR STRESS (Nm^{-2})	POWER (Nm^{-1} s)
Base flow	> 98	2 - 6	0.14 - 0.15	0.16 - 0.23	3.91 - 5.37	0.18 - 0.61	0.01 - 0.05
Low flow	98 - 60	6 - 32	0.15 - 0.21	0.23 - 0.41	5.37 - 7.0	0.61 - 1.86	0.05 - 0.31
Moderate flow	60 - 12	32 - 190	0.21 - 0.48	0.41 - 0.83	7.0 - 8.53	1.86 - 6.8	0.31 - 2.62
High flow / Flood	12 - 5	190 - 400	0.48 - 0.62	0.83 – 1.1	8.53 - 9.8	6.8 - 11.2	2.62 - 5.77
	< 5	400	>0.62	> 1.1	> 9.8	> 11.2	> 5.77

5.3.5 Geomorphic thresholds

The erosion, transport and deposition of sediments is a key aspect of river geomorphology, driving the shaping and forming of channels, with a balance existing between the erosive capacity of water flow and the ability of the channel bed and bank to resist erosion, with flow rate influencing the erosive power. The processes of sediment erosion, transport and deposition are influenced by the volume of sediment (both upstream and locally eroded material) and the size of the sediment. Fine materials such as clays, silts and fine sands are carried as the suspended load while coarse sediments are contained in the bedload. Estimated sediment entrainment is usually based on a 'critical' state or threshold. The presence of in-channel and riparian vegetation is also linked to fluvial geomorphology, impacting on sediment movement and channel conveyance.

Key geomorphic process discharge thresholds include:

- Coarse bed material mobilisation
- Fine bed surface material flushing
- Grass and shrub disturbance
- Macrophyte disruption.

Bankfull discharge is often accepted as the dominant discharge for alluvial rivers which control the smaller-scale features of active channel beds. Bankfull discharges have been found to occur over a range of recurrence intervals and the most commonly accepted discharge being between the two to ten year recurrence intervals (Reinfelds & Williams 2008). However, the 'flashy' hydrological system of Rocky Creek with rapid rates of rise and fall during high rainfall events precludes using this method.

Coarse bed material mobilisation

Incipient motion refers to the hydraulic conditions in which the movement of particles of a particular size is initiated. The point of movement of a particle depends on its physical features (such as size, shape and density) as well as the hydraulic conditions of the stream. Two methods were used to determine critical flow rates necessary to initiate movement of bed material at Sites 3, 5 and 7.

The Meyer-Peter and Muller approach (1948) was used to obtain sediment size at incipient motion (**Table 5-15**) as defined by:

$$d_s = \frac{S_O H}{K_1 \left(\frac{n}{D_{90}^{\ 0.167}}\right)^{1.5}}$$

Where d_s is the sediment size (mm), S_o is the bed slope (m/m), H is the flow depth (m) as determined by the hydraulic modelling, K_1 is a constant (0.058), n is Manning roughness coefficient, D_{90} is the bed material size where 90% of the material is finer (mm).

Table 5-15: Sediment size (mm) at incipient motion

FLOW MLd^{-1}	MEYER PETER MULLER			CRITICAL SHEAR STRESS		
	S3	S5	S7	S3	S5	S7
2	13	10	21	8	8	4
6	18	11	24	7	12	4
10	22	11	25	7	15	5
20	28	13	27	8	19	6
30	33	13	29	10	21	6
50	39	15	32	14	26	8
100	51	17	38	23	35	12
150	59	19	41	30	42	16
200	67	20	44	36	49	20
500	98	28	61	63	81	44
1000	128	36	78	110	116	81

Theoretically, median particles (D_{75}) at site 3 (210 mm) and site 7 (105 mm) require flows greater than 1000 MLd^{-1} for transportation, while smaller flows (around 500 MLd^{-1}) are required for site 5 (where the median particle size is only 25 mm).

The above approach was compared to the critical shear stress required to move a particle.

$$T_c = \theta_c \, g \, d \, (\rho_s - \rho)$$

Where T_c is critical shear stress (N/m^2), θ_c is the dimensional critical shear stress constant (assumed to be 0.045 for median-sized substrate), d is the representative particle size (m), g is acceleration due to gravity (9.807 ms^{-2}) and ρ_s and ρ are the densities of particles (1650 kg/m^3) and water (1000 kg/m^3) respectively. The shear stress (as provided in HEC-RAS modelling) at each key flow height was set as the critical shear stress for movement and the particle size capable of being entrained at that flow rate was calculated. HEC-RAS modelled data were extrapolated where necessary to determine theoretical flows for particle entrainment.

Flow required for the entrainment of different particle sizes for both methods are shown in **Table 5-16**.

Table 5-16: Flow required for particle entrainment

PARTICLE SIZE	SITE 3 (ROCKY CREEK)			SITE 5 (TERANIA CREEK)			SITE 7 (ROCKY CREEK)		
	(mm)	FLOW MLd^{-1} (MPM)*	FLOW MLd^{-1} (T_C)**	(mm)	FLOW MLd^{-1} (MPM)*	FLOW MLd^{-1} (T_C)**	(mm)	FLOW MLd^{-1} (MPM)*	FLOW MLD^{-1} (T_C)**
D_{16}	40	50	250	10	2	5	50	300	590
D_{50}	158	1590#	1726#	15	50	10	90	1440#	1120#
D_{84}	260	4770#	3619#	30	550	70	130	3500#	1700#

* As calculated using the Meyer-Peter Muller method

** As calculated using the critical shear stress method

\# extrapolated from HEC-RAS output tables

Fine bed surface material flushing

While unconsolidated fine materials (i.e. silts and sands) were mostly absent from the three sites assessed in detail, fine sediments may accumulate during extended periods of low flow. The flow at which mobilisation of unconsolidated fines on the channel bed surface occurs can be predicted using sediment-entrainment theories that are based on a 'critical' state or threshold of motion.

The Hjulström curves provide a general estimate of sediment entrainment by relating particle size to the average velocity required for erosion, transportation or deposition of particles (Gordon et al. 2004). The critical velocity (V_c) required to move a particle (>1 mm) is estimated by 0.155 where *d* is the average particle diameter. The water velocity near the bed (V_b) is estimated as 0.7*V* where V is the mean stream velocity. When the bed velocity exceeds the critical velocity the bed surface material becomes entrained.

Using the above method, an estimate of velocity required to initiate the movement of fine materials was calculated. The discharge corresponding to the critical velocity was determined from the HEC-RAS results (**Section 5.3.4**) was determined at each site.

Silts and fine sands require minimum flow (less than 2 MLd^{-1}) for entrainment while flows less than 10 MLd^{-1} will also remove medium sands at sites 3, 5 and 7 (**Table 5-17**). Similar flow rates will entrain very coarse sand and fine gravels at Sites 3 and 7 while larger flows are required at Site 3.

Table 5-17: Flow required for fine bed surface material entrainment

PARTICLE SIZE		V_c (ms^{-1})	SITE		
			S3	S5	S7
			FLOW (MLd^{-1})	FLOW (MLd^{-1})	FLOW (MLd^{-1})
Silt/ very fine sand	0.125 mm	0.05	< 2	< 2	< 2
Medium sand	0.5 mm	0.11	10	< 2	< 2
Very coarse sand/fine gravel	2 mm	0.22	80	10	15

No significant sand or gravel bars were evident during any of the surveys undertaken.

In-stream vegetation disturbance

It is unlikely that macrophytes and algal populations were abundant prior to the construction of Rocky Creek Dam with frequent high flows above 50 MLd^{-1} scouring these plants and restricting population growth (Sainty 1998). However, relatively long periods of low flow have allowed the establishment of some species particularly along flatter sections of the creek. Macrophytes were only recorded downstream of Site 7 where sediment had accumulated and the bed gradient had flattened out. Bedrock substrate at Site 3 restricts establishment of in-stream grasses and shrubs.

As summarised in Gippel & Anderson (2008), the colonisation of macrophytes can be prevented with sufficient water depth and velocity. Groeneveld & French (1995) (in Gippel & Anderson 2008), in their study of bending stress and stem rupture, estimated depth-velocity thresholds which will cause stem rupture. With HEC-RAS outputs, this depth-velocity relationship provides the means to estimate the flow required to cause macrophyte disruption.

The depth-velocity threshold to estimate a 95 percent chance of stem rupture is:

$$uD = \frac{12.8}{d}$$

u = average velocity (ms^{-1})

D = depth of submergence (m)

d = Stem diameter (m)

Stem diameter was assumed to be 11.9 mm, as recommended by Groenveld & French (1995). HEC-RAS outputs were used to determine the corresponding flows at which this threshold (i.e. uD = 0.152) is achieved (**Table 5-18**). No in-stream grass and shrubs were recorded at any of the sites (within the modelled wetted perimeter).

Table 5-18: Estimated flows to cause macrophyte disruption

SITE	FLOW AT WHICH MACROPHYTE DISRUPTION OCCURS (MLd^{-1})
S3	n/a
S5	38
S7	< 20

5.4 PROPOSED DAM SHORELINE EROSION

Bank slumping and wave action are the two key processes that would most likely cause shoreline erosion. Based on the proposed operating rules for the system, Dunoon Dam will generally be operated within 95-100 % of capacity, concentrating erosion on the top two metres of the storage.

The 'worst-case' scenario for shoreline erosion is that the entire circumference of the dam shoreline between 95 and 100% FSL, plus an additional allowance for wave height, would be eroded to the underlying (weathered) parent material and the eroded material is deposited within the storage. The size of waves created is dependent on wind speed and duration as well as the fetch (i.e. distances) over which the wind blows. An additional 0.65 m allowance for wave height was also provided for, based on Hawksley's formula for calculating wave height:

$H = 0.0138\sqrt{F}$	H =	Wave height (m)
	F =	Fetch distance over the longest exposed water surface (m)

The maximum potential volume of material that could be lost via shoreline erosion is assumed to be the product of the (assumed) soil depth, variation of storage water level (between 95% and 100% of FSL plus 0.65 m allowance for wave action) and the slope of the shoreline.

Lismore is the closest weather station where wind is measured (Bureau of Meteorology Station No. 058037; 1 January 1957 – 31 December 2003). Wind rose data indicates that wind direction is variable (**Figure 5-15**); morning winds are dominantly from the west (north-west, west and south-west) and the south; afternoon winds are generally from the east (north-east, east and south east) and the south. For the purposes of this assessment it has been assumed that all sections of the dam rim are equally exposed and susceptible to shoreline erosion over the long term. It is more than likely that different facing sections will be more susceptible to erosion because of prevailing wind directions and areas which may be sheltered or protected from erosion.

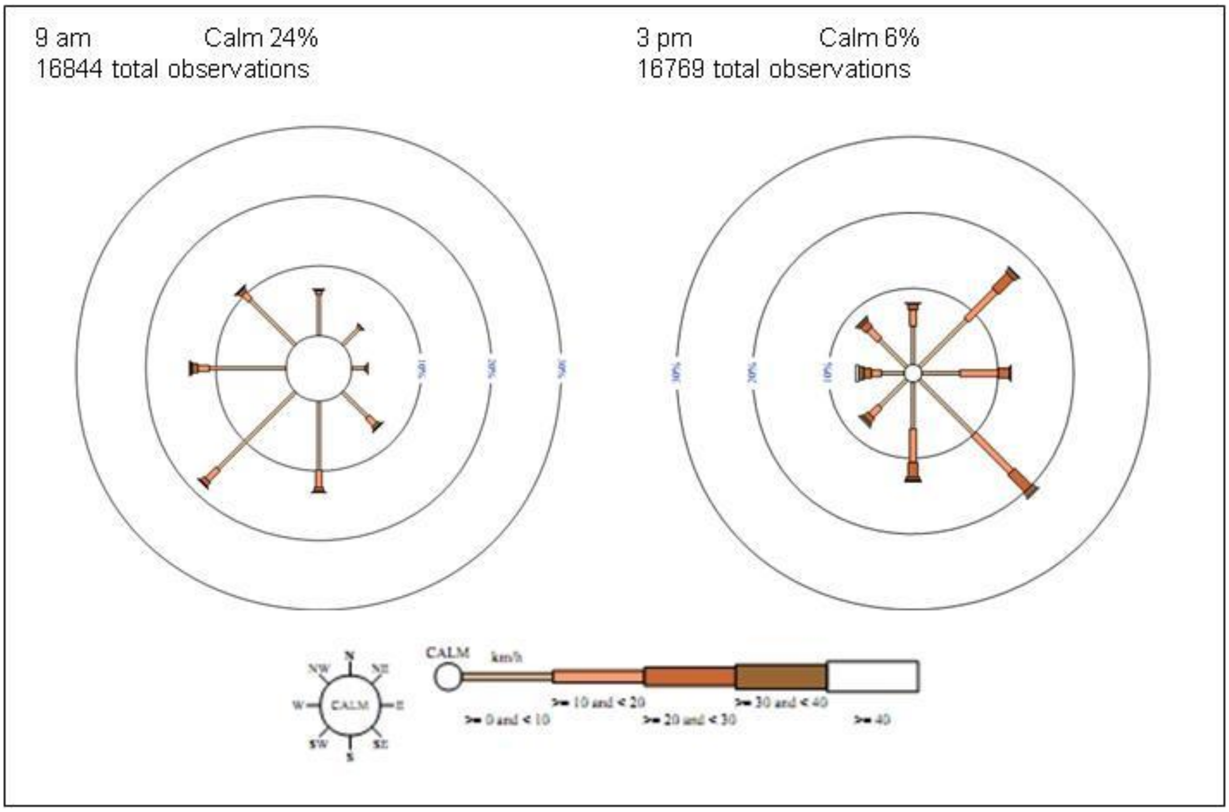


Figure 5-15: Lismore (Centre Street) wind roses (BoM Station No: 058037) (BoM 2011)

In the absence of detailed soil profile data, soil depths were assumed from the soil landscape units (**Section 2.4**). Based on conceptual dam design, the total perimeter of the storage is approximately 11.86 km excluding the dam wall. While the slope between 95% and 100% FSL varies around the perimeter, an average side slope was determined based on measurements taken from around the FSL.

The maximum total volume that could be lost from shoreline erosion was estimated to be 197,110 m^3, or around 0.4 percent of the total storage volume (**Table 5-19**), based on the assumptions noted above. This estimate assumes all sections of the shoreline are equally susceptible to equal rates of erosion regardless of wind direction and soil characteristics; it also assumes the entire soil depth is eroded and that no measures would be in place to prevent or reduce rates of shoreline erosion. No provision has been made for large slips of shoreline.

Table 5-19 Maximum potential volume of material lost from shoreline erosion

SOIL LANDSACPE UNIT [#]	CIRCUMFERENCE LENGTH (m)	MEAN SOIL DEPTH (m)*	POTENTIAL LOAD ERODED (m^3)
Rosebank (ro)	735 m	1 m	84 900
Georgica (ge)*	2030 m	1 m	
Coolamon (co)*	3876 m	1 m	
Wollongbar (wo)	270 m	1.5 m	107870
Calico (cl)*	4923 m	1.5 m	
Terania (te)*	142 m	2.5 m	4340
TOTAL	11867 m		197110

Morand 1994b

* as assumed from typical soil profiles provided in Morand 1994a

However, it is noted that 4800 ML of ‘dead’ storage has been nominated for the dam (Rous Regional Water Supply Strategy Planning Study 1995). This amount of dead storage was considered necessary due to the high potential for slips on the storage slopes for the initial proposal full storage level of 76000 ML. A smaller volume of dead storage may be required for a smaller dam.

5.5 GEOMORPHOLOGY REQUIREMENTS

Geomorphic assessment of the sites shows that the system as largely confined, with limited potential for erosion. The relatively small sediment source zone (as identified by Thoms 1998) will be inundated by the proposed dam and there is minimal potential upstream source of sediment as Rocky Creek Dam acts as a sediment capture pond.

In Rocky Creek, below Rocky Creek Dam, the character of the channel is dominated by boulder and bedrock structures. These channel types are largely controlled by very large flood events only and it is likely that the geomorphic nature of the system will not be affected substantially by the operation of the proposed dam. Maintenance of low levels of environmental flows combined with disruption from large flooding events will maintain channel form and processes.

6 Water Quality

6.1 INTRODUCTION & AIMS

Water quality plays a key role in the availability and suitability of creek environments for aquatic and semi-aquatic flora and fauna. Factors including nutrient and sediment load, temperature variability (seasonal and vertically within pools), pollutants and dissolved oxygen all play a critical role in determining habitat quality. The assessment of water quality for this study focussed on identifying seasonal patterns of water temperature and dissolved oxygen within pools, key nutrient loads especially those related to agricultural activities and suspended sediments. The specific aims were to:

- Describe the existing water quality of Rocky and Terania Creeks
- Identify the impact of Rocky Creek Dam on water quality in the Rocky Creek catchment
- Identify critical discharges and hydrological thresholds required to maintain/improve water quality in the system, particularly in deep pools.

6.2 METHODS

6.2.1 Desktop review

A review of literature relating to the water quality of Rocky Creek and the larger catchment was undertaken to gain an understanding of the system, in particular the *Preliminary Assessment of the Effect of Rocky Creek Dam on the Downstream Environment* (Bishop 1998). This preliminary assessment included an overview of water quality in Rocky Creek.

6.2.2 Field survey

A field survey program was designed and implemented to describe the key elements of the aquatic and riparian ecology of the system and assess the spatial variation along Rocky Creek and Terania Creek. Surveys were undertaken at Sites 1-5 (**Figure 3-1**). Reaches were selected to cover the range of typical habitat features (pool, riffle, run) and to provide a ‘control’ site on Terania Creek site upstream of the confluence.

Each site was surveyed three times: summer (21-26 November 2010); autumn (27 March-4 April 2011) and flushing flow (17-22 October 2010) following a flushing flow event. In the four weeks preceding the post-flushing flow survey (October 2010) there was over 400 mm of rainfall in the catchment. This meant that Rocky Creek Dam was at capacity at the beginning of October and any subsequent rain caused the dam to spill. Peak spillway discharge in this period of around 4700 MLd^{-1} was reached on 11 October 2010.

Physical and chemical properties were measured *in situ* (pool and riffle) at Sites 1 - 5 as part of the macro-invertebrate sampling suite. For the flushing flow and spring surveys a Hydrolab Quanta was used and a Horiba multi-parameter water quality meter was used during the autumn survey. While most variables could be measured by the Horiba unit, dissolved oxygen readings were only provided in mg/L. Properties recorded *in situ* included:

- Water temperature (°C)
- pH
- Dissolved oxygen (mg/L and % saturation)
- Conductivity (mS/cm)
- Turbidity (NTU).

Two replicate water quality samples were collected from flowing water on the same day as *in situ* physical-chemical water data for:

- Total suspended solids (g/L)
- Total phosphorous (mg/L)
- Ortho-phosphorous (mg/L)
- Total nitrogen (mg/L)
- Oxidised nitrogen (mg/L)
- Chlorophyll *a* (mg/L).

Duplicate samples were analysed at Richmond Water Laboratories for total phosphorus, ortho-phosphorus, total nitrogen and nitrogen oxides (**Table 6-1**). Duplicate water samples for chlorophyll *a* and total suspended solids (collected separately in 2 x 1 L plastic bottles) were filtered onto glass fibre paper (1.2 µm) and analysed at the University of New England. All samples were stored on ice in dark conditions until delivery to laboratories.

Table 6-1: Water samples collected in field, methods of collection, laboratory methods and practical quantisation limits

SAMPLE	FIELD COLLECTION METHOD	LABORATORY METHOD	PRACTICAL QUANTITATION LIMIT
Nitrogen – Total	Unfiltered	RWL 10.04	0.1 mg/L
Nitrogen – Oxidised	Filtered (1.2 µm)	RWL 10.04	0.01 mg/L
Phosphorus – Total	Unfiltered	RWL 10.04	0.05 mg/L
Phosphorus – Ortho	Filtered (1.2 µm)	RWL 10.04	0.01 mg/L
Total Suspended Solids	Filtered (1.2 µm)	APHA 2005	0.000001 mg/L (0.001 µm/L)
Chlorophyll *a*	Filtered (pre-weighed 1.2 µm)	APHA 2000	0.01 mg/L

Results were compared against ANZECC guidelines for south-eastern Australian slightly disturbed ecosystems for lowland streams (less than 150 m altitude). ANZECC trigger values are either given as a threshold value or as a range of desirable values. The Water Quality and River Flow objectives developed for the Richmond River Catchment (town water supply sub-catchment) by DECCW (2006) use the default trigger values stated within the ANZECC guidelines.

Dissolved oxygen and/or temperature profiles were recorded in two deep pools downstream of the proposed dam wall on Rocky Creek and Terania Creek. Vertical profiles of dissolved oxygen and temperature were recorded in two locations (the inside and outside of the bend) at the deep pool at Site 8 on Terania Creek. DO and temperature were recorded at half metre intervals from the surface down to pool bottom. DO and temperature at Site 8 were recorded during each aquatic ecology sampling trip (20 October 2010, 25 November 2011 and 28 March 2011).

At site 6 a thermister chain with 3 temperature data loggers was installed in the deep pool to record an hourly time series temperature profile. The thermometers were located at three positions in the water column: 0.5 m below the water surface; 0.5 m above the bottom of the pool and at the approximate mid-point in the column (around 2.5 m). The depth of the pool was around 5 m when the thermister chain was installed. Temperature differentials provide an indicator of thermal stratification. The thermister chain was installed on 23 September 2010 and removed on 29 March 2011 to represent the period of time when thermal stratification was most likely to occur.

6.3 RESULTS

6.3.1 Desktop review

Limited long-term water quality data are available for Rocky Creek. Bishop (1998) concluded that water quality recorded in 1977/78 at Gauging station 203036 (Rocky Creek at Gibbergunnyah Range Road) was of high quality, however, nutrient data from downstream sites was limited. Sampling undertaken in September 1998 found that total phosphorus and soluble phosphorus were very low. Nitrogen concentrations in all forms were found to be low and dominated by the organic fraction rather than agricultural or domestic residues. Sampling also found the water to be non-saline and pH levels to be slightly acidic, but less so than other Richmond catchments.

6.3.2 Field survey

Sites 1-5 Physical & chemical properties

Water temperature was generally warm, ranging from 16.88 ºC to 22.5 ºC (**Table 6-2**). These values reflect the overall sub-tropical climate of the region and the lotic, shallow nature of the water.

Table 6-2: Summary of water temperature (°C)

SITE	FLUSHING FLOW		SPRING		AUTUMN		MEAN
	RIFFLE	POOL	RIFFLE	POOL	RIFFLE	POOL	
Site 1	19.25	19.7	21.12	20.8	22.5	22.5	21.0
Site 2	16.88	16.97	20.14	20.26	20.2	20.2	19.1
Site 3	17.9	17.93	19.96	19.97	20.6	20.7	19.5
Site 4	17.71	17.73	21.67	21.67	20.7	20.8	20.0
Site 5	18.05	18.03	20.67	20.66	21.4	21.4	20.0

Water pH ranged from slightly acidic to basic with values ranging from 6.75 to 8.74 (**Table 6-3**). The autumn sampling results were considerably higher than the post-flush and spring sampling results.

Table 6-3: Summary of pH values

SITE	FLUSHING FLOW		SPRING		AUTUMN		MEAN
	RIFFLE	POOL	RIFFLE	POOL	RIFFLE	POOL	
Site 1	6.75	6.80	6.99	6.99	**8.07**	7.86	7.24
Site 2	6.89	6.90	7.29	7.98	**8.40**	**8.23**	7.62
Site 3	6.95	7.01	7.18	7.23	**8.70**	**8.74**	7.64
Site 4	7.09	7.07	7.35	7.34	**8.40**	**8.31**	7.59
Site 5	7.00	6.99	7.26	7.20	**8.08**	**8.30**	7.47

* ANZECC range 6.5-8.0; values that lie outside this range are in bold

Dissolved oxygen (% saturation) was generally less than 85%, the lower limit of the ANZECC range (85-110%) across the sampling period (**Table 6-4**), with exception of Site 5 during the autumn sampling period (87.4 % and 86.2 % in the riffle and pool respectively). The lowest recorded percentage was 65.5% within the pool at Site 2 during the spring sampling period. DO tended to be lowest during the spring sampling and highest in autumn across all sites.

Table 6-4: Summary of dissolved oxygen values (%)

SITE	FLUSHING FLOW		SPRING		AUTUMN		MEAN
	RIFFLE	POOL	RIFFLE	POOL	RIFFLE	POOL	
Site 1	**73.4**	**68.7**	**67.0**	**67.3**	**83.5**	**82.1**	**73.7**
Site 2	**82.8**	**76.7**	**66.6**	**65.5**	**83.5**	**84.4**	**76.6**
Site 3	**76.1**	**75.8**	**67.2**	**67.8**	**84.8**	**83.3**	**75.8**
Site 4	**70.7**	**71.9**	**70.0**	**70.8**	85.1	**81.7**	**75.0**
Site 5	**74.1**	**79.5**	**68.3**	**69.2**	87.4	86.2	**77.5**

* ANZECC range 85-110 %; values that lie outside this range are in bold

Specific conductivity readings for all sites were below the ANZECC range (0.125 - 2.20 mS/cm) across the sampling period with readings at each site remaining relatively constant (**Table 6-5**). Conductivity tended to increase down the system, being highest at Sites 4 and 5.

Table 6-5: Summary of specific conductivity values (mS/cm)

SITE	FLUSHING FLOW		SPRING		AUTUMN		MEAN
	RIFFLE	POOL	RIFFLE	POOL	RIFFLE	POOL	
Site 1	**0.053**	**0.053**	**0.055**	**0.055**	**0.052**	**0.053**	**0.054**
Site 2	**0.064**	**0.064**	**0.071**	**0.071**	**0.069**	**0.071**	**0.068**
Site 3	**0.069**	**0.069**	**0.077**	**0.077**	**0.072**	**0.072**	**0.073**
Site 4	**0.085**	**0.084**	**0.098**	**0.097**	**0.096**	**0.097**	**0.093**
Site 5	**0.080**	**0.079**	**0.091**	**0.090**	**0.097**	**0.090**	**0.088**

* ANZECC range 0.125-2.20 mS/cm; values that lie outside this range are in bold

Turbidity readings were generally at the lower end of the ANZECC desirable range (6-50 NTU) except for the pools at Site 1 and Site 2 where turbidity was marginally lower (**Table 6-6**). Turbidity tended to increase further down the system and was generally higher at Site 4 (Terania Creek upstream of the confluence).

Table 6-6: Summary of turbidity values (NTU)

SITE	FLUSHING FLOW		SPRING		AUTUMN		MEAN
	RIFFLE	POOL	RIFFLE	POOL	RIFFLE	POOL	
Site 1	7.6	**5.8**	**3.5**	**3.3**	**2.0**	**2.0**	**4.0**
Site 2	6.3	**5.9**	**3.0**	**3.1**	7.0	8.0	**5.6**
Site 3	6.2	6.2	**5.9**	**5.0**	**5.0**	**5.0**	**5.6**
Site 4	15.3	15.0	9.1	10.1	19.0	19.0	14.6
Site 5	9.8	9.8	8.6	9.0	14.0	14.0	10.9

* ANZECC range 6-50 NTU; values that lie outside this range are in bold

Total Suspended Solids (TSS) ranged between 0.0002 and 0.0036 g/L for all of the sites on all sampling occasion, with the exception of Site 4 which had 0.01 g/L TSS during the autumn sampling period (**Table 6-7**).

