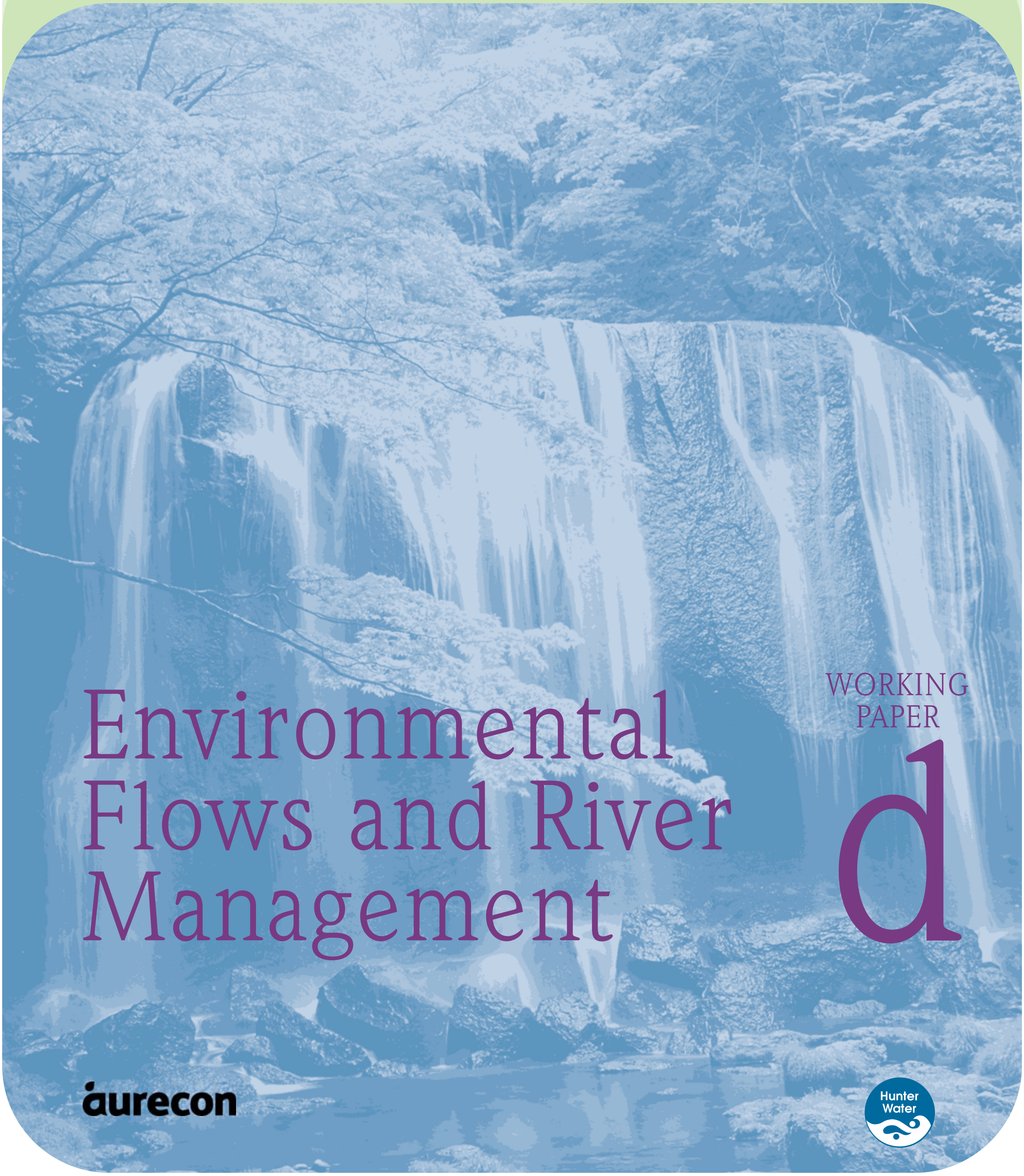
Tillegra Dam

Planning and Environmental Assessment



Environmental Flows and River Management

WORKING PAPER

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aurecon

Hunter Water

Document Control

Rev No	Date	Revision Details	Typist	Author	Verifier	Approver
1	Jul 08	Draft	BC	BC/DvS/TEL	DvS	CM
2	Aug 08	Final draft	BC	BC/DvS/TEL	DvS	CM
3	Oct 08	Final	BC	BC/DvS/TEL	DvS	CM

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Aurecon came into existence in March 2009 through the merger of Connell Wagner Pty Ltd and two South African companies, Africon (Pty) Ltd and Ninham Shand (Pty) Ltd. This post-dated Hunter Water Corporation's engagement of Connell Wagner in July 2007 for professional services for the Tillegra Dam Planning and Environmental Assessment. All references to Connell Wagner in this report should be taken to now refer to Aurecon.

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Appendices

Executive Summary

The environmental release strategy for the proposed Tillegra Dam has been assessed using the river flow objectives and guidelines provided by the NSW Dept of Water and Energy (DWE). These guidelines recommend development of a release strategy on the basis of an understanding of the relationships between flow components and ecosystem responses developed for the system. Based on this understanding and the current water demands of irrigators and domestic users a range of release strategies have been proposed and assessed to derive the preferred environmental release strategy. This strategy considers all aspects of the dam construction, filling phase and operational phase following completion of the dam. Flow predictions of the future dam operation were based on 77 years of historical daily flow data and maximum demand scenario commencing at day one.

The key components of the existing system hydrology, water quality, aquatic ecology and geomorphology have been identified through specific studies reported in Working Papers A, B and C, respectively. The generic River Flow Objectives described by Dept Water and Energy (2002) have been adapted to the Williams River system and the flows required to meet these objectives derived from the available data and interpretation of the key ecosystem and geomorphic processes that rely on specific components of the overall flow variability. The key flow components and related ecosystem and geomorphic characteristics are summarised in the Table 4.4.

Protection of low flows is deemed important to maintain river habitat connectivity, aquatic vegetation and macroinvertebrates. Moderate to fresh flow events provide biological triggers for fish and macroinvertebrate spawning and migrations, sufficient depth for fish passage, as well as flushing bed sediments and maintaining water quality. High flows contained within the river channel are important for mobilising bed sediments and shaping the river morphology as well as facilitating downstream fish migrations. Bankfull and overbank flood flows are important for sediment transport, maintaining connectivity between the river and adjacent floodplain and transporting/returning organic matter to the river.

River hydrology is closely linked to climate and rainfall. The climate of the region is characterised by high rainfall in late summer and autumn and less frequent lower rainfall events for the rest of the year. The number of rain days per month is evenly distributed throughout the year. The steep upper catchment and frequent rainfall results in a river hydrology characterised by frequent short lived flow events and significant base flow (groundwater seepage) during the wetter months. Interannual flow variations are marked by wet/dry periods in which the river can completely cease to flow for short periods during droughts and then also maintain large flows during wet cycles such as appears to have commenced over the past 12 months. The per cent exceedance statistics based on the 77 years of historic daily flow records at Tillegra have been used to determine the various flow components.

Depending on a river's particular ecosystem and geomorphic system characteristics, environmental release strategies may specify particular components of the flow such as a low flow "transparent" component, in which an equivalent inflow discharge is released, a moderate flow "translucent" component in which some fraction of the inflow is released and possibly specific flow event releases required to provide infrequent fresh or high flows to support those functions of the ecosystem linked to these flow components. A range of strategies were proposed and assessed to determine the optimal release strategy that provides protection to the river environment, continuing access to irrigators and water supply security to the

community.

The base case release strategy comprises constant run-of-river transfers, an environmental low flow “transparent” component, a moderate flow “60% translucent” component and flushing events. Hunter Water applied this strategy to their hydrological model to produce daily discharge estimates for this future scenario. These model outputs were used to assess the likely impacts on the river system downstream of the dam. Innovative improvements to the base case environmental release strategy are suggested to provide for the protection of the riverine environment with minimal loss of ecosystem function and include run-of-river event based transfers and seasonality of releases.

The final release strategy suggested for the dam includes:

- a transparent environmental flow to the 30th percentile of all flows
- replacement of constant run of river transfers and flushing events with a specifically tailored event based run of river transfer protocol of 4,300 megalitres, consisting of a peak discharge of 1500 megalitres declining over a ten day period
- inclusion of additional event based discharges from the dam consisting of a peak discharge of 270 ML/d, tailing off over a four day period. Such discharges will be released to ensure a minimum number of variable flows important for fish passage occur below the dam wall, should run of river releases or natural spills not occur
- ensuring releases occur at the appropriate time of year to maintain the seasonality of flows within the river
- preferential use of the multi-level offtake to control the water quality characteristics of releases, as opposed to allowing uncontrolled spillway discharges
- a whole-of-system approach through the increase of transparent environmental flows from Chichester Dam to a maximum of 20 ML/d.

Development of an appropriate environmental release strategy is an ongoing process and HWC would continue to refine its hydrology modelling following discussion with DWE to support a recommendation on the ultimate release strategy to be adopted. All releases from the dam, environmental or otherwise, will be subject to access rules within the Water Sharing Plan. This plan adopts recommendations from the Healthy Rivers Commission including that necessary for environmental protection and also regarding irrigation access rights. HWC does not make representations to DWE to alter these provisions. Any flows released from the dam would be able to be accessed by other users within the existing terms of the proposed plan.

1. Introduction

A holistic approach has been undertaken to determine the environmental flow requirements for the proposed Tillegra Dam. This approach aims to assess the flow requirements of the many interacting components of the Williams River system.

The benefits of a holistic approach are discussed in Arthington (1998) which states the narrow focus on single issues (eg the flow requirements of fish) and the many drawbacks associated with the flow assessments methods reviewed by Arthington and Zalucki (1998) have simulated the development of alternative approaches to the formulation of environmental flow guidelines.

As stated in Arthington (1998) the holistic approach aims to assess the water requirements of the complete system including such components as the source area, river channel, riparian zone, floodplain, groundwater, wetlands and estuary, as well as any particular important features such as rare and endangered species. The approach aims to identify the essential features of the natural hydrological regime, define their influence on key geomorphological and ecological processes of the river system and then construct a modified flow regime (Arthington, 1998).

1.1 Scope of assessment

Results from the water quality and hydrology, aquatic ecology and fluvial geomorphology assessments (Working Papers A, B and C of the EA Report) have been integrated to develop desirable environmental flow rules for the proposed Tillegra Dam.

This report presents information on the development and analysis of environmental flow objectives for the Williams River which includes the following:

- identification of critical flow components of the natural flow regime
- identification of critical aquatic ecology flow requirements
- identification of geomorphic processes and inundation flow thresholds
- analysis of a flow scenarios to determine if critical flow components and objectives are met
- suggested improvements to flow scenarios to meet objectives

The report is structured around the following chapters:

- Chapter 2 provides a summary of environmental flow regulations
- Chapter 3 provides a brief summary of existing river flow, habitat and ecosystems of the Williams River
- Chapter 4 summarises the critical environmental flow requirements of the Williams River
- Chapter 5 analyses the base case environmental release strategy and proposes innovative improvements to this strategy
- Chapter 6 provides information on river management
- Chapter 7 lists references used in this assessment
- Chapter 8 provides conclusions and key recommendations
- Appendices are presented at the end of the report

Table references in Chapters 4 and 5 refer to either tables within the chapter (eg Table 4.1 and Table 5.1) or tables within the appendices (eg Table A1 and Table B1).

1.2 Director-Generals requirements

The Director-General's requirements (DGRs) for the Project were issued on 8 January 2008. Supplementary DGRs were issued by the Director-General of the Department of Planning on 1 May 2009 following consultation between the Department and the Commonwealth Department of the Environment, Water, Heritage and the Arts. These requirements directed HWC to address specific issues relating to potential impacts of the Project on the Hunter Estuary Wetlands Ramsar site.

With specific reference to hydrology and water quality, aquatic ecology and fluvial geomorphology the assessment is required to address the following matters:

Hydrology and water quality

- a comprehensive assessment of the impacts of the project on surface hydrology, particularly with respect to quality, quantity and flow regimes
- details of a frameworks for managing water releases from the dam that is capable of meeting the objectives of the project (in terms of water delivery), ensures impacts to the Williams River ecosystem are minimised and takes account of the draft Water Sharing Plan. The framework shall include consideration of rates of rise and fall within the Williams River, timing of water releases including consideration of antecedent conditions within the river), flooding impacts and transparent and translucent flows
- details of how the Project will be designed and operated to meet water quality guidelines detailed in *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000) for both recreational uses and aquatic ecosystems within the inundation area and downstream of the proposed dam
- assess the potential impacts on surface water users, with details of how existing access rights will be protected, including with respect to availability, quantity and quality of water
- details of a general water balance for the project, noting any expected evaporation and infiltration losses
- details of cumulative water quality and connective flow impacts on the Hunter Estuary and mitigation measures
- assessment of cumulative water quality and connective flow impacts on the Hunter estuary and details of associated mitigation measures.

Ecology

- include a comprehensive ecological assessment, including both terrestrial and aquatic ecosystems, in accordance with the DEC's *Guidelines for Threatened Species Assessment* and DPI's *Fish Habitat Protection Plan No. 1: General*
- consider impacts on ecological values directly attributable to the project as well as indirect impacts that may be associated with changes in water quality conditions, fluvial geomorphology and flow characteristics of the river
- assess both construction and operation impacts on ecology

- assess impacts on any critical habitats, threatened species, populations or ecological communities listed under both State and Commonwealth legislation recorded within and around the project area
- address impacts on aquatic ecology upstream (to Barrington House) and downstream (to the Hunter estuary) of the dam wall, particularly through changes in the quality and quantity of water within the river system and changes to habitat
- consider both aquatic and riparian species that may be directly or indirectly affected by the project and the potential for introduction of pest and exotic species
- clearly detail measures to be applied to address impacts of barriers to fish migration, breeding cycles and fish passage an sudden or unnatural changes in flow regimes and habitat on aquatic ecology
- give consideration to the management of the hydroelectric plant with respect to water releases and subsequent impacts on aquatic flora and fauna
- consider impacts on terrestrial ecology including details on the location, composition, quality and quantity of habitat proposed to be affected
- present framework monitoring program(s), management and rehabilitation plan(s) and comprehensive compensatory habitat/biodiversity offsets package(s) to address impacts in aquatic and terrestrial ecology associated with the project and taking into consideration the amount and type of habitat that will be lost.

Fluvial geomorphology

- assess the impact of the project on fluvial geomorphology
- address pre and post-construction impacts upstream and downstream of the dam wall, including with respect to erosion risks, bank stability and sedimentation/deposition.

It should be noted that there is overlap between this Working Paper and the separate Working Papers of water quality and hydrology, aquatic ecology and fluvial geomorphology (Working Papers A, B and C, respectively). The above requirements are considered appropriate in this Working Paper, however, a more comprehensive, integrated assessment is provided in the separate working papers.

2. Environmental Flows Regulations

2.1 Legislative framework and key policy documents

2.1.1 Water Management Act 2000

Under the *Water Management Act 2000* all rivers and aquifers in NSW are subject to a legal water sharing plan, Water sharing plans allocate water between competing users, as well as designating water for environmental purposes. This Act is the main piece of water legislation in NSW. It governs the issue of new water licences, the trade of water licences and allocations for those water sources (rivers, lakes and groundwater) in NSW where water sharing plans have commenced.

Once a water sharing plan commences, the licensing provisions of the *Water Management Act 2000* would also come into effect in the water sharing plan area. The existing *Water Act 1912* licences are being progressively phased out and converted to *Water Management Act 2000* water access licences and water supply works and use approvals.

The Draft *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources* (Dept of Water and Energy 2008a) has recently closed for public exhibition and it is expected the plan would commence in 2008/9. The objectives of the Plan are to:

- protect, preserve, maintain or enhance the important river flow dependent and high priority groundwater dependent ecosystems of these water sources
- protect, preserve, maintain or 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 licences and water allocations within sustainability and system constraints
- provide recognition of the connectivity between surface water and groundwater
- provide sufficient flexibility in water account management to encourage responsible use of available water
- adaptively manage these water sources.

2.1.2 NSW State Water Management Outcomes Plan

The NSW State Water Management Outcomes Plan is a statutory document under the *Water Management Act 2000* that sets out the over-arching policy context, targets and strategic outcomes for the development, conservation, management and control of the State's water sources. The plan seeks to ensure that the NSW government's interim (river flow and water quality) environmental objectives for NSW waters are addressed in future water resource management.

River flow objectives, aimed at mimicking the natural river flow regime to improve and protect an ecosystem (Dept of Water and Energy 2002), have been adapted for the Williams River system for this assessment.

2.1.3 National Water Initiative

The National Water Initiative (NWI) is Australia's blueprint for national water reform and was signed by all governments by 2006. The objective of the initiative 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 National Water Initiative agreement includes objectives, outcomes and agreed actions to be undertaken by governments across eight inter-related elements of water management. Of specific interest is the integrated management of water for environmental and other public benefit outcomes.

2.2 Current operation of the Williams River

A number of licensing agreements exist within the Williams River catchment and include regulations at Chichester Dam, Seaham Weir and surface water access licences.

2.2.1 Chichester Dam

The following operating rules apply to Chichester Dam as set out in the Water Management Licence 2004 under the *Water Act 1912*. Requirements are to release up to 14 ML/day whenever inflow is higher than this value. This is considered as the 95^{th} percentile as back calculated from the Glen Martin gauge. [1]

(a) Hunter Water Corporation is entitled to divert water flowing into the storage and impounded behind Chichester Dam, subject to the conditions of this licence provided that diversions are limited to 150,000 megalitres in any three-year rolling period.

(b) When the combined inflows from the Chichester and Wangat are equivalent to, or greater than 14 ML/day, Hunter Water Corporation must maintain a minimum flow release of 14 ML/day from Chichester Dam.

(c) Notwithstanding, subclause (b), when the combined inflows from the Chichester and Wangat Rivers are equivalent to, or greater than, 14 ML/day, and Chichester Dam is not spilling, Hunter Water Corporation may operate Chichester Dam releases in the range of 5 ML/day to 30 ML/day as per the release pattern shown in Attachment 1 of their Licence until the supplementary study 1.1 is completed, and must operate releases as directed by the Ministerial Corporation to achieve the requirements of supplementary study 1.1.

(d) When combined inflows from the Chichester and Wangat Rivers into Chichester Dam storage are less than 14 ML/day, Hunter Water Corporation must maintain an equivaent daily flow release from Chichester Dam.

(e) The Minister may under section 45 (1) (b) of the Act, vary the rules under subclause (c), during the term of this Plan, based on an assessment of the implementation of release rules recommended in the 'Chichester Dam Flow Release Acceptance Levels Study'.

2.2.2 Seaham Weir

The following operating rules apply to Seaham Weir as set out in the Water

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[1] The 95th percentile at Chichester Dam has been calculated by HWC during this study to be 20 ML (rather than the historical estimate of 14ML back calculated from Glen Martin gauge)

Management Licence 2004 under the *Water Act 1912.*

<u>Operating:</u>

(a) Hunter Water Corporation must maintain the authorised works identified in this licence as Seaham Weir Floodgate structures. The earthen embankments associated with the floodgates are to be maintained at original design heights.

(b) Hunter Water Corporation may operate the Balickera pumps if the:
  - (i) upstream flow is less than 600 ML/day and the weir pool is greater than 0.42 metres AHD, or
  - (ii) upstream flow is greater 600 ML/day and the weir pool is greater than 0.32 metres AHD.

Drainage mode:

(c) If upstream flow is less than 600 ML/day, then the weir pool level is to be maintained within the range 0.42 metres AHD to 0.53 metres AHD. This may be achieved through any combination of operation of the weir gates and Balickera pumps.

(d) Notwithstanding condition (c), if, due to low upstream flows, the storage level decrease to below 0.42 metres AHD, the gates are to remain closed until such time as upstream flows:
  - (i) have been sufficient to raise the water level to 0.42 metres AHD, or
  - (ii) have exceeded 600 ML/day

High flow mode:

(e) If upstream flow is greater than 600 ML/day, and Hunter Water Corporation elects to pump at a rate less than 500 ML/day and the weir pool level is greater than or equal to 0.42 metres AHD, the gates are to be opened completely to draw down the weir pool level to 0.32 metres AHD.

(f) Notwithstanding condition (e), the gates may be closed if the differential between the tidal pool level and the weir level is less than 0.1 metres, and may then remain closed until the differential between the tidal pool level and the weir level is greater than 0.3 metres.

(g) If upstream flow falls to less than 600 ML/day the gates are to be closed until such time as the water level in the weir exceeds 0.42 metres AHD, returning the weir drainage mode as described in condition 5(c).

Normal mode:

(h) If Hunter Water Corporation elects to operate Balickera Pumps at a rate greater than 500 ML/day then:
  - (i) the gates remain closed until the weir pool levels reach a maximum of 0.92 metres AHD
  - (ii) if Hunter Water Corporation chooses to reduce pumping to less than 500 ML/day the target level become 0.32 metres AHD if flow remains greater then 600 ML/day or between 0.42 metres AHD and 0.53 metres AHD if flow is less than 600 ML/day.

2.2.3 Balickera Pumping Station

The decision of when to pump water from Seaham Weir to Grahamstown Dam is based on availability of water in the river, space in the dam and the quality of the water in the river. Pumping is suspended if nutrient or algae cell levels at Boag's Hill intake exceed pre-determined limits.

Balickera pump station has six large pumps which are used to transfer water from the Williams River into Grahamstown Dam. Hunter Water's Water Management Licence allows extraction of up to 1640 ML/day.

2.2.4 River access licences

There are 177 surface water extraction licences in the Williams River water source with a total entitlement of about 8,300 ML/year (Dept of Natural Resources 2007). The majority of access points for the licences are downstream of the Williams and Chichester Rivers confluence and around 97 per cent of licences are used for irrigation purposes.

Currently access rules are established for users above Seaham Weir Pool and users within the weir pool. Irrigation extraction upstream of Glen Martin is subject to cease to pump levels when flows are at or below 6 ML/day or 15 ML/day at Glen Martin for accredited and non-accredited users, respectively. The accreditation scheme is managed by the Dept of Primary Industries who asses good land management practices such as riparian zone planting and fencing. Users within Seaham Weir Pool cease to pump when levels in the weir pool are 0.38 metres or below.

2.2.5 Other water users

Whilst town water supply licences (eg Chichester and Balickera Pumps) and river access licences are the dominant licence types for the Williams River water source there are other water users that require consideration. Additional water users are basic landholders rights and domestic and stock access licences. All water users of the Williams River water source and the corresponding total entitlement or share component are listed in Table 2.1.

Table 2.1 Water users within the Williams River water source (Dept Water and Energy 2008a)

Category	Entitlement
Basic landholders rights	4.81 ML/d
Requirements for water under access licenses	
Share component of domestic and stock access licences	24 ML/year
Share component of major utility access licences	239,000 ML/year
Balickera Pumping Station	189,000 ML/year
Chichester Dam	50,000 ML/year
Share component of unregulated river access licences	8,239 unit shares

2.2.6 Environmental uses

In addition to licensing, water within the Williams River provides other productive uses such primary and secondary contact for leisure activities including swimming, boating and fishing.

Water and flow variability in the Williams River is essential to maintain ecosystem function. As a first priority, the *Water Management Act* requires that water be allocated for the environmental health of rivers and groundwater systems. Currently the plan does this on a river basin and local scale. On a river basin scale all water above the long-term average annual extraction limit is set aside for environmental needs. On a local scale cease to pump levels are implemented.

There are long term extraction limits for the Hunter Extraction Management Unit (which includes the Williams River water source) and cease to pump flow classes for the Williams River. Flow classes are; at or below 6 ML/day (very low flow class), at or below 15 ML/day (low flow class) and greater than 15 ML/day (A class).

Amendments to the draft *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources* may be made due to the construction and/or operation of Tillegra Dam (Clause 94). At the commencement of flow capture by the Tillegra Dam Storage, the minister may amend a number of clauses in the Plan relating to environmental releases, flow classes and long term extraction limits. In particular, the Minister may amend Clause 87(1) and (2) to establish rules for the release of water from Tillegra Dam (Clause 94 (1) (g)). Environmental releases from the dam, as noted in this report, would be incorporated into the water sharing plan in 2013 if deemed appropriate by Dept Water and Energy.

2.3 Environmental flow regimes

2.3.1 Water sharing plans

In order to balance the needs of the environment and other water users, rules for extraction of river and groundwater are stipulated in a water sharing plan that protects both the total volume of water for the environment and the natural variability in flows that is the low flows, moderate flows, freshes and floods (Dept of Water Energy 2008b). Water sharing plans consist of a number of components including access licenses, average annual extraction limits, daily access rules and environmental water.

Access licences

All water extraction from a water source, with the exception of basic landholder rights, must be authorised under a water access licence. The range of licence categories include; local water utility (eg town water), major water utility (eg HWC), domestic and stock, unregulated river of aquifer (eg irrigation), unregulated river high flow (extraction during high flows only) and aboriginal cultural and commercial.

Access licences provide the holder with a share of the available water in a water source. A licence holder’s access to water is managed in a water sharing plan through, firstly, the *long-term average annual extraction limit* which sets how much water licence holders in total can extract annually and secondly, through daily access rules (Dept of Water and Energy 2008b). These daily access rules regulate not only how much water may be extracted from a system but also the timing, location and rate of extraction permitted by a water user.

Every year, *available water determinations* are made which define how much of the share component would be available for each licence holder.

Daily access rules

There are rules within the plan which determine when licence holders can and cannot pump on a daily basis. Most water sources are divided into flow classes which describe the range of daily flow levels in a river and provide the framework for sharing water on a daily basis (Dept of Water and Energy 2008b). Flow classes vary between water sources but may include a very low flow class (95th percentile) or an A class (between 95th and 50th percentile).

Environmental water

A water sharing plan protects the environmental needs of a river system through extraction limits on a river basin and local scale.

2.3.2 Environmental release rules

The environmental rules in the water sharing plans are designed to limit extractions so that the major share of water is protected and replicate natural flow patterns or events so as to provide water when and where it will best meet environmental needs (Dept of Water and Energy 2008b).The environmental flow rules are based on broad river flow objectives that set out 12 aspects of flow considered to be critical for the protection or restoration of river health, ecology and biodiversity.

The environmental flow rules of a water source vary depending on which of the river flow objectives were considered most important for that particular system. Examples of environmental release rules for water storages throughout NSW, defined by Dept of Water and Energy (2008b), include:

- the transparent dam release rule which requires all dam inflows occurring at certain times to be passed immediately downstream, as though no dam was present. This maintains natural flow variability for that part of the year (usually the winter months) when dam releases would otherwise be minimal
- the translucent dam release rule which requires a proportion of dam inflows occurring at certain times to be passed immediately downstream. This restores the natural flow variability associated with specific flow ranges usually freshes and minor floods
- the environmental contingency allowance (ECA) which creates a ‘bank' or volume of water stored in the dam which can be released for specific environmental purposes, such as flushing blue-green algal blooms, reducing salinity or supporting bird-breeding or fish spawning events.

2.4 Examples of other NSW environmental flow regimes

To help restore ecological processes and biodiversity of water dependent ecosystems, the Sydney Catchment Authority (SCA) releases environmental flows from its water storages in the Hawkesbury, Nepean, Woronora and Shoalhaven Rivers. Under licence conditions the SCA is required to release the 95th percentile flows for environmental requirements as a constant flow when inflows exceed the 95th percentile. Releases of the 95th percentile flows are not required when a storage is naturally spilling or when natural inflow is less than or equal to these flows, the volume of release must equal the natural inflow volume. Note that there is no requirement to incorporate event based releases.

2.4.1 Shoalhaven System

Water is released from Tallowa, Wingecarribee and Fitzroy Falls reservoirs to help improve the environmental health of the river corridors downstream and sustain riparian rights (SCA, 2008). At Wingecarribee, a minimum of 3 megalitres of water is sent downstream every day for environmental purposes. Releases from Tallowa

Dam include 90 megalitres of water released daily for environmental flows. At Fitzroy Falls Reservoir, environmental release levels are linked to inflow rates measured at Wildes Meadow Creek (Sydney Catchment Authority 2008).

While the volume of water released at each site varies, the variance relates to the specific hydrological characteristics of each location. As required by the licence, they are set at the 95th percentile of all inflows.

2.4.2 Upper Nepean System

Flows released at the 95th percentile within the Upper Nepean System include a daily release of 4.4 megalitres from Nepean Dam, 1.9 megalitres from Cordeaux Dam, and 1.3 megalitres from Cataract Dam (Sydney Catchment Authority 2008). Downstream of the Upper Nepean dams, a minimum of 10.5 megalitres is released daily from Pheasants Nest Weir and 1.7 megalitres at Broughtons Pass Weir (Sydney Catchment Authority 2008).

3. Existing River Flow, Habitats and Ecosystems

For the purpose of this assessment the Williams River has been divided into five reaches from the rivers headwaters to the rivers confluence with the Hunter River. The five reaches along the Williams River were selected based on topography of the catchment and the existing ecosystem. The reaches of hydrological, geomorphological and ecological interest are listed in Table 3.1 and shown on Figure 3.1.

Table 3.1 River reaches and sampling sites

Reach number	Reach description	Site name	Site location	Approximate reach length (km)
1	Upper Williams River to Storage FSL	W1 - W2	Upstream of proposed storage area	34
2	Storage	W3 - W6	Within proposed storage area	19 at FSL
3	Storage to Glen Martin	W7 – W8	Downstream of proposed storage area and upstream of Chichester River confluence	63
		W9 - W12	Downstream of the Chichester River confluence and upstream of Glen Martin	
4	Seaham Weir Pool	Sampling not undertaken	Downstream of Glen Martin and upstream of Seaham Weir	23
5	Seaham Weir to Hunter River confluence	Sampling not undertaken	Downstream of Seaham Weir	15

Within the five reaches suitable sites for undertaking water quality, aquatic ecology and geomorphological sampling were selected to represent the length of the Williams River with a focus on the proposed dam area. Sites were selected above, within and below the proposed storage. Sites were selected in the reaches below the proposed dam to assess the impacts of changes in the flow regime. As impacts are expected to be greater in the length of river immediately downstream of the dam wall, sampling sites were concentrated in this reach with increasing distance between sites further downstream.

This assessment of environmental flows in the Williams River focussed on the reaches downstream of the dam, in particular the length of river between the proposed dam wall and the confluence of the Williams and Chichester Rivers.

3.1 Habitat

The upper reaches of the Williams River are comprised of numerous pool and riffle

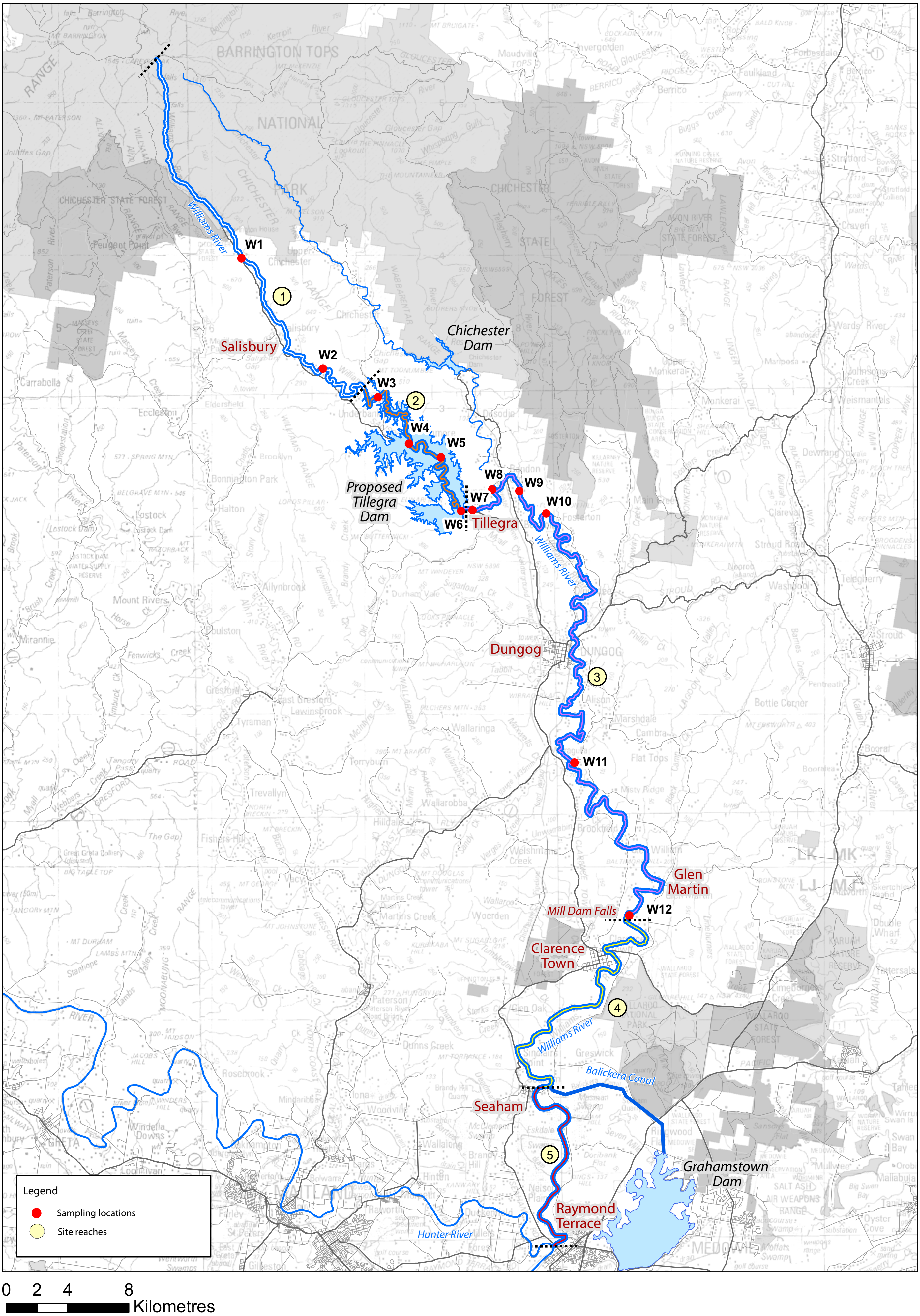


Figure 3.1 River reaches and sampling locations

sequences and many glides. With increasing distance from the rivers headwaters, the number of pool/riffle sequences decline with a single pool extending from Glen Martin (Mill Dam Falls) to Seaham Weir (Seaham Weir Pool). A typical pool/riffle sequence, located at site W7 immediately downstream of Tillegra Bridge, is provided in Figure 3.2. River flows are important drivers in the geomorphological processes of sedimentation, erosion and deposition which are responsible for structuring a variety of channel forms including pools, riffles and glides. These forms are important habitat for aquatic fauna.

A schematic diagram of a typical ecosystem and flow levels (low, moderate, fresh, high flow, bankfull and floods) for the Williams River are displayed in Figure 3.3.The figure highlights the complex interacting processes that occur within an ecosystem. Low flows maintain habitat connectively and provide refuge for biota from high flows. Fresh flows provide biological triggers for fish breeding and maintain water quality. Overbank flows return carbon to the river and maintain floodplain connectivity and recharge (refer Table 4.4).

3.2 Water quality and hydrology

The Williams River catchment is currently reasonably healthy, able to support diverse ecosystems and a range of land uses such as national parks, agriculture and human development (Dept of Urban Affairs and Planning 1996). The Healthy Rivers Commission (1996) inquiry into the Williams River concluded a similar health for the river water following a review of water quality monitoring data, scientific studies and community consultation. The catchment is however beginning to show signs of stress with results from recent studies along the Williams River providing evidence of declining water quality in recent years.

Present water quality of the Williams River does not always meet ANZECC (2000) guidelines for rivers and recreational use. This is particularly the case for phosphorus, nitrogen and faecal coliforms and is especially prevalent in the Seaham Weir Pool. Regular outbreaks of algal blooms occur in Seaham Weir Pool during the spring and summer.

Flows within the Williams River have been regulated with the construction of Chichester Dam in the 1920s and Seaham Weir in the late 1960s. The river has undergone extensive channel modification including de-snagging and bank stabilising works.

Over the last 77 years flows at Tillegra vary from nil to a flood peak of 54,488 ML/day, with an average flow of 260 ML/day. Observed flows at Glen Martin (some 60 kilometres downstream of the Tillegra gauge) range from nil to a flood peak of 137,448 ML/day, with an average of around 880 ML/day. The catchment area at Tillegra represents approximately 20 per cent of the catchment at Glen Martin and contributes approximately 40 per cent of the flow. Estimates of flow entering the Williams River estuary below Seaham Weir range from 2 to 54,554 ML/day. The median flow passing Seaham Weir is around 10 ML/day.

