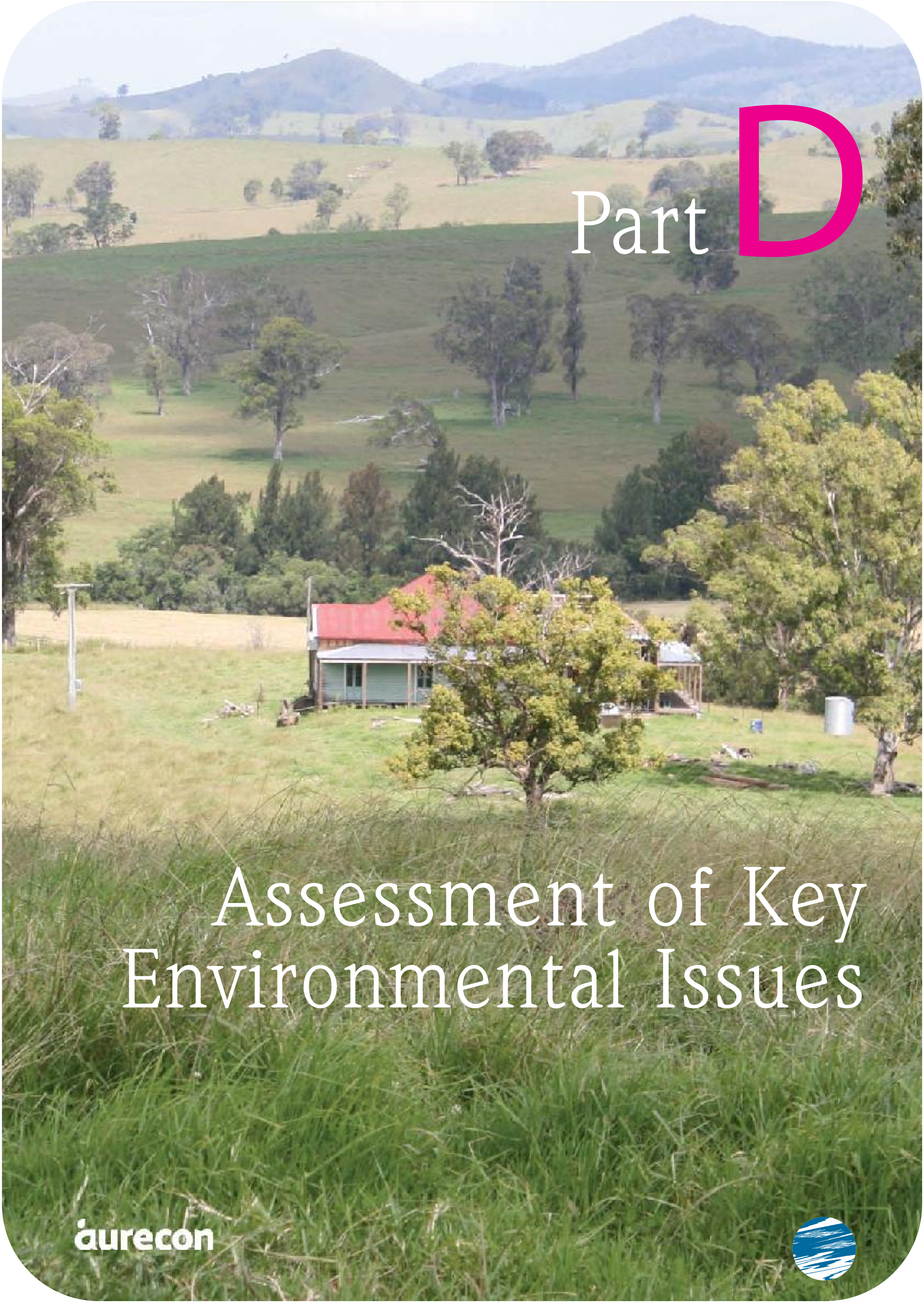


Part D

Assessment of Key Environmental Issues

Assessment and Management of Impacts on the Williams River

This chapter characterises key ecosystem and geomorphic processes and critical flow components required to sustain the current riverine system. It integrates the findings of the water quality and hydrology, fluvial geomorphology and aquatic ecology investigations (Working Papers A, B and C respectively) to develop a suitable environmental flow regime for the proposed Tillegra Dam and which is documented in detail in Working Paper D *Environmental Flows and River Management*. Discussion is supported by other specialist investigations undertaken for the Project such as those relating to terrestrial ecology with respect to potential impacts on the riparian environment.

10.1 Background

10.1.1 Catchment overview

The proposed dam would have a diverse range of impacts on the Williams River, notably in relation to modifications to the current flow regime (noting that it is already modified below the Chichester River confluence from the operation of Chichester Dam and, further downstream, the abstraction of water from the Seaham Weir Pool for transfer to Grahamstown Dam), water quality, channel morphology, and to aquatic and riparian ecology. The potential impacts on these environmental aspects have been investigated through separate but interlinked studies which are documented in detail in Working Papers A *Water Quality and Hydrology*, B *Fluvial Geomorphology*, and C *Aquatic Ecology*. The investigations into potential impacts on riparian ecology formed part of the terrestrial ecology studies and are documented in Working Paper E *Terrestrial Ecology*.

Consideration has also been given to potential impacts on the Ramsar wetland in the Hunter estuary. This was a specific requirement of the supplementary DGRs issued on 1 May 2009 following consultation between the Department of Planning and DEWHA. The specialist study investigating the potential impacts on the wetland is provided as Appendix 6 to the EA Report.

Characterisation of likely and potential impacts is best approached holistically to assess the flow requirements of the many interacting components of the Williams River system. This facilitates assessment of 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 important features such as aquatic and endangered species. A conceptual representation of this is provided in Figure 10.1.

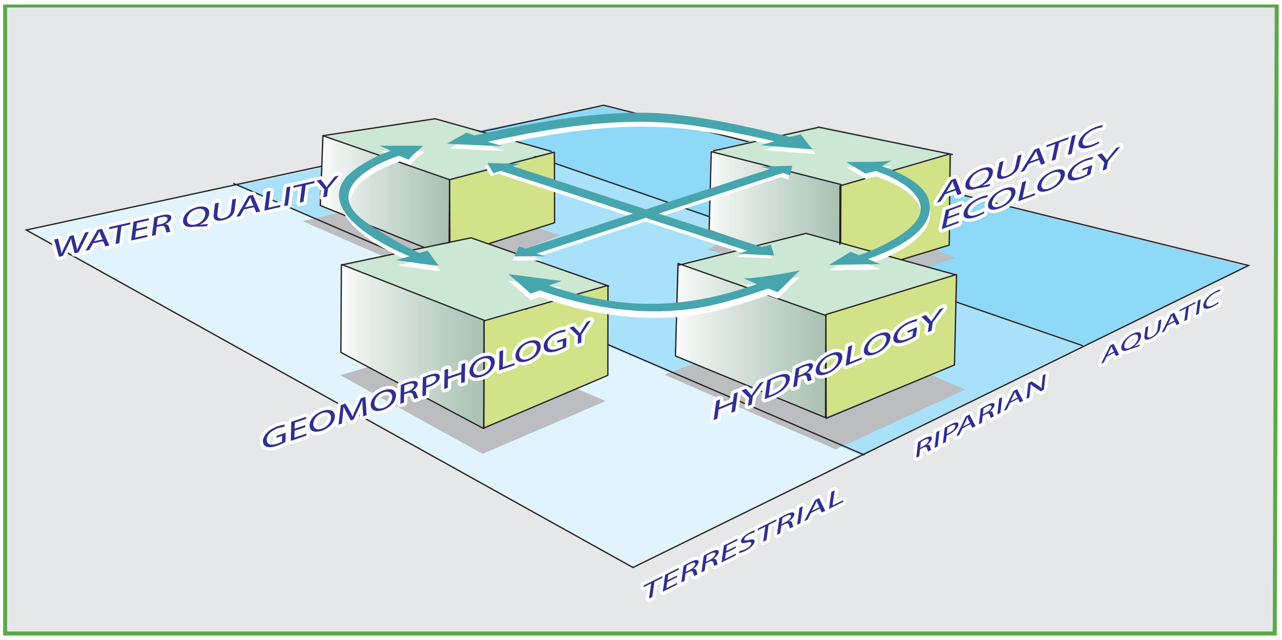


FIGURE 10.1 RIVER BASIN COMPONENTS

The objective of this chapter is to report on the identification of the essential features of the existing hydrological regime and to characterise their influence on key geomorphological and ecological processes of the Williams River system. Through this, it has been possible to construct a modified flow regime to address HWC's operational requirements but minimise negative impacts on these geomorphological and ecological processes.

10.1.1 Director-General's requirements

The Director-General's requirements identify a range of matters related to hydrology and water quality, fluvial geomorphology, and ecology. These are reiterated as follows.

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 framework 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 other groundwater and 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.

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.

Ecology

- include a comprehensive ecological assessment, including both terrestrial and aquatic ecosystems, in accordance with the DEC's [sic] *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, 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.

10.1.2 Supplementary Director-General's requirements

As noted in Section 8.2.1, supplementary requirements were issued by the Department of Planning on 1 May 2009. The environmental assessment is required to also provide:

- a description of the action and an assessment of the relevant impacts that the action has, will have or is likely to have on the ecological character of the Hunter Estuary Wetlands Ramsar site in relation to the EPBC Act Policy Statement 1.1 *Significant Impact Guidelines Matter of National Environmental Significance* (May 2006)
- a description of the environmental values, including the ecological character of the Hunter Estuary Wetlands Ramsar site
- a description of the relevant impacts should include direct, indirect, cumulative and facilitative impacts on the quality, quantity and hydrological flow regimes of surface and groundwater flow. These impacts should be described for the construction and operation phases of the proposed action
- a description of the seasonal dynamics of the Williams River in the context of flows into the Hunter River Estuary, including volume, timing, duration, and frequency, and the associated maintenance of ecological character of the Ramsar site including a consideration of (and justification for) the worst case scenario
- a description of the relevant water planning and allocation frameworks for the Williams River, such as the draft Water Sharing Plan, and in this context a description of the proposed release strategy and assessment of the potential impacts on the ecological character of the Hunter Estuary Wetlands Ramsar site
- a description of the data and modelling used to develop the scenarios and proposed release strategy, including the assumptions, sensitivities and the degree of confidence in the predictions
- a description of feasible mitigation measures, changes to the proposed action or procedures, which have been proposed by the proponent or suggested in public submissions, and which are intended to prevent or minimise relevant impacts
- to the extent practicable, a description of any feasible alternatives to the proposed action that have been identified through the assessment, and their likely impact
- sufficient information about the proposed action and its relevant impacts to allow an informed decision whether or not to approve the controlled action under the EPBC Act
- information to address the matters outlined in Schedule 4 to the *Environment Protection and Biodiversity Conservation Regulations 2000*.

10.1.3 Approach to assessment

For the purpose of the assessment the Williams River was divided into five reaches from the river's headwaters to its confluence with the Hunter River. The five reaches were selected on the basis of catchment topography and existing ecosystem characteristics.

Within the first three reaches, representative sites for undertaking water quality, aquatic ecology and geomorphological sampling were identified to represent the length of the Williams River but with a focus on the proposed dam area. These represent reaches of the existing river above and within the storage, and below the dam. As impacts were 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.

The Seaham Weir Pool was selected for water quality sampling only as there is an absence of pool riffle habitats for aquatic and geomorphological sampling. Aquatic species sampled in reaches 1 to 3 are representative of those found throughout the entire river system and are assumed to inhabit the weir pool (reach 4). Further, the hydrology of the weir pool is controlled by the existing weir gates. When the river is not in flood, the weir pool water level is kept between 0.38 and 0.42 mAHD as required under the water management licence. No significant hydrological changes to that existing are therefore anticipated. No sites were selected within the Williams River estuary as satisfactory data on water quality from previous studies already exists for this area (eg Sanderson and Redden 2001, Sanderson *et al* 2002, Manly Hydraulics Laboratory 2003, Sinclair Knight Merz 2005, Sanderson 2008).

Summary details for each reach are provided in Table 10.1, including the respective sample sites, while their locations are illustrated in Figure 10.2.

TABLE 10.1 RIVER REACHES AND SAMPLING SITES

REACH	DESCRIPTION	SAMPLING SITE	SITE LOCATION	APPROXIMATE LENGTH (km)
1	Upper Williams River to Storage FSL	W1, W2	Upstream of storage area	34
2	Storage	W3 to W6	Within storage area	19 at FSL
3	Storage to Glen Martin	W7 to W8	Downstream of storage area and upstream of Chichester River confluence	63
		W9 to W12	Downstream of the Chichester River confluence and upstream of Glen Martin	
4	Seaham Weir Pool	SWP	Downstream of Glen Martin and upstream of Seaham Weir	23
5	Seaham Weir to Hunter River confluence	Not sampled	Downstream of Seaham Weir	15

Regular interaction occurred between the separate teams undertaking the investigations, the purpose being to identify issues in common and to effectively manage interdependencies between the investigations.

Potential environmental impacts below the confluence (including on the Hunter Estuary wetlands) are discussed separately in Section 10.10.

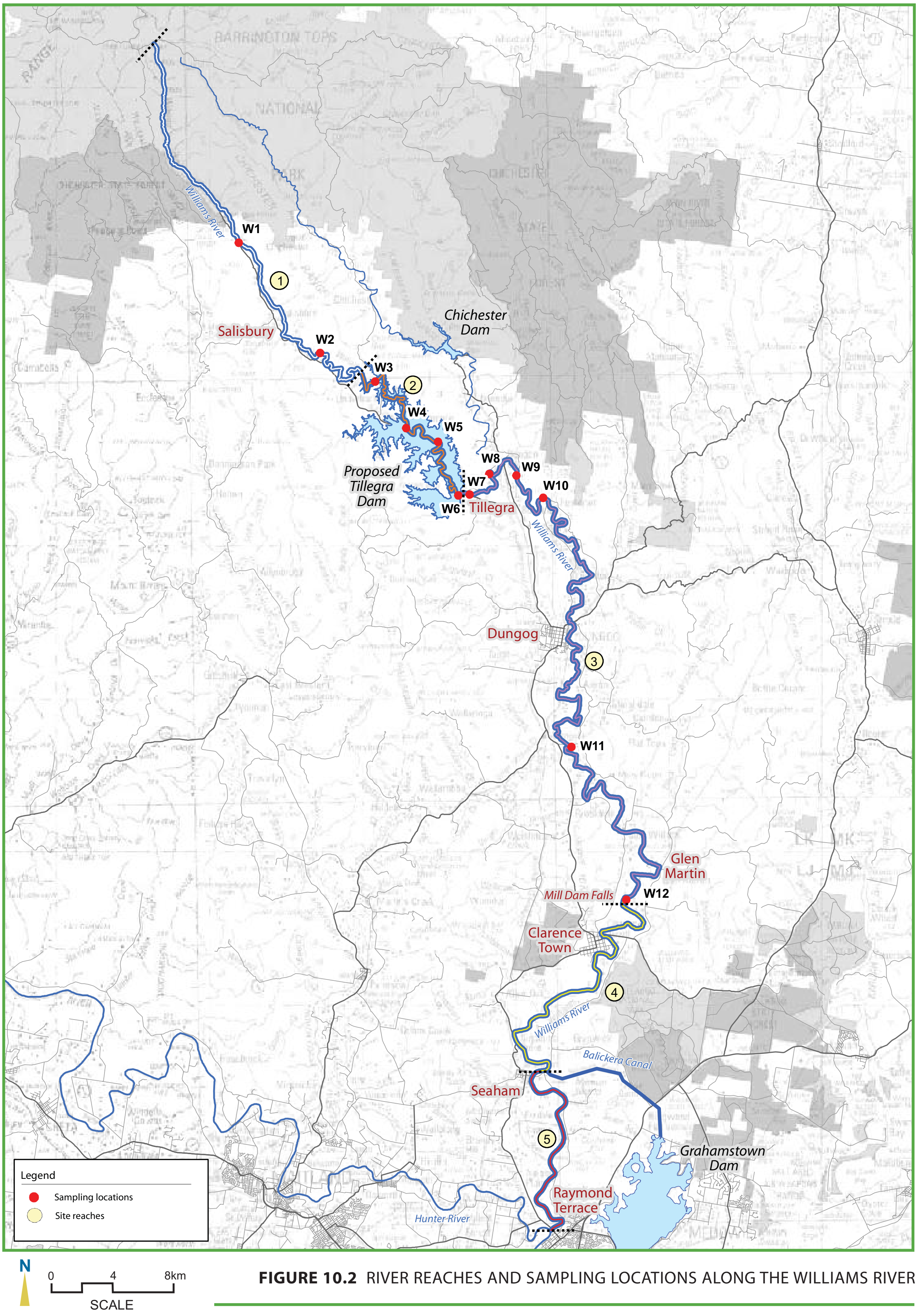


FIGURE 10.2 RIVER REACHES AND SAMPLING LOCATIONS ALONG THE WILLIAMS RIVER

10.2 Existing environment of the Williams River

10.2.1 General

The Williams River rises in the Barrington Tops National Park and flows southwest and then south to its confluence with the Hunter River estuary at Raymond Terrace. Subcatchments range in size from 7-200 km^2 (refer Figure 5.2). Areas for the subcatchments of interest are provided in the following table.

TABLE 10.2 WILLIAMS RIVER SUBCATCHMENTS RELEVANT TO PROJECT

CATCHMENT NAME	EXTENT	CATCHMENT AREA (km^2)	PER CENT OF TOTAL
Tillegra Dam	Williams River to Tillegra bridge	194	15
Chichester Dam	Chichester River to Chichester Dam	198	16
Glen Martin	Williams and Chichester Rivers to Glen Martin	993	78
Seaham Weir	Williams River to Seaham Weir	1,172	92
Total catchment to Hunter River	Williams River to Hunter River confluence	1,269	100

The upper catchment of the Williams River is characterised by steep vegetated slopes and the lower catchment by undulating and rolling hills with the majority of vegetation cleared for cattle grazing. Within the Williams River catchment, water is harvested from Chichester Dam and immediately upstream of Seaham Weir where it is pumped to Grahamstown Dam.

The Tillegra subcatchment is characterised by steep vegetated slopes rising to 1,500 mASL in the northern elevated region, and cleared agricultural land in the southern area of the catchment with an elevation of around 87 mASL at the site of the proposed dam at Tillegra Bridge.

The Chichester subcatchment is characterised by extensive virgin forests and steep slopes, and is regarded as one of the most pristine catchments in Australia with large areas unaffected by human activity (Hunter Water Corporation 2008b). Chichester Dam was constructed between 1917 and 1926.

Grahamstown Dam was constructed between 1955 and 1965 and is an off-river storage that is used to store water extracted from the Williams River. Water extracted from the Williams River at Seaham Weir Pool is transferred to Grahamstown Dam via the Balickera Canal. While water is primarily transferred into the dam from the Williams River, rainfall onto the surface of the dam as well as inflows from its own catchment can result in additional significant annual contributions to the storage of about 15 per cent of the total storage volume.

Seaham Weir was constructed in 1967 to provide a back-up fresh water supply, Seaham Weir Pool, to the Grahamstown Dam supply. The weir was founded on bedrock by dredging upstream and downstream of the weir which created deep pools on either side. Floodgates were incorporated into the weir structure in the 1970s to handle minor flows. Larger flood events overtop the weir.

The upper reaches of the Williams River comprise mainly numerous pool and riffle sequences and many glides. With increasing distance from the headwaters, the number of pool/riffle sequences decline with a single pool extending from Mill Dam Falls to Seaham Weir (Seaham Weir Pool). An example of a typical pool/riffle sequence is shown in Figure 10.3 (W7, immediately downstream of Tillegra Bridge). 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 features are important habitat for a variety of aquatic fauna.

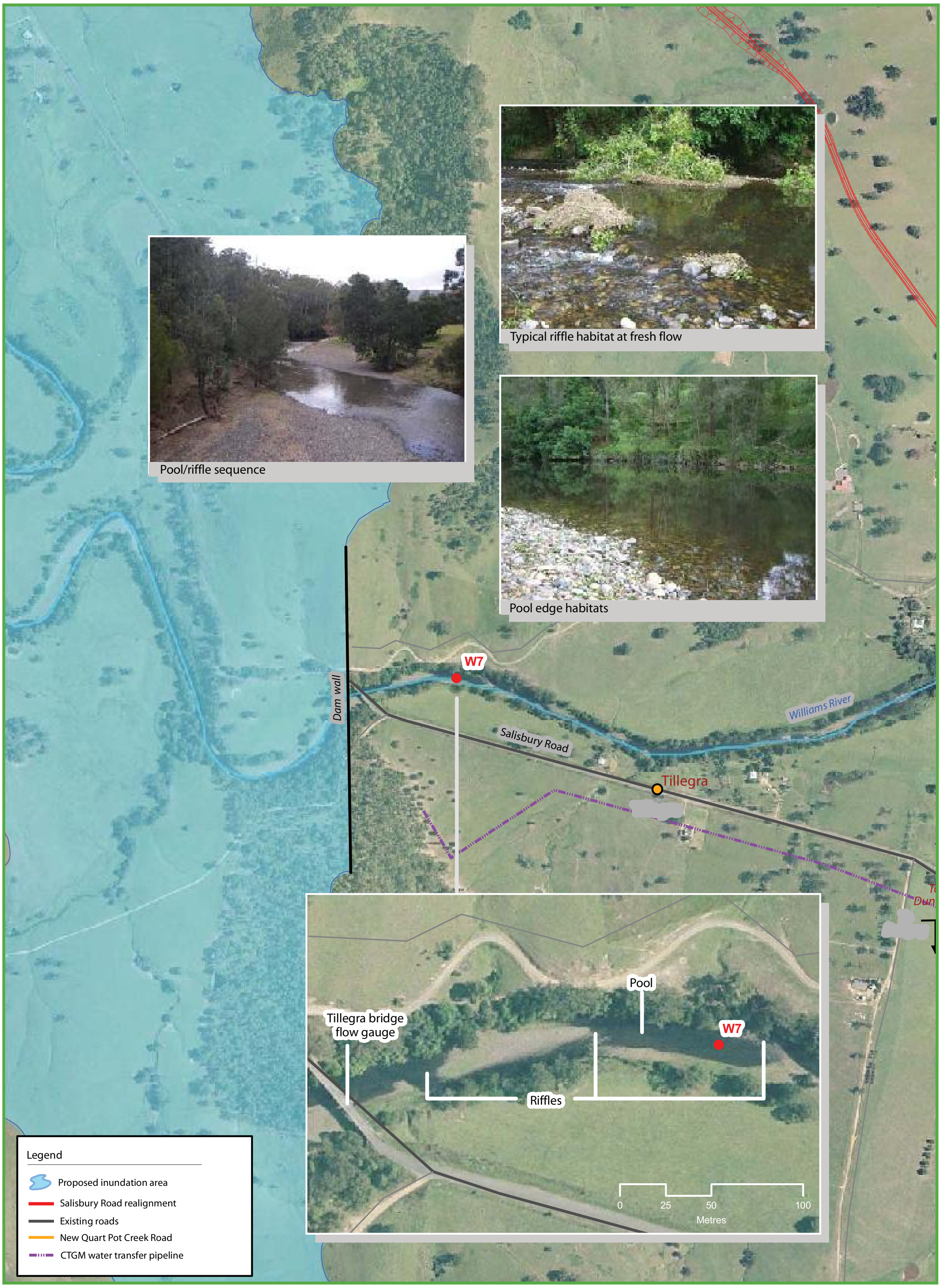


FIGURE 10.3 HABITATS WITHIN THE WILLIAMS RIVER

A schematic diagram of typical ecosystem and flow levels (low, moderate, fresh, high flow, bankfull and flood or overbank) of the Williams River are illustrated in Figure 10.4. This also highlights the complex interacting processes within an ecosystem. Low flows maintain habitat connectivity 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 10.6).

10.2.2 Hydrology and water quality

The Healthy Rivers Commission (1996) inquiry into the Williams River suggested the river was reasonably healthy 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 showing above elevated levels of nitrogen, phosphorus and faecal coliforms.

