Tillegra Dam

Planning and Environmental Assessment

WORKING PAPER

a

Water Quality and Hydrology

aurecon

Hunter Water

Document Control

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Executive Summary

Hunter Water Corporation (HWC) has commissioned Connell Wagner to undertake the Planning and Environmental Assessment for the proposed Tillegra Dam project. An assessment of water quality and hydrology along the Williams River is provided in this report to support the overall environmental assessment process. The assessment has been prepared in accordance with the requirements under Part 3A of the *Environmental Planning and Assessment Act 1979 (EP&A Act)* and the *Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act)*.

The broad aim of this investigation is to assess the potential issues associated with the construction and operation of the proposed Tillegra Dam on water quality and river flows. The assessment included:

- characterisation of the existing Williams River system
- field surveys of specific water quality and physico-chemical measurements at representative sites
- identification and assessment of potential impacts of dam construction and operation on water quality and hydrology upstream, downstream and within the proposed storage
- a strategy for maintaining the environmental values of the Williams River during both the construction and operation of the dam
- preliminary assessment of ecologically relevant flows.

To asses the water quality, aquatic ecology and geomorphological components, of the Williams River it was divided into five reaches, from the headwaters in the Barrington Tops National Park to the confluence with the Hunter River. Water, sediment and ecological sampling was carried out at thirteen sites within these reaches:

- Reach 1 Upper Williams River to Storage FSL (Sites W1 and W2)
- Reach 2 Storage (Sites W3-W6)
- Reach 3 Storage to Glen Martin (Sites W7-12)
- Reach 4 Seaham Weir Pool (Site SWP)
- Reach 5 Seaham Weir to Hunter River confluence.

The upper catchments of the Williams River are characterised by steep vegetated slopes and the lower catchments are characterised by undulating and rolling hills with the majority of the vegetation cleared for agriculture. Water quality in the catchment as a whole is relatively good with the river able to support diverse ecosystems. Water quality declines as you move downstream with the influence of agricultural activities reflected in elevated nutrient concentrations. The larger pools of the lower Williams River, above Seaham Weir experience regular algal blooms during the summer months.

Flows within the Williams River have been regulated with the construction of Chichester Dam in the 1920s and Seaham Weir in the late 1960s and extraction by irrigators. Average river flows within the catchment at Tillegra Bridge, Chichester Dam, Glen Martin and Williams River Estuary have been estimated as 262 megalitres per day, 251 megalitres per day, 881 megalitres per day and 745 megalitres per day respectively.

A number of key water quality issues have been highlighted for each reach of the Williams River, including stratification, algal blooms and nutrient trapping within the proposed storage; coldwater pollution, changes to river flow and quality downstream of the proposed dam to the Chichester River inflow; pool stratification and algal blooms within Seaham Weir Pool and potential saline ingress in the Williams River Estuary.

A strategy for maintaining the environmental values of the Williams River during both the construction and operation of the Tillegra Dam project has been outlined in this investigation and is discussed further in Working Paper D: Environmental Flows and River Management. Environmental flow is the amount of water required by a water course to maintain healthy natural ecosystems. An optimal environmental flow regime for a regulated river should take the following factors into consideration, including season, flow components (low flow, freshes, high flows, bank full and over bank flow), frequency of and duration of flow events, depth of flow and water quality.

Artist impression of proposed Tillegra Dam

1. Introduction

An assessment of water quality and hydrology along the Williams River has been undertaken by Connell Wagner, for Hunter Water Corporation (HWC), to support the Tillegra Dam Planning and Environmental Assessment process. The environmental assessment has been prepared in accordance with the requirements under Part 3A of the *Environmental Planning and Assessment Act 1979 (EP&A Act)* and the *Environmental Protection and Biodiversity Conservation Act 1999 (EPBC Act)*.

The proposed Tillegra Dam site is located on the Williams River within the Hunter region of NSW. The proposed dam site is approximately 74 kilometres north of Newcastle. The location of the Project in a regional context is illustrated in Figure 1.1.

The broad aim of this investigation is to assess the potential issues associated with the construction and operation of the proposed Tillegra Dam project on water quality and river flows. The assessment included:

- characterisation of the existing Williams River system
- field surveys of specific water quality and physico-chemical measurements at representative sites
- identification and assessment of potential impacts of dam construction and operation on water quality and hydrology upstream, downstream and within the proposed storage
- a strategy for maintaining the environmental values of the Williams River during both the construction and operation of the dam
- preliminary assessment of ecologically relevant flows.

Results from the water quality and hydrology studies contained within this investigation, in conjunction with aquatic ecology and geomorphological studies have been integrated to develop desirable environmental flow rules for the proposed dam.

The Director-General's requirements (DGRs) for the Project were issued on 8 January 2008. With specific reference to water resources, a comprehensive assessment of impacts on surface and groundwater hydrology, particularly with respect to surface and groundwater quality, quantity and flow regimes is required. Specifically, the assessment is required to address the following matters:

- details of a framework for managing water releases that is capable of meeting the Project's water delivery objectives, ensures impacts on the Williams River ecosystems are minimised and takes account of the draft Water Sharing Plan

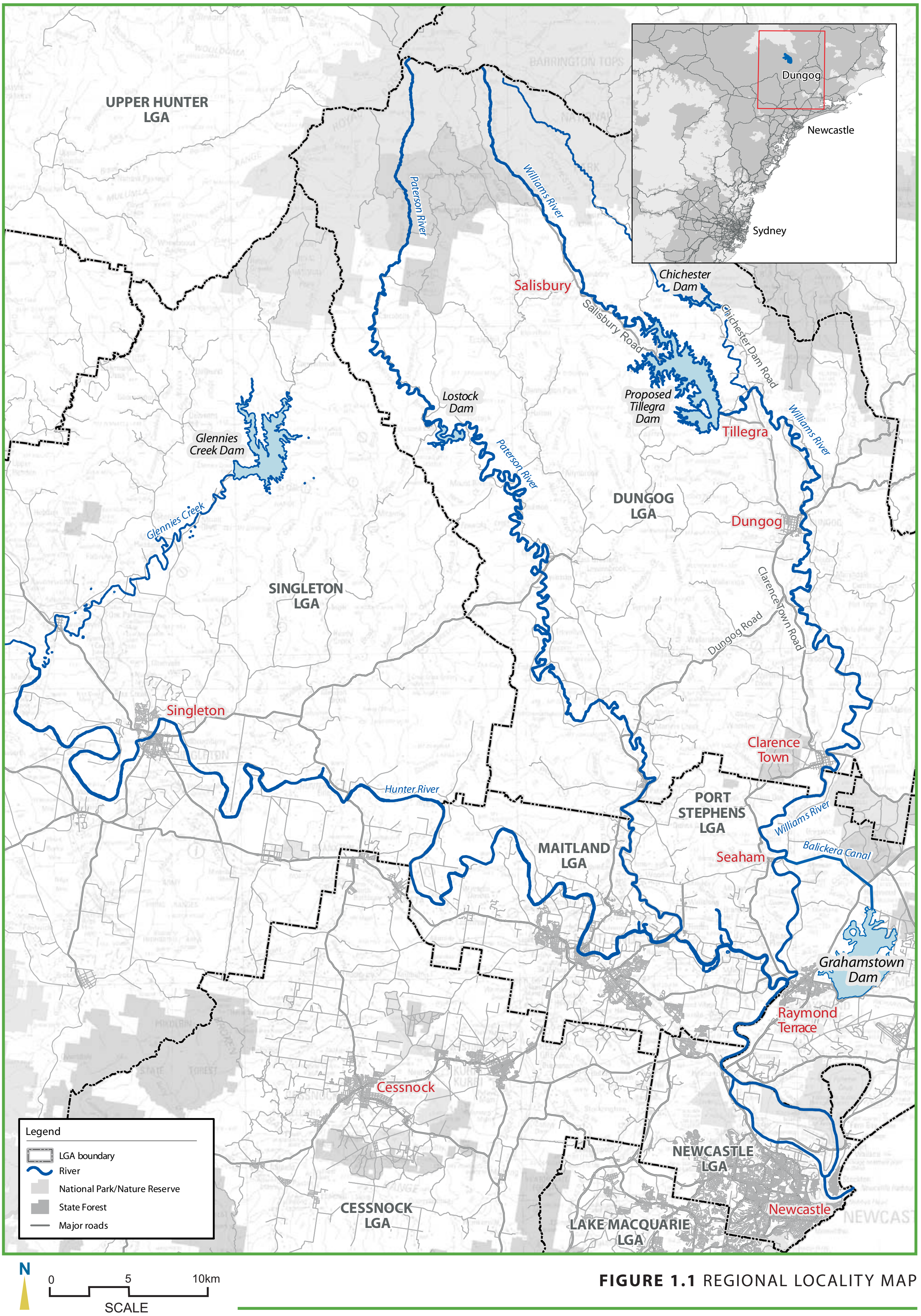


FIGURE 1.1 REGIONAL LOCALITY MAP

- 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
- details of a general water balance for the project, noting any expected evaporation and infiltration losses
- assessment of cumulative water quality and connective flow impacts on the Hunter estuary and details of associated mitigation measures.

It should be noted that there is substantial overlap between the areas of aquatic ecology, fluvial geomorphology, water quality and hydrology. The above requirements are considered as appropriate in this Working Paper, however, a more comprehensive, integrated assessment is provided in the separate environmental flows and river management report (refer Working Paper D of the EA Report).

2. Background

The following section provides background information on the Project, details the existing catchment characteristics, and provides a general description of water quality and hydrology within the Williams River System.

2.1 Project

To secure the water future of the Lower Hunter and the Central Coast regions for at least the next sixty years HWC is proposing to construct a 450 gigalitre dam at Tillegra. Tillegra Dam would double the existing water storage capacity of the Lower Hunter region.

The scope of works for the Project is to undertake an environmental assessment and to secure development approval for the Tillegra Dam project. The Project would comprise the following key components:

- dam wall and spillway construction
- multiple level offtake tower
- a mini hydroelectric power (HEP) plant
- a pipeline connection from Tillegra Dam to the Chichester Trunk Gravity Main (CTGM)
- relocation and reconstruction of Salisbury Road (including construction of three waterway crossings) and provision of alternative access currently provided from Quart Pot Creek Road;
- electrical and telecommunication installations (approximately 20 kilometres route)
- relocation/upgrade of other public infrastructure
- heritage conservation works (including relocation of Quart Pot / Munni cemetery and preservation of Munni House)
- carbon offset initiatives
- ancillary works as required (potential recreational access areas, lookouts and related facilities).

The capital cost of the scheme is approximately $396 million, with an ongoing operational cost of $600,000 per year. The dam would inundate around 2,100 hectares of predominately cleared farming land.

2.2 Catchment characteristics

The catchment characteristics of the Williams River and subcatchments of Tillegra and Chichester Dam are provided in the following sections. Information on Grahamstown Dam, Balickera Canal and Seaham Weir are also provided.

2.2.1 Williams River catchment

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. The Williams River catchment is approximately 100 kilometres in length and up to 49 kilometres wide and covers an area of approximately 1,300 square kilometres (HWC 2007a). Figure 2.1 illustrates the subcatchments of the Williams River which range in size from seven to two hundred square kilometres. Statistics for the subcatchments of interest are shown in Table 2.1.

The Williams River catchment is largely developed with the main land use activities as cattle crazing and dairying. The upper catchments are characterised by steep vegetated slopes and the lower catchments are characterised by undulating and rolling hills with the majority of the vegetation cleared for cattle grazing. The three main urban areas are Dungog, Clarencetown and Seaham.

Within the Williams River catchment water is harvested from Chichester Dam via the Chichester Trunk Gravity Main to reservoirs in Maitland, Cessnock and Newcastle and also harvested immediately upstream of Seaham Weir where it is pumped to Grahamstown Dam via the Balickera Canal. Chichester Dam and the Grahamstown Scheme each supply approximately 40 per cent of the total long term regional water needs of the Lower Hunter (HWC 2007b).

TABLE 2.1 WILLIAMS RIVER CATCHMENT AREAS

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

2.2.2 Tillegra Dam catchment

The Tillegra Dam subcatchment is approximately 194 square kilometres which accounts for around 15 per cent of the total Williams River catchment area. The catchment is characterised by steep vegetated slopes, rising to 1,500 metres above sea level in the northern elevated region and cleared agricultural land in the southern area of the catchment declining to around 87 metres above sea level at the proposed dam wall at Tillegra Bridge. The upper reaches of the catchment include the Barrington Tops National Park.

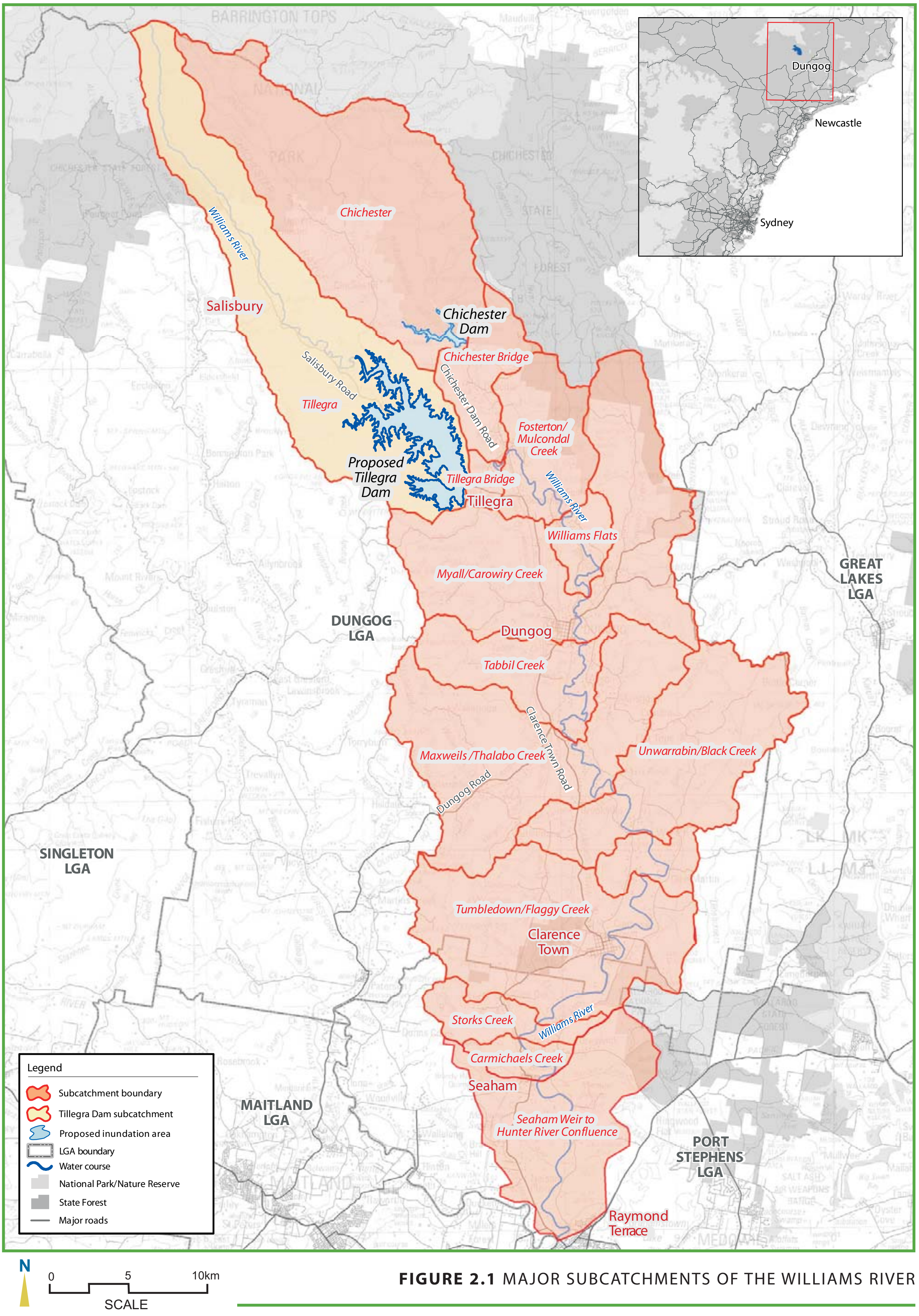


FIGURE 2.1 MAJOR SUBCATCHMENTS OF THE WILLIAMS RIVER

2.2.3 Chichester Dam catchment

The Chichester Dam subcatchment is approximately 198 square kilometres which accounts for around 16 per cent of the total Williams River catchment area. It is bound on the north and east by the Great Dividing Range, which separates it from the Gloucester, Barrington and Manning Rivers and on the southwest by the Chichester Range. The Chichester catchment 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 (HWC 2008). A few cleared holdings remain on the Chichester River, with minor cattle grazing and dairying activity (HWC 2007a). The catchment receives water from the Chichester and Wangat Rivers.

Chichester Dam was constructed between 1917 and 1926, underwent major modifications in the mid 1980s to increase the spillway capacity and the structural stability of the dam. An additional upgrade occurred in 2003 to meet the latest dam safety requirements.

2.2.4 Grahamstown Dam and Balickera Canal

Grahamstown Dam has a catchment area of 99.3 square kilometres and an available water capacity of 190,000 megalitres. The dam was constructed between 1955 and 1965 and is an off-river storage that is primarily used to store water extracted from the Williams River. Water is extracted from the Williams River and transferred to Grahamstown Dam via the Balickera Canal and pumping station. The canal intake is located in the Seaham Weir Pool about 500 metres upstream of Seaham Weir at Boag's Hill. The decision as to when to pump water is based on available storage space in Grahamstown Dam, the availability and quality of water in the Williams River and electricity tariffs.

2.2.5 Seaham Weir

The Seaham Weir comprises a 400 metre wide weir spanning the Williams River and adjacent floodplain. A fish way and spillway are located on the western side of the weir. The 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 bed rock by dredging upstream and downstream of the weir which created deep pools on either side. Soon after construction the weir was found to allow passage of salt water through its structure. To mitigate the problem the weir was sealed by cement clay grouting in three stages between 1972 and 1978. Flood gates were incorporated into the weir structure in the 1970s to handle minor flows while large flood events overtop the weir. The control gates are an automated open and shut arrangement that operates on the water level difference between the upstream pool and the downstream estuary.

2.3 Rainfall

The two closest Bureau of Meteorology stations to the Project area are Chichester Dam (194 metres AHD) and Lostock Dam (200 metres AHD). Summary details for monthly rainfall and temperature meteorological parameters for these two stations are presented in Table 2.2.

Weak seasonal variation in rainfall is apparent with magnitudes showing drier months in late winter (July to September), while the number of rain days is evenly distributed throughout the year. The area receives reliable rainfall throughout the year with Chichester gauge recording, on average, over 100 days of rain per year.

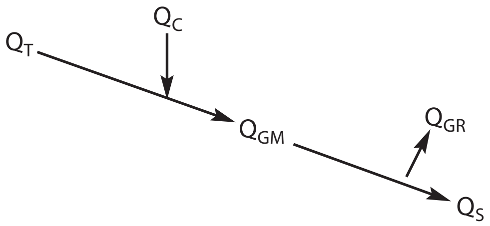
TABLE 2.2 MONTHLY RAINFALL AND TEMPERATURE SUMMARY STATISTICS

	MEAN RAINFALL (mm)		MEAN NUMBER OF RAIN DAYS >1 mm		MEAN MAXIMUM TEMPERATURE (ºC)		MEAN MINIMUM TEMPERATURE (ºC)	
	CD	LD	CD	LD	CD	LD	CD	LD
Jan	169.8	131.3	10.8	10.0	26.2	29.2	16.7	17.2
Feb	177.2	122.9	11.4	9.6	24.9	28.3	16.7	17.2
Mar	173.9	126.3	11.2	9.5	23.3	26.5	16.2	15.4
Apr	94.4	64.6	8.2	7.1	20.2	23.6	12.7	12.7
May	97.9	76.1	8.6	7.8	17.4	19.9	9.7	10.2
Jun	103.6	60.3	8.9	7.3	14.2	16.9	7.0	7.7
Jul	53.0	38.4	7.4	6.1	13.7	16.4	6.2	6.5
Aug	60.0	35.3	6.9	5.5	15.5	18.3	6.9	6.9
Sep	61.9	50.1	7.1	6.7	19.1	21.4	9.8	9.3
Oct	93.1	67.0	8.8	8.0	21.4	24.5	12.1	11.9
Nov	101.4	84.3	9.4	9.6	24.1	26.3	14.9	13.9
Dec	124.7	90.8	10.1	8.5	26.6	28.9	17.2	16.1
Annual	1,311.5	947.7	108.8	95.7	20.6	23.4	12.2	12.1

CD = Chichester Dam, LD = Lostock Dam
Source: Bureau of Meteorology 2007

2.4 General Hydrology

Flows within the Williams River catchment have been estimated at four subcatchment boundaries using observed and modelled discharge data for the period of available observations, 1931 to present. This was undertaken as part of HWC's hydrology study and includes historic flow estimates at Tillegra, Chichester, Glen Martin and Seaham Weir. The schematic below illustrates the relationship between the different catchments.



Q_T	Tillegra historic daily flows
Q_C	Chichester historic daily out flows
Q_{GM}	Glen Martin historic daily flows
Q_{GR}	Grahamstown historic daily transfers
Q_S	Seaham Weir daily historic flows

2.4.1 Tillegra Bridge flows

Flows at Tillegra Bridge over the 77 years of daily observations vary from nil to a flood peak of 54,488 megalitres per day. Statistical analysis was undertaken on the historic Tillegra flows and results are shown in Table 2.3. The seasonal percentage of time flow is exceeded and the distribution plots for log10(Q+1) flow data for the adopted Tillegra flow are illustrated in Figure 2.2. The figure shows that no flow is recorded at Tillegra Bridge for approximately three per cent of the time with these zero discharge events generally occurring during the summer months.