Table 6-7: Summary of total suspended solids values (g/L)

SITE	FLUSHING FLOW	SPRING	AUTUMN
Site 1	0.00260	0.00150	0.00075
Site 2	0.00130	0.00020	0.00190
Site 3	0.00070	0.00050	0.00175
Site 4	0.00360	0.00150	0.01000
Site 5	0.00310	0.00270	0.00315

Total Phosphorus (TP) concentrations were generally below the limit of detection for the post-flush survey. TP was detectable at Sites 4 and 5 during the spring and autumn surveys and were either at or over (0.015 mg/L) the ANZECC threshold of 0.05 mg/L (Site 4 and Site 5 respectively) (**Table 6-8**).

Table 6-8: Summary of total phosphorus values (mg/L)

SITE	FLUSHING FLOW	SPRING	AUTUMN
Site 1	<0.05	<0.05	<0.05
Site 2	<0.05	<0.05	<0.05
Site 3	<0.05	<0.05	<0.05
Site 4	<0.05	**0.060**	**0.065**
Site 5	<0.05	**0.050**	**0.050**

* ANZECC upper threshold 0.05 mg/L; values that lie outside this range are in bold

Orthophosphorus (OP) results were below the ANZECC threshold (0.02 mg/L) at all sites during the flushing flow survey. OP concentrations at Sites 1 and 2 were consistently below the ANZECC threshold for all sampling occasions. Sites 3-5 exceeded this threshold during the spring survey and Site 3 continuing this trend into autumn when the highest concentration across all sites occurred (0.065 mg/L) (**Table 6-9**).

Table 6-9: Summary of ortho-phosphorus (mg/L)

SITE	FLUSHING FLOW	SPRING	AUTUMN
Site 1	<0.01	<0.01	<0.01
Site 2	<0.01	0.010	<0.01
Site 3	<0.01	**0.020**	**0.065**
Site 4	0.010	**0.040**	0.015
Site 5	0.010	**0.030**	0.010

* ANZECC upper threshold 0.02 mg/L; values that lie outside this range are in bold

Total Nitrogen (TN) concentration was below the ANZECC threshold (0.50 mg/L) at all sites for all sampling occasions and ranged between 0.25-0.38 mg/L (**Table 6-10**). There were no clear trends between sites or sampling periods for TN results.

Table 6-10: Summary of total nitrogen values (mg/L)

SITE	FLUSHING FLOW	SPRING	AUTUMN
Site 1	0.30	0.33	0.25
Site 2	0.37	0.31	0.35
Site 3	0.38	0.30	0.33
Site 4	0.31	0.33	0.35
Site 5	0.37	0.31	0.33

* ANZECC upper threshold 0.50 mg/L; values that lie outside this range are in bold

Oxidised nitrogen (NO_x) exceeded the ANZECC threshold concentration of 0.4 mg/L at all sites during each of the sampling periods (**Table 6-11**). Generally NO_x was lowest at Site 1 for each survey and the lowest NO_x concentrations were found in the November sampling period.

Table 6-11: Summary of oxidised nitrogen values (mg/L)

SITE	FLUSHING FLOW	SPRING	AUTUMN
Site 1	**0.05**	**0.05**	**0.09**
Site 2	**0.16**	**0.08**	**0.19**
Site 3	**0.17**	**0.08**	**0.17**
Site 4	**0.12**	**0.07**	**0.14**
Site 5	**0.16**	**0.09**	**0.14**

* ANZECC range 0.04 mg/L; values that lie outside this range are in bold

Chlorophyll *a* concentrations were below ANZECC thresholds at all sites for all sampling occasions (**Table 6-12**). There were no clear trends between sites or sampling periods for Chlorophyll *a* results.

Table 6-12: Summary of chlorophyll *a* value (mg/L)

SITE	FLUSHING FLOW	SPRING	AUTUMN
Site 1	0.00030	0.00240	0.00159
Site 2	0.00120	0.00010	0.00077
Site 3	0.00040	0.00010	0.00055
Site 4	0.00010	0.00010	0.00149
Site 5	0.00020	0.00020	0.00083

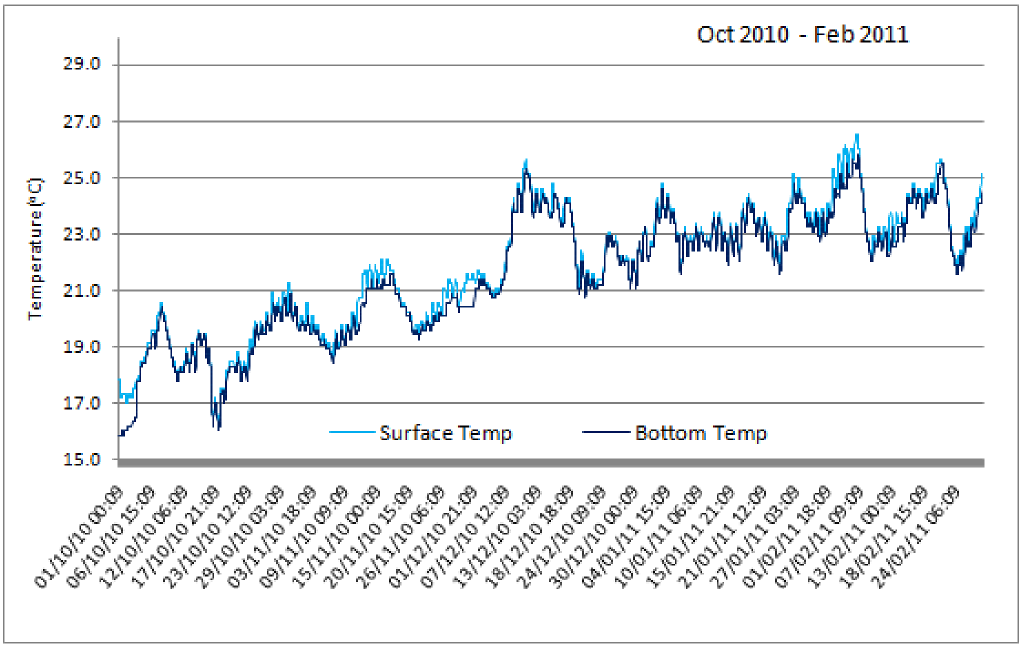
* ANZECC range 0.005 mg/L; values that lie outside this range are in bold

Sites 6 & 8 Deep pool results

The deep pools at sites 6 and 8 were surveyed to assess the potential for stratification in the water column. At Site 6 a thermister chain logged hourly temperature variations at three depths in the water column from 23 September 2010 to 29 March 2011 (**Figure 5-11**). These data showed that surface temperature slightly exceeded the temperature at the bottom of the pool for the majority of the time from September to March (**Table 6-13**). The average temperature difference was 0.32 ºC and the highest recorded was 2.92 ºC. Weak thermal stratification was still present for the majority of the survey period and there were several periods when the surface temperature exceeded the bottom temperature by more than 1 ºC. However, these periods of thermal stratification (temperature difference greater than 1 ºC) were short in duration, generally less than 1 day with flows of approximately 20 MLd^{-1} for several days being sufficient to remix the pool.

Table 6-13: Summary of temperature differences (°C) between pool surface and bottom (Site 6)

STATISTIC	TEMPERATURE DIFFERENCE (°C) (SURFACE – BOTTOM)
Mean	0.33
Median	0.18
Minimum	-0.01
Maximum	2.92



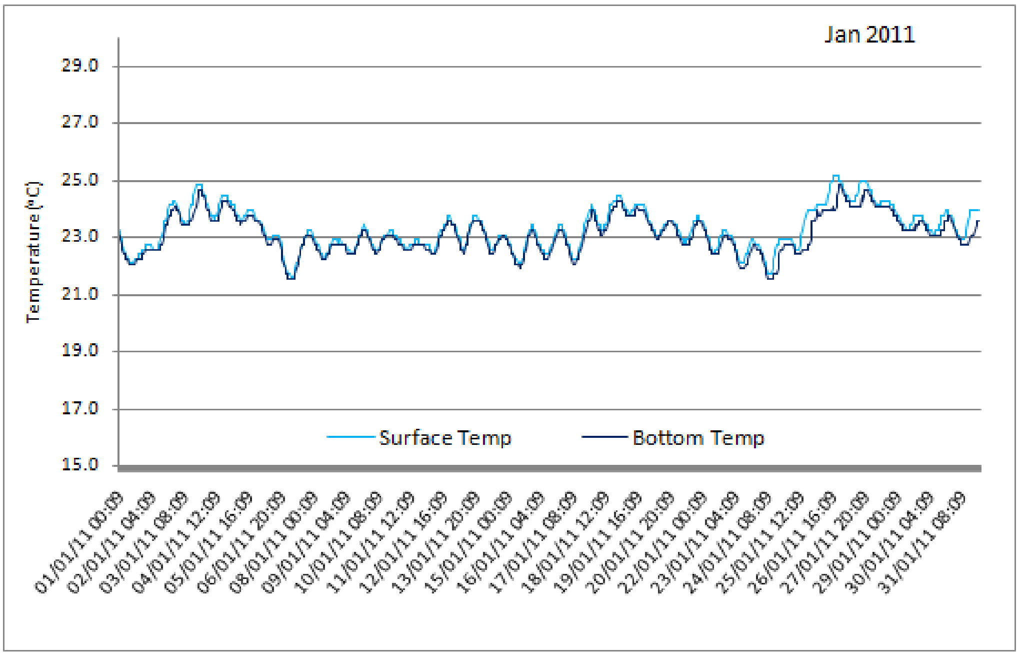


Figure 6-1: Water surface and bottom temperatures (Site 6 - deep pool, Rocky Creek; October 2010-February 2011; January 2011)

Temperature and dissolved oxygen profiles were recorded at two locations at the deep pool at Site 8; the inside and outside of the bend (**Figure 6-2**). There was no obvious stratification of temperature or dissolved oxygen at any of the sampling periods. The difference in temperature between the surface and bottom of the pool ranged from no difference up to 0.22 ºC, with the maximum difference recorded during the November survey (outside bend). The largest difference in dissolved oxygen (-1.6 %) also occurred in November, however, at the inside of the bend. The largest positive difference in dissolved oxygen (+0.48%) was also recorded at the inside during the autumn survey.

The post-flushing flow temperature profiles (October) were approximately 3-4 degrees colder than either the spring or autumn profiles. Dissolved oxygen was lowest at the spring sampling and highest at the autumn sampling.

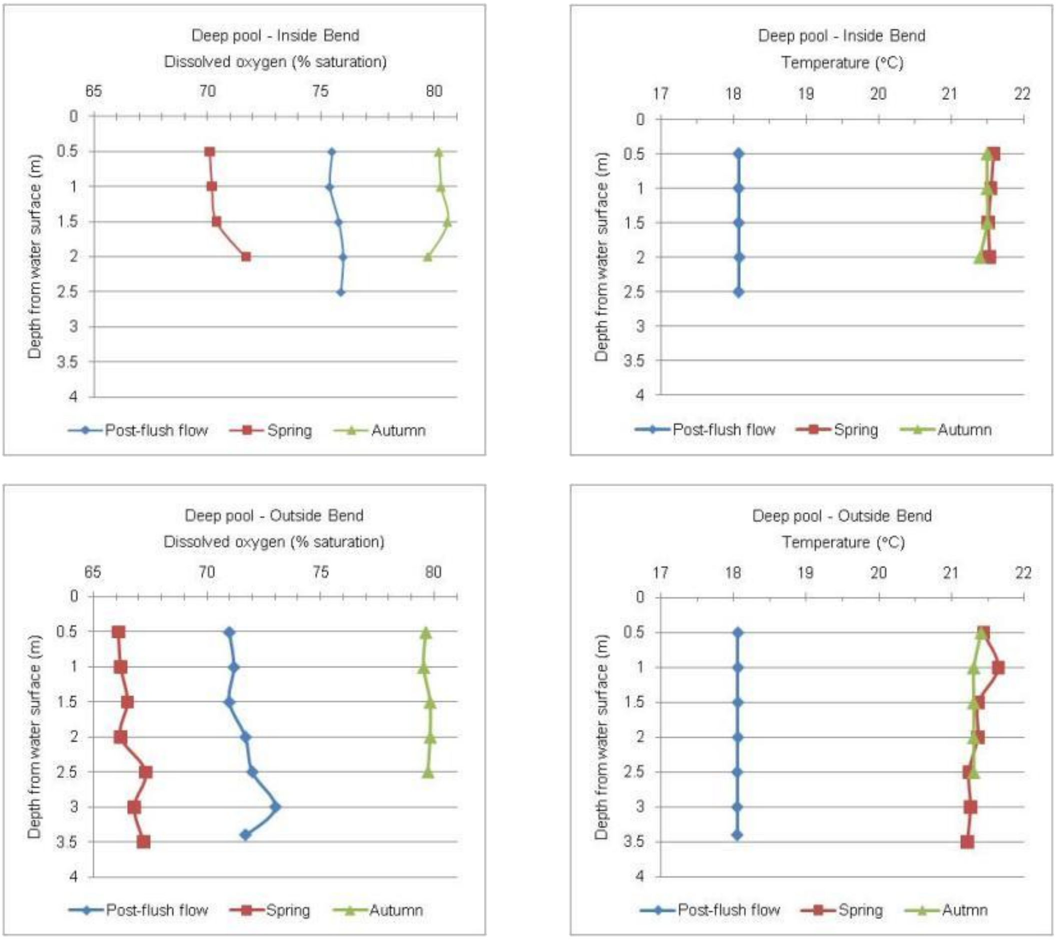


Figure 6-2: DO and temperature profiles at Site 8 (deep pool, Terania Creek)

6.4 WATER QUALITY FLOW REQUIREMENTS

Water quality in the system was indicative of good condition throughout the survey period. Nutrients, turbidity and chemical characteristics were all either well within the recommended ANZECC guidelines or where these guide lines were not met were in a range that is not critical to biota, ecological processes or physical function or the creek system.

The deep pool at site 6 remained stratified even during large flow events indicating that stratification is a normal and persistent part of the function of that pool.

Water quality is maintained in this system by low and even base flow levels.

7 Aquatic Ecology

7.1 INTRODUCTION & AIMS

This aquatic ecology assessment was undertaken to support the overall environmental flow assessment process. The specific aims of this assessment are to:

- Identify aquatic and semi-aquatic species and communities likely to occur within the Rocky Creek system
- Identify those species that may be vulnerable to impacts from the proposed dam
- Identify critical aquatic ecology flow requirements.

A separate Aquatic Ecology Impact Assessment has been prepared for Rous Water. This chapter provides aspects of the aquatic ecology assessment that relate to the development of environmental flows recommendations. The reader is referred to the Aquatic Ecology Impact Assessment (ELA 2012) for full methodology and assessment of aquatic ecology.

7.2 METHODS

7.2.1 Desktop review

A comprehensive desktop review of literature and database search relating to the Rocky Creek system was undertaken. Information reviewed included:

- Atlas of NSW Wildlife (OEH) (latitude -28.61128 to -28.71383, and longitude 153.21295 to 153.37416, Datum GDA94) (07/03/2011)
- EPBC Protected Matters Search Tool (DSEWPC 2011a) (10 km radius around latitude -28.67126 and longitude 153.00 Datum GDA94) (22/08/2012)
- Northern Rivers CMA Vegetation Mapping (ELA 2005)
- Preliminary Assessment of the Effect of Rocky Creek Dam on the Downstream Environment (Bishop 1998)
- Preliminary Investigations of Flora and Fauna at Two Potential Dam sites near Federal and Dunoon (Austeco Pty Ltd 1994)
- Proposed Dunoon Dam Site Flora and Fauna Survey and Revegetation Concept Plan (Ecos Environmental Planning 2001)
- Baseline Study to Assess the Potential Impact of a Proposed Water Storage Dam on the Platypus (Matthews 1996)
- Dunoon Dam Terrestrial Ecology Impact Assessment (SMEC 2011).

7.2.2 Field survey

Field surveys were undertaken to target:

- Aquatic and riparian flora (including exotic species)
- Macroinvertebrates (community composition and environmental tolerances)
- Fish (presence, abundance and community composition)
- Other (semi-) aquatic fauna (frogs and platypus).

Surveys were conducted at Sites 1-5 between October 2010 and April 2011 across three sampling periods (**Table 7-1**). Fish were sampled at large pools (Sites 6 and 9 only) on 15-16 September

2010. Sites were either located upstream, downstream or within the proposed dam inundation area (**Table 7-2**).

Table 7-1: Sampling dates and survey targets

SURVEY / SEASON	DATE	MACRO-INVERTEBRATE	RIPARIAN VEGETATION	FROGS	PLATYPUS	FISH
Fish survey	15-16 Sep 2010	-	-	-	-	✓
Post-Flush	17-22 Oct 2010	✓	-	i	✓	-
Spring	21-26 Nov 2010	✓	✓	✓	✓	-
Autumn	27 Mar -1 Apr 2011	✓	-	i	✓	-

i = incidental observations

Reaches were selected to cover the range of typical habitat features (pool, riffle, run) and to provide a 'control' site on Terania Creek site upstream of the confluence (Site 4). This control site provides a similar reference system by which the existing impacts of Rocky Creek Dam on macroinvertebrate composition and habitat can be identified. Sites 1-5 were defined by a 100 m reach.

Table 7-2: Survey site selection – aquatic ecology assessment

SITE NO.	LOCATION	AQUATIC ECOLOGY SURVEYS				
		AQUATIC & RIPARIAN FLORA	MACRO-INVERTEBRATES	FROGS	PLATYPUS	FISH
1	Rocky Creek: upstream of proposed Dunoon Dam inundation area	✓	✓	✓	-	-
2	Rocky Creek: within proposed inundation area	✓	✓	✓	✓	-
3	Rocky Creek: downstream of proposed dam wall	✓	✓	✓	✓	-
4	Terania Creek: upstream of Rocky Creek confluence	✓	✓	✓	-	-
5	Terania Creek: downstream of Rocky Creek confluence	✓	✓	✓	✓	-
6	Rocky Creek: deep pool downstream of proposed dam wall	-	-	-	-	✓
9	Rocky Creek: long pool in proposed inundation area	-	-	-	-	✓

Aquatic & riparian vegetation

At Sites 1-5, a 40 x 10 m quadrat was established along the stream bank for a floristic survey. The quadrat was positioned in the 100 m reach to encompass riparian zones adjacent to riffle and pool habitats. The survey included all native and weed species within the quadrat, all aquatic macrophytes in the channel and other significant flora within the reach. A cover abundance score (Braun-Blanquett method) was assigned to each species, where: 1 = <5%; 2 = 5–25%; 3 = 25–50%; 4 = 50–75%; and 5 = 75–100% of the surface.

Macroinvertebrates

Macroinvertebrates were sampled at Sites 1-5 on three occasions. Velocity, depth, silt and detritus cover, algal cover, substrate composition and aquatic vegetation of the two sampling habitats were recorded on each sampling occasion.

Macroinvertebrate collection was undertaken in accordance with a preserved-pick AUSRIVAS style survey in riffle, pool and edge habitats (Turak et al. 2004). Bags were sent to New England Limnology for family and taxa identification using the AUSRIVAS sample processing methods. Preserved samples were emptied on to a white tray for sorting whereby a preserved pick was undertaken on each sample for 40 to 60 minutes. Macroinvertebrates were then sorted and identified to family level, except for Acarnia, Cladocera, Copepoda, Oligochaeta and Ostracoda as per the NSW AUSRIVAS Method. One family of Collembola and Neuroptera could not be identified and were therefore also only identified to order level.

The Stream Invertebrate Grade Number – Average Level (SIGNAL 2) biotic index (Chessman et al. 1997, Chessman 2003) was used to provide an indication of water quality. Average SIGNAL 2 scores were calculated for each site by summing the pollution sensitivity grades assigned to each macroinvertebrate family and dividing by the number of families. Where a specimen was unable to be identified to family level, the order-class-phylum level SIGNAL 2 grade was used (Chessman, 2003). SIGNAL values range from 1 (most tolerant to pollution) to 10 (most sensitive to pollution). Water quality was defined after Chessman et al. (1997) as:

- Average SIGNAL 2 values greater than 6: clean water
- Average SIGNAL 2 values between 5 and 6: doubtful or mildly polluted
- Average SIGNAL 2 values between 4 and 5: moderately polluted
- Average SIGNAL 2 values less than 4: severely polluted.

EPT scores (Ephemeroptera, Plecoptera, Trichoptera) were also derived from the macroinvertebrate samples as these families are flow and pollution sensitive and rheophylic 'flow loving' taxa and would therefore be most impacted by altered flow regimes and loss of turbulent flow in riffles.

Fish

Fish surveys were undertaken by NSW Fisheries (then Department of Industry and Investment) at Sites 6 and 9 on 15-16 September 2010. These two sites were identified as having the potential to provide habitat for Eastern Freshwater Cod in the respective creek sections.

These surveys were undertaken to provide specific evidence of the presence of endangered and/or iconic species, such as the Eastern Freshwater Cod, in reaches which will be exposed to major impacts of the proposed dam. The presence of the exotic fish *Gambusia* (Mosquito fish) in the catchment is also of interest as predation by this species on native fauna is listed as a Key Threatening Process in NSW.

Site 6 was sampled using standard backpack electro-fishing techniques and site 9 was sampled using a combination of standard backpack and boat electro-fishing techniques. Unbaited bait-traps were also used at both locations. Fish species that were observed and not caught were also recorded. Water quality data were also taken at the time of sampling. All fish captured from both sampling methods were identified on site and subsequently released.

Fish barrier assessments

A number of potential barriers to fauna passage were identified along the reach of Rocky Creek downstream of the proposed Dunoon Dam site and along Terania creek downstream of the confluence during an initial field reconnaissance. Potential key barriers to fish passage were selected for field assessment, including five barriers in the vicinity of Site 3 and a further three barriers at Site 5.

The potential longitudinal open-passage thread/s through each key migration obstacle was assessed by recording water depth and velocity at different flow heights. Records were assessed against depth and velocity thresholds for juvenile species, adult Australian Bass and Eastern Freshwater Cod to determine if the passage was 'open' or 'closed' at that particular flow.

These assessments were completed at three different flow heights in an attempt to determine relationships between flow and fauna passage for the key fish species.

Amphibians

Frog surveys were undertaken at Sites 1, 2, 3 and 5 during the spring survey, and included:

- Active habitat searches for 30 minutes at each site on two consecutive days
- Frog Chorus census for 30 min at each site on two consecutive nights using acoustic recorders between 10-11pm
- 5 minutes call playback followed by 5 minutes listening and searching at each site on two consecutive nights targeted at threatened frog species potentially occurring within the catchment
- Opportunistic sightings.

Platypus

A targeted platypus survey was undertaken at Sites 2, 3 and 5 during each survey. This included a survey for likely habitat, targeted searches at dawn and dusk in potential platypus habitat areas and a survey of banks for burrow structures. Opportunistic sightings were also documented.

7.3 RESULTS

7.3.1 Database searches

Federal and state databases of Threatened Species, Threatened Populations and Communities and Key Threatening Processes were searched for relevance to the field area and proposed works.

Two listed threatened fish species either have been recorded or could potentially occur within the Rocky Creek catchment. These species are:

- *Maccullochella ikei* (Eastern Freshwater Cod)
- *Morgurnda adspersa* (Purple Spotted Gudgeon).

Twenty four other threatened flora and fauna species and one migratory bird species either previously recorded or likely to occur within the riparian habitat or use Rocky Creek for foraging or breeding purposes (**Table 7-3**) were identified from database searches.

Table 7-3: Threatened flora and fauna species previously recorded or potentially occurring along Rocky Creek

SCIENTIFIC NAME	COMMON NAME	LOCATION	CONSERVATION SIGNIFICANCE		LIKELIHOOD OF OCCURANCE
			TSC Act	EPBC Act	
Tinospora tinosporoides	Arrowhead Vine	Whian Whian Falls	V	-	Yes
Desmodium acanthocladum	Thorny Pea	Whian Whian Falls	V	V	Yes
Marsdenia longiloba	Slender Marsdenia	Brush Box Gully	V	V	Yes
Corokia whiteana	Corokia		V	V	Potential
Baloghia marmorata	Marbled Baloghia/Jointed Baloghia		-	V	Potential
Bosistoa transversa	Three-leaved Bosistoa		-	V	Potential
Macadamia tetraphylla	Rough-shelled Bush Nut		V	V	Potential
Elaeocarpus sp. Rocky Creek	Minyon Quandong		E	E	Potential
Hicksbeachia pinnatifolia	Red Boppel Nut		E	V	Potential
Owenia cepiodora	Onion Cedar		V	V	Potential
Syzgium hodgkinsoniae	Red Lily Pilly		V	V	Potential
Assa darlingtoni	Pouched Frog	Rocky Creek Catchment	V	-	Potential
Litoria brevipamata	Green-thighed Frog		V	-	Potential
Myxophyes fleayi	Fleay’s Barred Frog		E	E	Potential
Myxophyes iteratus	Giant Barred Frog	Rocky Creek Catchment	E	E	Potential
Dasyurus maculatus	Spotted-tailed Quoll		V	-	Potential
Myotis macropus	Southern Myotis	Rocky Creek Catchment	V	-	Potential
Nyctophilus bifax	Eastern Long-eared Bat	Rocky Creek	V	-	Potential

SCIENTIFIC NAME	COMMON NAME	LOCATION	CONSERVATION SIGNIFICANCE		LIKELIHOOD OF OCCURANCE
			TSC Act	EPBC Act	
		Catchment			
Ixobrychus flavicollis	Black Bittern		V	-	Potential
Ardea ibis	Cattle Egret		-	M	Potential
Ephippiorhynchus asiaticus	Black-necked Stork		E	-	Potential
Erythrotriorchis radiatus	Red Goshawk	Rocky Creek Catchment	E4A	V	Potential
Amaurornis olivaceus	Bush Hen	Rocky Creek Catchment	V	-	Potential
Irediparra gallinacea	Comb-crested Jacana		V	-	Potential

V= vulnerable; E = Endangered; E4A = Critically Endangered; M = Migratory

Two ROTAP species, *Archidendron muellerianum* (Veiny Lace Flower), category 3RCa, and *Quassia sp. 2,* category 3RC (3 = known from more than one specimen and occupying a range greater than 100 km; R = rare, but not endangered or vulnerable; C = conserved in some sort of reservation; a = adequately reserved), have previously been recorded in the area (Austeco 1994).

Database searches showed there are no listed threatened populations or communities of aquatic flora or fauna (fish or aquatic macroinvertebrates species) known to occur within the proposed study area. However; Lowland Rainforest EEC was identified to be occurring within the proposed inundation area within 10 m either side of Rocky Creek (SMEC 2011). This community is listed under the NSW TSC Act.

Threatening processes that are listed under the FM Act that are relevant to the proposed Dunoon Dam include:

- The removal of large woody debris from NSW rivers and streams
- The degradation of native riparian vegetation along NSW watercourses
- The installation of in stream structures and other mechanisms that alter natural flow regimes of rivers and streams (NSW DPI 2011).

Threatening processes that are listed under the TSC Act that are relevant to the proposed Dunoon Dam include:

- Predation by *Gambusia holbrooki* (Mosquitofish)
- Alteration to the natural flow regimes of rivers, streams, floodplains and wetlands (OEH 2011).

7.3.2 Literature review

Riparian vegetation

Previous studies found the condition of the riparian vegetation within the proposal area to be of variable condition. Riparian habitats located adjacent to forest vegetation were in good condition while areas further downstream and adjacent to agricultural land were in poor and reduced condition with invasive species present (Sainty 1998; Austeco 1994). Between Rocky Creek Dam and the Terania Creek confluence, approximately 20% of the left and 25% of the right banks had a combination of native and exotic riparian vegetation greater than 100 m wide (Sainty 1998).