The climate of the region is characterised by reasonably high rainfall with high intensity events in late summer and autumn and less frequent lower rainfall events for the rest of the year. The number of rain days per month is evenly distributed throughout the year. The steep upper catchment and frequent rainfall results in a river hydrology characterised by relatively short lived flow events and significant base flow during the wetter months. The interannual variability is marked by wet/dry periods in which the river can completely cease to flow for short periods during the droughts and also maintain large flows during the wet cycles such as has occurred

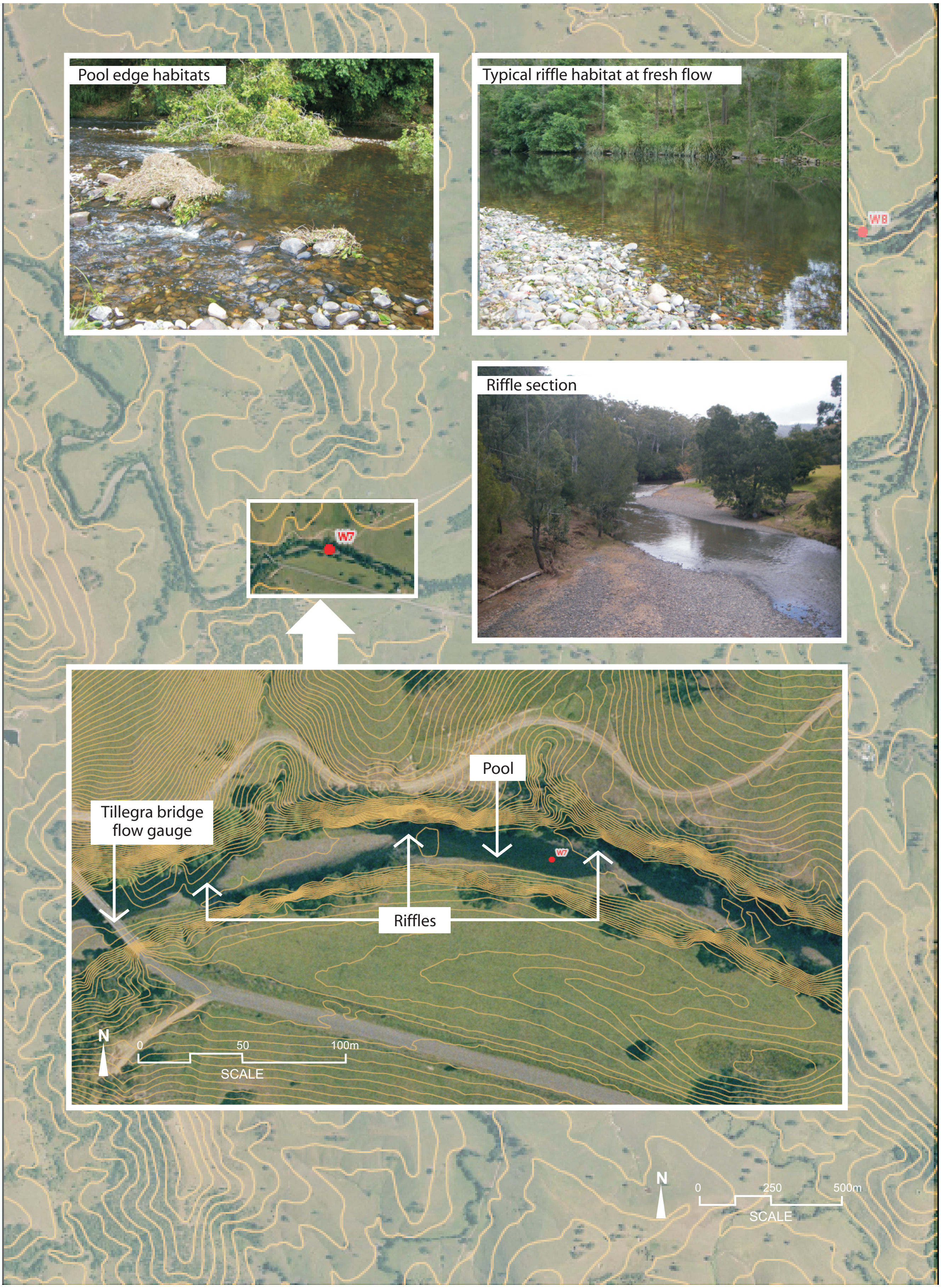


Figure 3.2 Habitats within the Williams River

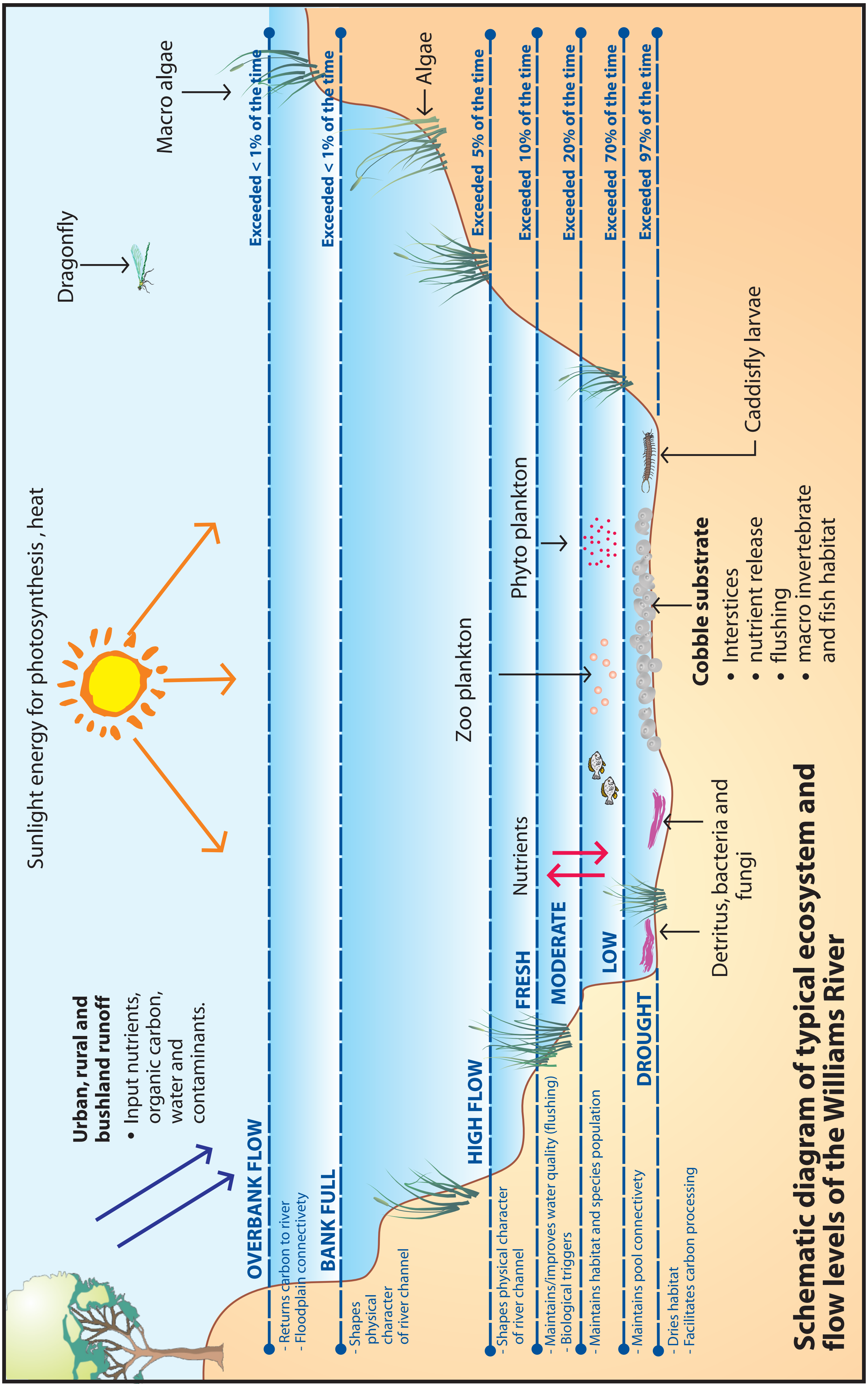


Figure 3.3 Typical ecosystem and flow levels of the Williams River

over the past 12 months.

The average recurrence interval (ARI) for floods at Glen Martin and Tillegra (Table 3.2) shows the average, or expected, value of the years between the occurrence of a flood as big as (or larger than) the selected event.

Table 3.2 Flood recurrence at Tillegra and Glen Martin (ML/day)

Average recurrence interval	Tillegra	Glen Martin
1 in 2 year flood	9,600	28,000
1 in 5 year flood	20,500	70,000
1 in 10 year flood	33,500	86,000
1 in 40 year flood	45,600	115,000

Further information on the existing water quality and hydrology of the Williams River is provided in Working Paper A of the EA Report.

3.3 Geomorphology

3.3.1 Geomorphic process discharge thresholds

Modelling of geomorphic process thresholds revealed a consistent pattern in the river. The bed material was at least partly mobile at most riffle sites under conditions of small freshes that occur multiple times per year. In general, the data indicate bed material was stable in pools even under high flow conditions. In practice, the bed material is likely to be mobile in the pool environments under high flow conditions. The hydraulic data from the Williams River were indicative of a river with active bed material transport, which confirmed the earlier assumptions made independently by Erskine and Brooks.

The bed of the river was observed to have few macrophytes present. The analysis indicates that hydraulic conditions were usually sufficient to exceed the thresholds associated with rupturing macrophyte stems, so it was not surprising that this plant form was uncommon.

The banks of the Williams River appear to be relatively stable, a characteristic that seemed to be imparted by the reasonably complete vegetative cover. However, the river was observed actively migrating in places; this was evidenced by bare banks cut into the alluvium, and fallen trees. The modelling suggested that matted grasses and shrubs were reasonably resistant to hydraulic disturbance under most conditions.

The modelling suggested that fine surface sediment was frequently flushed from the surface of the bed of pools and riffles. This was confirmed in the field, with virtually no fine sediment being evident on the wetted surface of the bed.

3.3.2 Geomorphic form discharge thresholds

The Williams River was evidently incised upstream of Glen William. The hydraulic/geomorphic modelling undertaken here suggested that the degree of incision was spatially variable. Between Tillegra and the Chichester River junction the river appeared to be deeply incised, such that the channel contained the 1 in 100 year event. At Sites W9 and W10 the river was evidently incised, but the floodplain was predicted to flood on average every 6 to 14 years. At W11 and W12 the river was apparently not incised, such that the floodplain was inundated on average every 1 to 3 years. The river had a series of low inset benches and stable gravel bars present at various levels in the cross-sections. These surfaces required events of 1,000 to 8,000 ML/day for inundation. Such events were frequent in the Williams River in the current discharge series, occurring on average more than once per year. Some sites had other higher benches present that were less frequently inundated. The riffles were mostly inundated by flows of around 350 to 500 ML/day. Such flows were very frequent in the current series, occurring multiple times per year on average.

Further information on fluvial geomorphology of the Williams River is provided in Working Paper B of the EA Report.

3.4 Aquatic ecology

The Williams River supports a substantial diversity of aquatic macroinvertebrate fauna. In general, the assemblages in the forested upper catchment are different to those found in waters that flow through agricultural land. Eighty-five taxa of aquatic molluscs, crustaceans, worms and insects were identified from riffle and pool edge habitat over the surveyed sites (W1-W10). Combined AusRivAS analysis for both edge and riffle habitat found macroinvertebrate assemblages upstream of the proposed dam (sites W1 – W 6) were comparable to reference condition. Sites downstream of the proposed dam (sites W7 – W10) were either comparable to reference condition or had significantly fewer taxa than expected, suggesting existing impacts on water quality and/or aquatic habitats. However, results from sites W7-W10 should be interpreted with caution as sampling took place during a period of elevated flows, which may explain the absence of expected taxa, rather than indicating degraded water quality or habitat.

Sixteen species of freshwater fish have been formally identified from surveys done in the Williams River upstream of Seaham Weir. During this study over 1,000 fish, representing six species were caught at the ten sites sampled (W1-W10) using fish traps, an electrofisher and seine nets. The most common species were Australian smelt, Cox's gudgeon and the long-finned eel. These results were similar to other surveys in the area in which fish assemblages were characterised by smelt, Cox's gudgeon, long-finned eel, Australian bass and freshwater catfish. The investigation by The Ecology Lab (TEL) did not catch any bass or catfish as the higher flows prevented the electrofisher being used effectively in pool habitat where they might be found. Table 3.3 highlights the species of fish that have been sampled in the study area by reach during this and previous investigations. Twelve species are considered to inhabit the reaches above the Tillegra Bridge, eight of which are putatively diadromous and must spend part of their lifecycle downstream of Seaham Weir in estuarine waters. A further two diadromous species are found in the reaches below the proposed dam.

No freshwater fish or aquatic invertebrate species recorded in the Williams River are listed as threatened or protected.

Further information on existing aquatic ecology in the Williams River is provided Working Paper C of the EA Report.

Table 3.3 Species of fish that have been sampled in the study area by reach

Common Name	Reach 1: Upstream of inundation area		Reach 2: Inundation area			Reach 3: Dam wall to Glen Martin						Reach 4: Glen Martin to Seaham Weir		Life History
						Dam wall to Chichester River confluence		Chichester River confluence to Dungog		Dungog to Glen Martin				
	Bionet 2008	TEL 2008	Bionet 2008	Brooks *et al* 2004	TEL 2008	Bionet 2008	TEL 2008	Bionet 2008	TEL 2008	Bionet 2008	TEL 2007	Bionet 2008	TEL 2008	
Shortfinned eel			✓	✓							ns		ns	Catadromous
Longfinned eel		✓	✓	✓	✓	✓	✓	✓	✓	✓	ns		ns	Catadromous
Freshwater herring			✓	✓				✓		✓	ns		ns	Catadromous
Gambusia#			✓	✓		✓			✓		ns		ns	Potamodromous
Giant herring	✓										ns		ns	Amphidromous
Sea mullet			✓	✓						✓	ns		ns	Catadromous
Freshwater mullet			✓	✓				✓		✓	ns		ns	Catadromous
Australian smelt		✓	✓	✓	✓	✓	✓	✓	✓	✓	ns		ns	Potamodromous
Striped gudgeon			✓	✓	✓	✓	✓			✓	ns		ns	Amphidromous
Cox's gudgeon		✓	✓	✓	✓	✓	✓	✓	✓	✓	ns		ns	Amphidromous/Potamodromous
Empire gudgeon								✓		✓	ns		ns	Amphidromous
Unidentified gudgeon			✓			✓					ns		ns	Amphidromous
Flathead gudgeon		✓	✓	✓						✓	ns		ns	Undefined
Dwarf flathead gudgeon			✓	✓		✓		✓		✓	ns		ns	Undefined
Australian bass			✓	✓		✓		✓		✓	ns	P	ns	Catadromous
Bullrout										✓	ns		ns	Catadromous/Potadromous
Freshwater catfish			✓	✓		✓		✓		✓	ns		ns	Potamodromous

= alien species.
√= Species present in survey
ns = no sampling took place in this reach

4. Environmental Flow Requirements for the Williams River

Flow requirements of the Williams River would be determined based primarily on the conservation of ecological processes however social and economic requirements of the river system are a consideration.

The flow regime is a key driver of river ecology. There are four guiding principles of flow regime influence on aquatic biodiversity (Bunn and Arthington 2002):

- flow is a major determinant of physical habitat (via geomorphological processes) and water quality (via hydrological processes), which in turn influence biological composition
- aquatic species have evolved life histories in response to natural flow regimes
- flows maintain natural patterns of longitudinal and lateral connectivity
- changes to natural flow regimes can facilitate the invasion and proliferation of exotic species, and unaltered natural flow regimes may impede the successful colonisation of exotic species.

River flows are important drivers in the geomorphological processes of sediment erosion, transport and deposition, and as such are responsible for structuring a variety of channel forms such as pools, riffles, bars and banks. These forms are important habitat and are often associated with particular aquatic assemblages. Flows also play an important role structuring macrophyte communities and riparian vegetation and can influence a variety of water quality characteristics that affect biological assemblages, such as dissolved oxygen, turbidity and algal activity.

Aquatic fauna have evolved and adapted to natural flow regimes in Australia, which can demonstrate high temporal variability at a range of scales, such as years, seasons and days. The life history traits and biological parameters of aquatic organisms, such as spawning behaviour, larval survival, growth patterns and recruitment, are often linked to these natural patterns in flow (Bunn and Arthington 2002). Flow regimes provide longitudinal hydrological connectivity along the river channel for organisms with life histories that require access to distant habitats, such as catadromous fish that must migrate downstream to estuarine waters to spawn. Lateral connectivity between the river channel and the floodplain can give periodic access of river biota to adjacent productive habitats. River systems with unregulated flows can be more difficult for exotic species to colonize. For example; the introduced carp, mosquito fish and water hyacinth are better adapted to aquatic systems with regulated flows and can have serious impacts on habitat and native biota once established.

However, quantitative understanding of the flow requirements of Australian aquatic biota is limited and qualitative knowledge is far from complete. A review of environmental flow regimes identified science's 'limited ability to predict and quantify biotic response to flow regulation as a major constraint to achieving ecological sustainability' (Bunn and Arthington 2002). It is therefore difficult to precisely determine a release strategy (including environmental flows and subsequent run-of-river transfers) that can meet the timing and magnitude of societal demand for water and maintain the ecological structure and function of the Williams River downstream of Tillegra Dam. A carefully designed monitoring and adaptive management programme would therefore be required as part of any environmental release strategy.

4.1 River Flow Objectives

The NSW River Flow Objectives (RFOs) are the agreed targets for surface water flow management. They identify the key elements of the flow regime that protect river health and water quality for ecosystems and human uses and are based on the principle of mimicking the key characteristics of the natural flow regime. The river flow objectives are:

1) protect natural water levels in pools of creeks and wetlands during periods of no flow
2) protect natural low flows
3) protect or restore a proportion of moderate flows, “freshes” and high flows
4) maintain or restore the natural inundation patterns and distribution of floodwaters supporting natural wetland and floodplain ecosystems
5) mimic the natural frequency, duration and seasonal nature of drying periods in naturally temporary waterways
6) maintain or mimic natural flow variability in all rivers
7) maintain rates of rise and fall of river heights within natural bounds
8) maintain groundwaters within natural levels, and variability, critical to surface flows or ecosystems
9) minimise the impact of in-stream structures
10) minimise downstream water quality impacts of storage releases
11) ensure river flow management provides for contingencies
12) maintain or rehabilitate estuarine processes and habitats

In order to meet River Flow Objectives in the Williams River a combined approach between various government agencies would be required. The objectives would be achieved through an appropriate release strategy from the proposed dam in conjunction with the implementation of an appropriate water sharing plan. Through appropriate dam release strategies HWC can assist in achieving RFOs 2, 3, 6, 7, 9, 10, 11, and 12. How the dam release regime may assist in achieving these priority objectives are listed in Table 4.1.

Table 4.1 River Flow Objectives and Tillegra Dam releases

River Flow Objectives (RFOs)		How dam release regime may assist in achieving priority RFOs
2	Protect natural low flows.	1. Transparent releases from storage.
3	Protect or restore a proportion of moderate flows, "freshes" and high flows.	1. Translucent releases from the storage. 2. Mimicking the natural flow regime during the release of fresh events and run-of-river transfers from the storage.
4	Maintain or restore the natural inundation patterns and distribution of floodwaters supporting natural wetland and floodplain ecosystems.	1. The Williams River does not support significant wetland areas.
6	Maintain or mimic natural flow variability in all rivers.	1. Transparent/translucent releases from the storage. 2. Mimicking the natural flow regime during the release of fresh events and run-of-river transfers from the storage.
7	Maintain rates of rise and fall of river heights within natural bounds.	1. Mimicking the natural flow regime during fresh event releases and run-of-river transfers from the storage.
9	Minimise the impact of in-stream structures.	1. Adopt an appropriate release regime 2. Maintain fish passage
10	Minimise downstream water quality impacts of storage releases.	1. Installation of a multi level offtake coupled with the release of water from an appropriate depth to meet downstream water quality requirements.
11	Ensure river flow management provides for contingencies.	1. The release of fresh events and run-of-river transfers may be timed to manage contingencies (eg algal bloom flushing)
12	Maintain or rehabilitate estuarine processes and habitats.	No significant change in flow volume to estuary is expected.

An independent inquiry into the Williams River, undertaken by the Healthy Rivers Commission (1996), recommended that the river flow objectives set out in Table 4.2, are realistically achievable for the Williams River.

Table 4.2 Recommended Williams River Flow Objectives (Source: Healthy River Commission 1996)

Flow Component	Objective	Corresponding RFO
Periods of no flow and Low Flows	The ecological refuge of pools should be protected during periods of no flow	1, 2
Freshes and high flows and floodplain and wetland connection	Patterns of freshes and high flows should closely approximate natural regimes	3,4
Variability of flow	Flow regimes should reflect natural variations	6

This report details methods for achieving the River Flow Objectives, however, the final decision of what would provide an appropriate balance between environmental, social and economic benefits would be discussed and analysed by the relevant authorities.

Provided the river flow objectives are achieved for the Williams River, biodiversity and ecosystem objectives which are interrelated to the flow components of a river will also be meet. Specific biodiversity and ecosystem objectives for the Williams River are addressed in the following section.

4.2 Objectives for the Williams River

The following biodiversity and ecosystem objectives for environmental flows in the Williams River were determined from hydrology, water quality, aquatic ecology and geomorphological information review, data analysis and field investigations conducted for this study:

- maintain fish assemblages
- maintain macroinvertebrate communities
- maintain instream vegetation
- maintain/improve water quality
- maintain carbon cycling to river
- maintain channel form diversity

The various components of river flow required to maintain these objectives are discussed in the following sections.

4.3 Flow components of the Williams River

River flow regimes can be characterised by their flow components which depend on the frequency of various flow levels. A combination of flow components used by the NSW and Victorian government are listed in Table 4.3. Consideration of the flow component aspects is also required to determine appropriate environmental flow scenarios (refer Table 4.3).

Table 4.3 Flow components and aspects

Flow components	Aspects of flow components
Floods (high flow, bankfull flow and overbank flow)	Seasonality
Freshes	Frequency
Moderate Flows	Duration
Low Flows	Magnitude
Drought	Depth of flow
	Water quality

Natural river flows in the Williams River are highly variable in both space and time. Historic daily flows at the Tillegra Bridge site over the last 77 years highlights this temporal variability as shown in Figure 4.1. The flow components and aspects described in Table 4.4 were derived from the analysis of data presented in Figure 4.1 and related to the existing ecological and geomorphic water requirements. Table 4.4 also details key functions of each flow component. Figure 4.2 provides a graphical representation of flow component aspects (timing, duration, frequency). More detailed information on flow components of the Williams River can be found in Working Paper A of the EA Report.

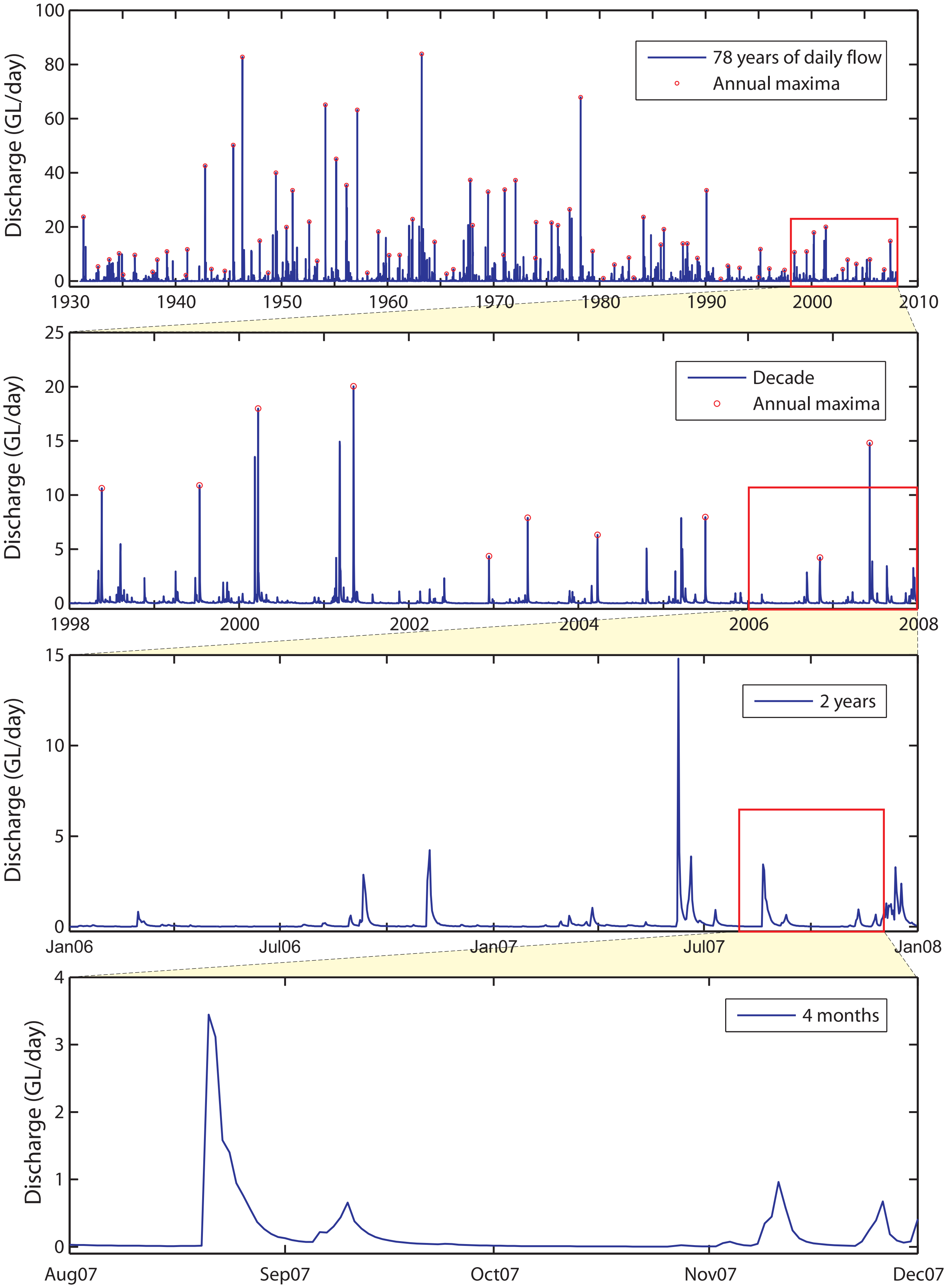


Figure 4.1 Historic daily flows at Tillegra Bridge

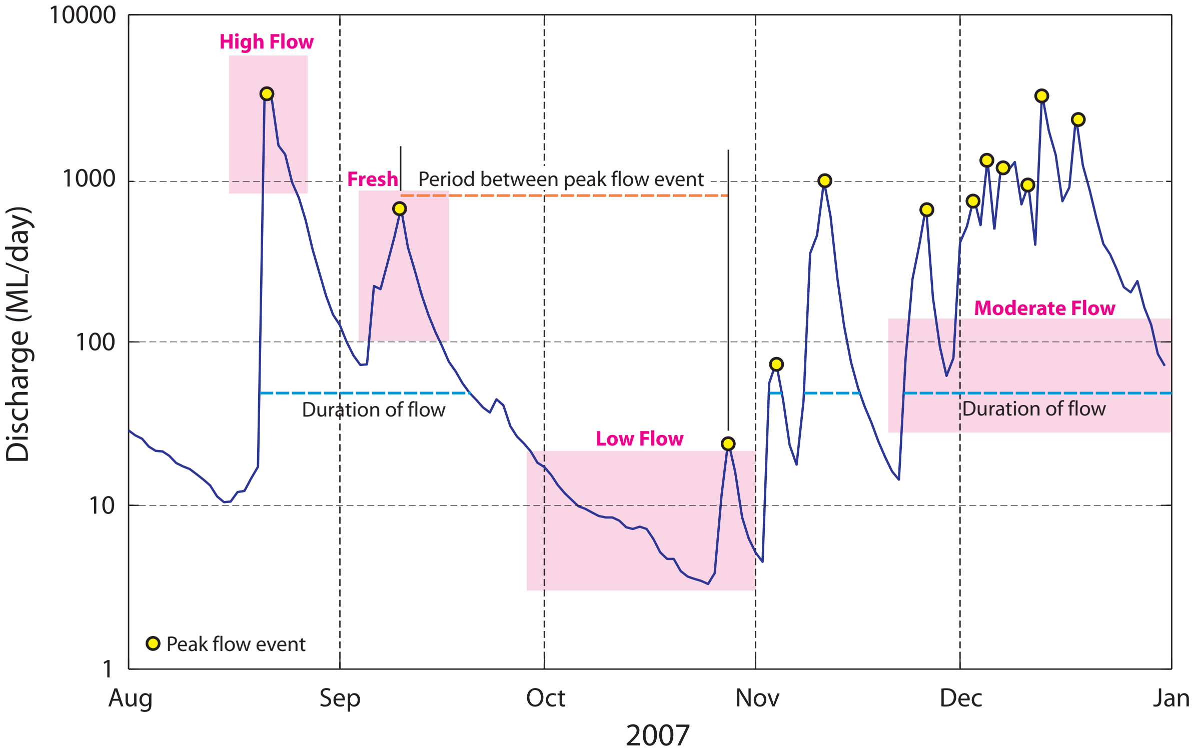


Figure 4.2 Tillegra discharge and flow components

Table 4.4 Key features and functions of flow components of the Williams River

Flow component		Flow component description	Timing	Frequency	Duration	Magnitude			Key functions
						% Exceed	Tillegra	Glen Martin	
Drought		No surface flow	Spring Summer	Annual	Days to months	No Flow	0ML/d	0ML/d	1. Dries habitats and substrates 2. Facilitates organic matter and carbon processing
Low Flow		Minimum flow in channel. Continuous flow in some part of channel	Spring Summer	Annual	Weeks to months	>70% exceed	24ML/d	48ML/d	1. Connects instream habitats 2. Maintenance of aquatic vegetation 3. Refuge from high flows for biota 4. Passage for juvenile fish
Moderate		Moderate flow in channel	Autumn Winter	Several annually	Weeks to months	70-30% exceed	24-100 ML/d	48-300 ML/d	1. Maintain habitat 2. Sustain species populations
Freshes		Flow greater than the median flow for that period	All seasons	Can be several in each period	Generally days	30-10% exceed	100-400 ML/d	300-1500 ML/d	1. Maintenance or improvement in water quality (flushing flows) 2. Biological triggers or requirements (eg fish breeding) 3. Passage for large fish
Floods	High flow	Less than bank full flow. May include flow in minor flood plain channels	Autumn Winter Summer	May be several annually	Weeks	5% exceed	>900 ML/d	>3000 ML/d	1. Habitat connection 2. Sediment movement/transport 3. Inundation of organic matter 4. Prevent encroachment of macrophytes 5. Facilitates migration
	Bankfull flow	High flow within channel capacity	All seasons	Generally at least annual	Days to Weeks	<1% exceed	~20,000 ML/d	~20,000 ML/d	1. Channel and habitat forming 2. Sediment movement/transport
	Overbank flow	Flow extends to flood plain surface flows	All seasons	Can be annual or less frequent	Days	<1% exceed	>20,000 ML/d	>20,000 ML/d	1. Floodplain connectivity and recharge 2. Carbon return to river

Source: Adapted from Sinclair Knight Merz *et al* 2002

4.4 Water quality flow requirements

Implementation of the river flow objectives listed in Section 4.1 would protect the natural river flow components and hence also positively influence water quality (Dept of Water and Energy 2008c). Many water quality issues are caused or exacerbated by a change in the river flow regime, therefore a regime which meets river flow objectives would also help protect water quality and ecological processes. An appropriate release strategy from the dam, managed by HWC, which meets relevant RFO's would also promote ecological processes and maintain water quality within the river.

Stratification, eutrophication and subsequent increase in algal blooms are important aspects in determining a rivers water quality. The maintenance of river flows in particular the protection of flushing flows, low flows and flow variability would limit the accumulation of nutrients, decrease residence times of pools, increase dissolved oxygen and suppress conditions favourable to blue-green algal blooms. Therefore, by meeting RFO's 2, 3 and 6 water quality within the river would be maintained.

Increased water turbidity and sedimentation of a waterway can deteriorate water quality. Flows which maintain the natural rates of rise and fall of a river would minimise bank slumping which increases turbidity. The maintenance of high flows which inundate the floodplain would support healthy riparian zones which act as buffers, stabilise banks and hence decrease sedimentation and erosion. In addition, floodplain inputs, as a result of high flows, are important to stimulate natural processes that regulate water quality. In meeting RFO's 4 and 7 sedimentation and water turbidity would be reduced.

The maintenance of ecological processes is required to regulate water quality. Fresh flows wet the banks and benches of a river which maintain habitat stimulating ecological processes that regulate water quality (RFO 3). Natural variable flows help maintain a dynamic ecosystem and diverse biological community, in turn stimulating ecological processes that regulate water quality (RFO 6).

Downstream water quality impacts of storage releases from the proposed Tillegra Dam would be reduced through the implementation of a multi-level offtake. The multi-level offtake, coupled with appropriate monitoring and release depths, would minimise the release of cold, high nutrient and metal laden waters to downstream reaches. This issue is addressed through meeting RFO 10.

4.5 Geomorphic flow requirements

The objective of managing the geomorphic aspects of a river is to maintain or rehabilitate channel forms and processes in order to assist achievement of certain ecological management objectives. In the case of the Williams River, the ecological objective is to maintain or improve the current ecological health. In this context, for the Williams River, the relevant geomorphic objectives are to maintain:

- substrate type, diversity and degree of mobility (habitat disturbance)
- presence and form of pools and riffles
- channel shape and dimensions, including the presence of backwaters and undercut banks
- presence of woody debris and riparian vegetation
- connectivity, described as the degree to which there are opportunities for biota, organic material and sediments to move both along the river and

laterally to/from in-channel features such as benches and bars, and to/from floodplains and wetlands.

Geomorphic objectives are closely linked to those for riparian and aquatic vegetation, because of the role of vegetation in stabilising sediments. The geomorphic objectives are all connected to the processes of sediment mobilisation, transport and deposition. Riparian zone condition is relevant to achievement of geomorphological objectives. Bank stability is partly related to the integrity, coverage and structure of riparian vegetation.

4.6 Aquatic ecology flow requirements

The flow requirements of macroinvertebrates and fish are summarised in Sections 4.6.1 and 4.6.2. Detailed information on these requirements is provided in Appendix A.

4.6.1 Macroinvertebrates

Macroinvertebrate diversity within the Williams River is dependent on habitat complexity as many taxa have close associations with particular habitat forms. Many macroinvertebrates are also adapted to the temporal variability of the natural flow regime. The flow requirements of aquatic macroinvertebrates are therefore those that maintain the hydrological and geomorphological processes that structure physical habitat, determine water quality and create flow seasonality within the river system.

The Williams River has a diverse array of habitat types utilised by macroinvertebrates, including frequent alternation of riffles and pools, instream wood debris, some sand/gravel banks and bars and macrophytes. The freshwater mussel, *Cucumerunio novaehollandiae*, is found in gravel beds with relatively swift flowing water on outer channel bends or in association with large boulders that help stabilize bed sediments (MUSSELpws 2008). Flow regulation has the potential to affect macroinvertebrate assemblages closely associated with riffles and pool-rocks as flow velocity and dissolved oxygen decline, and nutrients and silt accumulate (Growns and Growns 2001, Storey *et al* 1991). Passive filter feeders such as true flies (Simulidae) require high flows to suspend their food in the water column and their abundance is positively correlated to water velocity. Macroinvertebrates that are more closely associated to pool edges are less likely to be affected because of their tolerance of lentic conditions.

Many aquatic macroinvertebrates have life history attributes that are adapted to seasonal variability in natural flow regimes. Some taxa spawn during seasonal low flow so that vulnerable larvae are not swept downstream (Gooderham and Tsyrlin 2002), whilst others rely on seasonal flow events to trigger synchronous spawning or emergence as short-lived adults (Jones *et al* 1986). Temporal flow variability can increase stream productivity through nutrient diffusion and therefore have a positive effect on the growth of periphyton taxa that are important in the diet of many macroinvertebrate grazers.