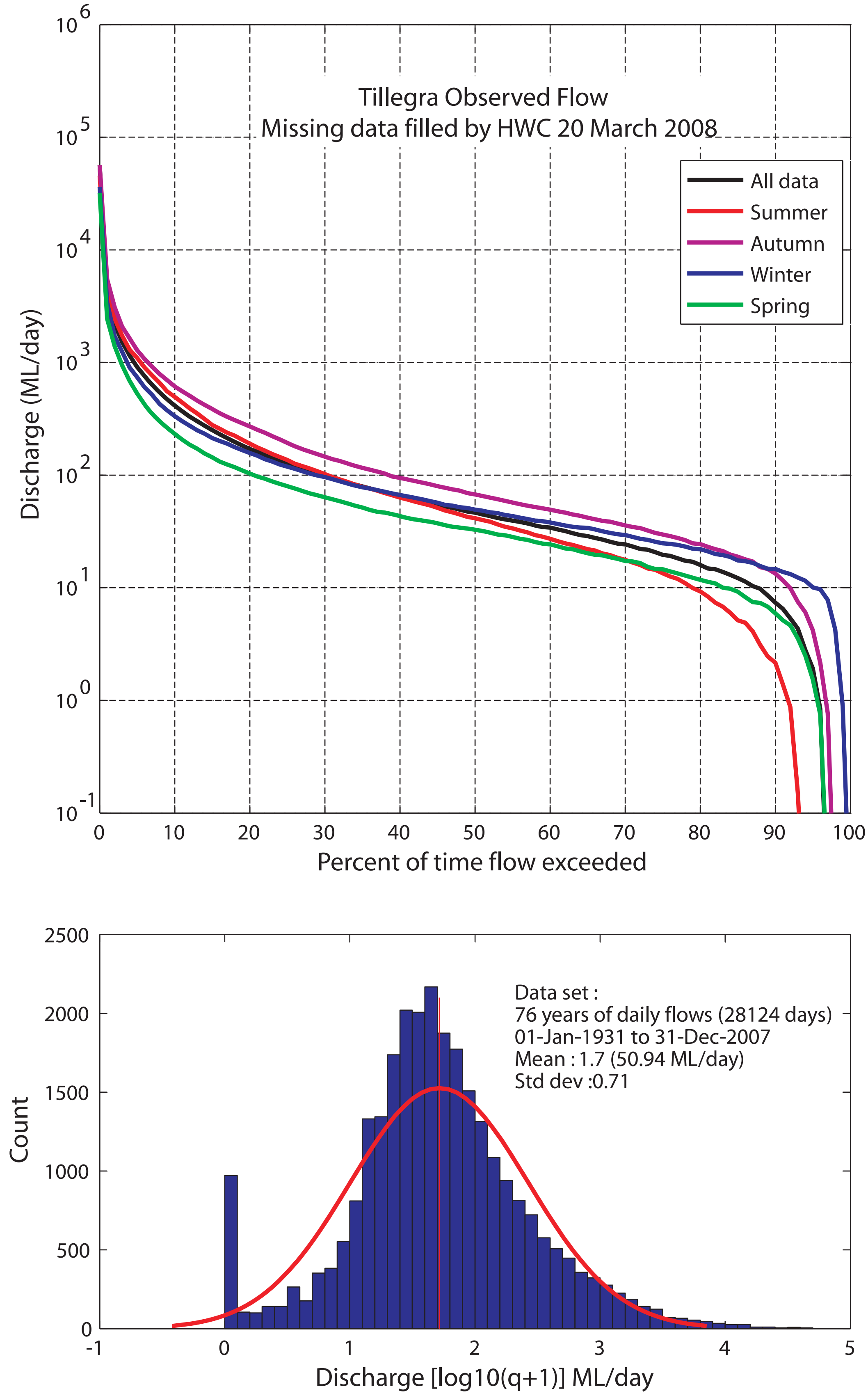


FIGURE 2.2 DAILY FLOW DISTRIBUTIONS FOR TILLEGRA GAUGING DATA

TABLE 2.3 STATISTICAL ANALYSIS OF TILLEGRA BRIDGE HISTORIC FLOWS (MEGALITRES PER DAY)

STATISTIC	ALL DATA	SUMMER	AUTUMN	WINTER	SPRING
Minimum	0.0	0.0	0.0	0.0	0.0
95th percentile exceedence	1.9	0.0	4.2	10.1	1.5
90th percentile exceedence	7.4	2.2	13.4	14.7	5.9
80th percentile exceedence	15.9	9.3	24.4	22.0	11.8
50th percentile exceedence	46.5	41.5	67.3	49.4	32.8
20th percentile exceedence	170.8	190.7	271.2	156.8	103.2
10th percentile exceedence	416.0	495.8	611.1	333.4	233.1
5th percentile exceedence	914.5	1099.5	1290.2	740.4	530.6
Maximum	56488.4	45594.6	56488.4	36195.1	32017.3
Mean	261.5	300.5	366.3	220.8	158.2
Mean (log q)	50.9	41.6	75.9	60.0	35.1

2.4.2 Glen Martin flows

Observed flows at Glen Martin (some 60 kilometres downstream of the Tillegra gauge) range from nil to a flood peak of 137,448 megalitres per day. The catchment area at Tillegra represents approximately 20 per cent of the catchment at Glen Martin and contributes approximately 40 per cent of the flow.

Statistical analysis was undertaken on the historic Glen Martin flows and results are shown in Table 2.4. The seasonal percentage of time flow is exceeded and the distribution plots for $\log_{10}(Q+1)$ flow data adopted for Glen Martin are illustrated in Figure 2.3. The figure shows that no flow is recorded at Glen Martin approximately five per cent of the time. During the summer months no flow is recorded for approximately 10 per cent of the time.

TABLE 2.4 STATISTICAL ANALYSIS OF GLEN MARTIN HISTORIC FLOWS (MEGALITRES PER DAY)

STATISTIC	ALL DATA	SUMMER	AUTUMN	WINTER	SPRING
Minimum	0.0	0.0	0.0	0.0	0.0
95th percentile exceedence	0.4	0.0	6.6	15.3	0.5
90th percentile exceedence	9.8	0.2	19.8	28.1	6.6
80th percentile exceedence	27.5	12.1	48.2	48.5	18.4
50th percentile exceedence	116.0	86.1	226.1	136.7	63.8
20th percentile exceedence	610.3	622.2	944.1	577.2	318.8
10th percentile exceedence	1494.1	1598.5	2143.6	1428.5	804.5
5th percentile exceedence	3165.8	3354.4	4649.9	3073.2	1787.8
Maximum	137448.1	104549.6	137448.1	75632.8	75304.2
Mean	880.8	911.1	1265.5	853.1	490.0
Mean (log q)	117.7	79.9	206.2	163.9	69.9

Flood average recurrence intervals (ARI) for Glen Martin and Tillegra are illustrated in Figure 2.4. The figure shows the average, or expected, value of the years between the occurrence of a flood as big as (or larger than) the selected event. The recurrence interval of floods at Tillegra and Glen Martin are shown in Table 2.5.

TABLE 2.5 FLOOD RECURRENCE AT TILLEGRA AND GLEN MARTIN (MEGALITRES PER DAY)

AVERAGE RECURRENCE INTERVAL	TILLEGRA	GLEN MARTIN
1 in 2 year flood	9,600	28,000
1 in 5 year flood	20,500	70,000
1 in 10 year flood	33,500	86,000
1 in 40 year flood	45,600	115,000

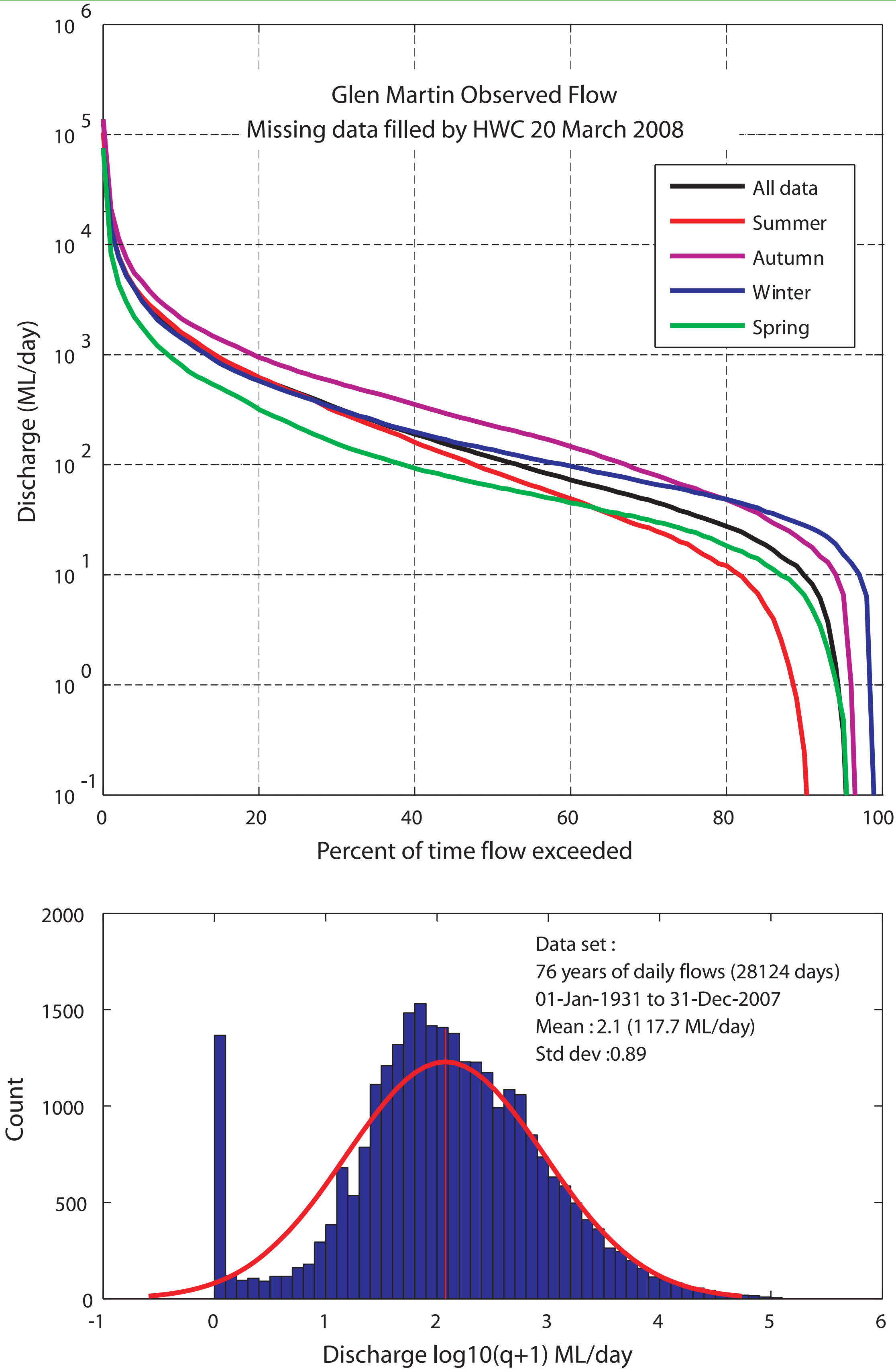


FIGURE 2.3 DAILY FLOW DISTRIBUTIONS FOR GLEN MARTIN GAUGING DATA

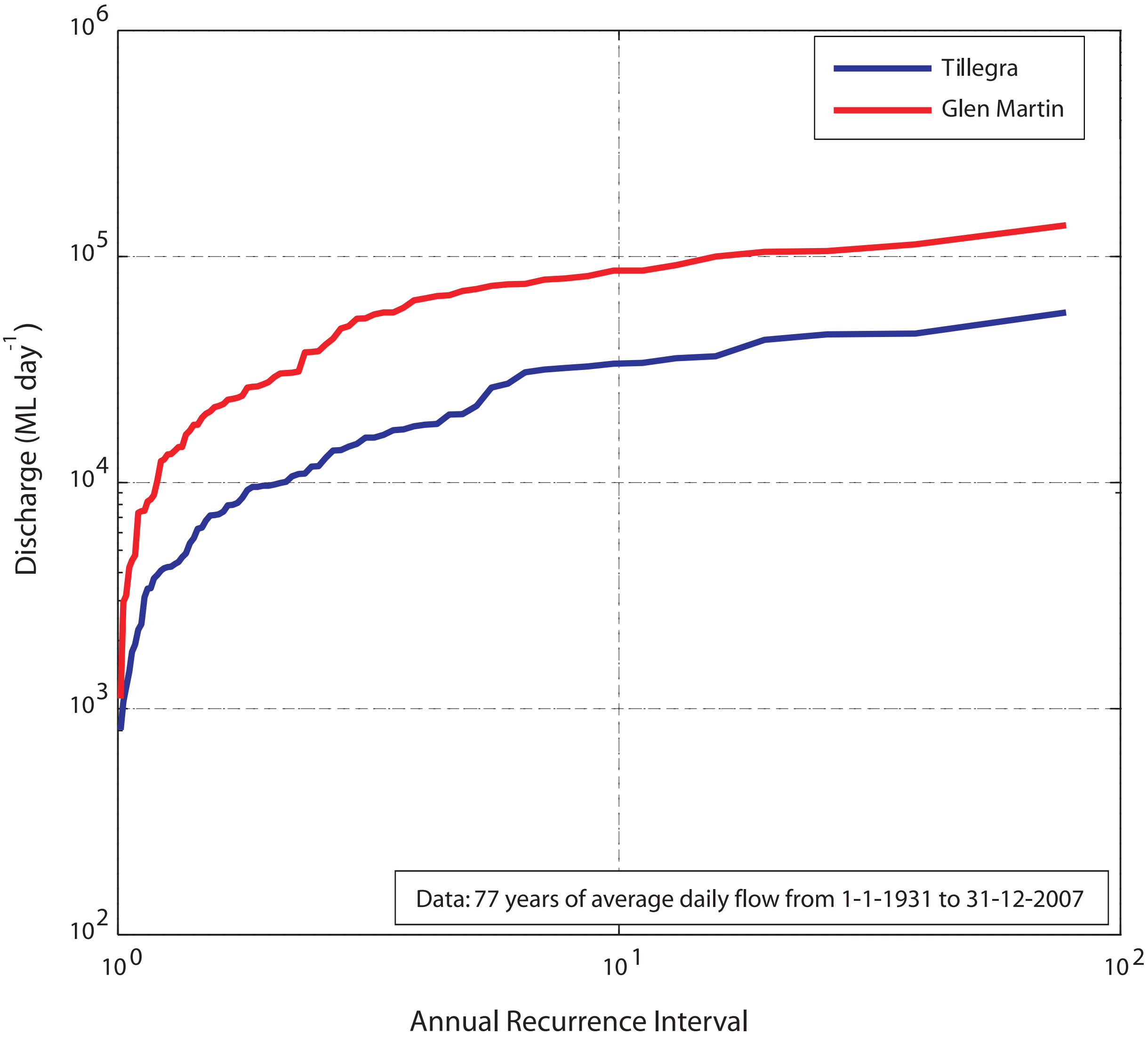


FIGURE 2.4 AVERAGE RECURRENCE INTERVALS FOR FLOOD EVENTS

2.4.3 Chichester Dam flows

Flows downstream of Chichester Dam vary from nil to 38,618 megalitres per day. The average flow is 251 megalitres per day with a median flow of 17 megalitres per day. Chichester Dam has a transparent environmental flow release up to the 95th percentile exceedence of inflow which is 14 megalitres per day. Statistical analysis of the adopted Chichester River flows are shown in Table 2.6.

The Chichester Dam capacity of 21.5 gigalitres represents less than one fifth of the annual average inflow to the dam. Hence Chichester Dam spills for a significant proportion of the time and the average flow downstream of the dam is similar to the average flow in the Williams River at Tillegra (compare Tables 2.6 and 2.3).

TABLE 2.6 STATISTICAL ANALYSIS OF CHICHESTER DAM FLOWS (MEGALITRES PER DAY)

STATISTIC	ALL DATA	SUMMER	AUTUMN	WINTER	SPRING
Minimum	0.0	0.0	0.0	0.0	0.0
95th percentile exceedence	0.4	0.5	0.7	0.3	0.2
90th percentile exceedence	0.7	0.8	1.1	0.7	0.5
80th percentile exceedence	1.5	1.4	2.5	2.0	1.1
50th percentile exceedence	16.6	11.3	83.3	25.2	3.2
20th percentile exceedence	231.6	252.4	368.7	197.6	80.6
10th percentile exceedence	472.4	559.0	754.0	403.5	287.1
5th percentile exceedence	972.1	1175.9	1438.8	705.6	475.2
Maximum	38618.3	38618.3	24798.4	18896.5	35686.1
Mean	250.6	289.4	377.5	199.3	135.6
Mean (log q)	22.8	20.3	53.1	25.0	9.7

2.4.4 Williams River estuary flows

Flows past Seaham Weir occur via controlled releases through the flood gates, via overtopping of the concrete/rock wall structures, via the fish way or through the weir structure itself. For brief periods at high water spring tides water can overtop the weir and flow upstream. A hydrology study undertaken in 2006 by HWC (HWC 2006b) investigated the component flows into and out of Seaham Weir and assessed the rate of water flow to the estuary under a range of river flow and pumping conditions. The estimates of flow to the estuary did not account for the Seaham Weir Pool catchment area or tidal levels downstream. Results indicate an average flow of 745 megalitres per day and a median flow of 173 megalitres per day past Seaham Weir to the estuary.

2.5 General water quality

The Williams River catchment is currently reasonably healthy, able to support diverse ecosystems and a range of land uses such as national parks, agriculture and human development (Dept of Urban Affairs and Planning 1996). The 1997 Healthy Rivers Commission inquiry into the Williams River concluded a similar health for the river water following a review of water quality monitoring data, scientific studies and community consultation. The catchment is however beginning to show signs of stress with results from recent studies along the Williams River providing evidence of declining water quality in recent years. Table 2.7 shows the long term trend analysis of data collected at Boags Hill, near the inlet to the Balickera Canal in the Seaham Weir Pool.

TABLE 2.7 WILLIAMS RIVER LONG TERM TREND ANALYSIS RESULTS 1987-2007 AT BOAGS HILL

PARAMETER	TREND	AVERAGE RATE
Alkalinity	No significant trend	
Total hardness	No significant trend	
Electrical conductivity	No significant trend	
Aluminium	Significant decreasing trend	-0.039 mg/L/yr
Copper	Significant increasing trend	0.10 mg/L/yr
Manganese	Significant decreasing trend	-1.2 µg/L/yr
Fluoride	Significant decreasing trend	-0.003 mg/L/yr
NFR	Significant increasing trend	0.183 mg/L/yr
Turbidity	No significant trend	
Ammonia	Significant decreasing trend	-0.003 mgN/L/yr
Total Kjeldahl nitrogen	Significant decreasing trend	-0.008 mgN/L/yr
Total oxidised nitrogen	Significant decreasing trend	-0.002 mg/L/yr
Total nitrogen	No significant trend	
Total phosphorus	Significant increasing trend	0.001 mg/L/yr
Total organic carbon	No significant trend	
Chlorophyll-a	Significant increasing trend	0.172 µg/L/yr
Thermotolerant coliforms	Significant decreasing trend	-0.0112 logcfu/100 mL/yr

Source: Catchment Report 2006-07, Hunter Water 2007a

Water quality monitoring within the Williams River Catchment occurs at a number of locations including Wangat River, Chichester River, Chichester Dam, Bandon Grove, the proposed Tillegra Dam site, Glen William Bridge and Boags Hill Inlet. The average surface water quality at the proposed Tillegra Dam site for the period September 1987 to May 2007 and appropriate ANZECC guidelines is shown in Table 2.8.

TABLE 2.8 SURFACE WATER QUALITY AT TILLEGRA DAM SITE

PARAMETER	AVERAGE	MAXIMUM	MINIMUM	ANZECC GUIDELINE[A]
Temperature (Celsius)	17.8	29.0	8.5	n/a
TN (mgN/L)	0.66	2.59	0.02	0.35 [B]
TP (mgP/L)	0.068	0.566	0.002	0.025B
pH	7.7	8.8	7.2	6.5-8.0
EC (µS/cm)	182	407	79	125-2200
Suspended solids (mg/L)	2.0	3.6	2.9	n/a
Turbidity (NTU)	28.6	222	0.6	6-50
Chlorophyll a (µg/L)	1.1	9.3	<0.01	3[B]

[A] South east Australian Lowland Rivers (<150m altitude), [B] Values for NSW and Victoria east flowing coastal rivers

As reviewed in Healthy Rivers Commission independent inquiry into the Williams River (Healthy Rivers Commission 1996), studies by Cole (1996) and the Environmental Catchment Management (1994) indicate the present water quality of the Williams River does not always meet ANZECC guidelines for rivers and recreational use. This is particularly the case for phosphorus, nitrogen and faecal coliforms and is especially prevalent in the Seaham Weir Pool.

The influence of agricultural activities in the catchment on river water quality is reflected in elevated concentrations of nutrients. Chlorophyll-a was found to exceed the guidelines only once during the monitoring period. The low chlorophyll-a indicates low phytoplankton abundance in the flowing waters of the river. The effects of land clearing on siltation of the river are reflected by turbidity measurements which exceeded the guideline 40 per cent of the time.

It is well documented that the Lower Williams River, above Seaham Weir experiences regular algal blooms as a result of high temperatures and reduced flows. During periods of low flow, long residence times and stratification provide stable conditions within the pool for blue-green algae to grow. Available cyanobacteria (blue-green algae) data collected by HWC at Boags Hill within Seaham Weir Pool suggest that less than one per cent of the time cyanobacteria values exceeded the recreational guideline of 50,000 cells per millilitre for the period of record (1991-2007).

3. Approach to study

The section details the approach of the water quality and hydrology assessment. The section provides information on the river reaches, sampling site selection and flow components of the Williams River.

3.1 River reaches

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

TABLE 3.1 DEFINITION OF RIVER REACHES

REACH NUMBER	REACH DESCRIPTION	APPROXIMATE REACH LENGTH (KM)
1	Upper Williams River to Storage FSL	34
2	Storage	19 at FSL
3	Storage to Glen Martin	63
4	Seaham Weir Pool	23
5	Seaham Weir to Hunter River influence	15

3.2 Sampling site selection

3.2.1 Habitat characterisation

Habitat characterisation of the Williams River involved identifying riverine features (pool and riffle sequences), potential barriers to fish movement, existing anthropogenic influences and sensitive ecosystems (eg. wetlands) to assist in selecting suitable locations for water quality, aquatic ecology and geomorphological sampling. Habitat characterisation of the Williams River was undertaken as part of this investigation on 14 November 2007 via a one day helicopter flyover.