Two types of rainforest vegetation (complex subtropical and dry rainforest) were found along the riparian zone; few areas of rainforest were of pristine condition. The remnant of complex rainforest was small yet significant. These remnants were found to be in good condition with dense vines and very small amounts of *Lantana camara* (Lantana) and Small-leaved Privet. Although the dry rainforest had a high diversity of canopy species it appeared to have been heavily disturbed previously and there was a minor Camphor Laurel invasion (Austeco 1994).

Five exotic species were identified within the study area; of note were Lantana, Small-leaved Privet and Camphor Laurel. Exotic species posed the biggest threat between the Channon Road Bridge (Robertson Bridge) and the Terania Creek confluence. In some areas Privet dominated the native species. Healthy assemblages of some native riparian plants were found, with species including *Tristaniopsis laurina* (Water Gum), *Acmena Smithii* (Narrow-leaf Lilly Pilly), *Callistemon viminalis* (Callistemon) and *Ficus coronata* (Sandpaper Fig) (Sainty 1998).

The *Dunoon Terrestrial Ecology Impact Assessment* (SMEC 2011) identified Sub-tropical Rainforest and Warm Temperate Rainforest communities within the proposed inundation area within 10 m either side of Rocky Creek. These communities are incorporated into the Lowland Rainforest EEC which is listed under the NSW TSC Act.

Aquatic vegetation

Sainty (1998) recorded 14 species of submerged, floating and floating attached flora species within Rocky Creek downstream of Rocky Creek Dam. The three dominant species included *Hydrilla verticillata* (Hydrilla), *Potamogeton javanicus,*and *Vallisneria nana* (Ribbon Weed). Due to long periods of low flows these flora species are abundant in all but the steepest parts of Rocky Creek. Further downstream of Rocky Creek Dam there are long elongated pools that contain large beds of Hydrilla and *Chara* spp. and occasional dense patches of *P. javanicus* and Ribbon Weed. Observations were also made along reference creeks upstream of Rocky Creek Dam and in the upper reaches of Terania Creek within Nightcap National Park. These observations found that the creeks were either totally devoid of, or had very small populations of, submerged, floating and floating attached flora species (Sainty 1998).

Sainty (1998) suggests that, prior to the construction of Rocky Creek Dam, high base flows, minor flood flows and occasional large floods would have scoured away sediments, removing habitat required for the establishment of emergent macrophytes. Field surveys conducted by Sainty (1998) post-construction of Rocky Creek Dam found 28 species of emergent macrophytes and 14 weed species. The number of species found was attributed to long periods of low flow which provided optimal conditions for these plants to colonise in all but the steepest sections. In some areas the density of vegetation was obstructing the flow of water. The most dominant emergent macrophytes were *Carex* spp., *Lomandra* spp., *Cyprus* spp., and *Juncus* spp. None of the weed species were classed as a serious threat at the time of this study. However, the presence and increased abundance of *Rorippa nastrurtium aquaticum* (Watercress) and *Myriophyllum aquaticum* (Brazilian Watermilfoil) were indicators that ample nutrients were entering the system.

Floating & attached algae

Sainty (1998) sampled algae from eight sites along Rocky Creek. Moderate to high densities of diatoms were found on rocks and submerged macrophytes in the creek, downstream of Rocky Creek Dam. The level of algae species diversity and abundance found in the system was assisted by lengthy periods of low flow. Only one species of blue-green algae was detected. The reference sites were found to have a comparatively low abundance of algae which may have been due to riparian vegetation and steep banks restricting light penetration to the streambed (Sainty 1998).

Aquatic macroinvertebrates

An assessment of aquatic macroinvertebrates was undertaken within Rocky Creek and six reference streams in 1998. Results showed that sites downstream from Rocky Creek Dam had fewer sensitive macroinvertebrates than the reference sites. Low food availability and large quantities of sediments and organic matter were also recorded downstream from the dam. Bishop (1998) determined that it was highly likely that the macroinvertebrate fauna had been impacted by the alteration of the hydrological cycle due to Rocky Creek Dam. The maximum occurrence of sensitive fauna downstream of the dam was less than the minimum number recorded within the reference condition sites.

Bishop (1998) recorded no large crayfish, however, potential crayfish burrows were observed at the water's edge. Bishop (1998) concluded that it is likely that two species of large spiny crayfish, *Euastacus sulcatus* (Mountain Crayfish) and *Euastacus valentulus* (Powerful Crayfish) occur in the system as Rocky Creek meets their distribution and habitat requirements.

Fish

Data from the Australian Museum, Industry & Investment NSW, EPBC records and previous studies were reviewed to obtain an inventory of fish fauna for the proposed Dunoon Dam study area. Austeco (1994) identified 26 fish species previously recorded as inhabiting two potential dam sites, Dunoon and Federal, and a further nine which could potentially occur at the sites. Three of the identified species are listed under the FM Act, two of which is also listed under the federal EPBC Act. These species are:

- *Maccullochella ikei* (Eastern Freshwater Cod) – FM Act and EPBC Act
- *Morgurnda adspersa* (Purple-spotted Gudgeon) – FM Act
- *Nannoperca oxleyana* (Oxleyana Pygmy Perch) – FM Act and EPBC Act. Likely to have been found in the Federal Valley Area, unlikely to be present in the Rocky Creek Area.

Austeco (1994) also suggested that significant populations of Australian Bass and Eastern Freshwater Cod are likely to occur in Rocky Creek Dam since their release into the storage between 1988 and 1990. Bishop (1998) also mentions previous recordings of *Tandanus tandanus* (Eel-tailed Catfish). Rocky Creek Dam has also caused a significant hydrological impact on fish downstream of the dam wall (Bishop 1998). However, Eastern Cod has been recorded in two separate pools downstream of Rocky Creek Dam in the 1990s (Bishop 1998).

Data provided by Industry & Investment NSW indicate that between 1975 and 2006 thirty-one fish species have been identified in the Leycester Creek sub-catchment of the Richmond River Catchment, an area that includes Rocky Creek. Of these species two are introduced, *Cyprinus carpio* (Common Carp) and *Gambusia holbrooki* (Eastern Gambusia). As these data encompass the entire Leycester sub-catchment is not clear which species were found within Rocky Creek.

Fish barrier assessments

The depth and velocity thresholds for juvenile and adult Australian bass and Eastern freshwater cod (the two key fish species of specific concern) used for this assessment are shown in **Table 7-4**.

Table 7-4: Fauna passage assessment – velocity and depth thresholds (Bishop 2001)

THRESHOLDS		JUVENILE SPECIES	ADULT BASS	ADULT COD
Minimum required depth for passage		0.1m	0.2m	0.3m
Maximum Velocity	**Burst**: Barrier < 10m or > 10m with regular sheltering points	0.8m/s	1.5m/s	2.0m/s
	Prolonged: Barrier > 10m with few sheltering points	0.6m/s	1.0m/s	1.5m/s

Amphibians

The Richmond River Area Water Sharing Plan – Background Document, developed by the NSW Office of Water (2010), lists seven threatened frog species known or expected to occur within Terania Creek:

- *Assa darlingtoni* (Pouched Frog)
- *Crinnia tinnula* (Wallum Froglet)
- *Litoria brevipamata* (Green-thighed Frog)
- *Myxophyes balbus* (Stuttering Frog)
- *Myxophyes fleayi* (Fleay's Barred Frog)
- *Myxophyes iteratus* (Giant Barred Frog)
- *Philoria Loveridgei* (Loveridge's Frog).

None of these threatened species were recorded during a targeted search within the survey area in 2001 which involved spotlighting and call playback. However, five native species and one exotic species were recorded (Eco Environmental Planning 2001).

Platypus

The length of creek downstream from Rocky Creek Dam to the Terania Creek confluence provides habitat suitable for platypus. Platypus are able to survive in considerably disturbed habitat (Grant 1998). Platypus observations were recorded in the upper sections of the survey area where there was a relatively low level of disturbance but also in the lower reaches of the survey area where the riparian zone is relatively degraded (Grant 1998). Matthews (1996) recorded platypus at pools just below Simes Bridge, within the proposed Dunoon Dam inundation area and in Terania Creek just upstream from its confluence with Rocky Creek while Grant (1998) observed platypus at three of four sites located between the proposed Dunoon Dam wall and the Rocky Creek and Terania Creek confluence.

7.3.3 Field survey

Aquatic & riparian vegetation

In total, 126 native flora species were recorded. There were 34 exotic species with significant exotic species including Camphor Laurel, Small-leaved Privet, Lantana, *Tradescantia fluminensis* (Wandering Jew), *Anredera cordifolia* (Madeira Vine) and *Cardiospermum grandiflorum* (Balloon Vine). Exotic ground layer species include *Ageratina adenophora* (Crofton Weed), *Amaranthus* sp., *Drymaria cordata* (Tropical Chickweed), *Rumex crispus* (Curled Dock), *Setaria sphacelata* (South African Pigeon Grass), *Solanum americanum* (Glossy Nightshade) and *S. seaforthianum* (Climbing Nightshade). Five are declared noxious weeds or weeds of national significance: Camphor Laurel, Crofton Weed, Lantana, Mistflower and Small-leaved Privet.

One Rare or Threatened Australian Plant species was also found *Helmholtzia glaberrima* (Flax Lily) at Site 1. One threatened species listed under both the TSC Act and EPBC Act *Desmodium acanthocladum* (Thorny Pea) was found at Sites 1 and 3.

Site 1 was dominated by a variety of native canopy species, with less diversity in the shrub and ground layer, as reported within the rainforest community. Site 2 was also dominated by a variety of native canopy species, however, Camphor Laurel was present and had the highest single cover score. There were two species in the shrub layer, including the exotic species Small-leaved Privet. Site 3 was also dominated by a variety of native canopy species; the shrub layer contained four shrub species, two of which were exotic, Lantana and Small-leaved Privet. There was also a diversity of ground cover species including *Tradescantia fluminensis* (Wandering Jew). Site 4 was dominated by exotic ground cover species, the shrub and canopy layer were not as abundant as the groundcover and were primarily composed of native species, however, Small-leaved Privet was present. Site 5 also had a diversity of mostly exotic groundcover species. The canopy and shrub layers were composed of three and two species respectively, with Camphor Laurel and Small-leaved Privet both present. Detailed riparian and aquatic vegetation descriptions for each site can be found in the Aquatic Ecology Report (ELA 2012).

Few macrophytes were found during the study which is consistent with the findings of Sainty (1998). The greatest number of macrophytes was found during the October survey. Generally macrophytes covered less than 5% of the 100 m reach. Aquatic species such as Ribbon Weed (*Vallisinaria* sp.) and *Myriophyllum papillosum* (Common Watermilfoil) which were recorded at Sites 4 and 5 are a food source and an important habitat feature for some of the fauna which inhabit the creek, in particular some species of fish which attach their eggs to vegetation or use it as shelter from prey.

Aquatic macroinvertebrates

A total of 5055 individual aquatic macroinvertebrates were collected from pool edge and riffle habitats comprising of 73 families distributed between 23 orders.

The average SIGNAL2 scores representing both pool-edge and riffle habitats ranged from 4.84 (Site 1) to 5.22 at Site 5 on Terania Creek over the study period, indicating all sites have mildly to moderately impacted macroinvertebrate communities (**Figure 7-1**). As expected, riffle habitats had consistently higher SIGNAL2 scores that the composited pool-edge habitat due to superior habitat and food availability. Average SIGNAL2 scores were generally higher in autumn following a high rainfall summer period rather than in spring as predicted, suggesting the macroinvertebrates have responded positively to the increased flow variability.

Survey results for this report reflect those of Bishop (1998) in that the sites nearest to Rocky Creek Dam are in a poorer condition than those located progressively downstream. The average SIGNAL2 score for pool and riffle habitats indicate that Site 5, the reference site for Sites 3 and 4 was generally found to be in better condition than sites 1, 2 and 3 whilst Site 4 had a slightly higher score during the October and November sampling and considerably lower in the March sampling.

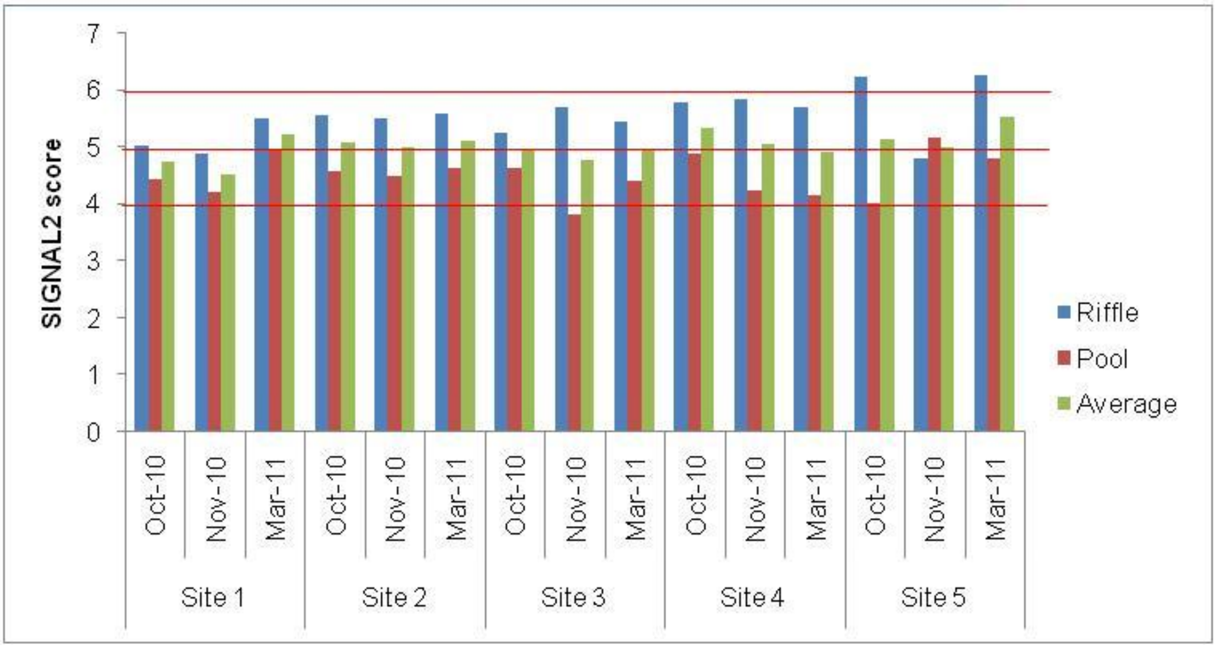


Figure 7-1: Abundance weighted SIGNAL2 scores for pool edge and riffle habitats

Fish

A fish survey was conducted on 15-16 September 2010 using a combination of backpack and boat electro-fishing, and baited traps only at Sites 6 and 9. Water quality was recorded at the time of sampling; all parameters measured were within the ANZECC guideline range.

Electro-fishing resulted in 154 individual fish representing 8 species being recorded at Site 6, and 59 individual fish representing 8 species being recorded at Site 9. The unbaited traps yielded 40 individuals representing 4 species at Site 6, and 5 individuals representing 2 species at Site 9.

A total of 13 species were caught with the electro-fisher and a total of 4 species were caught in the bait-traps across both sites (**Table 7-5**). All four species that were caught in the bait-traps were also caught with the electro-fisher. Striped Gudgeon were by far the most abundant species contributing almost half of the total individual caught or observed (160 individuals). Striped mullet were the next most abundant species (72 individuals) although they were only found at Site 9. There were no introduced species and no rare or threatened species caught or observed.

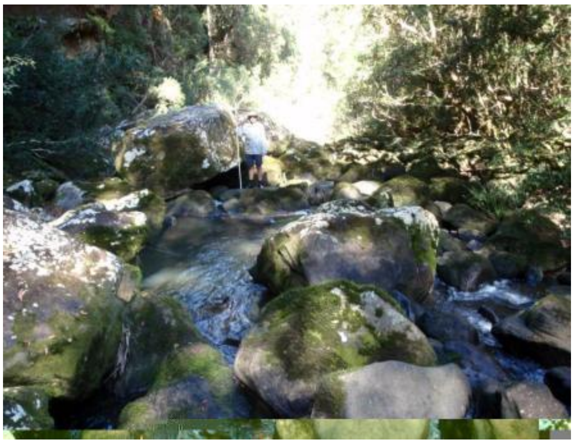
Table 7-5: Fish species detected during 2010 survey on Rocky Creek

SPECIES	COMMON NAME	SITE 6	SITE 9
Anguilla reinhardtii	Longfin eel	✓	✓
Hypseleotris compressa	Empire gudgeon	✓	
Hypseleotris galii	Firetail gudgeon	✓	✓
Hypseleotris klunzingeri	Western carp gudgeon	✓	✓
Gobiomorphus australis	Striped gudgeon	✓	✓
Gobiomorphus coxii	Cox's gudgeon	✓	
Macquaria novemaculeata	Australian bass		✓
Mugil cephalus	Sea mullet		✓
Myxus petard	Freshwater mullet		✓
Notesthes robusta	Bullrout	✓	
Philypnodon grandiceps	Flathead gudgeon		✓
Retropinna semoni	Australian smelt	✓	
Tandanus tandanus	Freshwater catfish		✓

Fish barrier assessments

Five potentially key barriers in the vicinity of Site 3 were assessed on Rocky Creek (two upstream and three downstream of Site 3). Three barriers were assessed along Terania Creek at Site 5 (**Table 7-6**).

Table 7-6: Fauna passage assessment – potentially key barriers

Site 3 – Rocky Creek  ***Barrier 1*** (immediately downstream of proposed wall); 10 m length, 2 m drop	***Site 3 – Rocky Creek***  ***Barrier 2*** (downstream of proposed wall); Subterranean barrier ~ 2 m length
Site 3 – Rocky Creek  ***Barrier 3*** (immediately downstream of Site 3); 16 m length; 1.2 m drop	***Site 3 – Rocky Creek***  ***Barrier* 4** (downstream of Site 3); Subterranean barrier ~ 7 m length

Site 3 – Rocky Creek	***Site 5 – Terania Creek***
	
Barrier 5 (downstream of Site 3); 3 m length, 0.7 m drop	***Barrier 6*** (downstream of confluence); Riffle
Site 5 – Terania Creek	***Site 5 – Terania Creek***
	
Barrier 7 (immediately upstream of Site 5); Riffle	***Barrier 8*** (immediately downstream of Site 5); Riffle

If the flow at the time of survey was less than the threshold criteria for each species (i.e. minimum depth is reached and exceeded and velocity is less than maximum allowable) the passage was classified as open.

Two key species of concern along Rocky Creek include Australian Bass and Eastern Freshwater Cod. It is noted, however, that only the Australian Bass was found during the fish assessment in 2010. Of these two species, the Eastern Freshwater Cod is the limiting species as it requires greater minimum depth for passage (0.2-0.3m) (**Table 7-4**). That is, if a barrier is open to Eastern Freshwater Cod it should also be open to bass (until the maximum threshold velocity of 1.5 ms^{-1} is reached).

Based on these thresholds, all of the potentially key barriers assessed along Rocky Creek were open at 130 MLd^{-1} with the exception of the barriers closest to the proposed dam. These top two barriers open up at flows between 130 MLd^{-1} and 142 MLd^{-1} (**Table 7-7**), however Barrier 3 just up from the deep pool was closed at this higher flow range.

Table 7-7: Fauna passage assessment – results

SITE	FLOW					
ROCKY CREEK	20 MLd^{-1}		130 MLd^{-1}		142 MLd^{-1}	
	Juv	*Adult*	*Juv*	*Adult*	*Juv*	*Adult*
Barrier 1	Closed	Closed	Closed	Closed	Closed	Open
Barrier 2	Closed	Closed	Closed	Closed	Closed	Open
Barrier 3	Open	Open	Closed	Open	Closed	Closed
Barrier 4	Open	Closed	Open	Open	Open	Closed
Barrier 5	Open	Open	Closed	Open	Closed	Closed
TERANIA CREEK	95 MLd^{-1}		340 MLd^{-1}		365 MLd^{-1}	
	Juv	*Adult*	*Juv*	*Adult*	*Juv*	*Adult*
Barrier 6	Open	Open	Open	Open	Open	Open
Barrier 7	Open	Open	Open	Open	Open	Open
Barrier 8	Open	Open	Open	Open	Open	Open

Amphibians

Frogs were surveyed during the spring sampling period. There were two frog calls identified at Site 1, *Litoria fallax* (Eastern Dwarf Tree Frog) and *Litoria pearsoniana* (Pearson's Green Tree Frog). There was one frog call heard at Site 5, however, it was unidentifiable due to the short duration of the call (~2 seconds). There were no frog calls heard at site 2 or 3. No threatened or endangered frog species were recorded during this sampling effort at any of the sites.

Platypus

Sites 2, 3 and 5 were surveyed for platypus burrows and sightings of individuals; these sites were deemed to be likely habitat for the species. Burrow clusters were found at each site on all sampling occasions with the exception of Site 5 during the autumn survey when none were visible.

Platypus sightings were made in the spring and autumn sampling periods at Site 2 and in the post-flush and spring sampling periods at Site 5. There were no platypus sightings made at Site 3 (**Table 7-8**). No burrows or foraging habitat was found further downstream than Site 3 on Rocky Creek.

Table 7-8: Platypus and platypus burrow observations from study sites 2, 3, and 5 along Rocky Creek and Terania Creek, Richmond River Catchment, NSW

	SITE 2			SITE 3			SITE 5		
	Oct-10	Nov-10	Mar-11	Oct-10	Nov-10	Mar-11	Oct-10	Nov-10	Mar-11
Burrows (clusters)	9	7	3	3	5	2	1	3	0
Sightings	0	1	1	0	0	0	2	2	0

7.4 AQUATIC ECOLOGY FLOW REQUIREMENTS

Aquatic ecology flow requirements can be thought of as discrete sets of flows required to maintain or improve the aspects of habitat for aquatic and riparian vegetation, macroinvertebrates, fish, amphibian and other aquatic vertebrates. Each of these is considered below.

7.4.1 **Aquatic & riparian vegetation**

There are several factors that determine the extent and composition of aquatic and riparian vegetation, including:

- Nutrients and sunlight
- Flow extremes
- Flow regimes
- Hydraulics
- Substrate composition
- Baseflow stability.

These factors result in spatial and temporal variability in macrophyte assemblage resulting in patchy distribution along a watercourse. It has been found that year round, stable base flows provide ideal conditions for aquatic plants, often resulting in excessive growth. It is also said that stable baseflows tend to encourage the growth of invasive natives such as *Typha* sp. and exotic species such as Water Hyacinth (Bunn & Arthington 2002). Whilst aquatic plants provide habitat and food for some species, excessive growth can be have negative impacts, for example, the Bush Hen which has been recorded in the area rarely swims through submerged vegetation in order to forage. The Large-footed Mouse-Eared Bat is also at risk from excessive growth of aquatic plants, potentially becoming entangled by vegetation as it skims the water surface to capture fish and insects (Bishop 1998a).

Scouring and deposition caused by floods influences riparian and aquatic vegetation composition. Mild scouring can remove dominant species which causes gaps, enabling colonisation by opportunistic species, typically herbs and bryophytes. Severe and frequent scouring which removes fine soil particles, leaving behind gravel, cobbles and rocks is more suitable to the colonisation of shrubs. Deposition of sediments is aided by riparian vegetation which results in further habitat heterogeneity which in turn influences the diversity of riparian vegetation. It is therefore suggested that a high variability in flood regime would promote species richness (Wintle and Kirkpatrick 2007).

As noted by Sainty (1998) Rocky Creek has low percentage cover of aquatic vegetation as high flow disruption scours fine sediments and physically removed vegetation. Maintenance of a regime that continues to deliver high flow and flood events as well as periods of base and low flows should maintain Rocky Creek in its current state.

7.4.2 **Aquatic macroinvertebrates**

A total of 5055 individual aquatic macroinvertebrates were collected from pool-edge and riffle habitats comprising 73 families distributed between 23 orders. The average SIGNAL2 scores representing both pool-edge and riffle habitats ranged from 4.84 at Site 1 below Rocky Creek Dam to 5.22 at Site 5 on Terania Creek, indicating all sites have mildly to moderately impacted macroinvertebrate communities. As expected, riffle habitats had consistently higher SIGNAL2 scores than the composited pool-edge habitat due to improved habitat and food availability.

Riffle habitats were consistently dominated by flow sensitive and rheophyllic taxa such as Hydropsychidae larvae (net spinning caddis flies), Elmidae larvae (Riffle Beetles), Baetidae nymphs (mayfly) and Simuliidae larvae (blackfly). These taxa were not abundant is pool-edge habitats, highlighting the necessity to maintain flow habitat requirements in riffles and runs for these taxa. The pool-edge habitat also contained pollution sensitive taxa such as Leptoceridae (long-horned caddisfly) that are impacted by sedimentation of habitat, indicating that maintaining flows to mobilise fine sediments is important for these communities.

Average SIGNAL2 scores were generally higher in autumn following a high rainfall summer period rather than in spring as predicted. Macroinvertebrate sampling was conducted approximately 30 days after the high flow, suggesting the macroinvertebrate community responds positively to high discharge events and increased flow variability.

7.4.3 **Fish**

Alteration of the natural hydrograph has associations with direct (e.g. barriers to dispersal) and indirect effects of flow regulation (Growns & James 2005). Reduced variability of flow influences aquatic habitat diversity (Merigoux & Ponton 1999) thereby affecting the flora, fauna and ecosystem processes that support fish populations. The impacts of flow regulation on flow regime are also likely to extend beyond the reach where a dam is present (Growns & James 2005).

An increase in species richness often occurs concomitantly with an increase in habitat complexity. Depth, velocity and cover are important variables influencing this relationship (Bunn & Arthington 2002). Habitat structure is also influential in determining fish assemblage structure. Flow variability at a range of spatial scales will also influence associations between fish and their habitat. Hydrologically variable streams have been found to be typically inhabited by fish species with generalist feeding strategies and a preference for low water velocity, silt and non-specialised substrata. Streams with predictable hydrological regimes and stable base flows generally contain more silt-tolerant species. As a result of this relationship between flow, habitat structure and fish species composition, modifications to flow regime can affect fish diversity and the functional organisation of fish communities (Bunn & Arthington 2002).

Flow requirements vary among taxa in both magnitude and also timing. Both water depth and flow velocity are proportional to flow volume, and impact localised fish movement and activity as well as longitudinal movement up and/or down a system or barrier. Typically fish can withstand faster speeds to pass through short barriers (known as ‘bursts’) while lower velocities can be sustained for a longer run. A minimum flow is the flow that provides sufficient depth for a fish to move through a ‘barrier’. Note that for flows to be suitable for migration or longitudinal movement, a certain velocity threshold must not be exceeded while the minimum flow depth is achieved.

The flow regime of a system can also provide cues for events such as the spawning behaviour and migratory patterns and processes such as larval survival and development of certain fish species which are dependent of habitat connectivity (Bunn & Arthington 2002). Fish can be characterised by their movement patterns, although traits for each species may vary between regions as they evolve to local conditions. Many species have facultative movement traits, when more than one migration pattern occurs but they do not wholly rely on one for survival (Pusey et al. 2004).

Although little research has been conducted on the fish species found in Rocky Creek, cues for migration and critical phases of spawning, larval development, larval movement and juvenile recolonisation are often related to water temperature, change in discharge, change in daylight hours or a unique relationship between these environmental conditions.