HWC has undertaken water quality monitoring in the Williams River at several locations, including Seaham, Glen Martin and Tillegra for approximately 20 years. Long term monitoring in the Williams River indicates that most water quality parameters are generally within the ANZECC guidelines with the exception of nitrogen and phosphorus which on average, consistently exceed the recommended guidelines[1]. Elevated levels of copper and zinc beyond the guidelines are also routinely recorded. While nitrogen and phosphorus levels exceed the recommended guidelines, the long term trend indicates an improvement in observed levels over time. Heavy metals in the river have also decreased while chlorophyll a, NFR (non-filterable residue) and thermotolerant coliforms have increased.

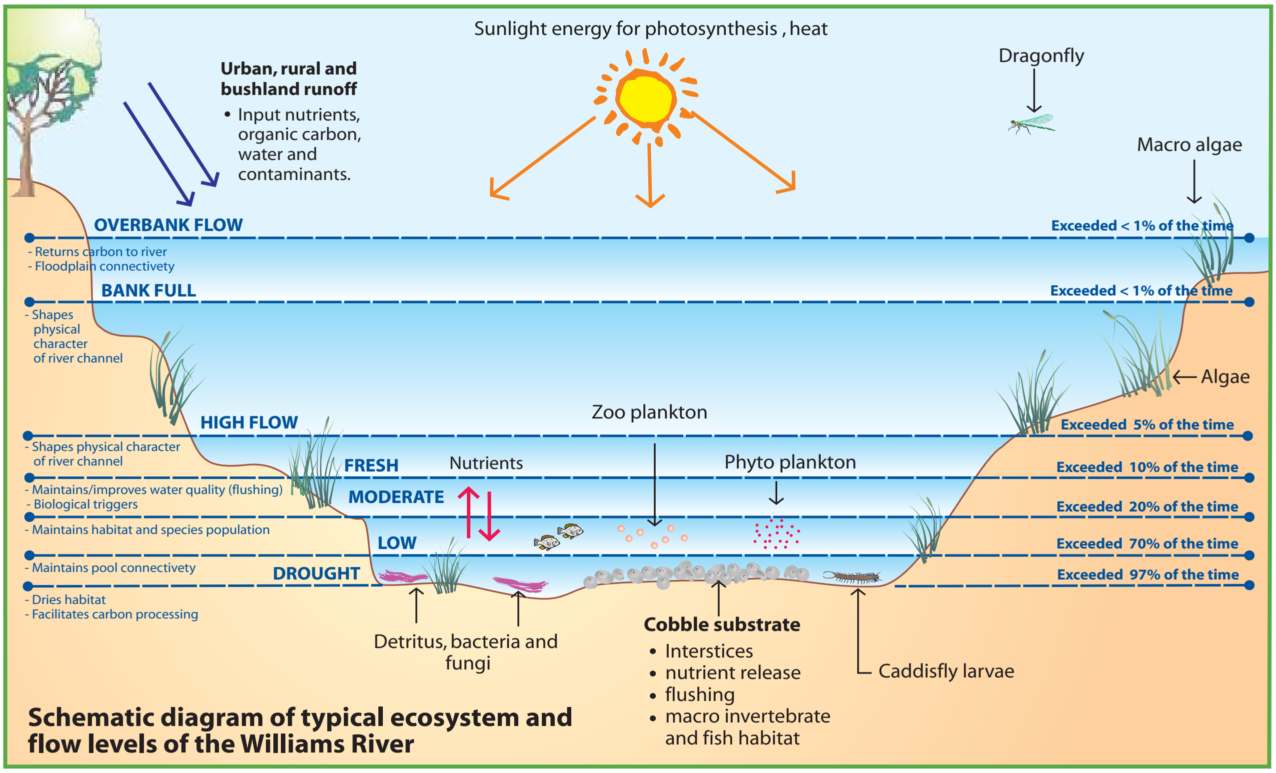


FIGURE 10.4 TYPICAL ECOSYSTEM AND FLOW LEVELS OF THE WILLIAMS RIVER

1 Unpublished HWC biennial water quality report for period 2005-07

The influence of agricultural activities in the catchment on river water quality is reflected in elevated concentrations of total nitrogen and phosphorus recorded in the long term monitoring results. While higher levels of total phosphorus (TP) recorded in the river above the ANZECC guidelines are indicative of the surrounding land use, it should also be noted that the concentrations of phosphorus in the Hunter and Williams Rivers are known to be significantly influenced by the underlying geology, a natural source of both phosphorus and zinc.

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 desnagging and bank stabilising works.

Of particular importance to an assessment of environmental flows is an understanding of the temporal variability of flows and their magnitude. The climate of the region is characterised by reasonably high rainfall with high intensity events in late summer and autumn, and less frequent rainfall events of the same magnitude, 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 baseflow during the wetter months. The inter-annual variability is marked by wet/dry periods during which the river can completely cease to flow for short periods during droughts but also maintain large flows during the wet cycles such as occurred between July 2007 and July 2008.

A detailed discussion on the existing water quality and hydrology of the Williams River is provided in Working Paper A.

10.2.3 Groundwater

As a general comment, the groundwater characteristics would be determined largely by the underlying geology that controls the permeability of the subsurface material. An overview of the location and setting of the Project including information on geology, landforms and soils has been provided in Chapter 5. A sequence of sedimentary rocks occurs at the project site and in the immediate environs which includes thickly bedded lithic sandstone (termed tuffaceous sandstone), with varying portions of mudstone (shale) and conglomerate with minor limestone (Dept of Commerce 2008b). The rock substance at the dam site is considered impermeable. Water movement is possible around parts of the impermeable rock mass, however, via bedding planes, shear zones and joint defects. There is a variety of soil landscape types present in the study area including alluvial, colluvial, erosional and stagnant alluvial (Henderson 2000).

Due to the underlying geology, there is no groundwater aquifer (such as a fractured rock aquifer) of any substantial nature at Tillegra as the thickly bedded lithic sandstone beds do not hold water. Groundwater at the site is contained within overlying the soil profile and in the first few metres of weathered rock, in line with normal gaining streams east of the divide. Rim stability and seepage reports completed by the Department of Commerce are contained within the technical annexures to this EA report.

Substantial longitudinal hyporheic flows are not characteristic of the Williams River and groundwater flows through soil infiltration are generally lateral, from the catchment into the main river channel. A representation of groundwater flows is shown in Figure 10.5. Groundwater is charged primarily by infiltration from rainfall rather than from river flow.

It is likely that the current longitudinal subterranean flows along an extended (several kilometres) reach of the river at Tillegra through the gravel beds would be minimal and only noticeable during

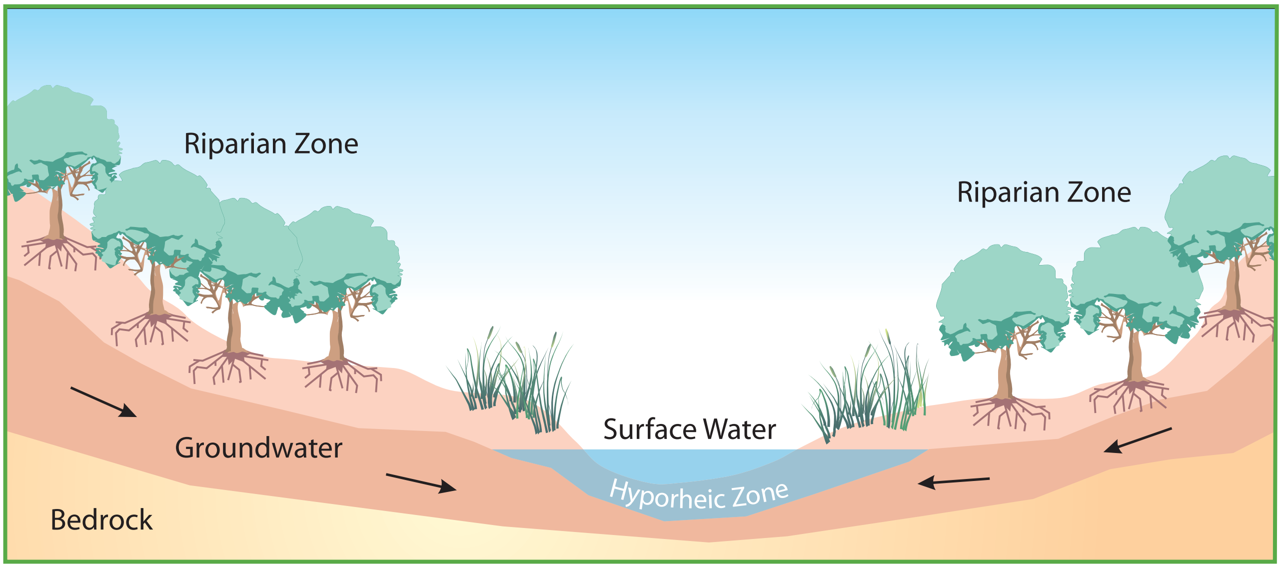


FIGURE 10.5 GROUNDWATER FLOW

drought times. Longitudinal subterranean flows at Tillegra Bridge were investigated and estimated to have an upper limit of 3 ML/d (refer Appendix E to Working Paper A). Leakage at the dam site through these gravel beds will be reduced as these will be removed during construction of the dam embankment. Prior to construction, gravel beds and associated overburden are removed to expose sound rock and a grout curtain is also installed. This ensures that the dam is built on solid foundations with minimal potential to be affected by leakage.

Recent geotechnical investigations undertaken by the Department of Commerce (refer Section 5.3.6) have included geological mapping of the dam site and storage perimeter, test pit investigations, a shallow seismic refraction survey of the dam site and diamond core boring. The borehole program has included both the measurement of depth to water table around the storage rim as well as pressure testing in various locations. Geotechnical investigations have been undertaken to understand rim stability and possible leakage from the dam.

The geotechnical investigations have shown that the proposed FSL of the storage lies well below the natural water table of the more elevated parts of the ridge systems surrounding the dam site. The lateral extent of groundwater has been found to extend past the extent of the proposed FSL indicating that groundwater movement will be into and towards the proposed storage rather than away from the dam and into adjacent valleys.

The rim of the storage was found to be stable and water tight with the exception of two saddles in close proximity to the left and right abutments of the dam. While leakage in these areas is considered to be a real possibility, this could be readily controlled at minimal cost by grouting affected areas. Grouting is a common technique applied to control flow through permeable rock strata and in simple terms involves the injection of water and cement under pressure into bore holes until a water tight seal is achieved in the underlying rock strata.

Minor leakage (as occurs at all dams) through the rock bedding planes at the base of the dam, after construction, is estimated to be about 1 ML/d. Longitudinal flows through and into the existing river alluvium will be preserved. In addition to grouting at the two low lying saddles near the left and right abutments grouting would be implemented at the dam wall to promote a water tight seal beneath the dam wall.

An assessment of the existing movement of water within the soils on the ridge lines and into the valley, as well as the minimal existing movement of longitudinal hyporheic flows through the rivers alluvium indicates that there would be no significant groundwater impacts from the Project. There is no potential for major leakage to occur from the storage or on this basis, for any impacts to existing groundwater users to occur. The rim stability and seepage reports have been independently reviewed by a panel of international experts.

10.2.4 Fluvial geomorphology

A comprehensive account of geomorphological conditions within the Hunter Catchment, including the Williams River is also available within the report River Styles within the Hunter Catchment (Cook and Schneider 2006) produced by the then Department of Natural Resources (DNR) and the HCRCMA. This report graded rivers in the Hunter as either having good, moderate or poor geomorphological condition.

The report notes that the Williams River is in good condition within the Confined Valley Setting Headwater area, upstream of Salisbury. Downstream, the river is considered to only have moderate geomorphological condition reflective of historical land use and river management activities, although some stretches, such as that near Thalaba Bridge are regarded to still be in good condition as this area was never desnagged as part of historic flood mitigation works.

The geomorphology of the Williams River is reasonably complex with four to five different descriptive geomorphologic styles relevant to the river noted within DNR and HCRCMA report. This work is complemented by recent investigations undertaken for the specific purpose of the Project. A detailed discussion of the fluvial geomorphology of the existing Williams River system is provided in Working Paper B.

Geomorphic process discharge thresholds

Modelling of geomorphic process thresholds revealed a consistent pattern in the river. The bed material is 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 is 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 bed of the river was observed to have few macrophytes present. The analysis indicates that hydraulic conditions are usually sufficient to exceed the thresholds associated with rupturing macrophyte stems.

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 to be actively migrating in places as evidenced by bare banks cut into the alluvium and by fallen trees. Modelling suggested that matted grasses and shrubs are reasonably resistant to hydraulic disturbance under most conditions.

The modelling also suggested that fine surface sediment is 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.

Geomorphic form discharge thresholds

The Williams River is evidently incised upstream of Glen William. The hydraulic and geomorphic modelling undertaken in this area suggested that the degree of incision is spatially variable as follows:

- between Tillegra and the Chichester River confluence the river appeared to be deeply incised such that the channel contains the 1 in 100 year ARI event
- at W9 and W10 the river is evidently incised but the floodplain is predicted to be flooded on average every 6-14 years
- at W11 and W12 the river is apparently not incised such that the floodplain is inundated on average every 1-3 years.

The river has a series of low inset benches and stable gravel bars present at various levels in the cross-sections. These surfaces require events of 1,000-8,000 ML/d for inundation. Such events are 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 are less frequently inundated. Riffles are mostly inundated by flows of around 350-500 ML/d. Such flows are very frequent in the current system occurring multiple times per year on average.

While the river is considered to be disconnected from the floodplain in many areas, according to Cook and Schneider (2006) this could potentially be a natural feature of the landscape between Fosterton and Glen Martin.

10.2.5 Aquatic and riparian ecology

The Williams River supports a substantial diversity of aquatic macroinvertebrate fauna. Eighty-five taxa of aquatic molluscs, crustaceans, worms and insects were identified from riffle and pool edge habitat over the surveyed sites. Edge and riffle habitat analysis (AusRivAS) found macroinvertebrate assemblages upstream of the proposed dam in forested catchment were comparable to reference conditions of similar systems. Sites downstream of the proposed dam where water flows through agricultural land were either comparable to reference conditions or had significantly fewer taxa than expected, suggesting existing impacts on water quality and/or aquatic habitats. However, results from these latter sites should be interpreted with caution as sampling took place during a time of relatively high flows, potentially under representing the number of taxa present rather than indicating underlying degraded water quality or habitat.

The most common fish species caught during the assessment 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.

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

A detailed discussion of the existing aquatic ecology of the Williams River is provided in Working Paper C.

The assessment undertaken for terrestrial ecology identified several different vegetation communities within the inundation area and downstream of the proposed dam wall. Downstream of Tillegra, past the confluence with the Chichester River, the riparian vegetation consists of a thin strip of trees *bordering cleared agricultural land. This vegetation is a combination of River Flat Eucalypt Forest on a Coastal Floodplain* and *Subtropical Coastal Floodplain Forest*, both of which are listed EECs.

The *Subtropical Coastal Floodplain Forest* EEC is the dominant vegetation type between Fosterton and Clarence Town with weeping myrtle (*Waterhousea floribunda*) and water gum (Tristaniopsis laurina) being dominant. Above the site of the proposed dam wall the dominant species were identified as grey myrtle (*Backhousia myrtifolia*) and lillypilly (*Acmena smithii*) and eucalypts. These species also occur below the dam wall location in both EECs.

Past Clarence Town, the river oak is replaced by the swamp oak and to a lesser extent, the forest oak due to the past saline influences above Seaham Weir. Eucalypts are also more common within the riparian habitats of this EEC.

During the terrestrial ecology field surveys, two platypuses (*Ornithorhynchus anatinus*) were observed foraging in pools of the Williams River in the vicinity of the Tillegra road bridge. Residents along the river also report observing platypuses and it is expected that individuals forage along the whole length of the river within the Project area and beyond. The exact size of the platypus population within the inundation area is unknown. Studies on other rivers have shown that on average, 1-2 platypuses per kilometre of river length is normal (The Australian Platypus Conservancy 2008). While not recorded during field surveys, the Australian water rat (*Hydromys chrysogaster*) is expected to occur in the larger pools of the Williams River and in larger farm dams. Neither species is listed as threatened but, as native species, are protected.

Further details on the ecology of the riparian zone are provided in Working Paper E *Terrestrial Ecology*.

10.2.6 Water users

There are 177 surface water extraction licences in the Williams River water source with a total entitlement of about 8,300 ML/yr (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.

While water extraction from the Williams River is predominately from surface water licences, there are a number of groundwater bores located with the area as shown in Figure 10.6. The figure shows all registered bores, however not all are used for water extraction, with some used for purposes such as water sampling or investigation. There are only four licensed groundwater bores in the river alluvium between the Tillegra Dam site and Dungog. The bore water from these is used for irrigation, stock and domestic supply.

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/d or 15 ML/d 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.

Town water supply licences and river access licences are the dominant licence types for the Williams River water source. There are, however, basic landholders rights and domestic and stock access licences that need to be taken into consideration. All water users of the Williams River water source and the corresponding total entitlement or share component are listed in Table 10.3.

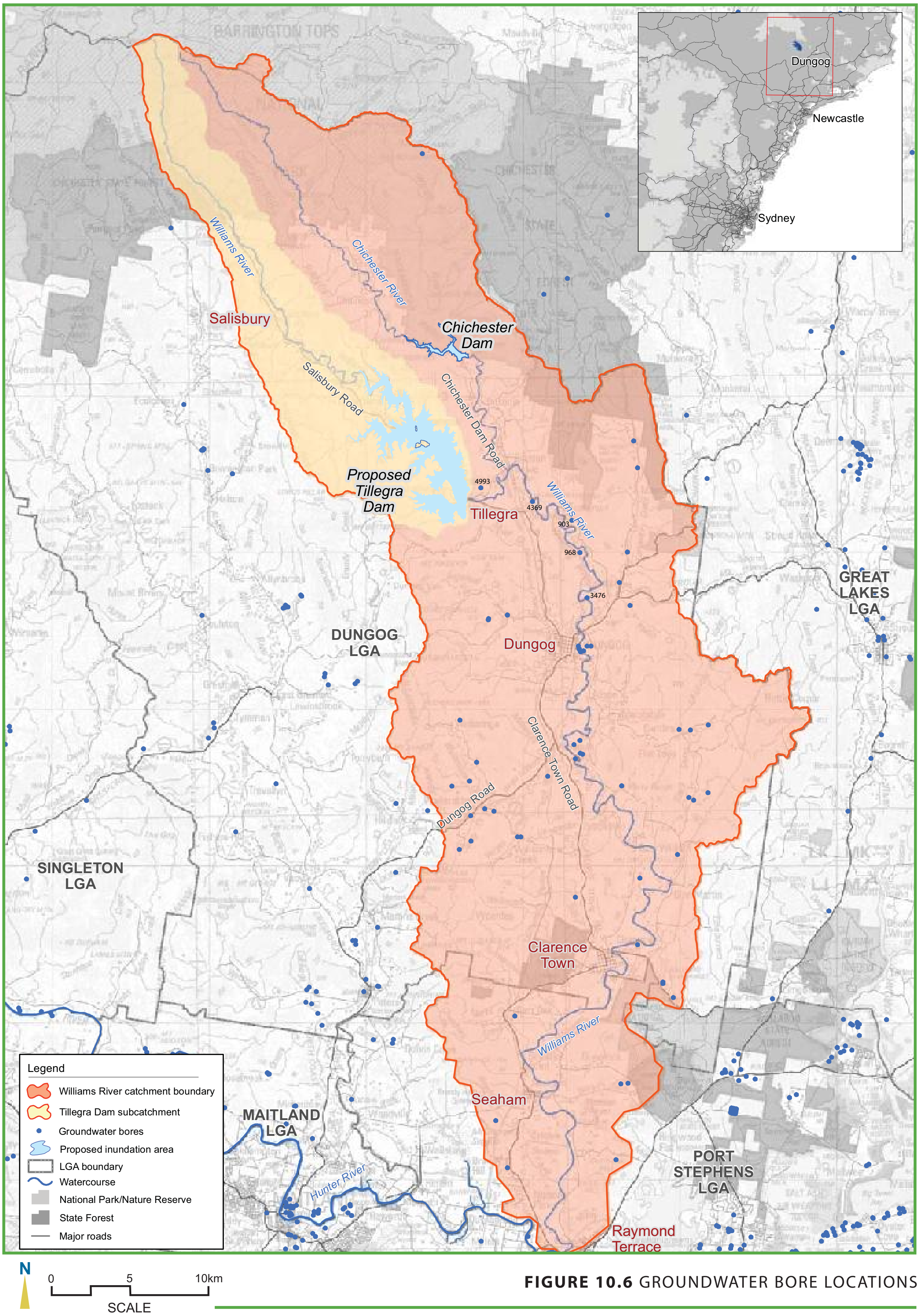


FIGURE 10.6 GROUNDWATER BORE LOCATIONS

TABLE 10.3 WATER USERS WITHIN THE WILLIAMS RIVER WATER SOURCE

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/yr
Share component of major utility access licences	239,000 ML/yr
Balickera pumping station	189,000 ML/yr
Chichester Dam	50,000 ML/yr
Share component of unregulated river access licences	8,239 unit shares

Source: Dept of Water and Energy, 2008a

In addition to licensing, water within the Williams River catchment provides for other productive uses such as 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 2000* 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. At the river basin scale, all water above the long term average annual extraction limit is set aside for environmental needs. At 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. These flow classes are:

- at or below 6 ML/d (very low flow class)
- at or below 15 ML/d (low flow class)
- greater than 15 ML/d (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 clauses 87(1) and 87(2) to establish rules for the release of water from Tillegra Dam (clause 94(1)(g)). Environmental releases from the dam would be incorporated into the water sharing plan in 2013 if deemed appropriate by the DWE.

10.2.7 Hunter estuary

The estuary reach of the Williams River between Seaham Weir and its confluence with the Hunter River at Raymond Terrace is approximately 15 kilometres in length and about six metres deep with a series of slightly deeper sections with the deepest of 14 metres located near the weir.

A number of investigations have been conducted into the water quality of the estuary. These include Sanderson *et al* (2001) and Manly Hydraulics Laboratory (2003). As part of the DWE water access licence review process an expert panel was established to review the impact of water extraction on the Williams River and in particular, downstream of the weir. The panel review included a reconnaissance trip and an estuary water quality monitoring program. Analysis of monitoring results found that surface warming and the formation of a density gradient downstream of the Seaham Weir results in stratification of the water column. The frequency, magnitude and duration of the stratification is dependant on a combination of solar radiation, catchment rainfall and flow over the weir.

The key findings of this study were:

- the water column downstream of the weir stratifies although the intensity of stratification was not as severe as that observed in the weir pool
- the deeper section to 14 metres depth immediately downstream of the weir is likely to be conducive to strong seasonal thermal and oxygen stratification due to limited mixing with surface and deep waters
- the potential for these anoxic conditions to develop can extend for several kilometres downstream of the weir
- a single flow event of 200 ML does not appear sufficient to fully mix the water column immediately downstream of the weir
- consecutive large flows (>600 ML) have the potential to mix the water column, however not immediately downstream of the weir
- water released from the weir appears sufficiently less dense than the receiving waters preventing vertical mixing immediately downstream
- water released from the weir is generally well oxygenated and at times can result in super saturation in surface waters downstream of the weir.

As a general comment, the behaviour of the estuary is rather complex with tidal flows and freshwater releases affecting mixing and water quality.

In 1996, HWC undertook a hydrology study at Seaham Weir (Hunter Water Corporation 2006c) to determine the component flows into and out of the weir pool and assessed the rate of water flows to the estuary under a range of river flow and pumping conditions. Flow components were estimated as follows:

- the average controlled gate outflow is 127 ML/d, the average length of opening is 1.35 hours and therefore the average discharge per event is 172 megalitres
- average daily outflow over the month through the existing fishway was calculated to be 5 ML/d
- a weir leakage loss (possibly including some farm usage and base flow losses) was calculated to be 5 ML/d
- average evaporative loss from the weir pool over the year is about 9 ML/d.