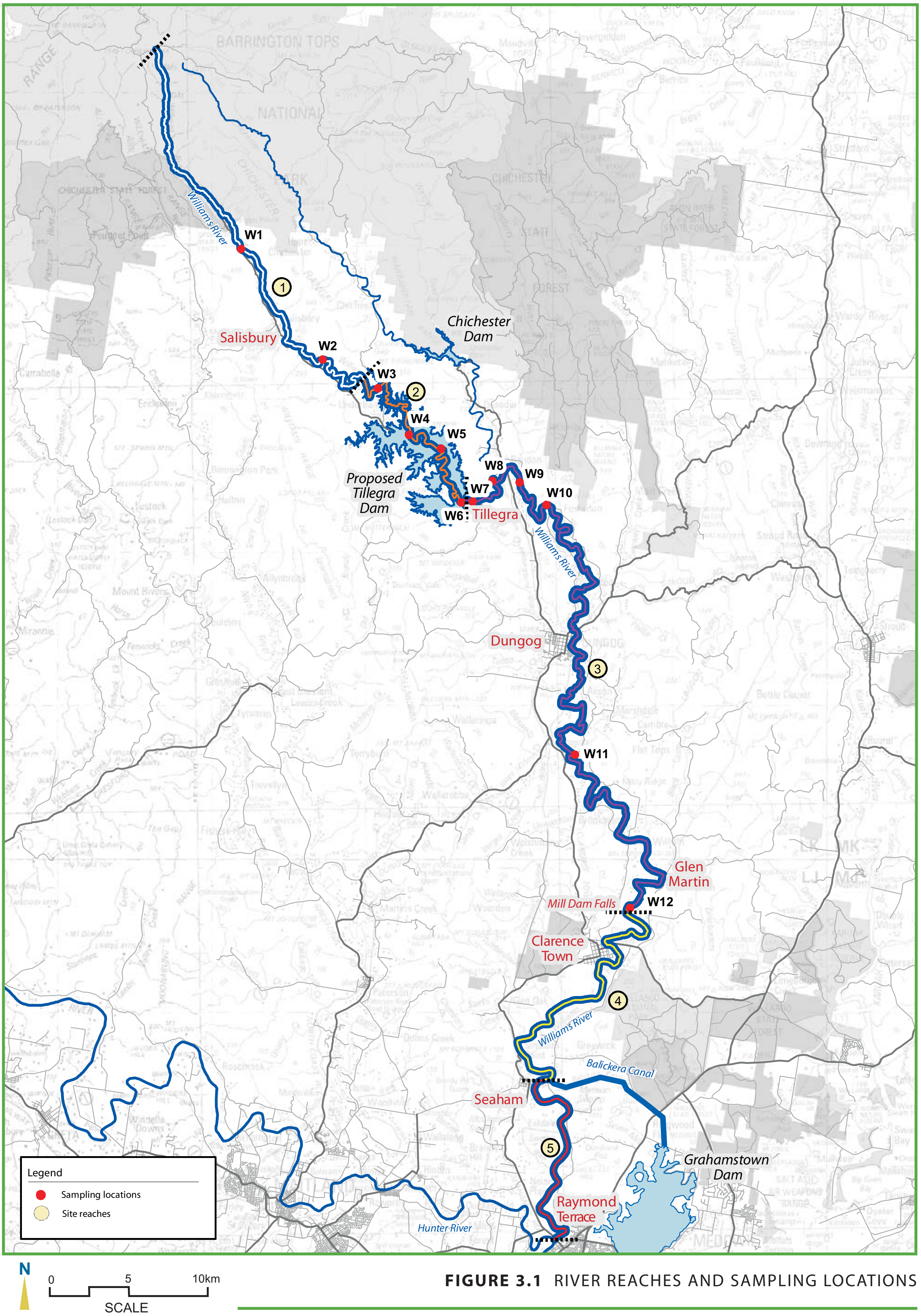


FIGURE 3.1 RIVER REACHES AND SAMPLING LOCATIONS

3.2.2 Spatial arrangement

Suitable sites for undertaking water quality, aquatic ecology and geomorphological sampling were selected to represent the entire length of the Williams River. Sites were selected above, within and below the proposed storage. Sites were selected in the reaches below the proposed dam to assess the impacts of changes in the flow regime. As impacts are expected to be greater in the length of river immediately downstream of the dam wall, sampling sites were concentrated in this reach with increasing distance between sites further downstream. Seaham Weir Pool was selected for water quality sampling only as there is an absence of pool riffle habitats for aquatic and geomorphological sampling. No sites were selected within the Williams/Hunter Estuary as data on water quality from previous studies exist for this reach of the Williams River River (eg Sanderson and Redden 2001, Sanderson *et al* 2002, Manly Hydraulics Laboratory 2003, Sinclair Knight Mertz, 2005, Sanderson 2008).

3.2.3 Site locations

Final site locations were selected based on a review of previous macroinvertebrate studies (Chessman and Growns 1994), information gleaned from the habitat characterisation, site accessibility and availability of suitable aquatic habitats. Sites selected for sampling, divided into river reaches are listed in Table 3.2 and illustrated in Figure 3.1.

A visual description highlighting the pool/riffle sequences and topography at each site is provided in Appendix A. Sites W11, W12 and Seaham Weir Pool are not illustrated as aquatic sampling of pool and riffles was not conducted, due to environmental constraints.

TABLE 3.2 SAMPLING SITE LOCATIONS

REACH NUMBER	REACH NAME	SITE NUMBER	EASTING(GDA 94)	NORTHING (GDA 94)
1	Upper Reaches to	W1	361880	6439807
	Storage FSL	W2	367296	6432547
2	Storage	W3	371023	6430879
		W4	372888	6427766
		W5	374949	6426790
	Storage to Glen Martin	W6	376149	6423500
3		W7	376699	6423457
		W8	378599	6424587
		W9	380808	6423576
		W10	382601	6422320
		W11	383704	6406824
		W12	387245	6397027
4	Seaham Weir Pool	SWP	382093	6385747

3.2.4 Water quality sampling

Physico-chemical measurements were collected at all sampling sites with the exception of W11 and W12. Due to elevated flows during the field exercise samples were not collected at these two sites. Physico-chemical sampling was undertaken by The Ecology Lab (TEL) between 26 November and 5 December 2007. The following physico-chemical variables were measured by a water quality probe:

- conductivity
- salinity
- temperature
- turbidity

- dissolved oxygen
- pH
- oxygen reduction potential.

Water samples were collected at all sites with the exception of W3, W5 and W7 and sent for laboratory analysis. Sites W3, W5 and W7 were not selected for sampling based on their proximity to other sites which were assumed to have a similar quality of water. The collected water samples were analysed for the following variables:

- metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al)
- nutrients (TN, TP, NO_x, PO_4^{3-})
- organochlorine pesticides
- anions (Cl, SO_4)
- suspended solids
- faecal coliforms (sites W8,W9, W11, W12, SWP)
- chlorophyll-a (sites W6, W9, W10, W11, W12, SWP only).

Not all sites were analysed for faecal coliforms and chlorophyll-a based on their expected water quality. Chlorophyll-a was expected to be low in the fast flowing upstream reaches of the river and faecal coliforms likewise upstream of the main urban areas. Sampling was undertaken by TEL on the 5 December 2007.

Sampling was undertaken through a range of flow conditions as rainfall lead to increasing flows during the field exercise. Initial measurements in the upper reaches were taken at relatively low flows and the lower reach measurements were taken in medium to high flows. Figure 3.2 displays a time series plot of flow past Tillegra Bridge and Glen Martin before, during and after the sampling regime.

Results were compared against ANZECC guidelines for SE Australian slightly disturbed ecosystems for either upland rivers (greater than 150 metres altitude) (W1, W2), low land rivers (less than 150 metres altitude) (W3-W12) or lakes and reservoirs (SWP) and exceedence noted.

Appendix B displays which analytes were tested at each site, the results of the water quality testing and comparisons against ANZECC guidelines.

For more detailed information on site selection, site descriptions and sampling methodologies refer to Working Paper C of the EA Report: Aquatic Flora and Fauna.

3.3 Water demand requirements

HWC extracts water from the Williams and Chichester Rivers and the Tomago and Anna Bay sandbeds for use in the Lower Hunter region. Approximately 60,000 megalitres per year is extracted from the Williams River via Chichester Dam and Seaham Weir. In addition there are 177 surface water extraction licences with a total entitlement of about 8,300 megalitres per year (Dept of Natural Resources 2007). The volume of water supplied from each of the sources is shown in Table 3.3. The sectors which account for the demand are also shown in Table 3.3 and include residential, non-residential and non-metered users.

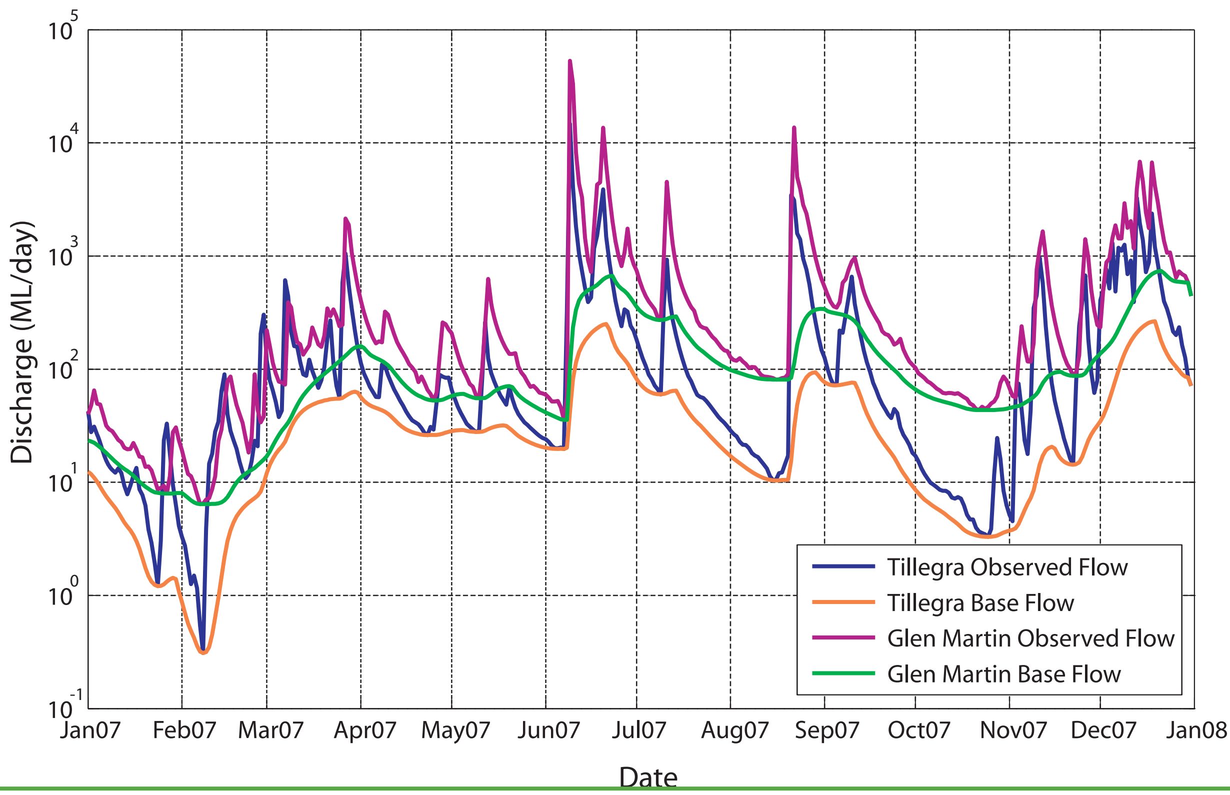


FIGURE 3.2 OBSERVED AND BASEFLOW AT TILLEGRA AND GLEN MARTIN

TABLE 3.3 WATER SUPPLY AND DEMAND 2005/2006

SUPPLY	VOLUME (GL)
Chichester	29.4
Grahamstown	31.5
Tomago Sandbeds	9.8
Anna Bay Sandbeds	2.1
Total	**72.8**
DEMAND	VOLUME (GL)
Residential	40.6
Detached	*36.2*
Units/Flats	*4.4*
Non-Residential	23.8
Large Users	*20.6*
Small Users	*3.2*
Non-metered	8.4
Total	**72.8**

Source: Hunter Water 2007b
Note: Non-residential demand includes 2GL supplied to the Central Coast

The current operation of the Williams River involves operating rules at Chichester Dam, Seaham Weir Pool and irrigation licensing. In summary, Chichester Dam is required to release the 95th percentile flow (14 megalitres per day) whenever inflow is higher than this value. Operation of Seaham Weir Pool is based on river flow and water level within the pool. Irrigation extraction upstream of Glen Martin is subject to cease to pump rules when flows are at or below six megalitres per day or 15 megalitres per day at Glen Martin, for accredited and non-accredited users, respectively. Users within the weir pool cease to pump when levels in the weir pool are 0.38 metres or below. There is no record of extraction water use.

For more information on the current operation of the Williams River refer to Working Paper D of the EA Report: Environmental Flows and River Management.

3.4 Preliminary assessment of operational modes

The construction and operation of Tillegra Dam would involve a number of different construction and operation modes as listed in Table 3.4.

TABLE 3.4 OPERATIONAL MODES

OPERATION MODE NAME	DESCRIPTION
1. Construction	During the construction phase when the dam is in by-pass mode
2. Post Construction	When the dam is filling.
3. Standard Operation	Standard dam operation once 90 per cent of FSL is reached

3.4.1 Construction mode

During the dam construction phase river diversion works would be put in place which would vary depending on the standard dam construction option elected. The Tillegra Dam Design Options Study Report (Dept of Commerce 2007) recommends a concrete faced rockfill dam (CFRD) design be adopted for Tillegra Dam.

River diversion works for the CRFD would consist of a lined tunnel, a bypass pipe located in the tunnel lining to provide environmental flows during outlet construction and a minimum supply during maintenance of the main outlet works, upstream and downstream cofferdams that divert normal river flows and small floods through the tunnel, and a main cofferdam located within the downstream batter line of the main embankment and reinforced with a steel mesh to enable large floods to be passed over, and to some extent, through the cofferdam (Dept of Commerce 2007).

River flows during dam construction will pass through the diversion channel with little attenuation of flows except during flood times (flows > 10,000 megalitres per day).

3.4.2 Post-construction mode

The duration of the post construction dam filling phase would depend on local rainfall variability and water releases. Based on the last 77 years of inflow records the filling time is likely to be between three years (during wet periods) and nine years (during drought periods). An estimate of filling time is provided in Figure 3.3 which takes into account evaporation from the dam but no releases. Based on the rainfall patterns since 1980 the approximate filling time would be around six years, although the recent (June 07) large flow events and wet summer would have almost half filled the dam in the past year.

3.4.3 Standard operation modes

The standard operation modes are listed in Table 3.5.

TABLE 3.5 STANDARD OPERATION MODES

STANDARD OPERATION MODES	DESCRIPTION
Reservoir below FSL	Dam operation when water level is below FSL (Drought Mode)
Reservoir Spilling	Dam operation when water level is above FSL (Non Drought Mode)
Reservoir in Transfer	Dam operation when water is being transferred

3.4.4 Reporting

The focus of this report is on the impact of standard dam operation on water quality and hydrology upstream, downstream and within the proposed storage. The construction mode will be briefly addressed as limited detail is available on the operation of the diversion works.

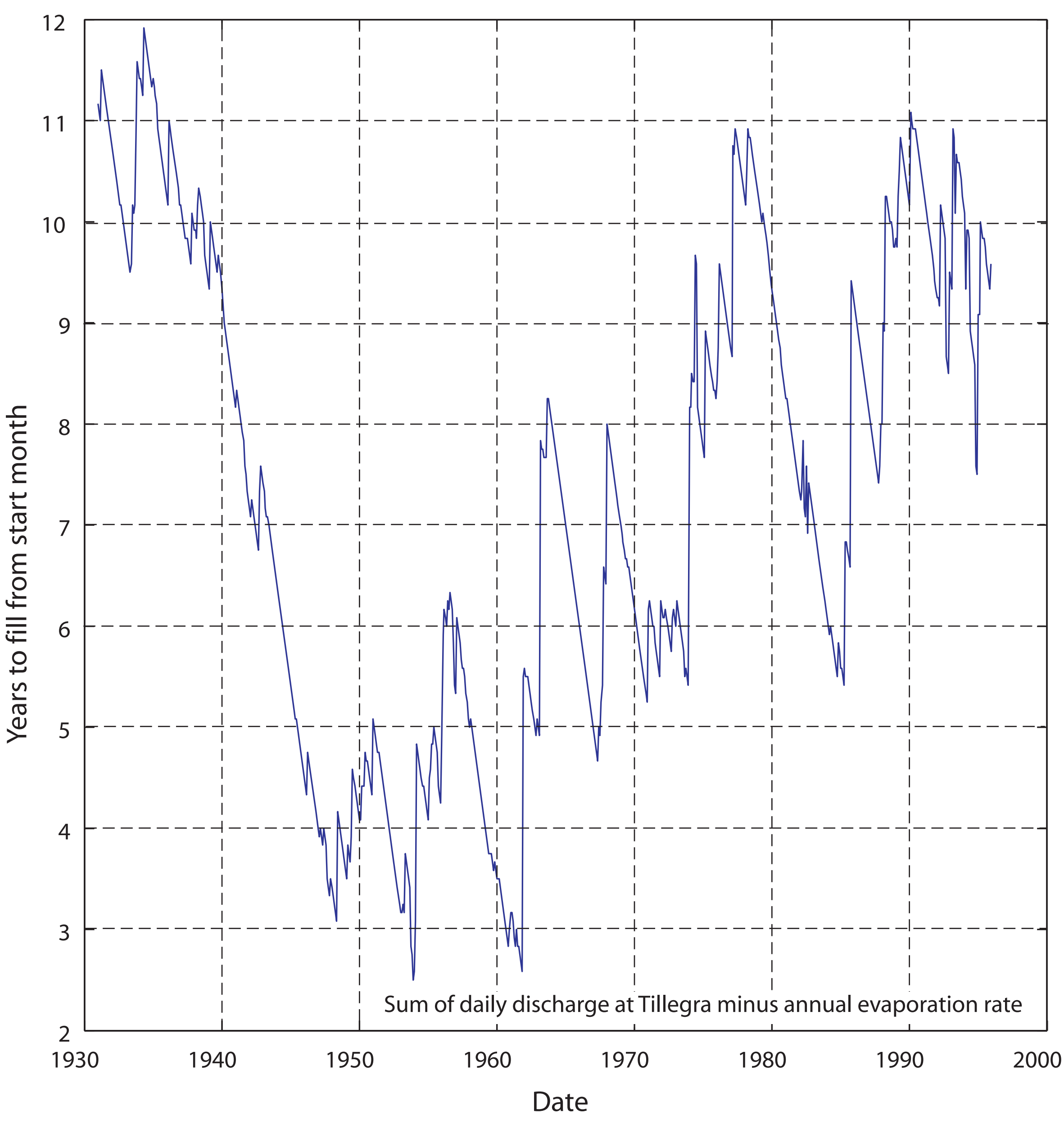


FIGURE 3.3 ESTIMATE OF TIME TO FILL STORAGE FROM EMPTY (450 GL)

3.5 Environmental flow requirements

3.5.1 Environmental flow scenarios

The final environmental release requirements of the proposed Tillegra Dam are still to be resolved with the Department of Water and Energy (DWE), however, current information suggests flows may include:

- a base environmental release
- periodic run-of-river transfers to Grahamstown reservoir
- surges that mimic natural flow variations,
- uncontrolled flows over the spillway

Preliminary results from the hydrology modelling of the post dam system indicate between 70 per cent and 80 per cent of historic average annual flow would pass the dam and between 75 and 85 per cent of historic average annual flow will reach Glen Martin.

3.5.2 Ecologically relevant flows

Environmental flow is the amount of water required by a water course to maintain healthy natural ecosystems. An optimal environmental flow regime for a regulated river should take the following factors into consideration:

- season
- flow components/events (low flow, freshes, high flows, bank full and over bank flow)
- frequency of and duration of flow events
- depth of flow
- water quality.

Flow components to help determine environmental water requirements are described in Table 3.6.

TABLE 3.6 WILLIAMS RIVER CATCHMENT AREAS

FLOW COMPONENT	FLOW COMPONENT DESCRIPTION	TIMING	FREQUENCY	DURATION
Drought	No surface flow	Summer Spring	Annual	Days to months
Low Flow	Minimum flow in channel. Continuous flow in some part of channel	Summer	Annual	Weeks to months
Moderate	Moderate flow in channel	Autumn Winter	Several annually	Weeks to months
Freshes	Flow greater than the median flow for that period	All seasons	Can be several in each period	Generally days
High Flow	Less than bank full flow. May include flow in minor flood plain channels	Autumn Winter Summer	May be several annually	Weeks to months
Bank full	High flow within channel capacity	All seasons	Generally at least annual	Days to Weeks
Over bank flow	Flow extends to flood plain surface flows	All seasons	Can be annual or less frequent	Days

Source: Adapted from Sinclair Knight Merz et al 2002

Representative riffle section

To help determine ecologically relevant flows for the Williams River a representative riffle cross section, for sites above Dungog, was constructed based on riffle cross section measurements collected during field investigations. Hydraulic modelling was undertaken using HEC-RAS software to determine the level and width of water at various discharge releases. The model was run for 15 flow scenarios and results are illustrated graphically in Figure 3.4 and in tabular format in Table 3.7.

Further to the representative cross section, the percentile exceedence of flow, water height, wetted perimeter and velocity were estimated for cross sections at sites W7, W8, W9 and Glen Martin. Results from these analyses are provided in Appendix C and results are discussed in Section 6.3.1.

TABLE 3.7 HEC-RAS MODELLING RESULTS FOR THE REPRESENTATIVE RIFFLE CROSS SECTION

DISCHARGE (ML/d)	LEVEL (m)	VELOCITY (m/s)	FLOW AREA (m^2)	TOP WIDTH (m)
1	0.03	0.32	0.04	2.13
5	0.06	0.41	0.14	6.79
10	0.07	0.51	0.23	7.45
20	0.09	0.64	0.36	8.35
50	0.13	0.82	0.7	10.08
75	0.15	0.92	0.95	11.07
100	0.17	0.93	1.24	14.08
250	0.25	1.15	2.51	19.13
500	0.33	1.4	4.13	20.84
750	0.4	1.55	5.61	22.94
1000	0.45	1.66	6.96	25.38
5000	0.95	2.5	23.16	36.44
10000	1.37	2.89	40	43.16
25000	2.71	2.63	109.81	57.28
50000	4.22	2.89	200.39	62.75

Drought

Drought is defined as a period of time with no surface flow. The 77 years of observed discharge and base flows for Tillegra are depicted in Figure 3.5. The base flow was calculated using an automated base flow separation technique with a digital filter (Arnold *et al*, 1995). The broad drought years on record for Tillegra and Glen Martin are 1940-1942, 1964-1967, 1979-1982, 1991-1994 as indicated by the lower points of the 5 yearly averaged baseflow. Statistics relating to the no flow components of the data sets for Tillegra and Glen Martin are listed in Table 3.8.

Low flow

Low flow is described as minimum flow in the channel and is classified as flow greater than the 70th precentile exceedence. The 70th percentile exceedence for Tillegra is approximately 24 megalitres per day and for Glen Martin is approximately 48 megalitres per day. Figure 3.6 illustrates the duration of low flow events for the 5th, 10th and 25th percentile exceedence flows at Tillegra and Glen Martin. Low flow events are generally less than 15 days in duration however during drought periods low flow conditions may persist for several months.