For example, *Hypseleotris compressa* (Empire Gudgeon) undergoes a peak spawning period between January and March in SE Qld during a possible combination of high water temperature (critical temp 20-30 °C) and elevated discharge. Adult fish migrate upstream for dispersal and reproduction and newly hatched larvae are washed downstream in the elevated waters. Juveniles then perform a mass upstream migration during high flows. They can complete their entire life cycle in freshwater but do occur in estuaries.

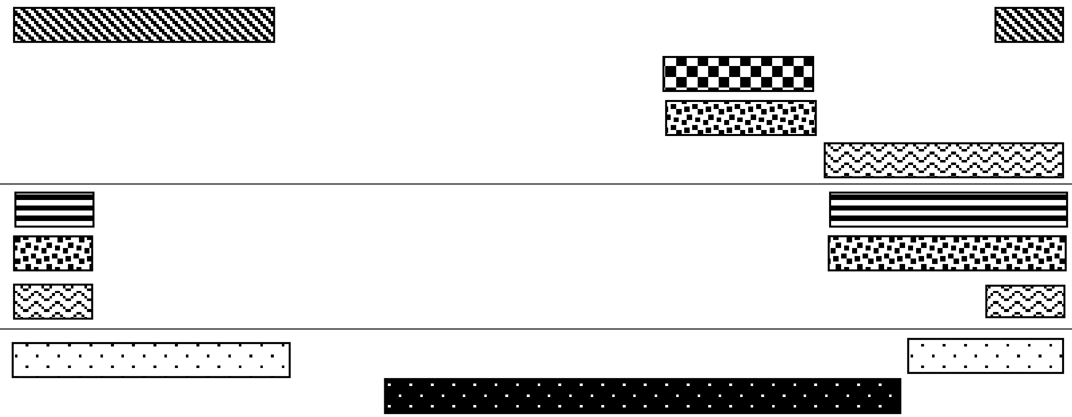
Contrasting the summer movement of the Empire Gudgeon, Australian Bass favour cooler conditions (critical temp 11-24 °C) and decreasing daylight hours. If flows are still elevated in autumn/winter, mostly females migrate downstream to spawn in brackish tidal and estuarine waters. Adults may not migrate in years of low flow. After spawning, males remain downstream while females migrate back upstream around Aug-Dec, possibly to the original pool. Juveniles (2-3 months old) migrate upstream during spring and summer and possibly only during short periods of stable low flow. Australian Bass are not prone to jumping barriers and have a threshold to shallow depth and high velocity as they move upstream.

Three significant fish species were identified as potentially being present in the Rocky Creek system; the Eastern Freshwater Cod, the Australian Bass and a species of Eel-tailed Catfish (*Tandanus* undient. subsp. A). The Australian Bass was the only one of these three species recorded during the current survey, however, there are records are all three species occurring in Rocky Creek downstream of the dam. Timing of critical biological activities for each of these species is provided in **Table 7-9**.

Reduced low-end flows can reduce the opportunity for movement by large fish species through riffle and run habitats with their body height and length limiting the ability to move through shallow areas. Therefore this assessment sought to determine the upper flow threshold that will allow movement of these species up to the proposed dam wall. It has assumed that maintaining transparent flows (i.e. low to moderate flows) up to this threshold will continue to provide opportunities for movement and migration of smaller fish species found in the system.

Table 7-9: Critical biological activities per month for key fish species in Rocky Creek (Bishop 1998)

COMMON NAME	MOVEMENT/ACTIVITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Eastern Cod	Juvenile Movement												
	Movement of adults for spawning												
	Spawning												
	Development of larvae & juveniles												
Eeltail Catfish	Nesting												
	Spawning												
	Development of larvae & juveniles												
Australian Bass	Movement of juveniles upstream												
	Movement of adults downstream												



Key:

Juvenile Movement	Movement of juveniles
Movement of Adults for Spawning	Movement of adults
Spawning	Nesting
Development of larvae & juveniles	

Flow-dependent habitat features which are important for maintaining these activities are shown in **Table 7-10** (Bishop 1998).

Table 7-10: Flow-dependent habitat features important in critical biological activities of the key fish species likely to occur Rocky Creek (Bishop 1998)

MONTH	EASTERN COD	EELTAIL CATFISH	AUSTRALIAN BASS
January	Up/downstream passage for juveniles	Water level stability in pools and high food supply	Upstream passage for juveniles
February	Up/downstream passage for juveniles	High food supply	Upstream passage for juveniles
March	Up/downstream passage for juveniles	-	Upstream passage for juveniles
April	-	-	
May	-	-	Downstream passage for adults
June	-	-	Downstream passage for adults
July	-	-	Downstream passage for adults
August	Up/downstream passage for adults and water level stability in pools	-	Downstream passage for adults
September	Up/downstream passage for adults and water level stability in pools	-	Upstream passage for adults
October	High food supply	Water level stability in pools	Upstream passage for adults
November	High food supply	Water level stability in pools	Upstream passage for juveniles
December	High food supply and up/downstream passage for juveniles	Water level stability in pools and high food supply	Upstream passage for juveniles

The field fish barrier assessment found that all major fish barriers up to Whian Whian Falls are open as the flow rises and falls between 130-142 MLd^{-1} (**Table 7-10**). Barriers 3, 4 and 5 (i.e. from the first deep pool downstream of Dunoon Dam to the Rocky Creek confluence) are all open as flows range between 20-130 MLd^{-1}.

It is likely that the top two barriers (Barriers 1 and 2) will be within the reach highly impacted by the proposed Dunoon Dam, with the dam wall itself providing a permanent artificial barrier to fish passage. Whian Whian Falls is a natural barrier to any further movement upstream of the proposed dam wall.

Barrier 3 (immediately upstream of the deep pool that is Site 6) is likely to be the limiting barrier for fish passage, given that it is located between the proposed dam wall and the largest pool in Rocky Creek downstream of the proposed wall.

Based on the thresholds of movement (velocity and depth) all of the potentially key barriers assessed along Rocky Creek were open at 130 MLd^{-1} (depth and velocity requirements of the three iconic species were met) with the exception of the barriers closest to the proposed dam.

Transparency of flows up to 130 MLd^{-1} should also maintain connectivity for smaller species in this low-moderate flow range.

7.4.4 Amphibians

Frogs are integral components of river ecosystems being both an important food source for birds, reptiles and fish and also predators of a large variety of small aquatic animals. Frogs can also be indicators of overall catchment health as they are sensitive to alterations in natural water regimes. Many frog species have highly specialised requirements in terms of the timing of inundation and frequency of inundation. Of those species recorded within the survey area (either during this survey or from earlier studies) five have similar flow requirements (**Table 7-11**). The Green-thighed frog, Pearson's Green Tree Frog, Stuttering Frog, Fleay's Barred Frog and the Giant Barred Frog all require increased flows during the spawning season (October through summer). Increased flows provide shallow water at the sides of streams in which females can lay their eggs or to provide habitat for tadpoles and clean the bottom substrates of sediments to allow tadpole attachment. The Giant Barred Frog uses terrestrial nest sites and requires flushing flows so that its eggs are washed in to the river. The Green-thighed Frog and Fleay's Barred Frog also need increased flows to stimulate breeding activity (Bishop 1998).

Table 7-11: Amphibian species recorded within the survey area from current and previous surveys

SPECIES	SPAWNING HABITS/REQUIREMENTS	SPAWNING PERIOD	FLOW REQUIREMENTS*
Green-thighed Frog *Litoria brevipalmata*	Eggs laid in ponds, flooded grasslands or ditches	After summer rains	Increased flows, flushing flows to clean sediments from the substrate to enable tadpoles to rest
Eastern Dwarf Tree Frog *Litoria fallax*	Attached to underwater vegetation	Spring and summer	
Pearson's Green Tree Frog *Litoria pearsoniana*	clumps of eggs laid in sheltered rock pools	October to February, warm summer nights after rain	Shallow water at the sides of streams and pools for tadpoles, therefore significantly increased flows
Marsupial Frog *Assa darlingtoni*	Male frog carries tadpoles in skin pockets they are later released as fully developed frogs		Does not need water to breed
Wallum Froglet *Crinia Tinnula*	Eggs are often attached to stems of plants	Autumn, but may also occur in late winter, spring and summer	
Stuttering Frog *Mixophyes balbus*	Females create a small hollowed-out nest in shallow flowing water and lay their eggs in it	Spring and summer	Tadpoles live in fast flowing streams

SPECIES	SPAWNING HABITS/REQUIREMENTS	SPAWNING PERIOD	FLOW REQUIREMENTS*
Fleay's Barred Frog *Mixophyes fleayi*	Females create a small hollowed-out nest in shallow flowing water and lay their eggs in it	Spring and summer	Significantly increased flows, flushing flows to clean sediments from the substrate to enable tadpoles to rest
Giant Barred Frog *Mixophyes iteratus*	Eggs are attached to leaves, rocks and grasses above the surface of the water	Spring and summer	Significantly increased flows, flushing flows to clean sediments from the substrate to enable tadpoles to rest

*Information source: Australian Frogs Database (2011)

7.4.5 Platypus

Platypus generally inhabit shallow rivers or streams with steep earth banks and a diversity of benthic habitats. As platypus build their burrows in the banks above the water level, riparian vegetation is important as roots assist in supporting and strengthening the banks whilst overhanging vegetation provides protection from predators. There are historical reports of platypus mortality due to flooding, in particular in association with bank erosion; generally platypus are able to survive flooding events, possibly due to the animal moving into adjacent wetlands and backwaters until waters have subsided (Scott and Grant 1997).

Research indicates that extended periods of bankfull flows are harmful to platypus, in particular where there are no backwaters available in which they are able to seek refuge. Bankfull flows tend to flood platypus burrows and the higher velocities result in the animal expending more energy whilst feeding. The availability of benthic invertebrates tends to decrease after sustained high flows. Cold water released from dams can also require platypuses to expend more energy in order to maintain body temperature. This increased energy requirement of the platypus and reduced availability of food triggered by higher flows can reduce the condition of the platypus (Scott and Grant 1997).

It is recommended that prolonged periods of bankfull discharge and sudden falls in water level be avoided whenever possible to ensure suitable habitat and minimise the occurrence of bank collapse. To ensure that platypuses are not continuously swimming against strong currents. Sufficient calm water must be available and the flow regime must be designed to ensure an abundance of aquatic macroinvertebrates for food (Scott and Grant 1997).

Cover over riffle areas during lower flows enables platypus to swim up through riffle areas without emerging from the water. Maintaining this minimum level enables the platypus to move safely between pools and provides a continuity of habitat (Scott and Grant 1997).

Mimicking natural flow patterns, including high flushing flows would be the optimal scenario for the platypus. Pulsed flood flows would also be of benefit as flushing of sediments would increase microhabitat availability for benthic organisms, a food source for the platypus (Grant 1998).

7.5 CONCLUSION

The plants and animals in Rocky Creek are adapted to a flow regime that is dominated by disruptive high flows that move large and small sediments and scour in-stream and riparian vegetation. Maintenance of a flow regime that continues to provide irregular high flows and maintains base to moderate flow variability, including natural rates of rise and fall, should be sufficient to maintain the habitat suitability in the Rocky Creek system downstream of the proposed Dunoon Dam.

8 Environmental Flow Requirements for the Rocky Creek System

8.1 INTRODUCTION

This project used a holistic approach to determine the key aspects of the creek flow, ecology, geomorphic process and function in order to devise a set of environmental flow rules that aim to maintain or enhance the environmental values of Rocky Creek and the associated downstream system. The current creek system (hydrology, geomorphology, aquatic ecology and water quality) and modelled natural hydrology were analysed to determine key aspects of the flow regime and develop an environmental flow regime. These physical elements were considered in respect to environmental flow regulations and current best practice to develop a set of proposed environmental flow rules for the proposed Dunoon Dam.

The objectives of this chapter are to:

- Present the key elements of the hydrology, geomorphology, aquatic ecology and water quality assessments as they relate to flow regime and aquatic system function
- Describe a set of flow rules for the proposed Dunoon Dam that retain key flow and function elements.

8.2 FLOW OBJECTIVES FOR ENVIRONMENTAL RELEASE

Detailed study relating to hydrology, geomorphology, water quality and aquatic ecology, including review of existing literature and data and specific field surveys, was undertaken to develop a proposed environmental release strategy in Rocky Creek downstream of the proposed Dunoon Dam.

Specific objectives of the proposed environmental flow protocols were to maintain or improve the environmental and habitat values downstream of the dam, including:

- Hydrological processes (including low- and medium-flow characteristics)
- Macroinvertebrate communities
- Water quality
- Fish assemblages and passage
- Ecological and biodiversity values of water dependent ecosystems
- Fluvial geomorphology.

8.3 HYDROLOGY REQUIREMENTS

Rocky Creek forms part of a network of creeks that flow into Terania Creek and then to Leycester Creek, the Wilsons River and the Richmond River, discharging to the Pacific Ocean at Ballina. At the confluence with Terania Creek, Rocky Creek has a catchment area of approximately 59 km^2 contributing approximately 40% of the total Terania Creek catchment area of 149 km^2 at the confluence. Assuming similar patterns of rainfall and land use in three main catchments that contribute discharge at the confluence, Rocky Creek would contribute approximately 40% of the total discharge to the system at this confluence.

Downstream of the confluence the gradient of Terania Creek system decreases markedly. In this reach there is a substantial alluvial floodplain and the nature of the creek system changes from primarily valley confined to meandering. Below the Rocky Creek confluence there are no significant inflows to Terania Creek until the confluence with the larger Leycester Creek.

Rocky Creek has been regulated via Rocky Creek Dam since the 1940s. The section of creek downstream of Rocky Creek Dam has formed a naturalised environment and ecology in response to the altered hydrology of the system. The proposed Dunoon Dam wall would be located approximately 2.5 km from the confluence with Terania Creek.

The region is characterised by annual rainfall of approximately 1830 mm that falls mostly as high intensity events, concentrated in the summer/autumn period. Rainfall is generally lowest in August and September. The seasonal pattern of natural flows in Rocky Creek largely reflects the rainfall patterns, with peak flows in late summer/early autumn and low flows in August to October.

Long-term modelled natural flows in Rocky Creek range from a minimum of 2 MLd^{-1} at the site of the proposed dam up to a maximum flood peak of 17, 280 MLd^{-1}. Flow is highly variable with the flow regime dominated by rapidly rising and falling flood events. Flows less than 43 MLd^{-1} occur more than 50% of the time and flows greater than 1000 MLd^{-1} occur less than 2% of the time.

Under existing flow conditions (i.e. with Rocky Creek Dam operating under current flow rules), flows at the site of the proposed dam range from 0.23 MLd^{-1} up to 17, 378 MLd^{-1}. Flows less than 17 MLd^{-1} occur more than 50% of the time and flows greater than 1000 MLd^{-1} occur less than 2% of the time. Anecdotal evidence provided by Rous Water suggests that seepage from Rocky Creek Dam during dry weather is relatively constant at 0.7 MLd^{-1} (Rous Water pers. comms. 21 December 2010).

Hydrographs of the system show highly variable flows with fast moving flood peaks. Hydrological analysis of the modelled natural system suggests that there were four main natural flow components within Rocky Creek:

- Base flow (2-6 MLd^{-1}) - Historical modelled flow rates indicate that there were no periods of zero flow, with a minimum flow of 2 MLd^{-1}. Base flows were most likely in spring/summer, on average occurred at least once a year and could last for months at a time.
- Low flow (6-30 MLd^{-1}) - Substantial periods (weeks to months) of low flow were common during August-November (corresponding with months of low rainfall).
- Moderate flow (30-200 MLd^{-1}) - Several periods of flows of moderate magnitude between 30-200 MLd^{-1}) occurred throughout a year, particularly during autumn and winter. Flows in this range typically lasted for periods of weeks.
- High flow/flood (>200 MLd^{-1}) - Freshes or pulses of flow between 200-400 MLd^{-1} occur most commonly over summer and autumn and can last from a single day to weeks. Floods greater than 400 MLd^{-1} can occur at any time of the year but are more likely in summer/autumn.

In addition to flow components, rates of rise and fall are important considerations for ecological and geomorphic processes. Analysis of the natural system hydrograph showed that under the natural regime the 90^{th} percentile rate of rise as calculated by the proportion of flow from the previous day is 2.72 and that the 10^{th} percentile rate of fall is 0.82.

8.4 GEOMORPHIC FLOW REQUIREMENTS

Geomorphic assessment showed that Rocky Creek below Rocky Creek Dam is largely a confined or armoured system with large cobbles, boulders and bedrock outcrops. Thoms (1998) identified a sediment source zone in the area that will be inundated by the proposed Dunoon Dam. Sediment supply is low in the system. It is likely that natural sediment supply was relatively low as the catchment was likely heavily vegetated. Under the current regime Rocky Creek Dam acts to trap upstream sediments.

In Rocky Creek (Sites 3 and 7) median clast size ranged from 90-200 mm. Modelling of process thresholds indicate that bed material in this calibre range are mobile during moderate to high flows which generally occur several times a year. The low number of macrophytes in Rocky Creek indicates that macrophyte disruption is common, likely through the movement of gravel to cobble sized particles.

Terania Creek downstream of the confluence with Rocky Creek is a low gradient alluvial system. Median riffle clast size was 15 mm at site 5 and the banks comprised finer mud and silt material. Macrophytes are more common in this reach of Terania Creek.

Given the primarily confined or armoured character of Rocky Creek, high and flood flows are the primary channel forming flows. Lower flows will generally not have the energy required to move sediments of median size or larger. Macrophyte disruption will also be maintained by moderate to high flow levels.

The Terania Creek system will largely be maintained by the flows from the unregulated catchment area upstream of the Rocky Creek confluence. High to flood level flows are the main driver of channel forming and maintenance processes.

8.5 WATER QUALITY FLOW REQUIREMENTS

Water quality in the system was high throughout the survey period. Nutrients, turbidity and chemical characteristics were all generally well within the recommended ANZECC guidelines. Where these guidelines were not met, physico-chemical characteristics were in a range that is not considered critical to biota, ecological processes or physical function of the creek system.

The deep pool at Site 6 downstream of the proposed pool (approximately 3.5 m deep) remained thermally stratified over the summer months even during large flow events, indicating that stratification is a normal part of the function of that pool.

Water quality is maintained in this system by low and even base flow levels.

8.6 AQUATIC ECOLOGY FLOW REQUIREMENTS

8.6.1 **Riparian & aquatic flora**

Aquatic flora is limited with likely regular scouring from high to flood level flows disrupting sediments and vegetation, and large sediment clast sizes limiting colonisation sites.

Riparian vegetation ranges from largely intact native communities to poor condition reaches dominated by exotic species.

The aquatic and riparian vegetation components of this creek system have developed in response to the variable flow regime including regular disruption from high to flood level flows.

8.6.2 Macroinvertebrates

Macroinvertebrate sampling and analysis gave SIGNAL2 scores between 4.84 and 5.22, indicating a moderately to mildly polluted system. The macroinvertebrate communities are already impacted by Rocky Creek Dam and sedimentation of fine material from agricultural/horticultural land use in the surrounding catchment. Maintenance of base flows with high to flood flow disruption are the primary flow conditions required by the macroinvertebrate communities to maintain flow habitat, flow habitat and food resource requirements.

8.6.3 Fish

Fish surveys and desktop research indicated that three fish species listed under the Fisheries Management Act are either potentially present or likely to be present in the system (Eastern Freshwater Cod, Australian Bass and Purple Spotted Gudgeon). The Eel-tailed Catfish was also identified as a significant fish species potentially occurring in the system.

Detailed fish barrier assessment for Eastern Freshwater Cod and Australian Bass was undertaken in Rocky Creek at rock/boulder barriers downstream of Whian Whian Fall and riffles in Terania Creek. Survey of key barriers found that all identified barriers are open for Eastern Freshwater Cod and Australian Bass in both adult and juvenile forms for flows between 130-142 MLd^{-1}. Barriers 1 and 2 have higher flow requirements, however, these barriers are located either within or immediately below the proposed dam wall site and are likely to be highly impacted by dam construction. Preservation of longitudinal connectivity of potential fish habitat to the proposed dam wall will be maintained at minimum flows of 20 MLd^{-1} in Rocky Creek and 95 MLd^{-1} in Terania Creek. Another key aspect to habitat preservation and functionality is that connecting flows must occur in key periods that relate to key life stages for fish migration and other cues for critical phases (e.g. spawning, larval development and juvenile colonisation).

8.6.4 Platypus

Platypus and platypus burrows were located along both Rocky and Terania Creeks. Key flow requirements for platypus include: relatively short periods of flows above bankfull to avoid damage to burrows and help reduce energy expended during feeding; water cover over riffles to permit safe pool to pool movement and flow pulses that remove fine particle build up and enhance habitat for benthic macroinvertebrates that provide a food source for platypus.

Grant (1998) suggested mimicking natural flow patterns, including high flushing flows and periods of base to low flows would be the optimal scenario for maintaining or enhancing platypus populations and their habitat.

8.6.5 Amphibians

Several amphibian species were recorded or had the potential to occur in the region. The key requirements of the majority of these species is increased flows primarily in spring to stimulate spawning, provide inundated fringing shallow habitat and remove finer particles from substrate.

8.7 RIVER FLOW OBJECTIVES

The NSW government has provided the NSW River Flow Objectives (RFOs) which are a set of agreed targets for surface water flow management that include environmental values. Any environmental flow scenarios considered for the proposed Dunoon Dam should consider how a flow release strategy can achieve key RFOs. **Table 8-1** lists the RFOs and details the relevance to the proposed Dunoon Dam project.

Table 8-1 NSW River Flow Objectives and Dunoon Dam flow releases

RIVER FLOW OBJECTIVES (RFOS)		HOW AN EF RELEASE CAN ASSIST IN ACHIEVING KEY RFOS
1	Protect natural water levels in pools of creeks and rivers and wetlands during periods of no flow	Base to low flow delivery to protect pool water levels
2	Protect natural low flows	Transparent release of base and low flows
3	Protect or restore a proportion of moderate flows, 'freshes' and high flows	Transparent release of base to moderate flows Regular spilling of high to flood flows from the proposed dam through operation of the dam at generally high levels Delivery of moderate level flows
4	Maintain or restore the natural inundation patterns and distribution of floodwaters supporting natural wetland and floodplain ecosystems	Transparent release for base to moderate flow levels Few small floodplain pockets on Rocky Creek. These areas are inundated by high flows
5	Mimic the natural frequency, duration and seasonal nature of drying periods in naturally temporary waterways	System (natural and current) has no predicted no-flow periods Transparent releases for base to moderate flow levels with concomitant natural partial channel drying
6	Maintain or mimic natural flow variability in all rivers	Transparent release for base to moderate flow levels Spilling of high flows Contingency flows to mimic rise and fall of natural events
7	Maintain rates of rise and fall of river heights within natural bounds	Transparent release to mimic rates of rise and fall Contingency flows to mimic rise and fall of natural events
8	Maintain ground water within natural levels, and variability, critical to surface flows or ecosystems	Maintain base flow levels
9	Minimise the impact of in-stream structures	Mimic natural rates of rise and fall to ensure bank integrity and maintain channel forming high flows
10	Minimise downstream water quality impacts of storage releases	Multi level off-take with variable intake depth to reduce downstream water quality impacts
11	Ensure river flow management provides for contingencies	Contingency allocation and delivery mechanisms to enhance fish passage and related aquatic and physical processes during extended low flows
12	Maintain or rehabilitate estuarine processes and habitats	Further studies may be needed to model impacts on downstream estuarine processes

8.8 ENVIRONMENTAL FLOW RECOMMENDATIONS

Conceptual designs for the proposed Dunoon Dam are for an approximate 50, 000 ML storage that will form part of the Rous Water regional water supply. Draft operating rules indicate that water from Dunoon Dam will be abstracted when Rocky Creek Dam falls below 20% capacity. Dunoon Dam will only be used for urban water supply and there will be not downstream transfer of water for consumptive use. Given this set of operating rules, it is anticipated that Dunoon Dam will generally operate at full or near full levels. In addition, flow transparency rules can provide a high level of flow protection for critical components of the environmental flow regime.

Analysis of the environmental and ecological components of the system indicated that Eastern Freshwater Cod was a key species in terms of flow requirements. Flows required to maintain longitudinal connectivity for the Eastern Freshwater Cod were generally higher than those required for other ecological functions. Considering Eastern Freshwater Cod requirements as a critical upper threshold for ecological function, the primary environmental flow consideration was for transparent flows to a level that would maintain connectivity for Eastern Freshwater Cod. While it is likely that connectivity for the Eastern Freshwater Cod and other larger taxa would cease under both the natural and existing flow patterns during dry periods, contingency provisions for release during prolonged dry periods have been provided for.

With this high level of flow transparency, key aspects of flow variability and the delivery of base flows, low flows and moderate flows in a largely unaltered manner would provide for all other key ecological functions, including: movement of smaller fish species; flushing of fine sediments; provision of habitat and food for macroinvertebrates; macrophyte disruption; provision of habitat and food for non-fish vertebrates.

A number of different flow rules were considered and modelled during the development of the recommended environmental flow rules that considered both the secure yield of the proposed dam and the above identified flow requirements.

General flow rules were designed to provide transparent flows for base to moderate level flows up to 100 MLd^{-1} with natural rates of rise and fall. Transparent flows to an upper limit of 100 MLd^{-1} provide for the majority of critical flow functions including mimicking natural flow variability, opening of key fish barriers and seasonal cues including temperature, in-channel wetting and drying, entraining fine sediment and general fauna habitat and food resource provision. Channel forming flows will be facilitated through spilling events, where high and flood flows pass through the dam and continue down the creek system.

During construction a bypass channel is recommended that allows transparent passage of all flows downstream.

The general flow rules are:

- Transparency of inflows up to 100 MLd^{-1} at Dunoon Dam (based on residual catchment inflow plus spills from Rocky Creek Dam)
- If inflow to Dunoon Dam exceeds 100 MLd^{-1}, maintain release of 100 MLd^{-1}
- When inflow to Dunoon Dam drops below 100 MLd^{-1}, allow natural rates of fall
- If the unregulated spill exceeds 100 MLd^{-1}, no transparent release.

To enhance the downstream environment specifically for fish species a set of contingency rules have been established to permit longitudinal channel connection in key fish migration periods during prolonged dry periods. These contingency flows will also benefit the downstream system through provision of habitat for other species. These rules are:

- If inflow to Dunoon Dam is less than 0.7 MLd^{-1}, maintain release from Dunoon Dam of 0.7 MLd^{-1}
  Ensures transparency of flows of existing leakage from Rocky Creek dam to maintain existing baseflows
- If, by March 1, there has been < 3 days of inflows >= 100 MLd^{-1} (either as one or multiple events) over the preceding 60 days, release 100 MLd^{-1} for 3 consecutive days
  January to March is a key period for juvenile movement for Eastern Cod and Australian Bass. This contingency provides opportunity for movement for both fish species toward the end of this critical period in the event of prolonged low flows during January and February.
- If, by August 1, there has been < 3 days of inflows >= 100 MLd^{-1} (either as one or multiple events) over the preceding 60 days, release 100 MLd^{-1} for consecutive 3 days.
  May to October is a key period of the downstream migration of adult Australian Bass. This contingency provides opportunity for movement within this critical period. It also provides opportunity for movement of adult Eastern Cod for spawning.
- If, by October 1, there has been < 3 days of inflows >= 100 MLd^{-1} (either as one or multiple events) over the preceding 50 days, release 100 MLd^{-1} for consecutive 3 days.
  August and September are key months for the movement of adult Eastern Cod for spawning. It also provides for the downstream migration of adult Australian Bass.