4.6.2 Fish

River flow plays an important role in structuring the fish populations in the Williams River. Seasonal elevated flows provide migration cues for some species and sweep amphidromous larvae downstream to productive estuarine nurseries. Seasonal low flows permit the local recruitment of non-diadromous fish juveniles and increases their opportunity of encountering prey. Flow magnitude affects longitudinal fish passage in the river channel by determining water depth over instream barriers and the velocity of flow that fish must migrate upstream against. Flow magnitude also governs lateral fish passage into productive adjacent wetlands and carbon inputs into downstream habitats. The size and timing of flow requirements or thresholds can vary among taxa, and for different size classes within taxa.

Depth requirements

Water depth in the river channel is proportional to flow volume. Freshwater fish in the Williams River have depth requirements for their ecology and life history. Fish may require a range of depths in their habitats for foraging, refuge, spawning or to make successful migrations. Table 4.5 lists the depths that fish were commonly collected in during various surveys undertaken in south east Queensland (complied Pusey *et al* 2004).

In addition to habitat requirements, fish have water depth requirements for passage during longitudinal migrations up and/or down the river channel. A depth threshold for fish passage represents the minimum flow required to generate sufficient depth for a fish to negotiate an obstacle or run. Different species and size classes have a variety of depth thresholds for passage although these remain poorly understood.

The effect of the proposed environmental release regime on upstream fish passage was assessed by estimating the change in the proportion of navigable flows during known migration seasons. Navigable flows or passage 'window' are the range of flows that lie above a depth threshold and below a velocity threshold. Depth thresholds used in the navigable flow calculations were taken from the literature where possible but many had not been established experimentally, therefore body depth (BD) was used as a crude surrogate (refer Table 4.6).

Peak flows

Seasonal elevated (or peak) flows trigger and/or facilitate the longitudinal migrations of a number of fish species. Downstream spawning migrations of some adult diadromous fish is cued and/or facilitated by peak flows. Following hatching, the larvae of amphidromous fish are swept downstream by elevated flows to estuarine nurseries. Other fish aggregate immediately downstream of barriers during elevated flow, preparing to begin migrations associated with upstream dispersal. Overbank flows can also allow fish access into productive adjacent wetlands and floodplains.

Historical median peak flow events at Tillegra are around 200 ML/day and around 450 ML/day at Glen Martin. Peak flow events at Tillegra and Glen Martin are separated by a maximum of 15 days approximately 60 per cent of the time. Only 10 to 15 per cent of peak flows are separated by 30 days or more. Refer to Working Paper A of the EA Report for more information on peak flows at Tillegra and Glen Martin.

Velocity thresholds

High velocity flows can impede local fish movements (e.g. foraging and seeking shelter), long distance upstream migrations and the ability to pass short instream barriers (such as an overtopping weir or high energy riffle). Similar to depth, flow velocity is proportional to flow volume. Table 4.5 lists the velocity that fish were commonly collected in during various surveys undertaken in south east Queensland (complied Pusey *et al* 2004). The majority of fish species in the Williams River have been sampled in habitats with a slow to moderate mean water velocity, ranging from 0.08 metres per second to 0.19 metres per second (refer Table 4.6).

Many fish species (practically small diadromous juveniles) conduct upstream migrations in the Williams River during periods of relatively stable low flow (and therefore low velocity). Fish can sustain faster speeds to overcome short velocity barriers although such "burst" speeds cannot be maintained for long and fish must rest in between attempts. Lower velocities can be sustained for more prolonged swimming, such as might be required navigating longer runs. Velocities for prolonged and burst swimming for fish that occur within the Williams River are summarised in Table 4.7. The flow velocity characteristics at a particular cross section vary significantly and while mean cross section velocity is used it must be recognised that fish are able to find velocity regimes within the flow field (eg back eddies or pressure waves) that allow them to migrate even though the mean velocity exceeds their swimming threshold.

"Burst" swimming speeds listed in Table 4.7 were used as a guide to estimating velocity thresholds used in calculation of passage 'windows'. Not all fish were assessed given the lack of information on the timing of migrations and swimming speeds, whilst others were assigned to the same velocity class as related species of a similar size and body shape. The classes of navigable flows used were:

Depth	Velocity	Species	Table in Appendix A
0 cm ≥ flows	≤ 0.8 m/s	longfinned elvers, shortfinned elvers, Cox's gudgeon, striped gudgeon	Table A1
3 cm ≥ flows	≤ 0.8 m/s	empire gudgeon, flathead gudgeon, dwarf flathead gudgeon, smelt	Table A2
3 cm ≥ flows	≤ 1.0 m/s	small juvenile bass, juvenile freshwater mullet	Table A3
5 cm ≥ flows	≤ 1.0 m/s	juvenile sea mullet (1 – 3 yrs)	Table A4
15 cm ≥ flows	≤ 1.4 m/s	adult freshwater mullet	Table A5
20 cm ≥ flows	≤ 1.4 m/s	adult bass and large juveniles	Table A6

Temporal flow requirements

The fish species of the Williams River are adapted to the temporal variability in the historic flow regime. Just as flow magnitude is critical to fish ecology the temporal pattern of these flows is important for providing spawning cues, stable spawning environments, to facilitate the passage of migrating fish and for structuring prey assemblages. The particular timing and magnitude of flows required can vary among taxa and age classes. At any time during the year, one or more species may be spawning, developing in nursery grounds or migrating upstream or downstream. Table 4.8 illustrates the breeding and migration patterns of fish that have been sampled in the Williams River.

The majority of historic fresh events in the Williams River occur in autumn with the least in spring.

4.7 Other flow requirements

4.7.1 Surface water licences (irrigation licences)

There is a requirement of the Williams River system to provide water for surface water extraction licences downstream of the proposed Tillegra Dam. Section 2.2 provides information on cease to pump levels for irrigators and other downstream water users.

Low flows need to be maintained so there is no interference of the existing extraction rights. Currently cease to pump levels occur for 8 per cent and 13 per cent of the time for accredited and non-accredited users, respectively. During the construction and operation of the proposed dam the per cent of time cease to pump flows exist should, at a minimum, remain the same as historic.

4.7.2 Drought security

The proposed Tillegra Dam has been deemed an important component of the NSW Government's State Plan to secure the water future of the lower Hunter region for at least the next 60 years. The performance of the existing system has been assessed in terms of historic stream flows and current demands and then with respect to population increase and climate change. Refer to HWC's document *"Why Tillegra Now'* for further information.

Table 4.5 Habitat attributes of some fish species found in the Williams River, Reaches 1 to 4

Scientific Name	Common Name	Maximum Recorded Altitude (mAHD)	Water velocity (cross section average)of habitat (m s^{-1})			Water depth of habitat (m)		
			Minimum	Mean	Maximum	Minimum	Mean	Maximum
Anguilla australis	Shortfinned eel	180	0	0.14	0.55	0.10	0.42	1.05
Anguilla reinhardtii	Longfinned eel	790	0	0.16	0.87	0.06	0.39	1.05
Retropinna semoni	Australian smelt	760	0	0.19	0.87	0.05	0.37	0.04
Gobiomorphus australis	Striped gudgeon	160	0	0.10	0.87	0.10	0.44	1.10
Gobiomorphus coxii	Cox's gudgeon	700	0	0.18	0.55	0.13	0.34	0.74
Hypseleotris compressa	Empire gudgeon	60	0	0.12	0.85	0.10	0.46	1.19
Philypnodon grandiceps	Flathead gudgeon	700	0	0.10	0.87	0.10	0.47	1.08
Philypnodon sp.	Dwarf flathead gudgeon	700	0	0.08	0.71	0.07	0.43	1.08
Macquaria novemaculeata	Australian bass	600	-	<0.10	-	0.30	>2.00	-
Notesthes robusta	Bullrout	100	0	0.16	0.55	0.22	0.58	1.05
Tandanus tandanus	Freshwater catfish	722	0	0.17	0.87	0.19	0.40	0.87

Data sources: McDowall 1996, Pusey *et al* 2004.
Note: majority of data from surveys in south east Queensland.

Table 4.6 Total length and body depth values for freshwater fish of the Williams River.

Scientific Name	Common Name	Maximum Total Length (mm)	Maximum Body Depth (mm)	"Common" Maximum Total Length (mm)	"Common" Maximum Body Depth (mm)	Juvenile Total Length (mm)	Juvenile Body Depth (mm)
Anguilla australis	Shortfinned eel	1100	66	700	42	80	5
Anguilla reinhardtii	Longfinned eel	2000	120	1000	60	80	5
Potamalosa richmondia	Freshwater herring	320	64	160	32	50	10
Gambusia holbrooki	Gambusia	60	14	35	8	15	3
Mugil cephalus	Sea mullet	900	208	500	115	150	35
Myxus petardi	Freshwater mullet	800	147	400	73	80	15
Retropinna semoni	Australian smelt	100	17	60	10	15	3
Gobiomorphus australis	Striped gudgeon	225	42	120	22	20	4
Gobiomorphus coxii	Cox's gudgeon	190	35	150	28	40	7
Hypseleotris compressa	Empire gudgeon	100	27	70	19	20	5
Philypnodon grandiceps	Flathead gudgeon	120	23	80	15	25	5
Philypnodon sp.	Dwarf flathead gudgeon	65	13	40	8	20	4
Macquaria novemaculeata	Australian bass	600	183	357	109	40	12
Notesthes robusta	Bullrout	350	108	200	62	30	9
Tandanus tandanus	Freshwater catfish	900	200	500	111	30	5

Total length is the length of a fish measured from the tip of the snout to the end of the tail. Maximum Total Length is the largest recorded total length. "Common" Maximum Total Length is the largest value in the range of commonly reported/encountered lengths. Body Depth is the measurement of the deepest portion of the fish, from the dorsal surface down to the belly and does not include dorsal or pelvic fins. Body Depth was calculated from the ratio of Total Length: Body Depth. Juvenile Total Length was length reported when juveniles first made diadromous or potadromous movements

Data sources: for total length (TL): McDowall 1996, Allen *et al* 2003, Pusey *et al* 2004 and Lintermans 2007.

Table 4.7 Recorded swimming abilities of fish that occur within the Williams River, or are closely related to fish that occur within the Williams River

Species or Cogeneric	Common Name	Length (LCF, mm)	Approximate life history stage	Prolonged swimming		Burst swimming	
				m/s	Duration (secs)	m/s	Duration (secs)
Anguilla australis	Shortfinned eel	55 - 80	Elver	0.34	35 - 1000	0.57	4 - 30
		54	Glass eels	0.29	≥ 300	0.79	3 - 24
Anguilla reinhardtii	Longfinned eel	51	Glass eels	0.32	≥ 300	0.75	3 - 24
Mugil cephalus	Sea mullet	40	Small juvenile	-	-	1.45	2
		86 - 130	Juvenile	-	-	1.60	2
Retropinna retropinna	NZ smelt	56 - 67	Adult	0.27	35 - 1000	0.50	4 - 30
Gobiomorphus cotidianus	NZ common bully	30 - 42	Small Juvenile	0.28	35 - 1000	0.60	4 - 30
Hypseleotris compressa	Empire gudgeon	-	-	-	-	1.00	-
Macquaria novemaculeata	Australian bass	40	Small juvenile	-	-	1.02	-
		64	Juvenile	-	-	1.40	-
		93	Large Juvenile	-	-	1.84	-

Maximum velocities (m/s) during sustained and burst swimming are indicated. Note: Mallen-Cooper's (1992) estimates are "negotiable velocity" and relate to the ability of 95% of a test population to negotiate a velocity barrier at the velocities specified. Empire gudgeon were observed negotiating a weir in Queensland (in Pusey et al 2004). All other values are neutral with respect to water velocity.

Sources of data: Mitchell 1989, Mallen-Cooper 1992, Langdon & Collins 2000, Pusey *et al* 2004

Table 4.8 Illustrative breeding/migration patterns of fish that have been sampled in the study area.

Spawning
Downstream migration
Upstream migration
Possible breeding season

Common name	Movement/activity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Catadromous													
Short-finned eel	Downstream migration of adults	Downstream migration	Downstream migration	Downstream migration	Downstream migration	Downstream migration					Downstream migration	Downstream migration	Downstream migration
	Recruitment of glass eels from sea to estuaries					Upstream migration	Upstream migration	Upstream migration	Upstream migration	Upstream migration	Upstream migration		
	Upstream migration of brown elvers	Upstream migration									Upstream migration	Upstream migration	Upstream migration
Long-finned eel	Downstream migration of adults	Downstream migration	Downstream migration	Downstream migration	Downstream migration	Downstream migration							
	Recruitment of glass eels from sea to estuaries	Upstream migration	Upstream migration	Upstream migration	Upstream migration	Upstream migration							
	Upstream migration from estuaries to freshwater	Upstream migration	Upstream migration	Upstream migration	Upstream migration							Upstream migration	Upstream migration
Freshwater herring	Spawning						Spawning	Spawning	Spawning				
	Downstream migration to spawn						Downstream migration	Downstream migration	Downstream migration				
Sea mullet	Adults spawn in ocean				Spawning	Spawning	Spawning	Spawning					
Freshwater mullet	Spawning	Spawning	Spawning	Spawning									
	Downstream migration of adults to estuaries	Downstream migration	Downstream migration	Downstream migration									Downstream migration
Australian bass	Spawning					Spawning	Spawning	Spawning	Spawning	Spawning	Possible breeding season	Possible breeding season	Possible breeding season
	Downstream migration of adults to estuaries				Downstream migration	Downstream migration	Downstream migration	Downstream migration					
	Upstream migration of adults to freshwater								Upstream migration	Upstream migration	Upstream migration		
	Upstream migration of juveniles to freshwater	Upstream migration	Upstream migration	Upstream migration	Upstream migration						Upstream migration	Upstream migration	Upstream migration
Bullrout	Spawning				Spawning	Spawning	Spawning	Spawning					
	Upstream migration of adults						Upstream migration	Upstream migration	Upstream migration	Upstream migration			

Table 4.8. Continued

Common name	Movement/activity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Amphidromous													
Striped gudgeon	Spawning												
	Larvae carried downstream												
	Juvenilles begin upstream migration												
Cox's gudgeon	Spawning												
	Larvae carried downstream												
	Upstream migration of juveniles												
Empire gudgeon	Spawning												
	Larvae carried downstream												
Potamodromous & Undefined													
Mosquitofish	Breeding												
Australian smelt	Spawning												
Flatheaded gudgeon	Spawning												
Dwarf flathead gudgeon	Spawning												
Freshwater catfish	Spawning												

5. Proposed Environmental Release Strategies

5.1 Overview of assessment

The development of an environmental release strategy appropriate for the Williams River is an evolving and ongoing process. Continued improvement and refinement of the HWC hydrology model has been undertaken to date and the following chapter details results of initial modelling and assessment. The ultimate environmental release strategy would be decided following an extensive review process and further assessment if required. The initial assessment summarised in this chapter includes the following:

- modelling a range of flow release strategies to determine a base case release strategy. The base case strategy comprised 90/30 environmental releases, constant run-of-river transfers and flushing events
- assessment of the base case strategy in regards to hydrology, water quality, geomorphology and aquatic ecology requirements
- suggested improvements to base case strategy to provide a reasonable protection of the downstream ecosystem (eg run-of-river event based transfers and seasonality of transfer releases)

5.2 Modelled release scenarios

A range of flow release strategies was modelled (Table 5.1) and potential environmental effects assessed to determine an appropriate base case release strategy that provides protection to the river environment, continuing water access to irrigators and drought water supply security to the community. In addition to the environmental flows run of river transfers and reservoir spilling would contribute to the flow in the river downstream of the dam. Once the dam is full, about 80 per cent of the average annual inflow would pass downstream as either spilling, run-of-river transfers or environmental release flows.

Table 5.1 Summary of possible release scenarios

Release scenario			Summary
Transparent cutoff*	Translucent cutoff*	Larger Events	
95th			- Protects low flows
80th			- Protects low flows
80th	60% of flows between 80 and 30		- Protects low and moderate flows - Provides additional water for selected fish species passage - Protects licence demands
90th	60% of flows between 90 and 30	Constant run-of-river transfers and flushing events	- Protects low and moderate flows - Provides additional water for range of fish species passage - Protects licence demands - Provides drought security

* refers to percent exceedence of inflow

Irrigator water rights comprise a flow allocation (around 8300 ML/year) and a cease to pump condition. This demand represents about 7 per cent of the mean annual flow in the Williams River and equates to around 23 ML/day or around the 70th percentile exceedence. Maximum peak daily demand may exceed this during dry periods. For the purpose of this assessment the irrigator and environmental releases have been combined into one release strategy as daily extraction volumes are not available and hence it is impractical to separate these components at the Tillegra Dam site.

Environmental flow releases are generally related to the dam inflow and discussed in terms of the inflow percentage exceedence distribution determined from long period flow records. Environmental release strategies generally aim to encapsulate the following flow components:

- a low flow “transparent” component, in which release is equivalent inflow
- a moderate flows “translucent” component in which some fraction of the inflow is released and
- specific flow event releases required to provide infrequent fresh or high flows to the river downstream.

Transparent to 95th percentile exceedence

The 95th percentile exceedence release scenario applies to the Chichester Dam that also spills around 5 times its volume annually. The 95th percentile at Tillegra is around 1.9 ML/day which would not be sufficient to satisfy the priority river flow objectives nor protect downstream stock and irrigator rights. This strategy was not considered further in the assessment.

Transparent to 80th percentile exceedence

The relationship between wetted perimeter and discharge is often used to estimate the minimum flow required to protect aquatic life (fish and macroinvertebrates). The technique is based upon the assumption that the break in the wetted perimeter versus discharge curve represents a reduction in water height from the bank to the bed of the river (Gippel and Stewardson 1998) and that habitat availability, connectivity and fish movement is protected when the minimum water height is maintained above this level. Flow versus wetted perimeter data for a number of typical cross sections suggest the breakpoint or minimum release to protect low-flow dependent aquatic life occurs at the 80th percentile exceedence of 15.9 ML/day at Tillegra.

A static release of 15.9 ML/day could provide protection of low-flow dependent aquatic life during low flow periods. The current ecosystem, however, is adapted to a range of higher flows and events and the assessment suggested that while the strategy may be appropriate for a relatively short filling period (say less than 3 years) it would not provide sufficient water to protect the current ecosystem variability downstream of the dam over the longer predicted filling period of around 7 years. This strategy was also excluded from further assessment

Transparent to 80th and translucent to 30th percentile exceedence

In order to protect moderate flows and provide variability downstream of the dam a translucency component was introduced up to the 30th percentile exceedence (100 ML/day). It was proposed to release 60 per cent of inflows between 15.9 and

100 ML/day so for inflows of 100 ML/day or greater the release flow is 63 ML/day.

By the time inflows at Tillegra reach 100 ML/day there would be significant runoff in the catchment below the dam contributing to the flow in the river downstream. River flows would recover to slightly less than pre dam flows within a relatively short distance of the dam suggesting that the aquatic life within the reach between Tillegra Dam and the confluence of the Williams and Chichester Rivers would be most sensitive to the changes.

Transparent to 90th and translucent to 30th percentile exceedence, constant releases and flushing events

The 90/30 plus constant releases and flushing events aim to protect the moderate, fresh and some high flows.

The 90/30 release scenario would provide sufficient flow to maintain the existing stock and irrigator licence demands. Surface water extraction upstream of Glen Martin is subject to cease to pump levels when flows are at or below 6 ML/day or 15 ML/day at Glen Martin for accredited and non-accredited users, respectively. A comparison of the per cent exceedence statistics of cease to pump flows for historic and proposed operational release flows from Tillegra Dam (Table 5.2) indicates that, on average, the cease to pump flows with the dam would be exceeded about 3 per cent more often than for the pre dam case and hence irrigators access is preserved.

Table 5.2 Per cent exceedence of cease to pump flows (6 and 15 megalitre per day) at Glen Martin pre and post dam.

Glen Martin (Percent Occurrence)	Discharge (ML/d)	All Data	Summer	Autumn	Winter	Spring
Pre Dam	6	92	84	95	98	90
	15	87	77	92	95	83
Base case	6	95	90	97	100	94
	15	91	84	94	99	88

Constant run-of-river transfers were triggered by demand in Grahamstown Dam. The general strategy for transferring water was based on the assumption that the total volume of water required at Grahamstown Dam was delivered as a constant flow over the month (30 days).

Additional flushing events were included in the model to provide flows capable of flushing the lower system and improve water quality. These flows would help minimise conditions favorable to blue-green algal blooms and also assist to maintain the estuarine salinity regime.

5.3 Base case environmental release strategy

The base case environmental release strategies for the proposed Tillegra Dam during the construction, filling and operational phases are detailed below and summarised in Table 5.3. The base case strategy comprised:

- 90/30 transparent translucent environmental releases

- constant run-of-river transfers (commencing from year 3 of the filling phase)
- flushing events (commencing from year 3 of the filling phase).

Table 5.3: Base case release and environmental flow scenarios

Operation mode	Release scenarios		
Construction	Transparent		
Filling Phase	Year 1 - 2	Initial Releases	- Static release of up to 80ML/d through bypass pipe until water level sufficient to operate offtake tower.
		Environmental Releases	- Transparent to 90th percentile exceedence (7.4ML/d) - 60% translucency from 90th to 30th percentile exceedence (7.4ML/d to 100ML/d) - 63ML/d released for flow greater than the 30th percentile exceedence (100ML/d)
		Fresh Releases	- Six fresh releases per annum - Peak flow of 270ML/d for 1.5-2 days in Jan, Mar, Apr, May, Jul and Aug
	Year 3	Environmental Releases	As above
		Run-of-River Transfers*	- Constant run of River transfers would commence from Year 3. Transfers at rates ranging from 250 to 500 ML/d for a particular month
		Flushing Events	- 2000ML/d release if average 3 month flow at Glen Martin drops below a set threshold in summer. These thresholds achieve 30 events over the 77 years of data
Standard Operation		Environmental Releases	As above
		Run-of-River Transfers	As above
		Flushing Events	As above

*Run-of-river transfers may commence from Year 3 of the filling phase depending on demand

5.3.1 Fresh release events

The base case scenario during the initial filling period would consist of 90/30 environmental transfer releases only as run-of-river transfers would not be expected. An environmental release strategy without run-of-river transfers (or equivalent) is not considered appropriate to protect the natural ecosystem and as such fresh event releases have been modelled during the filling phase.

The distribution, magnitude, duration and frequency of the modelled fresh releases were determined based on the historical flow data at Tillegra. The temporal variability in fresh releases was determined on historic seasonal patterns and ecological requirements. The majority of historic fresh events occur in autumn with the least in spring. As such releases during the filling phase consist of three in autumn, two in winter and one in summer. A fresh event is defined as an event with peak flow between 200 to 300 ML/day and using 3 hourly flow records for the past 20 years found 59 events. A curve was fitted to the representative fresh events to replicate the recession of the hydrograph (Figure 5.1). A double exponential recession curve provides a reasonable fit to the data. For three 3 hour interval adjustments to the release this curve is given by the formula:

$$Q(t) = \frac{270}{2}\left(e^{(-t/0.3)} + e^{(-t/1.2)}\right)$$

where Q(*t*) is the release discharge (ML/day) at time *t*, *t* = 0 is the event start and *t* has units of days.

5.3.2 Construction

River diversion works during the construction of the dam at Tillegra would consist of upstream and downstream cofferdams that would divert normal river flows and small floods through a 5.8 metre diameter tunnel. Construction of the dam, from when river diversion commences is expected to take approximately 2.5 years.

River flows during dam construction would pass through the diversion channel with little attenuation of flows except during flood times when flows are greater than around 10,000 ML/day. A flow of this magnitude is greater than the 1 in 2 year flood event at Tillegra, therefore, no significant impacts are anticipated to occur in the reaches below the dam wall as a result of river diversion during the construction phases. Appropriate sediment control systems would be installed around the construction area to minimise any turbid water runoff to the river.

5.3.3 Filling phase

At the start of the filling phase the 5.8 metre diversion tunnel would be plugged and environmental flows would be diverted through a 0.6 metre bypass pipe parallel to the diversion tunnel. The maximum flow through the bypass pipe would be 80 ML/day under 3 metres of head which should be attained within a few days.

Environmental flows would be released through the bypass pipe until the base of the inlet tower is inundated, which would occur when the storage reaches a depth of around 10 metres. It is likely a storage depth of 10 metres would be reached within a few weeks of filling commencement, even during low inflow periods.

During the filling phase flow modelling was carried out for three possible inflow scenarios of 5 years duration. These scenarios were selected from a five year running total over the last 20 years; high flow (1997-2001), median flow (1999-2003) and low inflow (2002-2006). The modelled flow includes daily inflow minus evaporation from the reservoir surface area, minus the 90/30 environmental flows and minus six fresh releases per year. Refer Figure 5.2 for the volume, water level and release flows of the scenarios. An estimate of filling time (without environmental releases) is provided in Working Paper A of the EA Report, Section 3.4.2.

5.3.4 Standard operation

The optimal operating range for the dam is estimated to be between 90 and 100 per cent of capacity so the dam would spill for around 20 per cent of the time.

Flow modelling for the standard operation of the dam was carried out by HWC using a hydrological model incorporating the subcatchments and infrastructure from top of catchment to Seaham Weir that is calibrated for the current system. The effect of

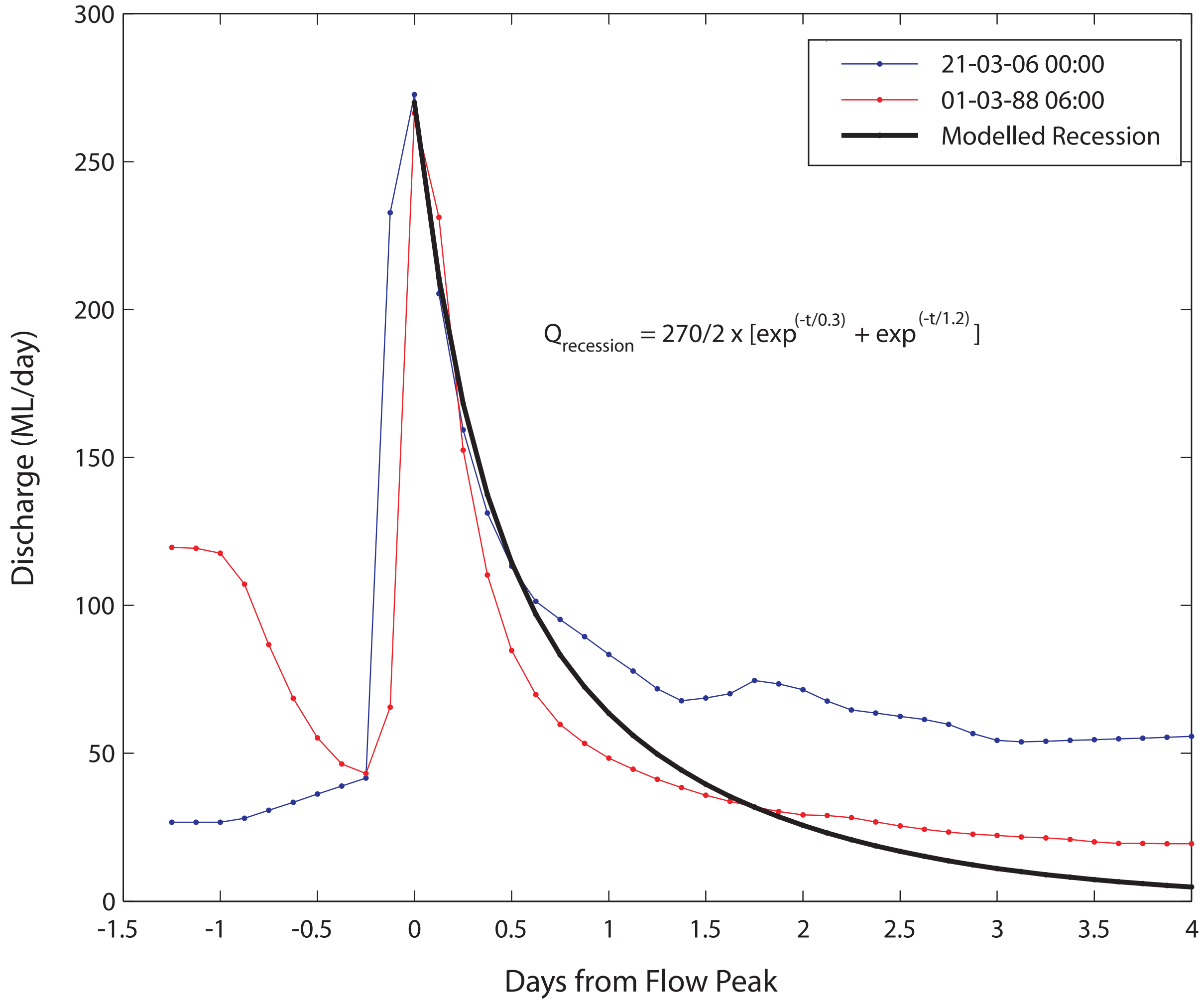


Figure 5.1 Fresh event recession curve

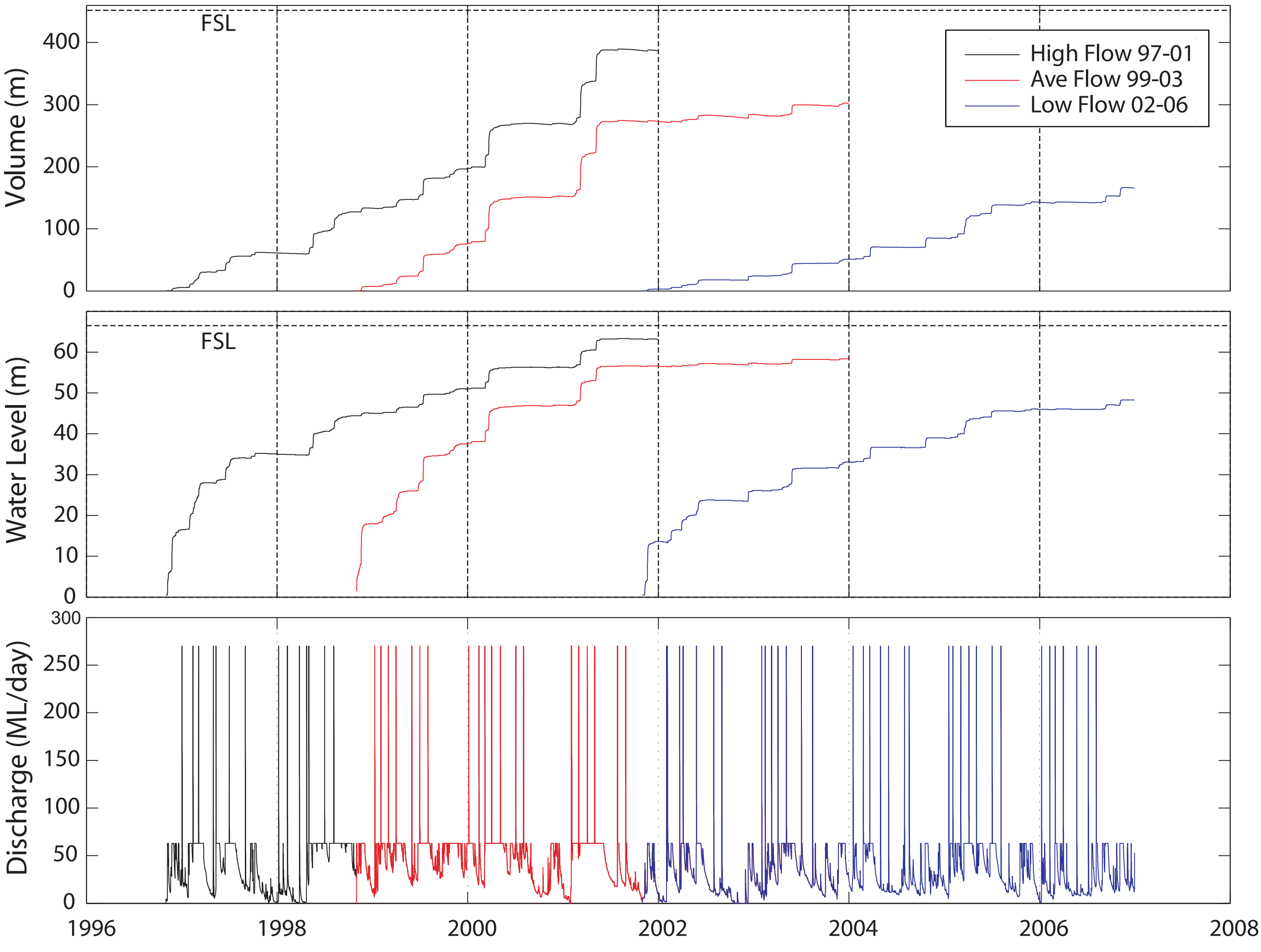


Figure 5.2 Volume, water level and discharge under 3 filling scenarios

Tillegra Dam on river flows was simulated by incorporating into the model a series of operational water transfer protocols for future domestic demand scenarios (constant run-of-river transfers), environmental release strategies and spilling flows. The model used the 77 year (1931 to 2007) daily inflow records and for the operational phase simulations assumed the dam was initially 90 per cent full. Model results for the maximum demand scenario are reported below for assessment of dam operation.

5.4 Filling phase assessment

5.4.1 Hydrology and water quality

The environmental release strategy during the filling phase is characterised by an increase in the per cent occurrence of low flows and the loss of fresh and flooding flows. Statistics for the three modelled inflow scenarios are provided in Table 5.4.

Table 5.4 Modelled filling phase flows under low, average and high flow periods at Tillegra (seasonal results provided in Table B1 of Appendix B)

Statistic Percent exceedence	Low Flow 1 Nov 2001 to 31 Jan 2006	Average Flow 1 Nov 1998 to 31 Jan 2003	High Flow 1 Nov 2001 to 31 Jan 2006
Minimum	0.0	0.0	0.0
95th	4.9	4.5	5.0
90th	8.8	9.7	10.0
80th	12.4	15.5	16.9
50th	25.1	38.1	45.3
20th	59.3	63.0	63.0
10th	63.0	63.0	63.0
5th	63.0	63.0	63.0
Maximum	270.0	270.0	270.0

The maximum release flow at Tillegra during the filling period would be 270 ML/day.

The historic median flow at Tillegra for the low flow period 1 November 2001 to 31 January 2006 is 39.6 ML/d. During this low flow period under the filling scenario the median flow would decrease to 25.1 ML/day (refer Table 5.4). By site W9 estimates indicate median flows would decrease from 52.5 ML/d (historic low flow period) to 41.5 ML/day (low flow filling scenario) suggesting impacts would be concentrated in the reach from the dam wall to the confluence with the Chichester River. Further downstream changes to the flow regime would diminish as the proportion of flow contributed by the Tillegra catchment decreases following inflows from the Chichester River and other tributaries along the main arm of the river.

The decline in median flow volume indicates a concomitant reduction in velocity, depth, channel ‘wetted width’, flow variability, and the magnitude and frequency of elevated seasonal flows.

The quality of water released is likely to be similar to the water quality of the current system, except, nutrient levels would be reduced as the dam would retain sediment bound nutrients. The reach between the dam and Chichester River confluence is mainly comprised of riffles and glides with shallow pools. Water residence time may increase slightly in the shallow pools which may lead to deterioration in water quality. Downstream of the Chichester confluence water quality is expected to remain similar to existing conditions.

Seaham Weir Pool currently experiences regular outbreaks of blue green algae. The adoption of 6 releases of 270 ML/day during the filling phase at different times of the year may assist in mixing Seaham Weir Pool to keep algal cell counts below the guidelines for recreational use. In addition, the dam would act as a sediment and nutrient trap reducing total suspended solids within the river as well as phosphorus and other nutrients. This may assist with improving water quality within the river and lower reaches such as within the weir pool.

5.4.2 Geomorphology

The dam filling phase would be one of no spills from Tillegra Dam. This would be a period of minimal bedload transport in the reach down to the Chichester River junction. In the time taken to fill the dam, there could be an accommodation adjustment to this section of channel. This would involve encroachment of vegetation into the channel. Upon filling of the dam, and subsequent spilling, the channel would be expected to re-adjust through bed material mobilisation processes (although woody vegetation that established in the channel in the interim period would act to resist this re-adjustment). Sediment starvation would lead to over-adjustment of the channel, as all but the coarsest (boulder-sized) bed material would eventually be scoured. This process would be most marked closer to the dam.

Channel form is an important co-variant in the relationship between flow volume and depth/velocity. The channel is narrower at the W7 and Glen Martin riffles, therefore for a given flow volume there is a greater corresponding depth and velocity than at the broader riffles at sites W8 and W9.

During the filling phase there is likely to be a reduction in the wetted width of the channel. This would result in the loss of a proportion of shallow riffles and gravel/sand bars in Reach 3, particularly in the broad low energy riffles above the Chichester confluence.