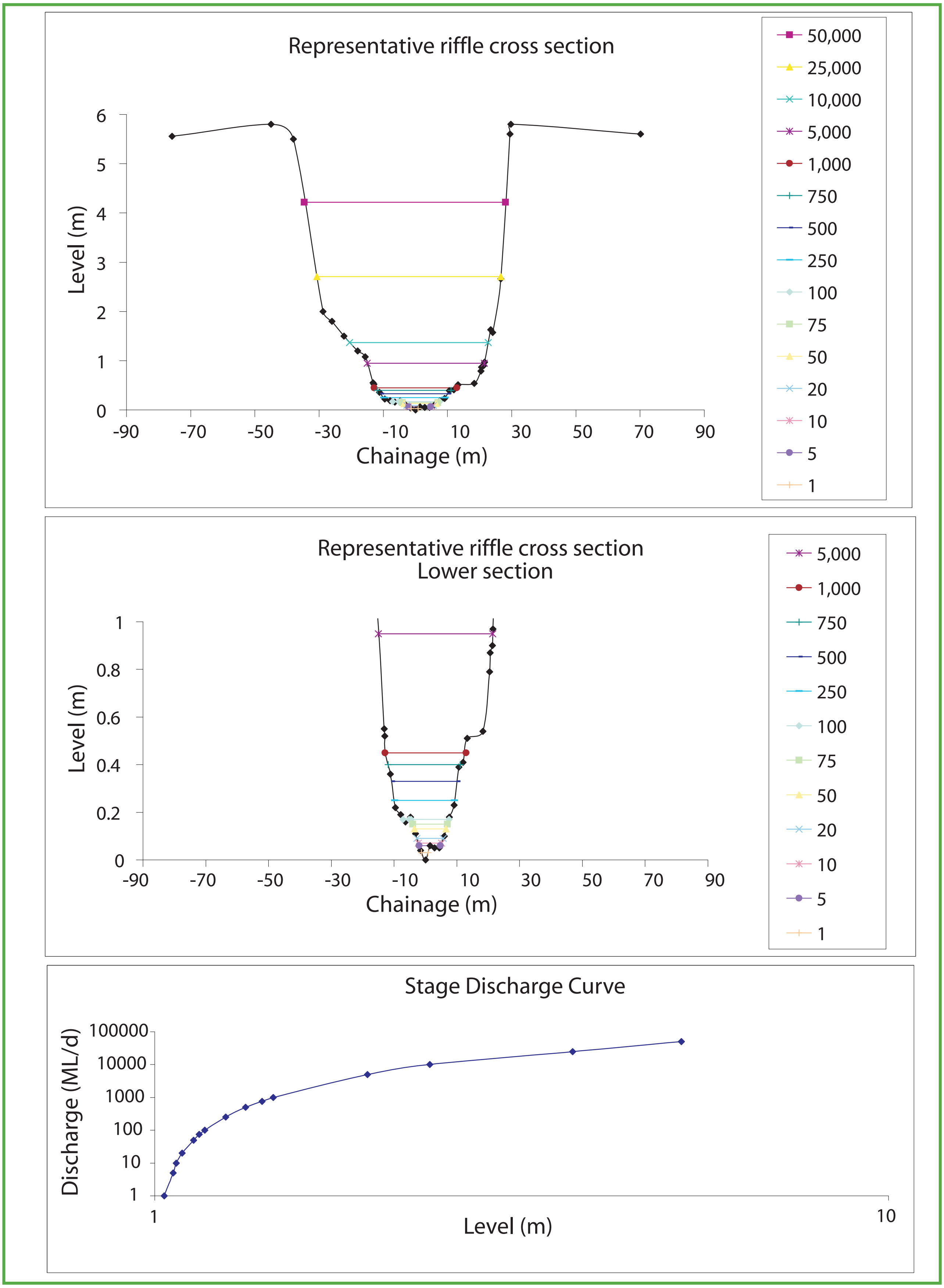


FIGURE 3.4 REPRESENTATIVE RIFFLE CROSS SECTION AND STAGE DISCHARGE RELATIONSHIP FOR THE STORAGE TO GLEN MARTIN REACH

TABLE 3.8 PERIODS OF NO FLOW AT TILLEGRA AND GLEN MARTIN

STATISTIC	TILLEGRA		GLEN MARTIN	
Occurrences of zero flow	58		35	
Maximum number of consecutive days with no flow	81 days		222 days	
Minimum number of consecutive days with no flow	2 days		2 days	
Percentile exceedence of zero – all data	3 per cent		5 per cent	
Percentile exceedence of zero – summer data	7 per cent		10 per cent	
Start date and duration (days) of major no flow events	24 Dec 1941	44	14 Dec 1941	80
	13 Dec 1964	48	9 Dec 1964	222
	12 Sept 1980	45	28 Nov 1979	166
	12 Mar 1991	62	7 Sept 1980	116
	23 Sept 1991	81	11 Mar 1991	72
			14 Sept 1991	92
			26 Sept 1994	74

Moderate flows, freshes, high flow and bank full flow

Descriptions and statistics for moderate flows, freshes, high flows, bank full and over bank flows are listed in Table 3.6 and Table 3.9.

Over bank flow

Over bank flow is described as flow that extends into the flood plain area. Our typical riffle cross section suggests this would occur at flows greater than 50,000 megalitres per day. However, in areas of low bank height flow is expected to reach the flood plain once every ten years for sites upstream near Tillegra Bridge and once every two years for sites downstream near Glen Martin. Table 3.9 provides further details on water depths at over bank flows.

Peak flow

Discharge above baseflow (observed flow – base flow) for the Tillegra Bridge site with peak events highlighted is illustrated in Figure 3.7. Peak flow events are defined as events which are at least three days apart and have flows greater than a 20 megalitres per day difference between observed and base flow. It can be seen that peak events do not have a strong seasonal bias. Figure 3.8 illustrates the per cent of time peak flow is exceeded versus peak flow discharge. Fifty per cent of the time peak flows at Tillegra are approximately 200 megalitres per day and at Glen Martin are approximately 450 megalitres per day. Figure 3.9 illustrates the per cent of time period between peak events are exceeded versus period between peak flow events. Fifty per cent of the time at both Tillegra and Glen Martin the period between peak flows is approximately 13 days.

TABLE 3.9 FLOW COMPONENTS AND KEY FEATURES

FLOW COMPONENT	PERCENTILE EXCEEDENCE	TILLEGRA BRIDGE RANGE IN FLOWS (ML/D)	TILLEGRA DEPTH OF WATER IN TYPICAL RIFFLE SECTION (CM)	TOP WIDTH (m)
Drought	No Flow	0	0	0
Low Flow	>70	24	<10	48
Moderate Flows	70 to 30	25-100	<25	50-600
Freshes	30 to 10	100-400	<35	350-1500
High Flow	5	>900	>45	>300
Bank full	<1	~20,000	3000	~20,000
Over bank flow	<1	>20,000	>3000	>20,000

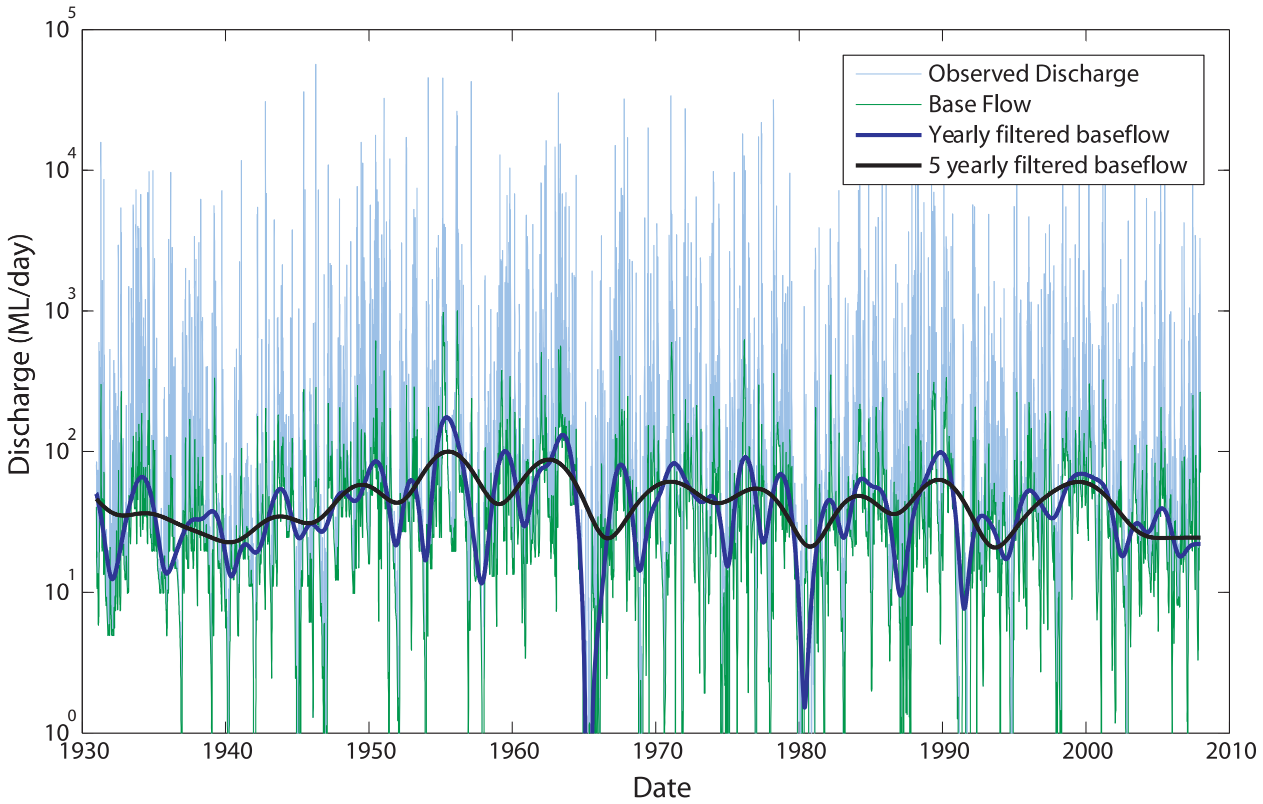


FIGURE 3.5 DAILY FLOW, BASEFLOW AND FILTERED BASEFLOW AT TILLEGRA

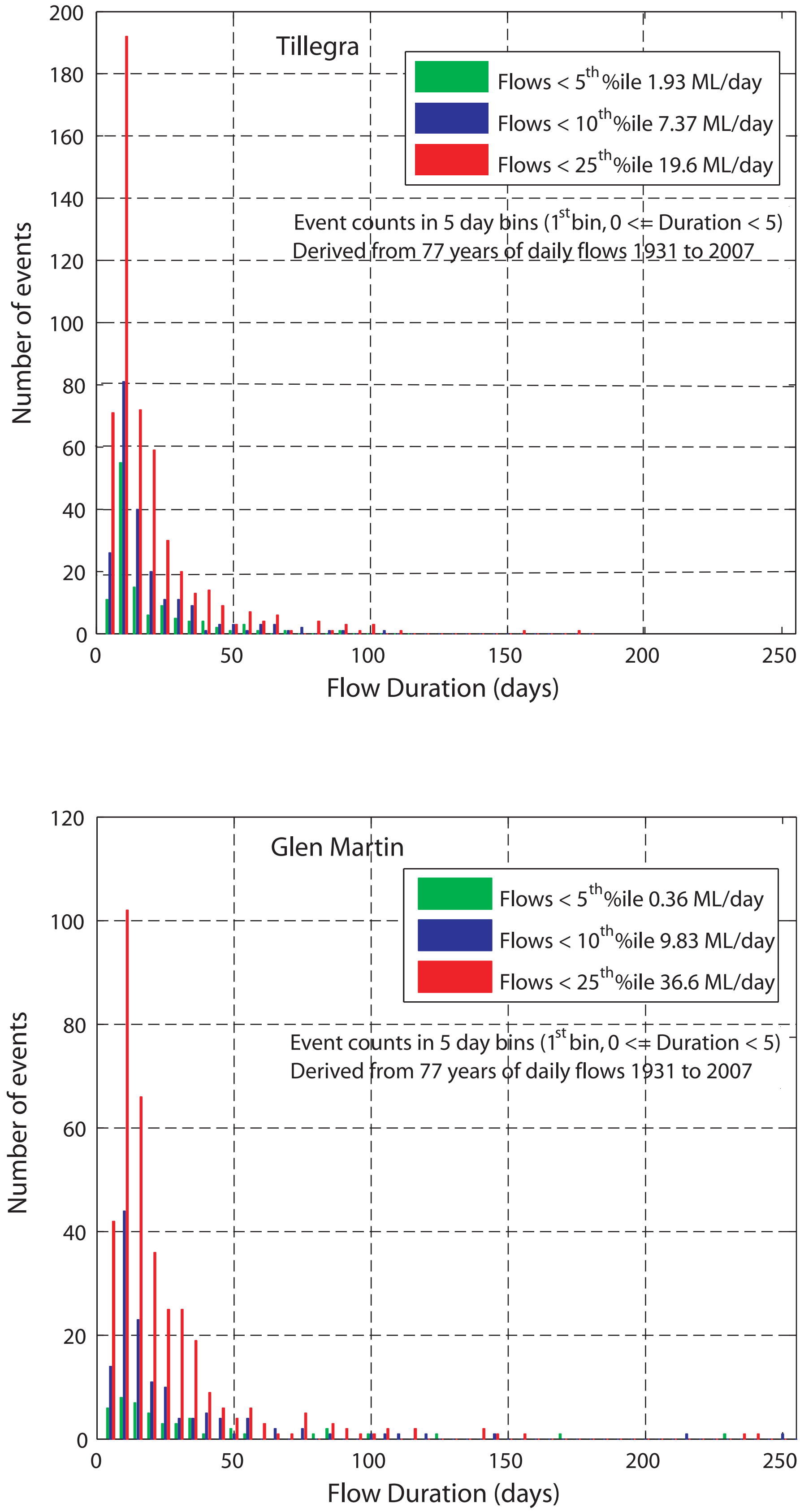


FIGURE 3.6 DURATION OF LOW FLOW EVENTS AT TILLEGRA AND GLEN MARTIN

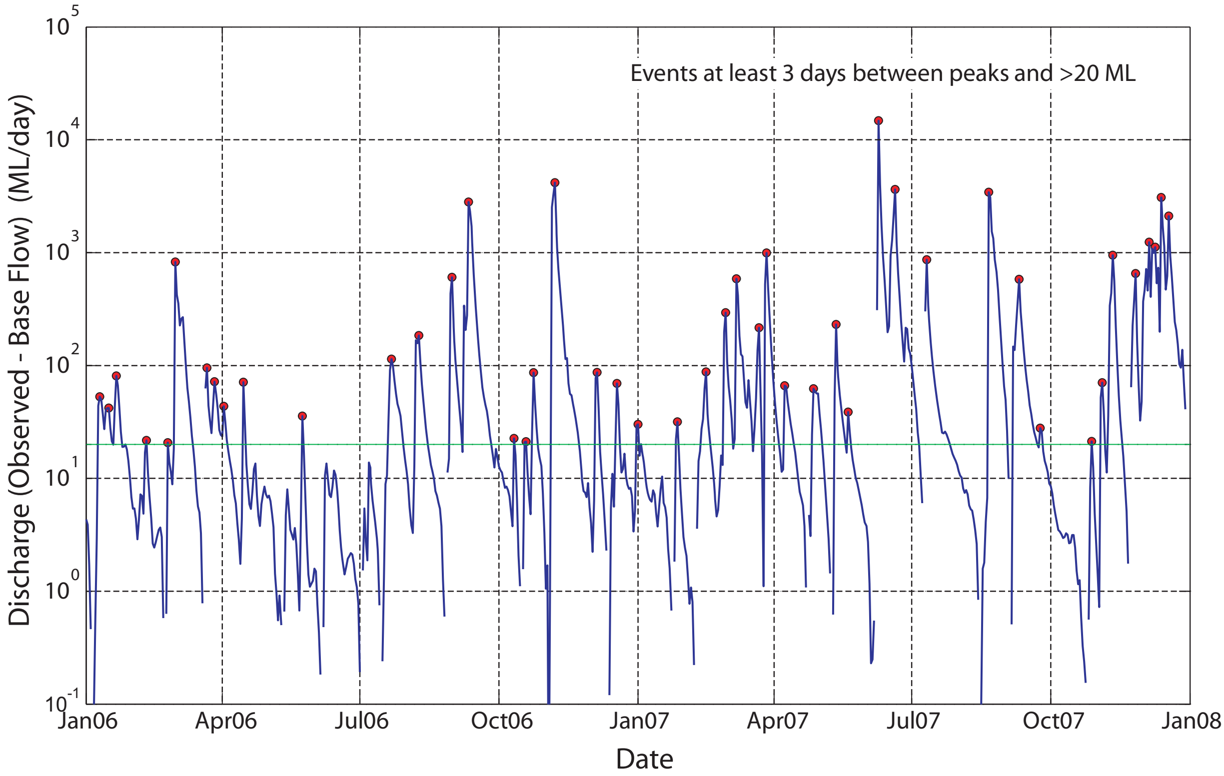


FIGURE 3.7 PEAK FLOW EVENTS AT TILLEGRA

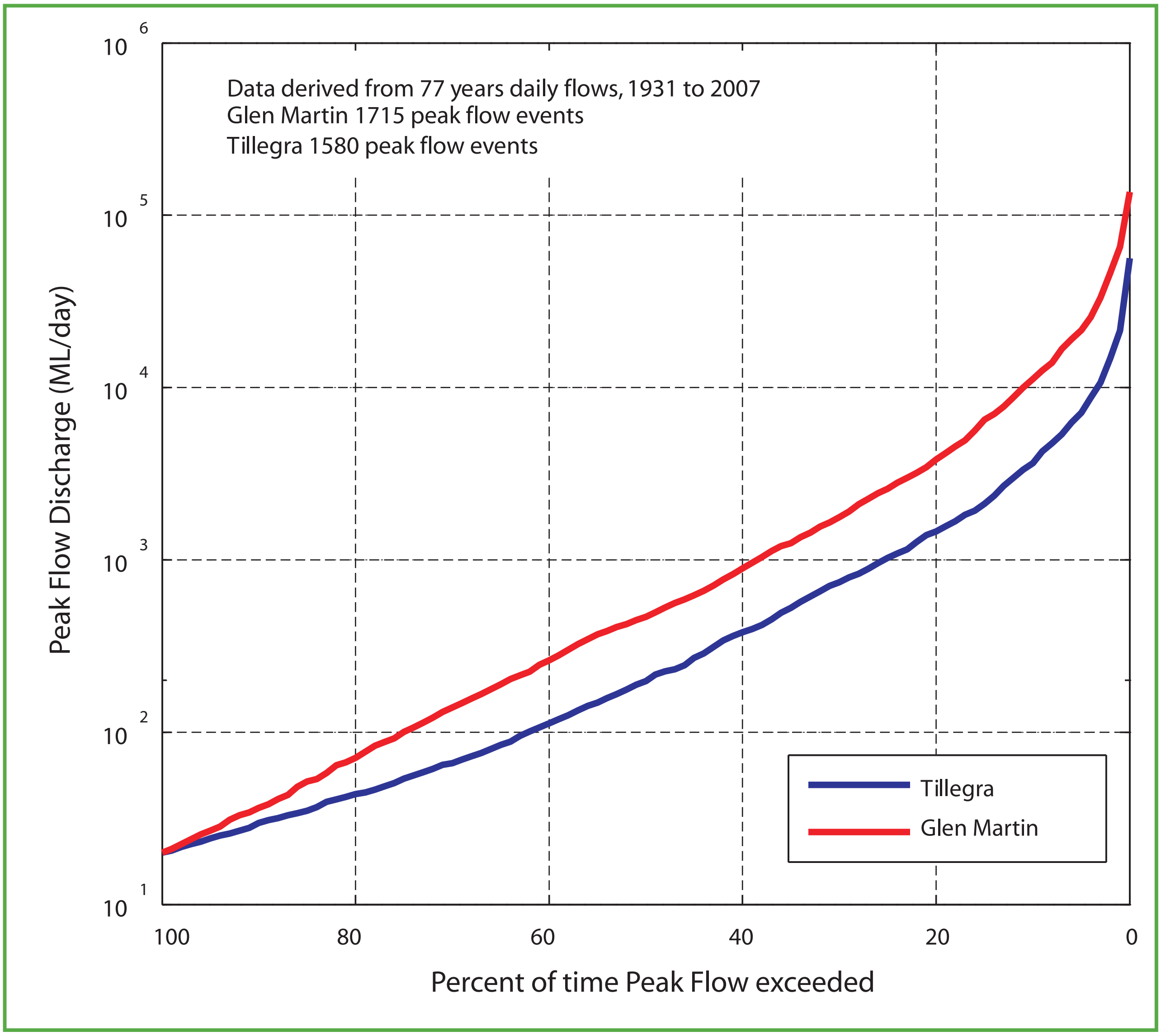


FIGURE 3.8 PERCENT OF TIME PEAK FLOW EXCEEDED VERSES DISCHARGE

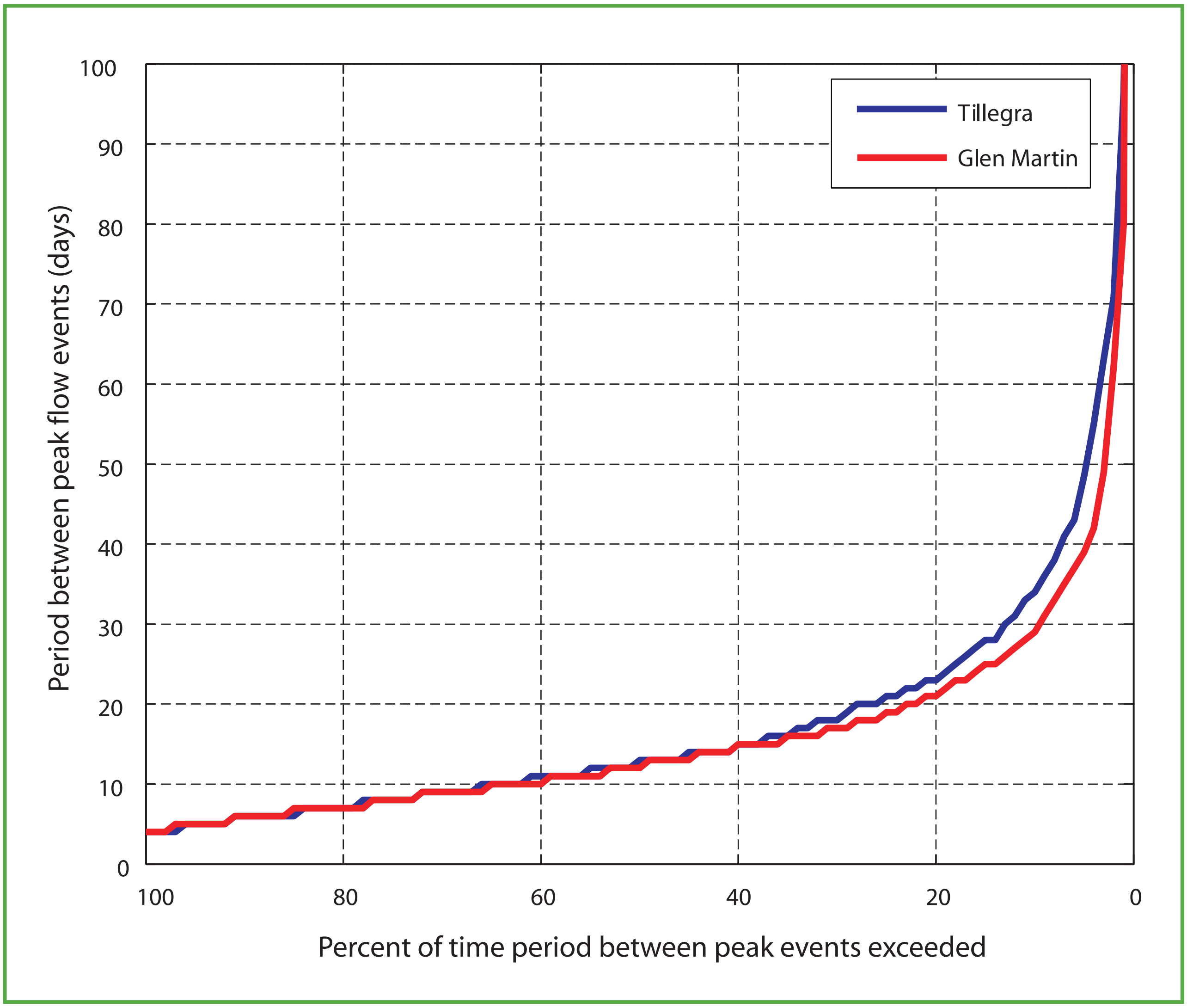


FIGURE 3.9 PERCENT OF TIME PERIOD BETWEEN EVENTS EXCEEDED VERSES PERIOD BETWEEN EVENTS

4. Upper Williams River to Storage FSL

The following section characterises the existing river reach from the Upper Williams River to the storage full supply level (FSL). The section identifies and assesses the potential water quality and hydrology issues associated with dam construction and operation for this reach of the Williams River.