An assessment of the effect of HWC's existing operations on flow to the estuary was undertaken for the period 1 January 1999 to 30 September 2005. As part of the current assessment, a statistical analysis was undertaken on the modified daily flow estimates to the estuary for the period 1 January 1999 to 12 February 2005. Results are shown in Table 10.4.

TABLE 10.4 STATISTICAL ANALYSIS OF FLOWS TO THE ESTUARY (1 JAN 1999 TO 12 FEB 2005)

STATISTIC	ALL DATA	SUMMER	AUTUMN	WINTER	SPRING
Minimum	2	2	10	10	2
95th percentile exceedance	9	8	11	10	6
90th percentile exceedance	10	9	11	11	10
80th percentile exceedance	11	11	22	11	10
50th percentile exceedance	173	165	316	174	11
20th percentile exceedance	394	366	1085	353	182
10th percentile exceedance	1,008	606	3,243	692	592
5th percentile exceedance	3,027	1,144	8,919	1,679	1,387
Maximum	54,554	5,994	54,554	31,261	10,365

All flows in ML/d

These analyses show that close to 50 per cent of the time flow passing Seaham Weir is around 10 ML/d. The low flow estimate of around 10 ML/d comprises a component of flow through the fishway (approximately 5 ML/d) and an additional approximately 5 ML/d derived as a loss from the weir. It is assumed that this loss actually flows over or through the weir. During the spring and summer months when thermal heating is greatest, low flows passing the weir occur least frequently. These conditions increase the likelihood of stratification downstream of the weir and are important issues to consider in the management of releases from the weir.

10.2.8 Current operation of the Williams River

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

Under the Water Management Licence issued to HWC there is a requirement for Chichester Dam to release the 95th percentile low flow (as historically back calculated from Glen Martin) whenever inflow is higher than this value. The 95th percentile at Chichester Dam, calculated from Glen Martin, is 14 ML/d.

Water is extracted from the Williams River at Seaham Weir and pumped to Grahamstown Dam via the Balickera pumping station. HWC may operate the Balickera pumps if:

- the upstream flow is less than 600 ML/d and the weir pool level is greater than 0.42 metres AHD, or
- the upstream flow is greater than 600 ML/d and the weir pool level is greater than 0.32 metres AHD.

The Seaham Weir Pool is required to remain within specific water level ranges depending on whether the weir pool is operating in drainage mode, high flow mode or normal mode.

In addition, there are cease-to-pump restrictions placed on surface water extraction licences which have been 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 (ctp) levels when flows are at or below 6 ML/d or 15 ML/d at Glen Martin for accredited and non-accredited users respectively. Users within the weir pool are required to cease pumping when levels in the weir pool are at or below 0.38 metres.

Town water supply and irrigation licences are the dominant licence types for the Williams River water source. There are, however, others users which include basic landholders rights, domestic and stock licences, and various environmental uses such as visual amenity and primary and secondary contact for leisure and commercial activities.

10.3 Water balance model

HWC has developed a hydrological and water balance model of the Williams River catchment and town water supply system to provide information for water yield estimates and to assist with planning of future operational strategies. The model incorporates rainfall-runoff modules to simulate catchment inflows to the storages and main arm of the river, direct rainfall on the main storage areas (Chichester and Grahamstown Reservoirs and Seaham Weir pool), evaporative losses from the water surfaces, seepage/infiltration losses along the river reaches culminating at Seaham Weir with freshwater discharge to the estuary.

For the Tillegra Dam environmental assessment process, the model is set up to simulate storage volumes and river flows based on 75 years of existing flow and rainfall measurements for the period 1932 to 2005. Evaporative losses are modelled on the basis of evaporation rates measured at

Chichester Dam and other relevant meteorological stations across the catchment. The model seepage/infiltration losses have been calibrated against the 75 years of flow data at the Tillegra and Glen Martin gauging sites. The model produces daily estimates of flow, evaporation and seepage losses at various locations along the river for the specified operation regime of water transfers via the CTGM and Ballickera Canal.

Annual averages in GL/yr over the 75 years for the existing conditions with 75 GL/yr water demand are summarised in the schematic Figure 10.7 (Pre-Tillegra).

Model simulations for the future scenario with increased demand of 120 GL/yr, incorporate Tillegra Dam and its operations with environmental releases and run-of-river transfers. The evaporative and seepage loss rates for the future scenario are assumed to behave the same as the existing system.

The annual average water balance over the 75 years of simulated operation with Tillegra Dam is summarised in Figure 10.7 (Post-Tillegra).

The water balance indicates that with the current demand of 75 GL/yr about 61 GL/yr out of a total inflow above Seaham Weir of 337 GL/yr is diverted to Town Water Supply. For the projected 2050 system when demand is expected to increase to around 120 GL/yr the total diversion from the river will increase by another 60 GL/yr and additional evaporative losses from the Tillegra Dam water surface will lead to a reduction in the total flow to the estuary by about 60 GL/yr from the current 275 GL/yr to 215 GL/yr.

The results of the hydrological modelling have been used to assist with the assessment of likely effects on the aquatic environment and with development of an environmental and operational flow regime.

10.4 Environmental flow requirements

10.4.1 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 RFOs are as follows:

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

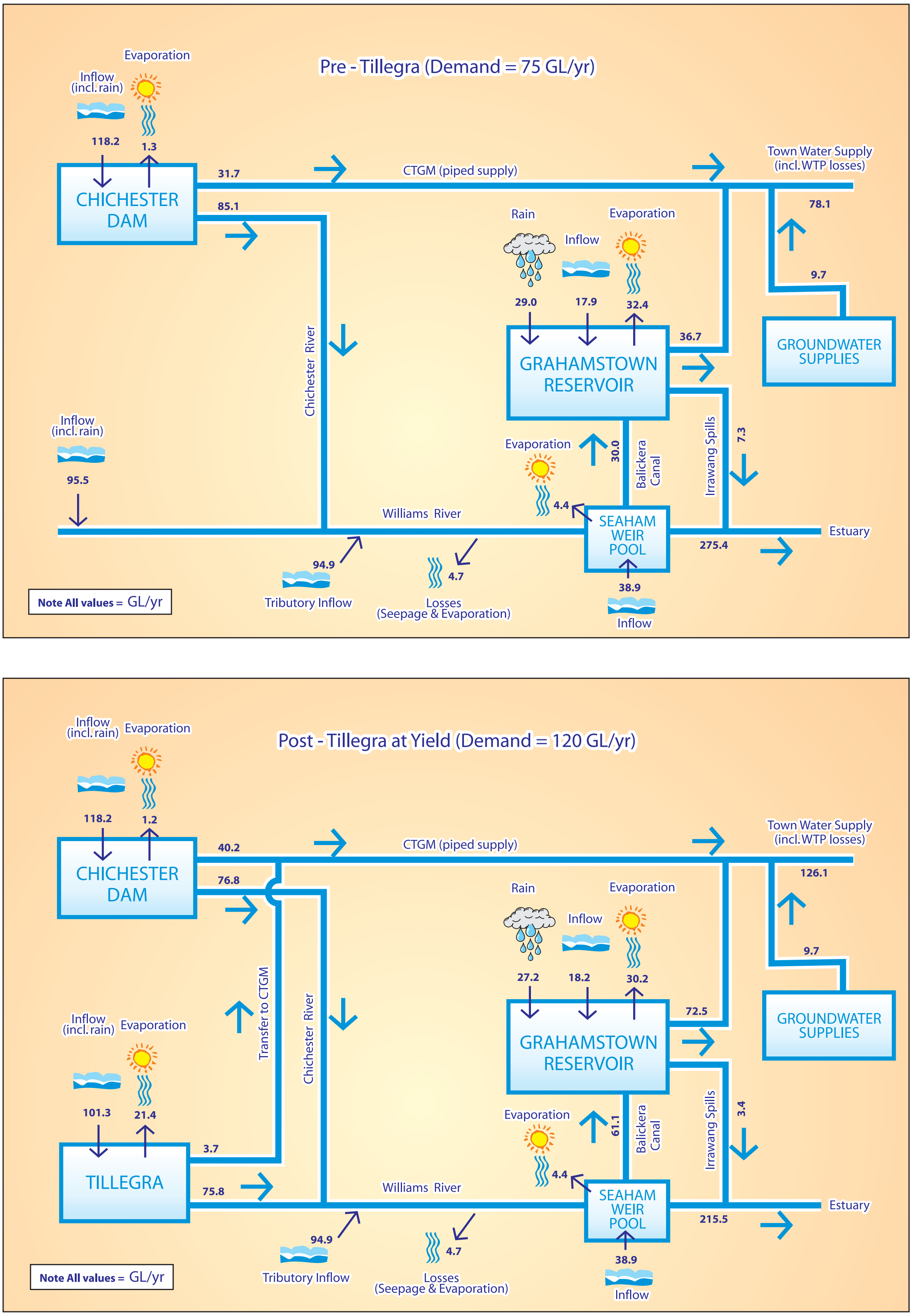


FIGURE 10.7 WATER BALANCE

9. Minimise the impact of instream 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.

A coordinated approach between relevant government agencies is required to meet the RFOs in the Williams River. 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. HWC could assist in achieving RFOs 2, 3, 4, 6, 7, 8, 9, 11 and 12 through appropriate dam release strategies. The way in which the dam release regime could assist in achieving these priority objectives is summarised in Table 10.5.

TABLE 10.5 RIVER FLOW OBJECTIVES AND TILLEGRA DAM OPERATION OPPORTUNITIES

PRIORITY RIVER FLOW OBJECTIVES		OPERATION OPPORTUNITY / COMMENT
2	Protect natural low flows	Transparent releases from storage
3	Protect or restore a proportion of moderate flows, freshes and high flows	Translucent releases from the storage Mimic 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	The Williams River does not support significant wetland areas maintained by overbank flows Transparent/translucent releases from the storage Mimic the natural flow regime during the release of
6	Maintain or mimic natural flow variability in all rivers	fresh events and run-of-river transfers from the storage Mimic the natural flow regime during fresh event releases and run-of-river transfers from the storage
7	Maintain rates of rise and fall of river heights within natural bounds	Improvements to Seaham Weir fishway and management of structures that impede fish passage
9	Minimise the impact of instream structures	Installation of a multi level offtake coupled with the release of water from an appropriate depth to meet
10	Minimise downstream water quality impacts of storage releases	downstream water quality requirements Time release of fresh events and run-of-river transfers may to manage water quality issues (eg algal bloom
11	Ensure river flow management provides for contingencies	flushing) No significant change in flow volume to estuary is expected
12	Maintain or rehabilitate estuarine processes and habitats	

10.4.2 Biodiversity and ecosystem objectives for the Williams River

The following biodiversity and ecosystem objectives for the Williams River were determined from hydrology, water quality, aquatic ecology and geomorphological information review, data analyses and field investigations conducted for the Project:

- 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 further in the following sections.

10.4.3 Flow components

River flow regimes can be characterised by their flow components which depend on the frequency of various flow levels. Flow components include floods (high flow, bankfull flow and overbank flow), freshes, moderate flows, low flows and drought. Consideration of flow component aspects such as seasonality, frequency, duration, magnitude, depth of flow and water quality is also required to determine appropriate environmental flow scenarios.

Natural river flows in the Williams River are highly variable in both space and time. The temporal variability of historic daily flows over the last 77 years at Tillegra Bridge is shown in Figure 10.8. The flow components and aspects described in Table 10.6 were derived from analysis of this data set and then related to the existing ecological and geomorphic water requirements. Table 10.6 also details key functions of each flow component. A graphical representation of flow component aspects (timing, duration, frequency) is shown in Figure 10.9.

More detailed information is provided in Working Paper A.

10.4.4 Water quality

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. Implementation of the RFOs in Section 10.3.1 would protect the natural river flow components and consequently have a positive influence on water quality.

For example, the river flow objective to maintain or mimic the natural flow regime (RFO 6) would minimise stratification of pools and conditions favourable to blue-green algae. Naturally variable flows help maintain a dynamic ecosystem and diverse biological community, in turn stimulating ecological processes that regulate water quality. Further examples of the river flow objectives and related processes that influence water quality are detailed in Working Paper D.

TABLE 10.6 KEY FEATURES AND FUNCTIONS OF FLOW COMPONENTS FOR 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	0 ML/d	0 ML/d	Dries habitats and substrates 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%	24 ML/d	48 ML/d	Connects instream habitats Maintenance of aquatic vegetation Refuge from high flows for biota Passage for juvenile fish
Moderate		Moderate flow in channel	Autumn Winter	Several annually	Weeks to months	70-20%	25-170 ML/d	50-600 ML/d	Maintain habitat Sustain species populations
Fresh		Flow greater than the median flow for that period	All seasons	Can be several in each period	Generally days	30-10%	100-400 ML/d	300-1,500 ML/d	Maintenance or improvement in water quality (flushing flows) Biological triggers or requirements (eg fish breeding) Passage for large fish Habitat connection
Flood	High flow	Less than bankfull flow. May include flow in minor floodplain channels	Autumn Winter Summer	May be several annually	Weeks	5%	>900 ML/d	>3,000 ML/d	Sediment movement/transport Inundation of organic matter Prevent encroachment of macrophytes Facilitates migration
	Bankfull flow	High flow within channel capacity	All seasons	Generally at least annual	Days to weeks	<1%	~20,000 ML/d	~20,000 ML/d	Channel and habitat forming Sediment movement/transport
	Overbank flow	Flow extends to floodplain surface flows	All seasons	Can be annual or less frequent	Days	<1%	>20,000 ML/d	>20,000 ML/d	Floodplain connectivity and recharge Carbon return to river

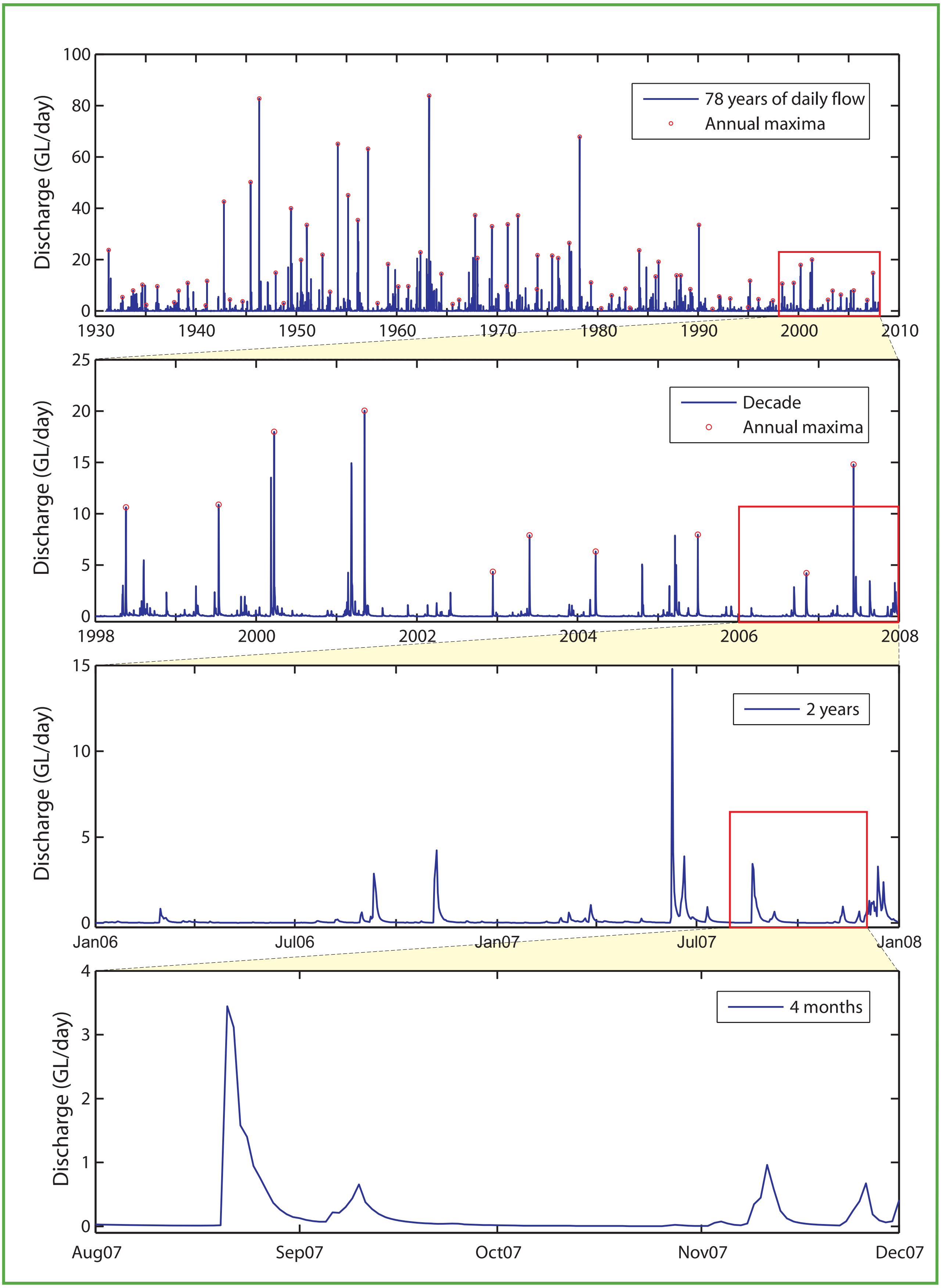


FIGURE 10.8 HISTORIC DAILY FLOWS AT TILLEGRA BRIDGE

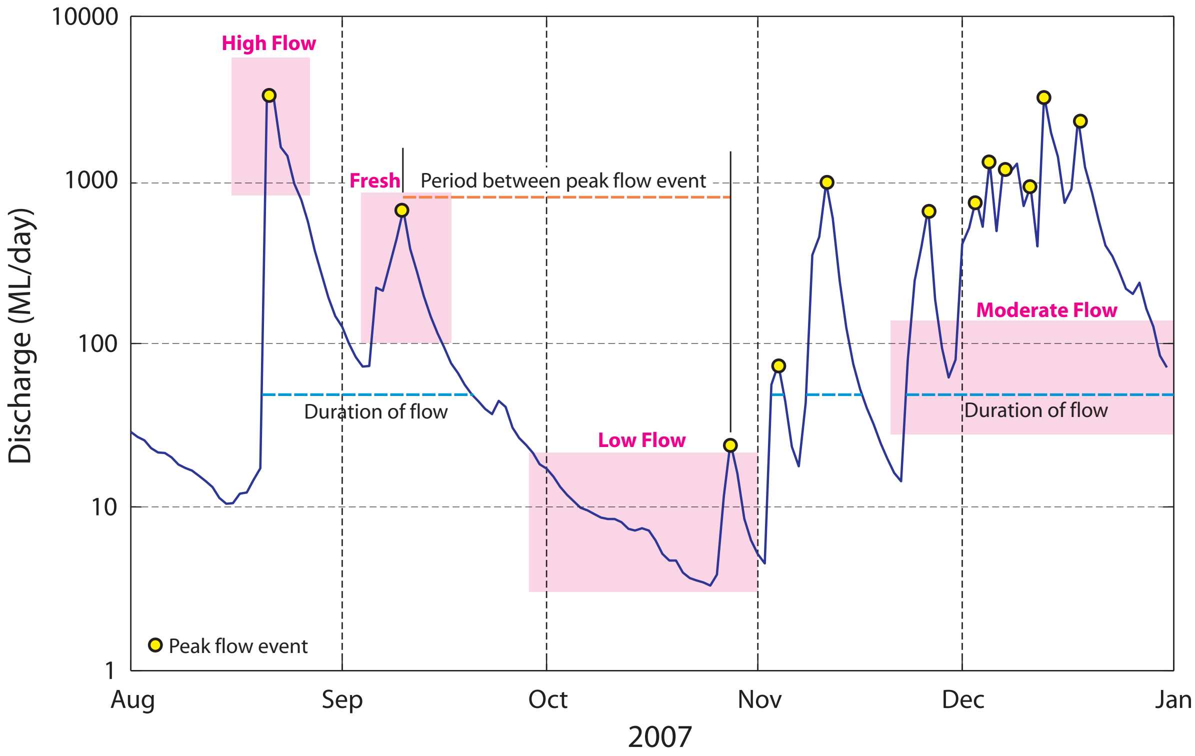


FIGURE 10.9 TILLEGRA DISCHARGE & FLOW COMPONENTS

10.4.5 Geomorphology

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, the relevant geomorphic objectives for the Williams River 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.

10.4.6 Aquatic and riparian ecology

Aquatic macroinvertebrates

Macroinvertebrate diversity within the Williams River is dependent on habitat complexity as many taxa have close associations with particular habitat forms (eg alternating pools and riffles, gravel banks/bars). 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.

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.

The important flow component aspects to maintain fish populations within the Williams River include depth of water for habitat and fish passage (migration and spawning), velocity thresholds for fish passage, temporal variability in flows and the magnitude of flows.

General flora and fauna

Aquatic ecology investigations noted that a range of emergent macrophytes, fringing riparian vegetation and aquatic vegetation exists within the Williams River. Species included Lomandra longifolia along the banks of the Williams River, emergents such as the common reed (Phragmites australis) sedges (Isolepsis nodosa, Schoenus nitens, Eleocharis sphacelate), cumbungi (Typha orientalis) and aquatic species such as water fern (Azolla filiculoides), water primrose (Ludwigia peploides ssp. montevidensis), water ribbons (Triglochin procerum) and other aquatic plants such as Vallisnera and Elodea. Freshwater algae such as Compsopogon, Melosira and Cladophora sp were also present along the length of the river.

The terrestrial ecology field investigations positively identified 16 frog species (none listed as threatened) within the Project area, most being recorded along the Williams River. While not recorded during the field survey, two locations were identified within the Project area where suitable habitat for the threatened stuttering frog (Mixophyes balbus) could occurr. Additional expert advice was sought on the value of this habitat. This indicated that the extent of this habitat was marginal due to its small size and as a consequence it was unlikely to sustain a viable population of the stuttering frog.

The underlying flow regime within a river can influence the both the distribution and abundance of aquatic flora and fauna. Two locally significant species of interest to the Project, the platypus and Australian water rat, are dependant on permanent flowing water.

The platypus is highly adapted to an aquatic lifestyle feeding on benthic macroinvertebrates, particularly insect larvae, freshwater shrimps and crayfish with the composition and percentage of food items changing with the season. A varied substrate of gravel, pebbles, cobbles, rocks, submerged logs and overhanging streamside vegetation are important for the supply of sufficient food items.

When not active the platypus shelters in a burrow situated in the river bank. The entrance is usually situated above the water level where the earth banks are consolidated by tree roots.

The Australian water rat is a carnivorous species which feeds mainly on aquatic items such as large insects, fish, crustaceans and shellfish, although birds eggs, waterbirds, frogs, lizards and small mammals are sometimes taken, particularly in winter when less time is spent in the water. It nests in burrows or hollow logs, with burrows running parallel to the river bank. Regular tracks are used along the river bank and middens of prey remains are often deposited on flat rocks near the water's edge. The water rat tends to be more terrestrial than the platypus, carrying out short foraging trips and consuming the resulting catch on land.

10.4.7 Other issues

Surface water licences

There is a requirement of the Williams River system to provide water for surface water extraction licences (the majority for irrigation) downstream of the proposed Tillegra Dam. Low flows need to be maintained so there is no interference to existing extraction rights. During both construction and operation of the dam the percentage of time cease–to-pump flows exist should at a minimum remain the same as historic.

Drought security

The proposed 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 50 years.

10.5 Environmental release strategy

Development of an appropriate environmental release strategy for the Williams River is an evolving and ongoing process. Review and refinement (where required) would form part of ongoing system operation, reflecting the dynamic nature of the environment.

The strategy put forward in this chapter reflects the modelling and assessment undertaken to date. The final environmental release strategy would be determined following an extensive review process and consideration of public submissions. 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 transparent and translucent environmental releases, constant run-of-river transfers and flushing events
- assessment of the base case strategy with regard to hydrology, water quality, geomorphology and aquatic ecology requirements
- suggested improvements to the base case strategy to provide protection of the downstream ecosystem (eg run-of-river event based transfers and seasonality of transfer releases to prevent sudden or unatural flow regimes occurring from the dam).