5.4.3 Aquatic ecology

An assessment of the potential impacts on macroinvertebrates and fish during the filling phase is provided Appendix A. A summary is provided in the following sections.

Macroinvertebrates

The potential impacts on macroinvertebrates during the filling phase as a result of increased frequency of low flows and reduced high flows are listed in Table 5.5. Potential impacts on macroinvertebrates should diminish downstream of the dam as flows would tend back to historical patterns with the inputs from Chichester River and other tributaries

Table 5.5 Potential impacts on macroinvertebrates during the filling phase

Flow component or aspect	Benefit	Detriment	Species examples
Reduction in wetted width		Decline in the abundance of taxa strongly associated with shallow habitat	▪ Philototamid caddisflies, ▪ water pennies (Psephenidae) ▪ Hyriid mussels
Reduction in wetted width/decline in water quality		Decline in sensitive macroinvertebrate species. Increase in taxa tolerant to reduced water quality.	Decline in: ▪ mayfly ▪ caddisfly Increase in: ▪ water snails ▪ silt-tolerant mayflys
Increase in low to moderate flows	Increase in fauna that are reliant on seasonal periods of stable low flow		▪ planktonic larvae
Reduction in high flows		Decline in species that require high flows	▪ passive filter feeders eg *C. novaehollandiae*

Fish

The potential impacts on fish during the filling phase as a result of increased frequency of low flows and reduced high flows are listed in Table 5.6.

Table 5.6 Potential impacts on fish during the filling phase

Flow component or aspect	Benefit	Detriment	Examples
Increased frequency of low to moderate flows	Increase in fish with life histories adapted to stable low flows		▪ Smelt ▪ Flathead gudgeon ▪ Introduced *Gambusia*
	Increase in fish who are tolerant to reduced water quality and prefer stable low flows		Increase in: ▪ Carp ▪ Mosquito Fish ▪ Striped gudgeon ▪ Long finned eel ▪ Sea mullet Decline in: ▪ Cox's gudgeon
Reduction in moderate to large flows		Reduction in species which require greater depth of habitat (pools, riffles and gravel beds)	▪ Adult bass ▪ Cox's gudgeon ▪ Small long-finned eels ▪ Freshwater catfish

Upstream Fish Passage Reach 3

The effect of the environmental release regime on navigable flows along Reach 3 is complex and is predicted to vary among taxa, seasons, riffle types and with distance downstream. The maximum velocities generated by the environmental flow range of 0 to 63 ML/day (excluding the 6 peaks) at the low energy riffles is less than 0.8 metres per second and would not exceed the upper flow thresholds of most fish. Therefore, for most species passage at these riffles during the filling phase would be entirely limited by depth. For fish with low depth swimming requirements (0 to 3 centimetres) this would result in a greatly expanded proportion of navigable flows. For fish with high depth requirements (15 to 20 centimetres) this would result in a reduced proportion of navigable flows. Table 5.7 summaries expected impacts on fish passage during the filling phase for different fish classes and respective depth requirements.

Table 5.7 Fish classes and expected impacts on fish passage

Depth requirement	Fish class	Species	Assessment	Table in Appendix A
0-3cm	Small weak swimmer	▪ Longfinned elvers ▪ Shortfinned elvers ▪ Cox's gudgeon ▪ Empire gudgeon ▪ Flathead gudgeon ▪ Dwarf flathead gudgeon ▪ Smelt	▪ Increased navigable flows at u/s low energy riffles ▪ Similar navigable flows at Glen Martin	A1, A2
	Small strong swimmer	▪ juvenile bass ▪ juvenile freshwater mullet	▪ Increased navigable flows at u/s low energy riffles ▪ Increased navigable flows at Glen Martin ▪ Increased recruitment in Reach 3	A3
15cm-1.4m	Large strong swimmer	▪ Adult freshwater mullet ▪ Adult bass and large juveniles	▪ Decreased navigable flows at u/s low energy riffles ▪ Decline in success of upstream migration for large fish	A5, A6

Upstream Fish Passage Reach 4

The proportion of navigable flows within Seaham Weir Pool is not anticipated to change as there are few, if any, depth barriers to passage. The low gradient and wide channel produce lower velocity flows.

Upstream Fish Passage Reach 5

The alteration of the flow regime during the filling phase may have an affect on the successful proportion of diadromous fish recruiting upstream from the estuarine habitat at Seaham Weir through the submerged orifice fishway. The model suggests a slight increase in occurrence of low flows that may:

- increase the upstream fish passage due to lower weir pool depths and increased low to negative head differentials with the tidal tailwater

- make it harder to locate the submerged entrance to the fishway due to reduced downstream flows.

Downstream Passage - Peak Flows

The significant loss of a range of larger peak flows may lead to a decline in successful spawning and/or recruitment upstream of the Chichester River confluence for some species. For example bass, longfinned eels, shortfinned eels, amphidromous larve/juveniles, empire gudgeon, flathead gudgeon, flathead gudgeon and sub-adult bass.

Summary

Impacts of the environmental release regime on aquatic biota during the filling phase are potentially complex and difficult to predict. It is anticipated that habitat and water quality may become degraded in some areas, which would lead to an increase in the proportion of taxa tolerant to reduced water quality. Macroinvertebrates associated with shallow habitats such as riffles and gravel/bars may decline in diversity and abundance. Australian bass, and potentially other diadromous species, are expected to experience reduced recruitment, whereas smelt, flathead gudgeon and introduced *Gambusia* and carp, should remain relatively unaffected, or even increase in abundance.

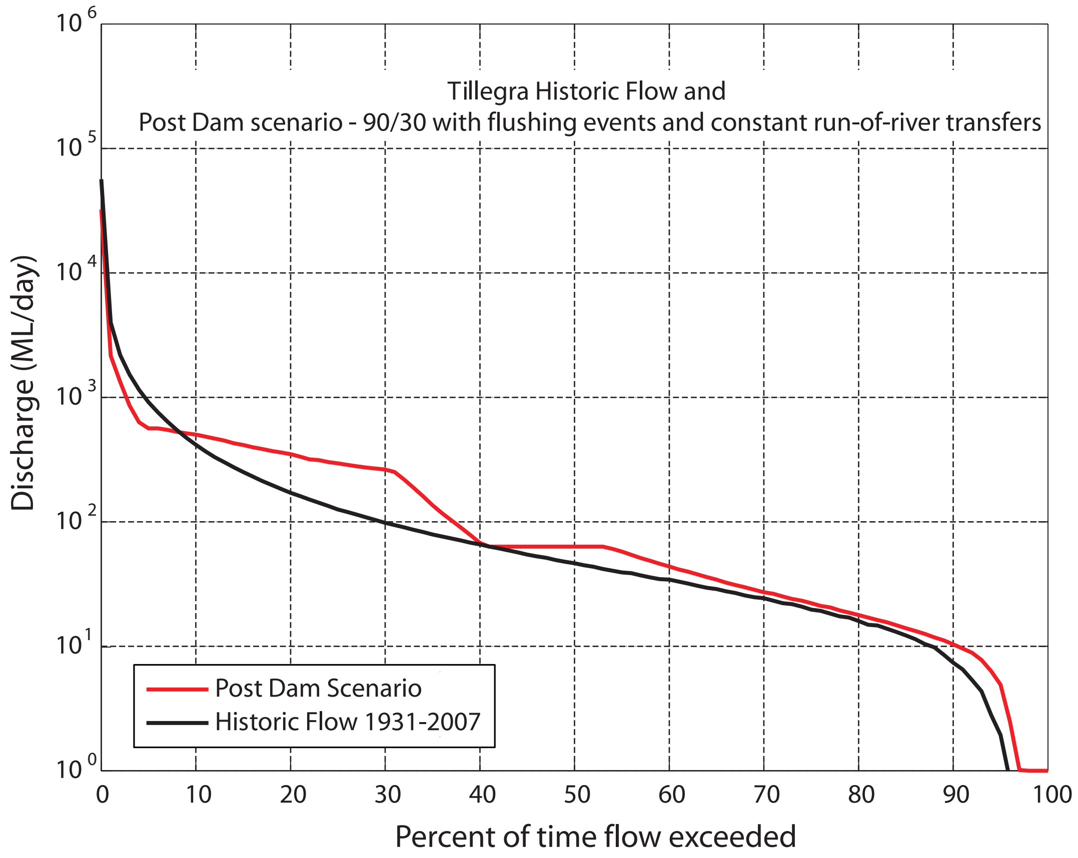
5.5 Standard operation phase assessment

5.5.1 Hydrology and water quality

An assessment of historic flows (1931-2007) and expected releases made from Tillegra Dam (under the standard operation phase which includes constant run-of-river releases modelled at yield) was undertaken for flows at Tillegra and Glen Martin. Per cent exceedence plots for Tillegra and Glen Martin are provided in Figure 5.3 and the statistics for all data for Tillegra and Glen Martin are provided in Table 5.8. The figure and tables compare pre and base case post dam scenarios.

Table 5.8 Tillegra Bridge and Glen Martin historic and modelled 90/30 release flows (seasonal statistics are provided in Tables B2 and B3 of Appendix B)

Statistic	Tillegra		Glen Martin	
	Historic	Release Scenario	Historic	Release Scenario
Minimum	0.0	1	0.0	0.0
95th percentile exceedence	1.9	4.9	0.4	6.7
90th percentile exceedence	7.4	10.4	9.8	17.5
80th percentile exceedence	15.9	17.8	27.5	36.4
50th percentile exceedence	46.5	63.0	116.0	224.7
20th percentile exceedence	170.8	348.4	610.3	553.9
10th percentile exceedence	416.0	501.0	1494.1	1057.3
5th percentile exceedence	914.5	563.0	3165.8	2093.9
Maximum	56488.4	32223.2	137448.1	101049.4



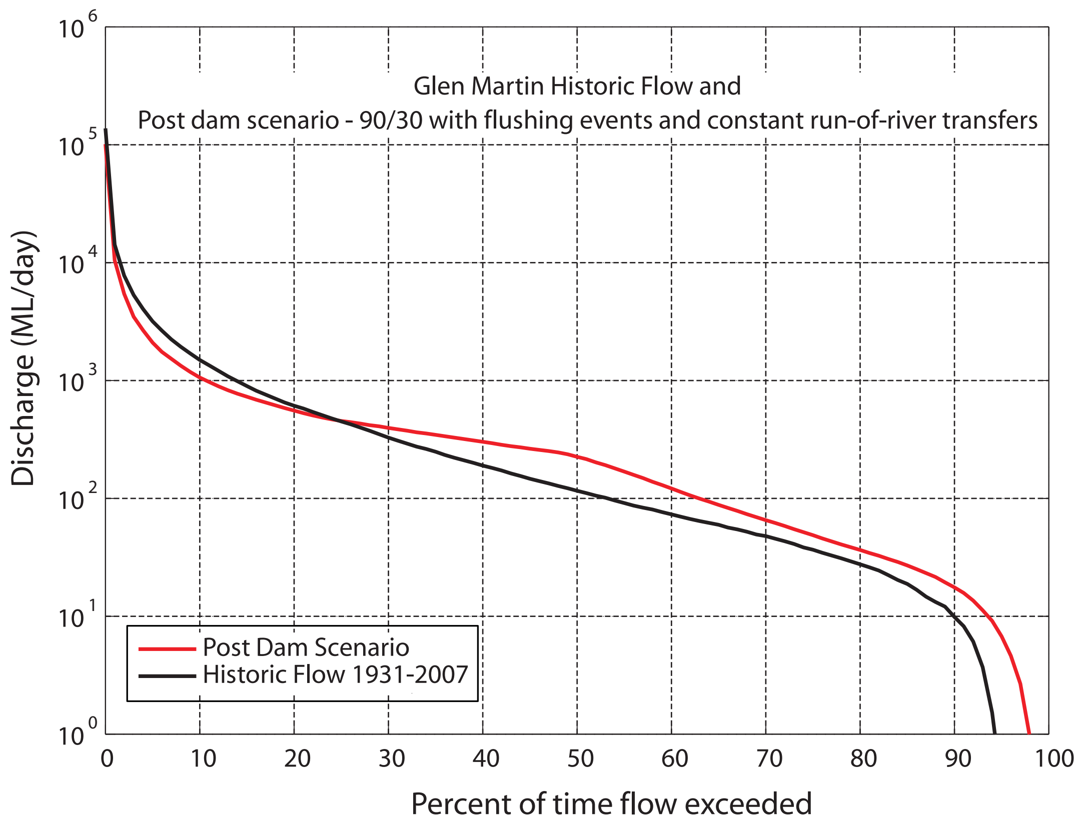


Figure 5.3 Daily flow distributions for Tillegra and Glen Martin (base case)

Statistic	Tillegra		Glen Martin	
	Historic	Release Scenario	Historic	Release Scenario
Mean	261.5	219.8	880.8	693.1

Additional statistics for the base case release scenario for spilling and transfer flows are provided in Table 5.9

Table 5.9 Tillegra Dam spilling and transfer flows

Statistic – Tillegra Dam	
Spilling	22 per cent of the time
Spilling Events over the 77 years of data	119
Mean spilling flow	461ML/d
Mean transfer flow	362 ML/d
Number of transfer events over 77 years	212
Mean transfer duration	30 days
Transfer occurrence	22.6 per cent of the time

Reach 3

During the operation phase, which includes run-of-river releases modelled at yield, the frequency of the majority of flows would increase with the exception of flood flows (less than 5 per cent exceedence at Tillegra and 20th per cent exceedence at Glen Martin). Concurrently the mean flow would decrease at both sites as smaller, more frequent flows are released from the dam.

The mean flow at Tillegra is currently 262 ML/day. Post 2060 the mean flow would be 220 ML/day. Mean flow at Glen Martin is currently 881 ML/day and post 2060 the mean flow would be 693 ML/day, but more constant in lower flow classes. This effect would occur gradually over the life of the dam as demand increases. The median flow during the operational phase would increase for all sites and seasons (except W7 and W8 in autumn) leading to a concomitant increase in median velocity, depth and channel wetted width.

Change to the historical flow regime would vary among seasons, with the greatest effects during the spring. This is due to the current operating protocols for calling down run-of-river transfers. Modelling has predicted that run-of-river transfers would not be distributed with the same seasonal pattern as historical flows of an equivalent size. Modelled run-of-river transfers would occur mainly in spring, a period historically dominated by relatively stable low to moderate flows.

The operational release scheme represents a loss of peak flows relative to the historical distribution. At Tillegra, 22 per cent of historical peak flows were greater than 900 ML/day whereas around 8 per cent of peak flows are predicted to be in this range during the operational regime. At Glen Martin, peak flows would also be generally smaller compared to historical data. Peak flow volumes are predicted to be lower for all peaks in the 70th – 0th percentile exceedence under the operational release strategy.

The operational release scheme should improve water quality in Reaches 3 and 4 relative to the filling phase by providing larger flushing flows. Flushing flows transport sediment, nutrients and organic carbon downstream, break up stratification in pools and increase dissolved oxygen levels.

Reach 4

As the median flow entering the Seaham Weir following dam construction would almost double it is likely that the effects on Seaham Weir Pool water quality would be negligible. Further run-of-river transfers during low flow periods may lead to enhanced mixing and improvements in water quality within the pool.

The water level within the weir pool is not expected to change significantly as a result of the operation of the proposed Tillegra Dam based on expected inflows to the weir pool. Available historic water level data (1981-2007) shows that around 80 per cent of the time the water level within the weir pool is between 0.32 and 0.65 mAHD (Dept of Commerce 2008). A similar range is expected during the operational phase of the dam, however, the rate of water level change within the weir pool and the pumping capacity requires consideration.

Reach 5 and beyond

Within the Williams River estuary the reduced flood flow magnitude may lead to more rapid upstream migration of the salt wedge than present conditions. It is anticipated that the salinity at the weir may increase slightly during low flow periods.

As the freshwater flow from the Williams River accounts for less than 3 per cent of the total volume of water below the confluence of the Williams and Hunter Rivers the potential impact on salinity concentrations below the confluence of the rivers is expected to be negligible.

5.5.2 Geomorphology

Frequency of geomorphic processes

For a given discharge threshold, the average recurrence interval (ARI) was predicted to decrease. The data indicated that bed material mobility would still be achieved under the dam release scenario, but the frequency of occurrence would generally decrease at each site. Macrophyte disturbance under the dam release scenario continued to be a common occurrence. However, there would possibly be more opportunities for macrophyte colonisation at Tillegra. Grass and shrubs are rarely disrupted under the current flow regime. Under the dam release scenario this would continue to be the case, although such events would be even rarer. Flushing of silt and sand from the bed surface would continue to be a common event under the dam release scenario.

The implication of the combined effects of reduced bed material mobilisation, increased chance of macrophyte colonisation, and reduced disruption to in-stream vegetation is that over time the channel may become more stable, with more in-stream vegetation. The flows would still maintain the basic geomorphic processes, but the useable (by biota) channel area may contract somewhat. This effect was predicted to lessen with distance from the proposed dam.

Frequency of inundation of geomorphic forms

The identified morphological forms identified at each site were associated with a level and a discharge. This was expressed as an ARI (based on peak flow series) for the current scenario and for the dam release scenario. The difference between these recurrence intervals was the predicted impact of the dam on inundation of these surfaces. The upper morphological surface is referred to here as 'bankfull' - this applies to a morphologically defined surface, not a process defined surface, so no implications are intended regarding the frequency of inundation.

At W7, the dam was predicted to have little impact on the frequency of inundation of geomorphic forms, largely because there were few forms identified. The low unvegetated and vegetated bars would experience reduced frequency of inundation, but would still be inundated frequently. The morphological bankfull level would be unchanged as it is terrestrial under the current flow regime.

At W8, there was a large variety of surfaces present. The low unvegetated bars are currently inundated multiple times per year. With the dam in place this frequency would reduce, but it would still be at least once per year for most of the surfaces. With the dam in place, the higher unvegetated bar and the low vegetated bench would likely change their character, as they would be inundated much less frequently, shifting from being flooded at least once per year on average to once every 3 to 5 years on average. The other benches are infrequently inundated under the current regime, and the frequency would reduce with the dam scenario in place. The bankfull level at this site could be described as a terrace, as it is infrequently inundated. With the dam in place, the 100 year ARI event would not reach this level, so the terrace would become fully terrestrialised.

At W9, three main surfaces were identified. With the dam in place, the low unvegetated gravel bar would continue to be inundated more than once per year. The mid-level bench would shift from being inundated once every 2.5 years to once every 9 years. At this site the bankfull level is an active floodplain under the present conditions, although it is flooded only once every 6 years. With the dam in place the floodplain would be inundated on average once every 60 to 70 years, effectively becoming an inactive terrace.

At W10, the low unvegetated bench would continue to be inundated multiple times per year with the dam release scenario. The intermediate level surfaces would be flooded every 5 to 11 years rather than every 2 to 3 years at present. The left floodplain surface was lower than that on the right bank. The left floodplain would flood once every 81 years, which represents a large change from the current once every 6.5 year frequency. The higher right bank floodplain surfaces would undergo terrestrialisation, shifting from being flooded every 11 to 14 years to not being inundated by the 100 year ARI event.

At W11, only a bankfull surface could be identified from the cross-sections, although in the field some narrower lower benches were visible. Under the present condition the floodplain was inundated reasonably frequently, at around once every 2 to 3 years. This is within the range of expected bankfull flood frequency for un-incised rivers. With the dam in place, the flood frequency would halve, so that the floodplain would inundate on average once every 2 to 8 years.

At W12, only a bankfull surface could be identified from the cross-sections, although in the field some narrower lower benches were visible. Under the present condition the floodplain was inundated reasonably frequently, at around once every 1 to 2 years. This is within the range of expected bankfull flood frequency for un-incised rivers. With the dam in place, the flood frequency would halve, so that the floodplain would inundate on average once every 1 to 4 years.

In summary, releases during standard dam operation would alter the natural hydrology of the river system. This would lead to altered channel and overbank hydraulics, meaning that some physical features such as bars and benches, floodplain surfaces and wetlands, would experience reduced frequency of inundation. The implication of this is reduced opportunities for flushing of carbon and propagules to the river. The vegetation composition and structure on these surfaces could change, with the trend towards terrestrialisation.

Sediment transport

Bed material sediment transport

There is little doubt that the Tillegra Dam would lead to bed scour of the Williams River downstream of the proposed dam site due to the trapping of the upstream sediment supply, but maintenance of flows that have the capacity to mobilise the bed material. This process also occurred on the Chichester River downstream of Chichester Dam when the dam was completed. The result was scour of the finer fraction of the bed material, leaving a mostly boulder sized bed in the area downstream of the dam. The same process would occur on the Williams River, with the bed scouring to bedrock and leaving the immobile boulders in place. This would change the physical (hydraulic) character of the bed, which would have implications for the biota.

The extent of potential downstream scour cannot be accurately predicted. However, it is likely that it would extend for some distance downstream of the Chichester River confluence, as this river is also starved of sediment (from Chichester Dam). Prior to the construction of Chichester Dam, this river would have been the major supplier of coarse bed load to the Williams River. Certainly, the Williams River has the capacity to transport the current bed material at the surveyed sites all the way down to Glen Martin. The impact of scour would be offset in the downstream direction to some extent, as unregulated tributaries would inject some coarse sediment to the river. The potential of these tributaries to provide coarse bed material to the Williams River was not investigated as part of this Project.

Sediment scour due to sediment starvation would be partly mediated by reduced frequency of flows with the capacity to transport coarse sediment. The Tillegra Dam was predicted to significantly reduce discharge peaks, and this would reduce the potential bedload transport rate at Tillegra by a factor of three. The modelling suggested that with the dam in place, in the reach down to the Chichester River junction the river had the capacity to transport an average annual load of 1,000 - 2,000 tonnes, although this varied from virtually nothing up to 18,000 tonnes per year depending on hydrological conditions.

Suspended sediment transport

The proposed Tillegra Dam would have a dramatic impact on suspended sediment load due to its high trapping efficiency. Immediately downstream of the Dam, the load would reduce from an average 10,000 tonnes per year to only 140 tonnes per year. Although the majority of the Williams River channel is constructed from coarse-grained material, the upper banks and some in-channel benches were observed to be constructed from fine alluvial material (silt and fine sand). With the proposed dam in place, these components would suffer reduced rate of construction. This could have ecological consequences, as the fine-grained channel forms are likely to favour different vegetation communities compared to the gravel beds, cobble bars and benches.

With the dam in place, the section of the Williams River immediately downstream of the dam wall in particular would tend to have clearer water than currently during high flows, which would mean lower nutrient concentrations, and greater light penetration. This could have implications for the ecology. Lower overall suspended sediment loads to the Seaham Weir pool would mean lower risk of algal blooms.

5.5.3 Aquatic ecology

An assessment of the potential impacts on macroinvertebrates and fish during the operational phase is provided in Appendix A. A summary is provided in the following sections.

Macroinvertebrates

The improvement of water and habitat quality in Reach 3 following the filling phase should facilitate the restoration of any impaired macroinvertebrate riffle and pool edge assemblages to pre-dam compositions. The distribution and abundance of sensitive taxa to declining water quality should return to within the historical range. The potential impacts on macroinvertebrates during the operational phase as a result of increased median flows are listed in Table 5.9.

Table 5.9 Potential impacts on macroinvertebrates during standard operation

Flow component or aspect	Benefit	Detriment	Examples
Increase in wetted width	Increase in abundance of macroinvertebrate fauna associated with riffle habitat and gravel/sand bars		
Increase in median riffle velocity		Reduction of benthic organisms less tolerant of higher velocity flows	
Decrease in low flows		Reduction in pool edge fauna with life history traits that require seasonal low flows	▪ planktonic larvae

Fish

The future operation of the proposed dam would lead to an increase in median flows. The potential impacts for fish during the operational phase are listed in Table 5.10.

Table 5.10 Potential Impacts of fish during the operational phase

Flow component or aspect	Benefit	Detriment	Examples
Bed scour		Localised decline in species in upper reach 3 who rely on riffle and gravel/sand habitat for prey.	▪ Cox's gudgeon ▪ Small long-finned eels ▪ Freshwater Catfish
Increase in median flows		Decline in fish species with life histories adapted to seasonal stable low flows	▪ Smelt ▪ Flathead gudgeon ▪ Introduced *Gambusia*
Improved habitat and water quality	Increase in sensitive fish species affected by filling phase		▪ Cox's gudgeon ▪ Small long-finned eels

Upstream Passage Reach 3

The replacement of low to moderate flows with run-of-river transfers would increase median velocities over most of the Reach 3 riffles, particularly during spring (and to a lesser extent summer) which is traditionally the period when fish would attempt the majority of upstream migrations. It is predicted that many species may experience a reduction in navigable flows along Reach 3 at high energy riffles due to an increase in velocity barriers, although at low-energy riffles large strong-swimming fish may benefit from an increase in median depth. Table 5.11 summaries expected impacts on fish passage during the operational phase for different fish classes and respective depth and velocity requirements.

Table 5.11 Fish classes and expected impacts on fish passage

Depth/Velocity requirement	Fish class	Species	Assessment
0-3cm <0.8 m/s	Small weak swimmer	▪ Longfinned elvers ▪ Shortfinned elvers ▪ Cox's gudgeon ▪ Empire gudgeon ▪ Flathead gudgeon ▪ Dwarf flathead gudgeon ▪ Smelt	▪ Decreased navigable flows at u/s low energy riffles due to increased velocity with run-of-river transfers ▪ Similar navigable flows at Glen Martin ▪ Decline in upstream dispersal in u/s Reach 3
0-5cm <1 m/s	Small strong swimmer	▪ juvenile bass ▪ juvenile freshwater mullet ▪ juvenile sea mullet	▪ Slight decline in navigable flows at u/s low energy riffles ▪ Slight decline in navigable flows at Glen Martin ▪ Fish would still have large navigable windows for passage at all riffles therefore a similar pattern is expected
15cm-1.4m	Large strong swimmer	▪ Adult freshwater mullet ▪ Adult bass and large juveniles	▪ Increased navigable flows at u/s low energy riffles ▪ Reduced navigable flows in winter at Glen Martin due to

increased velocity with run-of-river transfers

Upstream Passage Reach 4

The proportion of navigable flows within Seaham Weir Pool are not anticipated to change as there are few, if any, depth barriers to passage. The low gradient and wide channel produce lower velocity flows.

Upstream Passage Reach 5

The operational regime may however reduce the proportion of diadromous fish recruiting upstream into Reach 4 and Reach 3 via passage from estuarine habitat through the Seaham Weir fishway. The predicted increase in spring flow volume at Glen Martin due to the calling of run-of-river transfers would possibly decrease the number of days that the weir pool falls below RL 0.4 metres, and as such may decrease the amount of time during spring and summer when small fish can navigate the fishway.

Downstream Passage - Peak Flows

The increase in frequency, magnitude and duration of peak flows relative to the filling phase would benefit those species that require seasonal peak flows to cue and/or facilitate spawning or dispersal migrations. However, the predicted magnitude of peak flows is consistently lower than historical peak flows although the receding part of the flow hydrograph is longer. The recruitment of species such as Australian bass may remain at lower levels than the pre dam situation. These patterns may be similar for other species, although the exact nature of the relationship with peaks flows to recruitment is unknown.

Summary

The initiation of constant run-of-river transfers and spilling flows should improve water and habitat quality that may have become degraded during the filling phase, and therefore the recovery of sensitive macroinvertebrate taxa. A rise in channel wetted width would increase the overall productivity of riffle communities and habitat availability for associated fish species. However, scour of bed material in the upper section of Reach 3 would result in the localised loss of riffle and gravel/sand habitat and associated taxa.

The predicted increase of flows during the spring may decrease recruitment for those taxa that have life histories adapted to a period of historical stable low flows. The proportion of upstream navigable flow is predicted to decrease for most fish throughout Reach 3 and at the Seaham Weir fishway. However, for small, weak-swimming fish the change in access to upstream section of Reach 3 may be limited due to the relatively small change in navigable flows at the high energy Mill Dam Falls. There remains uncertainty regarding the effects on fish passage in Reach 3 due to the lack of knowledge about flow thresholds and migratory details for many species.

Seasonal peak flow volumes are consistently lower than historical flows and may therefore negatively affect ecological processes that are proportional to flow magnitude, such as bass recruitment.

5.6 Refinement of the base case scenario

5.6.1 Outcomes from base case scenario assessment

HWC modelling of the base case scenario assumed 90/30 transparent translucent flows, flushing events and constant run-of-river releases triggered by demand at Grahamstown Dam that generally occurs during spring and summer. An assessment of the base case scenario on water quality, hydrology, aquatic ecology and geomorphology was undertaken and the following noted regarding adequacy of releases in meeting downstream riverine requirements:

- the duration and distribution of run-of-river transfers were not similar to pre dam conditions. Run-of-river transfers were released at a constant flow for 30 days during any particular month
- no regular high flows (>900 ML/day), with the exception of infrequent flushing events, were released from the dam. Constant run-of-river transfers have a peak flow of 500 ML/day and mean spilling flows are 461 ML/day
- the seasonality of run-of-river transfers were not similar to pre dam conditions. Constant run-of-river transfers were generally triggered during the ecologically sensitive spring and summer months
- no additional releases to the 90/30 release strategy during wet years, when run-of-river transfers are not required.

Based on the above assessment, improvements to the base case environmental release strategy are suggested to provide a reasonable protection of the riverine environment with minimal loss of ecosystem function and include:

- run-of-river event based transfers
- change in seasonality of releases
- minimum number of event releases per year
- replacement of flushing events with run-of-river event based transfers

Information on the suggested improvements are provided in the following sections.

5.6.2 Run-of-river event based transfers

HWC modelling of the base case release scenarios assumed a constant release rate for the run-of-river transfers during any particular month. A constant release rate was not considered appropriate to protect the natural ecosystem and it is suggested that the transfers be modified to mimic the natural variability within the river. A run-of-river transfer has been modelled on natural peak flow events in the range 1000 and 1800 ML/day (149 events from the 77 years data). The events were defined by the period of three days prior to and 10 days after the event peak. A double exponential curve was fitted (refer Figure 5.4) to the receding median flow for each day:

$$Q(t) = 1500 * \left(e^{(-t/1)} + e^{(-t/4)}\right)/2$$

where Q(*t*) is the release discharge (ML/day) at time *t*, *t* = 0 is the event start and *t* has units of days

The event is defined by the 10 days from the peak 1500 ML/day to 61.3 ML/day on day 10. The total volume released over the 10 days is 4300 megalitres which is typical of the smaller simulated constant bulk transfer flows.

Replacing the constant run-of-river volumes modelled by the release pattern

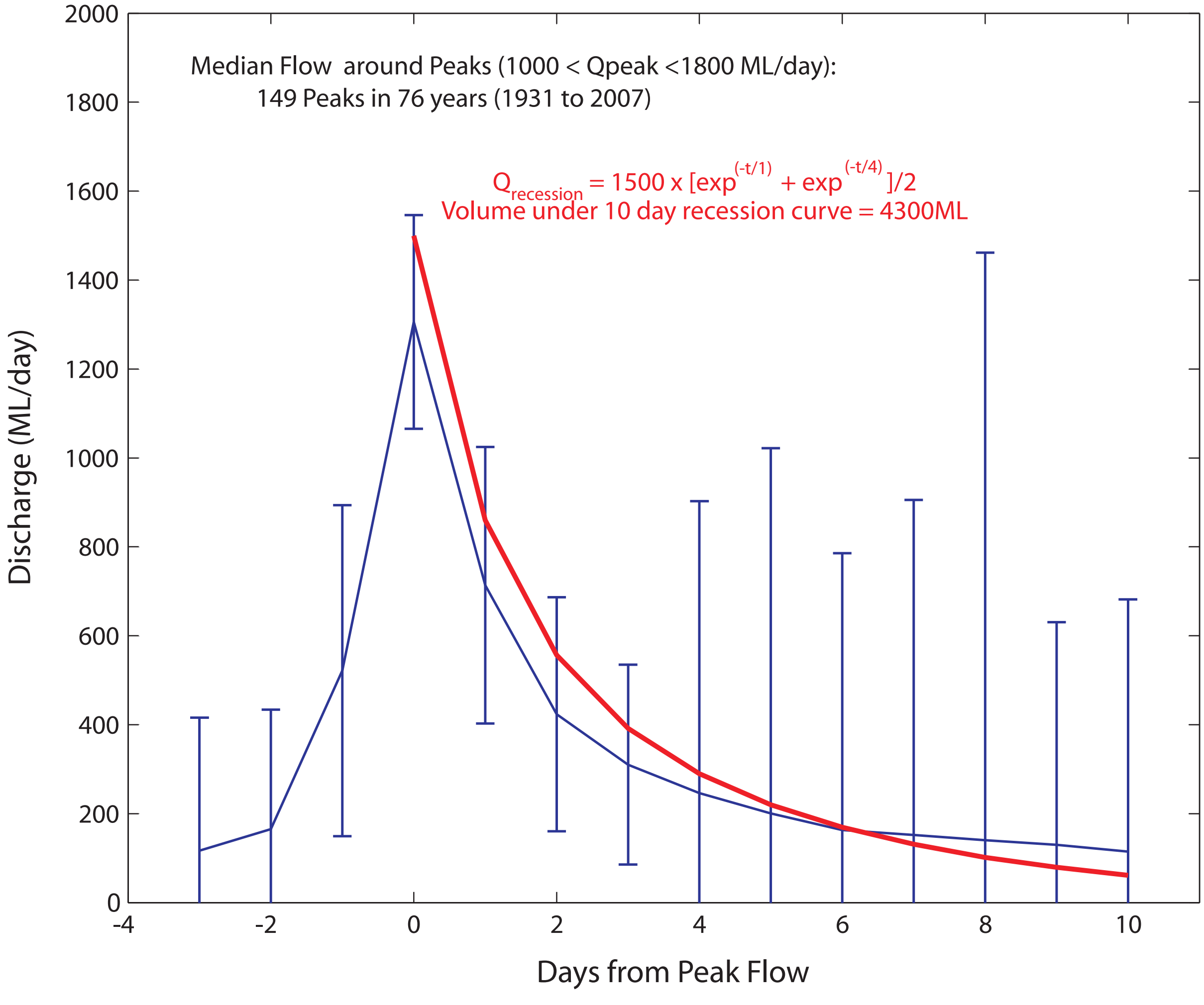


Figure 5.4 Run-of-river event based transfer recession curve

described above would, on average, need to occur around seven times per year for the maximum demand. The maximum demand modelling suggests the number of 10 day release events would range from zero to a maximum of 17 during the driest year.

5.6.3 Replacement of flushing events

Replacement of the flushing events in the base case scenario with appropriately timed run-of-river event based transfers would provide a similar benefit to the downstream ecosystem. The proposed flushing event consists of 2,000 megalitre release for one day while the run-of-river event based transfer has a peak flow of 1500 ML/day declining over the next 10 days. Both flow magnitudes would transport sediment, nutrients and organic matter downstream, break up stratification and increase dissolved oxygen levels downstream of the dam. Run-of-river event based transfers may also improve blue-green algal conditions within the Seaham Weir Pool.

5.6.4 Seasonality of run-of-river event based transfers

Run-of-river transfers in the HWC modelled base case scenario were triggered by demand at Grahamstown Dam. As a result the majority of transfers were made during the spring and summer months which are critical times for recruitment of taxa that have life histories adapted to stable low flows.

Therefore it is suggested to release the run-of-river transfers in a way that better reflects the natural seasonal flow distribution. Historically the majority of flows occur in autumn and winter with the least in summer and spring and this pattern should be mimicked as much as possible with the expected run-of-river transfers. Adopting an operational protocol that preferentially releases run-of-river transfers during the months of March, April and May will deliver positive environmental improvements to the river.

5.6.5 Minimum number of event releases per year

As discussed in Section 5.3.1 fresh releases, in addition to the 90/30 environmental releases, are proposed during the filing period. A minimum of six events would be required every year of dam filling and operation, should neither run-of-river transfers nor spilling flows occur. The six releases may be made up of a combination of run-of-river event based transfers, spilling flows or fresh releases.

In addition to the 6 events per year it would be desirable to increase the number of releases per year should the filling phase exceed 3 years to reduce any possible accumulating impacts. It is desirable to increase both the frequency and magnitude of the event releases to incorporate a combination of fresh and run-of-river transfer releases. Further information on the desired frequency distribution of additional releases is provided in Working Paper C of the EA Report. The number and type of releases was determined following analysis (magnitude and frequency) of peak events for the period of record (1931-2007).