4.1 Characterisation of existing Reach 1

4.1.1 Topography

The upper reaches of the Williams River are characterised by steep vegetated slopes, rising from 1500 metres above sea level in the northern end to 152.3 metres at the storage FSL. The average river bed slope for the entire reach is approximately 4.24 per cent and is approximately 34 kilometres in length.

The reach is comprised of an extremely steep and rocky upper section which has a bed slope of greater than 10 per cent and elevation from around 400 to 1500 metres AHD. A more gently sloping reach with a bed slope of approximately 1.2 per cent occurs from 160 to 400 metres AHD and length approximately 21 kilometres. For the purpose of this investigation the reach between 160 to 400 metres AHD would be assessed as it provides suitable habitat for aquatic species.

TABLE 3.8 PERIODS OF NO FLOW AT TILLEGRA AND GLEN MARTIN

Average bed slope	4.24 per cent
Average bed slope 400-500m	10.28 per cent
Average bed slope FSL-400m	1.18 per cent
Length of river reach FSL-400m	21 kilometres
Pool/riffle sequences	numerous shallow pool/riffle sequences with short pool length, numerous glides

4.1.2 Water quality

The water quality within the forested upper reaches of the Williams River is considered excellent (Chessman and Growns 1994). Two water quality sampling sites were located within this reach (W1 and W2) for this study (refer Figure 3.1). Physico-chemical measurements and water samples for laboratory analysis were collected at both sites and results, along with comparisons against ANZECC guidelines are displayed in Appendix B. When compared against appropriate ANZECC guidelines for south east Australian slightly disturbed ecosystems for upland rivers the following exceptions were noted:

- waters were slightly more acidic than guideline values at Site W1
- dissolved oxygen levels were less than guideline values for one replicate at sites W1 and W2
- nitrate and nitrite were above guidelines levels at W1 and W2
- total phosphorus concentrations were greater than guideline levels for one replicate at site W1and W2
- zinc concentrations were above guidelines for all samples taken at W1 and W2.

4.2 Potential hydrology and water quality issues in Reach 1

There would be limited water quality and hydrology issues as a result of dam construction and dam operation in the upper reaches of the Williams River catchment.

5. Storage

The following section characterises the existing river reach for the area to be inundated by the storage and assesses the potential water quality and hydrology issues associated with dam construction and operation. Information available from the nearby Glennies Creek Catchment and Lake St. Clair storage are also described to provide a comparative system of similar characteristics to the proposed Tillegra Dam Storage.

5.1 Characterisation of existing Reach 2

5.1.1 Topography

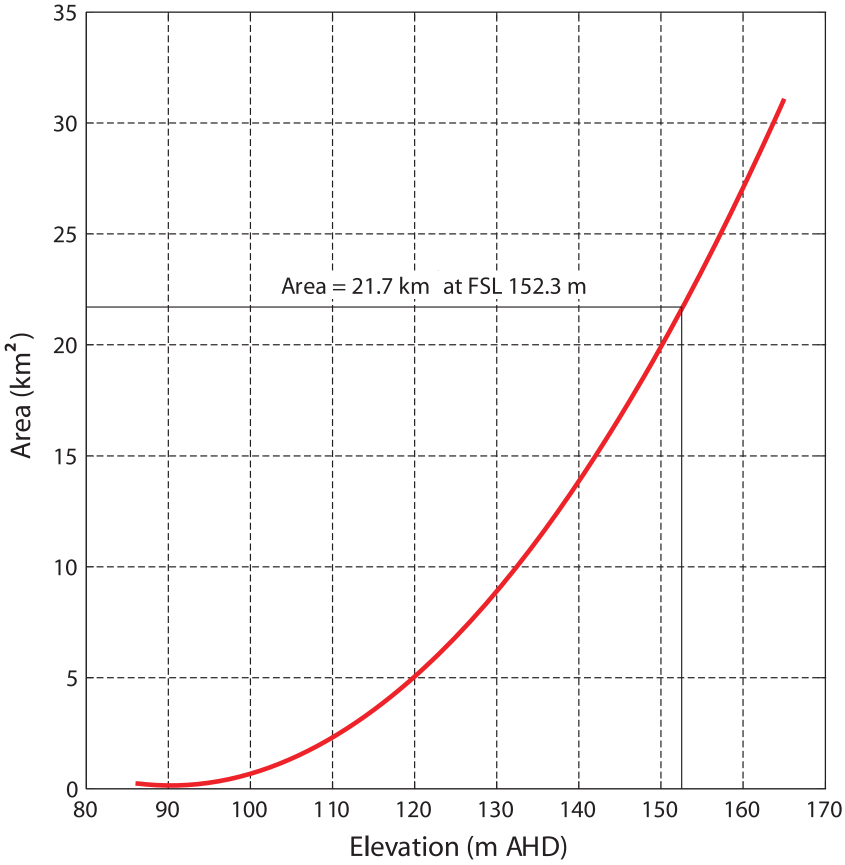
The storage will cover an approximate 19 kilometre stretch of the Williams River from elevation 87 metres AHD at the dam site to 152.3 metres AHD at full supply level. The reach has an average bed slope of approximately 0.34 per cent. Volume and surface area verses depth at the proposed Tillegra Dam is provided in Figure 5.1.

TABLE 5.1 CHARACTERISATION OF REACH 2 – STORAGE

Average bed slope	0.34 per cent
Length of river reach	19 kilometres
Pool/riffle sequences	numerous pool/riffle sequences with short pool length, numerous glides

5.1.2 Water quality

Water quality within the proposed storage area has limited data available for analysis, however, given the surrounding land use, the water quality is expected to be excellent to good. Four water quality sampling sites (W3, W4, W5, and W6) were located within the proposed storage reach for this study (refer Figure 3.1). Physico-chemical measurements were taken at all four sites and water samples were collected and sent for laboratory analysis at sites W4 and W6. Water quality results along with comparisons against ANZECC guidelines are displayed in Appendix B. When compared against



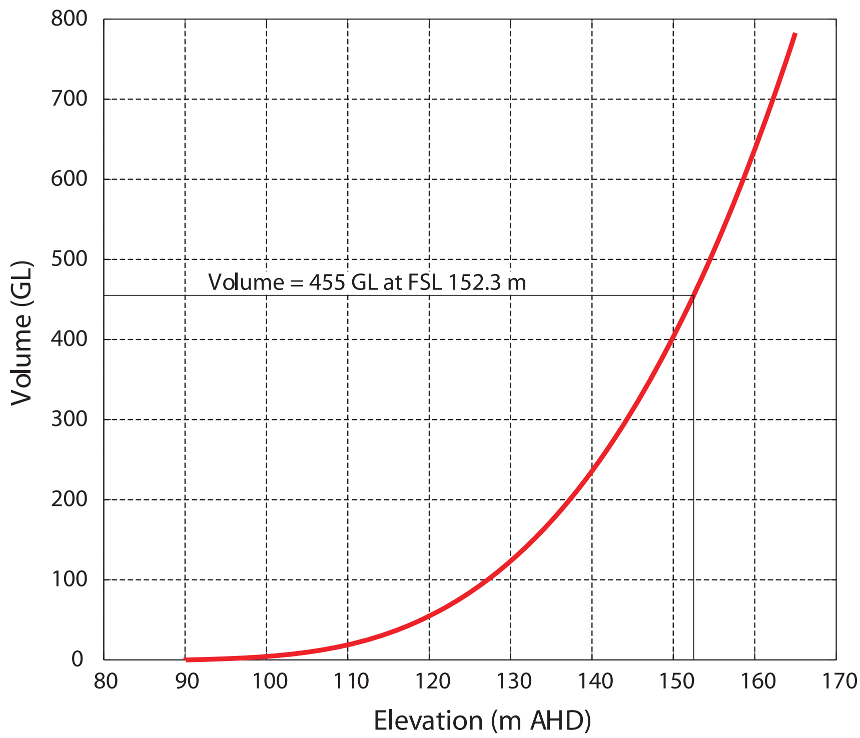


FIGURE 5.1 TILLEGRA DAM AREA AND VOLUME VERSES ELEVATION

ANZECC guidelines for south east Australian slightly disturbed ecosystems for lowland rivers the following exceptions were noted:

- waters were less saline than lower guideline limit at W2, W4 and W6
- dissolved oxygen concentrations were less than the lower guideline limit at all sites
- turbidity was lower than guideline lower limits at site W4
- total phosphorus concentrations were higher than guideline levels
- zinc concentrations were higher than guidelines

5.1.3 Hydrology

An analysis and description of river flows at the downstream end of this river reach, at Tillegra Bridge, is provided in Section 2.4.1 .

5.2 Glennies Creek storage

Information on the Glennies Creek catchment and storage is provided below as a comparative system of similar characteristics to the proposed Tillegra Dam storage. The proposed Tillegra Dam is similar in size, volume, catchment area and depth to the Glennies Creek storage. The dam characteristics for the proposed Tillegra, Glennies Creek and Chichester Dams are provided in Table 5.2.

TABLE 5.2 COMPARISON OF CHARACTERISTICS FOR TILLEGRA, GLENNIES CREEK AND CHICHESTER DAMS

DAM CHARACTERISTICS	TILLEGRA DAM	GLENNIES CREEK DAM	CHICHESTER DAM
Storage capacity	450 GL	283 GL	21.5 GL
Height of dam wall	76 m	67 m	43 m
Full supply level	152.3 AHD	186 m AHD	156.2 AHD
Length of dam wall	800m	535 m	254 m
Catchment Area	194 km²	233 km²	197 km²
Surface area at FSL	2165 ha*	1540 ha	180 ha
Level of off-take	MLO proposed	MLO	MLO

*Based on LiDAR data
Source: DoC 2007b, HWC 2008, Wright et al 1990.

5.2.1 Glennies Creek catchment characteristics

Information on the Glennies Creek Catchment is provided below as a comparative system of similar characteristics to the proposed Tillegra Dam storage. Details regarding the Tillegra catchment are contained within Section 2.2 of this report.

The Glennies Creek catchment is situated in the centre of the Hunter Valley and is approximately 30 kilometres to the west of the proposed Tillegra Dam (refer Figure 1.1). Glennies Creek has a catchment area of 512 square kilometers while the storage itself has a catchment area of 233 square kilometers and the foreshore area is 66 square kilometers.

The main land uses in the Glennies Creek catchment (including downstream of the dam) are conservation, agriculture, cropping, water supply, tourism and recreation, mining and quarrying. The upper forested section of the catchment lies within Mount Royal National Park and includes some privately owned land managed for conservation. Approximately 30 per cent of the Glennies Creek catchment is forested, most of the forested lands occur within the Lake St Clair catchment (Hunter-Central Rivers CMA 2004).

Main waterways within the catchment include Lake St Clair (water impounded by the Glennies Creek Dam) and many tributaries including Goorangoola Creek, Campbells Creek and Cross Creek. Carrow Brook and Fal Brook flow into Lake St Clair Storage.

The following water quality and hydrology issues have been associated with the Glennies Creek Storage (Dept of Land and Water Conservation 2003, Preece 2004, Wright *et al* 1990):

- the reservoir stratifies annually, starting in late August and mixing in early May. Large differences in surface and bottom water temperatures of up to 14 degrees Celsius have been recorded
- evidence of cold water pollution due to deep water release is localised to within 20 kilometres of the storage
- frequent algal blooms are recorded
- typical conditions in the reservoir include pH concentrations slightly above neutral, low turbidity and moderate concentrations of nutrients, especially phosphorus and nitrogen
- particularly high total phosphorous concentrations have been recorded at sites where cattle have access to the foreshore areas of the Lake St Clair storage
- elevated concentrations of total iron and total manganese have also been recorded in the dam.

Further information on the Glennies Creek Catchment is supplied in Appendix D.

5.3 Potential hydrology and water quality issues in Reach 2

The impacts of large dams on in-storage and downstream water quality and their effect on downstream river flow regimes are well documented. Given the proposed Tillegra Dam's storage capacity, height of dam wall and issues associated with the similarly characterised Glennies Creek storage it is suggested the following water quality issues are likely to occur in storage at Tillegra:

- stratification during the summer months (both temperature and dissolved oxygen stratification)
- release of metals (manganese and iron) from sediments when bottom waters are anoxic
- 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).

5.3.1 Subterranean flows

Coarse estimates of the subsurface flows (below river bed) at the Tillegra site have been calculated to estimate the likely volume of water that would flow from the dam through the gravel beds. Based on Darcy's Law and an estimation of hydraulic parameters for the Tillegra site, flow estimates are up to 3 megalitres per day.

It is suggested that losses from the gravel beds would not be significant and are unlikely to affect the level of the water table except perhaps during prolonged dry periods and drought. Further information on the assessment of subterranian flow is provided in Appendix E.

5.4 Assessment of potential issues in Reach 2

To assess the potential in-storage issues associated with Tillegra Dam an assessment of the thermal behaviour of the storage was made and an interpretation of Tillegra Bridge, Glennies Creek and

Chichester Dam data has been undertaken as part of the environmental assessment. In addition hydrodynamic and water quality modelling using the DYRESM/CAEDYM package was also carried out.

5.4.1 Hydrodynamic modelling

DYRESM/CAEDYM was used to model the varying levels of temperature, dissolved oxygen (DO) and chlorophyll-a (associated with cyanobacteria and diatoms) over a one year cycle in Tillegra Dam. DYRESM (DYnamic REServoir Simulation Model) is a one-dimensional hydrodynamic model for predicting the vertical distribution of temperature, salinity and density of reservoirs (CWR 2008) in response to surface heat fluxes, inflows and outflows.

The model was initially established for the Glennies Creek Lake St Clair storage as reported by CWR (Wright *et al* 1990 and Schladow 1991). Model inputs were then adjusted to simulate the proposed Tillegra Dam storage. Detailed information on the hydrodynamic modelling of Tillegra Dam is provided in Appendix F .

The model was run for a period of 365 days from 1 July 1990 to 30 June 1991. This period had reasonably representative meteorological data available to simulate a full year cycle. The hypsographic information was derived from LIDAR terrain data from Tillegra observations, and outflow estimated for typical withdrawal releases. The initial temperature profile of the reservoir was adapted from similar data at Glennies Creek on 1 July 1990. Available Glennies Creek meteorological data only covered an 8 month period and was used to verify the model. Results showed reasonable comparison with results for the same period of data from Warragamba Dam. To simulate a full year seasonal cycle long term data for Warragamba was applied to the model. Inflow nutrient concentrations and temperatures have been interpreted from measured values at Tillegra Bridge.

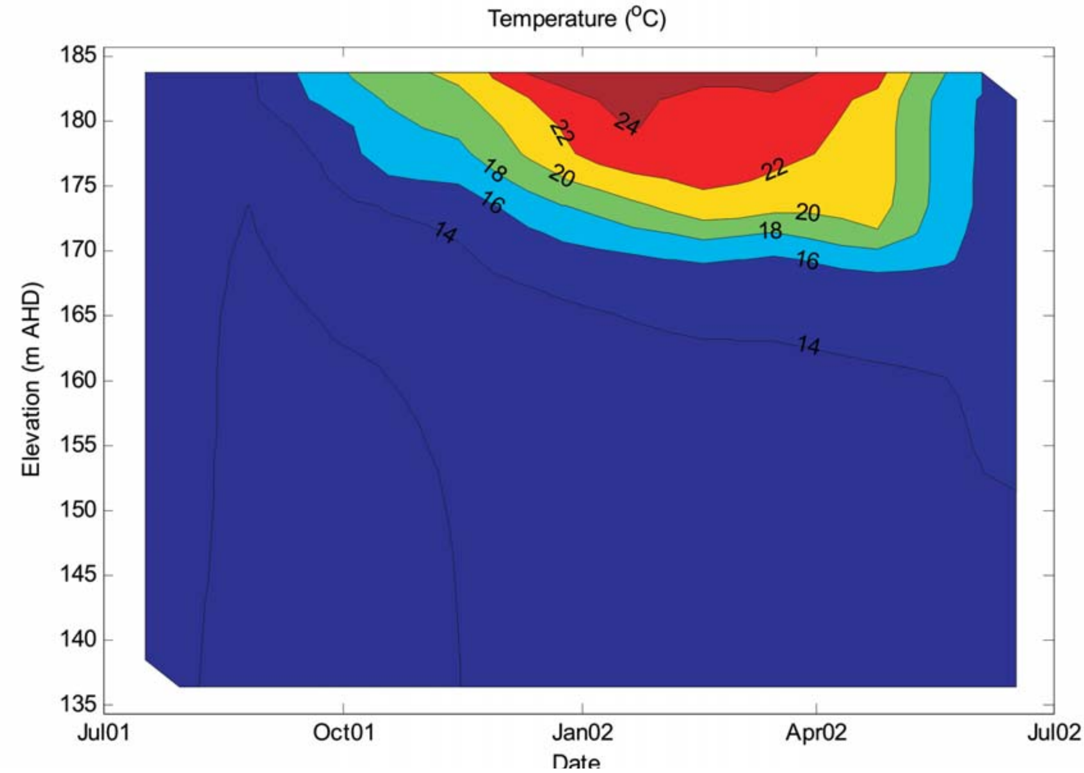
CAEDYM (Computational Aquatic Ecosystem DYnamic Model) is an aquatic ecological model that is designed to be coupled with a 'parent' hydrodynamic driver (DYRESM) to simulate varying levels of nutrients in water bodies (Hipsey *et al* 2006). The model equations involve complex interactions between state 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 storage.

5.4.2 Thermal behaviour of the storage

Temperature and dissolved oxygen contours derived from observed monthly profiles collected in the Glennies Creek Storage in 2001-2002 are illustrated in Figure 5.2. Temperature and dissolved oxygen contours for the proposed Tillegra Dam derived from the DYRESM model are illustrated in Figure 5.3.

Both dams typically stratify during spring/summer with cooling during autumn and winter becomes mixed from surface to bottom (refer Figures 5.2 and 5.3). The change in temperature from top to bottom is often characterised by a rapid change at a depth that is referred to as the thermocline. The depth of the thermocline increases as surface heating progresses through spring and summer, reaching about 15 to 20 metres at a maximum. The thermally mixed surface layer during summer generally extends over 5 to 10 metres depth. Winter temperatures in this depth range also tend to be warmer than in deeper waters. Surface (epilimnic) temperatures range from about 12 degrees Celsius in July to about 25 degrees Celsius in February. The bottom (hypolimnic) temperatures vary less than the surface temperatures and range from the winter minimum of about 11 degrees Celsius in August to about 15 degrees Celsius in May following complete mixing of the summer stratification. Note that a weak stratification persists in the Tillegra simulation at the end of the model run at the end of June. It is likely this will become completely mixed during colder periods in July and August.