While these contingency rules specifically address flow requirements for the movement of key fish species (assuming an upper limit of 100 MLd^{-1} provides for the opening of key fish barriers) (**Table 7-9**), other key ecological functions would also be provided for by these contingency flows, including the movement of smaller fish species.

8.9 ASSUMPTIONS

The following system operating rules were used for hydrological modelling:

- Full abstraction from Rocky Creek Dam until 20% of storage capacity remains, then full abstraction from Dunoon Dam until Rocky Creek Dam capacity exceeds 20%. If Dunoon Dam empties, then use Rocky Creek Dam.
- Emigrant Creek Dam supplies to Ballina only. If demand from Ballina is less than 7.5 MLd^{-1} (full capacity) then only actual demand is met.
- No inclusion of the Wilsons River Source as a water supply option.
- The industry standard operating rule (5/10/20%) also applies, whereby:

  1. Restrictions should not be in place > 5% of the time
  2. Restrictions should not be introduced (on average) more than once in 10 years during analysis period (which must be at least 100 years)
  3. System is to supply 80% of normal demand (i.e. 20% reduction in capacity) through a repeat of worst drought on record, starting with the storage drawn down to a level at which restrictions would be applied to satisfy the 5% and 10% rules).

Modelling of the environmental flows scenarios has assumed that the model uses average daily discharge (i.e. that the finest resolution is one day).

9 Impact Assessment

The proposed Dunoon Dam with concomitant infrastructure, inundation and changes to the regional urban water delivery extraction and operating rules will have an impact on the Rocky Creek system downstream of the existing Rocky Creek Dam. This section of the report considers the impact of the proposed dam on the hydrology, ecology, process and function of the system in light of the proposed environmental flow release recommendations.

The objectives of this chapter are to:

- Briefly describe the proposed Dunoon Dam project based on current available information
- Identify and assess the key likely and potential impacts of the recommended environmental flow regime of Dunoon Dam on the hydrology, geomorphology, aquatic ecology and water quality of the Rocky Creek system as they relate to flow regime and aquatic system function.

It is noted that this impact assessment identifies and considers those impacts resulting from the altered flow patterns as a result of the proposed Dunoon Dam environmental flow regime. It does not include impact assessment related to the construction of the dam or its associated infrastructure. The concept design for Dunoon Dam has not been finalised and the impacts addressed in this assessment are based on the information available to date and preliminary conceptual designs.

9.1 PROJECT DESCRIPTION

A new dam on Rocky Creek near Dunoon has been identified as a potential new source of water to supplement the Rous Regional Water Supply Strategy. Conceptual designs are still being undertaken, however, initial data suggests that the maximum inundation area (high water level) represents the 85 m AHD contour and will cover an area of approximately 253 ha. At full supply level, the dam will have a capacity of around 50000 ML (including approximately 4800 ML of dead storage).

Preliminary investigations conducted by NSW Public Works suggest a rock armoured zoned earthfill embankment. Based on conceptual designs to date, the proposed dam wall will be approximately 40 m in height. The proposed buffer area surrounding the dam inundation zone will be another 234 ha. Indicative locations of dam infrastructure (dam wall and spillway) are shown below and based on concept arrangements provided in May 2010 (**Figure 9-1**).

The construction and operation of the proposed dam would involve three main operational modes, these being construction (when the dam will operate in by-pass mode), filling and standard operation.

The Rous Water Regional Supply operation rules will commence once the dam reaches a nominated percentage of the full supply level (FSL) and Dunoon Dam commences standard operation. The nominated operational rules are:

- Full abstraction from Rocky Creek Dam until 20% of storage capacity remains, then full abstraction from Dunoon Dam until Rocky Creek Dam exceeds 20%. Continue using Dunoon Dam when Rocky Creek Dam is below 20% and if Dunoon Dam empties, extract from Rocky Creek Dam until it empties

- Emigrant Creek Dam (supplies to Ballina only) – if demand is less than full capacity (7.5 MLd^{-1}) only demand is met subject to availability from Emigrant Creek Dam (1 November and 28 February)
- No inclusion of Wilsons River Source (WRS) at this stage
- The 5/10/20% rule is also applied (**Section 2.7.2**).

These system rules were applied in the IQQM for Dunoon Dam online scenario.

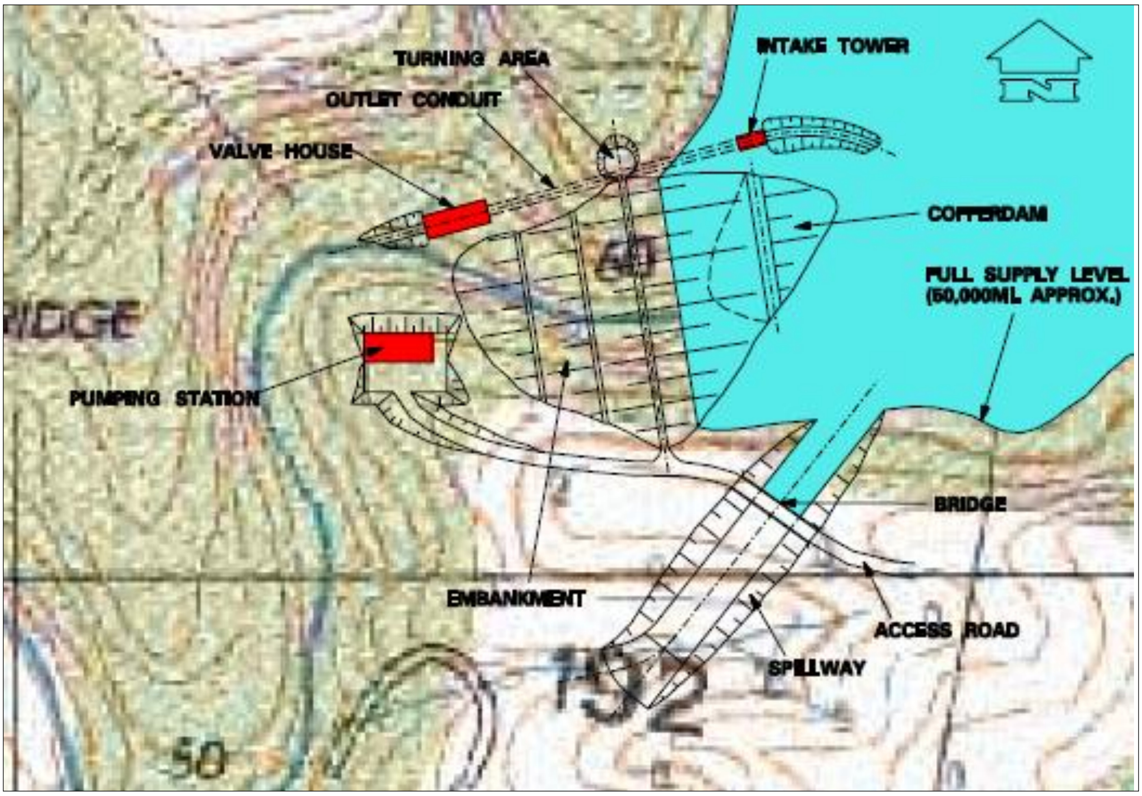


Figure 9-1: Proposed Dunoon Dam – conceptual arrangement (May 2010, NSW Public Works)

9.2 POTENTIAL IMPACT ZONES

To assess the potential impacts on the Rocky Creek system as a result of the recommended environmental flow regime for the proposed Dunoon Dam, possible impacts within a number of zones have been identified. Zones have been determined based on their location in relation to the proposed Dunoon Dam and the likely inundation and flow impacts (**Table 9-1; Figure 9-2**).

Table 9-1: Potential impact zones

IMPACT ZONE	DESCRIPTION
1	Rocky Creek Dam to the Dunoon Dam FSL (approximately 8 km)
2	Dunoon Dam inundation area (approximately 6 km)
3	Dunoon Dam wall to Terania Creek confluence (approximately 2.5 km)
4	Terania Creek confluence to Leycester Creek confluence (approximately 27 km)
5	Downstream of the Leycester Creek confluence

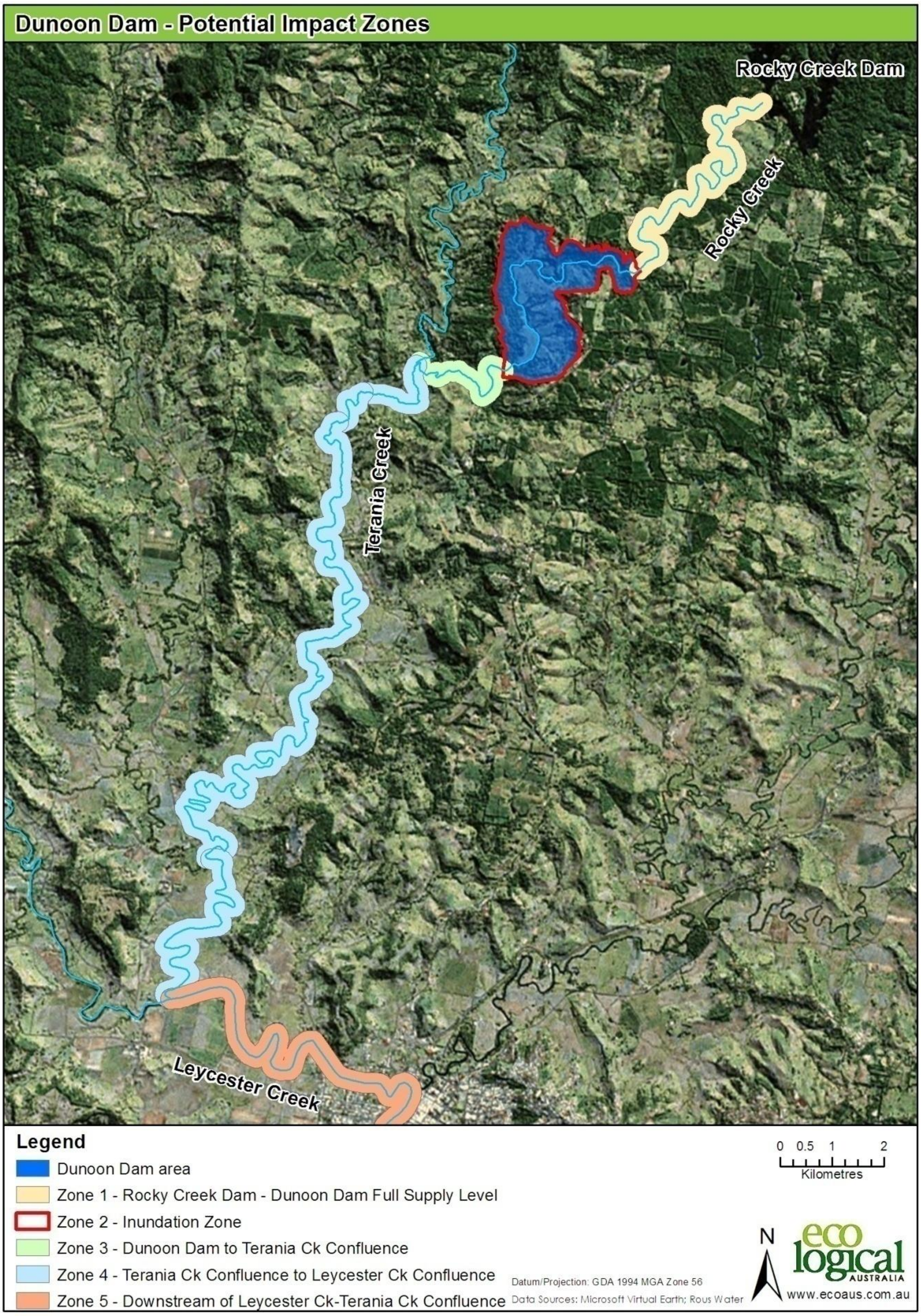


Figure 9-2: Potential impact zones

9.3 IMPACT ZONE 1

Impact zone 1 is an 8 km reach of Rocky Creek located between Rocky Creek Dam and the FSL of the proposed Dunoon Dam.

9.3.1 Hydrology

Daily flow data were extracted from the IQQM for the proposed environmental flow scenario to assess impact against the “natural” (i.e. unregulated) and current (naturalised) flow regimes of the Rocky Creek system. Around 60% of the Rocky Creek catchment is captured by Rocky Creek Dam (Bishop 1998a).

Bringing Dunoon Dam ‘online’ would alter the operational rules of Rous Water (although the 5/10/20 rule outlined in Section 2.7.2 still applies). Consequently, the flow regime between of Rocky Creek Dam and Dunoon Dam will be altered. This length of creek to the proposed dam wall is around 15 km, however, due to construction of the proposed dam and associated inundation it will be reduced to around 8 km in length.

Long-term modelled flows of all three scenarios immediately downstream of Rocky Creek Dam are shown in **Figure 9-3**. The reduction of flows due to both Rocky Creek Dam and the proposed Dunoon Dam can be clearly seen. Under natural conditions, there were no periods of no flow and the average flow rate is estimated at 82 MLd^{-1} (**Table 9-2**).

Under the existing operating rules, Rocky Creek Dam spills on average 30% of the time (i.e. 104 days/year), with a mean spill rate of 190 MLd^{-1}. It is noted that anecdotal evidence provided by Rous Water suggests that seepage from Rocky Creek Dam is relatively constant at 0.7 MLd^{-1} (Rous Water pers. comms. 21 December 2010). This consistent seepage is expected to be maintained as there are no proposed alterations to Rocky Creek Dam.

Under the new operating rules with Dunoon Dam online, the number of days when Rocky Creek Dam spills will be reduced to around 57 days/year with an average spill of 222 MLd^{-1}.

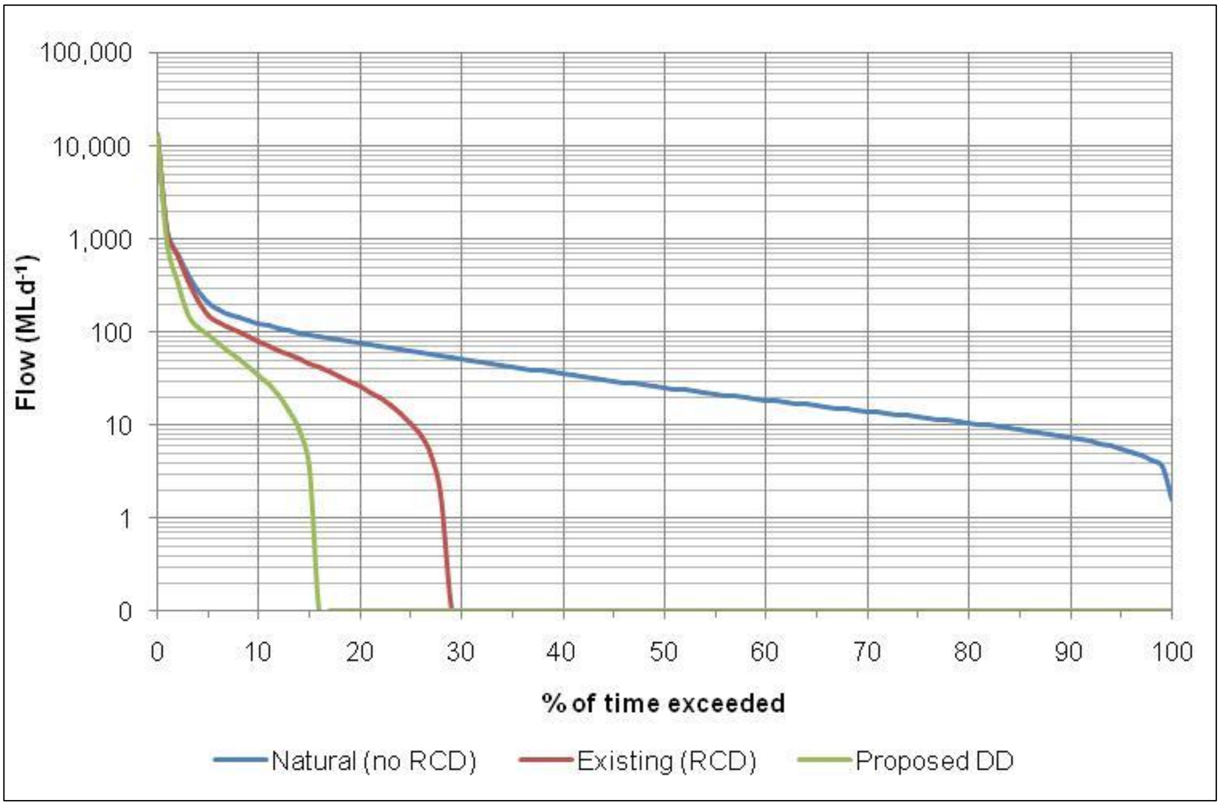


Figure 9-3: Flow duration curve (annual series) immediately downstream of Rocky Creek Dam

Table 9-2: Daily flow data immediately downstream of Rocky Creek Dam

PERCENTILE EXCEEDENCE	NATURAL[1] (MLd^{-1})	EXISTING[2] (MLd^{-1})	PROPOSED[3] (MLd^{-1})
95	5.62	0	0
90	7.43	0	0
80	10.6	0	0
50	25.4	0	0
40	35.7	0	0
30	51.2	0	0
20	75.0	26.2	0
15	93.2	46.2	3.53
10	125	79.4	34.2
9	134	88.8	41.8
8	145	99.0	51.8
7	158	113	62.5
6	175	128	76.5
5	204	152	92.8
4	286	220	114
3	420	354	153
2	686	643	337
1	1236	1192	877
Mean	82	54	35

[1] Natural flow (i.e. modelled unregulated by Rocky Creek Dam)

[2] Existing flow (i.e. Rocky Creek Dam online)

[3] Proposed flow regime (with Dunoon Dam online with environmental flow releases).

9.3.2 Geomorphology

This reach is located within the armoured zone dominated by an armoured bed of bedrock, boulders and cobbles. This reach has naturalised to conditions immediately downstream of Rocky Creek Dam and is resistant to channel change through the armoured nature of the channel banks and bed. Reduced flows from Rocky Creek Dam also mean there is potentially a reduced capacity for flows to flush sediments downstream. As Rocky Creek Dam acts as a significant sediment trap the primary source of sediment is the largely cleared side slopes adjacent to the channel.

A reduction in the frequency of flood flows will cause a reduction in occurrences of flushing flows causing temporary increased accumulation of fine sediments. However, these geomorphic impacts are expected to be minimal, with the larger spills continuing to provide flushing of fines along the creek reach. Residual catchment flows (i.e. from the catchment area downstream of Rocky Creek Dam) will also contribute to flows in the system.

Given the armoured nature of this reach and the regular spilling of Rocky Creek Dam with significant moderate to flood flows there is expected to be no significant impact on channel geomorphology of the altered flows delivered via Rocky Creek Dam to this reach.

9.3.3 Water quality

Changes to the flow patterns downstream of Rocky Creek Dam as a result of the proposed dam and the altered operating rules may cause the following changes to water quality:

- Increased stratification of pools and associated water quality issues
- Increased occurrence of algal blooms
- Less frequent flushing of fines and greater accumulation of silt and detritus cover on substrate and pool-edge habitats.

Unchanged seepage from Rocky Creek Dam is expected to maintain existing base flow. The number of days and the volume that Rocky Creek Dam spills will be reduced with Dunoon Dam online. However, given the limited sediment supply and high energy of the spill flows, fine sediments will continue to be flushed from the system into the Dunoon Dam inundation zone (impact zone 2).

Pools within this reach range from a depth of 0.2 m up to 2.5 m. A reduction in the number of flushing flows may increase the likelihood of stratification in the deeper pools and increase the potential for algal blooms and poor water quality (e.g., de-oxygenation and nutrient release) to occur.

This length of creek is a highly altered system given the upstream Rocky Creek Dam has no provision for controlled flow release. However existing water quality is within recommended ANZECC guidelines and is expected to be maintained by the altered flow conditions.

9.3.4 Aquatic ecology

Impact Zone 1 is a naturalised system that is highly impacted as a result of regulated flows from Rocky Creek Dam. Rocky Creek Dam seepage provides a base flow of 0.7 MLd^{-1} with the dam spilling and providing above base level flows less than 30% of the time. Within reach inputs from the catchment below Rocky Creek Dam (i.e. residual catchment flows) also provide some flow input. The environmental and ecological function in this reach has adjusted to this altered flow regime since the construction of Rocky Creek Dam in the 1940s. The altered flows as a consequence of the operation of Dunoon Dam (including its environmental flow releases) should maintain this existing altered state.

Aquatic & riparian vegetation

A large portion of Impact Zone 1 is currently dominated by a variety of native rainforest canopy species, with less diversity in the shrub and ground layer. Hydrology within this impact zone will be altered, primarily through a reduction in the number of spills from Rocky Creek Dam will (see Section 9.3.1). However, base flows (i.e. seepage from Rocky Creek Dam) will remain as will the larger variable flushing events which will maintain scouring and depositional processes and it is unlikely that the available habitat area will be reduced. Given the combination of low sediment supply, stable substrate and no significant change the available habitat area, it is unlikely that there will be any change to in-stream or riparian vegetation as a result of altered operating rules for Rocky Creek Dam.

Macroinvertebrates

A reduction of spills from Rocky Creek Dam could potentially result in reduced habitat availability and quality for aquatic macroinvertebrates. There is potential that fine sediments may accumulate between larger particles and reduce habitat and food resource availability through smothering, particularly during periods of prolonged low flows. These interstitial spaces provide habitat for invertebrates and consequently there may be a reduced habitat area.

Benthic invertebrates that colonise streams with highly variable discharge and bedrock/boulder substrata can be highly resilient to the effects of reduced flows (Gunderson, 2000), and the communities that have persisted in this reach are already adapted to altered flow conditions for over 70 years since the construction of Rocky Creek Dam.

It is predicted that the regular spill events from Rocky Creek Dam will provide flows with sufficient energy and frequency to flush fine sediments from the reach. Base flows from seepage will maintain continued aquatic habitat year round.

Fish

During this assessment, fish species in the reach immediately below Rocky Creek Dam were not targeted as part of the fish survey. However, Eastern Cod has been recorded in two separate pools in the 1990s (Bishop 1998). It is unclear if these records relate to natural communities (distinct from stocked populations) as Whian Whian Falls at the downstream end of this reach provides a significant natural barrier to fish migration.

Alteration to the Rocky Creek Dam operating rules will reduce the number of spilling flows. However, base flows will be maintained and high energy flushing and flood flows will still occur. It is unlikely that altered flow conditions will reduce the long-term quality of habitat for fish in the reach substantially from its already impacted state.

The physical barrier of the proposed dam wall will reduce longitudinal connectivity of this system with the potential of 14 km of current channel being disconnected from the lower Rocky Creek and Terania Creek system. However, Rocky Creek Dam and Whian Whian Falls provide substantial existing barriers to upstream connectivity.

Amphibians

Eastern Dwarf Tree Frog and Pearson's Green Tree Frog were recorded at Site 1 within this reach.

Many frog species have highly specialised requirements in terms of the timing and frequency of inundation. The Eastern Dwarf Tree Frog attaches its eggs to underwater vegetation during spawning in spring and summer. It is unlikely that the altered operation of Rocky Creek Dam will significantly impact habitat quality or availability for amphibian species, with inundated populations of macrophytes predicted to be maintained.

Platypus

Previous studies have recorded observations of platypus in the upper reaches of this zone, with the current Rocky Creek system providing good platypus habitat (including foraging, burrowing and nesting habitat) (Grant 1998).

Changes to the Rocky Creek Dam operating rules are unlikely to reduce habitat quality or availability in this zone as base flows will be maintained and flushing flows will be sufficient to maintain habitat quality and food resources.

The ability of platypus to survive in considerably disturbed habitat downstream of Rocky Creek Dam (Grant 1998) suggests that the altered flow regime and possible changes to water quality will have little impact on existing platypus distribution within this zone. However, it is also noted that Grant (1998) indicated that no change to the existing naturalised Rocky Creek flows would result in a reduction of platypus numbers, primarily due to a reduced flows, reduced habitat quality and quantity and subsequent reduced availability of benthic food species.

9.4 IMPACT ZONE 2

The full supply level of the proposed Dunoon Dam is expected to extend from the bottom of Whian Whian Falls for approximately 6 km downstream to the dam wall. This area of inundation is Impact Zone 2. The inundation zone will result in the loss of existing physical habitats along this reach, including pools, runs and riffles. Additional habitat will be destroyed due to the footprint of the dam wall.

9.4.1 Hydrology

The inflow to Dunoon Dam will be dependent on spills from the upstream Rocky Creek Dam and unregulated flows entering via the catchment below Rocky Creek Dam. Due to these unregulated catchment inflows, IQQM results indicate that there will always be water flowing into the dam. Regulation downstream of Dunoon Dam would commence upon completion of the dam wall during the filling phase. During construction we recommend a bypass channel be constructed to pass all flows through transparently.

9.4.2 Geomorphology

Due to almost permanent inundation the geomorphic nature of this reach will change from a flowing (lotic) to a lake (lentic) environment. Dunoon Dam will capture the majority of the upstream sediment, although it is noted that due to Rocky Creek Dam and the armoured nature of the reach above Whian Whian Falls that current sediment load into this reach is very low.

As estimated in Section 5, in excess of 197,110 m^3 of soil could be lost via shoreline erosion (or around 0.4 percent of the total storage volume). This estimate assumes all sections of the shoreline are equally susceptible to equal rates of erosion regardless of wind direction and soil characteristics. No provision has been made for large slips of shoreline, however, some 4800 ML of 'dead' storage has been nominated for the dam due to the high potential for slips on the storage slopes.

9.4.3 Water quality

Previous assessments indicate that the proposed inundation zone historically has good water quality, as further demonstrated by this assessment (Site 2). While it could be surmised that water quality in the proposed storage will also be of good quality, ongoing monitoring and assessment of water quality in Rocky Creek Dam and hydrodynamic modelling could be used to predict possible water quality concerns such as:

- Eutrophication of the reservoir
- Stratification (temperature and dissolved oxygen) and associated water quality issues such as anoxic conditions
- Algal blooms
- Sediment and nutrient trapping.

The inundation of this reach of Rocky Creek would create a highly altered system with different physico-chemical characteristics to the existing system.

It is noted that the inflows to the proposed dam will be regulated by the upstream Rocky Creek Dam, and therefore it is possible that the dam may stratify in the deep storage zone. The subsequent release of cold water into the downstream environment can have a detrimental impact on water quality and biota.

Bank erosion from wind action may also continue to provide sedimentation issues. Temporary impacts would include poor water quality due to decomposition of terrestrial vegetation and associated effects. This threat would be exacerbated if stratification of the dam occurs.

These impacts will need to be considered further during any formal impact assessment of Dunoon Dam.

9.4.4 **Aquatic Ecology**

Aquatic & riparian vegetation

An approximate 6 km reach of riparian vegetation is expected to be lost when the dam reaches its FSL. Macrophyte and riparian vegetation may colonise the shallower lake fringes with time, particularly given that Dunoon Dam will most likely operate at close to FSL for much of the time. The creation of stable conditions along the dam shoreline may increase the potential for colonisation by both native and exotic species in the shallows, for example *Typha* sp. and Brazilian Water Milfoil (*Myriophyllum aquaticum*). Brazilian Water Milfoil was observed along Terania Creek.

Temporary impacts within zone 2 would include poor water quality due to decomposition of terrestrial vegetation and associated effects (including lowered DO levels). This short-term decrease in water quality would likely temporarily discourage the use of this habitat by invertebrate species.