It is noted that immediately downstream of the dam, the reduction in the frequency, magnitude and duration of natural flows will lead to further decline in the current condition of the ecosystem especially if the filling phase is prolonged and additional releases are not made. The decline will occur as the current ecological system is dependent on a range of naturally occurring diverse and substantial flows to provide riverine habitat and stimulate biological processes. As releases of an equivalent nature to historical flows is not possible without affecting the dam's security of supply, the ecosystems between the dam and the Chichester River confluence would likely be affected.

In this regard, allocation of environmental releases from the dam during filling and operation would be based on a balance between what is possible given competing requirements of the environment and drought security and is also dependant on climatic conditions of the time.

5.6.6 Additional modelling and management of operational limitations

The assessment undertaken for the Project has identified a base case strategy that would accommodate environmental requirements with refinement. Opportunities to refine the strategy were identified to arrive at a preferred flow regime of;

- a transparent release from Tillegra Dam to the 90th percentile of flows
- a translucent release from Tillegra Dam consisting of the transparent flow and 60% of flow between the 90th and 30th percentile of flows.
- an event based run of river transfer of 4,300ML peaked at 1500ML/day declining over 10 days to mimic natural flow variability in the river.
- inclusion of additional event based discharges from the dam consisting of a peak discharge of 270 ML/d, tailing off over a four day period. Such discharges will be released to ensure a minimum number of variable flows important for fish passage occur below the dam wall, should run of river releases or natural spills not occur
- ensuring releases occur at the appropriate time of year to maintain the seasonality of flows within the river.

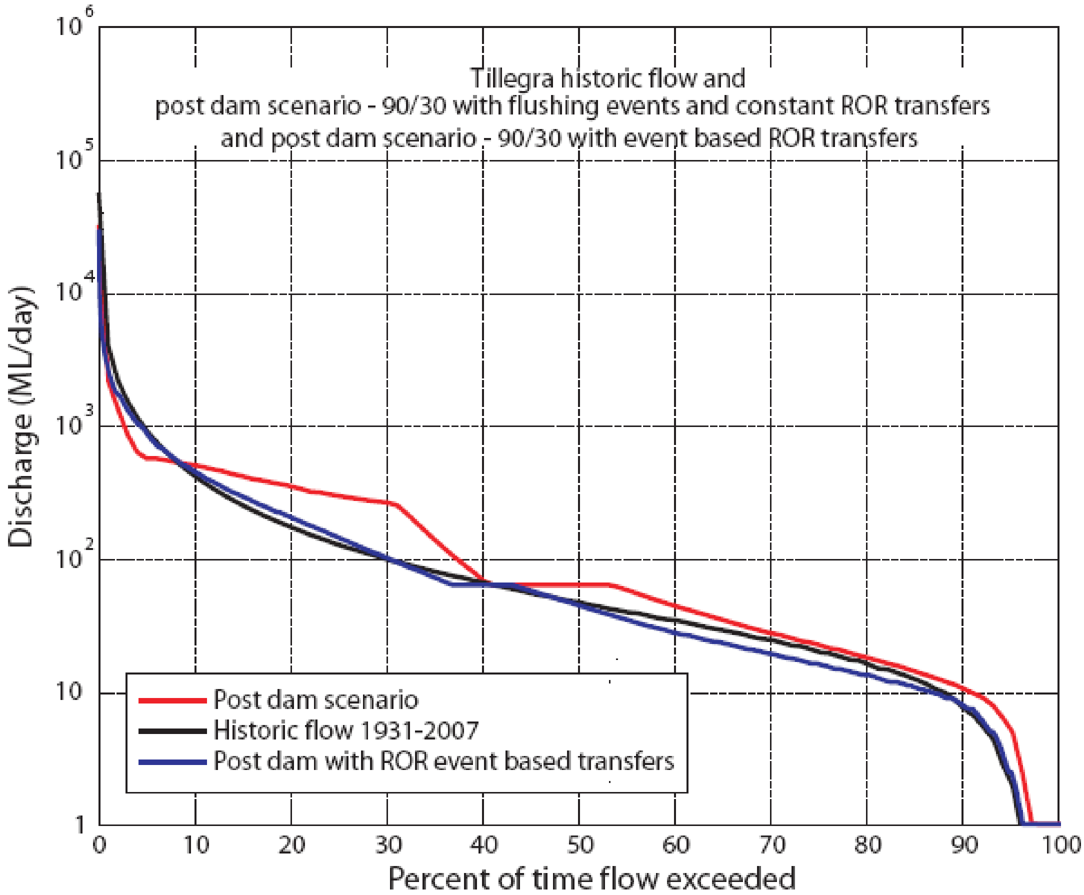
Results from the recent improvements to the base case release scenario are presented in Figure 5.5. The black curve is the historic Tillegra inflow, the red curve is the base case scenario with static releases and the blue curve is the most recent model results with events based run of river transfers and a change in the seasonality of releases. This approach represents a significant environmentally sympathetic improvement to current environmental release strategies operating in other NSW storages.

A comparison of the per cent exceedance statistics of cease to pump flows for historic and the modified base case release flows from the dam (Table 5.12) indicates that on average the cease to pump levels would be exceeded the same or more often than for the pre dam case, with the exception of flows during spring for non accredited users. Consequently the release strategy would require further refinement so irrigator access rights are preserved during the spring months.

Table 5.12 Per cent exceedence of cease to pump flows (6 and 15 megalitre per day) at Glen Martin pre and post dam.

Glen Martin (Percent Occurrence)	Discharge (ML/d)	All Data (%)	Summer (%)	Autumn (%)	Winter (%)	Spring (%)
Pre Dam	6	92	84	95	98	90
	15	87	77	92	95	83
Modified base case	6	93	86	97	100	90
	15	87	77	94	98	78

Following on from introductory meetings in 2007/08, Hunter Water again met with



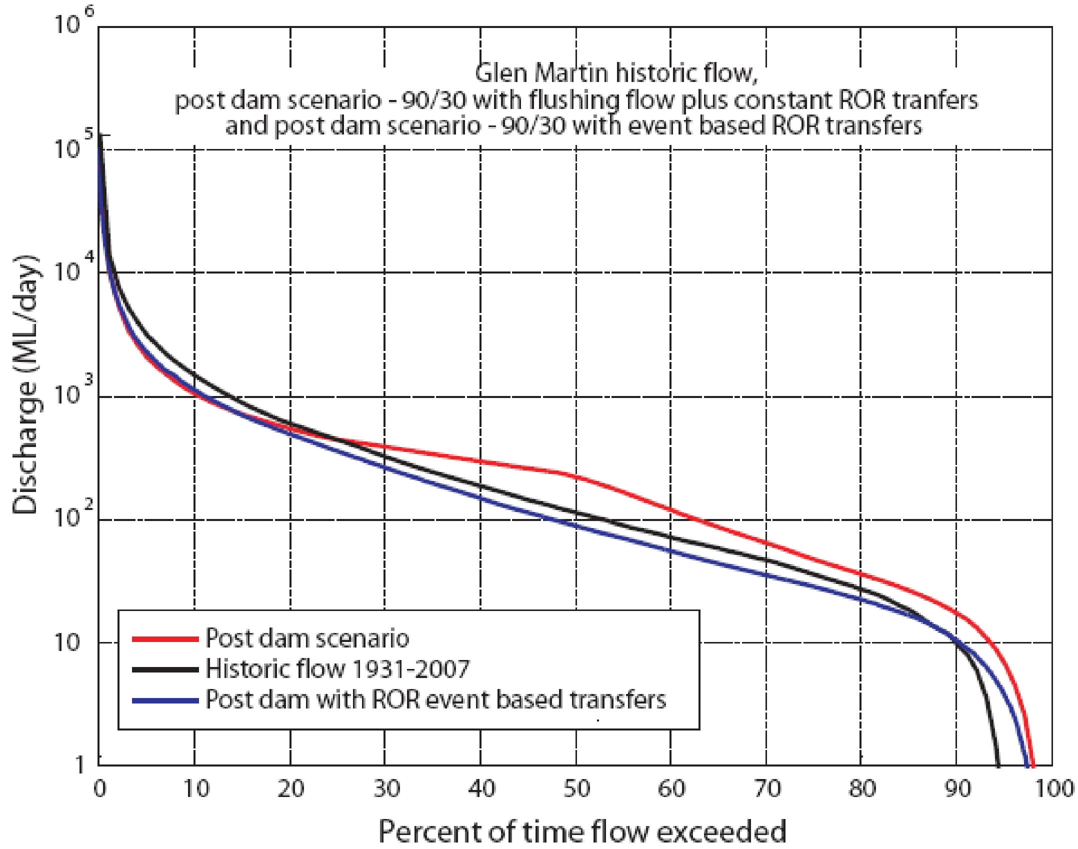


Figure 5.5 Daily Flow Distribution for Tillegra and Glen Martin

representatives from the Williams River Water Users in late 2008 and February 2009 to discuss this matter and general use of the dam. In relation to flow regimes, options discussed included increasing releases from the dam during the critical months of September, October and November by increasing the transparent release proposed for the dam to the 30th percentile. Alternatively, at least one event based run of river release could be programmed to occur during the spring period. Increasing the transparent release during the spring period was preferred, to ensure that more natural flow regimes sympathetic to environmental needs occurred.

To achieve the objectives discussed with the water users association and formalise a preferred operating regime to account for both existing licensed water use rights and downstream ecological needs, it was recognised that it would also be necessary to account for the following operational issues and modelling assumptions;

- Releases made from the proposed dam at Tillegra based on gauged real time data collected at Underbank, some 20 kilometres upstream of the Tillegra gauge, may incorrectly estimate the rate of release required to maintain historic measured flows. This could occur as catchments inflows into the dam from Dog Trap creek, Quart Pot Creek, Moolee Creek and directly onto the surface of the reservoir would not be measured. These inflows to the dam would occur below the Underbank gauging station.
- The calibration and performance of the HWC model is considered to be of an excellent standard. The hydrological model used by Hunter Water has been reviewed by Sinclair Knight Mertz (2003 & 2008) however the modelling scenarios have been undertaken on historic data, within the context of the dam performing at yield, approximately at the year 2050. The modelled outflows and duration curves are a product of the average of this long time series and do not necessarily represent river flows that would occur in the first 5 to 10 years (construction and fill up phase)[2]. Spilling flows and multiple run of river release flows (above the minimum six prescribed in the release strategy) would not occur early on in the dam's development and the proportion of flows released in the first few years of the dams life may be under-represented by the final model outputs.
- The dam and spillway in operation together, can act to attenuate flows. The low flow class directly below the wall, between the confluence of the Williams and Chichester Rivers are sensitive to the height of the dam wall parapet and spillway widths. Attenuated spillway flows may positively bias the percentile of low flows experienced downstream of the dam, however this is contingent on final detailed design.
- Flows from the multi-level offtake tower would be preferable than uncontrolled releases occurring across the spillway, to control thermal pollution issues. Rapid temperature changes below the dam wall should be avoided. It is advisable to ensure that the temperatures of outflows are matched to inflows as far as practical. Currently spillway discharges are calculated as being likely to occur 23% of the time. Operating the offtake in a manner to minimise uncontrolled discharges should be considered, with the spillway reserved for passing large floods.

HWC recognises that implementation of an environmental and operational release strategy is always a case of continual improvement. To ensure adaptive management (which is an objective of water sharing plans that are subject to periodic review and community consultation) regular reviews of system performance would be undertaken. The information collected from monitoring activities would be

[2] Construction and fill up flows from Tillegra Dam are detailed in Appendix B, Table B1.

used to determine whether and how the strategy should be modified, within the statutory water sharing plan process administered by the Department of Water and Energy.

As part of the continual improvement of the proposed flows, HWC considered the above matters and performed additional modelling scenario's to test the assumptions and address the issues listed. To allow the refinements to the base case release strategy and additional analysis to occur, between March 2008 and July 2009 HWC's model was adjusted to;

- Introduce the release shape and target time of year parameters for peaked 1500ML/year transfers.
- Introduce the 270ML/day peaked 'freshes' into flow maintenance strategies.
- Allow for the possible connection of Tillegra Dam to the CTGM.
- Refine rainfall runoff parameters to better account for rain falling directly in the surface of the proposed dam, and for runoff generated below the proposed gauge at Underbank.
- Refine evaporation allowances, and commensurately account for reduce evapo-transpiration rates, due to rainfall occurring directly on the surface of the dam.
- Refine target operating levels between the different sources of the proposed Tillegra Dam, Chichester Dam, Grahamstown Dam, Seaham Weir and Tomago / Tomaree Groundwater reserves.
- Test release scenario's designed to increased multi-level offtake discharges in lieu of uncontrolled spillway flows. This involves allowing for 100mm of airspace in the dam and preferentially discharging 1500ML peaked flows to minimise uncontrolled flows. Note that peaked flows or a sequence of peaked flows could be released up to the full capacity of the tower and need not necessarily be shaped around a full 1500ML discharge.

The final advanced round of modelling confirmed that the transparent and translucent flows would closely mimic natural flow conditions below the dam, however catchment flow contributions below the Underbank gauge were predicted to be reduced, by 15% to 20% for flows between the 50th and 75th percentile. The introduction of preferential offtake tower flows revolving around the preservation of 100mm of airspace in the dam further influenced the final flow duration curves previously estimated for the dam.

To achieve the formerly identified objective of maintaining historic flows at Tillegra at the 90th percentile, as well as a proportion of flows to the 30th percentile as identified in the first round of modelling, the following adjustments were therefore considered as valid options to consider:

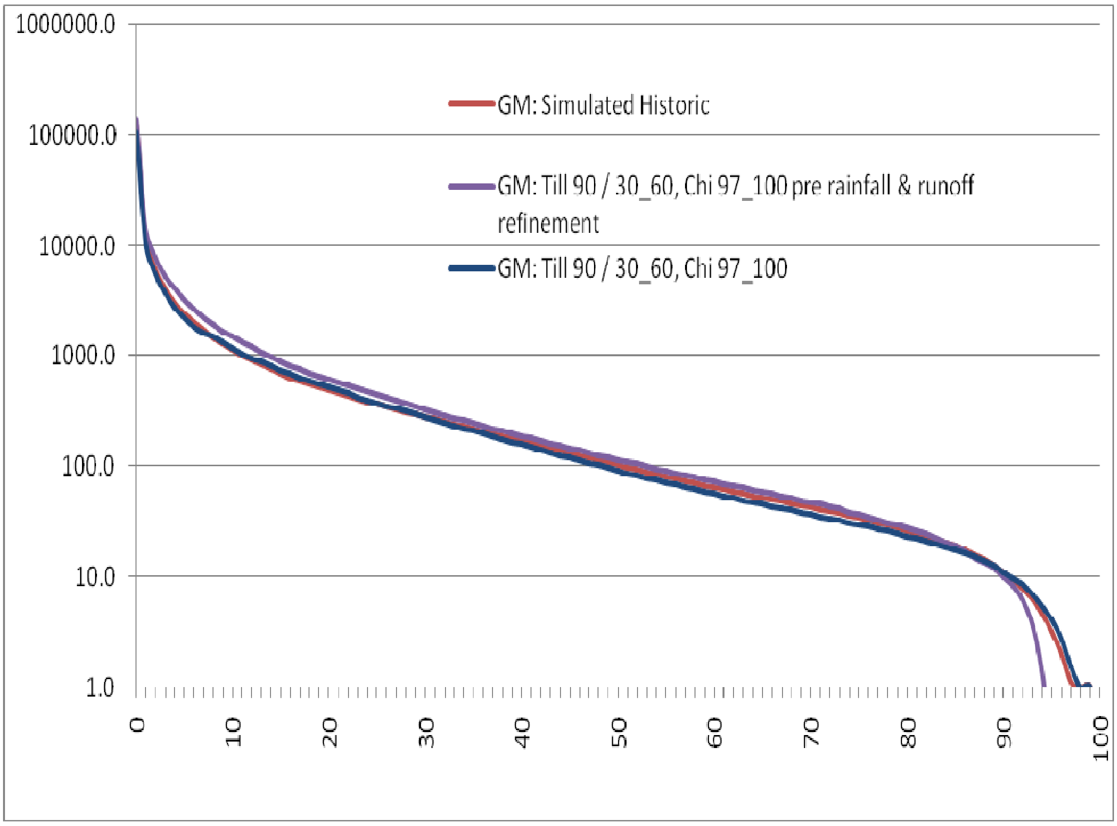
- Increased transparency of flows at Tillegra Dam to more closely match pre-existing historic flows, or
- Increased releases being made from Chichester to compensate for reductions in flow along the upper reach of the Williams River.

An analysis of modelled flows demonstrated that increasing the transparency rate of release to the 30th percentile at Tillegra Dam would be sufficient to achieve close replication of the historic low and moderate flow classes necessary to preserve the ecological integrity of the river, as well as existing water use rights. The addition of preferential discharges through the multi-level offtake tower, however, suppressed moderate flows and freshes, between the 75th and 30th percentiles at the Glen

Martin gauge (end of system) by 20-25 per cent.

Consequently both an increase in transparent flows from Tillegra Dam, as well as at Chichester Dam, would be necessary to mitigate changes to the existing flow regime. Increased transparent flows to 20ML day from Chichester would preserve flows through the entire river system, as measured at the Glen Martin Gauge, up to the 50^{th} percentile of all flows. Further, flows between the 50^{th} and 30^{th} percentiles (larger moderate flows and freshes) would only be suppressed by 10 to 15% which is considered as unlikely to have any significant negative ecological affect.

Per cent exceedance plots for the refined operational release regime, including preferential releases through the multi-level offtake tower against simulated historic flows are shown in Figure 5.6 and Table 5.13. The figure and complimenting data in the table compare pre and final post dam scenarios for the entire river, as measured at the end of system at the Glen Martin gauge.



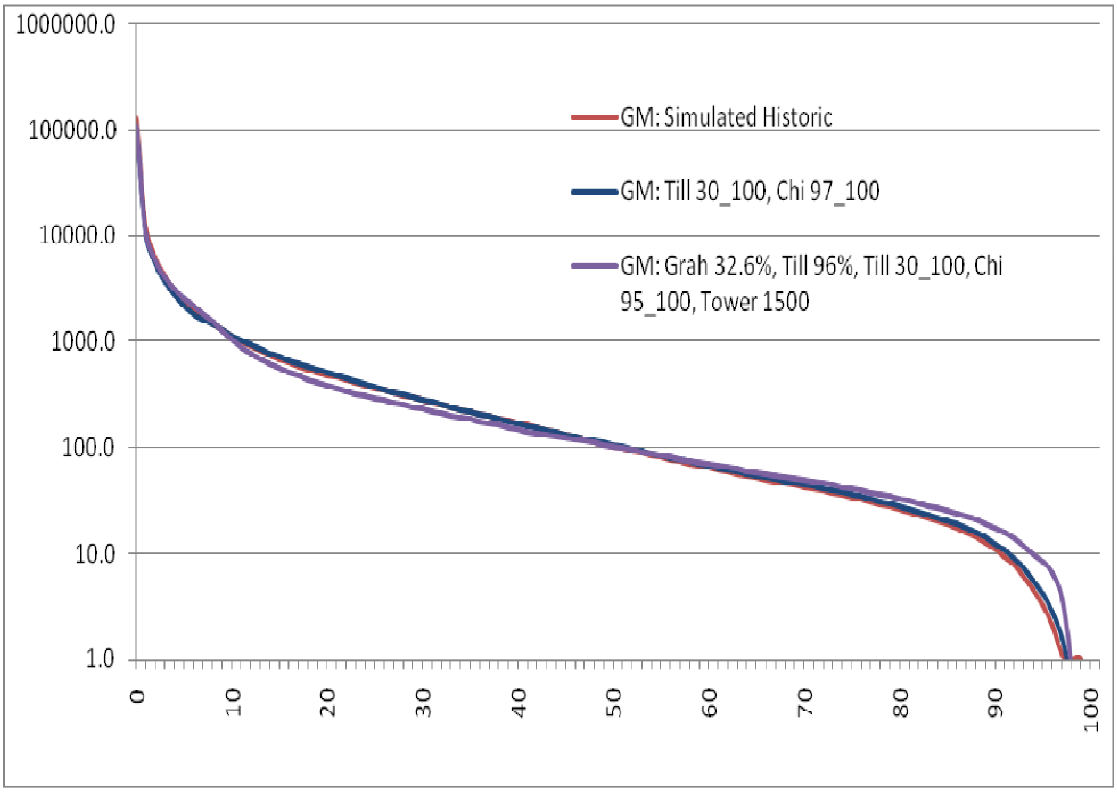


Figure 5.6 Daily flow distributions for Glen Martin for final flow release strategy

Table 5.13 Glen Martin historic and modelled release flows (ctp statistics are provided in Tables B4 and B5 of Appendix B)

Statistic	Historic	Base Case Tillegra Block Releases	Base Case fully refined - Tillegra transparent to 90th, 60% translucent to 30th percentile	Base Case fully refined + Tillegra transparent to 30th percentile	Tillegra transparent to 90th, 60% translucent to 30th percentile, Tower flow, Chichester transparent to 95th percentile	Tillegra transparent to 30th percentile, Tower flow, Chichester transparent to 95th percentile
Maximum	127029	101053	104846	104883	107283	107173
5th percentile exceedence	3166	2072	2185	2173	2618	2585
10th percentile exceedence	1139	1051	1174	1141	1115	1053
20th percentile exceedence	490	555	517	510	386	386
30th percentile exceedance	282	391	280	284	211	230
50th percentile exceedence	***104***	***222***	***92***	***107***	83	102
80th percentile exceedence	26	39	23	28	28	33
90th percentile exceedence	**11**	**19**	**11**	**12**	16	17
95th percentile exceedence	3	5	4	4	8	8
Minimum	**0**	**0**	**0**	**0**	**0.0**	**0.0**

6. River Management

6.1 Sediment management

There is little that can be done to prevent the scour process downstream of dams, short of ongoing augmentation of the sediment supply (Bunte 2004). In the United States, gravel augmentation for the purpose of salmonid spawning habitat improvement has been undertaken episodically by various government agencies since the 1960s and 1970s (Bunte 2004). These efforts stepped up after 1992, when there was a change to legislation that requested that all reasonable efforts be made to obtain a sustainable salmon population that would be doubled by 2002. Despite the numerous projects undertaken in the USA in the past and underway at the time, Bunte (2004) found little in the way of published technical data to substantiate whether the schemes were beneficial.

Merz & Ochikubo Chan (2005) found that cleaned gravels artificially sourced from adjacent floodplain materials were quickly incorporated into the stream ecosystem. Benthic macroinvertebrate assemblages on salmonid spawning enhancement materials, as indicated by species richness, diversity and evenness, were similar to those of adjacent un-enhanced spawning areas within 4 weeks of augmentation and supported higher benthic density and dry biomass for up to 22 weeks after placement.

The feasibility of adding an annual load of one million tonnes of sand to the Colorado River was evaluated by Randle *et al* (2007). They found local sources of sand, and devised delivery methods that were technically feasible, met environmental requirements, and did not impact cultural resources. However, the supply was expected to last for only one or two decades. The potential of sediment augmentation is currently under investigation in some large rivers in the United States, such as the Colorado (see above), the Platte, Trinity and Tuolumne rivers.

Bed material augmentation downstream of dams is an expensive and logistically difficult procedure, and would only be warranted if it could be demonstrated that there would be no significant negative impacts and the gravel-dependent ecological, economic and social assets of the river were of sufficient value. Many factors related to gravel transport processes are still poorly understood. The outcomes of gravel augmentation projects, therefore, involve a degree of uncertainty. Bunte (2004) suggested that one way forward was to use adaptive management. Under this strategy, the gravel augmentation project would be treated as a scientific experiment with uncertain outcomes, but managers would be prepared to make the necessary adjustments to the program as more was learned about the process through observation.

It is suggested that a scheme to bypass sediment around the reservoir would be extremely difficult to implement, may be impractical due to the availability of clean gravels and in general, cost prohibitive.

6.2 River management

In the long term the river would adjust to suit the new regime. The readjustment could involve initial bed scouring, and also building of in-channel benches at new levels. The channel may become more heavily vegetated with shrubs and trees. In the past there has been a policy of removing vegetation growing on bars in order to increase conveyance (presumably to reduce flood risk). The dam would have a significant flood mitigation effect, in which case the argument to remove vegetation on the grounds of reducing flood risk would be weakened. Increased riparian and in-stream vegetation is likely to improve habitat conditions for macroinvertebrates and fish. It would also act to slow the bed scouring process. Thus, the recommendation is to allow channel adjustments to take place and monitor vertical bed movement downstream of the dam.

6.3 Fishways

In order to maintain linkages between fish populations and facilitate fish passage past Tillegra Dam and Seaham Weir a fishway would need to be constructed at Tillegra Dam.

Tillegra Dam

Since the dam wall would be 76 metres a high fishway or fish lift design would be required. Fishways on high dams are rare in Australia although they have been shown to be successful overseas on dam structures as high as 100 metres (Gehrke *et al* 2001). Migrating fish are attracted to a trap on the fish lift using a water outflow and are then transported up the dam wall to the reservoir and released.

Dept of Commerce (2008) outlined a draft proposal for a fish lift at Tillegra Dam for upstream passage. The attraction system for upstream passage would require a dedicated continuous flow of 20 ML/day. To achieve downstream fish passage from the storage two options have been outlined, either; (i) a fish lock system incorporated into the intake tower (ii) an overflow gate and dedicated fish discharge channel integrated into the spillway (Dept of Commerce 2008). It is likely that downstream passage would in fact require both options to be implemented.

High fishways are relatively untested on native Australian fish species and would be a major capital works program involving considerable expense. While a fish passage device at the dam would be desirable to maintain biodiversity upstream it may be that the funds required would provide greater benefit applied elsewhere. For example, it may be possible to remediate several priority barriers elsewhere within the Hunter Region, to obtain better fish passage outcomes. In addition to Seaham Weir, priority barriers for improved fish passage identified by the Dept of Primary Industries include sites at Liddell Gauging Station (Jerry Plains), Mitchell Flats Causeway (Glendon Brook), Brushy Hill Causeway (Pages River), Cross Keys Road Causeway (Paterson River), Barnsley Causeway (Cockle Creek) and Dora Creek Weir (Lake Macquarie). The remediation of a number of these sites may improve fish passage within the Hunter region allowing greater beneficial use of public funds.

Seaham Weir

To mitigate potential impacts on fish passage at the Seaham Weir fishway from the proposed Tillegra environmental flow release strategy the existing submerged orifice fishway should be replaced with a structure(s) that operates over a much wider range of flows and allows the passage of smaller, weak swimming fish and macroinvertebrates which are more common in Australian freshwater systems (particularly diadromous juveniles).

Dept of Commerce (2008) has outlined several options for upgrading the Seaham Weir fishway, favouring a single exit ungated vertical slot fishway. Vertical slot fishways facilitate passage for a greater abundance and diversity of Australian fish than salmonid fishways (Stuart and Mallen-Cooper 1999, Stuart and Berghuis 2002, Stuart *et al* 2008a). Current designs have shallow slopes (1:32 or 3.1 per cent), creating a small differential head between each pool (around 0.05 to 0.1 metres) which generates lower maximum velocities (1.4 metres per second) and turbulence (~4.2 Wm^{-3}).

Although vertical slot designs allow passage for much smaller fish than salmonid fishways they can still represent a barrier to very small fish (e.g. < 30-40 millimetres TL). This can be a problem at tidal weirs where small juvenile diadromous fish attempt upstream migrations. Research is continuing into designs that would improve passage of small fish, including gated vertical slot fishways, fish locks and low slope narrow denil fishways (Mallen-Cooper and Stuart 2007, Stuart *et al* 2008b). The latter are dedicated purely to passage of small fish and are to be used in conjunction with other fishways that benefit larger species.

6.4 Fish stocking

Where it is not a public safety issue, vegetation in the inundated area should be left in place to provide habitat for fish. These standing snags would provide habitat for surviving or stocked native species. Stocking of Tillegra storage with Australian bass is a possible management option as it is a popular fishing area targeted by recreational fishers. Stocking of bass for the purpose of supporting a recreational fishery has been successful in other NSW artificial impoundments, such as Tallowa Dam (Gehrke *et al* 2002). Ultimately fish stocking would be a desirable activity for the dam.

6.5 Reservoir shoreline management

Treatment techniques for managing shoreline erosion range from rock rip-rap and gabion walls to bio-engineering (use of live and dead vegetation for reinforcement and protection of soil). Bio-engineering techniques may provide increased benefits to aquatic habitat, water quality, and aesthetics (United States Army Corps of Engineers 1992). It would be a major undertaking to protect the entire shoreline of the impoundment of Tillegra Dam. However, it may be justified to protect certain areas, depending on their perceived value or intended use. Monitoring of shoreline erosion in the storage is recommended to provide an assessment of effects and whether any mitigation measures are required.

6.6 Public safety and amenities

The event based run-of-river transfers and fresh event releases from the proposed dam would have peak flows of 1500ML/d and 270ML/d respectively. The larger releases (>1500 ML/day) from the dam may lead to minor flooding of low lying causeways and river crossings in the upper reaches of the Williams River. Based on the rating curves derived for the Tillegra Bridge gauge an increase in depth of 0.8 metres and a velocity of 0.6 m/s is expected directly below the dam wall at a peak of 1500 ML/d.

The impact of releases would be less likely further downstream due to the larger channel capacity. Based on the rating curve derived for the Glen Martin gauge an increase of 0.7 metres is expected. Levels would drop back considerably within a few days.

A release of this volume (1500 ML/d) and subsequent flooding may lead to public safety and amenities issues such as problems for recreational users of the river or for farmers and the location of their herds. It is suggested HWC would identify critical low lying river crossings, notify property owners prior to large releases and provide information on a website of scheduled run-of-river transfers.

The release of smaller fresh events (270ML/d) would have a minor effect on river levels with a 0.4 metres increase in water depth and a 0.2 m/s increase in velocity expected immediately below the dam and a 0.3 metres increase expected at Glen Martin.

It should be noted that channel form is important in the relationship between flow volume and water depth and velocity. Generally the upper reaches are narrower while in the lower reaches the channel broadens.

6.7 Seaham Weir

The existing flows past Seaham Weir are discussed in Section 8.1.3 of Working Paper A of the EA Report. The flows are strongly influenced from the operation of the weir gates as the gates can not be operated with the degree of finesse required to mimic small freshes and low flows past the weir. Currently around 50 percent of the time flows past the weir are constrained until such time that the gates are opened. Gates are opened when inflows into the weir pool increase to a sufficient size to warrant a release. When this occurs, due to each gates large capacity to release water, flows from the weir pool are often made in blocked discharges downstream.

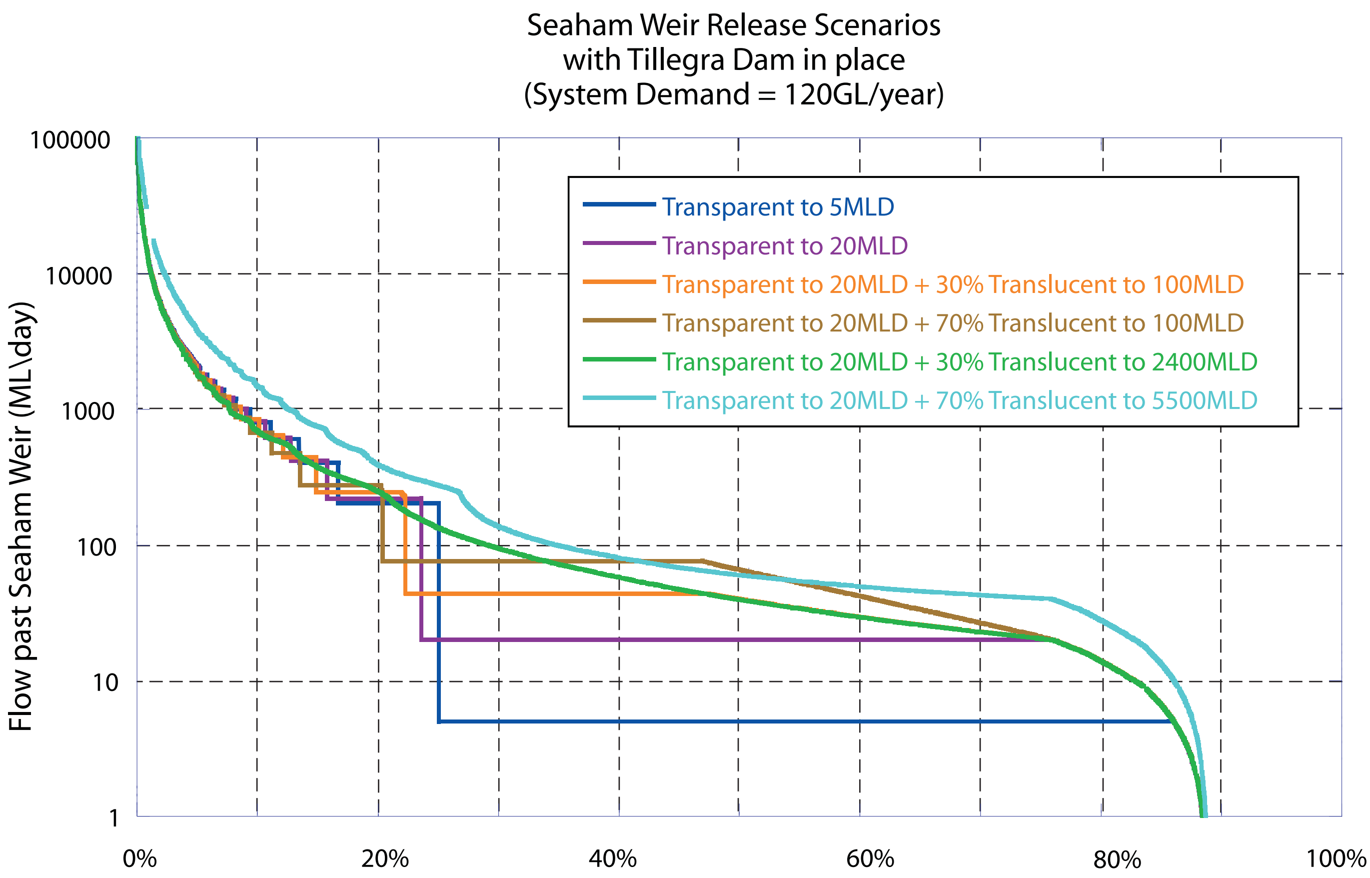
Operation of the weir gates is undertaken in a manner that complies with the requirements of a licence administered by DWE. The licence requires HWC to maintain pre-determined water levels in the weir pool (refer Section 2.2.2). At this stage is not proposed by HWC to change the manner in which water levels are maintained in the pool and as a consequence, the current terms of the licence.

Modelling by Hunter Water indicates that at yield with Tillegra Dam, under the current operating regime, low and moderate flows past Seaham Weir will be further modified. Figure 6.1 presents several different flow duration curves for alternate discharge regimes that could be adopted. The figure displays flows past Seaham Weir on both a log and linear scale (0-1000 ML/day). These flow duration curves would occur when additional water is pumped across to Grahamstown Dam, rather than allowed to flow pass the weir. It may be possible to ameliorate this predicted change by modifying the weir gates to allow passage of smaller flows.

A new fishway at Seaham Weir would improve connectivity between the Williams River estuary and Seaham Weir Pool. A new fishway would also result in an increase in net volume of water passed downstream compared to the existing structure. The fishway could be designed to include provisions to release additional water downstream, whilst maintaining current water level in the weir pool as required by the existing licence.

Within the Williams River estuary the reduced flow magnitudes as a result of the dam may lead to a more rapid upstream migration of the salt compared with the current system resulting in a slight increase in salinity at the weir during low flow periods.