Temperature isotherms in Glennies Creek Reservoir over the period July 2001 to June 2002



Dissolved oxygen isotherms in Glennies Creek Reservoir over the period July 2001 to June 2002

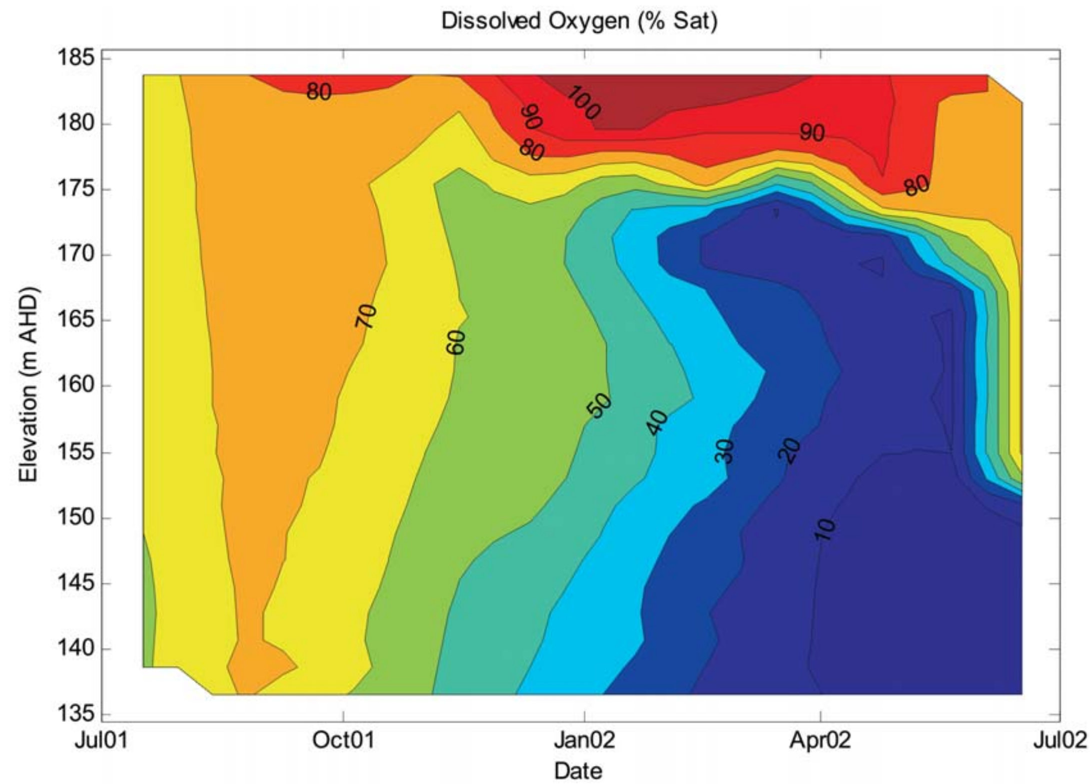


FIGURE 5.2 GLENNIES CREEK DAM TEMPERATURE AND DISSOLVED OXYGEN CONTOURS VERSES TIME

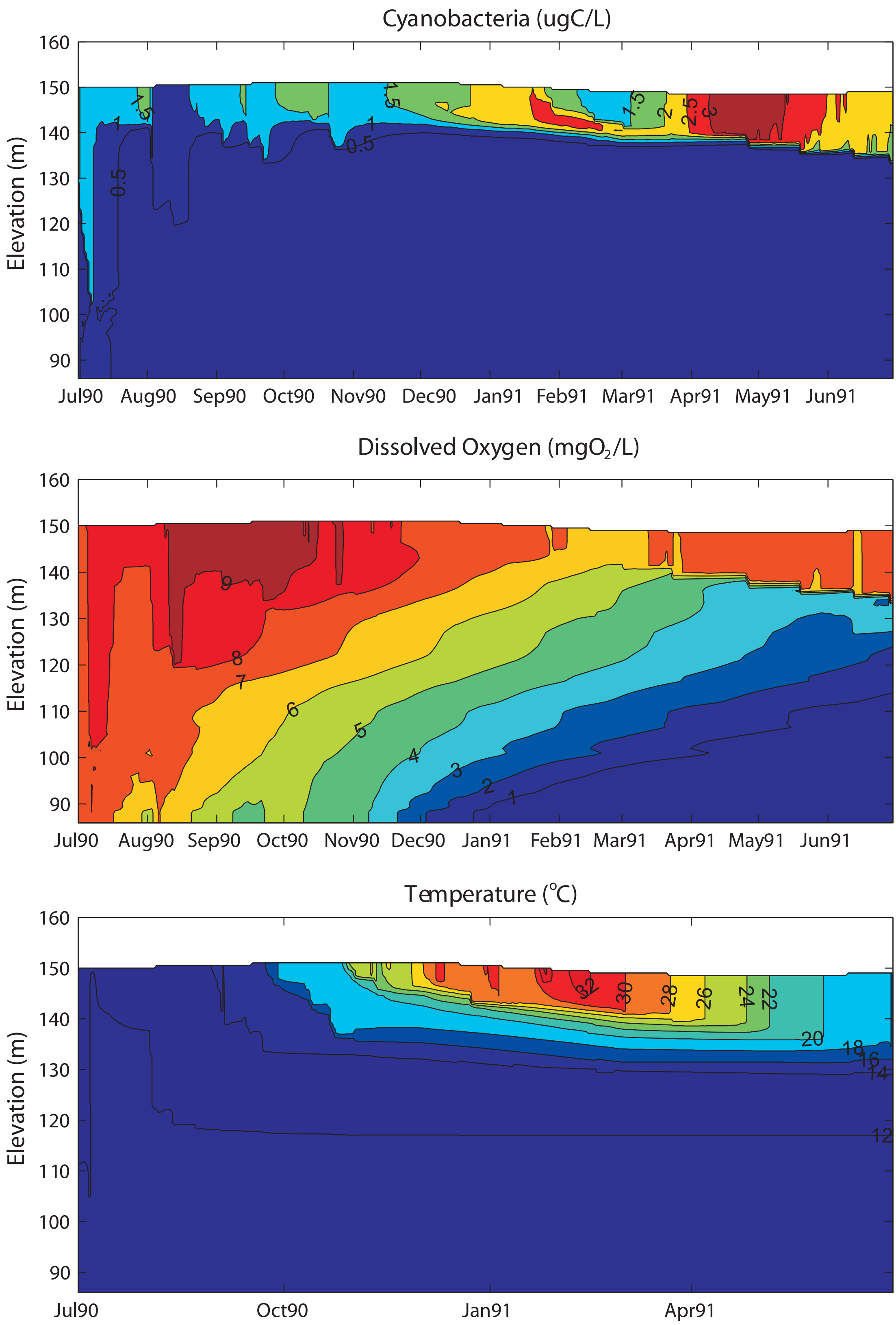


FIGURE 5.3 MODELLED•ILLEGRA DAM CYANOBACTERIA, TEMPERATURE AND DISSOLVED OXYGEN CONTOURS VERSES TIME

During the dam filling phase it is suggested 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.

Stratification may also be associated with other variations in chemical and biological properties including 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 the sediment.

5.4.3 Water quality

Based on data collected in Lake St Clair the key water quality issues of concern within the proposed Tillegra Dam storage, apart from stratification as described above, are dissolved oxygen stratification, the presence of blue green algae, the area of photic depth and likely in-storage nutrient concentrations. These issues are addressed below.

Dissolved oxygen

Typical dissolved oxygen concentration profiles at Lake St Clair are shown in Figure 5.2 and model results for Tillegra Dam in Figure 5.3. Concentrations in the waters above the thermocline meet the ANZECC (2000) guidelines of 80 per cent to 110 per cent saturation (~>6mgDO/L) in the surface mixed layer to about 8 metres depth. TEL (2008) measurements in the shallow river waters upstream and at the Tillegra Dam site showed similar concentrations of 76 per cent to 88 per cent saturation in November to December, 2007.

The dissolved oxygen 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, apparently due to nutrient inputs from agricultural runoff, accumulation and recycling from the 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 Tillegra Dam are expected be less, resulting in acceptable levels (<50,000 cells per millilitre) for the majority of the time. The water quality model (refer Figure 5.3) 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 whether they are likely to exceed guidelines.

Unfortunately, no profile data on blue-green were available for Lake St Clair. To determine the expected blue-green algal depth distribution at the proposed Tillegra Dam, profiles of blue-green algae in Chichester Dam, provided by HWC, were examined. Profiles were taken at the surface and 2 metres, 4 metres, 6 metres, 12 metres and 28 metres down the water column from 1992 - 2007 (data from 1999 only for depth of 28 metres). The CAEDYM model results indicate the algal concentration is well correlated with the thermal stratification and likely photic zone.

Analysis of Chichester Dam data showed that concentrations were within NH&MRC guideline levels (<50,000 cells per millilitre) at a depth of 6 metres for greater than 99 per cent of the time. Due to lower expected levels of algae at Tillegra Dam than at Lake St Clair the blue-green algal levels at a 6 to 8 metre depth may be expected to have infrequent exceedances of the guideline level. Results are displayed in Table 5.3.

TABLE 5.3 MINIMUM, MAXIMUM AND MEAN BLUE GREEN ALGAL COUNTS AT CHICHESTER DAM

DEPTH (m)	MINIMUM (CELLS/mL)	MAXIMUM (CELLS/mL)	MEAN (CELLS/mL)
Surface	0	1,840,000	4,582
2	0	250,000	1,758
4	0	230,000	1,640
6	0	140,001	1,559
12	0	25,196	1,105
28	0	33,292	1,381

Source: HWC Data, 1992-2007

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. The area of near shore lake bed exposed to light for different photic depth estimates (1, 2 and 4 metres) are illustrated in Figure 5.4. At FSL the bed area exposed to light could potentially range from 0.7 square kilometres (if the photic depth is 1 metre) to 1.4 square kilometres (for 2 metres photic depth) to 2.75 square kilometres (for 4 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 sediment whereas further offshore in deep water pelagic species and micro-algae (phytoplankton and cyanobacteria) would be most likely to dominate.

Due to the acceptable levels (<50,000 cells per millilitre) of blue-green-algae for the majority of the time, the photic depth is expected to be at the higher range indicated in Figure 5.4 for most months and in the lower range during the summer phytoplankton growing season. As the water levels are reasonably constant shallow areas may be expected to support growth of benthic macrophytes, associated macroinvertebrates and fish.

As a result of dam filling, the aquatic life in the inundated 19 kilometre reach of the Williams River would be replaced by the development of similar types of aquatic life in the photic zone of the lake inshore (littoral) areas. Although the species diversity may be lower than in the existing Williams River, particularly during summer, the area of habitat expected to be created is about twice that of the river during summer months. During the cooler months of the year, the littoral habitat is expected to be about 10-fold larger. Refer Working Paper C of the EA Report: Aquatic Flora and Fauna for further discussion.

Expected nutrient concentrations

Expected nutrient concentrations in the proposed storage were estimated by using the model of Dillon (1975) where the total phosphorus concentration (P) is estimated by taking into account the load (L), modified by the retention co-efficient (R), mean depth (Z) and the reservoir flushing rate (p). The total phosphorus concentration is given by the equation:

$$[P] = \frac{L(1-R)}{Zp}$$

The areal load at Tillegra Bridge is estimated, from the average TP concentration (0.068 mg/L), the average inflow (262 megalitres per day) and the storage area (21.7 square kilometres), to be L = 0.3 gP/m^2/year.

The retention coefficient is estimated at Glennies Creek Dam, from the ratio of the average TP inflow (0.150 milligrams per litre) and average TP outflow (0.062 milligrams per litre) concentrations, to be R = 0.587.

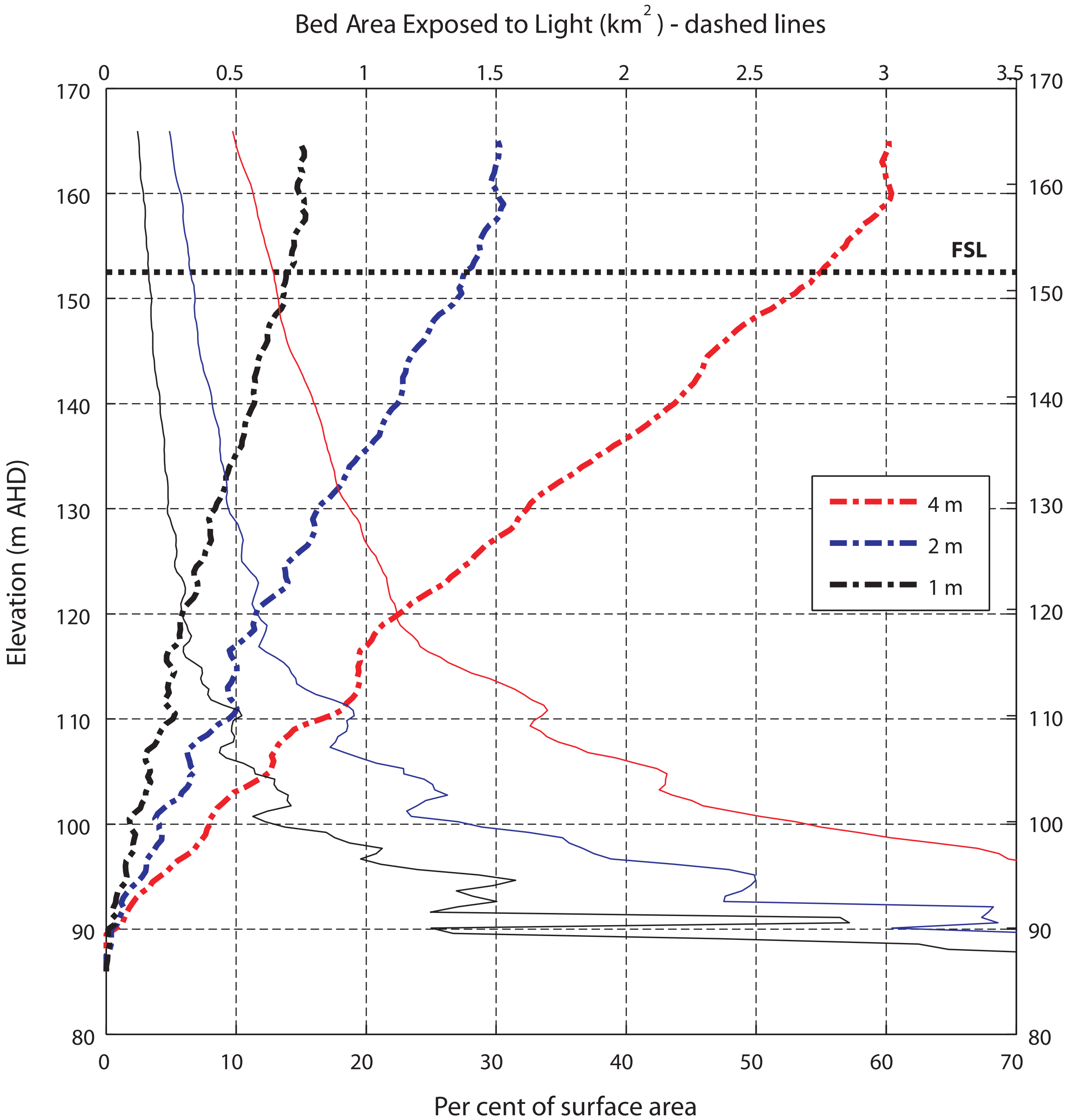


FIGURE 5.4 NEAR SHORE BED AREA EXPOSED TO LIGHT FOR DIFFERENT PHOTIC DEPTH ESTIMATES

The flushing rate is the number of times the stored volume (450 gigalitres) is flushed per year by the average annual release (220 megalitres per day) from the dam and is estimated to be p = 0.18 times per year.

Based on the model described above the total phosphorus concentration, P, in Tillegra Dam is estimated to be about half the inflow concentration (refer Table 5.4).

The total nitrogen concentration in Tillegra Dam was estimated from the average ratio of total nitrogen (TN) to total phosphosus (TP) in outflows from the Glennies Creek Dam. With a TN:TP ratio of 7.06, a total nitrogen concentration of 0.240 milligrams per litre is estimated for Tillegra. The nutrient concentrations in Tillegra Dam are expected to be greatly reduced due to dilution of the Williams River inflows by the large volume of the storage. This suggests the nutrient 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.

TABLE 5.4 EXPECTED/OBSERVED NUTRIENT CONCENTRATIONS AT TILLEGRA DAM AND GLENNIES CREEK

DEPTH (m)	TOTAL PHOSPHORUS (mg/L)	TOTAL NITROGEN (mg/L)
Tillegra Dam inflow (observed)	0.068[1]	0.663[2]
Tillegra Dam outflow (expected)	0.034	0.240
Glennies Creek inflow (observed)	0.150[3]	0.429[4]
Glennies Creek outflow (observed)	0.062[5]	0.438[6]
ANZECC guideline for lowland rivers	0.025	0.350

[1] estimated using data collected by HWC at Tillegra Bridge 1987-2007
[2] estimated using data collected by HWC at Tillegra Bridge 1995-2007
[3] estimated using data collected at inflow sites by DWE at Fal Brook and Carrow Brook 1985-2004
[4] estimated using data collected at inflow sites by DWE at Fal Brook and Carrow Brook 1995-2004
[5] estimated using data collected at the inflow sites by DWE at the dam wall 1984-2004
[6] estimated using data collected at the inflow sites by DWE at the dam wall 1992-2004

The expected nutrient concentrations at the proposed Tillegra Dam are relatively low compared to other storages in the area. This is expected to give a reduced frequency of exceedence of the NHMRC (2004) recreational blue-green algae concentration guidelines in the surface waters, compared to that in Glennies Creek Storage. Sub-surface releases via the multi-level offtake tower are expected to reduce the release of blue-green algae concentrations to the Williams River above the guidelines (refer Section 6.3.2).

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

5.5 Potential mitigation measures for Reach 2

A number of potential mitigation measures may be employed within the storage and catchment area to address the potential issues that may arise from the impoundment of the Williams River at Tillegra. Mitigation measures are outlined under potential issues in the following sections.

5.5.1 Issue: Stratification

A number of storages, including Glennies Creek Storage experience summer stratification and well mixed conditions during winter. During the autumn turnover problems of high manganese and iron levels in water supplies and intermittent algal blooms are experienced. To avoid these water quality problems attempts have been made to artificially break down the thermal stratification. Aeration devices are often used leading to sustained year round improved oxygen concentrations near the bottom. The use of artificial destratification has had varying degrees of success.

A detailed study in the 1990s was undertaken at Glennies Creek Storage to assess the use of aerators in water quality management (Wright *et al* 1990 and Schladow 1991). In 1986 a 42 metre long aerator was installed parallel to the base of the dam wall. A second aerator, 200 metres long, was installed in 1987 along the bed of the reservoir. While aerators promoted significant mixing residual thermal stratification remained and both attempts to destratify the reservoir were considered unsuccessful. During September 1989 a new aerator with total capacity of 600 litres per second was installed and was put into operation for the spring, summer and autumn months. The aerator operation over the 1989/1990 and 1990/91 disrupted the stratification process.

Chichester Dam is artificially destratifed and a study undertaken by HWC between July 2006 and June 2007 suggests the destratification proved effective with uniform temperatures recorded throughout the water column with a mean temperature difference between surface and bottom water of less than one degree. It is not clear whether this mixing lead to flow on improvements in water quality or whether the release of cooler water downstream was an issue.

It is suggested that the volume of Tillegra Dam would be too large to provide effective destratfication. The objectives of the destratfication process need to be clearly identified and the costs balanced against the benefits depending on water demands and uses.

5.5.2 Issue: Algal blooms

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

- physical controls such as artificially mixing the water column
- minimising nutrient levels in inflows to and in the storage (refer section 5.5.3)
- encourage water conservation measures
- chemical controls eg algicides.

5.5.3 Issue: Sediment and nutrient export from the catchment

A reduction in sediment and nutrient export from the catchment, and likely subsequent reduction in release of metals from the sediments, may lead to improvements in storage water quality and catchment watercourses. Potential management options are to implement a program to reduce catchment export of sediments and nutrients which may involve:

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

5.5.4 Issue: In-storage recreation

To reduce the effects of in-storage recreation on the water quality the following measures may be adopted:

- ensure recreational activities are consistent with maintaining water quality
- ensure recreational facilities (eg picnic areas/toilet facilities) are adequate to accommodate potential recreational users
- Ban recreational use during the filling period and review after 10 years.

6. Storage to Glen Martin

The following section characterises the existing river reach from below the proposed Tillegra Dam storage to Glen Martin and identifies and assesses the potential water quality and hydrology issues associated with dam construction and operation for this reach of the Williams River.

6.1 Characterisation of existing Reach 3

6.1.1 Topography

This riverine stretch encompasses the Williams River from the catchment below the proposed storage at Tillegra to the Mill Dam Falls, a natural rock weir, at Glen Martin and covers a river length of 63 kilometres. The reach declines in bed slope from 87 metres AHD at the dam wall to approximately 0 metres AHD at Glen Martin.

The number of pool/riffle sequences (refer Table 6.1) was estimated based on visual observation during the helicopter habitat characterisation (refer Section 3.2.1). The downstream end of this reach is characterised by a large pool initiating at Glen Martin approximately 2.5 kilometres in length and bounded by the Mill Dam Falls rock weir.

TABLE 6.1 CHARACTERISATION OF REACH 3 – STORAGE TO GLEN MARTIN

Average bed slope	0.15 per cent
Length of river reach	63 kilometres
Number of pool/riffle sequences	40
Average length of pool/riffle sequence	1.58 kilometres

6.1.2 Water quality

Water quality along the Williams River between the Storage 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).

For this present study six water quality sampling sites (W7 to W12) are located between the storage and Glen Martin (refer Figure 3.10). Physico-chemical measurements were taken at all sites with the exception of W11 and W12. Water samples were collected at all sites and sent for laboratory analysis with the exception of W7. Water quality results along with comparisons against ANZECC guidelines are displayed in Appendix B. When compared against ANZECC guidelines for SE Australian slightly disturbed ecosystems for lowland rivers the following exceptions were noted:

- conductivity concentrations are below lower limit thresholds at sites W7, W8, W9 and W10
- dissolved oxygen concentrations are below the lower guideline limit at sites W7, W8, W9 and W10
- faecal coliforms concentrations are higher than primary contact guidelines at all sites sampled
- total nitrogen concentrations are higher than guideline concentrations at sites W11 and W12 and one replicate at site W8
- nitrate and nitrite concentrations are above guideline values for W8, W11 and W12
- total phosphorus concentrations are above guideline levels at all sites
- zinc concentrations were above guidelines at all sites.

It should be noted that sites sampled for Chlorophyll-a had concentrations lower than guideline values. Sampling at the downstream sites commenced after rainfall and may be considered as 'first flush' samples likely to show elevated concentrations.

6.1.3 Hydrology

An analysis and description of river flows at Chichester Dam and at the downstream end of this river reach at Glen Martin, is provided in Sections 2.4.3 and 2.4.2.

6.2 Potential hydrology and water quality issues Reach 3

The construction and operation of the proposed Tillegra Dam may change the downstream river regime and river water quality. 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
- dam construction impacts on water quality, sediment and organic matter mobilisation

Cold water pollution is often associated with large dams which have fixed deep water outlets. A multi-level offtake structure is proposed to control the intake level of releases from the proposed Tillegra Dam. This would facilitate matching (as far as practicable) physico-chemical properties, in particular water temperature, dissolved oxygen and nutrient concentrations of storage water with the existing downstream river. The appropriate level of offtake is described in further detail below.

6.3 Assessment of potential issues in Reach 3

The downstream behaviour of the existing river system would be described with reference to the available data and information on similar systems such as Glennies Creek downstream of Glennies

Creek storage. The likely behaviour of the system, following reduction in flows due to the presence of the dam will be projected from this information and estimates of the change in frequency of flows for the two sets of environmental flow rules estimates.

6.3.1 Hydrology

As noted in Section 2.4.3 Chichester Dam spills for a significant proportion of time and the average flow is similar to the average flow at Tillegra Dam. This suggests that the potential effects of Tillegra Dam on the flow regime would be limited to the reach between Tillegra Dam and the confluence of the Williams and Chichester Rivers.