The draft *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources* makes an allowance to include operation of Tillegra Dam within its water management framework. The specific operating rules for the proposed dam will be incorporated into the plan in 2013 as decided by DWE but the rules are likely to reflect suggestions in the following sections.

10.5.1 Development of the 'base case' environmental release strategy

A range of flow release strategies were modelled (refer Table 10.7) and the potential environmental effects assessed to determine an appropriate base case release strategy that would provide a suitable level of protection to the river environment, continued water access to irrigators and drought water supply security to the community.

Irrigator water rights comprise a flow allocation (around 8,300 ML/yr) and a cease-to-pump condition. This demand represents about seven per cent of the mean annual flow in the Williams River and equates to around 23 ML/d or around the 70th percentile exceedence. For the purpose of the assessment, irrigator and environmental releases were combined into a single release strategy as daily extraction volumes were not available and it was impractical to separate these components at the Tillegra Dam site.

TABLE 10.7 INITIAL BASE CASE RELEASE STRATEGIES INVESTIGATED

TRANSPARENT CUTOFF*	TRANSLUCENT CUTOFF*	LARGER EVENTS	COMMENT
95th			• Protects low flows
80th			• Protects low flows
80th	60% of flows between the 80th and 30th percentiles		• Protects low and moderate flows • Provides additional water for selected fish species passage • Protects licence demands
90th	60% of flows between the 90th and 30th percentiles	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 per cent exceedence of inflow

Environmental flow releases are generally related to the storage 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, where the volume released is equivalent to the inflow
- a moderate flow 'translucent' component in which a proportion of the inflow is released
- specific flow event releases to provide infrequent fresh or high flows to the river downstream.

The outcomes of the four scenarios modelled are discussed as follows.

Transparent to 95th percentile exceedence

The 95th percentile exceedence release scenario applies to the Chichester Dam that also spills around five times its volume annually. The 95th percentile at Tillegra is around 1.9 ML/d which would not be sufficient to satisfy the priority RFOs nor protect downstream stock and irrigator rights. Given these issues, this strategy was not considered further.

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 are protected when the minimum water height is maintained above this level. Analysis of 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/d at Tillegra.

A static release of 15.9 ML/d 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 this strategy may be appropriate for a relatively short filling period (say less than three 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 seven years. Consequently, 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/d). This comprised the release of 60 per cent of inflows between 15.9 ML/d and 100 ML/d so for inflows of 100 ML/d or greater the release flow would be 63 ML/d.

By the time inflows at Tillegra reach 100 ML/d 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 release strategy together with constant releases and flushing events aims to protect the moderate flows, freshes and some high flows. This release strategy would also provide sufficient flow to maintain 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/d or 15 ML/d 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 indicated that on average, the cease-to-pump flows with the dam would be triggered less frequently, by three to four per cent against the pre-dam case. While this flow regime improves accessibility to the river for irrigators, constant flows of a persistent nature are generally not considered to be sympathetic to the natural environment and the maintenance of aquatic ecosystem functions.

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 would be delivered as a constant flow over the month (30 days).

Additional flushing events were included to provide flows capable of flushing the lower system and to improve water quality. These flows would help discourage the development of conditions favourable to blue-green algae blooms.

10.5.2 Refinement of the base case environmental release strategy

Modelling of the base case scenario assumed a transparent flow to the 90th percentile and a translucent flow to the 30th percentile at a rate of 60 per cent. The base case scenario also included flushing events and constant run-of-river releases that would be triggered when Tillegra Dam was above 90 per cent capacity or Grahamstown Dam being below 40 per cent capacity. Under this scenario transfers would generally occur during spring and summer. An assessment of this base case scenario on water quality, hydrology, aquatic ecology and geomorphology was undertaken and the following noted regarding the 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/d), with the exception of infrequent flushing events, were released from the dam. Constant run-of-river transfers have a peak flow of 500 ML/d and mean spilling flows are 461 ML/d
- the seasonality of run-of-river transfers was not similar to pre-dam conditions. Constant run-of-river transfers were generally triggered during the ecologically sensitive spring and summer months which are normally subject to low instream flow.
- 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, a number of opportunities to improve the base case environmental release strategy were identified which would provide for protection of the riverine environment with minimal loss of ecosystem function. These comprise:

- 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
- refinement and additional modelling to account for rainfall directly onto the surface of the reservoir, dam inflows below the Underbank river gauging station and understanding possible changes to the daily flow regime derived from preferential use of the multi-level offtake tower in lieu of uncontrolled spillway flows.

These are discussed further as follows.

Run-of-river event based transfers

Modelling of the release scenarios assumed a constant release rate for the run-of-river transfers during any particular month. The timing of these releases could instead be modified to more closely mimic the natural variability of flows in the river. A run-of-river transfer was modelled on natural peak flow events in the range 1,000-1,800 ML/d (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 to the receding median flow for each day as follows:

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

where Q(t) is the release discharge (ML/d) 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 1,500 ML/d to 61.3 ML/d on Day 10. The total volume released over the 10 days is 4,300 megalitres which is typical of the smaller simulated constant bulk transfer flows.

Replacing the constant run-of-river volumes modelled by the release pattern described above would need to occur, on average, around seven times per year for the 2050 demand. The 2050 demand modelling suggests the number of 10 day release events would range from zero to a maximum of 17 during the driest year.

As an initial variation from the base case scenario, releases from the dam were modelled assuming the 90/30 environmental flows and run-of-river event based transfers. The results are illustrated in Figure 10.10 and highlight the differences in flow distribution between the following three data sets:

- post-dam base case scenario
- historic flows
- post-dam flows with run-of-river event based transfers.

Flow distribution of the post-dam flows with run-of-river event based transfers more closely mimic the pre-dam flow regime.

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 downstream ecosystems. The proposed flushing event comprises a 2,000 megalitre release for one day while the run-of-river event based transfer has a peak flow of 1,500 ML/d 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 reduce the frequency of blue-green algae blooms within the Seaham Weir Pool.

Seasonality of run-of-river transfers

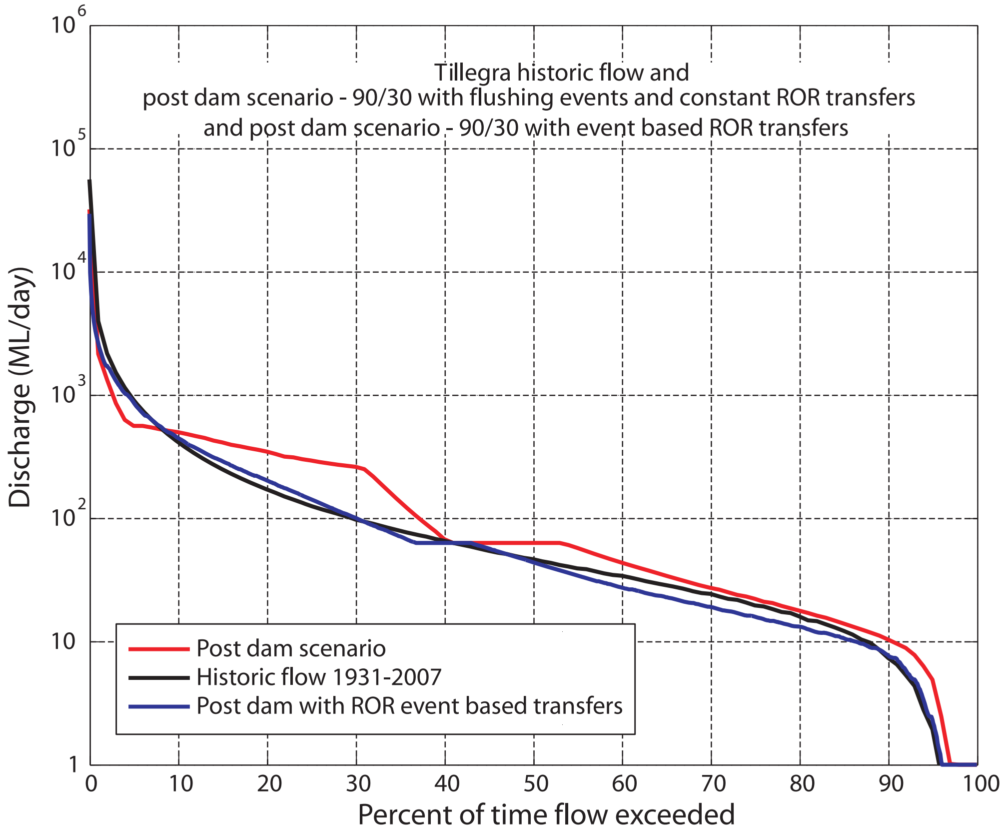
Run-of-river transfers in the modelled base case scenario were predominantly triggered by demand at Grahamstown Dam. As a result, the majority of transfers were made during the spring and summer months which are critical times for recruitment of taxa that have life histories adapted to stable low flows.

A preferable alternative to avoid sudden or unnatural flow regimes would be 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 spring and summer. This pattern should be mimicked as closely 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 (and to a lesser extent the months of January, July and August) would deliver positive environmental improvements to the river.

Minimum number of releases per year

As discussed earlier, fresh releases in addition to environmental releases are proposed during the filling 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 could be made up of a combination of run-of-river event based transfers, spilling flows or fresh releases.

In addition to these six events per year it would be desirable to increase the number of releases per year should the filling phase exceed three years to reduce any possible accumulating impacts. It would be desirable to increase both the frequency and magnitude of the event releases to



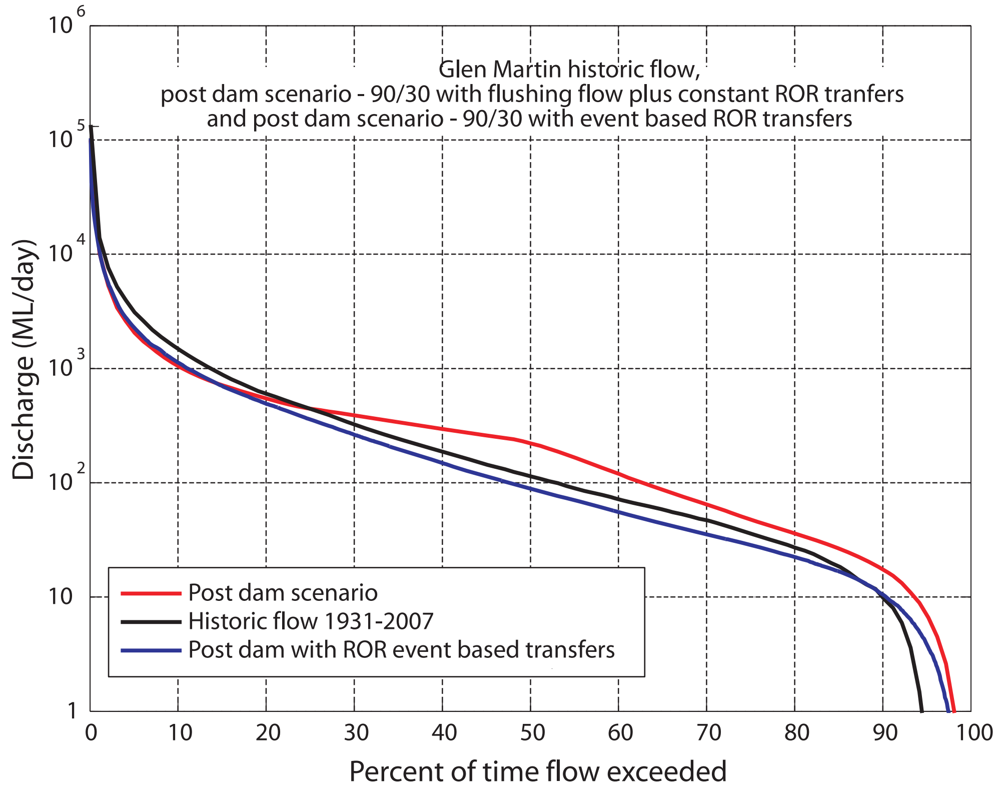


FIGURE 10.10 DAILY FLOW DISTRIBUTIONS FOR TILLEGRA AND GLEN MARTIN

incorporate a combination of fresh and run-of-river transfer releases. Further information on the desired frequency and distribution of additional releases is provided in Working Paper C. The number and type of releases were determined through an analysis (magnitude and frequency) of peak events for the period of record (1931-2007).

Immediately downstream of the dam, the reduction in the frequency, magnitude and duration of natural flows would lead to further decline in the current condition of the ecosystem especially if the filling phase is prolonged and additional releases were not made. The decline would occur as the existing ecosystem 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 would not be possible without affecting the dam's security of supply, the ecosystem between the dam and the Chichester River confluence would likely be affected.

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

Refinement and additional modelling

Recent improvements to the hydrological model have been incorporated by HWC and include event-based run-of-river transfers, a change in the seasonality of releases and an accounting for rainfall and evaporation of the surface of the storage, as well as an increase in gross yield from additional inflow from the catchment below Underbank. Further, the concept of allocating 100 millimetres of airspace into the storage to allow preferential discharges through the offtake tower, as opposed to allowing uncontrolled spillway discharges to occur, was considered.

The final advanced round of modelling confirmed that the transparent and translucent flows would closely mimic natural flow conditions below the dam. However, it was necessary to account for catchment flow contributions below the Underbank gauge as flows in the river would otherwise be reduced by 15-20 per cent between the 50th and 75th percentiles. The introduction of preferential off-take tower flows revolving around the preservation of 100 millimetres of airspace 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 Dam 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 to 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 20 ML day from Chichester would preserve flows through the entire river system (as measured at the Glen Martin gauge) up to the 50th percentile of all flows. Further, with the release of this additional water, flows between the 50th and 30th percentiles (larger moderate flows and freshes) would only be suppressed by 10-15 per cent which is considered unlikely to have any significant negative ecological effect.

Results from the hydrological model and base case release scenario are shown in Table 10.8. The recommended release strategy and environmental flow regime for the dam is therefore considered to be a fully transparent flow from the dam to the 30th percentile, preferential use of the multi-level off take tower and as part of a holistic approach to managing the river, increased flows from Chichester Dam (to 20 ML/d). This represents a significant environmentally sympathetic improvement compared to current environmental release strategies operating in many other NSW storages.

TABLE 10.8 GLEN MARTIN GAUGE HISTORIC AND FINAL RELEASE SCENARIO

STATISTIC	HISTORIC	BASE CASE FULLY REFINED TD TRANSPARENT TO 90TH, 60% TRANSLUCENT TO 30TH %ILE	BASE CASE FULLY REFINED + TD TRANSPARENT TO 30TH %ILE	TD TRANSPARENT TO 90TH, 60% TRANSLUCENT TO 30TH %ILE, TOWER FLOW, CD TRANSPARENT TO 95TH %ILE	TD TRANSPARENT TO 30TH %ILE, TOWER FLOW, CD TRANSPARENT TO 95TH %ILE
Maximum	127029	104846	104883	107283	107173
5th percentile exceedance	3166	2185	2173	2618	2585
10th percentile exceedance	1139	1174	1141	1115	1053
20th percentile exceedance	490	517	510	386	386
30th percentile exceedance	282	280	284	211	230
50th percentile exceedance	104	92	107	83	102
80th percentile exceedance	26	23	28	28	33
90th percentile exceedance	11	11	12	16	17
95th percentile exceedance	3	4	4	8	8
Minimum	0	0	0	0	0

All flows in ML/d

10.5.3 Preferred operating strategies

The preferred operating strategies for the dam are as follows:

- Tillegra Dam – transparent release to 30th percentile (100 ML/d)
- Chichester Dam – transparent release to 95th percentile (20 ML/d)
- peaked 1,500 ML run of river transfer flows declining over a 10 day period
- additional peaked 270 ML flows to ensure a minimum of six fresh events from the dam per year (to augment where necessary any combination of spillway flows or run-of-river flows)
- preferential use of multi-level off take tower to limit extent of uncontrolled spillway flows.

A full overview of the proposed flow regime from the dam during the construction, filling and operational phases is presented in the following table.

TABLE 10.9 FINAL ENVIRONMENTAL FLOW SCENARIO AS IMPROVED FROM BASE CASE

PHASE	RELEASE SCENARIOS		
Construction	Transparent – all water bypassed through diversion tunnel		
Filling	Years 1-2	Initial releases	Static release of up to 80 ML/d through bypass pipe until water level sufficient to operate offtake tower.
		Environmental releases	Tillegra: 100% transparency to the 30th percentile exceedance (100ML/day) Chichester: 100% transparency to the 95th percentile exceedance, as modelled for Chichester (20ML/day)
		Fresh releases	Minimum of six fresh releases per annum (consisting of natural spills, fresh releases or run-of-river transfers of any combination. Fresh releases are event based (triggered by monitored inflow to the reservoir) consisting of a peak flow of 270 ML/d for 1.5-2 days and will be preferentially made in the months of Jan, Mar, Apr, May, Jul or Aug
	Year 3	Environmental releases	As above
		Run-of-river transfers*	Run-of-river transfers with a peaked 1500ML discharge would commence at anytime from year 3.*#
Standard operation		Environmental releases	As above
		Run-of-river transfers*	As above. Releases generally made when Tillegra > 90% FSL or Grahamstown Dam < 40% FSL
		Off-take tower	Preferential use of off-take tower to reduce the incidence of uncontrolled spillway flows except in large floods

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

\# Flows peaked up to 1,700 ML may need to discharged after prolonged droughts and during summer periods to achieve a peaked river flow of 1,500 ML, to account for channel transmission losses through groundwater infiltration, above average evaporation rates and incidental extractions from licensed water users

10.5.4 Alternatives to run-of-river transfers

The only alternative to run-of-river transfers to deliver water from the dam to Grahamstown Dam would be the augmentation or duplication of the CTGM (bulk water main currently connected to Chichester Dam). This would not be cost effective nor practicable based on transfer volume requirements.

Run-of-river transfers would utilise existing infrastructure at Seaham Weir and Balickera Pumping Station with little additional cost. Further, river transfers would provide benefits to the river environment prior to extraction at Seaham Weir Pool provided appropriate release rules from the dam are observed to maintain the environmental health of the river.

In contrast, augmentation or duplication of the CTGM would not offer such benefits as flows would be diverted away from the river through the pipe network. Additionally, clearing and construction works would be required along the pipeline route, for augmentation or duplication of the CTGM, with the potential to impact on the local environment.

Using the river to deliver flows from Tillegra Dam to Grahamstown Dam would incur losses from evaporation, channel transmission and third party use. However, these losses would be comparatively minor.

Further to general environmental impacts that would be derived from the construction of a new pipeline, and even with the acknowledgement that positive environmental benefits can be realised by leaving the water in the river to the end of system in order to maintain aquatic ecosystems, preliminary estimates of cost by HWC indicate that augmentation or duplication of the CTGM would be in the order of $250 to $300 million. This estimate is based on HWC's experience with the construction and maintenance of other bulk water mains.

It is therefore considered that there is no feasible alternative to run of river transfers to allow water to be entrained into the town water treatment and distribution system. Duplication of the CTGM would incur substantial costs that would almost certainly make the project financially unviable as well as cause additional detrimental environmental impacts through pipeline construction works and reduced river flows.

10.6 Water quality and hydrology

10.6.1 Construction

The majority of impacts on water quality and hydrology associated with construction are expected to occur within the immediate Project area (the lower part of Reach 2 and the upper part of Reach 3). They will be related to:

- the relocation of Salisbury Road (including bridge construction)
- construction of the dam wall
- construction of dam detour road and bridge.
- construction of the coffer dams for river diversion.

Construction of the new section of Salisbury Road includes three waterway crossings, two over the Williams River and one over Moolee Creek. An additional bridge would be constructed across Quart Pot Creek.

Above the inundation area, construction activities would be associated with building the new section of Salisbury Road, the new access to the Quart Pot Creek area, and other matters such as the relocation of Quart Pot/Munni Cemetery and the RFS station.

Construction activities would involve widespread disturbance of soils at and around the construction sites. Consequently, there would be risk of erosion and for sediment-laden runoff to enter waterways. The construction phase is also likely to require the delivery, storage, use and disposal of environmentally hazardous substances such as diesel and lubricating oil. Both could pose a risk to water quality if not appropriately managed.

Construction activities adjacent to or within waterways (mainly related to construction of piers) would have potential for erosion and sedimentation with consequent impacts on water quality, notably an increase in levels of suspended sediment and turbidity if not appropriately managed.

In summary, the potential impacts during the construction of the dam and associated works would be:

- increased turbidity and suspended solids at or downstream of the construction sites
- accidental release of hazardous substances to waterways.

10.6.2 Initial filling

During the initial filling phase, water quality within the inundation area is expected to decline from baseline conditions as grassed paddocks and other vegetated areas are progressively submerged. High nutrient concentrations are expected during initial filling as organic matter breaks down and flushing is greatly reduced. There is likely to also be an increase in biological oxygen demand which would influence dissolved oxygen (DO) levels, particularly in the hypolimnion (bottom layer) should the storage stratify during filling. Additionally, with elevated nutrient levels, there would be greater potential for phytoplankton blooms. Initially, until successive zooplankton blooms occur as a control, strong diurnal fluctuations in DO and pH are also likely in response to both the effects of photosynthesis and respiration on water chemistry.

This could have implications for implementation of the environmental flow release strategy in that if water quality in the storage is poor, it may be preferable not to make a release in view of the potential effect on water quality (and consequential impacts on aquatic flora and fauna), particularly in the reach of the Williams River above the confluence with the Chichester River. Poor water quality at a level unacceptable for release is unlikely to persist within the storage for any significant length of time as cumulative inflows would rapidly dilute any initial response to flooding of pasture. This would also be less of an issue below the confluence due to the contribution from the Chichester River subcatchment.

Water quality would be expected to progressively improve as the storage volume increases and elevated nutrient concentrations are diluted. This is expected to occur within a few months following closure of the river diversion. If necessary, during this time water may be tankered to residents immediately downstream of the dam wall construction site for stock and domestic purposes.

10.6.3 Water quality within the storage during operation

Australian and New Zealand Guidelines (ANZECC & ARMCANZ 2000) for physical and chemical stressors for SE Australian slightly disturbed ecosystems have been used to compare the predicted water quality of storage. The ANZECC default trigger values for lowland rivers (<150m altitude – sites W3 to W12) are: 85-110 per cent DO saturation, 0.025 mg/L TP and 0.350 mg/L TN. Default trigger values for lakes/reservoirs (Seaham Weir Pool) are: 90-110 per cent DO saturation, 0.010 mg/L TP and 0.350 mg/L TN. National Health and Medical Research Council (2008) guidelines for recreational water have also been used to compare the predicted water quality of the storage. Default trigger values for blue-green algae is 50,000 cells/mL.

Guidelines under the standard suggest site specific trigger values are developed, however, for the purpose of this assessment the default trigger values have been utilised. The primary elements of concern are DO, TN and TP and are estimated in Working Paper A.

Given the dam's storage capacity, the height of the dam wall and issues associated with the similarly characterised Glennies Creek storage (Lake St Clair), the following water quality issues are likely to occur within the storage:

- stratification during the summer months (both temperature and dissolved oxygen stratification)
- release of metals (manganese and iron) from sediments when bottom waters are anoxic due to stratification.
- periodic outbreaks of blue-green algae (may also restrict some forms of recreation at certain times)
- trapping of sediments and nutrients
- water quality issues relating to in-storage recreation (use of motorboats etc).

To assess the potential in-storage issues associated with the proposed dam the following activities were undertaken:

- assessment of the thermal behaviour of the storage
- an interpretation of Tillegra Bridge, Lake St Clair and Chichester Dam water quality data
- hydrodynamic and water quality modelling using the DYRESM/CAEDYM package.

Information on the Lake St Clair catchment and storage was utilised as it is a comparable system with similar characteristics to the proposed storage.