Releases downstream of Seaham should be designed to maximise environmental outcomes below the weir and address any existing issues whilst maintaining water security. Currently, there is an absence of comprehensive data taken over a reasonable period of time, detailing dissolved oxygen, temperature, salinity and other water quality parameters below the weir, all of which should be taken into account when setting an appropriate release regime. A separate investigation commissioned by HWC has highlighted the water quality and hydrology issues immediately downstream of Seaham Weir (Connell Wagner 2008) and recommends



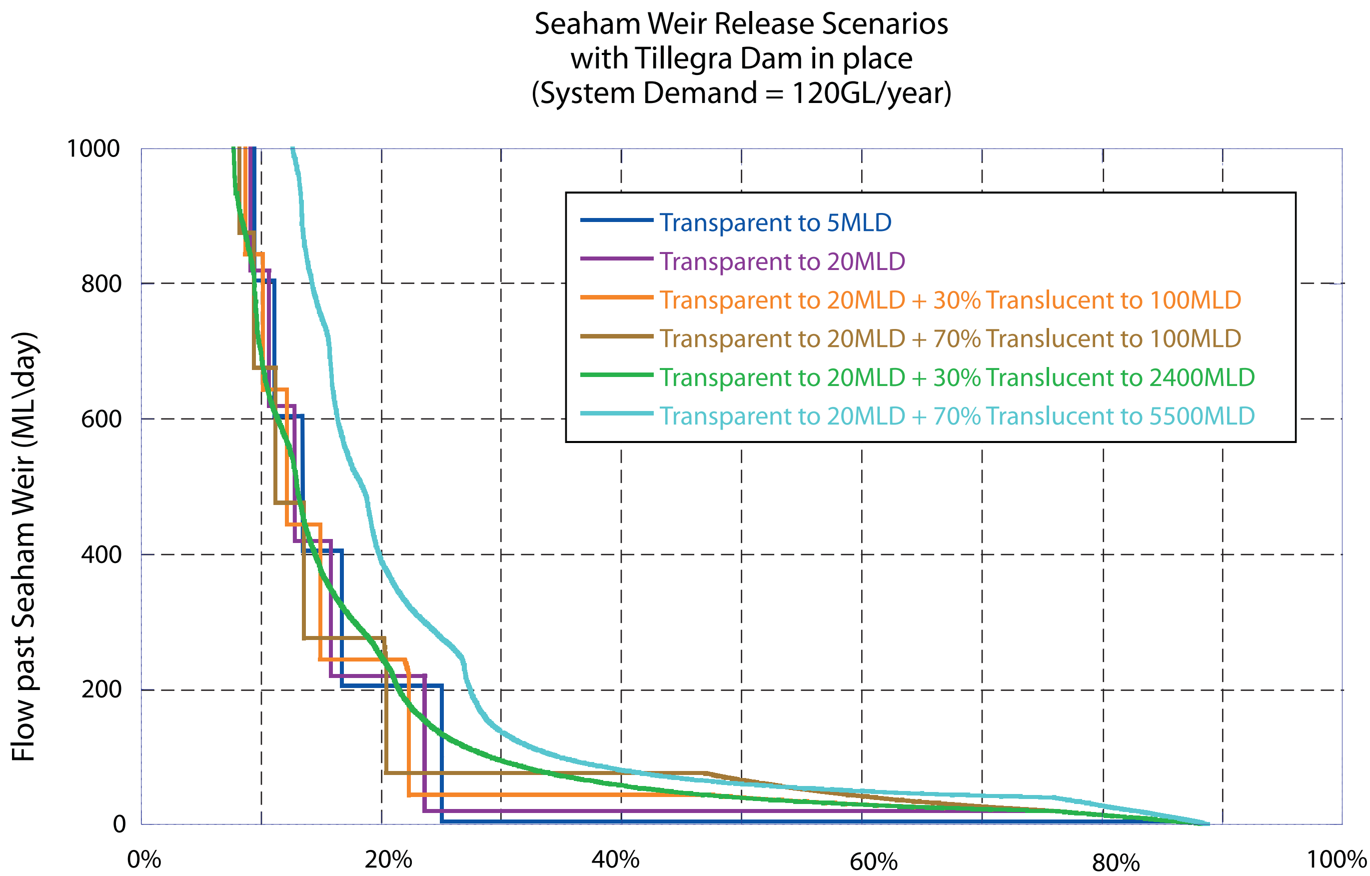


Figure 6.1 Seaham Weir Flow Duration Curves for Alternate Discharge Regimes

that HWC undertake a monitoring and assessment program downstream of the weir to collect baseline data. Based on the analysis of these data, appropriate recommendations for a release regime downstream of Seaham Weir can be set within the Water Sharing Plan in 2013, prior to Tillegra Dam commencing operation.

6.8 Monitoring

As part of a monitoring program to assess the potential impacts of Tillegra Dam on the Williams River ecosystem the following water quality, hydrology and aquatic ecology monitoring is recommended.

Water quality and hydrology monitoring

A water quality and hydrology monitoring program should be instigated to assess the potential impacts of the construction and operation of the proposed Tillegra Dam on water quality and to provide information on the appropriate water release depths from the dam. Specific components to be measured may include:

- a water quality monitoring program to provide information on vertical variability in temperature, dissolved oxygen and algal blooms to assist with selection of an appropriate withdrawal depth at the offtake structure. This would be particularly important during the initial 2 years of filling when in-storage water quality variability is likely to be high
- level/discharge monitoring of dam inflows would be required upstream of the storage to trigger the transparent and translucent environmental releases from the dam. At a minimum this information should be collected on a 3 hourly basis
- a monitoring program downstream of Seaham Weir should be instigated to provide a better understanding of the downstream ecosystem. Monitoring would consist of the collection of dissolved oxygen, temperature, salinity and other water quality parameters at various locations within the estuary.

Aquatic ecology

A monitoring program should be implemented to examine potential effects the environmental release strategy could have on aquatic biota and to demonstrate the efficacy of mitigation measures designed to reduce impacts from the construction and operation of Tillegra Dam. Specific ecosystem components to be measured should include:

- the passage of fish upstream via the Tillegra fish lift and upgraded Seaham Weir fishway should such structures be constructed. This should be monitored for a range of flow conditions, a number of fish species and size classes, with emphasis on small juvenile life stages
- macroinvertebrate assemblages in riffle and pool edge habitats within Reaches 3 and 4. Changes in macroinvertebrates assemblages would indicate the effect of encroachment of terrestrial vegetation into the river at different distances down the river. Focus should be on reaches nearest the dam wall and monitoring should begin before construction commences. Monitoring techniques should include quantitative methods and AusRivAS and monitoring should be at least twice within the Autumn and Spring AusRivAS sampling periods (March 15 to June 15 and September 15 to December 15, respectively)
- fish assemblages from Reach 1 to 4. Methods should target juveniles or

young-of-the-year of key species, such as Australian bass, and should focus on reaches 3 and 4. Monitoring should begin during filling phase. Adult populations could also be monitored in reaches 3 and 4 in conjunction with the study of upstream passage through Seaham Weir. Monitoring catches from recreational anglers could also be done to examine changes in adult populations of bass

- macrophyte communities should be monitored as indications of terrestrial encroachment into the river.

7. Conclusions

A comprehensive assessment of a base case scenario environmental release strategy has been undertaken as part of this investigation. The base case scenario assumed 90/30 transparent translucent releases and six fresh events during the filling phase and assumed 90/30 transparent translucent releases, constant run-of-river transfers and flushing events during the operational phase. Key findings of the base case release scenario assessment and subsequent improvements to the scenario in order to provide a better protection of the downstream ecosystem are provided below.

The information in this report provides a comprehensive assessment of a base case environmental release scenario and suggests improvements to this strategy to provide protection of the current riverine ecosystem. The development of the environmental release regime for the Williams River is however an ongoing process and HWC would continue to refine and improve the regime following community consultation and additional discussion with DWE.

7.1 Filling phase

The potential impacts on hydrology, water quality, geomorphology and aquatic ecology during the filling phase are detailed below.

Hydrology and water quality

- increase in the per cent occurrence of low flows and the loss of fresh and flooding flows
- decrease in the daily mean and median flow
- maximum release would be 270 ML/day
- the impacts of reduced flows at Tillegra would decrease further downstream following inflows from other tributaries along the river
- slight increase in water residence times of pools and a decline in water quality in comparison to present conditions above the Williams and Chichester River confluence.

Geomorphology

- minimal bedload transport in the reach down to the Chichester River confluence
- vegetation encroachment as no spilling or high flows would occur
- sediment starvation would lead to bed scour near the dam.

Aquatic ecology

- increase in the portion of taxa tolerant to declining water quality
- decline in abundance of macroinvertebrates associated with shallow habitats
- decline in abundance of taxa that require high flows
- increase in abundance of taxa with life histories adapted to stable low flows
- decline in recruitment of Australian bass and potentially other diadromous species (large strong swimmers)

- no change or slight increase in abundance of species such as smelt, flathead gudgeon and introduced *Gambusia* and carp (small/strong weak swimmers).

7.2 Operational phase

The potential impacts on hydrology, water quality, geomorphology and aquatic ecology during the operational phase are detailed below.

Hydrology and water quality

- increased frequency of the majority of flows with the exception of flooding flows
- decrease in mean flow as smaller more frequent flows would be released from the dam
- maintenance of flows during spring, a season historically dominated by low flows
- water quality in general would remain similar to present conditions below the Williams and Chichester River confluence. However, a decrease in nutrient levels would be expected downstream of the dam due to sediment trapping within the dam (refer Section 5.4.3 of Water Quality and Hydrology Working Paper).

Geomorphology

- reduced bed material mobilisation, increased chance of macrophyte colonisation and reduced disruption of in-stream vegetation
- reduced frequency of inundation of some physical features such as bars, benches and floodplain surfaces
- vegetation composition and structure of physical features would trend towards terrestrialisation
- reduced sediment transport due to trapping efficiency of the dam
- increased sediment scour in reaches immediately below the dam.

Aquatic ecology

- decreased recruitment of macroinvertebrate and fish taxa that have life histories adapted to stable low flows during the spring months
- decline in upstream dispersal in Reach 3 of small weak swimmers (eg gudgeon, smelt and long finned elvers)
- no change in abundance of small strong swimmers (eg freshwater mullet)
- reduced navigable flow of large strong swimmers in winter (eg Australian bass)

7.3 Improvement to release strategy

Based on assessment of the base case environmental release strategy, improvements to the strategy are suggested to provide a reasonable protection of the riverine environment with minimal loss of ecosystem function and include:

- run-of-river event based transfers
- change in seasonality of releases

- minimum number of event releases per year.
- preferentially diverting flows through the multi-level offtake tower in lieu of uncontrolled spillway discharges.
- adopting a transparent flow to the 30th percentile at Tillegra (100ML/day) rather than including a translucent component.
- increasing the transparent flow to the 95th percentile at Chichester (20ML/day).

7.4 Key recommendations for river management

A number of river management options are addressed in this investigation and the key recommendations for the project include:

- fishways at the proposed Tillegra Dam and replacement/upgrade of Seaham Weir fishway
- fish stocking
- monitoring.

8. References

ANZECC and ARMCANZ 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality.* Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Arthington, AH 1998, *Comparative Evaluation of Environmental Flow Assessment Techniques: Review of Holistic Methodologies*, LWRRDC Occasional Paper 26/98. ISBN 0 642267456.

Arthington, AH and J.M. Zalucki (eds) 1998, *Comparative Evaluation of Environmental Flow Assessment Techniques: Review of Methods.* (Authors – Arthington, AH Brizga, SO Pusey, BJ McCosker, RO Bunn, SE Loneragan, N Growns, IO and Yeates, M) LWRRDC Occasional Paper 27/98. ISBN 0 642267464.

Bionet 2008, *NSW Wildlife Search,* viewed 10 January 2008,

<http://www.bionet.nsw.gov.au>

Brooks, AP Gehrke, PC Jansen, JD & Abbe, TB 2004, 'Experimental reintroduction of woody debris on the Williams River, NSW: Geomorphic and ecological responses', *River Research and Application*, vol. 20, pp. 513-536.

Bunn, SE and Arthington, AH 2002, Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, 30(4), pp. 492-507.

Bunte, K 2004, *State of the Science Review Gravel Mitigation and Augmentation Below Hydroelectric Dams: A Geomorphological Perspective*, Engineering Research Center Colorado State University, Fort Collin, Stream Systems Technology Center USDA Forest Service Rocky Mountain Research Station, Fort Collins, Colorado.

Department of Commerce - Dams and Civil 2008, *Tillegra Dam Design - Consultancy 361802. Fish Passage Study for Tillegra Dam and Seaham Weir DRAFT Version 1.0*, *Report No. DC08026*, NSW DoC, Sydney.

Department of Natural Resources 2007, *Water sharing in the Williams River Water Source. Macro water Sharing Plan – Hunter Regulated water sources,* viewed 17 December 2007,

<http://www.hcr.cma.nsw.gov.au/water_sharing/macro_hunter_williams.pdf>

Department of Urban Affairs and Planning 1996, *Williams River Catchment Regional Environmental Study*, NSW DUAP, Sydney.

Department of Water and Energy 2002, *No. 6 Daily extraction management in unregulated rivers (2002 version),* NSW DWE, Sydney

Department of Water and Energy 2008a, *Draft Water Sharing Plan. Hunter unregulated and alluvial water sources,* NSW DWE, New South Wales.

Department of Water and Energy, 2008b, *Water for the Environment. Environmental rules for rivers,* viewed July 2008,

<http://www.naturalresources.nsw.gov.au/water/rivers.shtml>

Department of Water and Energy 2008c, *No. 11 Integrating water quality and river flow objectives in water sharing plans*, viewed January2008,<http://www.naturalresources.nsw.gov.au/water/pdf/policy

_advice_11-waterqualitymanagement.pdf>

Gehrke, PC Gilligan, DM and Barwick, M 2001, *Fish communities and migration in* *the Shoalhaven River – Before construction of a fishway*, Final Report No. 26, NSW Fisheries, Port Stephens.

Gehrke, PC Gilligan, DM and Barwick, M 2002, Changes in fish communities of the Shoalhaven River 20 years after construction of the Tallowa Dam, Australia, *River Research and Applications*, vol. 18, pp. 265-286.

Gippel, CJ and Stewardson, MJ 1998, Use of wetted perimeter in defining minimum environmental flows, *Regulated rivers: Research and Management, Vol 14 pp 53-67.*

Gooderham, J and Tsyrlin, E 2002, *The waterbug book: a guide to the freshwater macroinvertebrates of temperate Australia.* National Library of Australia Cataloguing-in-Publication, CSIRO. 232pp.

Growns, IO and Growns, JE 2001, Ecological effects of flow regulation on macroinvertebrate and periphytic diatom assemblages in the Hawkesbury-Nepean River, Australia. *Regulated Rivers - Research and Management,* 17, pp. 275-293.

Healthy Rivers Commission of New South Wales 1996, *Independent Inquiry into the Williams River: Final Report*, HRC, Sydney.

Jones, HA Simpson, RD and Humphrey, CL 1986, The reproductive cycles and glochidia of fresh-water mussels (Bivalvia: Hyrdiidae) of the Macleay River, Northern New South Wales, Australia. *Malacologia*, 27(1), pp. 185 – 202.

Langdon, SA and Collins, AL 2000, Quantification of the maximal swimming performance of Australasian glass eels, *Anguilla australis* and *Anguilla reinhardtii*, using a hydraulic flume swimming chamber. *New Zealand Journal of Marine and Freshwater Research*, 34, pp. 629-636.

Lintermans, M, 2007, Fishes *of the Murray-Darling Basin: an introductory guide*. Murray-Darling Basin Commission Publication No. 10/07, pp. 157.

Mallen-Cooper, M 1992, Swimming ability of juvenile Australian bass, *Macquaria novemaculeata* (Streindachner), and juvenile barramundi, *Lates calcarifer* (Bloch), in an experimental vertical slot fishway, *Australian Journal of Marine and Freshwater Research,* 43, pp. 823 – 834.

Mallen-Cooper, M and Stuart, IG 2007, Optimising Denil fishways for passage of small and large fishes. *Fisheries Management and Ecology*, 14, pp. 61-71.

McDowall, RM 1996, *Freshwater Fishes of South – Eastern Australia*. Reed Books, Sydney NSW.

Merz, JE and Ochikubo Chan, LK 2005, Effects of gravel augmentation on macroinvertebrate assemblages in a regulated Californian river. *River Research and Applications* 21: 61-74.

Mitchell, CP 1989, Swimming performances of some native freshwater fishes. *New Zealand Journal of Marine and Freshwater Research, 23,* pp. 181-187.

MUSSELpws, 2008 *Mussel of the Month.* Viewed 10 January 2008,

<http://clade.acnatsci.org/mussel/m/mom/archive/2007/07-11.html >.

Pusey, B Kennard, M and Arthington, A 2004, *Freshwater fishes on north-eastern Australia*. Centre for Riverine landscapes, Griffith University, CSIRO. 684pp.

Randle, TJ Lyons, JK Christensen, RJ and Stephen, RD 2007, Colorado River Ecosystem Sediment Augmentation Appraisal Engineering Report. Bureau of Reclamation, Department of the Interior, viewed 10 May 2008,

<http://www.gcmrc.gov/library/reports/physical/Fine_Sed/Randle2007.pdf >.

Sydney Catchment Authority 2008. Environmental Flows, viewed 15 May 2008,

<http://www.sca.nsw.gov.au/dams-and-water/environmental-flows>.

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*, VIC Department of Natural Resources and Environment, Melbourne.

Sinclair Knight Merz 2003 *Hunter Water – Water Resources Model Review.* Armadale, Australia.

Sinclair Knight Merz 2008 Review of Yield Estimates for the Hunter Region, Final Report to IPART, St Leonards Australia

Storey AW, Edward, DH and Gazey, P 1991, Recovery of aquatic macroinvertebrate assemblages downstream of the Canning Dam, Western Australia. *Regulated Rivers: Research and Management,* 6, pp. 213-224.

Stuart, IG and Mallen-Cooper, M 1999, An assessment of the effectiveness of a vertical slot fishway for non-salmonid fish at a tidal barrier on a large tropical/subtropical river. *Regulated Rivers: Research and Management*, 15, pp. 575-590.

Stuart, IG and Berghuis, AP 2002, Upstream passage of fish through a vertical slot fishway in an Australian subtropical river. *Fisheries Management and Ecology*, 9, pp. 111-122.

Stuart, IG Zampatti, BP and Baumgartner, LJ 2008a, Can a low-gradient vertical slot fishway provide passage for a lowland river fish community? *Marine and Freshwater Research*, 59, 332-346.

Stuart, IG Baumgartner, LJ, and Zampatti, BP 2008b, Lock gates improve passage of small-bodied fish and crustaceans in a low gradient vertical-slot fishway. *Fisheries Management and Ecology*, 15, pp. 241-248.

The Ecology Lab 2008, *Aquatic Ecology Assessment: For the construction and operation of Tillegra Dam*, TEL, Brookvale.

United States Army Corps of Engineers (USACE) 1992, *Bioengineering technique of reservoir shoreline erosion control in Germany*, Suppl 5, REMR Technical Note GT-SE-1.5, USACE, Environmental Laboratory, viewed 10 May 2008,

<http://el.erdc.usace.army.mil/elpubs/pdf/wgsw3-1.pdf>.

Appendix A

Aquatic ecology flow requirements and assessment

The Ecology Lab Pty Ltd
Marine and Freshwater Studies

A1 Aquatic ecology flow requirements

The flow regime is a key driver of river ecology. There are four guiding principles of flow regime influence on aquatic biodiversity (Bunn and Arthington 2002);

- Flow is a major determinant of physical habitat (via geomorphological processes) and water quality (via hydrological processes), which in turn influence biological composition
- Aquatic species have evolved life histories in response to natural flow regimes
- Flows maintain natural patterns of longitudinal and lateral connectivity
- Changes to natural flow regimes can facilitate the invasion and proliferation of exotic species, and unaltered natural flow regimes may impede the successful colonization of exotic species

River flows are important drivers in the geomorphological processes of sediment erosion, transport and deposition, and as such are responsible for structuring a variety of channel forms such as pools, riffles, bars and banks. These forms are important habitat and are often associated with particular aquatic assemblages. Flows also play an important role structuring macrophyte communities and riparian vegetation and can influence a variety of water quality characteristics that affect biological assemblages, such as dissolved oxygen, turbidity and algal activity.

Aquatic fauna have evolved and adapted to natural flow regimes in Australia, which can demonstrate high temporal variability at a range of scales, such as years, seasons and days. The life history traits and biological parameters of aquatic organisms, such as spawning behaviour, larval survival, growth patterns and recruitment, are often linked to these natural patterns in flow (Bunn and Arthington 2002). Flow regimes provide longitudinal hydrological connectivity along the river channel for organisms with life histories that require access to distant habitats, such as catadromous fish that must migrate downstream to estuarine waters to spawn. Lateral connectivity between the river channel and the floodplain can give periodic access of river biota to adjacent productive habitats. River systems with unregulated flows can be more difficult for exotic species to colonize. For example; the introduced carp, mosquito fish and water hyacinth are better adapted to aquatic systems with regulated flows and can have serious impacts on habitat and native biota once established.

However, quantitative understanding of the flow requirements of Australian aquatic biota is limited and qualitative knowledge is far from complete. Bunn and Arthington (2002, p.502) identified science's 'limited ability to predict and quantify biotic response to flow regulation as a major constraint to achieving ecological sustainability'. It is therefore difficult to precisely determine a release strategy (including environmental flows and subsequent run-of-river transfers) that can meet the timing and magnitude of societal demand for water and maintain the ecological structure and function of the Williams River downstream of Tillegra Dam. A carefully designed monitoring programme would therefore be required as part of any environmental release strategy.

The description of flow requirements of aquatic communities is focused predominantly on Reaches 3 and 4. The natural flow regime in Reach 1 should remain unaffected by the construction and operation of the Tillegra Dam. Recommendations for the management of the dam storage (Reach 2) are made in Section 5. The planned environmental release strategy during construction and dam filling, and subsequent run-of-river transfers and spilling flows during operation, is assessed for its impact on aquatic biota.

A1.1 Aquatic Macroinvertebrates

Macroinvertebrate diversity within the Williams River is dependent on habitat complexity as many taxa have close associations with particular habitat forms. Macroinvertebrate taxa found in the region are also adapted to the temporal variability of the natural river flows. Therefore, a viable environmental flow regime should maintain the hydrological and geomorphological processes that structure the physical habitat and determine water quality, as well as maintaining seasonality within the system. Changes to natural flow regimes within stream habitats have been found to significantly alter invertebrate biota downstream of dams and weirs (Walker 1985, Bennison *et al* 1989, Growns and Growns 2001).

Reach 3 of the Williams River had a diverse array of habitat types utilised by macroinvertebrates, including frequent alternation of riffles and pools, instream wood debris, some sand/gravel banks and bars and macrophytes. The freshwater mussel, *Cucumerunio novaehollandiae*, is found in gravel beds along the Williams River (Chessman and Growns 1994). The finer fraction of bed material was found to be relatively mobile at some sites sampled along Reach 3 (Gippel and Anderson 2008). *Cucumerunio novaehollandiae* prefers relatively swift flowing waters and its habitat is only likely to occur in stable deposition zones downstream of riffles and runs, and on outer channel bends (MUSSELpws 2008). It is often found in association with large boulders that help stabilise stream bed sediments. Flows that maintain these geomorphic forms are important for the continuation of freshwater mussel populations.

Growns and Davis (1994) classified macroinvertebrates found in an Australia stream with regard to flow exposure in order to better understand the flow requirements necessary to sustain different populations. Passive filter feeders such as true flies, Simuliidae, and caddisflies, Hydropsychidae, all found by the present study in Reach 3, require high flows to suspend their food in the water column and their abundance is positively correlated to water velocity. Significant reductions in flow would have negative impacts on these and other taxon with similar life history feeding traits.

Depending upon the degree of flow regulation, there is also a potential for reduction in macroinvertebrate assemblages closely associated with riffles and pool-rocks (Growns and Growns 2001, Storey *et al* 1991). This can be directly attributed to the upstream diversion of water and the subsequent reduction in habitat. Macroinvertebrates that are more closely associated to pool edges are less like to be affected because of their tolerance of an environment characteristic of lentic conditions. A reduction in flow is generally characterized by decreased oxygen concentrations and increased nutrients and the biota that become established in these areas are limited to those that have adaptations to survive these conditions (Growns and Growns 2001).

Many aquatic macroinvertebrates have life history attributes that are adapted to seasonal variability in natural flow regimes and temperature. For example, spring and summer spawning is common for a number of macroinvertebrates, such as *Cherax* spp., chironomids, trichopterans and *Ephemeroptera* spp. These taxa are adapted to a higher proportion of zero to low flow events during the warmer months. For example, the freshwater shrimp, *Paratya australiensis* (Family Atyidae), commonly occur in slower flowing pools and runs of the Williams River. *P. australiensis* breed during seasonal low flow periods so that the larvae are not washed downstream during the early planktonic phase of their life cycle (Gooderham and Tsyrlin 2002). The young grow during summer in sheltered pool edges until they are bigger and better able to negotiate currents. Other species may have life history traits that allow them to survive periods of drying, such as burrowing into moist sediments or a desiccation-resistant stage in their life cycle.

Many different macroinvertebrates, such as mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), have reproductive and recruitment life history strategies that rely heavily on the timing of their emergence as winged adults from the aquatic larval stage. Because they live for a relatively short period of time as reproductively mature adults, they must time their emergence exactly to that of other individuals of their same species. The environmental flows and temperature cues that occur seasonally trigger these emergence events and a flow scheme that follows that pattern would allow for successful reproduction and gene transfer among populations of these important organisms within the entire Williams River catchment. The freshwater mussel, *C. novaehollandiae* has a highly synchronised spawning period in autumn, thought to be cued by falling water temperatures immediately following flood flows (Jones *et al* 1986). This species then retains its glochidia larvae over winter and releases them in early spring, where upon they attach to the gills of fish for up to 12 months before becoming a free-living adult.

Temporal flow variability over the scale of days, weeks, and months in unregulated streams increases stream productivity through nutrient diffusion as well as removing inorganic particles and dead or senescent cells. This has a positive effect on the growth of a periphyton assemblage composed of diatoms and other small microflora that are important in the diet of many macroinvertebrate grazers present in Reaches 3 and 4 such as Mayflies (*Baetidae* and *Leptophlebiidae*), Beetles (*Elmidae* and *Psephenidae*), and Caddisflies (*Philopotamidae* and *Glossosomatidae*). Chester and Norris (2006) found that even small changes in flow (7-8 times base flow) discharged from Bendora Dam in the Cotter River stimulated increases of production within the stream and growth of healthy periphyton communities similar to those found in nearby reference streams. This resulted in a greater diversity of macroinvertebrates than what was found at sites downstream of dams without managed environmental flows, suggesting a more suitable food supply that shifts the macroinvertebrate community closer to what is found in unregulated streams.

A1.2 Fish

River flow plays an important role structuring the fish populations in the Williams River. Seasonal elevated flows provide migration cues for some species and sweep amphidromous larvae downstream to productive estuarine nurseries. Flow magnitude affects longitudinal fish passage in the river channel by determining water depth over instream barriers and the velocity of flow that fish must migrate upstream against. Flow magnitude also governs lateral fish passage into productive adjacent wetlands and carbon inputs into downstream habitats. The size and timing of flow requirements or thresholds can vary among taxa, and for different size classes within taxa.

8.1.1 Flow volume requirements

Depth requirements

Water depth in the river channel is proportional to flow volume. Freshwater fish in the Williams River have depth requirements for their ecology and life history. Fish may require a range of depths in their habitats for foraging, refuge, spawning or to make successful migrations.

The fish species that occur in Reaches 3 and 4 have been found in other surveys at mean depths ranging from 0.34 to 0.47 metres, with bullrout at 0.58 metres and the larger bass from deeper pools (Table 4.6). The Cox's gudgeon, which prefers riffles in moderate velocity water, was found more commonly in shallower depths. These species were recorded in a variety of habitats, including riffles, runs and pools. Breeding catfish build nests in runs and pools at depths ranging from 0.2 to 1.8 metres but would abandon them if water levels falls to low (Pusey *et al* 2004).

Most freshwater fish found in the Williams River make longitudinal migrations up and/or down the river channel and require adequate depth to pass potential instream barriers. Of the 15 species present in Reach 3, ten have a diadromous life history that requires them to migrate to estuarine habitats at some stage during their life cycle (Table 3.3). Seven of these species are catadromous and must migrate to estuarine or marine waters to spawn. Striped gudgeon, empire gudgeon and Cox's gudgeon are putatively amphidromous, their larvae are swept downstream to estuarine waters, and the juveniles later migrate back upstream into freshwater habitat. However, it is possible that two of these ten species, bullrout and Cox's gudgeon, may be able to complete their life cycles in freshwater (Pusey *et al* 2004).

Other species, such as smelt and flathead gudgeon are known to make facultative migrations within freshwater systems and into estuaries. These movements are not related to spawning but are probably dispersal mechanisms for juveniles and sub-adults, or are made by fish recolonising upstream areas after being swept away by floodwaters. Tagging studies of catfish have indicated adults are sedentary and often do not move further than 50 metres (Pusey *et al* 2004). However, barriers to movement are considered a possible threat to this species by some researchers (Morris *et al* 2001). Catfish did not occur historically in the Williams River but instead are believed to have been translocated from the western part of their distribution (Pusey *et al* 2004).

Potential barriers to passage along Reaches 3 and 4 include natural barriers such as riffles, rockfalls and logjams or artificial barriers such as weirs, fishways and grading structures. Seaham Weir, located at the downstream (tidal) boundary of Reach 4, is considered a high-priority barrier to fish passage in the Hunter-Central Rivers CMA region requiring remedial action (Dept of Primary Industries 2006). The weir contains a submerged orifice fishway that was originally designed to facilitate the passage of strong swimming salmonids in the northern hemisphere. A gradient of 1:5 and a head loss of 0.3 metres at each pool generate a maximum velocity of 2.4 metres per second and high turbulence (Dept of Commerce 2008). Passage for most species (particularly small fish) is only possible when the head differential between the weir pool and tailwater is close to zero or negative during high tides. Large fish can occasionally negotiate passage when the weir is 'drowned-out' or the weir gates are open, but only for relatively low head differentials. A report by the Dept of Commerce (2008) claimed that the ineffective Seaham Weir fishway may be responsible for the putative decline of freshwater herring and sea mullet in the Williams River. Mill Dam Falls, a high-energy riffle near the Glen Martin gauge station and located at the base of Reach 3 - marks the pre-Seaham Weir historical tidal extent and can also be important potential barrier to passage. Inability to pass Mills Dam Falls restricts access to 63 kilometres of freshwater habitat upstream, or downstream to the Seaham Weir pool and to the estuary beyond.

A depth threshold represents the minimum flow required to generate enough depth for fish passage. Different species and size classes have a variety of depth thresholds for passage although these remain poorly understood. Adult bass have been observed to swim on their sides in depths as shallow as 5 centimetres for short periods and experimental flume trials found some adults (283 to 357 millimetres total length (TL)) could negotiate depths as low as 2.5 centimetres (Richardson 1984 in Pusey *et al* 2004). However, for 100 per cent of adult bass to successfully navigate a reach, research indicates that depths of 20 cm are required (Richardson 1984 in Pusey *et al* 2004).

Other species in the Williams River are capable of traversing much shallower water, particularly as many upstream migrants are juveniles (Mitchell 1989, Koehn and O'Connor 1990, McDowall 1996, Langdon and Collins 2000, Baker 2003, Pusey *et al* 2004). Three centimetres depth was needed to allow the passage of 100 per cent of small juvenile bass (27 to 38 millimetres TL) over short distances in experimental flume trials, although some individuals were able to cross depths of only 0.5 centimetres (Richardson 1984 in Pusey *et al* 2004). Other species, such as striped gudgeon, Cox's gudgeon, short-finned eel and long-finned eel are all able to pass through very shallow waters, indeed, they have been observed moving across wetted rocks, climbing around rapids and waterfalls and the latter three species can scale the vertical surfaces of weirs and dams (McDowall 1996, Langdon and Collins 2000, Gehrke *et al* 2001, Pusey *et al* 2004). However, this form of movement exposes fish to an increased risk of mortality from predation and physical stress. The short-finned eel has become less abundant in the northern part of its range and barriers to passage are believed to have contributed to this decline (Pusey *et al* 2004). Other species such as adult bullrout, freshwater mullet and sub-adult sea mullet, are larger and deeper bodied than juvenile gudgeons or elvers/glass eels and therefore require deeper waters and hence larger flows for passage. The sea mullet typically does not enter freshwater until after its first year, and mature adults are usually found in larger, slower moving rivers or estuaries and reproduce at sea (Pusey *et al* 2004). It is thought that sea mullet found in Reach 3 are therefore likely to be 1 to 3 years old (150 – 330 millimetres TL), whilst more mature fish may prefer habitat of the weir pool or remain downstream in Reach 5.

The effect of the proposed environmental release regime on upstream fish passage along Reach 3 was assessed by estimating the change in the proportion of navigable flows during known migration season(s) .Navigable flows, or passage 'window', are the range of flows that lie above a depth threshold and below a velocity threshold. Depth and velocity are both proportional to flow volume. The historical (albeit regulated) range of navigable flows is discussed in Section 4.5.2 and listed in Tables A1 to A6. It should be noted that the historical range of seasonal navigable flows is not 'natural' as the flow regime in Reach 3 and 4 has been affected by Chichester Dam, extraction by irrigators, extensive de-snagging and channel modification. Therefore, the historical flow data and channel profiles represent a 'shifting baseline' (Pauly 1995) in attempts to identify natural flow requirements and the effect of flow modification caused by Tillegra Dam release strategy.

Depth thresholds used in the navigable flow calculations were taken from the literature where possible (e.g. bass, longfinned and shortfinned elvers) but many had not been established experimentally, therefore body depth (BD) was used as the best available, albeit crude surrogate (Table 4.7). The 20 centimetres threshold for 100 per cent passage of adult bass is approximately equal to the body depth of the largest recorded bass (~ 60 centimetres total length (TL), ~ 18 centimetres BD) or twice the approximate body depth of the largest bass used in the study (36 centimetres TL, ~ 11 centimetres BD). Body depth was calculated from TL and the relationship of BD:TL varied among species. For most species body depth of the largest recorded individual was approximately equal to twice the body depth of the largest commonly encountered size. This value was used as a guide to depth threshold. These depth thresholds may be conservative; as the estimate for bass adults related to depths required to guarantee the passage of 100 per cent of individuals, therefore a number of fish would still be able to negotiate passage at lower depths (Richardson 1984 in Pusey *et al* 2004). The method assumes no difference in behavioural barriers to passage among taxa. The depth threshold used for longfinned eels, shortfinned eels, striped gudgeon and Cox's gudgeon is zero as they are able to move upstream out of the water across the wetted surface of rocks (Pusey *et al* 2004).

Peak flows

Seasonal elevated (or peak) flows are cues for some species of fish to begin mass migrations. For example, Australian bass begin their downstream spawning migrations following elevated flow events in autumn (in combination with water temperature and photoperiod cues). During extended periods of low flow bass may delay their spawning migrations or not even reproduce at all (Pusey *et al* 2004). Recruitment in NSW bass populations is proportional to the magnitude of discharge during the previous spawning season (Harris 1986). Growns and James (2005) found recreational catch of bass was positively associated with median flow volume and the number and duration of high flow events occurring in the previous year. High flow events cue adults to migrate, facilitate their downstream passage over depth barriers, and provide nutrients and organic matter to increase primary productivity in nursery areas (Pusey *et al* 2004).

Short-finned and long-finned eel downstream spawning migrations may also be triggered by seasonal elevated flows but the exact cues are unknown (Pusey *et al* 2004). Migrating eels are often observed moving downstream during flood conditions but this may simply facilitate dispersal to spawning grounds. Temperature and day length (photoperiod) may also be important as the eels undergo a range of physiological and biochemical transformations prior to (and during) these migrations.

Following hatching, the larvae of striped gudgeon, empire gudgeon and possibly Cox's gudgeon, are swept downstream to estuarine waters below Seaham Weir. The relationship of flow volume to recruitment is unknown for these species, however it is possible that large peak flows in late summer and early autumn facilitate this downstream dispersal, particularly past reaches characterised by low flow velocity, such as the Seaham Weir Pool.

Some fish require elevated flows to cue upstream dispersal migrations. Sub-adult bass (1 to 2 years) may require an initial discharge event to stimulate their upstream movement (Pusey *et al* 2004). Empire gudgeons make potomadromous and amphidromous facultative mass migrations, involving juveniles, subadults and adults. Juvenile and sub-adult (15 to 25 millimetres TL) empire gudgeons have been observed aggregating below barriers after increases in flow suggesting that upstream dispersal is cued by elevated flows (Pusey *et al* 2004). In the Burdekin River, Queensland, mass upstream migrations of juveniles were observed during a large summer flood event and in the Kolan Bridge fishway, the majority of empire gudgeons sampled over a 1.5 year period were taken during a single flow event of 5^{th} percentile exceedence, with a peak flow of 1837 ML/day (Pusey *et al* 2004). Juveniles in estuarine waters in Reach 5 may require seasonal peak flows through or over Seaham Weir to cue their upstream dispersal.

Flathead gudgeons also have a facultative mass dispersal phase and have been observed massing below weirs following increases in flow (Pusey *et al* 2004). It is unknown how important migrations are to flathead gudgeons, and whilst not related to spawning, they may allow the dispersal of juveniles and subadults.