Macroinvertebrates

Aquatic macroinvertebrates that require lotic habitats (rheophyllic taxa) will be lost, although it is likely that over time a new assemblage that is adapted to reservoirs (pelagic and planktonic taxa) may establish. The colonization of macrophytes is dependent on the availability of suitable shallow water habitat. The 6 km of still water will be a complete barrier to macroinvertebrate (and larval fish) downstream drift.

Fish

Artificial lentic conditions would replace the current flowing habitats. These new conditions may favour some species of fish which will continue to persist in the new condition. Some species of fish may be reduced in density due to the unavailability of preferred habitat and the disturbed environment, or lost capacity to migrate.

It is noted that exotic fish species such as goldfish and carp can thrive in disturbed environments, particularly reservoirs with stable water conditions, thereby creating an indirect impact on existing native taxa through competition and predation.

Amphibians

Any existing frog populations and/or habitat would be inundated by the storage. However, the lake environment may provide additional habitat areas as the lake system vegetation establishes.

Platypus

Platypus and their habitat (including burrow clusters) were found within Zone 2 (upstream of the Frasers Road crossing at Site 3). Existing platypus habitat within Impact Zone 2 will all be inundated. However, platypus are known to use artificial lake environments and the dam may provide increased opportunity for habitat and food resources.

9.5 IMPACT ZONE 3

Impact Zone 3 comprises Rocky Creek from the proposed dam wall to the confluence with Terania Creek (approximately 3 km). It is likely that the impacts of Dunoon Dam on downstream flows will be greatest in this zone.

9.5.1 Hydrology

Modelled flow data indicate that flows in this reach with Dunoon Dam online range from 3 MLd^{-1} (95^{th} percentile flow) to flows greater than 2522 MLd^{-1} (1^{st} percentile flow). Flows smaller than 17 MLd^{-1} occur more than 50% of the time and the mean daily flow is 125 MLd^{-1}. Due to the environmental contingency provisions, the minimum flow from the dam is never less than 0.7 MLd-1. Discharge from Little Rocky Creek to Rocky Creek will also provide additional baseflows immediately downstream of Dunoon Dam.

Under the current system, the minimum flow (estimate only) at the site of the Dunoon Dam is around 0.23 MLd^{-1}. However, a minimum flow of 0.7 MLd^{-1} will be maintained under the proposed flow regime (i.e. a minimum flow of 0.7 MLd^{-1} is to be released when inflows to Dunoon Dam are equal to or less than 0.7 MLd^{-1}). Modelling shows that minimum flow levels will occur on average once per year.

Comparisons of key flow percentiles of the three flow regimes are provided in **Table 9-3**. Key flow percentiles remain almost unaltered from the existing regime up until about the 35^{th} percentile, when the operation of Dunoon Dam will cause reduced flows. However, at about the 8^{th} percentile of flows, flows tend to be closer in size. That is, the main flows affected by Dunoon Dam are those in the moderate flow range 30 to 210 MLd^{-1} with base flows (2-6 MLd^{-1}) and low flows (6-30 MLd^{-1}) relatively unchanged.

Table 9-3: Daily flow data at the proposed site of Dunoon Dam

PERCENTILE EXCEEDENCE	NATURAL[1] (MLd^{-1})	EXISTING[2] (MLd^{-1})	PROPOSED[3] (MLd^{-1})
95	8.43	2.61	2.63
90	11.5	3.85	3.91
80	17.1	6.23	6.36
50	43.1	16.84	17.36
20	129	82.8	76.0
10	219	172	158
5	400	338	342
4	512	453	427
3	713	646	662
2	1137	1075	1151
1	2112	2063	2522

Mean	141	113	125

[1] Natural flow (i.e. unregulated by Rocky Creek Dam)

[2] Existing flow (i.e. Rocky Creek Dam online)

[3] Proposed flow regime (with Dunoon Dam online with environmental flow releases).

This effect of Dunoon Dam on flows can also be seen in the flow duration curves for the different regimes (natural, existing and proposed) (**Figure 9-4**). **Figure 9-5** shows flows between the 5th and 35th percentiles where the effect of Dunoon Dam on the existing flow regime is the greatest. There is little reduction of low end flows.

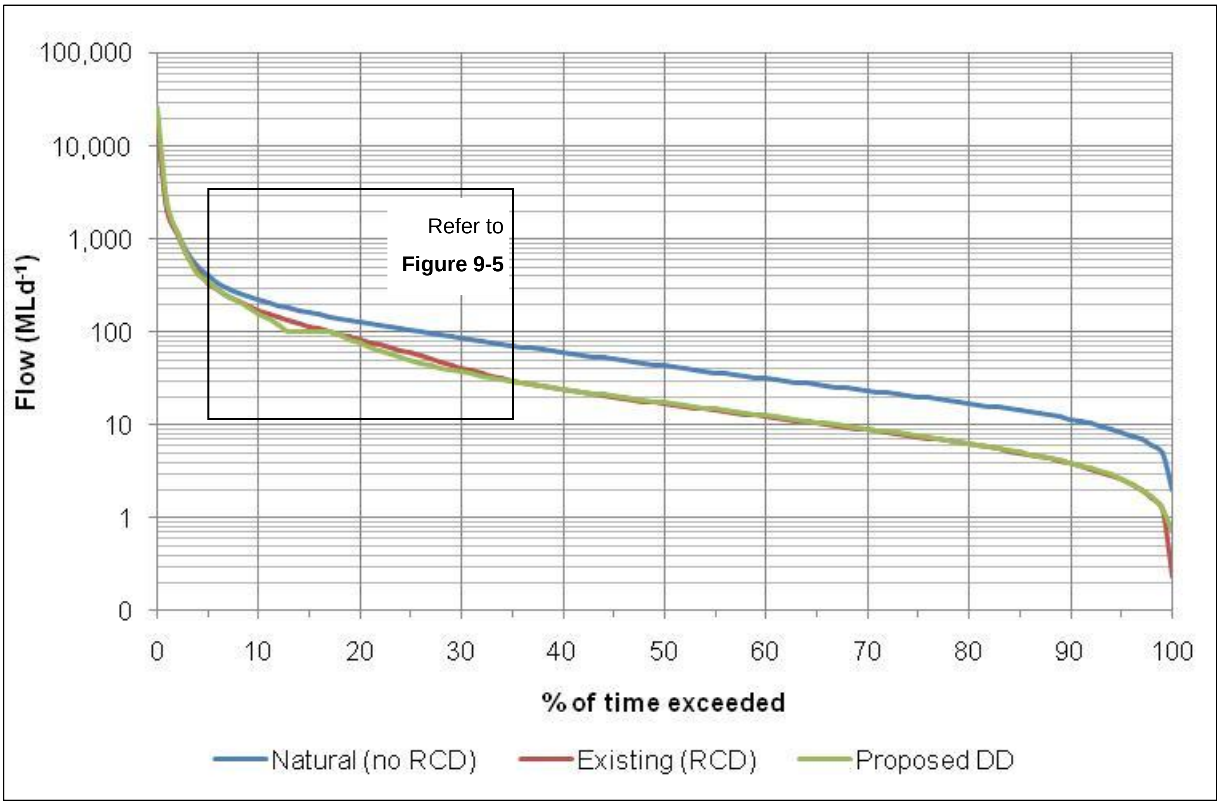


Figure 9-4: Flow duration curve at the site of the proposed Dunoon Dam

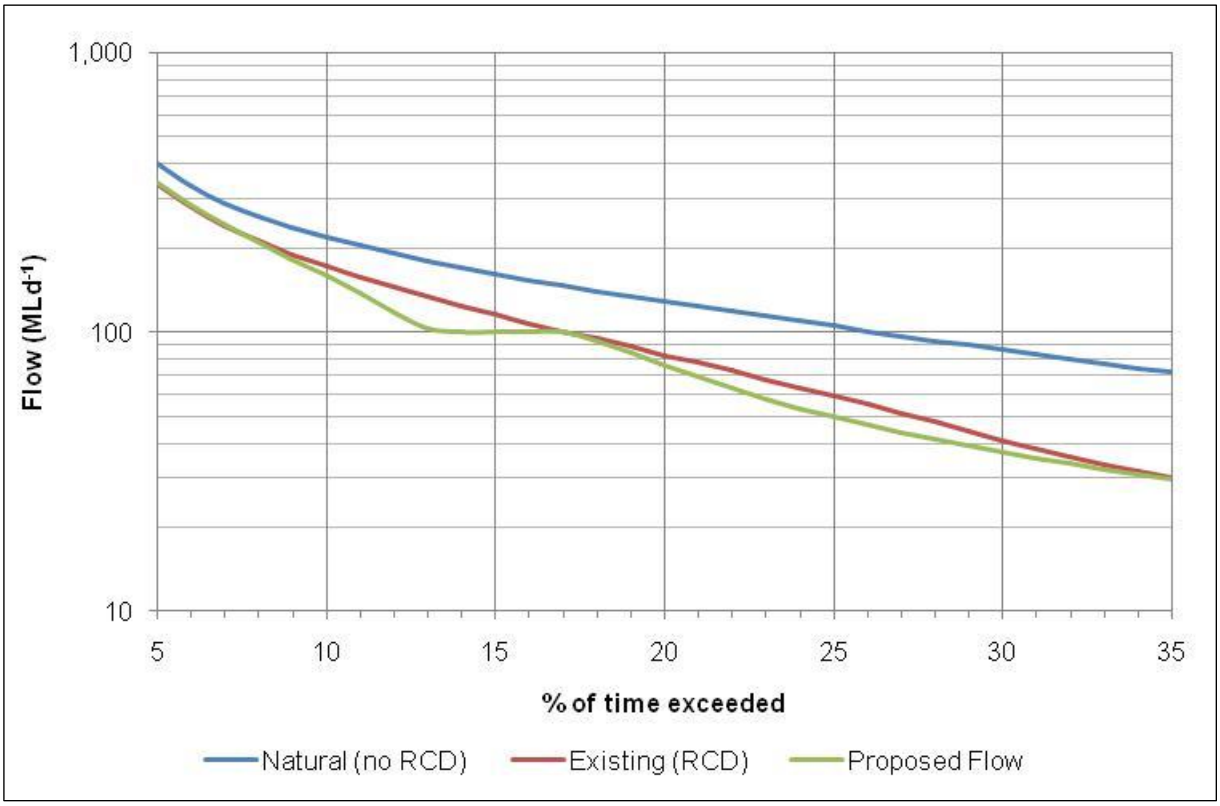


Figure 9-5: Flow duration curve at the site of the proposed Dunoon Dam (10-1000 MLd^{-1})

The proposed flow scenario does not remove the natural seasonal pattern of flows in Rocky Creek. Typical hydrographs of the system show that highly variable flows with short-lived flood peaks still occur (**Figure 9-6**). However, comparison of historic daily flow data show that some of the moderate flood peaks would be removed, particularly where the natural peak is between around 1000 to 3000 MLd^{-1}, and during years of low rainfall (**Figure 9-7**).

Examination of the hydrographs comparing the three flow regimes showed that the flood peak under the natural flow regime was generally higher than the peak under the existing regime or with Dunoon Dam online. However, this was not always the case, with some floods, particularly under the Dunoon Dam scenario, exceeding the natural flood peak (**Figure 9-7**; **Figure 9-8**). These irregular increases in discharge are explained by the surface area of water in Dunoon Dam. When full the dam acts to increase catchment runoff efficiency, with all rain that falls directly onto the water surface delivered directly into downstream flow when the dam is spilling. This phenomenon results in increased peak magnitude of the modelled flood events when these conditions are met

These increased flood events are irregular in occurrence, generally within the range of magnitudes and have similar rates of rise and fall of natural flood events, so are unlikely to have additional adverse impacts on the downstream environment. Modelling shows that the magnitude of the largest floods may also be increased, with the largest flows in the natural regime of 17280 MLd^{-1} shifting to 20456 MLd^{-1} with Dunoon Dam operating. However, the IQQM model is least reliable for these extreme events. The IQQM is a catchment scale model with block parameters for catchment features such as a rainfall runoff coefficients. While it is anticipated that the altered catchment conditions will increase peaks for some floods the magnitude of the increase will require more detailed study prior to full investigation of the potential impacts. As the modelled events in this range aren't considered to be reliable enough to assess impacts of increases to the discharge and corresponding level of inundation this study does not examine the impact of this potential increase in flood peak magnitude on the environment.

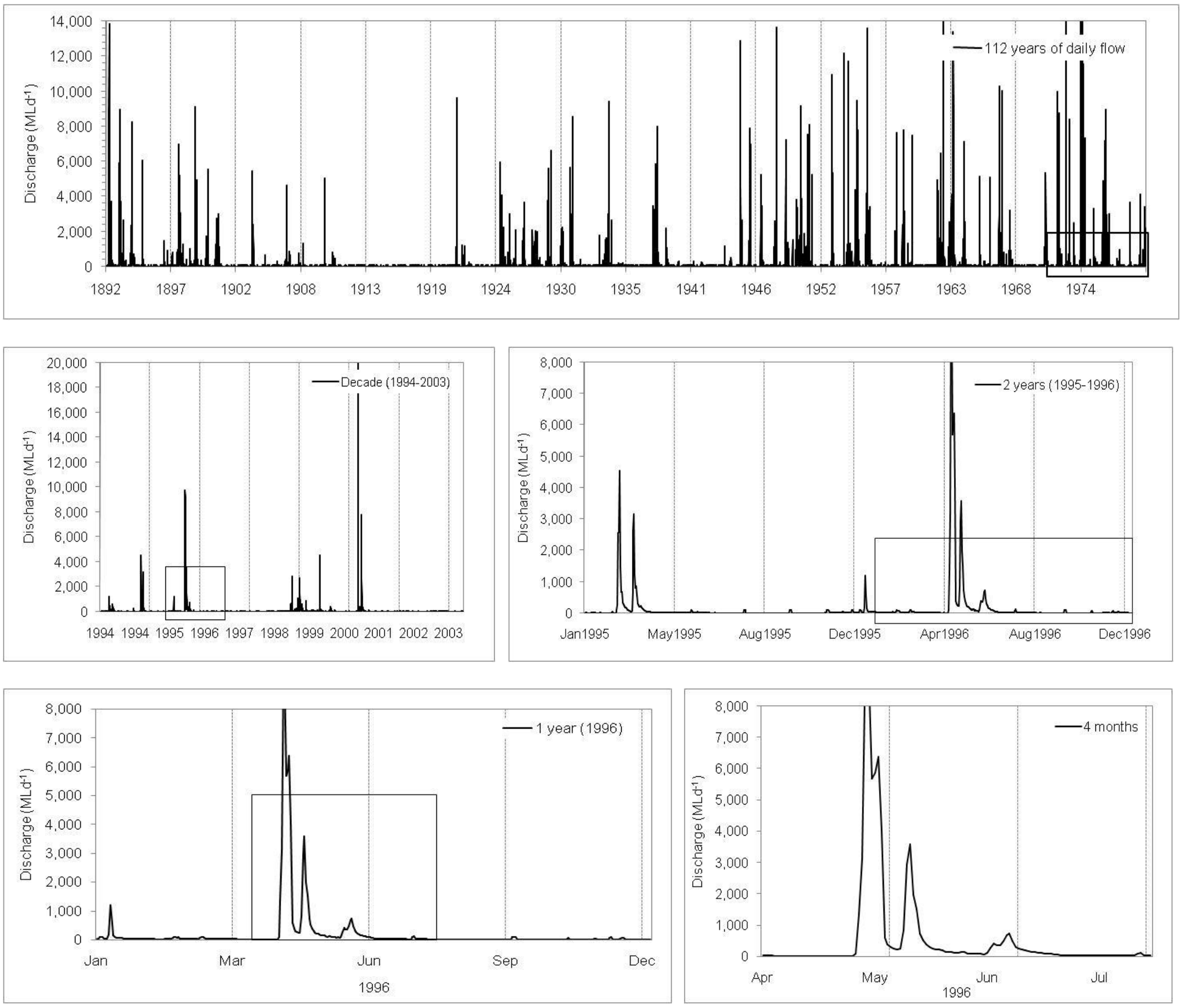


Figure 9-6: Daily flows immediately downstream of Dunoon Dam with environmental flow regimes in place

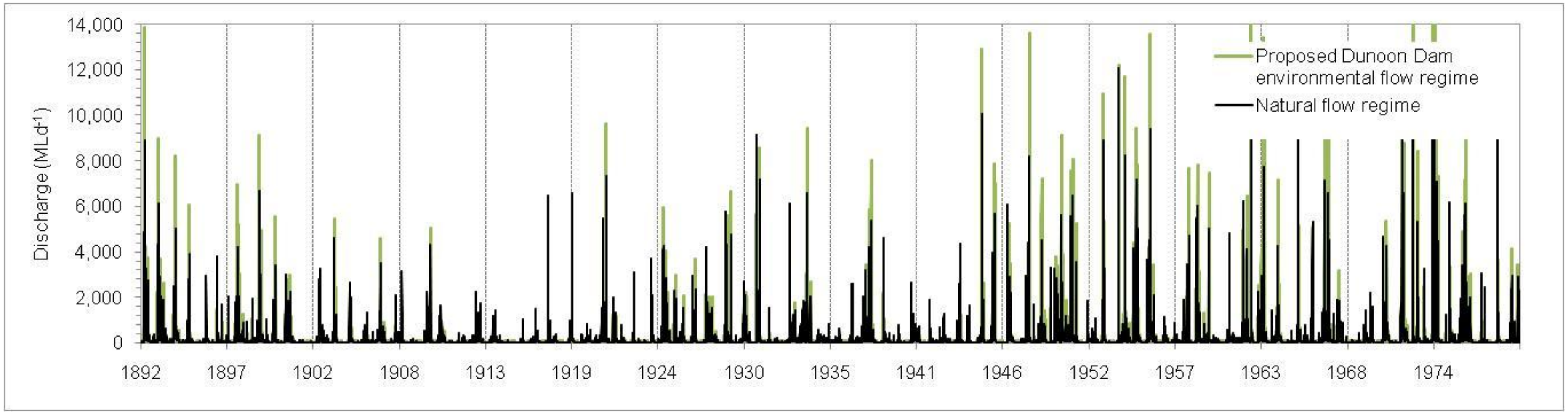


Figure 9-7: Historic daily flows – natural flow regime vs. proposed Dunoon Dam flows

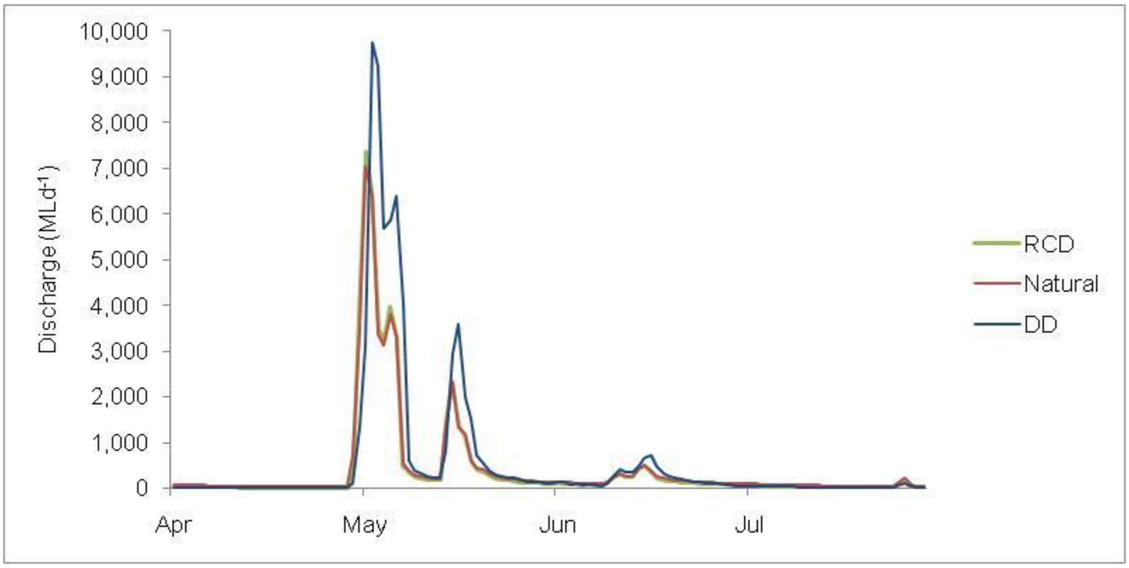


Figure 9-8: Flood hydrograph for 1996 comparing flood peaks for the three modelled regimes

AEPs and average flood recurrence intervals (ARIs) for the proposed dam are shown in **Table 9-4**. The mean annual flood of the natural system (i.e. the mean of the annual exceedence series) was estimated to be 6680 MLd^{-1} (45% AEP or 2.22 ARI) which increased slightly under the existing flow regime with Rocky Creek Dam online (6780 MLd^{-1}). The flow regime proposed for Dunoon Dam (together with the impact of the altered operating rules) will increase the estimated annual flood to 6780 MLd^{-1}. Due to the increased efficiency of the catchment when Dunoon Dam is full the magnitude of large floods will increase slightly across the entire range of floods events. As these increased flood peaks are within the range associated with the current and natural regime it is unlikely that there will be significant increases in disturbance from flood events.

Table 9-4: Annual exceedence probabilities for flood events on Rocky Creek

AEP	ARI	NATURAL FLOOD[1] (MLd^{-1})	EXISTING FLOOD[2] (MLd^{-1})	PROPOSED FLOOD[3] (MLd^{-1})
99	1.01	4251	4337	5976
95	1.055	4663	4752	6409
90	1.11	4951	5042	6730
80	1.25	5381	5475	7227
50	2	6537	6637	8632
20	5	8354	8458	10952
10	10	9701	9805	12728
5	20	11106	11208	14621
2	50	13099	13195	17360
1	100	14736	14824	19656
45	2.22	6680	6780	8890

[1] Natural flow (i.e. unregulated by Rocky Creek Dam)

[2] Existing flow (i.e. Rocky Creek Dam online)

[3] Proposed flow (i.e. Dunoon Dam online)

In addition to flow components, rates of rise and fall are also important considerations for ecological and geomorphic reasons. Unnaturally rapid fluctuations in flow can strand biota and cause bank slump from rapid wetting/drying fronts.

The maximum rate of rise (i.e. 90th percentile value of all recorded rates of rise for the proposed flow regime) system expressed as a proportion of the flow of the previous day was calculated to be 3.75, which is just higher than the existing regime of 3.40. The maximum rate of fall, possibly the more important of the two given its potential to strand fauna, was very similar to the existing rate of fall (0.76 compared to 0.74 respectively) (**Table 9-5**). The rates of rise and fall for the natural and existing system have been provided for comparative purposes in the table below.

Table 9-5: Maximum rates of rise and fall (expressed as a proportion of flow of the previous day)

	NATURAL[1]		EXISTING[2]		PROPOSED[3]	
STATISTIC	RISE	FALL	RISE	FALL	RISE	FALL
Mean	1.97	0.92	2.40	0.90	2.33	0.91
SD	4.26	0.13	7.15	0.15	5.02	0.16
10th %	-	0.82	-	0.74		0.76
90th %	2.72	-	3.40	-	3.75	

[1] natural flow (i.e. unregulated by Rocky Creek Dam)

[2] Existing flow (i.e. Rocky Creek Dam online)

[3] Proposed flow regime (with Dunoon Dam online with environmental flow releases)

The duration of flows is an important environmental and ecological consideration. A summary of the duration of key flows is provided below, comparing duration of certain flow heights for all three regimes (**Table 9-6**). The greatest changes to flow duration as a result of Rocky Creek Dam are for flows between 5 MLd^{-1} and around 500 MLd^{-1}. Changes to duration as a result of Dunoon Dam also occur in this flow range, however, there is an increase in the duration of flows between 50 to 100 MLd^{-1} (moderate flows).

Table 9-6: Duration of time flow threshold is achieved

FLOW THRESHOLD (MLd^{-1})	DAYS/YR THAT FLOW THRESHOLD IS ACHIEVED* WHERE FLOW IS EQUAL OR LESS THAN			SHIFT IN DURATION BETWEEN		
	NATURAL[1]	EXISTING[2]	PROPOSED[3]	EXISTING & NATURAL	PROPOSED & NATURAL	PROPOSED & EXISTING
≤ 1	0	2	2	2	2	0
≤ 5	4	55	54	51	50	-1
≤ 10	27	123	120	96	93	-3
≤ 15	60	170	166	110	106	-4
≤ 20	90	201	199	111	108	-3
≤ 50	199	265	274	66	75	9
≤ 100	270	303	317	33	47	14
≤ 200	324	334	335	10	11	0
≤ 250	334	341	340	6	6	0
≤ 300	341	345	345	4	4	0
≤ 400	347	349	350	2	3	1
≤ 500	350	352	352	1	2	1
≤ 1000	357	358	357	0	0	0
≤ 1500	360	360	359	0	0	-1
≤ 2000	361	361	361	0	-1	-1
≤ 5000	364	364	364	0	-1	-1
≤ 10000	365	365	365	0	0	0

* Averaged across 112 years of modelled data
[1] Natural flow (i.e. unregulated by Rocky Creek Dam)
[2] Existing flow (i.e. Rocky Creek Dam online)
[3] Proposed flow (i.e. Dunoon Dam online)
[*] Negative (-) = reduction in number of days at that flow

9.5.2 Geomorphology

Discharge Event Frequency

Ideally, flood frequency analysis would be undertaken using peak instantaneous daily discharge data (Gippel & Anderson 2008) as the identified flows for a given ARI occur only momentarily and not for an entire day. For example, certain events (such as geomorphic process thresholds) may only need to reach an hydraulic threshold momentarily (rather than for 24 hours). As only modelled daily discharge data were used for this project it is likely that the results are conservative with instantaneous peaks being higher than the modelled daily peaks.

Geomorphic thresholds were considered against the flood frequency analysis (**Table 9-4**) to estimate the frequency of key geomorphic processes.

Geomorphic Thresholds

Macrophyte disruption and surface flushing of silts and sands would occur regularly, at a minimum in the 1 in 1 year flood (**Table 9-7**).

For all sites under all three flow regime scenarios (i.e. natural, naturalised and the proposed flow regime downstream of Dunoon Dam), the 1 in 1 year flood would cause most of the bed material to become mobile.

Table 9-7: Discharges (MLd^{-1}) corresponding to geomorphic process thresholds

SITE	LOCATION	BED MATERIAL MOBILISATION			MACROPHYTE DISRUPTION	SURFACE FLUSHING (0.5 m/s)	
		D_{16}	D_{50}	D_{84}	Q_m^{95}	SILT	COARSE SAND
Site 3	Rocky Creek - downstream of Dunoon Dam	50	1600	4770	n/a	< 2	80
Site 7	Rocky Creek – upstream of confluence	300	1440	3550	38	< 2	15
Site 5	Terania Creek - downstream of confluence	5	50	550	< 20	< 2	10

The limitations of the HEC-RAS model should be noted here, with cross sectional data collected for only up to the 10 000 MLd^{-1} (or around the 1 in 10 year flood under current operational flows).

The data extracted from the HEC-RAS model were only for the downstream extent of each reach modelled and were typically at the downstream extent of a run or riffle. Larger flows may therefore be required to flush materials in any pools downstream of these sections.

Both field and hydraulic assessments indicate that the bed of Rocky Creek and Terania Creek are relatively stable under existing conditions.

Channel banks at site 3 are stable, with rock benches forming channel banks. Debris found higher on the valley side indicates the flow level of large flow events, however, there was little evidence of any erosion despite the large flow events that occurred during the field component of the project.

While the main channel bed of site 7 is stable (comprised of large boulders) and its banks extensively vegetated, the right hand bank at the bench top is made up of relatively unstable material (soil and organic matter). It is likely that this material may become mobile at flows of greater than 2000 MLd^{-1}.