Further to the representative cross section discussed in Section 3.5.2, the historic percentile exceedence of flow, water height, wetted perimeter and velocity were estimated at sites W7, W8, W9 and Glen Martin. As the median flow downstream of the Williams and Chichester Rivers confluence is approximately 50 per cent greater than in the Williams upstream of the confluence, analysis of sites upstream (W7 and W8) and downstream (W9) of the confluence was undertaken. The rock bar at Glen Martin is a potential barrier to fish passage and analysis was undertaken for this section as well. A summary of the 50th percentile exceedence values at these sites is given in Table 6.2 and full results are shown in Appendix C.

Results show the height above the cease to flow levels in the riffles in the upper reaches is less than 0.2 metres for the majority of the time and less than 0.5 metres for the majority of the time at Glen Martin. These results suggest fish in the Williams River use the regular fresh flow events to migrate up and downstream the river.

TABLE 6.2 50TH PERCENTILE EXCEEDENCE OF FLOW, HEIGHT, WETTED PERIMETER AND VELOCITY

SITE	FLOW (ML/d)	HEIGHT ABOVE BED (m)	WETTED PERIMETER (m)	VELOCITY (m/s)
W7 Riffle	46.5	0.20	5.3	1.00
W7 Pool	46.5	1.63	13.9	0.03
W8 Riffle	46.5	0.15	16.9	0.77
W8 Pool	46.5	0.92	20.4	0.04
W9 Riffle	72.7	0.09	16	0.81
W9 Pool	72.7	0.45	19.4	0.12
Glen Martin Riffle	224.7	0.34	9.2	1.40
Glen Martin Pool	224.7	2.09	39	0.05

6.3.2 Downstream water quality

In recent years, temperature and dissolved oxygen concentrations in discharges from dams have gained increasing prominence in relation to downstream aquatic life, particularly native fish populations. The maintenance of acceptable water quality in releases from the proposed Tillegra Dam, for protection of aquatic life downstream of the dam, depends upon the development of appropriate release strategies.

Management of the releases to meet relevant water quality objectives are proposed to be achieved by release of surface water from the dam. HWC propose to install a multi-level offtake at Tillegra Dam which would enable warmer, well oxygenated surface water to be released to the Williams River. The benefits of this, compared to a water release from the bottom of the reservoir, are assessed in the following sections to demonstrate the benefits to downstream aquatic life.

The key water quality criteria considered to be relevant to demonstrate the benefits of the proposed off-take to downstream aquatic life are temperature, dissolved oxygen and blue green algae.

Lake St Clair has been used as a conceptual model for assessing the expected water quality characteristics in and downstream of the proposed Tillegra Dam. This was undertaken by examination of the vertical distribution of temperature, dissolved oxygen and blue green algae to optimise the water depth at which the offtake would provide acceptable levels of temperature and dissolved oxygen while minimising blue-green algae releases.

The aim of the surface release is to mimic the dam inflow temperatures and dissolved oxygen and to have blue-green algae levels in the river which meet the NH&MRC guidelines for recreational use. These measures are expected to protect downstream aquatic life, including fish-spawning and larval development. This assumes that the biological requirements of the fish and other aquatic life are adapted to the natural seasonal variation in the Williams River temperatures.

Expected water quality releases from Tillegra Dam

Under normal operations, HWC would store water in the dam for release during drought conditions. This means releases will be due to run-of-river transfers, spills and surface water environmental flow releases via the multi-level off take. Expected changes in the Williams River downstream temperature, dissolved oxygen and blue-green algae are based upon dam and river data for Lake St Clair provided by State Water, for Chichester Dam provided by HWC and water quality data collected in the Williams River during this investigation.

DWE have a flow gauging station approximately 1 kilometre downstream from the Glennies Creek Dam as well as an inflow gauge. Releases have been from a depth of 13 metres and cold water pollution has been reported in Glennies Creek (DIPNR, 2004) with a significant reduction in temperature at 1 kilometre below the dam wall. Water temperatures were restored to natural within some 20 kilometres downstream of the dam (Preece, 2004).

To estimate the level of temperature achieved at 1 kilometre downstream of the proposed Tillegra Dam, water quality measurements, including dissolved oxygen, were made in the Williams River at several points upstream and downstream of the proposed dam site during this investigation.

Expected downstream temperatures

As described in Section 5.4.2, Glennies Creek Dam typically stratifies during summer and becomes mixed during winter. The warm surface layer during summer generally extends over 5 to 10 metres. Winter temperatures in this depth range also tend to be warmer than in the deeper waters. It is proposed that surface water from this layer (5-10 metres) would be released.

Temperatures were extracted from the DYRESM model results to highlight the differences between the inflow and storage temperatures at different levels. Figure 6.1 shows the modelled surface water temperature, the temperature at 22.5 metres below FSL and the inflow temperature derived from Glennies Creek and Warragamba Dam inflows.

Surface (epilimnic) temperatures range from about 12 degrees Celsius in July to about 25 degrees Celsius in February. The depth of the thermocline increases as summer progresses, reaching about 20 metres at a maximum. The bottom (hypolimnic) temperatures vary less than the surface temperatures and range from about 11 degrees Celsius for August to approximately 15 degrees Celsius in May.

The natural river temperatures upstream of the dam during summer are about 21 degrees Celsius and are 3 to 4 degrees Celsius cooler than the dam surface water but similar to that in the 5 to 10 metres depth range (refer Figure 5.2). During winter, the upstream temperatures are about 9 to 13 degrees Celsius and about 2 degrees Celsius cooler than in the dam surface waters.

Some confirmation that the Glennies Creek temperatures can be applied to the Tillegra Dam site is provided by the water quality sampling undertaken in this investigation from 26 November 2007 to 4 December 2007. Results of 17.1 degrees Celsius on 26 November for upstream of Tillegra were similar to the 17.0 degrees Celsius measured upstream of Glennies Creek Dam on the same date. Sampling at the proposed Tillegra Dam site a few days later from 3 and 4 December, indicated at rapid rise in temperature to 22.4 to 24.1 degrees Celsius. The Glennies Creek upstream temperatures also increased to 22.1 to 23.7 degrees Celsius on those days.

A release from the 5 to 10 metres depth range should not cause a significant effect on the downstream temperatures or on the spawning success of fish in the Williams River.

Expected downstream dissolved oxygen

Dissolved oxygen profiles for Glennies Creek are described and presented in Section 5.4.2. Concentrations in the waters above the thermocline meet the ANZECC (2000) guidelines of 80 per cent to 110 per cent saturation in the thermally mixed surface layers to about 8m depth. Measurements collected during this investigation upstream and at the Tillegra Dam site showed similar concentrations of 76 per cent to 88 per cent saturation in November and December 2007.

The Lake St Clair profiles and CAEDYM model results for the proposed Tillegra Dam Storage show a decrease in dissolved oxygen with depth, even during winter. To mitigate these effects it is proposed that surface releases from the dam be facilitated by the intake infrastructure. The available water quality data indicates a release from the 5 to 8 metre depth range in Tillegra Dam would be expected to give similar downstream dissolved oxygen concentrations as presently occur upstream of the dam. During the short period of well mixed conditions in July/August releases from any depth would provide similar quality water to the inflow quality.

Expected downstream blue-green algae concentrations

To determine the depth at which releases could be expected to avoid significant releases of blue-green algae to the Williams River, profiles of blue-green algae in Chichester Dam were examined (Section 5.4.3). The criteria for selection of the depth, was to avoid releases above the NH&MRC recreational guidelines of 50,000 cells per millilitre. At Chichester Dam the 50,000 cells per millilitre essentially occurs above 6 metres depth. Similar concentrations at depth are expected at Tillegra Dam as indicated by the water quality model results (refer Figure 5.3).

Release depth

From the above examination of the available profile data, releases of acceptable levels of temperature and dissolved oxygen, as well as blue-green algae to meet the NH&MRC guidelines is expected to be achieved by a multi-level intake structure set at around 6 to 8 metres below the surface most of the year.

The intake level should be designed with a rapid level adjustment to facilitate a quick response to any event based adverse environmental conditions within the storage and thereby minimise impacts on release water quality. A monitoring program would also be required to provide information on vertical variability to assist with selection of the appropriate withdrawal depth at the offtake structure.

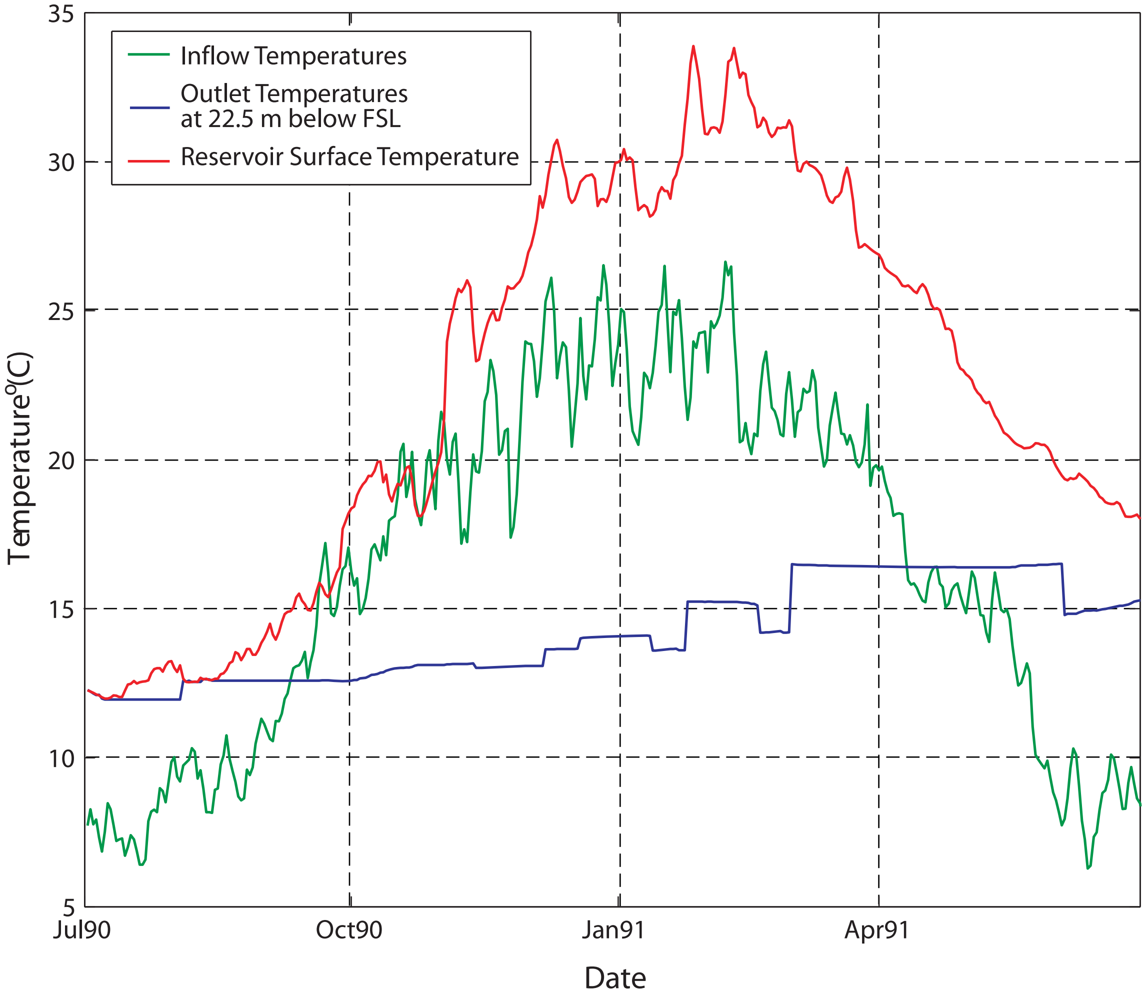


FIGURE 6.1 MODELLED SURFACE WATER TEMPERATURE, TEMPERATURE AT 22.5 METRES BELOW FSL AND INFLOW TEMPERATURE

Summary of assessment of effects

The assessment of release depth is based on existing State Water, HWC water quality data and preliminary modelling to examine likely vertical variability within the proposed Tillegra Dam storage and suggest optimal intake depth for releases to the Williams River. The optimisation of downstream temperature, dissolved oxygen and blue-green algae releases of water from the dam via the multi-level intake associated with this proposal involved:

- historical variations in temperature and DO downstream of the Glennies Creek Dam
- Williams River water quality measurements
- profiles of temperature and DO in the Glennies Creek storage (Lake St Clair)
- bue-green algae profiles in Chichester Dam storage
- blue green algae model results.

The proposed multi-level intake depth is expected to allow the Tillegra Dam water release strategy to mimic inflow temperatures and dissolved oxygen while meeting the blue-green algae recreational guidelines in the Williams River. 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.

6.4 Potential mitigation measures for Reach 3

The controlled release of water from the dam would form an important component for conservation of downstream aquatic ecosystems. As highlighted above release of surface waters for most of the year coupled with an ability to adjust levels to react to events is an appropriate way to mitigate the effects of in-storage water quality stratification on the downstream environment.

7. Seaham Weir Pool

The following section characterises the existing Seaham Weir Pool which extends from Glen Martin to Seaham Weir, and identifies and assesses the potential water quality and hydrology issues associated with dam construction and operation for this reach of the Williams River.

7.1 Characterisation of existing Reach 4

7.1.1 Topography

The 23 kilometre reach of river from Glen Martin to Seaham Weir, known as the Seaham Weir Pool originally formed the freshwater pool of the tidal estuary prior to construction of Seaham Weir in the 1960s (refer Table 7.1). The approximate bed topography upstream and downstream of Seaham Weir is shown in Figure 7.1.

The volume and surface area of Seaham Weir pool versus depth in the pool is provided in Figure 7.2. At mean sea level (0 metres AHD) the pool volume is about 9,600 megalitres increasing to 12,100 megalitres at 1 metre AHD.

Table 7.1 Characterisation of Reach 4 – Seaham Weir Pool

Average bed slope	0.03 per cent
Length of river reach	23 kilometres
Number of pool/riffle sequences	1 long pool, no riffles, depths 10-22m
Average length of pool/riffle sequence	Seaham Weir Pool is a continuous stretch of water

The weir pool is fed by the upper Williams River and a significant local catchment (96 square kilometres). Water is extracted from the pool by licensed farmers adjoining the pool and Hunter Water via the Balickera Canal inlet located near the weir at Seaham.

7.1.2 Water quality

Water quality in the pool is affected by the inflows, and internal processes such as thermal stratification during low flow periods in the warmer months. The Seaham Weir Pool regularly experiences outbreaks of blue-green algae during the spring and summer when temperatures are

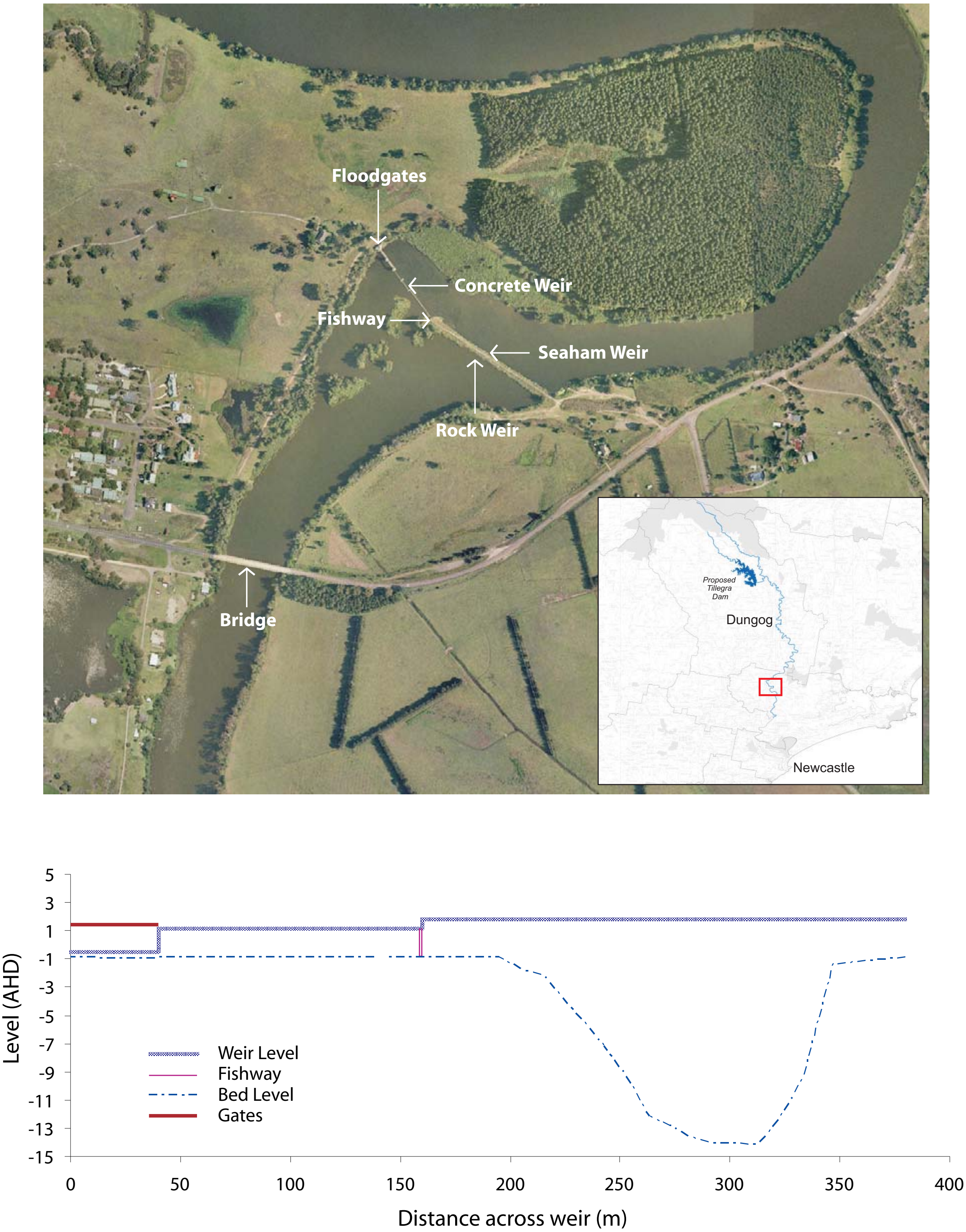


FIGURE 7.1 SEAHAM WEIR AND APPROXIMATE BED LEVEL UP AND DOWN STREAM CROSS SECTION

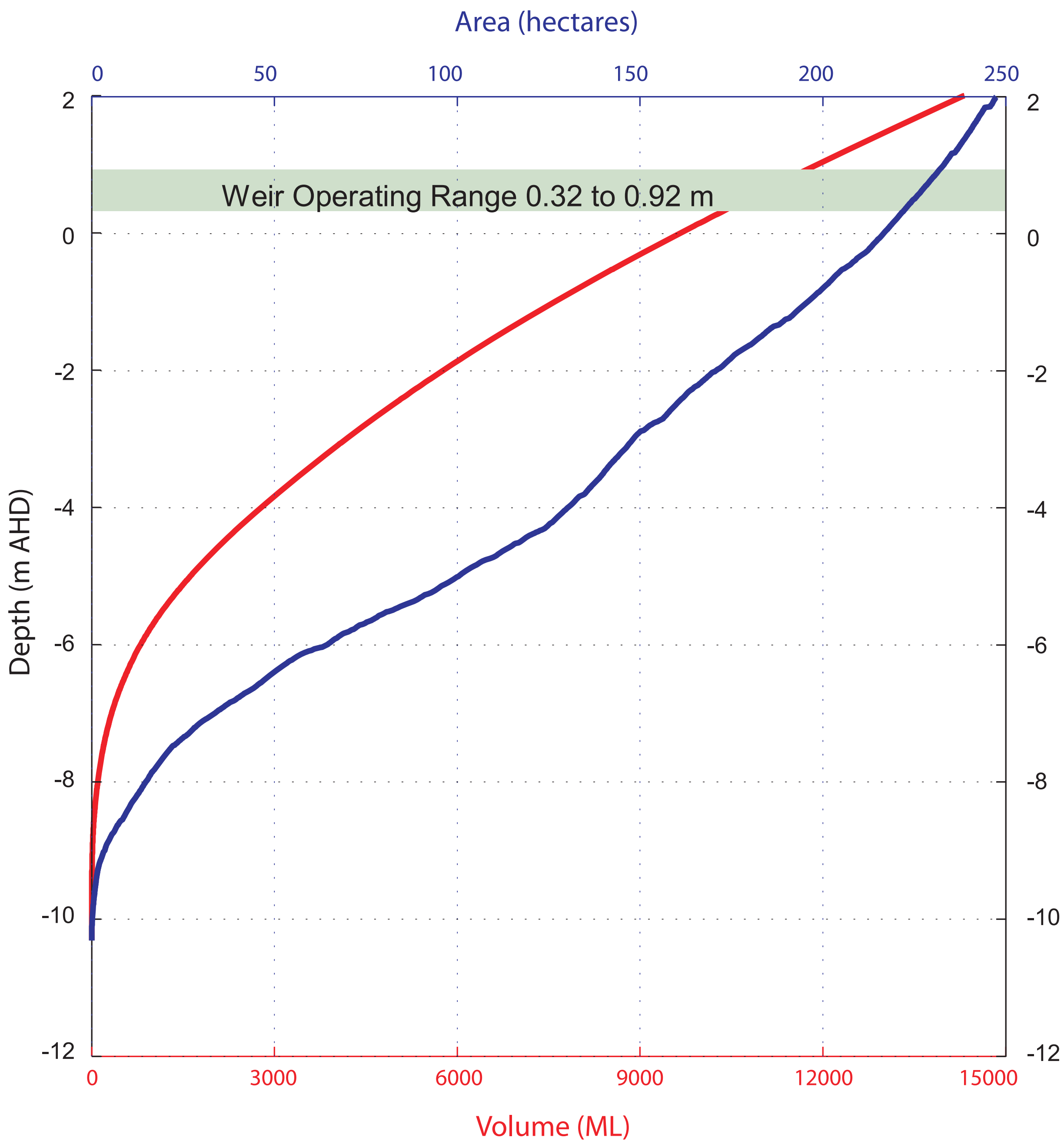


FIGURE 7.2 SEAHAM WEIR POOL VOLUME AND SURFACE AREA VERSES DEPTH

high and flows are decreased. These outbreaks are well documented with a number of continuous studies undertaken by Hunter Water at Boags Hill (measured from 1992) and at Clarencetown (measured from 2004). Analysis of blue-green algae data collected at Boags Hill showed only a low frequency of exceedence (less than 1 per cent of the time) of the total cell count guideline of 50,000 cells per millilitre.