Historical median peak flow events at Tillegra are approximately 200 ML/day and at Glen Martin are 450 ML/day (Connell Wagner 2007). At Tillegra 60 per cent of peak flow events (80th – 20th percentile exceedence) lie within the range of around 40 to

1,500 ML/day and at Glen Martin 60 per cent of peak flow events (80th – 20th percentile exceedence) lie within the range of around 70 to 3,500 ML/day (Connell Wagner 2007). Peak flow events at Tillegra and Glen Martin are separated by a maximum of 15 days approximately 60 per cent of the time. Only 10 to 15 per cent of peak flows are separated by 30 days or more.

Floods that overflow banks can be important to allow access of adult and/or juvenile fish to productive adjacent wetlands. This is less important in the slope reaches of Tillegra to Glen Martin (Reach 3) where there is little adjacent wetland habitat, but perhaps more significant in lower sections of the Seaham Weir pool. At Glen Martin overbank flows are those greater than 20,000 ML/day and occur in the range of 5th percentile exceedence and are slightly more frequent than the 1 in 2 year flood (Connell Wagner 2007).

Velocity thresholds

High velocity flows can impede local fish movements (e.g. foraging and seeking shelter), long distance upstream migrations and the ability to pass short instream barriers (such as an overtopping weir or high energy riffle). Like depth, flow velocity is proportional to flow volume. Where minimum depth requirements represent lower flow volume thresholds for fish passage, velocity barriers represent upper flow volume thresholds to upstream passage. Many fish species – especially small diadromous juveniles - conduct upstream migrations in the Williams River during periods of relatively stable low flow (and therefore low velocity), such as the juvenile bass, long-finned elvers, short-finned elvers, striped gudgeon, Cox's gudgeon and bullrout (Pusey *et al* 2004). Passage for these species past natural and artificial barriers is possible within the range of flows that provide adequate depth for passage but within the velocities that allow the fish to make headway upstream.

Fish can sustain faster speeds to overcome short velocity barriers. Such "burst" speeds cannot be maintained for long and fish must rest in between attempts. Lower velocities can be sustained for more prolonged swimming, such as might be required navigating longer runs. Understanding the swimming ability of fish within the Williams River is therefore important in determining the impact of run-of-river transfers and environmental releases on upstream fish passage. Nikora *et al* (2003) defined the following speeds:

- sustained swimming – aerobic, long term and does not involve fatigue. Able to maintain this condition for periods greater than 200 min
- prolonged swimming – includes aerobic and anaerobic components and, if maintained, would end with fatigue similar to burst mode. Able to maintain this condition for periods ranging from 30 seconds to 200 minutres
- burst swimming – short, high speed swimming with anaerobic motion. Time frames identified as being from 15 to 30 seconds, although many other authors consider burst speeds of much shorter duration.

The majority of fish species in the Williams River have been sampled in habitat with a slow to moderate mean water velocity, ranging from 0.08 metres per second to 0.19 metres per second (Table 4.6). On occasion, many of these taxa have been sampled in high energy riffles with velocities ranging from 0.55 metres per second to 0.87 metres per second (Pusey *et al* 2004). However these data measure unimpeded water velocity and do not provide information about the capacity of the fish to make headway upstream. These values may also be biased towards safe sampling conditions (i.e. relatively low flows). For example, Australian smelt have also been observed schooling in waters during velocities of 1.35 metres per second and aggregating in slackwater eddies during periods of high flow (Pusey et al 2004).

Studies that have investigated the maximum swimming abilities or the swimming behaviour of Australian or New Zealand (closely related) fishes include Mitchell (1989), Mallen-Cooper (1992, 1994), Langdon and Collins (2000), Baker (2003) and Nikora *et al* (2003). Most of these studies (except bass) were done in hydraulic flumes and as such the velocities represent fish swimming speed and not the ability of the fish to make headway into a flow of equivalent velocity. Swimming velocities for prolonged and burst swimming are summarised in Table 4.8. For species other than Australian bass, prolonged swimming velocities ranged from 0.28 metres per second to 0.34 metres per second, with most species close to 0.3 metres per second. Burst speeds for these species then ranged from 0.5 metres per second (New Zealand smelt) to 1.6 metres per second for sea mullet, and durations of burst speeds were reported to range from 2 to 30 seconds (Table 4.8). Empire gudgeon have been observed to negotiate flows of up to 1 metres per second for short distances through weirs when they are able to gain purchase with fins on coarse substratum and young sea mullet have successfully ascended fishways into 1.2 metres per second (Pusey *et al* 2004). Research indicates that Australian bass are able to negotiate higher velocity flows than most other fish species in the Williams River. Mallen-Cooper's (1992) study in a 1.5 to 1.8 metres fishway found that 95 per cent of 40 millimetres (TL) bass (small juveniles) could pass through flows (i.e. make headway) of 1.02 metres per second velocity. 95 per cent of 64 millimetres (TL) juveniles made headway through 1.4 metres per second flows and 95 per cent of 93 millimetres (TL) juveniles navigated 1.84 metres per second flows (although mortality of 20 per cent individuals in this latter size class was observed for flows of 2 metres per second). Another study found some adult bass (283 – 357 millimetres TL) could negotiate velocities as high as 2.1 metres per second but that 50 per cent of individuals successfully negotiated velocities of 1.85 metres per second (Richardson 1984 in Pusey *et al* 2004).

For the majority of species within the Williams River prolonged and burst swimming speeds remain unknown. However, some researchers in Australia and New Zealand have suggested a mean velocity of around 0.3 metres per second through artificial hydraulic structures (eg fishways and culverts) as a 'coverall' that would most likely to facilitate passage of native fish species, particularly juveniles of diadromous species (30 – 80 millimetres TL) (Mitchell 1989, Mallen-Cooper 1992, Harris and Mallen-Cooper 1994, Cotterell 1998, Langdon and Collins 2000). Suggested maximum velocities ranged from around 0.75 to 1 metres per second. Mallen-Cooper (1992) recommended a maximum velocity of 1.4 metres per second further upstream for migrating juvenile bass which had presumably grown larger and stronger. Mitchell (1989) felt that ascending flows of 0.5 metres per second was achievable for most fish over short structures (less than 1 – 2 metres), but that velocities greater than 1.5 metres per second in artificial structures were likely to exclude all species except those that could cling or climb, and that velocities down to 0.5 metres per second would be a species selective deterrent depending on the distance over which they were maintained.

Most of the species listed in Table 4.8 would be able to make headway against a flow velocity of 0.3 metres per second. However there would appear limited utility in applying this 'cover-all' flow velocity, originally intended for fishways, as the recommended (or required) mean flow across potential velocity barriers such as high-energy riffles during migration season. At the Glen Martin riffle, only 1 per cent of flows are less than or equal to 0.3 metres per second but greater than 0 metres per second (i.e. cease-to-flow and zero depth) and they generate less than 2 centimetres depth. Upstream at the W9 riffle, which is fed by flows from Tillegra catchment and the Chichester Dam, the minimum flow is 0.31 metres per second, which provides 1 centimetre of depth. The pattern is similar further upstream at W8 and W7 where flows less than or equal to 0.3 metres per second (but greater than 0 metres per second) make up 2.5 per cent and 1.7 per cent of the flows respectively. All diadromous species expected at the corresponding elevations are found above these riffles and have therefore successfully navigated passage past them.

The depth and frequency of 0.3 metres per second flows would not appear sufficient to facilitate the passage of all fish which suggests they can negotiate a much larger range of velocities. It has been demonstrated that some flume studies can underestimate the true 'burst' speeds of fish (Haro *et al* 2004, Tudorache *et al* 2007). Laboratory-based studies have also observed that fish are able to find low-velocity paths where possible, suggesting alternative strategies for negotiating velocity barriers. For example, some fish are able to use turbulence and eddies to assist their forward movement or station holding; the common New Zealand bully (*Gobiomorphus cotidianus*), a congeneric of Cox's gudgeon, were able to rest passively on the bottom of a flume at water velocities of up to 0.44 metres per second (Mitchell 1989). Mallen-Cooper (1992) observed Australian bass moving through deeper and slower velocity sections of an experimental fishway, avoiding the faster-moving surface waters. In natural riffles, variable depths and roughness elements may create low-velocity pathways and rests that fish can utilise to facilitate passage. Indeed, small species such as smelt were observed swimming upstream in the shallow and slower outer margins of the elevated flows during this survey (B. Hunt, The Ecology Lab, Pers. Comm.).

The 'burst' speeds listed in Table 4.8 were used as a guide to estimating velocity thresholds used in calculation of passage 'windows'. Not all fish were assessed given the lack of information on the timing of migrations and swimming speeds, whilst others were assigned to the same velocity class as related species of a similar size and body shape. The classes of navigable flows assigned were:

0 cm ≥ flows ≤ 0.8 m/s	longfinned elvers, shortfinned elvers, Cox's gudgeon, striped gudgeon	Table A1
3 cm ≥ flows ≤ 0.8 m/s	empire gudgeon, flathead gudgeon, dwarf flathead gudgeon, smelt	Table A2
3 cm ≥ flows ≤ 1.0 m/s	small juvenile bass, juvenile freshwater mullet	Table A3
5 cm ≥ flows ≤ 1.0 m/s	juvenile sea mullet (1 – 3 yrs)	Table A4
15 cm ≥ flows ≤ 1.4 m/s	adult freshwater mullet	Table A5
20 cm ≥ flows ≤ 1.4 m/s	adult bass and large juveniles	Table A6

The upstream passage 'windows' are not intended to be precise estimates of the historical proportion of navigable flows but rather as a metric which may be useful to predict coarse effects of environmental release strategy on fish passage. A large loss of navigable flows could lead to declines in recruitment, and potentially, the breeding adult population. Therefore this relatively crude technique may identify problems with the intended flow regime and/or identify fish species to monitor following dam operation.

Temporal flow requirements

The fish species of the Williams River are adapted to the temporal variability in the historical flow regime. Just as flow magnitude is critical to fish ecology the temporal pattern of these flows is important for providing spawning cues, stable spawning environments, to facilitate the passage of migrating fish and for structuring prey assemblages. The particular timing and magnitude of flows required can vary among taxa and age classes. At any time during the year, one or more species may be spawning, developing in nursery grounds or migrating upstream or downstream (Table 4.9).

Autumn

Autumn has highest median flow of all the seasons (Connell Wagner 2007). Elevated autumn flows, in combination with water temperature, act as cues for the downstream migration of female bass, their oocyte maturation and the onset of spawning in estuaries (Pusey *et al* 2004). Recruitment of bass is proportional to volume of discharge during the spawning season. Freshwater mullet are still migrating downstream in early autumn although their peak spawning activity is usually in the late summer months. Sea mullet begin spawning in late autumn and continue into winter and presumably mature fish migrate downstream during autumn.

Striped gudgeon, empire gudgeon and Cox's gudgeon are all thought to spawn during late summer and autumn (Pusey *et al* 2004). The peak flows of summer and autumn probably carry hatched larvae downstream to estuarine areas as these species are putatively amphidromous.

Winter

Winter has similar total flow volume to summer, but is not as variable, with less frequent low flows and flooding flows (Connell Wagner 2007).

Freshwater herring migrate downstream to estuaries in winter where they would spawn. Sea mullet continue spawning from autumn and into winter at sea, in the surf zone off near the mouth of rivers. It has been suggested that the bullrout can complete its lifecycle in freshwater as small juveniles (20 to 30 millimetres TL) have been observed far upstream and above dams (Pusey *et al* 2004). However, it is putatively catadromous, with numerous records of downstream movement into estuarine areas during the colder months. In the Tweed River peak gonad development has been recorded when water temperatures were lowest (14 to 16 degrees Celsius)(Pusey *et al* 2004). Bullrout have been observed moving upstream through barriers such as fishways after spawning in estuarine areas, most often during periods of low flow and in winter and spring.

During winter the juveniles of striped gudgeon, empire gudgeon and Cox's gudgeon develop in estuaries before beginning their migration upstream into freshwater in spring (Pusey *et al* 2004). Smelt have an extended spawning period from winter to summer but it is concentrated in late winter and spring, usually during periods of relatively low stable flow. It has been suggested that this is so that the planktonic larvae do not get swept downstream and have a greater opportunity of encountering invertebrate prey (Pusey *et al* 2004). However, spawning has been observed to take place in a range of flow sizes, such as freshes and occasional high flows in summer.

Following spawning, adult female bass migrate upstream from late winter and into spring. During winter at narrow high energy riffles such as W7 and Glen Martin approximately 42 per cent of flows provide depths greater than 20 centimetres but less than or equal to 1.4 metres per second velocity which should enable the passage of most adult bass (Table A6). This declines to around 31 per cent during spring. At the broader low energy riffles, such as W8 and W9, this depth is achieved less frequently and the proportion of navigable flows range from 10.5 to 14.3 per cent during winter and 6.8 to 9.7 per cent during spring.

Winter requires moderate to larger flows to facilitate the upstream passage of adult bass (particularly over the broader, shallower riffles) and the downstream movement of adult freshwater herring, sea mullet and bullrout. However periods of stable low flow are also required by smelt and potentially juvenile and adult bullrout moving upstream.

Spring

Spring has the lowest median flow of all seasons. Periods of stable low flow are important during this season because many small juvenile diadromous fish begin their upstream migrations from estuarine nurseries, whilst in the freshwater reaches other species spawn so that their larvae are not swept downstream. However, periodic elevated flows are also required during spring to cue and/or facilitate migration.

Small juvenile bass migrating upstream from beneath Seaham Weir would initially recruit into available habitat within the Seaham Weir pool. Bass are strong swimmers, and for those that migrate into Reach 3, nearly half of all spring flows at the high energy Glen Martin riffle are negotiable and nearly 70 per cent of flows further upstream at W9 (Table A3). Although juvenile bass tend head upstream during stable low flows, sub-adult bass wait for moderate flow events before beginning upstream movements (Pusey *et al* 2004).

The brown elvers of short-finned eels and long-finned eels migrate upstream over similar months to juvenile bass although the cues for their upstream movement are poorly understood. The elvers are much weaker swimmers than the juvenile bass, and as such they are only able to negotiate approximately one fifth of the spring flows at Glen Martin but the proportion of navigable flows increases up to around 70 per cent at low energy riffles (Table A1). Studies in New Zealand found that elvers progressed upstream at the rate of 1.5 to 2 kilometres per day (Pusey *et al* 2004). Juveniles of striped gudgeon and Cox's gudgeon also initiate their upstream migration during spring and are predicted to have similar passage 'windows' to elvers.

Australian smelt can make facultative mass migrations and they have been observed massing beneath barriers, attempting to move upstream during periods of stable low flows in spring (Pusey *et al* 2004). Smelt movements are not entirely confined to low flows and they have been observed attempting upstream passage of fishways during flows of 140 ML/day. The proportion of navigable flows at Glen Martin is again low for these smaller fish, at approximately 14 per cent, rising to nearly two thirds at W8 (Table A2). Smelt continue to spawn through spring.

Flathead gudgeon has an extended breeding season from October to March but tends to spawn when temperatures are higher and during periods of predictable low flows for similar reasons to smelt (Pusey *et al* 2004). Flathead gudgeon also have a facultative mass dispersal stage, but they have been observed to mass beneath instream barriers following increases in flow during spring (Pusey *et al* 2004). Relatively little has been published about the dwarf flathead gudgeon, but it is also believed to have similar extended breeding season to flathead gudgeon that extends from spring to autumn.

Like flathead gudgeon and sub-adult bass, empire gudgeon also aggregate under barriers following increases in flow, appearing to require seasonal peak flows to stimulate upstream migration (Pusey *et al* 2004). However, small empire gudgeon have been observed to have difficulty ascending vertical-slot fishways in

Queensland (Pusey *et al* 2004) and as such their capacity for upstream passage was assessed for the same flow thresholds as smelt.

Shortfinned eels initiate downstream spawning migrations in spring and their passage is facilitated by the occasional higher flows during these months.

The introduced mosquito fish (*Gambusia holbrooki*) has an extended breeding season that goes into summer but its peak spawning activity probably occurs during extended low flow periods in spring.

Summer

Summer flows are also characterized by stable periods of low flow or even cease-to-flow conditions, with larger flows in the later months. The proportion of flows that are navigable in summer is generally lower than spring due to an increase in the number of freshes and flood flows. Periodic high flows are also important during these months. Cox's gudgeon, striped gudgeon and empire gudgeon all spawn from summer into autumn, and they rely on flows carrying larvae to downstream waters. Similarly, adults of freshwater mullet and long-finned eels make downstream migrations to spawn at this time (Pusey *et al* 2004).

Water Quality

Table A12 lists the fish tolerances for various water physical parameters.

A2 Assessment of potential impacts on aquatic ecology

The potential effects on aquatic ecology of the proposed environmental release strategy was assessed with respect to the flow requirements of aquatic macroinvertebrate and fish assemblages of Reaches 3 and 4, in so much as they have been met by the historical flow regime. It should be noted that the biota and historical flow regime of the Williams River is not completely 'natural', and has been affected by Chichester Dam, Seaham Weir, extraction by irrigators, extensive de-snagging and channel modification.

Riffles are important to the assessment of environmental impacts of the proposed release strategy. Riffles are relatively shallow high-energy aquatic habitat and are more likely to create depth and velocity barriers to fish passage. The wetted width of riffles is a useful proxy for comparing habitat loss experienced by macroinvertebrates and fish among different release regimes. Therefore velocity, depth and wetted width are relevant parameters to consider with respect to aquatic ecology. The effects of the environmental releases and run-of-river transfers would be considered at four sites in Reach 3 where the relationship between flow volume and these parameters is understood and also at the Seaham Weir fishway.

- Site W7 and Site W8 are located in the upper most section of Reach 3 upstream of the confluence with Chichester River. The flows in this section of Reach 3 are almost entirely composed of discharges from the Tillegra catchment and would therefore be most affected by the environmental release strategy. There is 1 km and 4 km of habitat upstream of sites W8 and W7 respectively before the dam wall.
- Site W9 is located just downstream of the confluence with Chichester River. It represents upstream sections of Reach 3 that are fed by the Tillegra catchment and also by spilling or environmental releases from the Chichester Dam.
- Glen Martin is the last significant riffle before the Seaham Weir Pool. Being the furthest of the sites downstream of the Tillegra catchment contributes 40 per cent of the flow at the Glen Martin riffle as there are additional inputs from smaller creeks downstream of the Chichester confluence. It is an important site to consider fish passage as there is 63 km of habitat upstream to the dam wall (and a further 53 km upstream of Tillegra Dam) and conversely all fish from Reach 3 moving downstream to the estuary beyond Seaham Weir must first pass this point.
- Seaham Weir fishway determines the majority of fish passage at Seaham Weir. The weir regulates access to estuarine habitat downstream and 86 km of main stem habitat upstream (Reach 4 and Reach 3)

Channel form is an important co-variant in the relationship between flow volume and depth/velocity. The channel is narrower at the W7 and Glen Martin riffles, therefore for a given flow volume there is a greater corresponding depth and velocity than at the broader low-gradient riffles at sites W8 and W9.

A2.1 Filling Phase

Macroinvertebrates

The predicted reduction in the wetted width of the channel will result in an overall decline of the productivity of shallow habitat such as riffles and gravel/sand bars and the abundance of strongly associated taxa, such as Philototamid caddisflies, water pennies (Psephenidae) and perhaps some of the Hyriid mussels. Other taxa are adapted to prolonged dry periods and have desiccation resistant stages or behaviour. For example, some Hyriid freshwater mussels are able to bury themselves in sediment and seal their shells to reduce water loss (Gooderham and Tsyrlin 2002).

The diversity and abundance of sensitive macroinvertebrate species may decline in areas where habitat and/or water quality declines, such as a reduction in dissolved oxygen and increases in nutrients and algal activity. As assemblages became increasingly impaired they would be dominated by relative few (but abundant) pollution tolerant taxa. Chessman and Growns (1994) found pool rock macroinvertebrate assemblages downstream of Chichester Dam quite different to those in equivalent unregulated habitat, with a reduction in sensitive mayfly and caddisfly species and increase in water snails and silt-tolerant mayflys. Macroinvertebrate communities within Seaham Weir pool are already dominated by taxa tolerant to pollution but research has shown that macroinvertebrate assemblages in Reach 3 are in relatively good condition, with sensitive species well represented (Chessman and Growns 1994, Environment Protection Authority, 2004). AusRivAS assessments made for this report indicated that macroinvertebrates communities had been significantly impaired at some Reach 3 riffles and pools, although these results were likely affected by the elevated flows during sampling. Pollution sensitive and pollution tolerant taxa found by The Ecology Lab survey in Reaches 3 and 4 are listed in Working Paper C of the EA Report.

A regime dominated by less variable low to moderate flows may benefit fauna that are reliant on seasonal periods of stable low flow and those more tolerant of lentic conditions. For example, planktonic larvae are less likely to get swept downstream potentially increasing survival and local recruitment. It is uncertain whether the environmental release strategy would capture or mimic enough flow volume or temporal variability for other taxa. For example, species with higher flow requirements, such as passive filter feeders may experience local declines in abundance or distribution, but it may be that the peaks contained within the translucent flows or the added freshes are sufficient to cue those species that require seasonal elevated flows to synchronously spawn or emerge from an aquatic larval stage (e.g. *C. novaehollandiae*). Potential impacts on macroinvertebrates should diminish downstream as flows would tend back to historical patterns with the inputs form Chichester Dam and other tributaries.

Fish

The environmental release strategy would favour some fish with life histories adapted to stable low flows. The larvae/juveniles of species that spawn during seasonal stable low flows, such as smelt, flathead gudgeon and the introduced *Gambusia*, may experience increased survivorship. Research in coastal NSW has indicated that certain native species are tolerant of river regulation and that some would actually benefit (Gehrke and Harris 2001). The introduced carp and mosquito fish prefer stable flows and are tolerant of reduced water quality; therefore their abundance and distribution may increase during the filling phase. The effect of reduced water quality would vary amongst native taxa. Species such as striped gudgeon, longfinned eel and sea mullet are more tolerant of low dissolved oxygen and increased nutrient concentrations than sensitive species such as bullrout and Cox's gudgeon (Pusey *et al* 2004).

The loss of moderate to large flows in the upper section of Reach 3 may cause a reduction in the availability of habitat used for foraging, spawning or shelter. Adult bass prefer deep pools and it is possible these may become less available, although declines in depth would have greater impact in shallow habitat. The predicted decline in riffle coverage and productivity would have the greatest effect on species which prefer this habitat such as Cox's gudgeon and smaller longfinned eels. Similarly, any loss of gravel beds within the upper range of 0.2 – 1.8 metres during spring and summer may affect the spawning success and local recruitment of freshwater catfish. This species typically has a short home range and limited dispersal (relative to other fish) and is therefore more vulnerable to local habitat degradation.

Upstream Passage

The effect of the environmental release regime on navigable flows along Reach 3 is relatively complicated and is predicted to vary among taxa, seasons, riffle types and with distance downstream. The maximum velocities generated by the environmental flow range of 0 – 63 ML/day (excluding the 6 peaks) at the low energy/gradient riffles is less than 0.8 metres per second and would not exceed the upper flow thresholds of most fish. Therefore, for most species passage at these riffles during the filling phase would be entirely limited by depth. For fish with low depth requirements (0 – 3 centimetres) this would result in a greatly expanded proportion of navigable flows (Tables A1 to A3). The expansion of passage 'windows' for small weak-swimming fish is not as great at sites downstream of the Chichester junction (W9) as the additional inflow from other sub-catchments would generate flows that exceed their velocity threshold (0.8 metres per second).

For the weak-swimming small fish the potential increase in navigable flows at upstream low energy riffles may be limited by a much smaller change to passage at downstream 'bottleneck' high-energy riffles like Glen Martin. The upper range of translucent flows at Glen Martin would generate velocities in excess of the upper limits of these fish, especially given additional inputs downstream of the Chichester junction. Therefore, the range of navigable flows at Glen Martin for these fish is expected to remain similar to historical conditions.

Small strong swimming fish, such as juvenile bass, juvenile freshwater mullet (and to a lesser extent larger juvenile sea mullet) can ascend against velocities generated by the range of environmental releases at low energy riffles (Table A3). They also have low depth requirements and therefore would also experience an expansion of navigable flows at broad low energy riffles. Glen Martin is less of a passage bottleneck for these fish as they have historically been able to ascend 48 per cent of flows during spring and 36 per cent in summer, which would be expected to increase during the filling regime. Recruitment of these fish may increase into Reach 3 populations.

Large strong swimmers, such as adult bass and adult freshwater mullet may experience a decline in the proportion of navigable flows. Gains at Glen Martin from increases in the number of lower velocity flows during the filling phase would be offset by increases in flows under depth thresholds of these deep-bodied fish. Passage at low energy riffles is calculated to decrease considerably as the low to moderate dominated flows cannot generate enough passage to guarantee passage for adults, particularly during winter and spring for adult bass (Tables A5 to A6). It is unlikely that bass would experience a recruitment failure in the upper sections of Reach 3 as the 20 centimetres lower limit was considered a threshold to 100 per cent passage. Smaller adults would be able to negotiate upstream but it is anticipated that large fish such as adult bass and freshwater mullet may experience a decline in the success of upstream migrations throughout Reach 3.

The proportion of navigable flows within Reach 4 are not anticipated to change as there are few, if any, depth barriers to passage and the low gradient and wide channel produce lower velocity flows. Larger returning adult fish, especially sea mullet, may preferentially stay in the slower, deeper pools of Reach 4.

The alteration of the flow regime may have an affect on the successful proportion of diadromous fish recruiting upstream into Reach 4 and Reach 3 via passage from estuarine habitat past Seaham Weir. Upstream passage for small diadromous juveniles is probably exclusively via the relatively ineffective submerged orifice fishway. A rise in the proportion of low to moderate flow events may increase the frequency of weir pool depths that cause low to negative head differentials with the tidal tailwater and therefore facilitate an increase in upstream passage through the fishway. However, this phenomenon would not assist those species which may have behavioural barriers to using a submerged orifice fishway, such as freshwater herring and the surface schooling sea mullet. Reduced freshwater outflows from the fishway may also make it harder for migrating fish to locate the submerged entrance. The filling phase would also cause a decline in flows that ‘drown-out’ the weir or cause the gates to be opened, which larger fish can occasionally negotiate during low head differentials (Dept of Commerce 2008).

Downstream Passage - Peak Flows
The significant loss of a range of larger peak flows would lead to a decline in successful spawning and/or recruitment for some species. The positive correlation of bass recruitment with flow volume and peak flows indicates that recruitment would probably decline during the filling regime (Harris 1986, Grown and James 2005). The exact relationship between peak flows and recruitment of longfinned eels and shortfinned eels is unknown, although successful migrations may be facilitated by high flows. The loss of peak events may result in the decline in the number of amphidromous larvae/juveniles that successfully make it to downstream to estuarine nurseries and/or a decline in the number of empire gudgeon, flathead gudgeon and sub-adult bass that are cued to migrate upstream. Similarly, a decline in the transport of nutrients and carbon into estuaries from flooding flows may reduce their productivity and capacity to support diadromous juveniles.

Summary

Impacts of the environmental release regime on aquatic biota during the filling phase are potentially complex and difficult to predict. It is anticipated that habitat and water quality may become degraded in some areas, which would lead to an increase in the proportion of pollution-tolerant taxa. Macroinvertebrates associated with shallow habitats such as riffles and gravel/bars may decline in diversity and abundance. Australian bass, and potentially other diadromous species, are expected to experience reduced recruitment, whereas smelt, flathead gudgeon and introduced *Gambusia* and carp, should remain relatively unaffected, or even increase in abundance.

A2.2 Standard operation

Macroinvertebrates

The improvement of water and habitat quality in Reach 3 should facilitate the restoration of any impaired macroinvertebrate riffle and pool edge assemblages to pre-dam compositions. The distribution and abundance of pollution sensitive taxa should return to within the historical range.

The predicted increase in the availability of riffle habitat and gravel/sand bars may result in an overall increase in the abundance of associated macroinvertebrate fauna. In the upper sections of Reach 3 this increased productivity may be offset by bed scour unless a replenishment program is initiated. Bedrock habitat is relatively featureless, and would not support the same assemblages as the lost habitat forms.

The largest predicted increase in median riffle velocity is 0.42 metres per second at the Glen Martin riffle in spring, followed by 0.32 metres per second during summer at the same riffle (Table A8). It is possible that an increase in sheer stress may select against benthic organisms less tolerant of higher velocity flows. Macroinvertebrate assemblages have changed downstream of hydroelectric dams that make high velocity releases for power generation (Bunn and Arthington 2002). Although deep pools can be a velocity refuge during high volume flows, pool edge fauna with life history traits that require seasonal low flows (i.e. planktonic larvae) may be affected by the larger run-of-river transfers (around 500 ML/day). Run-of-river transfers of this magnitude would generate 30 day duration flows with velocities of around 0.25 metres per second at intermediate pools (W7: median depth 1.63 metres) increasing to around 0.43 metres at shallow pools (W9: median depth 0.52 metres) (Table A11). The freshwater mussel, *C. novaehollandiae,* retains its glochidia larvae over winter and then releases them in spring to find fish hosts.

Fish

The increase in median discharges is predicted to be greatest during spring (and summer) due to the timing of run-of-river transfers (Table A7). This may affect those taxa adapted to a season that has been historically characterised by relatively stable low flows. The larvae/juveniles of fish spawning in freshwater reaches (and their prey) may be more likely to be swept downstream, particularly as run-of-river transfers may reach 500 ML/day and last for 30 days. For non-diadromous fish this may reduce local recruitment in upstream areas and/or an increase in mortality as these fish are forced to take longer and more frequent dispersal migrations. Although high velocity flows in shallow gravel runs might disrupt catfish spawning they have an extended spawning season and would re-attempt following a return to lower flows.

Improved water and habitat quality would benefit the more sensitive fish species that may have been affected during the filling phase. An increase in riffle habitat availability and riffle fauna productivity may increase the abundance of fish species, such as Cox's gudgeon and small longfinned eel, which prefer this habitat and prey on associated macroinvertebrates. Conversely, these fish would lose habitat in upstream areas affected by scour where it is anticipated that riffle habitat would be lost. Similarly, the freshwater catfish may lose gravel nesting habitat.

Upstream Passage

The replacement of low to moderate flows with run-of-river transfers would increase median velocities over most of the Reach 3 riffles (Table A8), particularly during spring (and to a lesser extent summer) which is traditionally the period when fish would attempt the majority of upstream migrations (Table 4.8).

For weak swimming fish (upper limit 0.8 metres per second) there would be relatively little change in the historically small proportion of navigable flows at the high-energy riffles such as Glen Martin relative to the historical period (Tables A1 and A2). They would lose a relatively small proportion of navigable days at such riffles following the initiation of run-of-river transfers as many of the replaced flows were already too fast to negotiate. These fish would have lost considerably more navigable flows at the low-energy riffles (W8 and W9) as the replacement of low to moderate flows with fresh-sized run-of-river transfers increased the proportion of flows that generate velocities above their upper limit. Therefore the upstream dispersal of these juvenile fish in Reach 3 might be expected to decline relative to the historical period, although access to lower Reach 3 past Mill Dam Falls is not expected to decline considerably.

Small to intermediate strong swimming fish such as small juvenile bass, juvenile freshwater and sub-adult sea mullet would experience a slightly larger decline in the number of navigable flows at both low and high energy riffles (Table A3 and A4). However, these fish have had a larger historical passage window and are still able to navigate a third of the flows at high energy riffles and half of those at low energy sites. It is possible that the similar numbers of fish may still be able to ascend through upstream through this reduced passage window. The larger and stronger adult freshwater mullet continuing into Reach 3 would experience most difficulties during negotiating passage at Glen Martin in winter. Returning adult bass would benefit from the increased flows during spring which would provide them greater depth to pass low energy riffles (Table A6), however they too are predicted to experience a dramatic decline in passage at Glen Martin during winter (down to just 5 per cent of flows). This is because the run-of-river transfers and spilling flows would generate velocities slightly in excess of 1.4 metres per second at Glen Martin. The conservative upper limit of 1.4 metres per second used for bass was selected due to the difference in reported success of bass passage at around 1.8 metres per second (Richardson 1984 in Pusey *et al* 2004, Mallen-Cooper 1992). Had 1.8 metres per second been used as an upper limit for bass then 43 per cent of flows at Glen Martin during winter would be passable. Whilst not all adult bass may be able to ascend into 1.8 metres per second at Glen Martin the impact on total passage is not expected to be nearly as large as predicted in Table A6.

The proportion of navigable flows within Reach 4 are not anticipated to change as there are few, if any, depth barriers to passage and the low gradient and wide channel produce lower velocity flows.

The operational regime may however reduce the proportion of diadromous fish recruiting upstream into Reach 4 and Reach 3 via passage from estuarine habitat through the Seaham Weir fishway. Flow data from 2002 demonstrated that seasonal low flow periods during spring (and to a lesser extent summer) resulted in the weir pool remaining below the preferred RL0.4 to RL0.5 metre range for prolonged periods, thereby inadvertently facilitating the upstream migration of diadromous juveniles through the fishway (Dept of Commerce 2008). The predicted increase in spring flow volume due to the calling of run-of-river transfers would possibly decrease the number of days that the weir pool falls below RL0.4 metres, and as such may decrease the amount of time during spring and summer when small fish can navigate the fishway.

Downstream Passage - Peak Flows

The increase in frequency, magnitude and duration of peak flows relative to the filling phase would benefit those species that require seasonal peak flows to cue and/or facilitate spawning or dispersal migrations. However, the predicted magnitude of peak flows is consistently lower than historical flows for much of the peak distribution. Therefore, the recruitment of species such as Australian bass would remain at lower levels than had the dam not been built. These patterns may be similar for other species, although the exact nature of the relationship with peaks flows to recruitment in unknown.

Summary

The initiation of run-of-river transfers and spilling flows should improve water and habitat quality that may have become degraded during the filling phase, and therefore the recovery of sensitive macroinvertebrate taxa. A rise in channel wetted width would increase the overall productivity of riffle communities and habitat availability for associated fish species. However, scour of bed material in the upper section of Reach 3 would result in the localised loss of riffle and gravel/sand habitat and associated taxa.

The predicted increase of flows during the spring may decrease recruitment for those taxa that have life histories adapted to a period of historical stable low flows. The proportion of upstream navigable flow is predicted to decrease for most fish throughout Reach 3 and at the Seaham Weir fishway. However, for small, weak-swimming fish the change in access to upstream section of Reach 3 may be limited due to the relatively small change in navigable flows at the high energy Mill Dam Falls. There remains uncertainty regarding the effects on fish passage in Reach 3 due to the lack of knowledge about flow thresholds and migratory details for many species.

Seasonal peak flow volumes are consistently lower than historical flows and may therefore negatively affect ecological processes that are proportional to flow magnitude, such as bass recruitment.