Suspended sediments

It is likely that the spillway delivery of water via Dunoon Dam will cause bed scour in Rocky Creek downstream of the proposed dam wall. However, the reach of creek downstream of the dam is mostly very stable (bedrock and large boulders) and it is unlikely that, outside of the zone of influence of the spillway, there will be any significant change to bed level. If the channel cross sections therefore remain relatively unchanged, it is unlikely that there will be any increase in bank instability.

Bank instability and erosion could also be caused from changes to flow regime. The suggested flow regime has specified rates of rise and fall to not exceed those of the current system (see Section 8.3.1). Maintaining these rates of rise and fall for any new flow regime should mean that any occurrences of bank slumping due to rapid wetting and/or drying of channel banks are not increased from the current flow regime.

It should be noted that the position of the spillway in the current concept design is along Little Rocky Creek, this study did not include a field assessment of this small creek. Further assessment of the affected reach of Little Rocky Creek will be required pending project progression and the final dam design.

9.5.3 **Water quality**

Water quality along Rocky Creek downstream of the storage was consistently high, with general trends (such as conductivity, total phosphorus and turbidity increasing down the system) possibly reflecting an accumulation of catchment wide issues.

Possible changes to the flow regime and water quality downstream of the proposed Dunoon Dam include:

- Cold water pollution and subsequent change to downstream temperature regime
- Stratification of deep pools and associated water quality issues such as anoxic conditions
- Increased algal blooms
- Less frequent flushing of fines and great accumulation of silt and detritus cover on substrate and pool-edge habitats.

Long term water quality in the system is maintained by low and even base flow levels. The proposed flow regime has been designed to protect these base- and low-flows (see **Section 9.2**), thereby maintaining and potentially improving the existing conditions. Provision has been made to maintain a minimum flow of 0.7 MLd^{-1} even when inflows to the proposed dam are negligible.

The monitoring undertaken during summer 2010/2011 showed that the deep pool at site 6 remained weakly stratified during the survey period and there were several period of clear thermal stratification (greater than 1 ºC) indicating that stratification is a normal part of the function of that pool. The slightly altered hydrological pattern (i.e. removal of some high end flows) is unlikely to have a significant impact on water quality within this pool.

Studies have indicated that flow is an important controlling factor for the development of cyanobacterial blooms in Australian rivers with low flows contributing to the stabilization of the water environment, increased light availability, longer retention times and provision for the release of nutrients from sediments. Flow management strategies such as pulsed and flushing flows and artificial de-stratification have been used to control cyanobacterial blooms in regulated rivers. Provision has been made for contingency flows of up to 100 MLd^{-1} and while these are primarily to facilitate fish passage, these flow events will also help to provide moderate flows during any extended periods of low flows (when there would otherwise be reduced flow).

Water discharged without consideration of temperature or dissolved oxygen concentration may have a negative impact on downstream water quality and ecological systems and functions. Controlled release of water from Dunoon Dam (specifically to address temperature, dissolved oxygen and blue green algae) is recommended to reduce as much as possible any detrimental impacts from controlled discharges from the dam, particularly during the summer months when stratification of the storage is most likely to occur.

The main cause of poor water quality in regulated rivers is not necessarily the flow regulation itself, rather from altered land-use practices and channel management, although flow management may be influential in determining the ecosystem's response to poor water quality. Water quality parameters such as suspended solids and turbidity may improve due to sediment capture by the proposed dam.

9.5.4 **Aquatic ecology**

Aquatic & riparian vegetation

Aquatic and riparian vegetation is influenced by factors including flow regimes and base flow stability. Limited impact on the extent and composition of vegetation is expected due to the transparency of flows up to 100 MLd^{-1} (base to moderate flows) and the protection of base flows. Little change to the existing velocity, depth, wetted width of the channel or flow variability is likely. Flow regime maintenance should also assist in preventing invasive weed species establishing within this reach of Rocky Creek.

Macroinvertebrates

Macroinvertebrate assemblages within Zone 3 are already impacted and stabilised to the flow regime since the construction and operation of Rocky Creek Dam. Flow changes resulting from the proposed Dunoon Dam are unlikely to further significantly impact on this already modified system. The proposed flow regime for Dunoon Dam has been designed to protect low-medium flows maintaining important habitat variables such as depth, velocity and cover. Consequently, minimal reduction in habitat complexity and assemblages is expected.

Under the existing conditions, the condition of the system improves progressively downstream from Rocky Creek Dam. Given that the altered flow regime will largely maintain (or improve with the protection of baseflows), this trend is expected to continue. Other existing patterns, such as riffle habitats recording consistently higher SIGNAL2 scores than the composited pool-edge habitat due to improved habitat and food availability, are also expected to persist.

The altered flow change will result in some loss of high end flows on Rocky Creek, however, hydrological analysis suggests that there is still variability in the occurrence of the high to flooding flows. Maintenance of high end flows will continue to prevent the detrimental consequences of sedimentation on invertebrate communities. Results also suggested that the macroinvertebrate assemblages responded positively to increased flow variability (i.e. after flushing flows) despite initial decreases in abundance.

Research has suggested that while in-stream disturbances and flow reductions can be expected to decrease aquatic invertebrate density and diversity downstream, benthic invertebrates can be highly resilient to these effects. This resistance can be seen by the condition of the sites assessed along Rocky Creek downstream of the existing dam.

Macroinvertebrate assemblages should not change significantly and it is expected that the distribution and abundance of pollution sensitive tax should not be significantly affected by the operation of the proposed Dunoon Dam.

Fish

Careful consideration was given to the hydrological requirements for fish passage downstream of the proposed Dunoon Dam. Significant changes to low to moderate flows could lead to fragmented fish populations and habitats, change to fish passage and disturbance of spawning cues.

Maintaining fish longitudinal connectivity and migration cues was the primary reason for designing an environmental flow regime with transparent flow releases to 100 MLd^{-1}. Field assessment of key barriers along Rocky Creek show that natural flows to 100 MLd^{-1} will allow fish connection (Australian Bass and Eastern Freshwater Cod, adult and juvenile) between all habitat features to the deep pool at site 6 just downstream of the proposed Dunoon Dam. While there are two more key barriers located upstream of site 6 before the dam wall, these barriers are located within an area likely to be highly disturbed and/or altered as a result of dam construction and related infrastructure works.

It should be noted that the Rocky Creek system is dynamic and that high flow/flood events will occur causing channel rearrangement (including the shifting of large cobbles and boulders which currently form identified 'barriers). These natural events will continue to form and reform fish migration barriers. However, on average it is expected that the flow stage required to 'open' fish barriers will remain at the current level.

Further, to enhance habitat availability, flow contingency rules were designed to provide flows that connect habitat and potentially stimulate migration in key seasons if no flows occur in these key times. These flow contingencies will provide connecting flows during dry periods where no connecting flows would occur under the current flow regime. For these contingency flows the maximum rate of rise (10^{th} percentile value of all recorded rates of existing rates of rise) have been specified within the proposed environmental flow regime.

The maintenance of flow variability will continue to maintain existing flow-dependant habitat variables that impact upon fish populations in the system, including fine and coarse substrates, food supply and habitat availability.

Amphibians

While no threatened or endangered frog species were recorded during field work conducted for this assessment, seven threatened frog species are expected to occur within the larger Terania Creek catchment.

Many frog species have highly specialised requirements in terms of the timing of inundation and frequency of inundation. Flow requirements for frogs include flushing flows for cleaning sediment from substrate, shallow water for tadpole habitat and underwater vegetation for spawning during spring and summer. The maintenance of low to moderate flows and flow variability of high-end flows should avoid any detrimental impacts on amphibians as a result of the environmental flow regime.

Platypus

Platypus burrows were observed in this reach, although no platypus were seen. This suggests that the current system condition provides suitable platypus habitat (including foraging, burrowing and nesting habitat) (Grant 1998).

Changes to the existing flow regime are unlikely to reduce the quality and/or availability of habitat, particularly feeding habitat. Due to the relatively high transparency levels of flows from Dunoon Dam little change to platypus habitat quality or availability is expected. As noted previously, the ability of platypus to survive in considerably disturbed habitat (Grant 1998) suggests that the small alterations within Impact Zone 3 as a result of the proposed environmental flow regime for Dunoon Dam will cause little impact on platypus occurrences.

9.6 IMPACT ZONE 4

Impact Zone 4 is the reach of Terania Creek downstream of the Rocky Creek confluence to its confluence with Leycester Creek.

9.6.1 Hydrology

Any reduction in flows as result of the environmental flow provisions from Dunoon Dam are reduced downstream of the confluence of Rocky Creek with Terania Creek due to the contribution of flows from the unregulated catchments on the upstream Terania Creek system.

The impact of Dunoon Dam on low end flows is almost negligible immediately downstream of the confluence with Terania Creek (**Figure 9-9**).

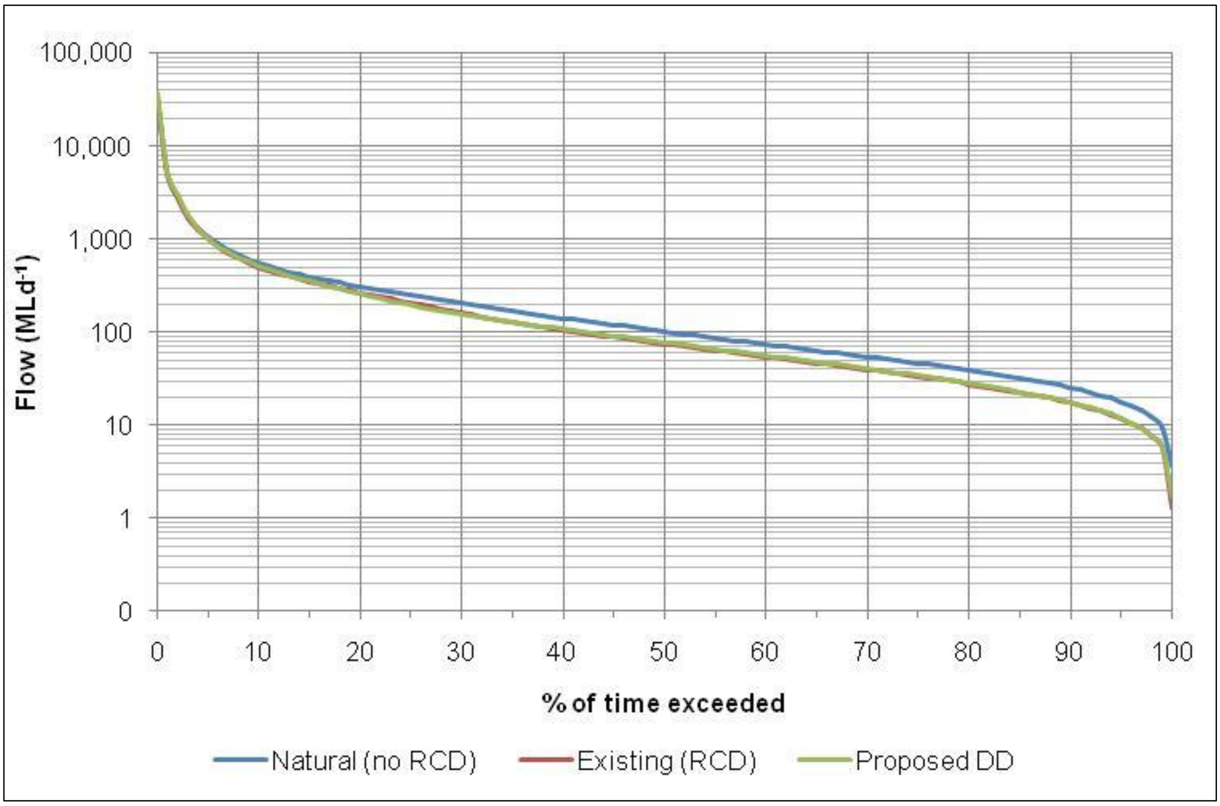


Figure 9-9: Flow duration curve (annual series) downstream of the Terania Creek and Rocky Creek confluence

The Terania Creek catchment immediately upstream of the confluence with Rocky Creek is approximately 90 km^2 (Bishop 1998a). Under natural conditions the Rocky Creek system contributed around 45% of the total discharge in Terania Creek at low flows, this input decreases to around 40% during high flow periods. The relative flow contribution by Rocky Creek at the confluence is reduced to about 22% due to Rocky Creek Dam (**Table 9-8**). This reduction in flow contribution continues up until around the 1st percentile of flows.

The changed hydrology as a result of Dunoon Dam sees little change in flow rate for flows up until the 5th percentile. The mean daily flow also increases.

The altered catchment conditions with increased runoff potential when Dunoon Dam is full leads to a potential increase in the magnitude of flood events as discussed in **Section 9.5.1**. In this reach the modelling shows that largest discharge event will increase from 32676 MLd^{-1} under natural conditions to 36779 MLd^{-1} if Dunoon Dam is operating. As discussed previously the ability of the IQQM to accurately model these large events is limited and further detailed assessment of these large events is required prior to impact assessment.

Table 9-8: System flows downstream of the Rocky Creek & Terania Creek confluence

PERCENTILE EXCEEDENCE	NATURAL[1] (MLd^{-1})	EXISTING[2] (MLd^{-1})	PROPOSED[3] (MLd^{-1})
95	17.9	11.8	11.9
90	25.3	17.5	17.7
80	38.8	27.8	28.4
50	101	74.7	77
20	310	265	258
10	547	501	522
5	1049	987	1016
1	5150	5069	5376
Mean	345	317	329

[1] Natural flow (i.e. unregulated by Rocky Creek Dam)
[2] Existing flow (i.e. Rocky Creek Dam online)
[3] Proposed flow regime (with Dunoon Dam online with environmental flow releases)

9.6.2 Geomorphology

Due to the minimal impact that the Dunoon Dam environmental flows has on the hydrology of Terania Creek, it is unlikely that there will be any changes to the existing geomorphic patterns and process thresholds. Average recurrence intervals for given discharge thresholds will not decrease substantially and bed material mobility would still be achieved at similar frequencies. High end flows which are important for channel forming process will be maintained.

9.6.3 Water quality

While Dunoon Dam is expected to have a high trapping efficiency for suspended solids, only a small reduction in suspended sediment transport could be expected downstream of the confluence. Due to relatively small contribution of Rocky Creek, significant sediment loads are still expected from the upstream Terania Creek catchments.

Stratification has not been observed in the deep pool that was monitored on Terania Creek. The minimal change to hydrology downstream of the Rocky Creek/Terania Creek confluence suggests that other water quality parameters are unlikely to alter significantly.

9.6.4 Aquatic ecology

Due to the minimal impact the Dunoon Dam environmental flow regime has on the hydrology of Terania Creek, it is unlikely that there will be any significant changes to the existing aquatic ecology patterns and processes on Terania Creek.

Aquatic & riparian vegetation

As flow variability and patterns remain largely unaltered, aquatic and riparian vegetation compositions are not expected to change.

Macroinvertebrates

If the predicted sediment load decreases are maintained at Terania Creek, it is possible that the available habitat area will increase in the upstream reaches of Impact Zone 4. If accumulated fine sediments are reduced from the riffle areas in particular, interstitial spaces within the substratum may be opened up to provide habitat. These improvements are likely to decrease further down Zone 4.

Fish

Due to the minimal impact the Dunoon Dam environmental flows has on the hydrology of Terania Creek, it is unlikely that there will be any significant changes to fish in creek downstream of the confluence.

Fish barrier assessment on riffles in Terania Creek showed that all barriers in this system were open at less than 100 MLd^{-1}. In the unlikely scenario whereby flows in Terania Creek are negligible yet Rocky Creek is still flowing, the 100 MLd^{-1} releases from Dunoon dam will provide for open fish passage in Terania Creek. In addition, during extended dry periods with concomitant low flow the contingency releases of 100 MLd^{-1} from Dunoon Dam will act to open all fish barriers in Terania Creek downstream of the confluence with Rocky Creek.

Given the minor impacts expected within Impact Zone 4 (water quality, geomorphology etc) no impacts on fish are expected due to the environmental flow releases from the proposed Dunoon Dam.

Amphibians

Given the minor impacts expected within Impact Zone 4 (water quality, geomorphology etc) no impacts on frogs are expected due to the environmental flow releases from the proposed Dunoon Dam.

Platypus

Platypus and their burrows were observed in this reach indicating that the current conditions of the system are suitable for platypus habitat.

Given that the impacts of environmental flow releases are expected to be minimal, the altered flow regime is unlikely to change the quality and/or availability of existing platypus habitat.

9.7 IMPACT ZONE 5

The final impact zone considered in this assessment is Impact Zone 5 located downstream of the confluence of Terania Creek with Leycester Creek.

9.7.1 Hydrology

Below the confluence with Rocky Creek the gradient of Terania Creek decreases markedly and there are no significant inflows to Terania Creek until the confluence with Leycester Creek. Due to the small size of the Rocky Creek catchment in relation to the total Leycester Creek catchment, flow contributions from Rocky Creek to Leycester Creek are relatively small (see Section 2.7).

A flow duration curve generated from long-term modelling data of the three flow scenarios (natural, naturalised and proposed) indicates that there is very little change in flow patterns on Leycester Creek as a result of the proposed environmental flow rules for the Dunoon Dam (**Figure 9-10; Table 9-9**).

As with the two upstream reaches the altered catchment conditions with increased runoff potential when Dunoon Dam is full leads to a potential increase in the magnitude of flood events (refer to **Section 9.5.1)**. In this reach the modelling shows that largest discharge event will very small increase from 172,415 MLd^{-1} under natural conditions to 172,679 MLd^{-1} if Dunoon Dam is operating. As discussed in **Section 9.5.1** the ability of the IQQM to accurately model these large events is limited and further detailed assessment of these large events is required prior to impact assessment.

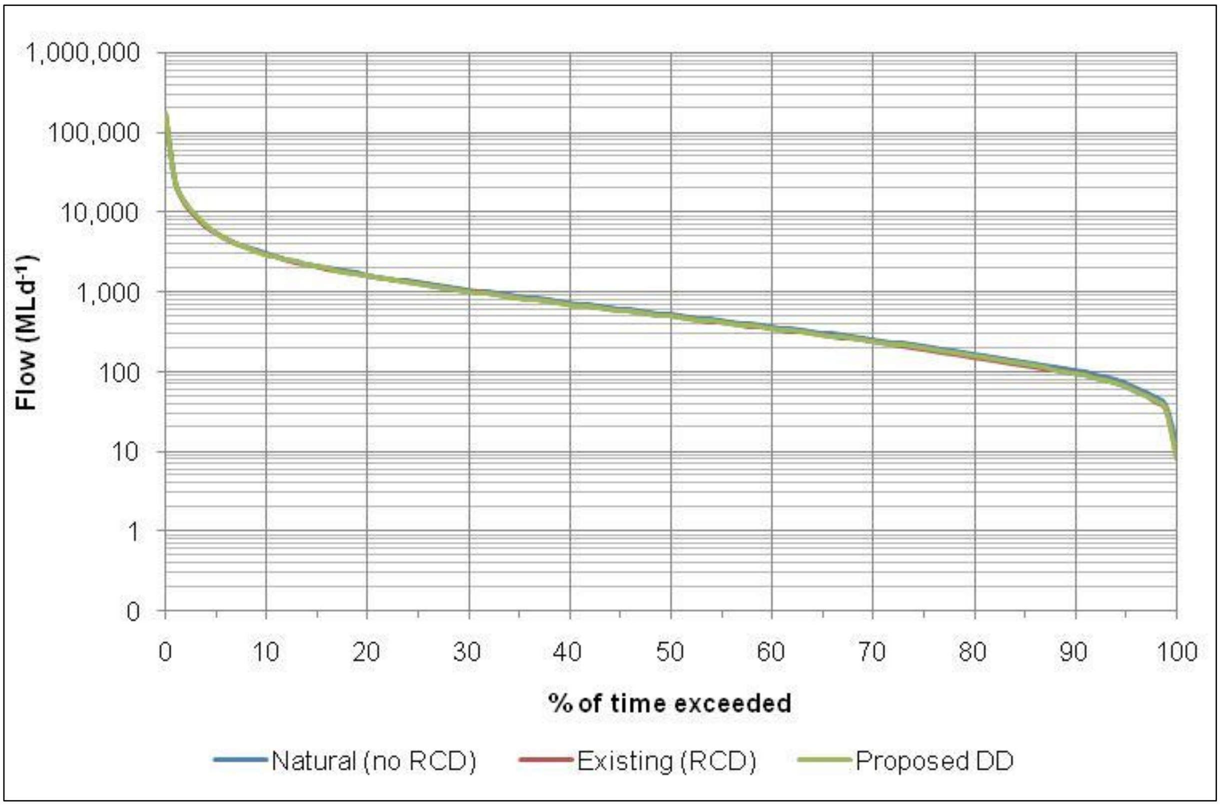


Figure 9-10: Flow duration curve (annual series) downstream of the Terania Creek and Leycester Creek confluence

Table 9-9: System flows downstream of the Terania Creek and Leycester Creek confluence

PERCENTILE EXCEEDENCE	NATURAL[1] (MLd^{-1})	EXISTING[2] (MLd^{-1})	PROPOSED[3] (MLd^{-1})
95	72	65.5	66.1
90	104	95.8	96.7
80	167	155	159
50	523	496	497
20	1647	1603	1596
10	3050	3002	3013
5	5603	5566	5555
1	25184	24726	25262
Mean	1736	1707	1720

[1] Natural flow (i.e. unregulated by Rocky Creek Dam)
[2] Existing flow (i.e. Rocky Creek Dam online)
[3] Proposed flow regime (with Dunoon Dam online with environmental flow releases)

9.7.2 Geomorphology

Due to the minimal impact the Dunoon Dam environmental flows has on the hydrology of Leycester Creek, it is unlikely that there will be any change to the existing geomorphic patterns and process thresholds.

9.7.3 Water quality

The effects of the high trapping efficiency of Dunoon Dam are expected to be almost negligible on Leycester Creek given the minor contributions flow from Rocky Creek has to the system at this point in the catchment. Other land use practices within the Terania and Leycester Creek catchments are expected to remain unchanged; therefore any changes to water quality as a result of the proposed environmental flows from Dunoon Dam are not likely.

9.7.4 Aquatic ecology

As already noted, any impacts from the proposed environmental flow releases from Dunoon Dam are expected to decrease down the system. As aquatic ecology impacts within Impact Zone 4 on Terania Creek are likely to be minimal and given the size of contributing flows from Leycester Creek proper (i.e. considering the minor flow contributions made by Rocky Creek to Leycester Creek), it is unlikely that there will be any significant changes to the existing aquatic ecology patterns and processes on Leycester Creek downstream of the confluence with Terania Creek.

10 Management & Monitoring

The objectives of this chapter are to:

- Provide a summary of identified potential issues for each impact zone along the system as a result of the environmental flow regime for the proposed Dunoon Dam in relation to creek flow, ecology, process and function
- Identify any management and mitigation measures as they relate to flow regime and aquatic system functioning
- Recommend any monitoring requirements prior to and/or post commissioning of the Dunoon Dam.

The mitigation measures and monitoring requirements recommended in this chapter address the impacts resulting from the altered flow patterns in Rocky Creek as a result of the proposed dam. Mitigation measures, based on conceptual dam design only, are provided for each of the impact zones. Impacts from dam construction will be required to be assessed during the EIS stage of the project.

The mitigation measures recommended in the follow chapter should be adopted as relevant into all applicable management plans, including:

- Construction Environmental Management Plan (CEMP)
- Operational Environmental Management Plan (OEMP)
- Foreshore Management Plan.

These plans should be prepared prior to any on-ground works commencing and most likely will be stipulated in the conditions of approval for the project.

10.1 POTENTIAL IMPACTS

The potential issues arising from the operation of Dunoon Dam as identified during the course of this assessment are summarised in **Table 10-1**.

Table 10-1 Summary of potential issues within each impact zone

IMPACT ZONE		POTENTIAL IMPACTS
1	Rocky Creek Dam to the Dunoon Dam FSL	Reduction in number of times Rocky Creek Dam spills each year Reduction in magnitude of low-moderate flows Reduction in frequency and magnitude of high-end flows Increased accumulation of silt and detritus cover Possible increased stratification of deep pools
2	Dunoon Dam inundation area	Potential stratification of the storage Blue green algae outbreaks Colonisation of invasive native and exotic species Trapping of sediments and nutrients Permanent barrier for aquatic biota Fragmentation of Rocky Creek Loss of riparian and aquatic vegetation and existing macroinvertebrate assemblages Inundation of habitat for vertebrate and amphibians
3	Dunoon Dam wall to Terania Creek confluence	Reduction of flows (between 8th and 35th percentiles) Increase in mean daily flow rate Removal of some high end flows, particularly during drought years Potential change to downstream temperature regime Potential release of anoxic water or water high in nutrients Downstream disturbance as result of release of flows Possible increase in frequency of deep pool stratification Potential increased flood peaks when Dunoon Dam is full
4	Terania Creek confluence to Leycester Creek confluence	Minor reductions to existing hydrological patterns and subsequently minimal/no impacts on geomorphology, water quality and aquatic ecology Potential increased flood peaks when Dunoon Dam is full
5	Downstream of the Leycester Creek confluence	Almost negligible impact to hydrology and subsequently minimal/no impacts on geomorphology, water quality and aquatic ecology Potential slightly increased flood peaks when Dunoon Dam is full

10.2 RECOMMENDED MANAGEMENT & MITIGATION MEASURES

10.2.1 Impact Zone 1

The altered system operating rules will alter the hydrology of the system downstream of the existing Rocky Creek Dam with concomitant impacts on the environment (**Table 10-2**).

As there are no current provisions for controlled release of water from Rocky Creek Dam, there are few if any flow related management measures that can be implemented. The channel form and ecological function of impacted reaches have stabilised to the current operation of Rocky Creek Dam.

Practical management in this reach should focus on improving general catchment and riparian condition to minimise sedimentation processes through stock exclusion and the planting of riparian endemic native species. Minor flow-based management may be achieved through refinement of operating rules to achieve balance between sustainable yield of both dams and minimising hydrological impacts on this reach of dam may be an option during further assessment of the proposed Dunoon Dam.

Table 10-2: Recommended mitigation and management measures – impact zone 1

POTENTIAL IMPACTS	POSSIBLE MITIGATION & MANAGEMENT MEASURES
Sediment loading from catchment	Implement measures to reduce riparian erosion (e.g. stock exclusion from the riparian zone, riparian plantings etc) Address more general catchment issues (land management practices, soil conservation etc) to reduce general sediment loads to the system

10.2.2 **Impact Zone 2**

Impact zone 2 is the inundation zone (or storage zone) of the proposed dam. Potential management and mitigation measures are outlined below.