Hydrodynamic modelling

DYRESM/CAEDYM was used to model the varying levels of temperature, DO and chlorophyll-a (associated with cyanobacteria and diatoms) over a one year cycle for the storage. DYRESM (DYnamic REServoir Simulation Model) is a one-dimensional hydrodynamic model for predicting the vertical distribution of temperature, salinity and density of reservoirs in response to surface heat fluxes, inflows and outflows (Centre for Water Research 2008). The model was initially established for the Lake St Clair storage as reported by the Centre for Water Research (CWR) (Wright *et al* 1990, Schladow 1991). Model inputs were adjusted to simulate the proposed Tillegra Dam storage. The model was run for a period of 365 days from 1 July 1990 to 31 June 1991.

CAEDYM (Computational Aquatic Ecosystem DYnamic Model) is an aquatic ecological model designed to be coupled with a 'parent' hydrodynamic driver (DYRESM) to simulate varying levels of nutrients in water bodies (Hipsey *et al* 2006). The model equations involve complex interactions between state variables essentially determined by a large number of rate coefficients. There are numerous parameters and coefficients used in the simulation of the reservoir. The coefficients and parameters values used in the standard CAEDYM distribution were adopted for application to the Tillegra Dam storage. Model results are discussed in further detail in the following sections.

Thermal behaviour of the storage

Predicted temperature contours for the storage derived from the DYRESM model are illustrated in Figure 10.11. Modelling suggests the storage would stratify during spring and summer with cooling during autumn. In winter it would become mixed from surface to bottom. The depth of the thermocline increases as surface heating progresses through spring and summer, reaching about 15-20 metres at a maximum. The thermally mixed surface layer during summer generally extends over 5-10 metres depth. Winter temperatures in this depth range also tend to be warmer than in deeper waters. A weak stratification persists in the Tillegra simulation at the end of the model run at the end of June. It is likely this would become completely mixed during colder periods in July and August.

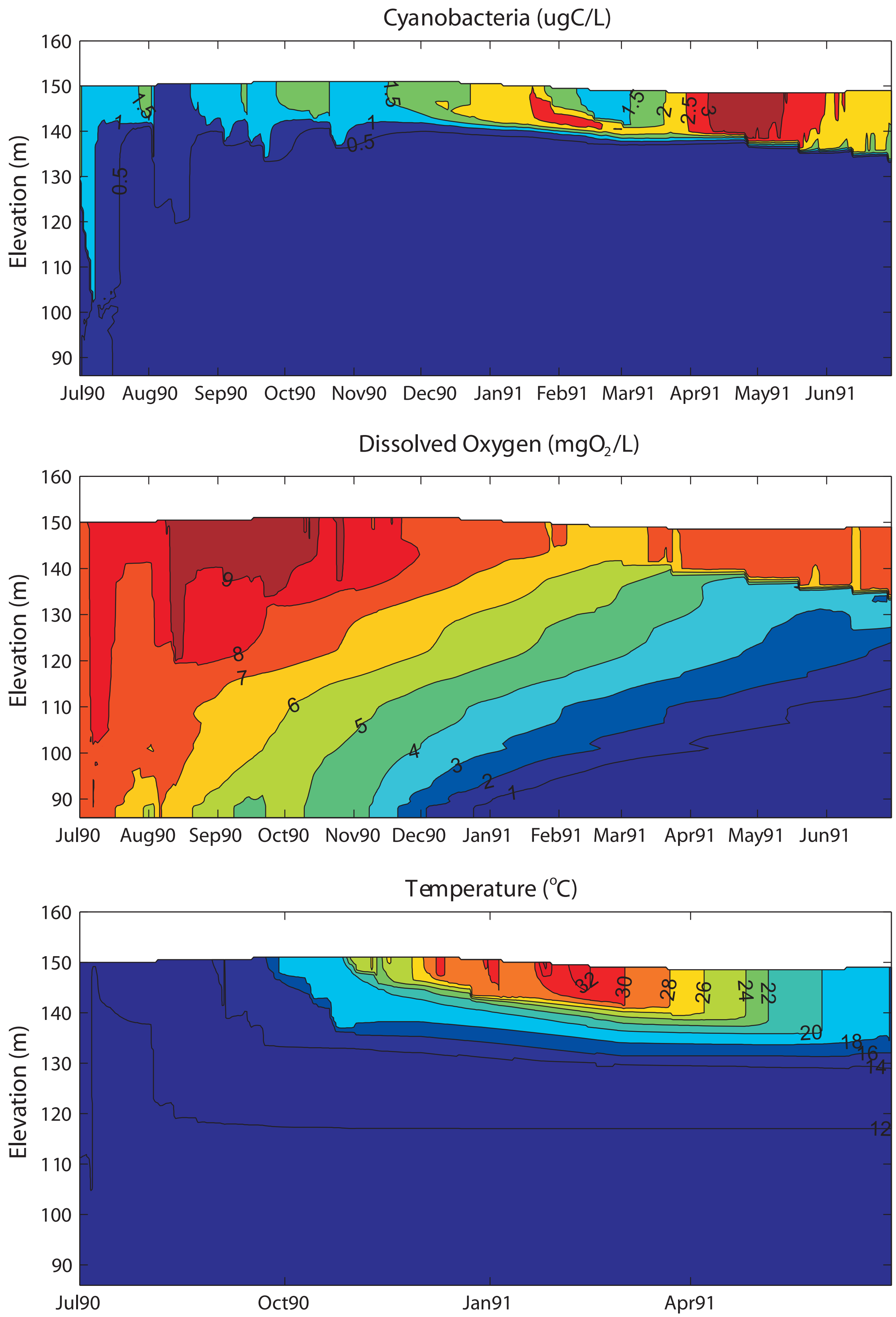


FIGURE 10.11 TD CYANOBACTERIA TEMP & DO CONTOURS VS TIME

During the filling phase, it is expected that stratification of the storage would develop on an annual basis once mean depth was greater than about 10 metres which is expected to occur within a few months of closure of the diversion. Stratification may also be associated with other variations in chemical and biological properties. These include the release of nutrients and trace metals, such as iron and manganese that tend to accumulate in bottom waters following the onset of thermal stratification, subsequent deoxygenation and chemical release from sediments.

Dissolved oxygen

Predicted DO concentration contours for the storage derived from the DYRESM model are shown in Figure 10.11. Concentrations in the waters above the thermocline meet the ANZECC (2000) guidelines of 85-110 per cent saturation (approximately >6 mg DO/L) in the surface mixed layer to about eight metres depth. The Ecology Lab (2008) measurements in the shallow river waters upstream and at the Tillegra Dam site showed similar concentrations of 76-88 per cent saturation in November to December 2007.

The DO concentration of deeper water is likely to decline during summer leading to conditions favourable to the release of nutrients, iron and manganese from the sediments as currently occurs at Lake St Clair.

Blue-green algae

Blue-green algae (or cyanobacteria) regularly occur in Lake St Clair. This is apparently due to nutrient inputs from agricultural runoff, accumulation and recycling from sediments. Based on lower nutrient inputs and a slightly higher flushing rate at Tillegra Dam, when compared to Lake St Clair the surface blue-green algae levels in the storage are expected to be less, resulting in manageable levels (<50,000 cells/mL) for the majority of the time.

The water quality modelling results (refer Figure 10.11) indicate a succession from a diatom bloom in spring to a dominance of cyanobacteria in summer. Given the coarse sensitivity of the model it is not possible to infer the magnitude of blooms and conclusively note whether they are likely to exceed guidelines. It is likely however that from time to time, alerts, warnings or public notifications may need to be made of possible impending outbreaks. Public notifications of increasing algae levels are normally undertaken at several stages prior to the recommended guidelines for different species of algae being exceeded.

Analysis of Chichester Dam blue-green algae depth-distribution data showed that concentrations were within Guideline for Managing Risks in Recreational Waters (NHMRC, 2008) levels (<50,000 cells/mL) at a depth of six metres for greater than 99 per cent of the time. Due to lower expected levels of algae in the Tillegra Dam storage than at Lake St Clair, the blue-green algal levels at 6-8 metres depth may be expected to have infrequent exceedances of the guideline level. The multi-level offtake would allow water to be drawn and released from the storage below any algal outbreak should one occur.

Photic depth

The photic depth is defined as the depth to which sufficient light intensity penetrates to support photosynthesis and is dependant on water clarity. At FSL the bed area exposed to light could potentially range from 0.7 km^2 (if the photic depth is one metre) to 1.4 km^2 (for two metres photic depth) to 2.75 km^2 (for four metres photic depth) depending on the operation range of the storage level.

This rim area is likely to support macrophytes and other plants that can attach to the substrate whereas further offshore in deeper water, pelagic species and micro-algae (phytoplankton and cyanobacteria) would be most likely to dominate. The photic depth is expected to be at the higher range mentioned above for most months and in the lower range during the summer phytoplankton growing season.

Expected nutrient concentrations

Expected nutrient concentrations in the storage were estimated by using the model of Dillon (1975) where the total phosphorus concentration is estimated by taking into account phosphorus load, retention co-efficient, mean depth and the reservoir flushing rate. Based on the model, the total phosphorus concentration in Tillegra Dam is estimated to be about half the inflow concentration of 0.068 mg/L.

The total nitrogen (TN) concentration in the Tillegra Dam storage was estimated from the average ratio of TN to total phosphorus (TP) in outflows from Glennies Creek Dam. A TN concentration of 0.24 mg/L was estimated for the Tillegra Dam storage. Nutrient concentrations in the storage are expected to be greatly reduced due to dilution of the Williams River inflows by the large volume of the storage. In addition, the storage will act as a nutrient trap for sediment and nutrients suggesting concentrations in the river downstream of the dam may be expected to be similar to the ANZECC (2000) guidelines for protection of aquatic life in lowland rivers. The low nutrient concentrations are also expected to give a reduced frequency of exceedance of the National Health and Medical Research Council (2008) recreational blue-green algae concentration guidelines in the surface waters, compared to those in Glennies Creek storage.

The nutrient/algal situation during the initial filling period would need to be monitored as inflow nutrient concentrations would have a limited volume of dilution and reduced flushing during this period.

10.6.4 Downstream water quality and hydrology during operation

Historically, water quality along the Williams River between Tillegra and Glen Martin was considered 'fair' north of Dungog and poor downstream of Dungog (Chessman and Growns 1994). Water quality monitoring during wet weather in the early 1990s suggested that faecal coliform concentrations were high and that the sources of pollution may include dairy shed effluent, cattle, recreational activities and the Dungog sewage treatment works (Dept of Urban Affairs and Planning 1996). More recent reports, such as the most recent long term water quality monitoring report produced by HWC, indicate modest improvements in the water quality of the river in recent years.

Operation of Tillegra Dam would change the downstream hydrological regime, particularly in the reach of the Williams River below the dam wall down to the Chichester River confluence. Changes will be restricted to high flows and floods, beyond the 30th percentile of annual exceedance of all flows. There are also likely to be changes to water quality, again most pronounced immediately downstream of the dam. Issues associated with these changes in flow and quality may include:

- cold water pollution with a change in the downstream temperature regime
- changes in flow water quality (nutrient loads, turbidity, metals, dissolved oxygen)
- river morphology and sediment types within the river (pool and riffle sequences)
- pool stratification and associated issues (anoxia and sediment recycling)
- increased algal bloom frequency.

Treatment of water prior to discharge into the Williams River is not proposed and the maintenance of acceptable water quality in releases from the storage for protection of aquatic life downstream of the dam would depend on the adopted release strategies. As a general comment, these would involve the release of water that matches, as closely as possible, the physico-chemical characteristics of the water entering the storage and known to occur naturally within the downstream receiving environment as measured and correlated prior to construction. This would be facilitated through the establishment of a monitoring station on the river at the headwaters of the dam and based on the data collected, the operation of the multi-level offtake would be undertaken to allow water to be drawn from the most appropriate depth in the storage (typically near the surface).

The storage will be designed and operated to pass water of the same quality or better that is entrained into the storage through the use of the multi level offtake. Default trigger ANZECC and NHMRC guidelines have been used in the assessment, however, it is important to note that baseline concentrations already exceed these trigger values. For example the catchment is naturally high in phosphorus and zinc due to the underlying geology and TP estimates entering the storage are three times greater than guideline values (refer Working Paper A). Therefore the dam, may not necessarily release water that meets default trigger levels given the current land use and natural background levels within the catchment.

An assessment of appropriate release depths using existing State Water and HWC water quality data and preliminary modelling of the storage was undertaken to examine likely vertical variability within the storage and to suggest an optimal intake depth for releases to the Williams River. Releases of acceptable levels of temperature and DO as well as blue-green algae to meet the NHMRC guidelines would be achieved through drawing off of water from around 6-8 metres below the surface most of the year. At this depth, the discharge temperatures are expected to be similar to the present river system and hence should not affect sensitive biota or behaviours such as the spawning of native fish species in the river.

Chichester Dam spills for a significant proportion of time and the average flow from this storage is similar to the predicted average flow for Tillegra Dam. This suggests that the potential effects of Tillegra Dam on the flow regime below the confluence of the Williams and Chichester Rivers would be substantially less pronounced. Certainly the effect of Tillegra Dam on the river's flow regime would be attenuated with distance downstream of the dam.

Further downstream in the Seaham Weir Pool, a number of water quality issues already exist including:

- outbreaks of algal blooms
- water residence time
- strength and duration of stratification
- nutrient releases from sediments.

Flows entering the Seaham Weir Pool following completion of the dam would be reduced by about 11 per cent. It is expected that this change would have a negligible effect on water quality. While the annual volume of water flowing into the weir pool would be reduced by increased evaporation and channel transmission losses from the dam, the frequency of low and moderate flows would be moderately increased. There is potential for run of river transfers during low flow periods to lead to improvements in water quality in the weir pool.

While low and moderate flows into the weir pool may increase, and total volumes may be moderately decreased, the overall management of the weir pool by HWC as required under the existing licence issued by DWE, could continue within the existing license conditions.

10.6.5 Groundwater

The potential impacts of the Project on groundwater are considered to be an extremely minor risk as significant groundwater aquifers are not present at the Tillegra Dam site. Small longitudinally connected groundwater bodies do exist within river gravels and alluvium of the Williams River at the base of the valley floor. Impacts could therefore include:

- a local rise in the water table level, particularly in the immediate vicinity of the dam, due to water leakage occur along bedding and joint defects below the storage FSL (152.3 mAHD)
- a reduction in the baseflow component of river flows downstream of the dam, though this is expected to be minimal as groundwater would still be recharged through rainfall, as well as through environmental flow releases and spills; further, while the dam foundations would be grouted, minor seepage at the base of the dam wall is expected (around 1 ML/d) as experienced at most other comparable dams in NSW. This ongoing minor leakage would closely match the current groundwater flows through river gravel beds and alluvium and accordingly this is not considered an issue of consequence.

This issue could be further managed by:

- providing for transparent/translucent releases from the storage within the overall release strategy
- releasing run-of-river transfers from the storage to reflect natural levels and variability (also part of the overall release strategy)
- grouting of storage locations of identified high potential for leakage.

Management of groundwater impacts would be addressed holistically as part of overall management of the storage. Further discussion on this is provided in Section 10.10 Post-construction management of the Williams River.

10.7 Fluvial geomorphology

10.7.1 Base case 'with dam' scenario

As a starting point for the assessing the effects of the dam on channel and floodplain morphology, a base case scenario for operation of the dam was assumed. This comprised constant run-of-river transfers of water from the dam to Seaham Weir, of 250-500 ML/d, persisting for up to 30 days at a time. The base case scenario also assumed for environmental and third party purposes, transparent releases from the dam to the 90th percentile exceedance on the hydrograph at Tillegra, as well as a translucent release of 60% of water between the 90th and 30th percentiles. An intermittent flushing flow of 2000ML was also considered as part of the base case.

The objective of the assessment was to consider the impacts of the base case flow regime on the geomorphology of the Williams River below the dam wall and as part of the process, help develop alternate or additional mitigation and management measures that could be adopted by HWC to improve and refine the operational release scenario.

Discharge event frequency

A flood frequency analysis was undertaken to estimate the discharge associated with a range of ARIs under the base case 'with dam' scenario (refer Table 10.10). For each ARI, the discharge was reported as both the mean daily and the peak instantaneous daily value. These relationships enabled calculation of the ARI corresponding to the defined geomorphic process and form thresholds.

Impact on frequency of geomorphic processes

The base case 'with dam' scenario would have the effect of reducing the event magnitude for each ARI. Thus, for a given discharge threshold the ARI was predicted to decrease. The data indicated that bed material mobility would still be achieved under the base case 'with dam' scenario, but the frequency of occurrence would generally decrease at each site. Macrophyte disturbance under the base case 'with dam' 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 base case 'with dam' scenario, this would continue to be the case with such events even rarer. Flushing of silt and sand from the bed surface would continue to be a common event under the base case 'with dam' scenario.

The implication of the combined effects of reduced bed material mobilisation, increased chance of macrophyte colonisation and reduced disruption to instream vegetation is that under the base case 'with dam' scenario, the channel could become more stable with more instream vegetation. The flows would still maintain the basic geomorphic processes but the useable (by aquatic biota) channel area may contract somewhat. This effect is predicted to lessen with distance downstream from the dam.

Impact on 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 the peak flow series) for the current scenario and for the base case 'with dam' 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.

Comparison of the flood frequency curves with the curves for the current situation indicated that the dam would have a significant impact on flood frequency.

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.

TABLE 10.10 'WITH DAM' SCENARIO DISCHARGES FOR VARIOUS FLOW DURATION INDICES

TILLEGRA			DOWNSTREAM OF CHICHESTER RIVER		GLEN MARTIN	
ARI (YEARS)	MEAN DAILY	PEAK DAILY	MEAN DAILY	PEAK DAILY	MEAN DAILY	PEAK DAILY
0.2	300	400	1,250	1,750	6,350	9,050
0.3	500	650	1,950	2,750	8,700	12,350
0.4	700	900	2,600	3,650	10,750	15,250
0.5	900	1,100	3,250	4,550	12,550	17,850
0.6	1,050	1,350	3,850	5,400	14,200	20,200
0.7	1,250	1,550	4,450	6,250	15,750	22,400
0.8	1,450	1,800	5,000	7,000	17,150	24,400
0.9	1,600	2,000	5,500	7,800	18,450	26,300
1	1,800	2,200	6,050	8,500	19,700	28,050
2	3,350	4,050	10,300	14,500	29,350	41,750
3	4,650	5,600	13,500	19,050	36,050	51,350
4	5,850	6,950	16,100	22,650	41,300	58,800

TABLE 10.10 'WITH DAM' SCENARIO DISCHARGES FOR VARIOUS FLOW DURATION INDICES

TILLEGRA			DOWNSTREAM OF CHICHESTER RIVER		GLEN MARTIN	
ARI (YEARS)	MEAN DAILY	PEAK DAILY	MEAN DAILY	PEAK DAILY	MEAN DAILY	PEAK DAILY
5	6,900	8,150	18,250	25,700	45,600	64,900
10	10,050	11,800	25,200	35,500	60,300	85,800
15	12,950	15,050	29,300	41,300	68,300	97,200
20	15,200	17,550	32,000	45,100	73,500	104,600
25	17,000	19,550	33,900	47,800	77,300	110,000
30	18,700	21,450	35,400	49,900	80,300	114,250
35	20,200	23,150	36,500	51,450	82,800	117,850
40	21,550	24,650	37,500	52,850	84,900	120,800
45	22,800	26,000	38,300	54,000	86,600	123,250
50	23,950	27,300	39,000	55,000	88,200	125,500
75	28,650	32,450	41,400	58,350	93,800	133,500
100	32,400	36,500	42,900	60,500	97,500	138,750

Note: all flows in ML/d

At W8, there was a high variety of surfaces present. The low unvegetated bars are currently inundated multiple times per year. Under the base case 'with dam' scenario, this frequency would reduce but it would still be at least once per year for most of the surfaces. Under the base case 'with dam' scenario, 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 3-5 years on average. The other benches were infrequently inundated under the current regime, and the frequency would reduce under the base case 'with dam' scenario. The bankfull level at this site could be described as a terrace as it was infrequently inundated. With the dam in place, the 100 year ARI event would not reach this level so the terrace would become fully terrestrial.

At W9, three main surfaces were identified. Under the base case 'with dam' scenario, 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 two and a half years to once every nine years. At this site the bankfull level was an active floodplain under the current scenario, although it was flooded only once every six years. Under the 'with dam' scenario the floodplain would be inundated on average once every 60-70 years, effectively becoming an inactive terrace.

At W10, the low unvegetated bench would continue to be inundated multiple times per year under the 'with dam' scenario. The intermediate level surfaces would be flooded every 5-11 years rather than every 2-3 years. The left floodplain surface was lower than that on the right bank. The left floodplain would flood once every 81 years on average 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 11-14 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 current scenario the floodplain was inundated reasonably frequently at around once every 2-3 years. This is within the range of expected bankfull flood frequency for unincised rivers. Under the base case 'with dam' scenario, the flood frequency would halve so that the floodplain would inundate on average once every 2-8 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 current scenario, the floodplain was inundated reasonably frequently, at around once every 1-2 years. This is within the range of expected bankfull flood frequency for unincised rivers. Under the base case 'with dam' scenario, the flood frequency would halve so that the floodplain would inundate on average once every 1-4 years.

Impact on coarse sediment load (modelled)

The following results report the estimated annual average bedload transport rates at each site. Bedload transport rate predictions for both the 'current' and the 'with dam' flow series are presented in this section. A plot of annual bedload transport for each scenario is provided in Working Paper B Fluvial Geomorphology to allow comparisons to be drawn between the two cases. To assist the comparison, the mean transport rate of the entire period of record (1931-2007) is also listed.

Predicted coarse sediment load:

Bedload transport rates for W7 to W12 are presented in Figures 26-31 respectively of Working Paper B. Transport rates at W10 are different from each of the other sites due to the very low water surface slopes simulated through the reach. Consequently, the capacity for flow to transport material was predicted to be substantially lower at W10.

Bedload transport rates were lower under the base case 'with dam' flow scenario than the 'current' scenario in every case. The greatest proportional reduction in transport was predicted at W7, with the mean annual transport rate declining by a factor of three. Sites W8, W9 and W10 also showed large reductions in bedload transport, reducing by a factor of two in each case (although the results at W10 must be interpreted with caution due to the nature of the hydraulics at this site). Near the downstream end of the system the predicted impact of the dam was less with W11 and W12 maintaining about 80 per cent of the current bedload transport under 'with dam' flows.

Impact on suspended sediment load (modelled)

A suspended solids concentration series was modelled at each of the following three hydrological zones:

- the Williams River from Tillegra Dam site to the Chichester River junction (W7 and W8)
- the Williams River just downstream of the confluence with the Chichester River (W9 and W10)
- the Williams River near the Glen Martin gauge (W11 and W12).

The concentration of suspended solids was factored to account for the trapping efficiency of Chichester Dam in both the 'current' and base case 'with dam' scenarios, and Tillegra Dam under the base case 'with dam' scenario only. Annual loads are presented for each of the three hydrological zones in Figures 32, 33 and 34 of Working Paper B.

The result for the period of discharge records suggests that the Williams River at Tillegra under the current flow regime conveys, on average, almost 10,000 tonnes of suspended load per year with marked inter-annual variation. Under the base case ' with dam' scenario, this load was predicted to drop to only 120 tonnes of suspended load directly below the dam as a consequence of trapping of sediment behind the dam.

The current suspended load downstream of the confluence with the Chichester River is similar to that at Tillegra, being around 10,000 t/yr (Figure 33 in Working Paper B). The similarity in the loads is due to the assumption that Chichester Dam traps 88 per cent of the suspended load. Under the 'with dam' case the reduction in suspended sediment is again remarkable, being estimated at only 470 tonnes per annum.

By the time the river reaches Glen Martin it picks up significant additional suspended load (Figure 34 in Working Paper B). Under the 'current' scenario the predicted load is more than six times higher than at the Tillegra Dam site (at 66,400 t/yr). Under the 'with dam' scenario this would drop to less than 30 per cent of the 'current' load due to the effect of both sediment trapping and discharge reductions in the 'current' scenario. The mean annual suspended load was greater than the bedload at W11 and W12 yet following the construction of Tillegra Dam, bedload was predicted to become the dominant proportion of the total load.