Table A1. Upstream fish passage 'window': percentage (%) of riffle flows with depths greater than or equal to 0 cm and velocities less than or equal to 0.8 m/s for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	19.5	27.5	12.1	11.8	27.0
Site W8	63.7	63.7	56.6	63.4	71.1
Site W9	49.2	51.8	33.4	46.2	65.6
Glen Martin	14.4	24.3	8.9	5.7	19.3

b) Filling phase release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	42.0	44.0	24.0	46.0	54.0
Site W8	99.0	99.0	98.0	99.0	99.0
Site W9	76.0	84.0	50.0	80.0	88.0
Glen Martin	na	na	na	na	na

c) Operational release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	16.8	22.8	12.5	12.6	19.5
Site W8	56.4	59.7	55.7	58.0	52.2
Site W9	38.0	39.6	30.5	41.0	41.0
Glen Martin	10.0	17.7	6.4	2.4	13.9

Table A2. Upstream fish passage 'window': percentage (%) of riffle flows with depths greater than or equal to 3 cm and velocities less than or equal to 0.8 m/s for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	15.9	20.0	9.4	11.2	23.4
Site W8	58.1	53.0	52.5	61.9	65.2
Site W9	39.3	34.7	26.0	42.7	53.3
Glen Martin	9.3	13.8	5.4	4.4	14.4

b) Filling phase release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	40.0	43.5	24.0	46.0	47.0
Site W8	95.0	92.0	98.0	99.0	89.0
Site W9	75.0	84.0	50.0	80.0	82.0
Glen Martin	na	na	na	na	na

c) Operational release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	11.4	13.3	7.4	11.1	13.3
Site W8	49.3	47.8	49.5	55.9	44.0
Site W9	32.2	29.5	25.3	19.7	34.2
Glen Martin	8.5	15.2	5.8	0.2	11.1

Table A3. Upstream fish passage 'window': percentage (%) of riffle flows with depths greater than or equal to 3 cm and velocities less than or equal to 1.0 m/s for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	45.9	44.9	34.9	46.2	57.8
Site W8	78.7	72.2	73.7	84.6	84.2
Site W9	59.0	51.1	48.4	67.1	68.5
Glen Martin	34.0	36.0	23.3	29.5	47.9

b) Filling phase release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	77.0	81.5	66.0	85.0	75.0
Site W8	96.0	93.0	100.0	100.0	90.0
Site W9	91.0	97.0	82.0	94.0	89.0
Glen Martin	na	na	na	na	na

c) Operational release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	35.4	33.3	30.9	40.7	36.1
Site W8	61.5	57.3	62.5	72.0	54.0
Site W9	49.7	45.8	44.5	40.2	48.2
Glen Martin	29.8	31.5	23.1	28.5	33.9

Table A4. Upstream fish passage 'window': percentage (%) of riffle flows with depths greater than or equal to 5 cm and velocities less than or equal to 1.0 m/s for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	45.4	44.4	34.4	45.8	57.2
Site W8	74.1	64.7	70.9	83.3	77.0
Site W9	42.2	34.0	38.6	51.4	43.4
Glen Martin	33.5	35.3	22.9	29.3	47.1

b) Filling phase release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	76.5	80.5	66.0	85.0	74.5
Site W8	91.0	86.0	98.0	96.0	83.0
Site W9	61.0	67.0	66.0	62.0	51.0
Glen Martin	na	na	na	na	na

c) Operational release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	32.8	29.6	29.2	39.3	33.1
Site W8	51.8	46.4	56.3	61.5	42.8
Site W9	34.1	29.1	34.7	26.0	30.5
Glen Martin	29.3	30.4	22.7	24.0	33.4

Table A5. Upstream fish passage 'window': percentage (%) of riffle flows with depths greater than or equal to 15 cm and velocities less than or equal to 1.4 m/s for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	61.1	52.5	64.5	70.3	57.1
Site W8	39.7	36.5	48.6	43.1	30.7
Site W9	21.1	19.5	28.1	21.5	13.8
Glen Martin	45.5	36.9	38.2	55.1	51.4

b) Filling phase release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	57.0	55.0	76.0	53.0	45.0
Site W8	20.0	17.0	31.0	14.0	17.0
Site W9	7.5	3.0	18.0	6.5	0.7
Glen Martin	na	na	na	na	na

c) Operational release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	32.5	30.3	37.1	37.0	25.6
Site W8	33.0	30.4	29.3	31.3	39.2
Site W9	32.3	31.5	30.7	21.8	38.4
Glen Martin	36.5	29.9	35.4	12.6	32.8

Table A6. Upstream fish passage 'window': percentage (%) of riffle flows with depths greater than or equal to 20 cm and velocities less than or equal to 1.4 m/s for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	37.6	33.3	44.0	42.3	30.9
Site W8	14.2	14.5	18.6	14.3	9.7
Site W9	10.3	9.9	13.4	10.5	6.8
Glen Martin	32.0	24.7	29.0	42.0	32.2

b) Filling phase release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	27.0	24.0	45.0	20.0	22.0
Site W8	0.5	1.0	10.5	1.0	0.5
Site W9	2.0	0.8	4.0	1.8	1.0
Glen Martin	na	na	na	na	na

c) Operational release flows

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	12.4	9.1	13.5	16.3	10.6
Site W8	27.5	26.7	22.5	23.5	35.6
Site W9	17.3	18.1	15.9	9.4	22.3
Glen Martin	24.4	20.9	24.9	4.7	20.0

Table A7. Median riffle flow (M/L) (50th percentile exceedence) for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows - median riffle flow (ML/day)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	46.5	41.5	67.3	49.4	32.8
Site W8	46.5	41.5	67.3	49.4	32.8
Site W9	72.7	68.5	144.8	73.7	47.7
Glen Martin	116.0	86.1	226.1	136.7	63.8

b) Filling phase release flows - median riffle flow (ML/day)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	25.1	23.7	40.5	22.8	18.8
Site W8	25.1	23.7	40.5	22.8	18.8
Site W9	41.5	39.1	80.4	36.9	33.3
Glen Martin	na	na	na	na	na

c) Operational release flows - median riffle flow (ML/day)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	63.0	63.0	63.0	63.0	63.0
Site W8	63.0	63.0	63.0	63.0	63.0
Site W9	145.0	129.2	212.8	110.6	128.8
Glen Martin	224.7	219.2	275.4	182.1	205.3

Table A8. Median velocity (m/s) of riffle (50th percentile exceedence) for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows - median riffle velocity (m/s)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	1.00	0.98	1.08	1.02	0.93
Site W8	0.77	0.76	0.78	0.77	0.75
Site W9	0.81	0.78	0.88	0.81	0.65
Glen Martin	1.17	1.07	1.40	1.23	0.95

b) Filling phase release flows - median riffle velocity (m/s)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	0.88	0.87	0.98	0.86	0.83
Site W8	0.71	0.71	0.71	0.71	0.71
Site W9	0.64	0.63	0.84	0.63	0.63
Glen Martin	na	na	na	na	na

c) Operational release flows -median riffle velocity (m/s)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	1.07	1.07	1.07	1.07	1.07
Site W8	0.78	0.75	0.78	0.78	0.79
Site W9	0.88	0.88	1.01	0.87	0.88
Glen Martin	1.40	1.39	1.48	1.33	1.37

Table A9. Median riffle depth (m) (50th percentile exceedence) for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows - median riffle depth (m)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	0.20	0.20	0.24	0.21	0.18
Site W8	0.15	0.14	0.16	0.15	0.11
Site W9	0.09	0.09	0.14	0.09	0.08
Glen Martin	0.25	0.23	0.34	0.27	0.21

b) Filling phase release flows - median riffle depth (m)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	0.16	0.16	0.19	0.16	0.15
Site W8	0.09	0.09	0.13	0.09	0.08
Site W9	0.07	0.07	0.09	0.07	0.06
Glen Martin	na	na	na	na	na

c) Operational release flows - median riffle depth (m)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	0.23	0.23	0.23	0.23	0.23
Site W8	0.16	0.16	0.16	0.16	0.16
Site W9	0.14	0.13	0.16	0.12	0.13
Glen Martin	0.34	0.34	0.38	0.31	0.33

Table A10. Median wetted width (m) of riffle (50th percentile exceedence) for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows - median wetted riffle width (m)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	5.30	5.10	6.20	5.40	4.60
Site W8	16.90	14.40	21.80	17.90	9.30
Site W9	16.00	15.80	20.30	16.00	15.00
Glen Martin	8.20	7.90	9.30	8.40	7.70

b) Filling phase release flows - median wetted riffle width (m)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	4.2	4.1	5.0	4.0	3.7
Site W8	5.7	5.2	13.9	5.0	4.5
Site W9	14.5	14.2	16.3	14.0	13.6
Glen Martin	na	na	na	na	na

c) Operational release flows - median wetted riffle width (m)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	6.00	6.00	6.00	6.00	6.00
Site W8	21.10	21.10	21.10	21.10	21.10
Site W9	20.30	19.30	22.20	17.90	19.20
Glen Martin	9.20	9.20	9.70	8.80	9.10

Table A11. Median pool depth (m) (50th percentile exceedence) for a) historical flows b) filling phase release flows c) operational release flows. Data for filling period are from the lowest 5 year running total from the last 20 years and represent a low inflow scenario for the environmental release strategy during the filling phase. na = data not available.

a) Historical flows - median pool depth (m)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	1.63	1.62	1.67	1.64	1.60
Site W8	0.92	0.91	0.93	0.92	0.90
Site W9	0.45	0.44	0.51	0.45	0.41
Glen Martin	1.97	1.93	2.09	1.99	1.90

b) Filling phase release flows - median pool depth (m)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	na	na	na	na	na
Site W8	na	na	na	na	na
Site W9	na	na	na	na	na
Glen Martin	na	na	na	na	na

c) Operational release flows - median pool depth (m)

Riffle	All	Summer	Autumn	Winter	Spring
Site W7	1.66	1.66	1.66	1.66	1.66
Site W8	0.93	0.93	0.93	0.93	0.93
Site W9	0.52	0.50	0.57	0.48	0.50
Glen Martin	2.09	2.08	2.13	2.04	2.07

Table A12. Range of water physical chemistry values recorded in association with fish sampling. Data recorded during fish surveys from various rivers in Southeast Queensland.

Scientific Name	Common Name	Water Temperature (^oC)			Dissolved Oxygen (mg/L)			pH			Conductivity (µS/cm)			Turbidity		
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Anguilla australis	Shortfinned eel	8.4	18.4	27.8	2.6	7.3	10.4	5.9	7.4	8.5	110.0	386.2	1231.7	0.5	10.9	112.3
Anguilla reinhardtii	Longfinned eel	8.4	19.5	31.7	0.3	7.6	16.2	5.6	7.6	9.1	19.5	456.4	2247.0	0.4	8.8	331.4
Retropinna semoni	Australian smelt	8.4	19.7	31.7	0.6	8.0	16.2	6.0	7.7	9.1	51.0	387.4	1642.2	0.4	5.5	144.0
Gobiomorphus australis	Striped gudgeon	8.4	18.7	29.3	1.7	6.9	11.9	4.4	7.3	8.5	97.5	471.5	2247.0	0.3	12.5	200.0
Gobiomorphus coxii	Cox's gudgeon	13.4	19.0	28.0	5.5	8.4	16.2	6.5	7.5	8.8	54.0	158.0	590.0	1.0	4.2	36.0
Hypseleotris compressa	Empire gudgeon	11.7	20.3	31.0	1.7	6.9	11.3	4.4	7.4	9.1	97.5	586.5	2744.0	0.3	12.9	200.0
Philypnodon grandiceps	Flathead gudgeon	11.0	20.4	31.0	2.6	7.8	12.0	6.0	7.7	8.6	122.1	586.3	2495.0	0.7	5.4	36.0
Philypnodon sp.	Dwarf flathead gudgeon	8.4	20.3	31.7	0.3	7.5	12.7	6.3	7.6	8.9	107.0	608.5	4002.0	0.2	4.7	36.0
Macquaria novemaculeata	Australian bass	15.8	19.6	26.1	5.5	8.4	9.3	6.3	7.3	8.1	82.0	273.5	970.0	3.0	6.6	9.1
Notesthes robusta	Bullrout	11.7	21.0	27.1	4.8	7.4	10.0	6.3	7.6	9.0	6.0	158.2	1035.0	0.3	3.5	16.0
Tandanus tandanus	Freshwater catfish	8.4	19.5	33.6	0.3	7.6	17.1	4.8	7.7	9.1	19.5	3580.0	488.9	0.2	6.3	250.0

Data source: Pusey *et al* 2004.

A3 References

Allen, GR Midgeley, SH and Allen, M 2003, *Field guide to the freshwater fishes of Australia*, Western Australian Museum, Perth, Western Australia, pp.394.

Baker, CF 2003, Effect of fall height and notch shape on the passage of inanga (Galaxias maculatus) and common bullies (Gobiomorphus cotidianus) over an experimental weir. New *Zealand Journal of Marine and Freshwater Research*, 37, pp. 283-290.

Bennison, GL Hillman, TJ and Suter, PJ 1989. *Macroinvertebrates of the River Murray: Review of Monitoring 1980-1985*, Water Quality Report No. 3, Murray Darling Basin Commission, Canberra.

Bunn, SE and Arthington, AH 2002, Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity, *Environmental Management*, 30(4), pp. 492-507.

Chessman, B and Growns, J 1994, Williams river aquatic macroinvertebrate study. Australian Water Technologies, Ensight. Report No. 94/84. Prepared for Hunter Water Corporation and Hunter Catchment Management Trust.

Chester, H and Norris, R, 2006, Dams and flow in the Cotter River, Australia: effects on instream trophic structure and benthic metabolism, *Hydrobiologia*. 572, pp. 275-286.

Connell Wagner 2007, *Preliminary Environmental Assessment. Tillegra Dam Planning and Environmental Assessment.* Neutral Bay.

Cotterell, E 1998, *Fish Passage in Streams: Fisheries guidelines for design of stream crossings.* Fish Habitat Guideline FHG001, Queensland Department of Primary Industries, Brisbane, Qld. 40 pp.

Department of Primary Industries 2006, *Reducing the Impact of weirs on aquatic habitat - NSW detailed weir review*. Hunter/Central Rivers CMA Region. Report to the NSW Environmental Trust. NSW Department of Primary Industries, Flemington, NSW.

Environment Protection Authority 2004 *River health in the New South Wales lower north coast, hunter and central coast catchments*. A report of AusRivAS assessments 1994 – 1999. Environment Protection Authority, viewed 10 January 2008, <http://www.environment.gov.au/water/publications/environmental/rivers/nrhp/catchments-nsw/reportcards.html>

Gehrke, PC Gilligan, DM and Barwick, M 2001, *Fish communities and migration in the Shoalhaven River – Before construction of a fishway*, Final Report No. 26, NSW Fisheries, Port Stephens.

Gehrke, PC and Harris, JH 2001, Regional-scale effects of flow regulation on lowland riverine fish communities in New South Wales, Australia. *Regulated Rivers: Research and Management,* 17, pp. 369 – 391.

Gippel, C & Anderson, B 2007, *Tillegra Dam Planning and Environmental Impact Assessment, Preliminary Environmental Assessment: Fluvial Geomorphology*

Component, prepared for Connell Wagner and Hunter Water Corporation by Fluvial Systems Pty Ltd, Stockton, in association with Water Technology Pty Ltd.

Gooderham, J and Tsyrlin, E 2002, *The waterbug book: a guide to the freshwater macroinvertebrates of temperate Australia.* National Library of Australia Cataloguing-in-Publication, CSIRO. 232pp.

Growns, IO and Growns, JE 2001, Ecological effects of flow regulation on macroinvertebrate and periphytic diatom assemblages in the Hawkesbury-Nepean River, Australia. *Regulated Rivers - Research and Management,* 17, pp. 275-293.

Growns, IO, and Davis, JA, 1994, Longitudinal changes in near-bed flows and macroinvertebrate communities in a Western Australian stream. *Journal of the North American Benthological Society*, 13, pp. 417-438.

Growns, I and James, M 2005, Relationships between river flows and recreational catches of Australian bass, *Journal of Fish Biology*, 66, pp. 404 – 416.

Haro, A, Castro-Santos, T Noreika, J and Odeh, M, 2004, Swimming performance of upstream migrant fishes in an open-channel flow: a new approach to predicting passage through velocity barriers. *Canadian Journal of Fisheries and Aquatic Sciences*, 61, pp. 1590-1601.

Harris, JH 1986, Reproduction of the Australian bass, Macquaria novemaculeata, (Perciformes: Percichthyidae) in the Sydney Basin. *Australian Journal of Marine and Freshwater Research,* 37, pp. 209-235.

Harris, JH and Mallen-Cooper, M 1994, *Fish passage development in the rehabilitation of fisheries in mainland south-eastern Australia*. In: Proceedings of the International Symposium and Workshop on Rehabilitation of Inland Fisheries, Hull, UK, Cowx, I (eds), Fishing News Books, Australia, pp. 195-193.

Jones, HA Simpson, RD and Humphrey, CL 1986, The reproductive cycles and glochidia of fresh-water mussels (Bivalvia: Hyrdiidae) of the Macleay River, Northern New South Wales, Australia. *Malacologia,* 27(1), pp. 185 – 202.

Koehn, JD and O'Connor, WGO 1990, *Biological Information for Management of Native Freshwater Fish in Victoria*. Department of conservation and Environment, Freshwater Fish Management Branch, Arthur Rylah Institute for Environmental Research, Ivanhoe, Victoria, 165pp.

Langdon, SA and Collins, AL 2000, Quantification of the maximal swimming performance of Australasian glass eels, Anguilla australis and Anguilla reinhardtii, using a hydraulic flume swimming chamber. *New Zealand Journal of Marine and Freshwater Research*, 34, pp. 629-636.

Lintermans, M 2007, *Fishes of the Murray-Darling Basin: an introductory guide. Murray-Darling Basin Commission,* Publication No. 10/07, pp. 157.

Mallen-Cooper, M 1992, Swimming ability of juvenile Australian bass, Macquaria novemaculeata (Streindachner), and juvenile barramundi, Lates calcarifer (Bloch), in an experimental vertical slot fishway*, Australian Journal of Marine and Freshwater Research*, 43, pp. 823 – 834.

Mallen-Cooper, M 1994, Swimming ability of adult golden perch, Macquaria ambigua (Percicthyidae) and adult silver perch, Bidyanus bidyanus (Teraponidae) in an experimental vertical-slot fishway. *Australian Journal of Marine and Freshwater Research,* 45, pp. 191-198.

Mallen-Cooper, M and Stuart, IG 2007, Optimising Denil fishways for passage of small and large fishes. *Fisheries Management and Ecology*, 14, pp. 61-71.

McDowall, RM 1996, *Freshwater Fishes of South – Eastern Australia.* Reed Books, Sydney NSW.

Mitchell, CP 1989, Swimming performances of some native freshwater fishes. *New Zealand Journal of Marine and Freshwater Research*, 23, pp. 181-187.

Morris, SA Pollard, DA Gehrke, PC and Pogonoski, JJ 2001, *Threatened and potentially threatened freshwater fishes of coastal New South Wales and the Murray-Darling basin*. Report to Fisheries Action Program and World Wide Fund for Nature. NSW Fisheries, Final Report No. 33.

Nikora, VI Aberle, J Biggs, BJF, Jowett, IG and Sykes, JRE 2003, Effects of fish size, time-to-fatigue and turbulence on swimming performance: a case study of Galaxias maculatus. *Journal of Fish Biology*, 63, pp. 1365-1382.

Pauly, D, 1995, Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology and Evolution*, 10, pp. 430.

Pusey, B Kennard, M and Arthington, A 2004, Freshwater fishes on north-eastern Australia. Centre for Riverine landscapes, Griffith University, CSIRO. 684pp.

Storey AW, Edward, DH and Gazey, P, 1991, Recovery of aquatic macroinvertebrate assemblages downstream of the Canning Dam, Western Australia. *Regulated Rivers: Research and Management*, 6, pp. 213-224.

Tudorache, C Vianen, P Blust, R and De Boeck, G 2007, Longer flumes increase critical swimming speeds by burst-glide swimming duration in carp Cyprinus carpio, L, *Journal of Fish Biology*, 71, pp. 1630-1638.

Walker, KF, 1985, A review of the ecological effects of river regulation in Australia. *Hydrobiologia* 125, pp. 111-129.

Appendix B

Hydrology Assessment

Table B1 Modelled filling phase flows under low, average and high flow periods at Tillegra

Statistic	All data	Summer	Autumn	Winter	Spring
Low flow filling period (1 November 2001 to 31 January 2006)					
Minimum	0.0	0.2	7.7	7.5	0.0
95th percentile exceedence	4.9	2.4	11.1	9.0	0.0
90th percentile exceedence	8.8	5.8	13.2	9.9	3.1
80th percentile exceedence	12.4	11.3	18.7	12.3	9.4
50th percentile exceedence	25.1	23.7	40.5	22.8	18.8
20th percentile exceedence	59.3	52.7	63.0	46.4	50.6
10th percentile exceedence	63.0	63.0	63.0	63.0	63.0
5th percentile exceedence	63.0	63.0	63.0	63.0	63.0
Maximum	270.0	270.0	270.0	270.0	270.0
Average flow filling period (1 November 1998 to 31 January 2003)					
Minimum	0.0	0.0	11.0	7.6	0.0
95th percentile exceedence	4.5	2.4	20.4	12.5	0.0
90th percentile exceedence	9.7	5.6	25.6	17.5	2.9
80th percentile exceedence	15.5	13.1	35.8	21.7	9.0
50th percentile exceedence	38.1	35.5	63.0	36.5	18.1
20th percentile exceedence	63.0	63.0	63.0	63.0	62.3
10th percentile exceedence	63.0	63.0	63.0	63.0	63.0
5th percentile exceedence	63.0	63.0	63.0	63.0	63.0
Maximum	270.0	270.0	270.0	270.0	270.0
High flow filling period (1 November 2001 to 31 January 2006)					
Minimum	0.0	0.0	0.2	14.5	0.0
95th percentile exceedence	5.0	2.4	1.5	20.6	6.1
90th percentile exceedence	10.0	6.1	7.2	23.3	9.3
80th percentile exceedence	16.9	12.4	21.5	31.1	12.2
50th percentile exceedence	45.3	32.5	63.0	53.9	31.5
20th percentile exceedence	63.0	63.0	63.0	63.0	63.0
10th percentile exceedence	63.0	63.0	63.0	63.0	63.0
5th percentile exceedence	63.0	63.0	63.0	63.0	63.0
Maximum	270.0	270.0	270.0	270.0	270.0

Table B2 Tillegra Bridge historic and modelled 90/30 with constant run-of-river transfers and flushing events

Statistic	All data	Summer	Autumn	Winter	Spring
Historic flows					
Minimum	0.0	0.0	0.0	0.0	0.0
95th percentile exceedence	1.9	0.0	4.2	10.1	1.5
90th percentile exceedence	7.4	2.2	13.4	14.7	5.9
80th percentile exceedence	15.9	9.3	24.4	22.0	11.8
50th percentile exceedence	46.5	41.5	67.3	49.4	32.8
20th percentile exceedence	170.8	190.7	271.2	156.8	103.2
10th percentile exceedence	416.0	495.8	611.1	333.4	233.1
5th percentile exceedence	914.5	1099.5	1290.2	740.4	530.6
Maximum	56488.4	45594.6	56488.4	36195.1	32017.3
Mean	261.5	300.5	366.3	220.8	158.2
Base case scenario release flows					
Minimum	1	1	1	1	1
95th percentile exceedence	4.9	1.1	5.3	10.7	3.3
90th percentile exceedence	10.4	6.1	13.3	13.3	9.1
80th percentile exceedence	17.8	13.2	23.0	20.0	15.9
50th percentile exceedence	63.0	63.0	63.0	63.0	63.0
20th percentile exceedence	348.4	354.6	381.1	284.9	378.3
10th percentile exceedence	501.0	493.1	563.0	429.9	468.6
5th percentile exceedence	563.0	563.0	827.0	563.0	510.9
Maximum	32223.2	32223.2	25641.4	11590.6	4609.2
Mean	219.8	225.5	282.3	180.2	190.8
Modified base case scenario release flows					
Minimum	1.0	1.0	1.0	1.0	1.0
95th percentile exceedence	2.3	1.0	4.9	9.6	1.6
90th percentile exceedence	7.7	2.5	11.6	11.9	6.1
80th percentile exceedence	13.2	9.0	19.6	17.6	10.2
50th percentile exceedence	43.9	35.8	63.0	54.2	24.5
20th percentile exceedence	203.1	182.0	347.8	195.9	100.5
10th percentile exceedence	448.9	450.0	681.2	368.5	266.3
5th percentile exceedence	866.7	1002.5	1279.7	685.1	520.9
Maximum	29759.4	26643.0	29759.4	10567.5	12298.6
Mean	208.8	223.4	312.0	178.1	120.9

Table B3 Glen Martin historic and modelled 90/30 with constant run-of-river transfers and flushing events

Statistic	All data	Summer	Autumn	Winter	Spring
Historic flows					
Minimum	0.0	0.0	0.0	0.0	0.0
95th percentile exceedence	0.4	0.0	6.6	15.3	0.5
90th percentile exceedence	9.8	0.2	19.8	28.1	6.6
80th percentile exceedence	27.5	12.1	48.2	48.5	18.4
50th percentile exceedence	116.0	86.1	226.1	136.7	63.8
20th percentile exceedence	610.3	622.2	944.1	577.2	318.8
10th percentile exceedence	1494.1	1598.5	2143.6	1428.5	804.5
5th percentile exceedence	3165.8	3354.4	4649.9	3073.2	1787.8
Maximum	137448.1	104549.6	137448.1	75632.8	75304.2
Mean	880.8	911.1	1265.5	853.1	490.0
Base case scenario release flows					
Minimum	0.0	0.0	0.0	5.8	0.0
95th percentile exceedence	6.7	1.6	12.6	22.1	4.1
90th percentile exceedence	17.5	6.5	28.2	29.8	12.7
80th percentile exceedence	36.4	21.9	55.1	45.2	26.7
50th percentile exceedence	224.7	219.2	275.4	182.1	205.3
20th percentile exceedence	553.9	522.0	842.2	539.9	419.0
10th percentile exceedence	1057.3	1038.9	1664.6	958.5	615.4
5th percentile exceedence	2093.9	2158.6	3449.5	1790.8	1102.6
Maximum	101049.4	101049.4	100865.2	53510.3	50160.3
Mean	693.1	689.3	1039.2	628.6	412.2
Modified base case scenario release flows					
Minimum	0.0	0.0	0.0	0.9	0.0
95th percentile exceedence	3.7	0.7	12.3	19.0	2.3
90th percentile exceedence	10.6	2.9	23.0	24.6	6.0
80th percentile exceedence	22.7	11.6	40.1	36.2	13.3
50th percentile exceedence	90.1	75.0	188.5	109.6	42.0
20th percentile exceedence	498.2	478.4	888.7	473.4	227.8
10th percentile exceedence	1141.4	1081.6	1846.2	980.2	601.5
5th percentile exceedence	2302.2	2376.2	3753.8	2009.5	1219.6
Maximum	104846.3	102653.7	104846.3	53222.4	53299.4
Mean	664.0	662.6	1040.8	610.5	338.6

Table B4 Modelled Scenarios – Glen Martin

Percent of flow exceeded	GM: Historic Data	GM: Simulated Historic	GM: Block releases from Tillegra	T: Block releases from Tillegra	GM: Till 90 / 30_60, Chi 97_100 pre 2009	GM: Till 30_60, Chi 97_100	GM: Till 30_100, Chi 97_100	GM: Till 30_100, Chi 95_100	GM: Till 30_60, Chi 95_100	GM: Till 30_60, Chi 95_100, Tower 1200	GM: Till 30_60, Chi 95_100, Tower 1500	GM: Till 30_100, Chi 95_100, Tower 1500
0	137448	127029	101053	32223	137448	104846	104883	104973	104936	107018	107284	107173
	14176	12473	10398	2135	14194	10730	10633	10563	10662	11020	11183	11038
	7752	6184	5420	1272	7810	5562	5535	5524	5550	5795	5895	5832
	5288	4154	3482	826	5301	3696	3664	3653	3673	3929	4075	4025
	4030	3035	2655	610	4045	2736	2712	2701	2720	2990	3146	3090
5	3166	2426	2072	566	3179	2185	2173	2162	2177	2498	2618	2585
	2644	1998	1721	566	2648	1809	1800	1793	1802	2171	2265	2232
	2225	1693	1507	549	2226	1617	1614	1615	1613	1897	1900	1846
	1928	1462	1322	530	1926	1502	1475	1466	1499	1652	1623	1572
	1693	1283	1173	517	1684	1326	1287	1278	1312	1490	1354	1259
10	1494	1139	1051	501	1492	1174	1141	1128	1156	1272	1115	1054
	1344	1016	965	484	1340	1047	1028	1015	1034	1047	957	896
	1203	916	888	465	1200	958	945	932	949	896	831	778
	1083	833	823	448	1076	879	859	849	868	776	730	694
	983	757	769	427	977	805	787	776	796	681	653	622
15	894	691	724	411	889	739	720	713	728	610	587	567
	819	638	685	397	816	684	670	664	675	550	535	518
	758	592	648	383	754	636	624	617	632	501	488	476
	700	552	616	370	696	594	580	575	587	458	450	444
	649	519	583	360	644	554	543	537	549	426	419	414
20	610	490	555	345	607	517	510	505	514	392	387	386
	577	462	528	331	572	484	479	473	481	363	359	364

Percent of flow exceeded	GM: Historic Data	GM: Simulated Historic	GM: Block releases from Tillegra	T: Block releases from Tillegra	GM: Till 90 / 30_60, Chi 97_100 pre 2009	GM: Till 30_60, Chi 97_100	GM: Till 30_100, Chi 97_100	GM: Till 30_100, Chi 95_100	GM: Till 30_60, Chi 95_100	GM: Till 30_60, Chi 95_100, Tower 1200	GM: Till 30_60, Chi 95_100, Tower 1500	GM: Till 30_100, Chi 95_100, Tower 1500
	540	436	504	318	537	457	451	446	452	340	338	342
	507	409	486	315	503	427	422	418	424	318	317	323
	477	387	470	302	472	401	397	393	398	298	297	308
25	450	367	454	293	446	375	374	371	372	281	280	293
	424	347	441	284	421	354	354	350	351	265	265	279
	400	328	429	279	397	334	334	330	331	250	250	266
	375	310	416	273	371	314	316	313	313	236	236	253
	350	297	405	268	347	296	300	298	294	224	224	241
30	328	282	391	260	325	280	284	283	279	211	212	230
	308	268	382	243	307	263	270	267	263	200	201	220
	291	255	372	211	290	249	255	253	248	191	191	211
	275	242	363	181	273	234	241	239	234	181	181	202
	262	230	355	156	260	221	228	227	221	172	172	193
35	248	219	345	133	245	209	217	217	209	163	163	185
	233	208	336	115	231	197	206	206	197	155	155	177
	221	198	327	100	219	186	196	196	187	148	148	170
	210	189	316	88	209	176	187	187	178	140	140	162
	200	179	307	76	199	167	177	179	168	133	133	155
40	190	171	298	66	189	158	169	170	160	127	127	149
	181	163	289	66	180	149	160	163	151	121	121	143
	172	155	281	66	171	141	153	155	143	116	116	138
	162	147	275	66	161	132	145	148	136	111	111	132
	154	141	269	66	154	125	139	142	129	106	106	128

Percent of flow exceeded	GM: Historic Data	GM: Simulated Historic	GM: Block releases from Tillegra	T: Block releases from Tillegra	GM: Till 90 / 30_60, Chi 97_100 pre 2009	GM: Till 30_60, Chi 97_100	GM: Till 30_100, Chi 97_100	GM: Till 30_100, Chi 95_100	GM: Till 30_60, Chi 95_100	GM: Till 30_60, Chi 95_100, Tower 1200	GM: Till 30_60, Chi 95_100, Tower 1500	GM: Till 30_100, Chi 95_100, Tower 1500
45	147	134	262	66	146	119	132	136	123	102	102	123
	140	126	256	66	139	113	126	130	117	98	98	119
	134	120	250	66	133	107	121	125	111	94	94	115
	127	114	244	66	126	102	116	120	106	90	90	111
	122	109	235	66	121	97	111	116	102	87	87	107
50	116	104	222	66	***115***	92	107	112	97	84	84	103
	111	99	210	66	110	87	102	107	92	81	81	99
	105	94	199	66	105	83	98	103	88	78	78	95
	101	90	188	66	101	79	93	98	85	75	75	91
	96	85	177	63	95	75	89	94	81	72	72	88
55	91	81	166	59	91	72	84	90	78	70	70	84
	87	78	156	56	86	69	80	86	74	67	67	81
	83	74	146	53	83	65	77	82	71	65	65	78
	80	71	136	51	80	63	74	79	68	62	62	75
	77	68	128	48	76	60	70	76	65	60	60	72
60	73	65	120	46	73	57	67	73	63	58	58	70
	70	62	113	44	70	54	65	70	60	56	56	68
	67	59	106	42	67	52	62	68	58	54	54	65
	64	57	100	40	64	50	59	65	55	52	52	63
	62	54	94	39	62	47	57	63	53	50	50	61
65	60	52	89	37	60	45	55	60	51	49	49	59
	56	50	84	35	56	43	52	58	49	47	47	57
	54	48	79	34	54	42	50	56	48	45	45	55

Percent of flow exceeded	GM: Historic Data	GM: Simulated Historic	GM: Block releases from Tillegra	T: Block releases from Tillegra	GM: Till 90 / 30_60, Chi 97_100 pre 2009	GM: Till 30_60, Chi 97_100	GM: Till 30_100, Chi 97_100	GM: Till 30_100, Chi 95_100	GM: Till 30_60, Chi 95_100	GM: Till 30_60, Chi 95_100, Tower 1200	GM: Till 30_60, Chi 95_100, Tower 1500	GM: Till 30_100, Chi 95_100, Tower 1500
	52	46	75	33	52	40	49	54	46	44	44	53
	49	45	71	31	50	38	46	52	44	42	43	51
70	48	43	67	30	**48**	37	45	51	43	41	41	49
	45	41	64	29	46	35	43	49	41	40	40	48
	43	39	60	28	43	34	41	47	40	38	38	46
	41	38	57	27	41	32	40	46	38	37	37	45
	38	36	54	26	39	31	38	44	37	36	36	43
75	37	34	51	25	37	30	36	42	36	35	35	41
	34	33	48	24	35	29	35	41	35	33	33	40
	33	31	46	24	33	27	33	39	33	32	32	38
	31	29	43	23	31	26	31	37	32	31	31	36
	29	28	41	22	29	25	30	36	31	30	30	35
80	28	26	39	21	**28**	23	28	34	29	29	29	33
	26	25	37	20	26	22	27	32	28	27	27	32
	24	23	35	20	24	21	25	31	27	26	26	30
	22	22	33	19	22	20	23	29	26	25	25	28
	20	20	32	18	21	19	22	28	25	24	24	27
85	19	19	30	17	19	18	20	26	23	23	23	26
	17	17	28	17	17	16	19	25	22	22	22	24
	15	16	26	16	15	15	17	23	21	20	20	23
	13	14	24	15	13	14	16	22	20	19	19	21
	12	13	21	14	12	13	14	20	18	18	18	19
90	**10**	**11**	**19**	**12**	10	**11**	**12**	**18**	**17**	**16**	16	17

Percent of flow exceeded	GM: Historic Data	GM: Simulated Historic	GM: Block releases from Tillegra	T: Block releases from Tillegra	GM: Till 90 / 30_60, Chi 97_100 pre 2009	GM: Till 30_60, Chi 97_100	GM: Till 30_100, Chi 97_100	GM: Till 30_100, Chi 95_100	GM: Till 30_60, Chi 95_100	GM: Till 30_60, Chi 95_100, Tower 1200	GM: Till 30_60, Chi 95_100, Tower 1500	GM: Till 30_100, Chi 95_100, Tower 1500
	8	9	17	11	8	10	11	16	15	15	15	16
	6	8	14	10	6	8	9	14	14	13	13	14
	4	6	11	8	4	7	7	12	12	11	11	12
	2	5	8	6	1	5	6	11	10	10	10	10
95	0	3	5	5	0	4	4	9	9	8	8	8
	0	2	2	2	0	3	3	7	7	6	6	6
	0	1	0	1	0	2	2	5	4	4	4	4
	0	0	0	1	0	1	1	1	1	1	1	1
	0	0	0	1	0	0	0	0	0	0	0	0
100	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table B5 - CTP Glen Martin – Including Seasonal distribution

	GM: Historic Data	GM: Simulated Historic	GM: Till 30_60, Chi 97_100	GM: Till 30_100, Chi 97_100	GM: Till 30_100, Chi 95_100	GM: Till 30_60, Chi 95_100	GM: Till 30_60, Chi 95_100, Tower 1200	GM: Till 30_60, Chi 95_100, Tower 1500	GM: Till 30_100, Chi 95_100, Tower 1500
Annual >=6	92.0%	**93.1%**	93.6%	93.8%	96.5%	96.4%	96.2%	96.2%	**96.2%**
Annual >=15	86.8%	**87.6%**	87.2%	88.5%	91.7%	91.2%	90.8%	90.8%	**91.3%**
Spring >=6	90.5%	**89.8%**	90.1%	90.3%	95.1%	95.0%	94.8%	94.8%	**95.0%**
Spring >=15	82.8%	**80.2%**	78.1%	80.8%	86.5%	85.5%	85.3%	85.3%	**86.5%**
Summer >=6	84.5%	**85.8%**	87.2%	87.5%	92.3%	92.2%	91.2%	91.2%	**91.4%**
Summer >=15	77.1%	**78.0%**	78.3%	80.5%	84.6%	83.7%	82.3%	82.3%	**83.2%**
Autumn >= 6	95.1%	**96.8%**	97.3%	97.3%	98.5%	98.5%	98.5%	98.5%	**98.5%**
Autumn >=15	91.9%	**96.7%**	94.1%	94.4%	96.1%	96.0%	96.0%	96.0%	**96.1%**
Winter >= 6	98.0%	**99.8%**	99.9%	99.9%	99.9%	99.9%	99.9%	99.9%	**99.9%**
Winter >= 15	95.1%	**100.0%**	98.2%	98.4%	99.5%	99.4%	99.4%	99.4%	**99.4%**