Table 10-3: Recommended mitigation and management measures – impact zone 2

POTENTIAL IMPACTS	POSSIBLE MITIGATION & MANAGEMENT MEASURES
Hydrology	During the construction phase it is recommended that a bypass channel be constructed to pass all flows transparently The release valves from the dam should be designed and constructed in such a way that provides for the recommended releases (i.e. provide for the release of 0-100 ML/day from the storage that allows for the natural rates of rise and fall as document in this assessment)
Stratification	Artificial breakdown of stratification (for example via aeration)
Algae outbreaks	Minimise nutrient levels into the Rocky Creek and the Dam proper through reducing sediment input (see below) Physical control (e.g. artificial water column mixing)
Sediment and nutrient trapping	Reducing sediment loading and nutrient exports from the Dunoon Dam catchment may improve quality of impounded water (e.g. addressing more general catchment issues as recommended above) Reducing foreshore erosion – given the potential for landslip further analysis is required to determine best practice for shoreline erosion management to suit soil and landscape conditions. Addressing broader-scale catchment issues (land management, soil conservation, fertilizer use etc)
Invasive weeds along dam shoreline	Monitoring of dam shoreline for occurrences of any weeds/invasive species. Specific management plans for potential species to be developed and implemented
Aquatic ecology	Vegetation in the inundation area should be left to provide habitat for vertebrate species Avoid prolonged periods of bankfull discharge and sudden drops in water level to ensure suitable habitat remains for platypus (i.e. maintain natural rates of rise and fall). Consideration to platypus should also be provided in foreshore management plans and operational plans

10.2.3 Impact Zone 3

The proposed environmental flow regime for Dunoon Dam has been devised to protect the key aspects of creek hydrology, ecology, process and function. Maintaining (or improving) the environment through the environmental flow regime will largely negate the requirements for further significant mitigation measures. The low flow contingency releases will act to improve the environment for key species with longitudinal habitat linkages and additional habitat provision when the current flow regime would remain unconnected.

The construction of a fish ladder or lift is not recommended for this site as it would likely only provide artificial lake habitat for most migrating species as Whian Whian Falls at the upstream end of the proposed Dunoon Dam lake acts as a natural migration barrier. If species were able to migrate beyond Whian Whian Falls they could only access the additional reach to the Rocky Creek Dam wall. In this case the potential habitat quantity and quality above the proposed dam wall does not justify the expense of a fish ladder.

In preference to a fish ladder, offset and/or conservation options within the larger Terania Creek catchment are recommended. For example, the exclusion of stock from the riparian zone and the establishment of an endemic native riparian buffer will improve the aquatic and riparian habitat by reducing the inflow of sediment and nutrients to the creek and improving water quality via shading and provision of endemic organic material and the creation of habitat for riparian and semi-aquatic species.

The development and implementation of an Offset Strategy prior to dam construction could be considered as part of a broader catchment management program and would address other compensatory requirements for impacts of the dam, such as impacts to terrestrial biodiversity. An Offset Strategy would identify and detail the location of suitable offset sites, restoration needs and on-going management requirements of the conservation areas.

Whole-of-catchment solutions will also assist in mitigating impacts of the proposed dam in the impact zones both upstream and downstream of the dam. The conservation of native vegetation riparian zones, including the buffer zone surrounding the dam (Impact Zone 2) as well as the creeks that make up the Terania system (i.e. Rocky Creek, Tuntable Creek and Terania Creek) will help to maintain and improve water quality and habitat for aquatic species.

Table 10-4: Recommended mitigation and management measures – impact zone 3

POTENTIAL IMPACTS	POSSIBLE MITIGATION & MANAGEMENT MEASURES
Hydrology	Implement the specified environmental flow regime
Water quality	Multi-level off-take structure to control level of intake (i.e. match as much as possible certain physico-chemical parameters such as temperature) (e.g. Krchnak et al. 2008) Rapid level adjustment of the intake to provide response to event based conditions that may adversely impact downstream conditions, combined with ongoing monitoring program of water profile (ie vertical variability) to allow selection of suitable depth for off-take Artificial mixing of the water column
Fauna passage	Implement the specified environmental flow regime

POTENTIAL IMPACTS	POSSIBLE MITIGATION & MANAGEMENT MEASURES
General	Development and implementation of an Offset Strategy in consideration of a broader catchment management program and other compensatory requirements

10.2.4 Impact Zone 4

There would be limited impacts as a result of environmental flows from Dunoon Dam in the reach of the system downstream of the confluence of Rocky and Terania Creeks. Catchment-scale measures, such as riparian fencing and rehabilitation may assist in improving general water quality of the reach.

Table 10-5: Recommended mitigation and management measures – impact zone 4

POTENTIAL IMPACTS	POSSIBLE MITIGATION & MANAGEMENT MEASURES
Water quality	Implement measures to reduce riparian erosion (e.g. stock exclusion, riparian plantings etc) Address more general catchment issues (land management, soil conservation etc) to reduce general sediment loads to the system

10.2.5 Impact Zone 5

There would be limited impacts as a result of environmental flows from Dunoon Dam in the reach of the system downstream of the confluence of Terania and Leycester Creeks. Based on the outcomes of this assessment, no mitigation or management measures are recommended.

10.3 MONITORING RECOMMENDATIONS

A monitoring program to assess the potential impacts of the proposed environmental flows from Dunoon Dam is recommended. Monitoring should be implemented prior to construction of the dam as well as during operation to better understand the impacts of environmental flows on the Rocky Creek system and on a larger scale. Monitoring will also provide opportunity for ongoing improvements and refinements to the recommended flow regime.

Monitoring that is undertaken prior to construction should ideally be undertaken for as long as possible to collate baseline data. These data will then help inform performance objectives for the dam's operation. Any monitoring undertaken prior to construction should inform development of any management plans. Additional flow modelling will be required for detailed design and it is anticipated the outcome of that modelling will also feed into subsequent management plans. More detailed performance objectives should be provided at that stage of the project.

Monitoring undertaken during the operational phase should be undertaken for the first three years and then reviewed at the end of that time period. Any management plans developed should include a provision for review to facilitate adaptive management of the dam and its releases.

Indicative costing for each of the monitoring recommendations has been provided in **Appendix A.**

Table 10-6: Monitoring recommendations for the proposed Dunoon Dam

ASPECT	RECOMMENDED MONITORING
Pre-Dam Construction	
Hydrology	Establish a flow gauge on Rocky Creek upstream and downstream of the proposed dam, and on Little Rocky Creek, to determine existing flows and further calibrate and refine IQQM results and Environmental Flow recommendations
Water quality	Long-term monitoring of deep pools within each impact zone (with the exception of zone 2) to determine occurrences of thermal stratification and impact of different sized flows on stratification Water quality monitoring upstream and downstream of the existing Rocky Creek Dam under a range of flow conditions to create a hydrodynamic model on which the impacts on water quality can be determined. This modelling will provide for more detailed consideration of the impact of Dunoon Dam on physico-chemical properties of flow releases downstream Detailed assessment and consideration of soil profiles within the proposed full supply level and predicted top water levels to determine potential for mass movement/slumping of the soil profile to identify areas where erosion controls may be required Water quality monitoring (including total suspended solids) during flooding flows
Aquatic ecology	Monitoring of macroinvertebrate assemblages in zones 1, 3 and 4 to gain better longer-term understanding of the seasonal variation in the system and resilience to flow disturbance. Monitoring should ideally include AUSRIVAS style assessments in autumn and spring Monitoring of fish assemblages (zones 1 and 3 in particular) to gain more detailed understanding of habitat and migration patterns of current assemblages and populations These data can be used as a reference against which to measure the success of environmental flow management
Operation Phase	
Hydrology	Establish flow gauge for real-time monitoring of inflow to Dunoon Dam to facilitate transparent environmental releases. A minimum of a three-hourly time step should provide sufficient temporal resolution for the transparent release requirements Establish long-term monitoring of deep pools within each impact zone (with the exception of zone 2) to determine occurrences of thermal stratification and impact of different sized flows on stratification
Geomorphology	Regular assessment of creek geomorphology (bed and bank) to highlight any erosion or deposition issues and recommend suitable management options. Assessment should include bed sediment texture assessment and description of the morphology of key pools in Rocky Creek, both above and below the dam
Water quality	Monitoring of water quality during the initial filling period to assist in controlled releases during fillin It is recommended that a water quality probe (temperature and dissolved oxygen) is installed and maintained in the large pool downstream of the dam wall. Although thermal stratification occurs at present, it may be prudent to monitor and limit these events even if they have occurred in the past

	Within dam water quality monitoring (temperature, dissolved oxygen and algal) to determine vertical variability to allow selection of suitable depth for intake for controlled releases Monitoring of shoreline erosion to determine if (additional) mitigation measures are required
Aquatic ecology	On-going monitoring of macroinvertebrate assemblages in zones 1, 3 and 4 to gain understanding of the impact of the environmental flow regime on the system. Additional monitoring sites to those used for this assessment would indicate impacts at different points down the system Monitoring of fish assemblages (reaches 1 and 3 in particular) to determine impact of environmental flows and/or the dam on fish assemblages. Methods should target juveniles of key species and commence during the dam filling phase Monitoring of dam shoreline for invasive plant species Platypus and frog monitoring (zones 1 and 3 in particular)

10.4 FURTHER HYDROLOGICAL ANALYSIS

Modelling of flow regimes that included Rocky Creek Dam and Dunoon Dam at full capacity indicated that some flow events may lead to increased flood peaks above those that might have occurred in a natural regime. There is a logical explanation for this phenomenon as the water surface of each dam will act to transfer all rainfall on the water surface to runoff (i.e. the dam surface acts as an impervious surface) and increase the efficiency of the overall catchment to deliver rainfall to runoff. However, the model used for this study (IQQM) is designed to assess catchment-scale flow changes and is not of sufficient accuracy to predict the magnitude of any increases in flood peak discharge and hence cannot reliably be used to predict additional impacts on the downstream environment. In addition, the data created for this study were at a daily time-step which is insufficient to determine likely instantaneous peak discharges and hence effects of increased flood inundation.

Further study of this increase in the peak magnitude of flood events is required to assess any impacts from this effect. This modelling should examine a range of these events using more detailed information on the final dam design including inundation extent, dam crest and spillway and should use a much finer time-step to understand actual flood peak magnitude. If developed, this model should include capacity to model water temperature, sediment and other water quality parameters to provide for a detailed hydro-dynamic assessment of the proposed dam.

11 Conclusions

Based on an holistic approach, key aspects of the creek flow, ecology, process and function of the Rocky Creek system were identified. An environmental flow release strategy has been designed to maintain or enhance the environmental and habitat values downstream of the proposed Dunoon Dam, including hydrological processes, macroinvertebrate assemblages, water quality, fish assemblages (including fish passage throughout the system), ecological and biodiversity values of water dependant ecosystems and fluvial geomorphology.

The environmental release recommendations from this study are comprised of general flow rules to provide transparency of base to moderate flow levels (up to 100 MLd^{-1}). These important flow components provide for the majority of critical flow functions including mimicking natural flow variability, opening of key fish barriers and seasonal queues, in-channel wetting and drying, entraining fine sediment and general fauna habitat and food provision. Additional environmental contingency provisions have also been recommended to enhance the downstream environment specifically to provide for longitudinal channel connectivity for icon fish species.

Given that the proposed environmental flow regime has been developed to protect flows for key system functions and processes, the impacts of the release strategy on the system are expected to be minimal. Appropriate management of releases will assist in managing certain aspects, such as cold-water pollution and the secondary impacts on downstream systems. It is acknowledged that the proposed operation of Rocky Creek Dam with Dunoon Dam online will also impact on the system upstream of the new dam to Rocky Creek Dam. However, given the impacted nature of this reach, armoured bed and banks and continual supply of water from seepage from Rocky Creek Dam the impact on this reach is expected to be minimal.

The recommended mitigation measures provided in this assessment should be incorporated into relevant environmental management plans relating to both construction and operation to manage impacts on the system as a result of the proposed environmental flow regime. It is noted that these mitigation measures are based on the conceptual design of the dam; further measures may come to light once the detailed design has been completed. Some pre-construction monitoring of the existing system, such as long-term monitoring of deep pools, water quality and fish assemblages are also recommended to gain a more detailed understanding of the system. Outcomes of this monitoring should also be incorporated as necessary into any management plans.

Should the Dunoon Dam project progress, Rous Water will be required to lodge an application with the Department of Planning and Infrastructure (DoPI). Further assessment and/or refinement of the environmental flows assessment may be required to meet the requirements of DoPI.

References

Allen, P. and Bainbridge, T. 2006. *The Lismore Source Environmental Impact Statement*. Parsons Brinckerhoff, Australia.

American Public Health Association (APHA), American Water Works Association (AWWA) & Water Environment Federation (WEF). 2005. *Standard Methods for the Examination of Water and Wastewater* (21st ed.). American Public Health Association, Washington D.C.

Austeco. 1994. *Preliminary investigations of flora and fauna at two potential dam sites, near Federal and Dunoon, north-east New South Wales.*

Bishop, K.A. 1998a. *Preliminary Assessment of the Effect of Rocky Creek Dam on the Downstream Environment.* Rous County Council, NSW Department of Public Works and Services.

Bishop, K.A. 1998b. Unpublished dataset *Rocky Creek long data for October 1998*.

Bishop, K.A. 2001. *Emigrant Creek Dam Environmental Flows Investigation*. Prepared for Rous County Council. August 2001.

Bovee, K D. and Cochnaur, T. 1977. *Development and Evaluation of Weighted Criteria, Probability-of-Use Curves for Instream Flow Assessments: Fisheries*. Instream Flow Information Paper No. 3. Cooperative Instream Flow Service Group. U.S. Fish and Wildlife Service. Fort Collins, Colorado. FWS/OBS-77/63.

Bureau of Meteorology (2009) Retrieved from http://www.bom.gov.au/climate/averages/tables/cw_058037.shtml. Accessed 11/08/2011 Station number 058037.

Charlton, R. 2007. *Fundamentals of Fluvial Geomorphology*. Routledge, London.

Connell Wagner. 2008. *Tillegra Dam Planning and Environmental Assessment Working Paper D: Environmental Flows and River Management*. Reference no. 29340.

Cottingham P., Stewardson M. and Webb A. 2005. *Victorian Environmental Flows Monitoring and Assessment Program: Stage 1 Statewide Framework*. CRC Freshwater Ecology and CRC Catchment Hydrology report to the Department of Sustainability and Environment.

Cunnane, C. 1979. *A note on Poisson assumption in partial duration series method of flood frequency analysis*. Water Resources Research, 15, 489-494.

Department of Infrastructure, Planning and Natural Resources. 2004. *Rous Water Augmentation Water Supply Scheme: Hydrologic modelling study using Wilsons River IQQM*. NSW Department of Infrastructure, Planning and Natural Resources.

Department of Mineral Resources. 2002. *Statewide Digital Geology 1:250,000.* NSW Government.

Department of Sustainability, Environment, Water, Populations and Communities. 2011. *State of the*

Environment Reporting. Retrieved from http://www.environment.gov.au/soe.

Earth Tech. 2006. *Environmental Flow Determination for the Bunyip and Tarago Rivers – Flow Recommendations Paper*. Unpublished Report to Melbourne Water by the Bunyip and Tarago Rivers Environmental Water Requirements Technical Panel.

Ecology Lab Pty Ltd. 2008. *Tillegra Dam Planning and Environmental Assessment Working Paper C: Aquatic Ecology Assessment for the Construction and Operation of Tillegra Dam*. Prepared for Connell Wagner, Report Number 040708 A.

Eco Logical Australia. 2005. *A Vegetation Map for the Northern Rivers Catchment Management Authority to support application of the Biodiversity Forecasting Toolkit*.

Ecos Environmental Planning. 2001. *Flora and Fauna Survey and Revegetation Concept Plan.*

Fowler, R. 2004. *The recovery of benthic invertebrate communities following dewatering in two braided rivers*. Hydrobiologia, 523(1–3),17-28.

Gippel, C. and Anderson, B. 2008. *Tillegra Dam Planning and Environmental Assessment Working Paper B: Fluvial Geomorphology*. Fluvial Systems Pty Ltd, Stockton, in association with Water Technology Pty Ltd. Connell Wagner, Neutral Bay.

Gordon, N.D., McMahon, T.A., Finlayson, B.L., Gippel, C.J. and Nathan, R.J. 2004. *Stream Hydrology: an Introduction for Ecologists* (2nd ed.). John Wiley & Sons, Chichester.

Grant, T.R. 1998. 'The Platypus – Appendix F'. In Bishop, K. *Preliminary Assessment of the Effect of Rocky Creek Dam on the Downstream Environment*. Rous County Council, NSW Department of Public Works and Services.

Green, D., Petrovic, J., Moss P., and Burrell, M. 2011. *Water Resources and Management Overview: Macquarie-Bogan Catchment*. NoW, Sydney.

Groenveld, D. and French, R. 1995. *Hydrodynamic Control of an emergent aquatic plant (Scirpus acutus) in open channels*. Water Resources Bulletin, June 1995, 31(3), American Water Resources Association.

Howell, J. And Benson, D. 2000. *Predicting potential impacts of environmental flows on weedy riparian vegetation of the Hawkesbury-Nepean River, south-eastern Australia*. Austral Ecology, 25, 463-475.

Hudson, H.R., Byrom, A.E. and Chadderston W.L. 2003. *A Critique of IFIM - Instream Habitat Simulation in the New Zealand Context.* Department of Conservation, Wellington, New Zealand.

Kelly, I. 1998. *An overview of land-use, groundwater, hydrogeology and water quality for a preliminary study in the Rocky Creek catchment, downstream of Rocky Creek Dam*. Appendix B. In Bishop, K. Preliminary Assessment of the Effect of Rocky Creek Dam on the Downstream Environment, Rous County Council, NSW Department of Public Works and Services.

Krchnak, K., Thomas, G., and Richter, B. 2008. *Integrating Environmental Flows into Hydropower Dam Planning, Design, and Operations.* Water Partnership Program.

Matthews, D.B. 1996. *A baseline study to assess the potential impact of a proposed water storage dam on the Platypus.* Report on an Integrated Project under the supervision of Dr. Ross Goldingay. Southern

Cross University, Lismore.

McDonald, R.C., Isbell, R.F., Speight, J.G., Walker, J. and Hopkins, M.S. 1990. *Australian Soil and Land Survey: Field Handbook* (2nd ed.). Inkata Press, Melbourne/Sydney.

MDBA. n.d. Retrieved from http://www.mdba.gov.au/. Accessed 15 December 2011.

Milton, D. A. and Arthington, A.H. 1985. *Reproductive strategy and growth of the Australian smelt, Retropinna semoni (Weber) (Pisces: Retropinnidae), and the olive perchlet, Amabassis nigripinnis (De Vis) (Pisces: Ambassidae), in Brisbane, South-eastern Queensland*. Australian Journal of Marine and Freshwater Research, 36(3), 329-341.

Morand, D.T. 1994a. *Soil Landscapes of the Lismore-Ballina 1:100 000 Sheet Report*. Soil Conservation Service of NSW, Sydney.

Morand, D.T. 1994b. *Soil Landscapes of the Lismore-Ballina 1:100 000 Sheet Map*, Soil Conservation Service of NSW. Sydney.

National Parks and Wildlife Service Northern Zone CRA Unit. 1999. *Forest Ecosystem Classification and Mapping for the Upper and Lower North East CRA Regions*. Project Number NA35/EH, Department of Urban Affairs and Planning and the Forests Taskforce, Department of the Prime Minister and Cabinet.

NSW Department of Land and Water Conservation. 1998. *Stressed Rivers Assessment Report: NSW State Summary*. NSW DLWC, Sydney.

NSW Office of Water. 2009. *Report Card for the Terania Creek Water Source*. Report Card 17 of 22, Draft Water Sharing Plan for the Richmond River Area unregulated, regulated and alluvial water sources, Publication Number 09_147.1.

NSW Office of Water. 2010. *Water Sharing Plan for the Richmond River Area Unregulated, Regulated and Alluvial Water Sources – Guide*. NSW Office of Water, DECCW, Publication Number 10_328a.

NSW Office of Water. 2011. *Algal Management Strategy*. In Prevention and Control. Retrieved from http://www.water.nsw.gov.au/Water-management/Water-quality/Algal-information/Prevention-and-control/Prevention-and-control/default.aspx#AlgalManagementStrategy.

NSW Public Works. 1994. *Rous Regional Water Supply Strategy Study: Report on Preliminary Geological and Geotechnical Investigations – Rocky Creek*. NSW Dams and Civil Section, Report No. DC94010, July 1994.

Office of Environment and Heritage. 2006. *Richmond River Water Quality and River Flow Objectives*. Retrieved from NSW OEH website: http://www.environment.nsw.gov.au/ieo/richmond/report-02.htm.

Peat, M.S. and Norris, R.H. 2007. *Adaptive management for determining environmental flows in the Australian Capital Territory*. In Wilson, A.L., Dehaan, R.L., Watts, R.J. Page, K.J. Bowmer, K.H. and Curtis, A. (Eds.), Australian Rivers: Making a Difference, Proceedings of the 5th Stream Management Conference, Charles Sturt University, 21–25 May 2007, Albury, NSW. Retrieved from: http://www.csu.edu.au/research/ilws/news/events/5asm/proceedings.htm.

Pilgrim, D.H., and Doran, D.G. 1987. *Flood frequency analysis*. In Australian Rainfall and Runoff, Pilgrim, D. (Ed.), The Institute of Engineers, Australia.

Pusey, B,, Kennard, M. and Arthington, A. 2004. *Freshwater Fishes of North-Eastern Australia*. Centre for Riverine landscapes, Griffith University, CSIRO.

Reinfelds, I. and Williams, S. 2008. *Hydraulic modelling to estimate threshold discharges for sediment entrainment in the Snowy River, Australia.* Snowy River Recovery: Snowy River Flow Response Monitoring, Department of Water and Energy, Sydney

Rous Water. 2007. *Environmental Flows*, Info Sheet 10. Retrieved from Rouse Water website: http://www.rouswater.nsw.gov.au/cp_themes/default/page.asp?p=DOC-NYG-58-41-45..

Rous County Council. 1995. *Rous Regional Water Supply Strategy Planning Study – Scheme Options: Final Report*. Report No. LI 169, May 1995.

Scott, A. and Grant, T. 1997. *Impacts of water management in the Murray-Darling Basin on the platypus (Ornithorhynchus anatinus) and the water rat (Hydromys chrysogaster).* CSIRO Land and Water Technical Report 23/97.

Simons, M., Podget, G., and Cooke, R. 1996. *A hydrological modelling tool for water resources and salinity management*. Environmental Software, 2, 185-192.

Sinclair Knight Merz & Cooperative Research Centre for Freshwater Ecology, Freshwater Ecology and Lloyd Environmental Consultants. 2002. *FLOWS – a method for determining environmental water requirements in Victoria.* Victorian Department of Natural Resources and Environment, Melbourne.

SMEC. 2011. *Dunoon Dam Terrestrial Ecology Impact Assessment.* Prepared for Rous Water.

Tharme, R.E. and King, J.M. 1998. *Development of the Building Block Methodology for Instream Flow Assessments, and Supporting Research on the Effects of Different Magnitude Flows on Riverine Ecosystems.* Water Research Commission Report No. 576/1/98.

Thoms, M.C. 1998. *The geomorphology of Rocky Creek downstream of Rocky Creek Dam and its significance for environmental flow regimes*. Appendix A of Bishop, K.A. 1998a. Preliminary Assessment of the Effect of Rocky Creek Dam on the Downstream Environment, Rous County Council, NSW Department of Public Works and Services.

U.S. Army Corps of Engineers. 2010. *HEC-RAS River Analysis System, Version 4.1.0.* Developed by the U.S. Army Corps of Engineers Hydrologic Engineering Centre, downloaded from www.hec.usace.army.mil.

Water Services, NSW Department of Commerce. 2009. *Rous Regional Water Supply – Regional Water Management Strategy*. Prepared for Rous County Council (Rouse Water).

Wealands, V.A., Boon, P., Pope, A. and Arnott, C. 2007. *Determination of environmental flow requirements for the Merri River – Recommendations.* Report P106016_v08 prepared by Alluvium for Glenelg Hopkins Catchment Management Authority, Hamilton Victoria.

Wintle, B.C. and Kirkpatrick, J.B. 2007 *The response of riparian vegetation to flood-maintained habitat heterogeneity*. Austral Ecology, 32 (5). pp. 592-599.

Appendix A: Estimated monitoring costs

ASPECT	RECOMMENDED MONITORING	ESTIMATED COST (BASED ON 2012 PRICES) *
Pre-construction Stage (until construction commences)		
Hydrology	Establish flow gauges Rocky Creek (upstream and downstream of the proposed dam) and Little Rocky Creek	$25,000/gauging station
Water quality	Thermister chains (each with minimum of three water temperature data loggers)	$500 / thermister chain + installation ($1,200) Regular downloading of data is required
	Water quality monitoring (suspended sediment, Total Kjehldahl Nitrogen and Nitrates) upstream and downstream of the existing Rocky Creek Dam	$275 / site (triplicate samples) $1,100 / sample collection
	Detailed soils assessment within the proposed full supply level and predicted top water levels	$13,000 Assumed approximately 1 bore hole / kilometre of perimeter and soil testing of two horizons
Aquatic ecology	AUSRIVAS-style macroinvertebrate monitoring (minimum of five sites)	Sample collection $6,250 / trip Bug identification $750 / trip Note that autumn and spring monitoring is recommended
	Monitoring of fish assemblages (upstream of, within and downstream of inundation area, including sites upstream and downstream of Terania Creek)	$3,600 / site
Operation Phase		
Hydrology	Establish flow gauge for inflow to Dunoon Dam	$25,000
	Thermister chains	$500 / thermister chain + installation ($1,200) Regular downloading of data is required
Geomorphology	Geomorphic assessments	$5,000
Water quality	Water quality during dam filling	$2,000

	Dissolved oxygen probe maintained in large pool downstream of the dam wall	$5,000
	Within-dam water quality monitoring (temperature, dissolved oxygen and algal)	$10,000
	Monitoring of shoreline erosion	$3,300
Aquatic ecology	AUSRIVAS-style macroinvertebrate monitoring (minimum of five sites)	Sample collection $6,250/ trip Bug identification $750 / trip
	Monitoring of fish assemblages (upstream of, within and downstream of inundation area, including sites upstream and downstream of Terania Creek)	$3,600 / site
	Monitoring of dam shoreline for invasive plant species	$3,300
	Monitoring and mapping of platypus population	$6,000

* All costs assumed based ex-Lismore

HEAD OFFICE
Suite 4, Level 1
2-4 Merton Street
Sutherland NSW 2232
T 02 8536 8600
F 02 9542 5622

SYDNEY
Level 6
299 Sussex Street
Sydney NSW 2000
T 02 8536 8650
F 02 9264 0717

ST GEORGES BASIN
8/128 Island Point Road
St Georges Basin NSW 2540
T 02 4443 5555
F 02 4443 6655

CANBERRA
Level 2
11 London Circuit
Canberra ACT 2601
T 02 6103 0145
F 02 6103 0148

NEWCASTLE
Suites 28 & 29, Level 7
19 Bolton Street
Newcastle NSW 2300
T 02 4910 0125
F 02 4910 0126

NAROOMA
5/20 Canty Street
Narooma NSW 2546
T 02 4476 1151
F 02 4476 1161

COFFS HARBOUR
35 Orlando Street
Coffs Harbour Jetty NSW 2450
T 02 6651 5484
F 02 6651 6890

ARMIDALE
92 Taylor Street
Armidale NSW 2350
T 02 8081 2681
F 02 6772 1279

MUDGEE
Unit 1, Level 1
79 Market Street
Mudgee NSW 2850
T 02 4302 1230
F 02 6372 9230

PERTH
Suite 1 & 2
49 Ord Street
West Perth WA 6005
T 08 9227 1070
F 08 9322 1358

WOLLONGONG
Suite 204, Level 2
62 Moore Street
Austinmer NSW 2515
T 02 4201 2200
F 02 4268 4361

GOSFORD
Suite 5, Baker One
1-5 Baker Street
Gosford NSW 2250
T 02 4302 1220
F 02 4322 2897

DARWIN
16/56 Marina Boulevard
Cullen Bay NT 0820
T 08 8989 5601

BRISBANE
PO Box 1422
Fortitude Valley QLD 4006
T 0400 494 366