Finally, 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 occurs during high flows. This would mean lower nutrient concentrations and greater light penetration which could have implications for the river's ecology. Lower overall suspended sediment loads to the Seaham Weir Pool would mean lower risk of algal blooms.

Impact on bed material sediment transport

There is little doubt that the presence of Tillegra Dam would lead to bed scour of the Williams River downstream of the dam. The reason for this is the trapping of the upstream sediment supply behind the dam together with 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 established. 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 immobile boulders in place. This would change the physical (hydraulic) character of the bed which would have implications for the biota.

Where the river is currently controlled by bedrock bars there would be no change to the bed level or the bed character. Bedrock bars are common downstream of Tillegra so most of the scour is expected to be localised, rather than a uniform bed lowering. The lower section of river may be naturally incised however throughout the entire system, this river has a long history of instability and bed lowering due to ill-conceived works programs so it has already incised down to resistant points of bed control. Consequently accelerated bank undercutting and destabilisation is not predicted. More discussion on this matter is provided in the following section of this report on bank stability.

The downstream extent of potential downstream scour cannot be accurately predicted. However, localised incidences cannot be excluded for some distance downstream of the Chichester River confluence as this river is currently starved of sediment (due to the presence of Chichester Dam). Prior to the construction of Chichester Dam, this river would have been the major supplier of coarse bedload to the Williams River. The impact of scour would be offset further downstream to some extent as unregulated tributaries 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 the Project. However, it is likely that significant inputs would not occur until Dungog, once the number of tributaries in the catchment had increased. Further, gravel sediment inputs from these tributaries may be of a finer nature.

Sediment scour due to sediment starvation would be partly mitigated by the reduced frequency of flows with the capacity to transport coarse sediment. The base case 'with dam' scenario 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 t/yr depending on hydrological conditions.

If the bed of the Williams River scours in the vicinity of the junction of the confluence of the Chichester River, this would lower the base level of the Chichester River. This would be expected to lead to scour of the bed of the Chichester River through a process of upstream nickpoint migration. However, this is not expected to occur or this effect would be limited in scale and extent because the Chichester River has long been subjected to sediment starvation due to the presence of Chichester Dam. The Chichester River has already passed through a post-dam phase of scour followed by adjustment to a new stable state. Thus, scour of the bed of the Chichester River is unlikely as it has already occurred.

On the basis of the previous independent work of Erskine (2001) and Brooks *et al* (2006) plus observations made during investigations undertaken for the Project, significant lowering of the bed of the Williams River is not regarded as a high risk. Any bed scour associated with operation of the proposed dam would likely involve localised scour in areas of deep deposits of bed material (ie gravel bars could degrade), general removal of the finer component of the bed material (leading to bed armouring–a coarse upper layer) and greater exposure of bedrock outcrops.

Impact on bank stability

The banks of the Williams River were observed to be relatively stable but instances of bare eroded banks were not difficult to find. Significant lowering of the bed could potentially lead to an initially increased rate of bank instability as channel cross-section adjustment to the new bed level could involve bank profile adjustment. However, while bed scour would be expected to occur downstream of the proposed dam, significant general bed lowering is not expected.

Apart from bed lowering, the only other dam-related cause of increased bank erosion would be the changed flow regime. Most instances of significant bank collapse in the Williams River are probably associated with large flood events. The frequency of such events would decline with the dam in place. Bank scour can also occur under conditions of long duration flows that are above the level of the bank toe. At times of low flow, the Williams River flows over a gravel, cobble and bedrock bed. Under the base case 'with dam' scenario, bulk water transfers would occur over the range 250–500 ML/d which is within the range of flows that are generally confined to the coarse bed. Thus, these flows would be unlikely to result in accelerated bank erosion.

With refinements to the base case release strategy to include a peaked 1,500 ML discharge, long duration flows as a result of the dam wouldl not occur. The discharge has been formulated to mimic a natural flow and therefore would not contribute to accelerated bank erosion beyond that naturally occurring (refer Section 10.6.2).

10.7.2 Peak event bulk water transfers and maximum outlet capacity

Peak event scenarios

Sudden or unnatural flow regimes from the dam have never been proposed by HWC for operation of the dam. A base case constant flow regime was proposed as a starting point from which to analyse the merits of various simulated transparent, translucent and peaked environmental and operational release regimes. These regimes were proposed to prevent unnatural or sudden flow changes and a range of scenarios were discussed during a series of meetings with interested natural resource management agencies, including DWE, DECC, HCRCMA and DPI.

In the base case 'with dam' scenario, detailed as the starting point for the analysis, bulk water transfers were simulated in the hydrological model over the range 250-500 ML/d. As an alternative, to mimic natural flow variability within the river, these transfers were then proposed to be made as a series of freshes (simulated minor flow events) with a peak up to 1,500-1,700 ML/d, receding over a period of 10-15 days (total volume of each event being around 4,300 ML). On average there would be around seven of these events per year (refer Working Paper D for further details).

Some smaller events of 270 ML/d peak and receding over two days could also be released as part of an environmental flow regime to address aquatic habitat maintenance requirements. These events would be smaller in magnitude than the 500 ML/d maximum water transfer rate evaluated as part of the base case 'with dam' scenario. For the purpose of evaluating geomorphology impacts, a 500 ML/d peak flow was analysed on the assumption that a 270 ML/d peak flow would have a significantly lower impact.

The maximum capacity of the dam outlet works at the time of preparation of the EA report is 4,000 ML/d. Final design may include additional capacity as once installed, it would not be possible to retrofit a larger outlet should this be a required upgrade in the future. While HWC does not propose to release water from the dam at this rate or above, the geomorphic impacts of such a release were considered to cover the possibility of such an event ever being released for some reason.

If run-of-river releases made as peaked events were incorporated into a flow regime to replace static releases within the original base case, it is not expected that the impacts on the other aspects of the geomorphology of the river would be significantly different from those evaluated for the base case 'with dam' scenario in detail elsewhere in this chapter.

The 4,000 ML/d release, if it was ever made, would be a very rare occasion triggered by the need to undertake urgent maintenance. A 4,000 ML/d flow however, is not a rare event naturally, occurring on average more than three times per year as a peak event and twice per year as a mean daily event. Thus, release of a 4,000 ML/d flow would be extraordinary only if it was to occur for an extended duration. Under the current natural flow regime, most events exceeding 4,000 ML/d were of 1-2 days duration (median 1.5 days), but eight events in the period 1931 to 2007 were of five or more days duration.

The three flow series evaluated from the perspective of bedload transport rates comprised:

- one 4,000 ML/d event
- four 1,500 ML/d events
- fifty-two 500 ML/d events.

The chosen length of these series is not that important as the main objective of the analysis was to estimate and compare the sediment transport potentials of three different sized releases from the dam. Essentially, the analysis compared high frequency/low magnitude versus low frequency/high magnitude. Sediment transport rates were computed for each flow series at a number of riffle cross-sections at W7, W8, W9 and W10.

Results of bedload transport modelling

The modelling suggested that bedload transport rates were highly sensitive to event magnitude. Bedload transport would be reduced by reducing the peak discharge magnitude. Limiting the duration of time that the flow is close to the peak would also reduce the total bedload transport. The reach downstream of the dam site and upstream of the confluence with the Chichester River (represented by W7 and W8) would be the most vulnerable to bedload transport and scour under the modelled flow regime.

Even here, the 1,500 ML/d peaked events would not result in wholesale bedload transport but selective transport of a proportion of the finer fraction. The bed would, over time, likely become armoured (ie develop a coarse, protective surface layer) which would slow the bed material transport rate. Total bedload volumes transported through each flow series and site are provided in Working Paper B.

Impacts of peaked flow events on bank erosion

At Tillegra, under the current flow regime events of 1,500 ML/d peak magnitude are very common, occurring on average around seven to eight times per year. Geomorphologically, these events mobilise the finer fraction of the bed material and flush fine silt and organic material from the bed surface. The low gravel bars are inundated at these flow levels, and the toes of the banks would be wet at most sections. However, as the duration of the events would be short, such events would not be expected to cause bank erosion to any greater extent than would similar events that regularly occur in the current flow regime.

Although the overall risk of increased rate of bank erosion in response to operation of the proposed dam is not regarded as high, the naturally occurring process of bank erosion and channel migration would undoubtedly continue into the future. These processes are typical of lowland rivers whether regulated or not. In the case of the Williams River, it would not be possible to attribute future bank erosion to operation of Tillegra Dam as this process occurs under the current flow regime and would continue into the future with or without a dam at Tillegra.

This erosion may or may not be associated with local bed level adjustments. Erosion could be related to natural channel migration, local scour from flow diversions (from large trees for example), high shear stresses during large floods, or low bank strength due to degraded riparian vegetation (due to loss of natural vegetation covering or damage by stock). None of these factors are inherently related to the operation of a dam.

Bank erosion is currently, and would into the future, be the result of multiple factors. While monitoring bank morphology through a program of repeated surveys may indicate stability or otherwise of the banks at the selected monitoring sites, it would not reveal the cause of any change in bank morphology. Also, it would not be possible to monitor any change to the rate of channel stability post-dam due to the lack of baseline data. Many years (in the order of 20 plus years) of careful data collection would be required before the rate of these processes could be established (as the rate of erosion would be calculated by establishing the long-term mean of sediment movement derived from a pattern of high energy short-term variable events or a flood response).

10.7.3 Risk to instream structures

The river contains a number of structures managed by the Hunter-Central Rivers CMA. These mainly comprise bank revetments and grade control structures. There is also a rock ramp fishway at Bandon Grove that was constructed by HWC. These structures would have been designed to withstand a range of flows including those of a high magnitude. Tillegra Dam would not increase the risk of failure of these structures due to high flows as the dam would reduce the frequency of high flow events. However, these structures could be threatened by undermining if the bed progressively scoured deeper over time.

The overall risk of undermining due to bed changes is assessed to be relatively low as these are structures designed to be more stable than the surrounding natural river materials. However, this risk depends to some degree on the characteristics and situation of each structure. The grade control structures are at relatively low risk because they create hydraulic conditions that promote bed stability such as at W9. Some structures may be at risk of failure from local bed scour but this risk would apply irrespective of the presence of the dam.

It is normal for instream structures to occasionally fail and require maintenance or reconstruction. Thus, should a dam be built at Tillegra, it would not necessarily be the case that all future maintenance that may be required on these instream structures would be attributable to a situation brought about by the dam. It would be necessary to independently determine the cause of each failure.

10.7.4 Stability of channel banks in the Seaham Weir Pool

The Seaham Weir Pool has been noted as a site of bank erosion. Power boating has been implicated as the main cause in the upper weir pool and in the lower weir pool cattle access and wind waves are involved (Healthy Rivers Commission 1996). The flow rate of the river in a weir pool such as this does not play a major role in bank erosion per se. The main issue is the relatively constant water levels regardless of flow rate. Power boating and wind are such problems here because of the relatively constant water level which focuses the erosive energy of the waves on a very narrow band of the bank causing undercutting. Large flow events may play a role in removing weakened bank material but it is the constant water level that creates the conditions conducive to bank erosion.

The flow regime changes that may come about from operation of Tillegra Dam would be relatively inconsequential for the risk of erosion in the Seaham Weir Pool. While the pattern of flow may change in some respects, these flow changes would have only a very small or no effect on the regime of water levels in the weir pool. Changes to the pattern of water levels in Seaham Weir are largely controlled by operation of the weir itself. The weir gates are opened during large events and this practice would not change with Tillegra Dam. The frequency of large events would fall with the dam operation so the rate of erosion due to large events weakening bank material would be reduced.

10.7.5 Loss of dam capacity through river sediment inputs

Reservoirs and dams are efficient sinks of both suspended solids and bedload. When a dam fills with sediment to the extent that the reduced capacity compromises the functionality of the storage, it is either decommissioned or sediment has to be extracted. Either way, this situation presents a potential environmental hazard as there would be potential for release of undesirable quantities of sediment to the river below the dam.

In general, 100 per cent of the bedload that enters a dam is trapped while a small proportion of the suspended load is conveyed downstream. Tillegra Dam would trap approximately 95 per cent of the suspended load (9,300 t/yr) plus all of the bedload (3,100 t/yr), totalling 12,400 t/yr on average. Assuming an underwater bulk density of 1.5 for suspended material (partially organic) and 2.6 for bedload (assume hard rock), this rate of sediment trapping equates to 6,200 m^3/yr of suspended material and 1,200 m^3/yr of coarse material per year. This represents 0.002 per cent of the proposed dam's capacity. In 100 years this would account for only 0.2 per cent of the dam's capacity so sedimentation of the dam would not be a significant problem over the normal life expectancy of the dam.

10.7.6 Potential shoreline erosion

The potential maximum long-term volume of shoreline erosion was calculated assuming that all of the soil between the 96 per cent of FSL and FSL would be removed (plus an allowance for 0.4 m wave height).

The volume of eroded material per linear metre of shoreline varied with the slope and assumed soil depth. In general, the western shoreline zone would have lower slopes than the other two defined zones so the predicted volume lost per linear metre would be higher there (also, it had none of the shallower Williams Range soils). The maximum volume of material calculated for assumed soil depths and slopes was 1,537,000 m^3 which represented only 0.3 per cent of the storage volume. This is an estimate of the maximum potential volume (ie it assumes all soil would be eroded around the entire rim).

In reality, the lower and middle northern and eastern zones, and some southeast facing sections would be more susceptible to erosion as they would face the prevailing winds. Sheltered parts of the storage rim may not erode to the same extent. These erosion volumes also assume no management action would be taken to prevent erosion. Regardless of the assumptions made, shoreline erosion would not threaten to significantly reduce the capacity of the dam.

The width of exposed shoreline was predicted to vary markedly with slope but was less sensitive to soil depth. In general, the western shoreline zone would have lower slopes than the other two defined zones so the exposed shoreline width was predicted to be generally higher there. At 96 per cent of FSL, the predicted exposed widths varied up to 90 metres. At FSL the predicted exposed widths were much narrower (up to 60 metres).

On average, at 96 per cent of FSL the average width of the exposed shoreline on the three zones ranged from 18-35 metres. At FSL the average was predicted to be 12-25 metres. This represents an estimate of the maximum potential exposed width. In reality, the sections facing the prevailing winds would be more susceptible to erosion. Sheltered parts of the storage rim may not erode to the same extent. These predicted widths assume no management action would be taken to prevent erosion.

10.7.7 Summary of potential impacts

No pre-construction impacts on fluvial geomorphology are anticipated. The following potential geomorphologic issues have been identified for the Williams River system downstream of the proposed dam at Tillegra following its construction:

- altered frequency, duration and timing of channel maintenance flow events in the Williams River downstream of Tillegra potentially leading to changes in the physical channel structure that could impact ecological processes. The channel would initially become more stable and have denser instream vegetation cover.
- reduced sediment transport in the Williams River downstream of Tillegra due to trapping by the proposed dam, potentially leading to changes in the physical channel structure that could impact ecological processes. The bed would scour, leaving coarse sized bed material, and the channel bed would deepen. This effect would be partly mitigated by the dam itself, which would reduce the frequency of flows with the capacity to transport coarse bed material. Bedload transport capacity would be reduced downstream of the dam by a factor of three, but scour would occur due to the dam removing the upstream supply that would otherwise replace the transported material.
- reduction of the base level of the Williams River in the vicinity of the confluence with the Chichester River due to bed scour could lead to the migration of a head cut up the Chichester River. This would probably not be of a catastrophic scale because the Chichester River has long been subject to scour due to the existence of Chichester Dam, and because any migrating head cut would only reach as far upstream as the first major bedrock bar or deposit of coarse, immobile bed material.
- the altered bed material transport regime would present a risk to increasing bank instability but the risk is considered to be relatively low. Many factors contribute to bank instability and the existence of bank erosion at the present time demonstrates that at least some of these factors are currently active.

- risks to stability of instream structures, such as revetments and grade control structures. The main risk comes about the potential for bed scour, not from altered hydrology. However, the risk is considered to be relatively low in most cases as general bed lowering is not expected along the length of the river and these structures were designed to create geomorphologically stable conditions.
- increased water clarity and lower nutrient concentration in the water immediately downstream of the dam. The difference compared to the current situation would be most apparent during minor to moderate flood events.
- altered hydrology leading to altered channel and overbank hydraulics, meaning that some physical features such as bars, benches, terraces and floodplain surfaces 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 increased terrestrialisation.
- the risk of erosion of the channel banks within the Seaham Weir Pool would not be increased significantly by operation of Tillegra Dam.

The above issues require consideration for the dam filling phase, normal operation and drought operation as the pattern of outflows from the dam would be different in each case.

The following potential geomorphological issues have been identified for the proposed inundation area upstream of the dam wall:

- erosion of the storage shoreline, largely due to the effect of wind waves, leaving an exposed bank and delivering a volume of eroded soil to the storage. The volume of eroded material would be relatively small and would not significantly threaten the capacity of the storage (predicted maximum 0.3 per cent loss of storage capacity).
- deposition of river-sourced inflowing bed material within the storage, potentially decreasing its capacity over time. However, the rate of infilling would be very slow and the volumes relatively small. This process would not significantly threaten the capacity of the storage (predicted 0.2 per cent loss of dam capacity over 100 years).

10.8 Aquatic and riparian ecology

Aside from the direct effects of construction, principally at the dam wall and spillway locations, and the waterway crossings, impacts on aquatic and riparian ecology are expected to be more medium to long term in effect. These would be principally related to:

- the permanent presence of a significant barrier within the Williams River, ie the dam wall and its storage
- the loss of approximately 19 kilometres of existing aquatic and riparian habitat upstream of Tillegra (ie the location of the dam wall) through inundation
- changes to the existing hydrological regime affecting downstream aquatic habitats, particularly between Tillegra and the confluence with the Chichester River
- the water quality of releases made from the storage, particularly where there were significant differences between the water quality of the storage and downstream of the dam and especially in the reach above the confluence with the Chichester River.

These are discussed as follows.

10.8.1 Aquatic ecology

Presence of dam wall

The dam would form a barrier approximately 76 metres high and 800 metres wide across the Williams River at Tillegra permanently isolating the uppermost 19 kilometres of the storage and the remaining 35 kilometres of main river channel and associated tributaries (representing approximately 15 per cent of the total catchment at the Hunter River confluence). In the absence of a suitable mechanism (such as a high fishway or fish lift (refer discussion in Section 10.10.4), this would effectively prevent upstream and downstream movement of aquatic species along in this part of the river permanently.

Twelve species of native fish were sampled in Williams River at experimental sites in Munni, at 120 mASL (Brooks *et al*. 2004). Reach 1 begins just upstream at 150 mASL therefore it is possible that this reach is within the upstream range of all 12 species. Nine of the 12 species are definitely known to occur at altitudes greater than 150 mASL and seven of these have been recorded from 600-760 mASL in other areas. The aquatic ecology investigations for the Project identified four of these fish species in Reach 1.

Eight of these 12 species have a diadromous life history, meaning they migrate to estuarine habitats although Cox's gudgeon can apparently complete its life cycle in freshwater (Pusey *et al*. 2004). Six of the eight are catadromous and must migrate to estuarine waters to spawn.

Adults returning from estuarine or marine spawning grounds and/or juveniles from nursery areas would not be able to return or recruit to Reach 1 populations. As such, these species would eventually be excluded from the storage and the river above the dam wall. Cox's gudgeon, short-finned eel and long-finned eel are known to climb barriers such as dam walls. However, populations observed above dams can be smaller than those immediately below suggesting the barrier has had a negative impact on recruitment (Gehrke *et al*. 2001). This is particularly true for the Cox's gudgeon which has in some instances has been lost above dams and weirs, even though it may not be strictly amphidromous (Pusey *et al*. 2004).

These three species are expected to persist in Reach 1 following the completion of the dam wall, albeit with diminished abundances. Other species likely to maintain viable populations in Reach 1 are potamodromous (or undefined) and include the freshwater catfish, the flathead gudgeon, the dwarf flathead gudgeon, smelt and the introduced mosquitofish. The diadromous species expected to disappear from Reach 1 due to recruitment failure include sea mullet, freshwater mullet, striped gudgeon, freshwater herring and the Australian bass, unless artificially stocked. Stocking considered is a satisfactory approach to provide a recreational fishery but generally undesirable for the long term maintenance of sustainable fish populations and general aquatic biodiversity.

For the non-diadromous species that persist in Reach 1, their once continuous populations would become fragmented by the dam barrier and their ability to utilise habitat downstream (eg for foraging) would end. Some of these species are known to migrate or move large distances within river systems. For example, smelt and flathead gudgeon have been observed to make facultative amphidromous and potamodromous migrations (Pusey *et al*. 2004).

Effects of permanent inundation

As the storage fills, approximately 19 kilometres of the main Williams River channel (ie Reach 2) would be progressively inundated as would sections of tributaries that currently flow into this reach. Outside of drought periods, the storage would be maintained between 90-100 per cent of FSL so much of this section of the river would be permanently inundated. The existing lotic habitat (flowing water) would be replaced by a lentic habitat (still water).

This section of the Williams River would transform from lotic to lentic habitat as the storage fills. Only those species that could either climb the dam wall or are potamodromous/ undefined and can also inhabit lentic environments are expected to persist in the storage. Smelt, short finned eel, long finned eel, freshwater catfish, flathead gudgeon, dwarf flathead gudgeon and the introduced mosquitofish are all able to inhabit lentic environments and are often observed in lakes and dams (McDowall 1996, Pusey *et al*. 2004). Should Cox's gudgeon persist in the storage it would do so in much lower densities.

As the storage gradually fills, fish species preferring lotic environments and whose life history permits them to survive in an entirely freshwater system would move upstream towards the faster moving water in Reach 1. All of these species mentioned above have diets that rely heavily on macroinvertebrates (Pusey *et al*. 2004) and their increased abundance in this reach would impose higher predation pressures on the populations of macroinvertebrates found there. Should carp become established in the dam and colonise Reach 1 there is a possibility that habitat degradation could lead to an increase in pollution-tolerant macroinvertebrate taxa.

During filling, water quality in the inundated area is likely to be poor due to the decomposition of terrestrial vegetation and associated effects such as depleted DO levels and elevated levels of nutrients. This would discourage use of this habitat by most invertebrate and fish species. This is expected to be only temporary as water quality improves as the storage volumes increase.

Changed hydrological regime

The dam would have an effect on flows right across the current flow range though as previously noted, this is expected to be largely limited to the reach between Tillegra Dam and the confluence of the Williams and Chichester Rivers. The geomorphological investigations noted that as a consequence of the reduction in the frequency of flow events, there would be reduced bed material mobilisation in turn encouraging macrophyte colonisation and reduced disruption to instream vegetation. The consequence of this would be a reduction in the channel area useable by aquatic biota, though lessening with distance downstream from the dam.

Flows would be maintained during filling (refer Table 10.9) albeit at a reduced frequency and magnitude compared to the pre-dam situation. The decline in median flow volume would have a consequent reduction in velocity, depth, channel 'wetted width', flow variability, and the magnitude and frequency of elevated seasonal flows. The changes would be greatest in the four kilometre section of the river between the dam wall and the Chichester River confluence as discharges from the Tillegra catchment represent all of the flow in this part of the Williams River.

Further downstream the effects would diminish as the proportion of flow contributed by the Tillegra catchment decreases due to inflows from the Chichester River and other tributaries. The hydrology of the Seaham Weir Pool (Reach 4) is controlled by the existing weir gates and management of the gates is expected to remain unchanged following dam operation. As such, the existing aquatic ecosystem in this reach is not anticipated to be impacted upon in any diverse manner. Seaham Weir to confluence of Williams and Hunter Rivers (Reach 5) is part of the Hunter estuary and no impacts are predicted to the existing aquatic community. Details on estuarine impacts are provided in Section 10.9.

The reduction in the wetted width of the channel would result in the loss of a proportion of shallow riffles and gravel/sand bars below the dam, particularly in the broad low energy riffles above the Chichester River confluence. These geomorphological forms are important habitat for a variety of associated invertebrate and fish species. The reduction in these features would result in an overall decline of the productivity of shallow habitat such as riffles and gravel/sand bars and the abundance of associated macroinvertebrate taxa such as Philototamid caddis flies and water pennies (Psephenidae). Larger invertebrates such as mussels and crayfish may also be affected by altered instream habitat.

With an increase in the proportion of low flows, natural and artificial barriers to fish passage in Reach 3 may become more problematic, fragmenting and/or reducing access to spawning and foraging habitat.

During filling, there would be minimal bedload transport in the reach between the dam and the Chichester River confluence. While the higher translucent flows should flush silt from the majority of riffles, a flood event would be required to remove fines that may accumulate in more stable pools. The accumulation of fines can smother habitat such as gravel beds, the interstices of pebble/cobble substrata, macrophytes and the surfaces of large woody debris. This is expected to be offset in the longer term by the reduction of suspended sediment in flows discharged from the storage.

The expected increase in frequency of low to moderate flows and the loss of high flows in Reach 3 during the filling phase may result in reduced water quality, fragmented fish populations and habitat, disruption of spawning cues and changes to fish passage past natural and artificial instream barriers. The Project includes the upgrade of the fishway at Seaham Weir. The upgrade is anticipated to improve the rivers connectivity with the estuary during times of low flow and will assist catadromous and amphidromous species living in the river complete there life cycles. Improved recruitment of long finned eel, short finned eel, freshwater herring, sea mullet, freshwater mullet, flathead gudgeon, empire gudgeon and Australian bass into existing populations are expected.

The filling period may tend to favour species that prefer stable low flows. Many potadromous species such as smelt and flathead gudgeon have peak spawning periods during the naturally low flow periods of spring so that larvae/juveniles have a greater chance of encountering invertebrate prey and are not swept downstream by larger flows (Pusey *et al*. 2004). Research has indicated that some native species are more tolerant to river regulation (Gehrke and Harris 2001). The introduced carp and mosquito fish prefer low flows and are tolerant to reduced water quality therefore their abundance might be expected to increase during filling. The potential for the introduction of additional pest and exotic species would be minimal. Some native species, such as striped gudgeon, long finned eel and sea mullet are less sensitive to degraded water quality such as reduced DO and increased nutrient concentration and would not be as affected should water quality decline, unlike the more sensitive bullrout and Cox's gudgeon (Pusey *et al*. 2004).

It is expected that diadromous fishes migrating upstream (ie adults returning from spawning or new juvenile recruits) would mass at the base of the dam wall in an attempt to find a route past the barrier. Potamodromous species can also exhibit this behaviour, for example large aggregations of smelt and flathead gudgeon have been observed on the downstream side of barriers (Pusey *et al*. 2004). These fish may then experience increased mortality as predators exploit the aggregations or from density-dependent stresses.

The loss of moderate to large flows between the dam and the Chichester River confluence 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.

The ability of fish to negotiate longitudinal passage in Reach 3 past potential natural barriers such as riffles, rockfalls and log jams or artificial barriers such as fishways and grading structures may be affected. Fish passage is limited by water depth and velocity, both of which are proportional to flow magnitude. A depth threshold represents the minimum flow required to generate sufficient depth for passage and a velocity threshold represents the maximum flow a fish can make headway into. The range of navigable flows therefore lies between these lower and upper limits. The size and timing of flow requirements for passage can vary among taxa and for different size classes within taxa. Therefore changes to the flow regime can affect the capacity of fish to move up and downstream.

AusRivAS assessments made during the field survey for the Project 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. Other studies have indicated that sensitive taxa are well represented.

Sensitive taxa relatively common in Reach 3 during the survey included beetles (Elmidae and Psephenidae), caddis flies (Leptoceridae, Hydropsychidae and Philoptamidae) and the mayfly (Leptophlebiidae). 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 caddis fly species and an increase in water snails and silt-tolerant mayflies. Pollution-tolerant taxa relatively common to Reach 3 that might be expected to increase in abundance include the introduced water snail (Physidae), freshwater shrimp (Atyidae), water boatmen (Corixidae), segmented worm (Oligochaeta) and water striders (Veliidae).

As previously noted, large aggregations of diadromous and potamodromous fish are expected to accumulate at the base of the dam wall. Many of these fish have diets that rely heavily on macroinvertebrates (Pusey *et al*. 2004) and their increased numbers would impart higher predation pressures on the macroinvertebrate communities that are present.

Potential downstream effects of differences in storage and receiving water quality

The physical and chemical characteristics of water in reservoir would be different to those of the relatively narrow, shallow Williams River. Eventually, the storage is expected to stratify, with cold, deoxygenated water lying on the bottom. The storage would also be a sink for suspended sediment, bed material and organic carbon flowing in from the upper catchment. The installation of a multi–level offtake tower as proposed, to manage releases, is an imperative for the Project.

Water quality results revealed that all sites sampled in this reach had total phosphorus concentrations in excess of ANZECC guidelines. The two sites tested for chlorophyll a were within ANZECC trigger limits but flow velocity and water temperature may have been the limiting factors for algal activity. Other freshwater algae have been observed in this reach. The stratified storage may develop conditions in summer suitable for blue-green algae blooms. Due to the size of the storage, it is unlikely that artificial destratification (such as through the use of aeration devices) would be a practicable and effective option.

Sites in the Williams River between the dam and Glen Martin (ie Reach 3) have recorded total phosphorus (TP) levels in excess of ANZECC trigger values and the weir pool has experienced blue-green algal blooms in the past. A regime dominated by lower flows may decrease downstream water quality due to a reduction in flushing flows. Below the Chichester River confluence, the river would continue to receive inflows from the Chichester River and from unregulated creeks which may help to minimise increases in algal activity. In addition an increase in run-of-river flows has the potential to alleviate existing algal bloom problems during the summer months which in turn may improve water quality in the downstream reaches.

During initial filling, water quality in the storage would be affected by the decomposition of vegetation inundated as water level rises. This would be reflected in elevated levels of nutrients and possibly low DO. This is likely to be a short term issue lasting no longer than three to six months depending on rainfall and climatic conditions. It would reduce over time as the storage volume increases and provides a dilution effect, particularly following significant inflows.

This matter would be managed by monitoring the water quality in the storage, prior to making any release In some instances it may be preferable to delay releases if downstream impacts would be greater from poor water quality than from declining flows. Additional flows may be released from Chichester Dam if necessary, to compensate for any short term reductions in flow releases from Tillegra Dam. Should this occur, temporary reductions in flows directly below the dam site would only adversely affect approximately 4 kilometres of river length and would not result in any long term irreversible impacts

10.8.2 Riparian ecology

As previously noted, the principal impact on riparian ecology would occur through the inundation of approximately 19 kilometres of the main channel of the Williams River above the dam wall as well as a number of tributaries (eg Quart Pot Creek) that flow into the Williams River along this reach. As the storage fills, there would be a progressive loss of the existing habitat.

Further discussion on impacts on terrestrial ecology, together with mitigation of impacts, is also provided in the following chapter.

Vegetation

Prior to land clearing and river training works, the riparian vegetation in the inundation area would have mainly comprised *River-flat Eucalypt Forest on Coastal Floodplains* EEC plus small areas of intergrade *Subtropical Coastal Floodplain Forest* EEC. Both EECs are also present downstream of the site of the proposed dam wall from below the confluence of the Chichester and Williams Rivers.

Alteration of the flow regime and a reduction in flooding magnitude and frequency has potential to impact upon the hydrological regime supporting these communities. The ARI of flood events would be altered by the presence of the dam. Below Dungog, changes to the ARI would be less pronounced and unlikely to have any adverse affect. Above Dungog however, the frequency and extent of flooding would be considerably changed (reduced). Nonetheless, riparian vegetation in this area is restricted to a thin strip fringing the river, bordered by cleared agricultural land. It is estimated that the extent of vegetation affected would be minor and colonisation further into the channel would be likely as it adjusts to the altered hydrological regime. Accordingly, no significant impacts on the extent or quality of riparian vegetation are expected downstream of the dam wall.

Frogs

Many of the 16 species of frogs that occur within the Project area breed in still water sites on the floodplain. Within the inundation area, these breeding sites would be removed together with large areas of foraging and shelter habitat. Most frogs cannot utilise large, open water bodies. Some species would be able to occupy the new fringing habitat areas that would form around the storage shoreline but most of the relatively flat terrain would be covered by water. The surrounding areas would be mainly hill slopes with fewer locations where rain water could pool and pond breeding species could breed.

There would likely be a change in the composition of the vegetation around the storage shoreline. The nature of the vegetation changes would determine which frog species benefit and which frog species may lose further habitat.

The changed hydrological regime downstream of the dam would likely affect frog species. Frogs dependent on periodic flooding could be greatly disadvantaged by the construction of the dam and the loss of high water flow periods. Similarly, frogs dependent on the persistence of standing pools may find that pools are not as deep or that the pool habitat is otherwise detrimentally affected; for some species this may be sufficient to prevent spawning.

Mammals

Platypuses are seldom found in the deep waters of impoundments and are normally restricted to their headwaters (Grant 1991). As a result, approximately 19 kilometres of the Williams River and parts of its associated tributaries would become largely unsuitable for occupation by platypuses. Additionally, the storage and dam wall may represent a barrier to normal breeding and foraging movements by adults and to the dispersal of juveniles. Little is known of these aspects of the species' breeding biology.

The inundated section of the river would become unsuitable for occupation by platypus through loss of burrows and alteration of foraging areas. There could also be the consequential effect of a potential increase in predation as individuals are displaced as the water level in the inundation area rises.

Downstream of the dam, the altered hydrological regime could also affect the platypus. The environmental assessment for Tallowa Dam (LesryK Environmental Consultants 2006) identified the following potential impacts:

- if there are insufficient flows to periodically flush out the river bed, siltation would decrease foraging areas and reduce the water depth
- loss of refuge pools if water levels become too low, particularly during drought
- changes to food availability through the loss of riffle areas and if the temperature of storage releases are too low (platypus foraging in cold water would require an increased food intake
- potential increase in predation could occur if a platypus is required to travel over land from its burrow to reach suitable foraging pools.

It should be noted that management of these potential impacts would largely be addressed through the adopted operating regime which would be designed to mimic pre-dam conditions as far as practicable, and would provide for maintenance of environmental requirements (refer discussion elsewhere in this chapter).

The impacts on the Australian water rat are unlikely to be as great as those identified for the platypus. The species is more terrestrial than the platypus, has a higher birth rate and it forages on a wider range of prey species, including terrestrial vertebrate species. The local population would still suffer a loss of shelter burrows which could affect breeding success and a reduction in aquatic prey once the storage reaches a depth greater than 10 metres. A lack of vegetation cover adjacent to storage shoreline during filling and when the storage reaches its normal operating range (90-100 per cent of FSL) may lead to increased predation from birds of prey, foxes and cats in this particular part of the catchment.

10.8.3 Construction impacts

Above the storage (Reach 1), it is anticipated there would be limited impacts on aquatic ecology related to construction. These would largely be associated with the upper Williams River and Moolee Creek crossings. Other construction activities in this part of the catchment would be associated with the northern half of the Salisbury Road relocation, the new Munni/Quart Pot Creek cemetery and the new RFS station. These construction sites would generally be some distance from and unlikely to impact upon waterways.

At the site of the dam wall and spillway, construction would be undertaken within the main channel of the Williams River. Two coffer dams would be constructed upstream and downstream of the dam site to provide a dry working site (refer Chapter 7) with the river diverted around the work site. There would, however, still be the risk of mobilisation of sediment during construction of the coffer dams.

Away from the river channel, exposed surfaces would be associated with the three quarry areas and haulage routes, and with road-related construction activities. There would be a risk of mobilisation of sediment from these areas and movement of this via drainage lines into waterways.

As noted in Chapter 7, construction plant would include a concrete batch plant. A range of criteria have been identified (refer Table 7.1) to guide location of the plant to minimise risks from contaminated process water. However, uncontrolled runoff from the area occupied by plant could potentially reach the Williams River and impact on water quality and consequently aquatic habitats. A further risk to water quality and consequently aquatic habitats may occur through the storage and use of environmentally hazardous materials during construction such as fuels, lubricating oils, etc.

Reduced water quality can be due to a variety of causes and have a range of impacts including:

- increased turbidity may result in a decline in light penetration and therefore primary productivity, including macrophyte beds,
- an increase in associated nutrients which may encouraging algal growth and blooms,
- contaminants (if present) bound in sediments could be released during suspension into the water column.

The likelihood and scale of impacts of an increased sediment load would depend on the amount of sediment mobilised into the water and over what period it occurs. The mobilisation of sediments can usually be controlled with standard sediment control procedures for construction.

Impacts on aquatic habitat downstream in Reach 3 may occur as a result of sediment mobilised at the dam wall construction site. The likelihood and magnitude of an impact on habitat would decrease with distance downstream as sediment settles out of suspension.

Impacts on aquatic habitats in Reach 4 would be similar to those for Reach 3, though being further downstream, the likelihood and magnitude of any impact on aquatic habitats is expected to be lower than in Reach 3.

10.9 Downstream water users

As noted in Working Paper D *Environmental Flows and River Management*, low flows need to be maintained so there is no interference to existing abstraction rights. Currently, cease-to-pump levels occur for eight per cent of the time for accredited users and 13 per cent of the time for non-accredited users. The timing, frequency and quality of controlled releases of water from the dam would be critical in maintaining existing downstream water use rights.

The multi-level offtake tower would be a key supporting component of the release strategy by allowing water to be drawn from a level within the storage that matches as closely as possible the required water quality for downstream releases. Water releases from the storage would be suitable for irrigation and stock and domestic purposes. During construction when water quality impacts may be unavoidable due to instream works HWC would tanker water to any affected householder that relies on water between Tillegra and the confluence of the Williams/Chichester Rivers.

The adopted operational release strategy would be the principal strategy for managing and avoiding potential adverse downstream effects. The preferred operating regime has been described in Section 10.4. The following table illustrates the small difference between the historic measured flows at Glen Martin and the preferred operating regime (refer Table 10.9). The modelled historic flows are also shown to illustrate the close agreement between these and measured flows.

TABLE 10.11 PER CENT EXCEEDANCES FOR HISTORIC FLOWS (AT GLEN MARTIN) COMPARED TO MODELLED FLOWS FOR PREFERRED OPERATIONAL REGIME

	HISTORIC MEASURED		HISTORIC MODELLED		PREFERRED OPERATIONAL REGIME	
Discharge (Ml/d)	6	15	6	15	6	15
Annual	92	87	93	88	96	91
Spring	91	83	90	80	95	87
Summer	85	77	86	78	91	83
Autumn	95	92	97	97	99	96
Winter	98	95	100	100	100	99

The conclusions to draw from the table are that confidence can be placed in the modelling of low flows and that the preferred operational regime would essentially preserve low flows in the Williams River. On the basis of available information, it is unlikely that there would be any interference to existing groundwater extraction rights for users between Tillegra Dam and Dungog.

During construction, water will always be available down stream from the dam as water is bypassed through the diversion tunnel. Further, during fitting of bulkheads to the diversion tunnel and its connection to the multi-level offtake tower, water will be passed through a bypass pipe that can provide a static release of up to 80 ML/day.

As previously noted at Section 10.6.2, a minor risk to water quality has been identified during the first ever filling of the storage that could affect releases prior to the multi-level offtake tower coming on line. This occurs through the initial decomposition of pasture within the inundation area potentially having a high biological oxygen demand and also affecting nutrients and subsequent plankton blooms; however this risk to water quality occurs only during the first filling of the dam and within the first few months of closing the river diversion tunnel.

Should releases need to be held in abeyance for a few months until water quality improves, this matter will be managed by:

- tankered supply of water being provided to stock and domestic users
- increased releases being made from Chichester Dam to compensate for any flow reduction in the river from the Upper Williams River subcatchment, thereby limiting any impacts to approximately four kilometres of river directly below the dam, to the Chichester confluence
- provision of stock feed/fodder to any party immediately below the dam, and the confluence of the Chichester River, who would have otherwise have provided feed or produced hay/fodder through irrigation.
- direct financial compensation being paid to any farmer immediately below the dam and above the confluence of the Chichester River where it can be demonstrated that a reduction in water has caused the loss of an irrigated crop or otherwise caused a financial loss through reduced agricultural production as a direct result of Hunter Water not releasing water from the dam in accordance with the proposed environmental and operational flow regime.

Consequently, it is expected there would not be a material impact on existing surface and groundwater users.

10.10 Hunter estuary and Ramsar wetland

The potential impact of Tillegra Dam on the Hunter estuary and Ramsar wetland has been assessed in line with the supplementary DGRs and with reference to the ecological character of the wetland as summarised in the Information Sheet submitted in 2002 to the Ramsar Convention on Wetlands. Based on these analyses it was concluded that the ecological character of the Hunter estuary and Ramsar wetland would not be significantly changed by the construction of the Tillegra Dam.

It is noted that in addition to the wetland, the broader estuary contains important aquatic habitat that sustains both commercial and recreational fisheries, oyster production and other aquatic values of importance to the community.

For example, the estuary prawn trawl fishery is the largest fishery operating in the estuary with approximately 29 licenced trawlers. Catches fluctuate between 30 to 100 tonnes depending on the season. In the period 1999 to 2001, the value of these catches was estimated to be between $325,000 and $750,000 (NSW Fisheries 2003). Oyster production statistics from leases at Fern Bay are not available due to confidentiality reasons; however while valued, production is likely to be significantly less than occurs from many other NSW estuaries.

All Tillegra Dam flow scenarios (including Tillegra Dam fill-up, construction and operation) would have limited impact on the flows received at the Hunter estuary and Hunter Estuary Wetland due to the overriding control of flows at Seaham Weir. Further, inflows from the Hunter River mask any discernable impacts on the estuary's hydrology that would otherwise be apparent. Flood, advection, dispersion and tidal modelling results, as well as nutrient mass balance estimates only showed minor deviations in baseline water quality and hydrological parameters.

On this basis, it is considered that no impacts to the estuary, the Ramsar site and activities such as commercial fishing, recreational fishing and aquaculture will occur. It is noted that estuarine productivity including prawn catches have been correlated with flooding and high flows to estuaries (Ruello 1973). High flows and floods transport detrital matter and organic carbon from floodplains and this stimulates primary production. In the case of the Williams River, much of the river is a discontinuous river style (Cook and Schneider 2006). This was also noted within investigations within Working Paper B *Fluvial Geomorphology*. This means that while flooding occurs, the frequency and extent of floodplain inundation is limited. Consequential entrainment of carbon is therefore suppressed. This existing situation will not substantially change as a result of the dam project. Further, as noted in the Ramsar assessment report, the total cumulative reduction in total organic carbon to the system from the existing situation is calculated to be 0.7 per cent.

Change in peak flood level for more frequent recurrence intervals are generally less than 0.05 m within the estuary and wetlands. Tillegra Dam would reduce the peak flow at Seaham Weir for all events based on the flood frequency analysis. However, modelling showed that below the weir, there would be minimal change in the simulated water level near the wetland due to the existing control of flows at Seaham Weir. The presence of the weir and its effect on the pre and post-Tillegra Dam flows to the wetland is very important when considering the potential impact of the dam on the estuary and wetlands.

Hydrological changes are predicted to create small differences in tidal height (low water mark is predicted to be within ±1 cm of current levels; high water mark is predicted to be within -1.2 cm to

+1 cm of current levels) or maximum salinity (up to a approximately 3 ppt change in salinity levels) and have little effect on the key ecosystem processes. Freshwater will continue to enter all areas of the estuary and the majority of nutrients entering the estuary will continue to come from the ocean or cycled within the estuary itself.

The simulation of salinity concentrations in the Hunter River show relatively minor differences (typically less than 0.5 ppt) in salinity as a result of changes in flow at Seaham Weir along the South Arm and North Arm of the Hunter River. The greatest difference in salinity is estimated under 90th percentile flow conditions at Seaham Weir coupled with median flow conditions in the Hunter River and Paterson River. Differences in the average salinity concentration are greatest (approximately 3 ppt) near the upstream extents of the Ramsar site (approximately 20 kilometres upstream of the ocean). In the vicinity of the wetland area between Hexham and Newcastle Harbour the difference in salinity is typically less than 0.5 ppt under 25th percentile flow conditions, 1 ppt under 50the percentile flow conditions, 2 ppt under 75th percentile flow conditions and 3 ppt under 90the percentile flow conditions.

In relation to water quality, the modelling and analysis suggest that the total nitrogen and total phosphorus loads to the estuary would be reduced by 1.1 per cent and 1.3 per cent respectively. This can be attributed to the expected reduction in flow volume downstream of Tillegra Dam.

The results of the water and nutrient budget illustrate the relatively small contribution of loads to the estuary from the Williams River catchment. Flow inputs from the Williams River are less than 1.5 per cent of the total volume of inputs considered by the budget. Consequently, changes to the concentration of total organic carbon (TOC) as a result of Tillegra Dam are not expected to result in considerable changes within the Hunter estuary wetland.

Based on an estimated average annual flow volume reduction of 0.3 per cent from the Williams River alone, the percentage reduction of the total organic carbon load into the system from the sources included in the assessment would be approximately 0.7 per cent (ie a reduction from 3.1 per cent pre-Tillegra to 2.4 per cent post-Tillegra). Tides play an important role in flushing of the lower estuary in which the study area is located and is considered to play a more dominant role in the expected water quality conditions during average annual conditions.

The potential impacts from the dam were also considered within the context of other factors impacting on the estuary such as tidal and oceanic influences, climate change and sea level rise, and activities in the wider catchment area. The modelling indicates there would be minimal hydrodynamic changes to the estuary, particularly when the predicted changes are evaluated in the context of daily tidal fluctuations, predicted impacts from climate change and sea level rise, and the broad environmental tolerances of most estuarine species are taken into account.

The following summarises consideration of the relevant NES matters with respect to the Ramsar wetland:

- **Areas of the wetland being destroyed or substantially modified** – no areas of the Hunter estuary wetland would be destroyed or substantially modified
- **Substantial and measurable change in the hydrological regime of the wetland** – extensive modelling of potential changes to the hydrological regime of the wetland has been undertaken with no substantial or measurable changes predicted, especially as 92 per cent of the water to the wetlands comes from ocean tides. The low water mark is predicted to be within ±0.1 cm of current levels and the high water mark within -1.2 cm to +1 cm compared to the current daily tidal range under average tidal condition of 0.7 1.45 m. Modelled changes in inundation height are predicted to be in the magnitude of 1-2 cm.

- **The habitat or lifecycle of native species dependent upon the wetland being seriously affected** – there would be no direct impacts on native species or vegetation communities within the wetlands given the minor alterations in nutrient and salinity regimes and water inundation levels. The vast majority of nutrients entering the Hunter estuary come from tidal sources. The dam would result in a small decrease in the amount of nutrients entering the estuary due to the trapping of sediments and nutrients within the dam. As the predicted changes in flow regime are minor the habitat areas available for flora and fauna of the estuary would not be affected.
- **A substantial and measurable change in the water quality of the wetland** – as the estuary is dominated by oceanic influences with approximately 92 per cent of water entering the estuary coming from ocean tides, it is unlikely there would be any substantial or measurable change in the water quality of the estuary. Modelled scenarios changes in salinity are predicted to be 1-3 ppt and nutrients less than two per cent.
- **An invasive species that is harmful to the ecological character of the wetland being established** – as construction and operation of the dam would not connect the Hunter estuary to any new waterways it does not present an invasion pathway for aquatic pests to enter the estuary. Neither would the dam change conditions to the extent that current pest species present in the wetlands would be affected.

Based on the available description of the ecological character of the Hunter estuary wetland, material cumulative and consequential impacts from construction and operation of Tillegra Dam are not expected. In making this conclusion, the minor extent of change that would result from the proposed dam provides confidence that it would not substantially contribute to any cumulative impacts or changes to the Hunter estuary wetlands. Further the potential impacts of climate change and, in particular, sea level rise could be severe given current climate scenario and vulnerabilities of estuarine wetland. These are expected to far outweigh any minor environmental changes associated with the dam.

A full analysis of potential changes to the hydrology of the estuary, changes to the extent and frequency of flooding, and consequential impacts to habitat and dependant estuarine ecosystems, including potential affects on the Hunter estuary Ramsar wetlands are described in detail in Appendix 6.

10.11 Management of construction impacts

Management of construction-related impacts with respect to the environmental aspects discussed in this chapter, ie water quality and hydrology, fluvial geomorphology, and aquatic and riparian ecology focus predominantly on water quality and managing the risk of erosion and sedimentation, and transport of pollutants into waterways. The effective management of these would serve to manage consequent impacts on aquatic habitats. Impacts on fluvial geomorphology and riparian habitats are considered to be more longer term in nature and are addressed in Section 10.11.

The objective of the following measures would be to protect water quality during the construction phase of the proposed Tillegra Dam and associated works. These would largely focus on erosion control thereby reducing the potential for sediment export from construction sites. Attention would need to be given to reducing the risk of occurrence of events (eg fuel spills) that could affect water quality and to have appropriate measures in place to manage these events if they did occur.

Design and construction of erosion and sediment controls would be undertaken in accordance with the guideline *Managing Urban Stormwater: Soils and Construction* ('The Blue Book') (Landcom 2004).

The effective implementation of these controls would be managed through a formal erosion and sediment control plan which would comprise part of the overall construction EMP.

Erosion control at construction sites

- as far as practicable, minimise disturbance of vegetation at construction areas
- where practicable, stage vegetation clearing to limit the area and duration of soil exposure
- progressively restabilise sites as construction activities are completed
- undertake vegetation clearing in a manner that minimises erosion (eg leaving the root system intact)
- stabilisation of site access
- if and where possible, timing major construction phases to coincide with low rainfall periods
- locate spoil stockpiles as distant as practicable from waterways and major drainage lines
- locating construction facilities (eg amenities, site offices) in already cleared and stabilised areas, as far as practicable
- appropriate placement of stockpiles to minimise access disturbance.

Sediment export from construction sites

- establishment of temporary sediment basins to remove coarse grained particles from site runoff
- provision of diversion bunds to direct clean stormwater runoff away or around construction sites
- installation of sediment fences or barriers (eg hay bales) to remove particles from runoff
- appropriate containment sediment measures during bridge pylon construction, such as use of floating booms and sediment curtains, or temporary installation of sheet piling.

Accidental release of hazardous material

- development of management protocols for responsible delivery, storage, use and disposal of hazardous substances (eg fuel, chemicals)
- development of response strategies for implementation in the event of spillages
- provision of suitable resources (eg spill kits) and training in their use
- appropriate remediation of disposal of material contaminated by spills (eg to a licensed waste receival facility).

Regular inspection and maintenance of erosion and sediment control measures would be undertaken during construction to facilitate their ongoing effectiveness. This would include regular water quality monitoring upstream and downstream of the construction sites. Monitoring would be continued until areas disturbed by construction activities had become adequately stabilised.

10.12 Post-construction management of the Williams River

10.12.1 Storage water quality management

Control of sediment and nutrient export from the catchment above the storage

Management and mitigation measures to address impacts associated with the initial filling of the storage would focus on reducing nutrient concentrations and the consequent impacts from any releases of nutrient-rich water. There are likely to be few practicable options to address this issue, however, these may include:

- selective clearing of vegetation prior to inundation–which would be undertaken principally as a hazard reduction strategy but would be of some benefit to reducing nutrients where any such cleared vegetation was removed from the inundation area (such as to provide habitat for displaced fauna)
- monitoring of nutrient and algae concentrations, particularly during the first two years of the filling phase, to assist in the appropriate selection of release levels.

For clarification, it is noted that vegetation would be cleared in the main body of the storage where it would otherwise pose a public safety risk for recreational boating, however vegetation will be retained around the rim of the reservoir to provide aquatic habitat and reduce shoreline erosion (where it would protrude through the surface of the reservoir and be clearly visible as a navigation hazard to be avoided), as well as in the headwater and creeks entering the storage.

Note that Chapter 16 *Management of Other Environmental Issues* addresses the issue of potential contaminated land within the storage area. This includes identification of management and mitigation measures which would contribute to mitigating such water quality impacts.

In the longer term, a reduction in sediment and nutrient export from the catchment and the likely subsequent reduction in the release of metals from sediments could lead to improvements in storage water quality and catchment watercourses. Potential management options to achieve this include:

- implementing measures to reduce foreshore erosion (eg fencing off waterways to prevent stock access)
- review of land management practices and soil conservation
- enhancement of riparian vegetation along creeks and rivers feeding the dam
- avoiding excessive use of fertilisers and manures on agricultural land within the catchment.

The extent to which these measures could be implemented may be limited as they would need to be undertaken on land not under HWC ownership or control. Recognising this, a draft integrated land use plan (Working Paper N) has been prepared to facilitate management of the land around the storage, addressing strategies such as these. This issue is also being addressed through the establishment of a buffer zone which is discussed as follows.

Storage shoreline management

Protection of water quality in the storage would require effective management of the shoreline. Identified risks to water quality include elevated levels of nutrients in runoff from surrounding land and erosion of the storage shoreline, particularly on the eastern side of the storage. Neither of these are considered major risks but where there are cost-effective opportunities to reduce the risk, they should be taken.

Treatment techniques for managing shoreline erosion range from the installation of 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 (US Army Corps of Engineers 1992).

The principal management measure in this regard would be the establishment of a nominal 50 metre wide buffer zone around the entire perimeter of the storage. Within this buffer zone, vegetation would be permitted to grow with the ultimate aim being to establish substantial ground cover and an understorey.

Destratification

To avoid water quality problems associated with stratification during summer and well mixed conditions during winter, attempts have been made to artificially break down the thermal stratification within reservoirs.

Aeration devices are often used leading to sustained year-round improved oxygen concentrations near the bottom of the storage. Destratification by aeration has been successfully employed at Chichester Dam, however, in general, the use of artificial destratification has had varying degrees of success.

Destratification is generally employed to improve water quality where it may be immediately entrained into a water supply system or to resolve an unusual environmental conditions caused by a barrier or weir. The storage volume of Tillegra Dam is likely to be too large for effective destratification. If employed, the objectives of the destratification process would need to be clearly identified and the costs balanced against the benefits depending on water demands and uses.

The current assessment indicates that while stratification would likely occur in the storage, and this is normal for all large dams, the quality of water released from the reservoir could be appropriately managed by appropriate operation of the multi level offtake tower.

Control of blue-green algae blooms

The development of blue-green algae blooms are a natural part of any aquatic system and it is unlikely that algal blooms could be completely eliminated from the storage. A number of management methods are available to help prevent, reduce severity and control blue-green algal blooms. These include:

- physical controls such as artificially mixing the water column
- minimising nutrient levels in inflows to and within the storage

Artificial mixing is not currently considered to be a pragmatic activity for management of the dam as previously discussed, however an integrated land use plan has been prepared to promote sustainable land use practices in the immediate vicinity of the dam. This would assist in reducing the risk of nutrients being transported into the storage.

Management of recreational activities on and around the storage

It is anticipated that recreational activities would be permitted on and around the storage (refer Chapter 12 and Working Paper N for further discussion). These would carry a degree of risk to water quality though this would likely be relatively low. To minimise the risk of recreational activities on water quality, consideration would be given to adoption of the following measures:

- provide appropriate and adequate infrastructure at recreational facilities (eg toilet facilities, waste receptacles, etc) to accommodate anticipated level of use
- implement an appropriate management regime for recreational areas to facilitate early detection of potential issues which could impact on water quality.

10.12.2 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. 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. 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.

The feasibility of adding an annual load of one million tonnes of sand to the Colorado River was evaluated by Randle *et al* (2007). This study found local sources of sand, 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.

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.

While considerably less sediment would need to be bypassed at the Tillegra Dam site, when compared to the Colorado River example cited it is considered that a scheme to bypass sediment around the storage would be extremely difficult to implement, may be impractical due to the availability of clean gravels and in general, cost prohibitive.

10.12.3 River management

Over the longer term (decades), the river would adjust to the new flow regime. The readjustment would likely involve initial bed scouring but this is expected to be localised and discontinuous. Mobilisation of bed material could also lead to deposition in some places such as building of in-channel benches at new levels. The predicted bed scour would not necessarily lead to increased rates of bank instability because the bed level of the river is fixed in many places by bedrock bars.

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 (generally 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. Consequently, the preferred response is to allow channel adjustments to take place.

10.12.4 Hydro-electric plant (HEP)

Water drawn off through the offtake tower and passed downstream as an environmental flow or run-of-river flow may be passed through a hydro-electric turbine and provision for this has been made in the design of the dam. Power generation would be opportunistic and the timing entirely dependent on the timing of these types of releases which will be made in accordance with the adopted release strategy. Accordingly, operation of the HEP would not contribute to any variation in the hydrology of the river downstream. Therefore, there would not be any resultant impacts on aquatic flora and fauna downstream of the storage from operation of the HEP.

10.12.5 Fish passage

Seaham Weir represents an existing barrier to fish passage along the Williams River. A fishway is in place at Seaham Weir but this is an older modified orifice type design which limits the potential for fish to negotiate the structure.

The new dam at Tillegra would represent a further barrier for fish passage. In order to maintain linkages between fish populations and allow fish passage past the dam, a fishway would need to be constructed at the dam.

The specialist investigations undertaken for the Project have included a study of opportunities to improve the fishway at Seaham Weir and the feasibility and cost-effectiveness of provision of a fishway at Tillegra Dam (Dept of Commerce 2008c). The following discussion summarises the findings of this study.

Fish passage at Tillegra Dam

The dam wall would be 76 metres high which would require 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). High fishways are relatively untested on native Australian fish species and would be a major capital works program involving considerable expense.

The total length of the Williams River from its headwaters to the Hunter River confluence is approximately 154 kilometres. Tillegra Dam would be located approximately 101 kilometres upstream of the confluence. Migratory fish are common near the dam site which suggests that apart from Seaham Weir, there are no significant barriers to fish passage along the Williams River.

Nominally the dam would represent a barrier to the upstream one third of the main channel length. It is noted, however, that the upper reaches of the Williams River are much steeper than downstream reaches. To some extent the associated higher flow velocities would serve to discourage fish passage. As such, not all of the Williams River above FSL (approximately 34 kilometres) would necessarily represent useable habitat for fish species that might migrate up from the lower reaches.

Fish passage at Seaham Weir

As previously noted, Seaham Weir incorporates an existing submerged orifice fishway. The study undertaken for the Project noted that upstream fish passage at the weir can potentially occur:

- during high flow events (floods) when the whole structure is submerged
- through the weir gates if water velocities are less than the swimming ability of fish downstream
- through the existing fishway.

With regard to the last point, it was noted that the high water velocities and high turbulence produced by the steep gradient of the existing fishway are impassable to almost all sizes and species of native fish when the weir is operating as intended with 30 centimetre head losses at each baffle. This is offset to some extent when upstream and downstream levels equalise at high tide. At these times, fish can negotiate the fishway as velocities are much lower.

The presence of the fishway and the operation of the weir, with water levels that often equalise, appear to have provided passage for many migratory fish species and have allowed them to maintain populations in the Williams River system above the weir. The river is well known for Australian bass and DPI survey data confirm that this species is common in the Williams River. It is likely that provision of more effective fish passage would improve these populations.

Two fish species that have been impacted by Seaham Weir are freshwater herring and striped mullet, with both being very uncommon upstream of the weir. The study noted that this may be related to their behaviour in fishways and their ability (or lack of) to use the Seaham Weir fishway. A wide range of herring species are known not to pass through fishway orifices and freshwater herring are probably reluctant to pass through those at Seaham. Striped mullet are a surface species which may also be reluctant to swim to the bottom of the fishway to pass through the orifice.

Preferred mitigation strategy

The aquatic ecology investigation (Working Paper C) recommended provision of a fishway at Tillegra Dam to mitigate impacts on migratory fish populations. The cost of this has been estimated at approximately $30 million. This would not be an insignificant cost to the Project and it is considered there would be greater environmental and social benefits for less cost by taking a catchment-wide view of opportunities to offset impacts.

This would include improving fish passage at Seaham Weir by replacing the existing submerged orifice fishway with a structure(s) that operates over a much wider range of flows and allows the passage of smaller, weaker fish and macroinvertebrates which are more common in Australian freshwater systems (particularly diadromous juveniles). The draft Fish Passage Study for Tillegra Dam and Seaham Weir (Dept of Commerce 2008c) outlines several options for upgrading the Seaham Weir fishway, favouring a single exit ungated vertical slot fishway.

HWC is also consulting with DPI (Fisheries) in relation to other opportunities to improve aquatic habitats in the lower Hunter region. It would be possible to remediate several other priority barriers to fish passage within the Hunter region, in lieu of a high lift fishway. This would provide substantial improvements to fish passage along several hundred kilometres of rivers within the region for a more measured investment of community funds.

10.12.6 Fish stocking

The Williams River catchment is a popular fishing area targeted by recreational anglers. Stocking of the Tillegra Dam storage with Australian bass is a possible management option. Stocking of bass for the purpose of supporting a recreational fishery has been successful in other artificial impoundments in NSW such as Tallowa Dam (Gehrke *et al* 2002). This opportunity is acknowledged in Working Paper N *Draft Integrated Land Use Plan* which identifies fishing as one of a possible number of recreational activities which could occur on or around the storage.

As part of the aquatic offset package negotiated with the DPI(Fisheries), a commitment has been made within the terms of the package to stock the storage with Australian Bass.

Where it would not pose a risk to watercraft or other aquatic recreational activities, vegetation in the inundation area would be left in place to serve as habitat for fish. These standing snags would provide habitat for surviving or stocked native species. The incremental impact on GHG emissions from the breakdown of this organic material would be negligible.

10.12.7 Public safety and amenity

Public safety and amenity related to the flooding of low–lying areas, roads, causeways and crossings would be improved by Tillegra Dam directly as large flows directly below the dam that would have otherwise naturally occurred, would be suppressed.

The proposed release regime for flows from the storage may however cause the temporary inundation of private causeways and river crossings in the upper reaches of the Williams River. While this impact would generally progressively decrease with distance downstream due to a larger channel capacity, it would still represent a potential public safety and amenity issue.

As a mitigation measure, HWC would identify critical low–lying river crossings, notify property owners prior to significant releases and provide information on its website of the schedule of run-of-river transfers.

10.12.8 General operation of Seaham Weir

Operation of the weir gates is undertaken in a manner that complies with the requirements of a licence administered by the DWE. The licence requires HWC to maintain specified water levels in the weir pool. At this stage, HWC does not proposed to change the manner in which water levels are maintained in the pool and as a consequence, the existing terms of the licence would remain unchanged.

A new fishway at Seaham Weir would improve connectivity between the estuary and the Seaham Weir Pool. It would also result in an increase in the net volume of water passed downstream compared to the existing structure. The fishway could be designed to include provisions to release additional water downstream while maintaining current water levels within the weir pool.

As water levels within the Seaham Weir Pool are not expected to change significantly following construction and operation of the dam, the risk of erosion of channel banks within the weir pool would not be increased.

Historically, the tidal and navigable limit of the Williams River extended to Clarence Town. In 1967, construction of Seaham Weir was completed to create a tidal barrier across the river approximately 20 kilometres downstream of Clarencetown to prevent the intrusion of saltwater into this section of the river. Currently salt levels below the weir typically range from between 4–7 ppt (parts per thousand) depending on depth and the position of the salt wedge in the estuary at any one time.

A salt wedge within the estuary occurs when water from the ocean intersects with freshwater from the river. As salt water is denser than fresh water, it sinks to the bottom of the river whilst the fresh water floats over the surface creating a wedge. A salinity gradient is then formed both longitudinally and vertically within the river.

Within the estuary, the reduced flood flow magnitudes and frequency as a result of the dam may lead to a minor decrease in flows that would otherwise act to flush salt back down the river away from the weir, when compared with the current system. The effect is predominantly relevant to the Williams River and may also result in a slight increase in salinity at the weir during low flow periods. The degree of change has been estimated to be 3 ppt within the worst case scenario and during normal climatic conditions, more normally about 0.5 ppt. Such changes below the weir can occur as the position of the salt wedge and therefore salinity profile is naturally mobile in response to tidal flows, channel morphology, and freshwater inflows.

Given that modelling suggests that the wider estuary and wetlands are not sensitive to flow changes downstream of Seaham, HWC does not propose to change the current manner in which Seaham Weir is operated. Recent investigations have, however, highlighted the absence of comprehensive monitoring data downstream of the weir and accordingly it has been recommended that HWC undertake monitoring and assessment program to collect baseline data. This information would be useful to measure any change to the downstream environment as a consequence of upgrading the existing fishway, as well as providing for the management of the aquatic environment of the river directly downstream of the weir, within an adaptive management and continual improvement process prescribed under the water sharing plan.

10.12.9 Monitoring

Water quality

A water quality and hydrology monitoring program would be instigated to monitor the effects the construction and operation of the dam on water quality and to provide information on the appropriate water release depths from the storage. Specific components would include:

- a water quality monitoring program to provide information on vertical variability in temperature, dissolved oxygen and algal blooms within the dam to assist with selection of an appropriate withdrawal depth at the offtake structure. This would be particularly important during the initial filling period when in-storage water quality variability is likely to be high
- water temperature logging at Underbank, Tillegra and Dungog prior to construction in order to assist with calibration and future operation of the offtake tower
- a monitoring program immediately downstream of Seaham Weir will be instigated to provide a better understanding of the downstream ecosystem and determine any changes from upgrades performed on the weir. Monitoring would consist of collection of DO, temperature, salinity and other water quality parameters at various locations within the estuarine component of the Williams River.

HWC currently monitors water quality with the Williams River at several points, including at Boags Hill, Chichester and Tillegra. This monitoring program has collected data on both a daily and monthly basis (depending on sampling site and analyte) for approximately 25 years. This existing monitoring program is required for the management of Chichester Dam, Grahamstown Dam and the Seaham Weir Pool. The existing program will be continued well into the foreseeable future. The above proposed monitoring actions will augment the existing monitoring regime.

Storage inflows

A new water level recording station has been established upstream of the storage. This would ultimately replace the existing gauge at Tillegra which would need to be removed prior to commencement of construction. The new gauge allows collection of concurrent records and a correlation between the two sites to be established.

The new gauge would include appropriate instrumentation to allow real time monitoring of inflows into the storage. This would facilitate timing and sizing of the transparent environmental and operational releases from the dam. It is proposed that releases made through the multi-level offtake tower will be linked by SCADA telemetry to allow automated releases to be made on hourly time steps. Depending on final design constraints, it may be possible to increase the adjustment of releases to half hour intervals. The use of hourly or half hour time steps will also ensure that there are no unnatural or sudden changes to the existing flow regime that currently exists in the Williams River. This will therefore prevent impacts on habitat and the river's aquatic ecology.

Aquatic ecology

A monitoring program would be implemented to examine potential effects of the dam on aquatic biota and to demonstrate the efficacy of mitigation measures designed to reduce dam impacts. Specific ecosystem components to be measured include aquatic habitat, fish passage and aquatic faunal assemblages.

An aquatic ecosystem offset package has been developed in consultation with DPI(Fisheries) and includes the following:

- remediation of fish passage at four high priority barriers in the Hunter catchment; subject to final confirmation from DPI(Fisheries), this will include fishways at Seaham Weir, Liddell gauging station (Hunter River at Jerries Plains), Dora Creek Weir and Barnsley Creek Weir (alternative sites are listed in the NSW Weir Review for the Hunter and could include such sites as Cross Keys Road on the Paterson River or other sites of a similar nature should it be necessary to adjust targeted sites due to issues beyond the control of HWC or DPI)
- the reintroduction of at least 10 kilometres of large woody debris (LWD) into the Williams River to provide for enhanced geomorphic and aquatic habitat diversity in the Williams River
- sponsorship of a comprehensive monitoring and research program including components such as habitat mapping, fish surveys using electro-fishing sampling techniques, the assessment of movement patterns using acoustic sonar tags, habitat utilisation, PIT tagging and LWD monitoring
- a five year community small grants scheme of $100,00 annually for the rehabilitation and management of wetlands, riparian zones and in-stream aquatic habitat within public lands
- provision of funds to provide a project officer to oversee the implementation of the package, including fish way construction, the installation of LWD and administration of the small grants scheme.
- in-kind contributions from the DPI for the provision of boats, equipment, sampling gear and the facilitation of fish stocking (Australian Bass) into the storage.

The current value of the offset package has been estimated to be worth in the order of $11 million dollars (nominal) invested over the next 10 years.

10.13 Summary

Preferred operating regime

Baseline operating strategies have been developed to address maintenance of environmental requirements in the Williams River during construction filling and operation. During construction, a transparent release strategy would be adopted and it is expected there would be minimal impacts with respect to modification of the hydrological regime.

During filling, several release strategies would be implemented, these being determined by the depth of water in the storage. Initially, releases of up to 80 ML/d would be made via the bypass pipe until there was sufficient depth in the storage for the offtake tower to commence operating. Once there was sufficient depth for the offtake tower to operate, a transparent release of low and moderate flows would be made to provide for environmental requirements. These would be supplemented by six releases with a peak flow of 270 ML/d for 1.5-2 days in January, March, April, May, July and August to simulate the movement of minor flood events (freshes) through the system.

The initial release strategy is expected to be required for the first one to two years of operation but would obviously be dependent on inflows to the storage. As the volume of water in the storage increases, the release strategy would be modified slightly. It is expected that sufficient water would now be available for transfer via run-of-river to Grahamstown Dam. Transfers would be made at a rate peaking at about 1,500 ML/d declining over a 10 day period. The transparent release for environmental requirements would be maintained.

During normal operation, environmental releases, run-of-river transfers and fresh events would be as for the second stage of filling to prevent unnatural or sudden changes to the hydrology of the river. This will ensure that impacts do not occur on the habitat or aquatic ecology of the river.

The assessment undertaken for the Project has identified an operational flow strategy through an iterative process that accommodates environmental requirements. HWC recognises that implementation of the strategy would be a case of continual improvement. Regular reviews of system performance would be undertaken with information collected from monitoring activities used to determine whether and how the strategy should be modified.

The review and refinement process would be undertaken in consultation with relevant stakeholders such as DWE. Reviews could be synchronised to support and feed into other reviews relevant to the management of the river such as the statutory reviews prescribed by the water sharing plan.

Mitigation and management of impacts

Management of construction-related impacts with respect to the environmental aspects discussed in this chapter, ie water quality and hydrology, fluvial geomorphology, and aquatic and riparian ecology would focus predominantly on water quality and managing the risk of erosion and sedimentation, and transport of pollutants into waterways. There are readily available accepted strategies and techniques for this and it is expected that impacts would be managed satisfactorily. These management activities would form part of the overall environmental management plan for the Project's construction.

Management of impacts on the Williams River related to water quality and hydrology, fluvial geomorphology, and aquatic riparian habitats during initial filling and subsequent operation would be addressed principally through implementation of a storage release strategy that addresses maintenance requirements for these environmental aspects while still meeting operational requirements. The full release strategy proposed for the dam is detailed in Working Paper D *Environmental Flows and River Management*. The strategy has been designed to account for and manage sudden and unnatural changes to flow regimes as far as practical. A range of additional management works will also be undertaken to mitigate or offset instream environmental impacts and these are detailed in full within the Statement of Commitments.

Conclusion

The characterisation and assessment of potential impacts of the Project on the Williams River in relation to water quality and hydrology, fluvial geomorphology has been undertaken holistically. This has facilitated assessment of the flow requirements of the many interacting components of the Williams River system. Through this approach, consideration has been given to such components as the source area, river channel, riparian zone, floodplain, groundwater, wetlands and estuary, as well as important features such as rare and endangered species.

The essential features of the existing hydrological regime have been identified and their influence on key geomorphological and ecological processes of the Williams River system have been characterises. Through this, it has been possible to construct a modified flow regime to address HWC's operational requirements while minimising negative impacts on geomorphological and ecological processes.