Cole (1999) undertook a study to determine the feasibility of artificially mixing Seaham Weir Pool to control blue-green algae blooms. Based on a review of current information, field studies, scientific literature and expert advice, artificial mixing of Seaham Weir Pool would not be cost effective. The report summarises the current Seaham Weir Pool conditions and presents: routine temperature and dissolved oxygen data collected by HWC (1993 to 1997), a profiling run along the weir pool undertaken in April 1998, and a profiling run undertaken in January 1995. The following observations are noted regarding these data sets:

- routine data collected by HWC (1993-1997) can be used as a guide to show general temperature variations, however, there appears to be insufficient resolution to highlight any seasonal stratification issues
- the profiling run in 1998 highlights the longitudinal temperature and dissolved oxygen gradient in Seaham Weir Pool, however, profiles do not show a stratified system
- the profiling run in 1995 shows stratification of the water body at the time of sampling.

Water quality sampling was undertaken in Seaham Weir Pool as part of the current investigation and was measured at Boags Hill inlet in December 2007 following reasonably high flow (refer Figure 3.2). Profile physico-chemical measurements were taken every half meter down the water column and water samples were collected at the surface and bottom. Results are tabulated in Appendix B. Water quality results along with comparisons against ANZECC guidelines are also displayed in Appendix B.

When compared against ANZECC guidelines and the following exceptions were noted:

- conductivity concentrations are above guidelines levels throughout the water column
- dissolved oxygen concentrations were below the guideline limit throughout the water column
- surface waters contained elevated levels of chlorophyll-a
- nitrogen, nitrate and nitrite concentrations are above guideline values for bottom waters
- total phosphorus concentrations are above guideline values for surface and bottom waters
- zinc levels were elevated in the surface and bottom waters.

Results obtained are consistent with previous investigations showing temperature and dissolved oxygen stratification (refer Table 7.2) and high chlorophyll-a concentrations.

TABLE 7.2 DIFFERENCE BETWEEN SURFACE (0.5METRE DEPTH) AND BOTTOM WATERS (8METRE DEPTH)

VARIABLE	SURFACE	BOTTOM	DIFFERENCE
Temperature (°C)	26.45	19.84	6.61
Conductivity (mS/cm)	0.214	0.277	-0.063
Salinity (ppt)	0.1	0.13	-0.03
pH	7.26	7.09	0.17
ORP	450	125	325
DO (%sat'n)	72.8	0.9	71.9
DO (mg/L)	5.8	0.1	5.7
Turbidity (ntu)	4.73	13.13	-8.4

7.1.3 Stratification

The level of stratification and its persistence in Seaham Weir Pool is influenced by a) thermal heating of the surface waters resulting in temperature stratification and cooling leading to vertical mixing, and b) river flows which induce turbulent mixing. Stratification within the weir pool would start to develop in spring as surface waters heat and river flows decrease. Stratification of the water body would weaken with inflow events and as surface waters begin to cool in autumn.

Results from previous studies as detailed in Section 7.1.2, provide further information on stratification at select times throughout the year. The results are summarised in Table 7.2 and displayed in Figures 7.3 to 7.5.

These examples illustrate the complex nature of the processes leading to the development and break down of stratification within the long pool. It is important to consider the persistence and magnitude of stratification that would impact on the volume of flow required to break down the stratification. Profiles collected in January 2005 and December 2007 remained stratified after significant river flow as preceding conditions of the low flows and high surface heat input lead to a strong stratification. As in the deep Tillegra Dam storage the residence time of deep waters in Seaham Weir Pool would be affected by thermal stratification.

TABLE 7.3 STRATIFICATION OF SEAHAM WEIR

PROFILE DATE (SOURCE)	WATER BODY CONDITION	FLOW CONDITIONS	COMMENT	FIGURE NUMBER
11 January 1995 (Cole 1999)	Stratified	High Flow (>MLday)	• Temperature differences up to 3 to 4 degrees from surface to bottom • DO levels at 30 per cent in bottom waters	7.3
7 April 1998 (Cole 1999)	Cooling	Low flow (<ML/day)	• Temperature differences up to 0.6 degrees from surface to bottom • DO levels at 50 per cent in bottom waters	7.4
5 Dec 2007 (This study)	Stratified	High flow (>1000ML/day)	• Temperature differences up to 6.6 degrees from surface to bottom • DO levels at <1 per cent in bottom waters	7.5

7.1.4 Hydrology

Flows entering Seaham Weir Pool can be estimated as the flow past Glen Martin. Analysis of this flow data is provided in Section 2.4.2.

7.1.5 Flushing of weir pool

The fresh water flushing time for the Seaham Weir Pool may be estimated as the time required for the discharge to replace the pool volume (10,700 megalitres at 0.5 metres AHD). At low flows (<90th percentile exceedence) pool flushing time is greater than 30 days. This estimate assumes the pool is well mixed. Under stratified conditions in spring and summer the warmer inflows are likely to flow through the pool as a surface layer and exit though the pool as a surface discharge over Seaham Weir

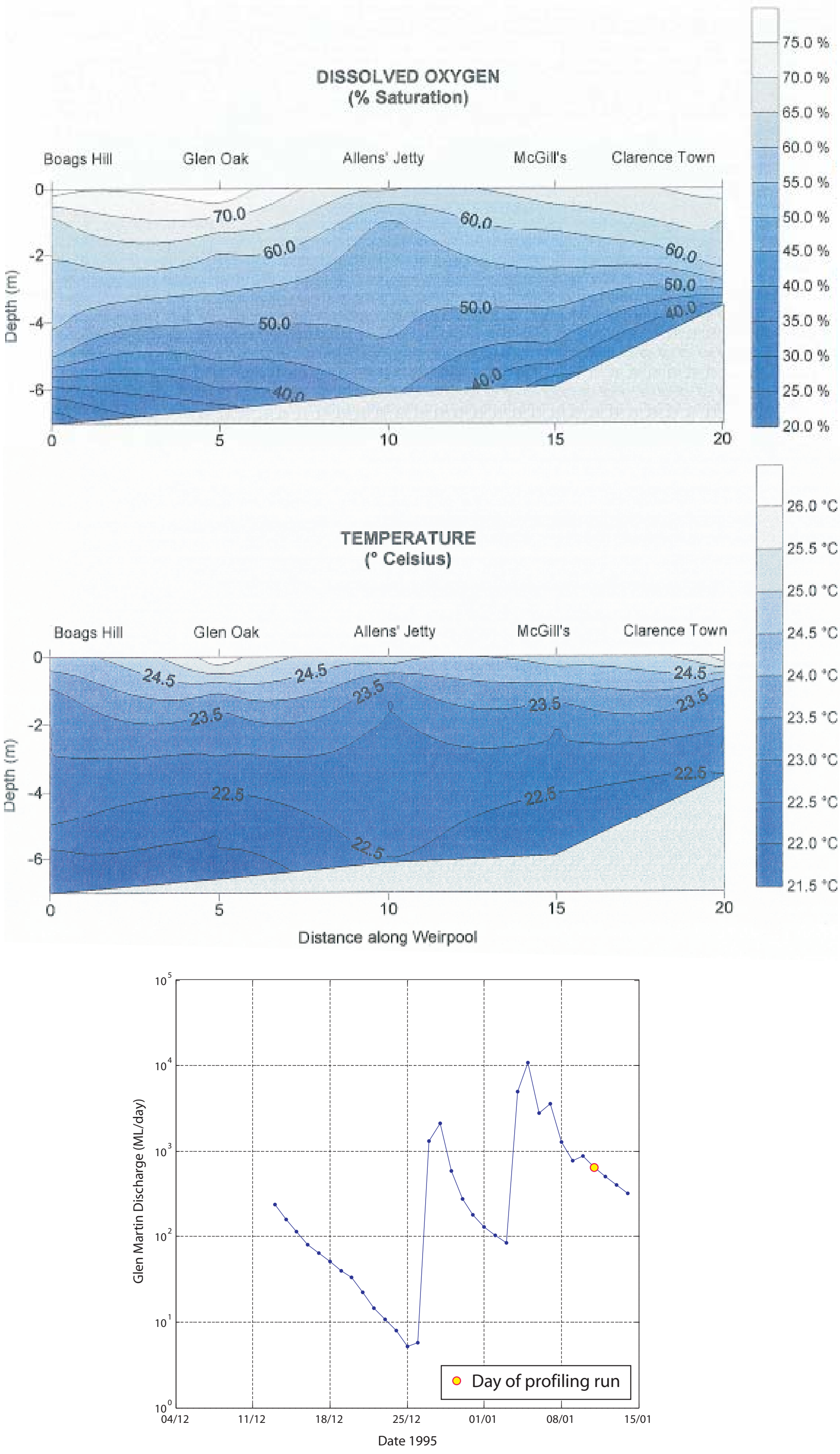


FIGURE 7.3 DISSOLVED OXYGEN AND TEMPERATURE CONTOURS ALONG SEAHAM WEIR POOL JANUARY 1995

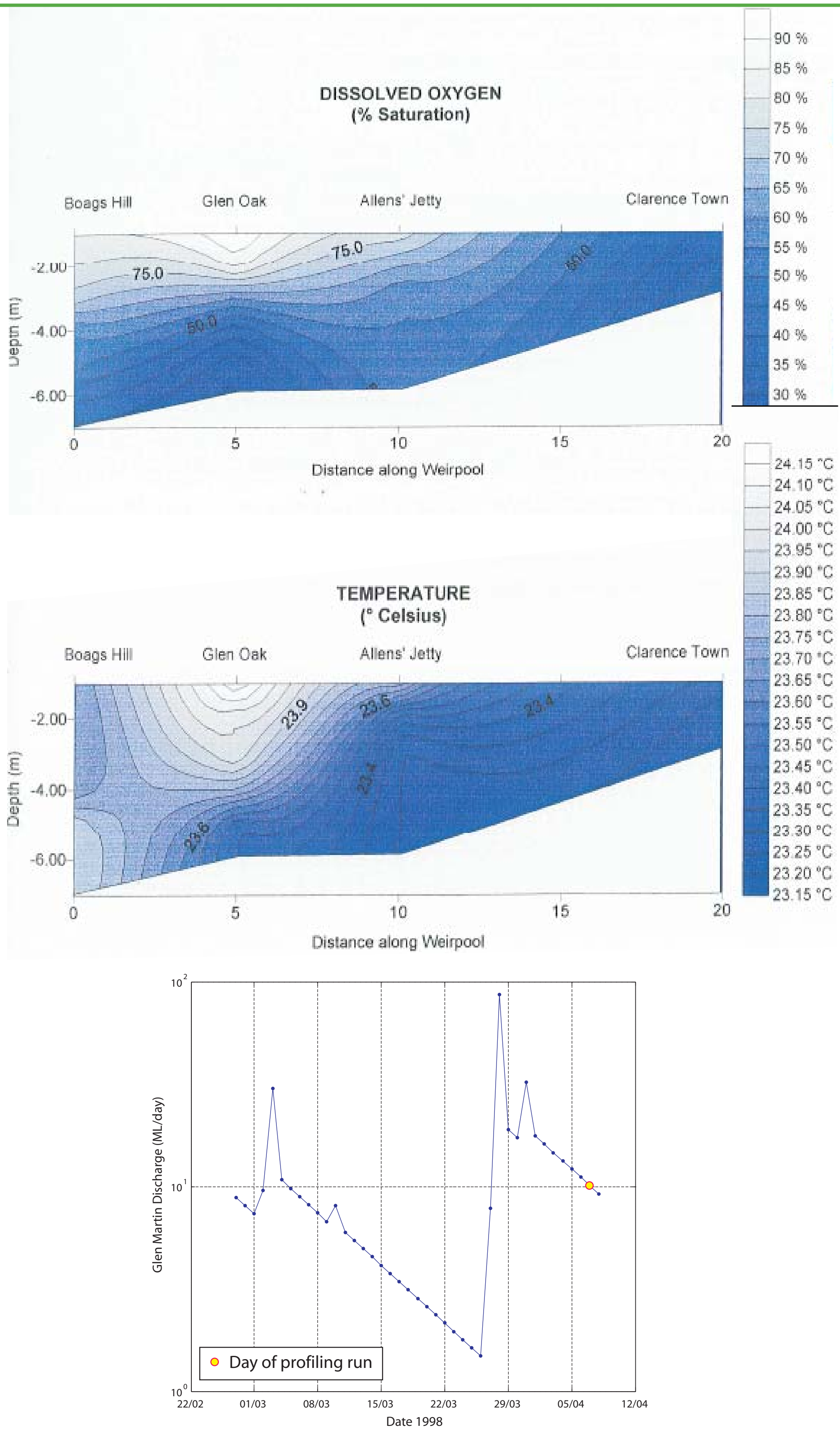


FIGURE 7.4 DISSOLVED OXYGEN AND TEMPERATURE CONTOURS ALONG SEAHAM WEIR POOL APRIL 1998

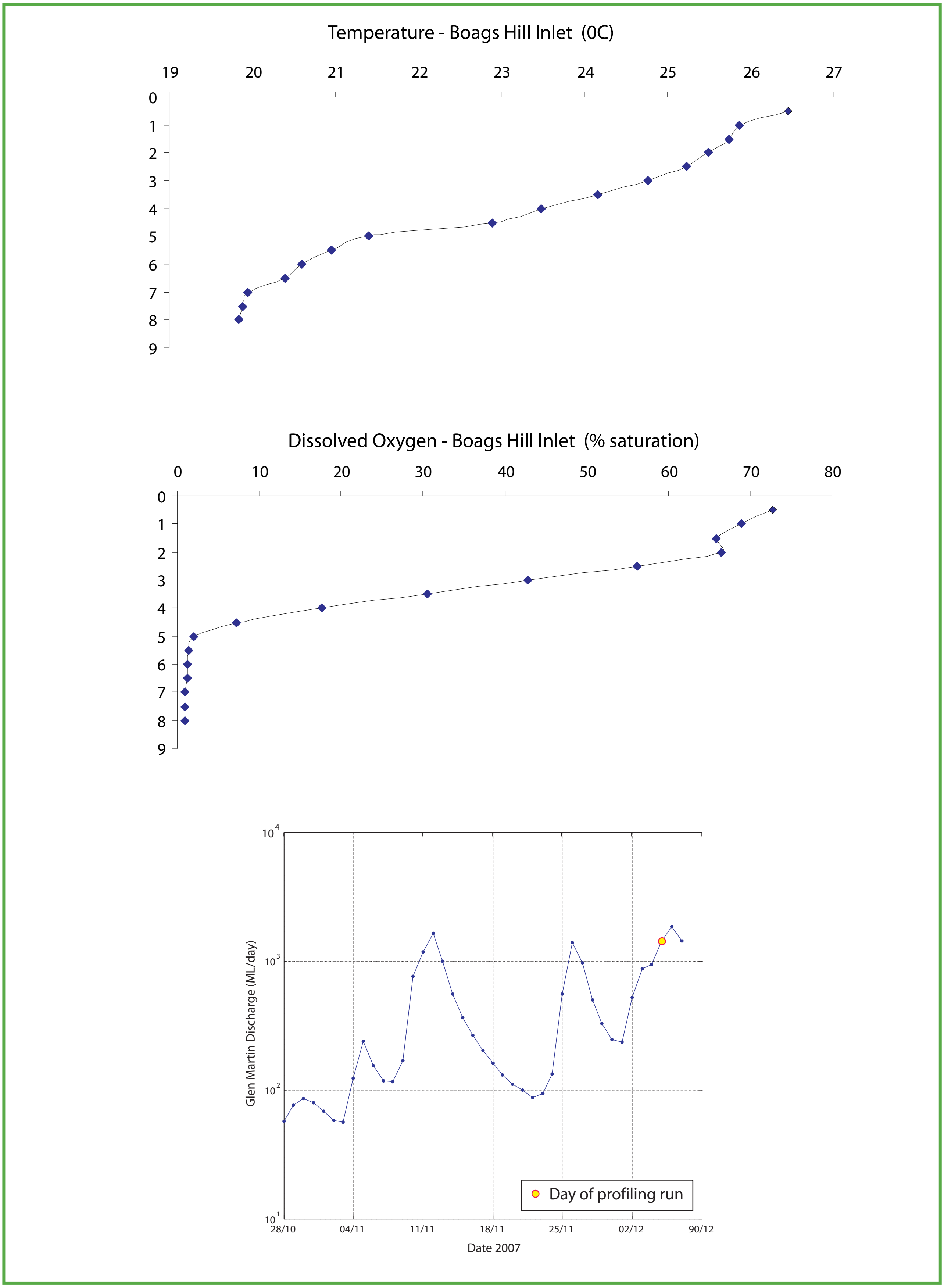


FIGURE 7.5 DISSOLVED OXYGEN AND TEMPERATURE PROFILES AT BOAGS HILL INLET DECEMBER 2007

or at Balickera Canal. Deeper water may remain stagnant for prolonged periods until the next reasonable fresh event flushes the pool. Water quality of the deeper waters gradually declines during these low flow periods in spring/summer. Cooling of the river waters during Autumn and Winter causes convective mixing to efficiently mix the surface and deep waters on a regular basis and the issues associated with stratification are less likely to occur during these seasons.

7.2 Potential hydrology and water quality issues Reach 4

A number of water quality issues already exist within Seaham Weir Pool and it is expected the issues may be exacerbated if flows into the weir pool are reduced further without the inclusion of flushing events. The potential water quality issues may include:

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

7.3 Assessment of potential issues in Reach 4

As the flows entering the Seaham Weir following dam construction are only reduced by about 10 per cent it is likely that the effects on Seaham Weir Pool water quality will be negligible. Further transfers during low flow periods may lead to improvements in water quality.

8. Seaham Weir to Hunter River confluence

The following section characterises the existing Williams River Estuary which extends from the Seaham Weir to its confluence with the Hunter River. The section identifies and assesses the potential water quality and hydrology issues associated with dam construction and operation for this reach of the Williams River.

8.1 Characterisation of existing Reach 5

8.1.1 Topography

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 6 metres deep with a series of slightly deeper sections with the deepest of 14 metres near the weir. The approximate bed topography upstream and downstream of Seaham Weir is shown in Figure 7.1.

8.1.2 Water quality

An investigation by Sanderson *et al* (2002) looked at the salinity structure in the Hunter River Estuary measuring the influence of the neap-spring cycle and fresh water inflow on the distribution of salt in the estuary. As part of the Hunter River Estuary Processes (Manly Hydraulics Laboratory 2003) vertical profiles were collected in the Hunter River on 23 days in 2001 and in the Williams River on eight of these occasions. Vertically averaged salinities and along estuary gradients were estimated for the Hunter and Williams River estuaries. The salinity gradient for the Williams estuary was estimated as –2.04±0.2 ppt/km for an inflow of 25 megalitres per day at Seaham Weir.

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.

During the reconnaissance trip the expert panel looked at the likely habitat value of flora and fauna of the Williams Estuary. The panel comprised many members including Dr Brian Sanderson who looked specifically at the estuarine physical processes (Sanderson 2008). Water quality profiles were collected at seven irregularly scattered stations in the Williams Estuary on 12 October 2005. The following findings were noted:

- compared to the Hunter River, vertical stratification is much higher relative to along channel gradients as a result of the weir which reduces tidal currents and hence vertical mixing
- near Seaham weir vertical temperature gradients play an important role stratifying the water column
- the e-folding depth of light intensity (attenuation coefficient) is about 0.7 metres
- at depth, and immediately downstream of the weir, oxygen levels are too low to support fish
- near surface chlorophyll-a is high throughout the Williams River downstream of Seaham Weir
- turbidity of near surface water falls progressively upstream
- the density difference between surface and deep water was about 2-3 kg/m^3 near the mouth of the Williams River and about 1 kg/m^3 a short distance downstream of the weir.
- it is unlikely releases of 200 megalitres per day will maintain freshwater downstream of the weir during drought conditions given the 9 gigalitre volume of the Williams River downstream of the weir.

As a second component to the Expert Panel review, an estuary water quality monitoring program was undertaken in October 2005 to investigate the interaction between releases from Seaham Weir and responses in the river system downstream (Sinclair Knight Merz 2005).

Monitoring of a range of physical parameters was undertaken on six occasions over 14 days at 18 sites, located at regular intervals downstream of the weir for a total distance of 14 kilometres (confluence with the Hunter River). Water quality profiles of temperature, dissolved oxygen, pH and salinity were taken through the water column from 0.5 metres below the surface to the bottom at 1 metre depth intervals. Results of the study are shown in Figure 8.1 (pre weir opening) and Figure 8.2 (post weir opening).

Study results indicated 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. Key findings from the study are:

- 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 megalitres does not appear sufficient to fully mix the water column immediately downstream of the weir.
- consecutive large flows (>600 megalitres) 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.

Figure 8.3 shows the tide level as recorded at Seaham Road Bridge (approximately 500 metres downstream of the weir) and releases from the weir as detailed in the Sinclair Knight Merz (2005) study are shown in the figure along with sampling dates. This figure and the profiling results (Figures 8.1 and 8.2) highlight the complex nature of the system with tidal flows and freshwater releases affecting mixing and water quality.

8.1.3 Hydrology

HWC undertook a hydrology study at Seaham Weir in 2006 (HWC 2006b) to determine the component flows into and out of the weir pool. Flow components were estimated as follows:

- the average controlled gate outflow is 127 megalitres per hour, with all calculated outflows occuring in a relatively narrow range of 100 to 144 megalitres per day. The average length of opening is 1.35 hours and the average discharge per event is 172 megalitres. Essentially releases are short pulse flows occurring during ebbing tides.
- peak fishway outflow was calculated to be 12.5 megalitres per day at low tide and peak reverse flow up to 25 megalitres per day at the month maximum tide. Reverse flow occurs only for a relatively short portion for each day, with a net positive outflow occurring on each day ranging from 1 to 7.5 megalitres per day. Average daily outflow over the month was calculated to be 5 megalitres per day.
- the average pan evaporation, as recorded at the George Schroder Pump Station, is around 143 mm/month equating to an average evaporative loss of about 9 megalitres per day from the weir pool over the year.
- the model water balance indicated additional losses (possibly weir leakage, farm usage and/or base flow losses) was calculated to be 5 megalitres per day.

An assessment of HWC existing operations on flow to the estuary was also undertaken for the period 1 January 1999 to 30 September 2005. Figure 8.4 reproduces model results as shown in the HWC hydrology report (HWC 2006b). The top plot of Figure 8.4 displays a 6.5 week period from 01 June 2005 to 13 July 2005 while the second plot zooms in on the period circled in the top plot. Natural flow to the estuary (orange line) is assumed to be inflow less evaporation from the length the weir pool. The natural flows across the entire study period vary from zero to nearly 70,000 megalitres per day. Modified flow to the estuary (green lines) is assumed to be gate releases, flow through the fishway, uncontrolled gate releases and other losses. Modified flows across the entire study period range from 0 to around 55,000 megalitres per day. Discrete gate operations over a range of river flow conditions can be seen in Figure 8.4. Weir outflow is around 10 megalitres per day when the gates are closed and up to 3,000 megalitres per day for the brief periods of time the gates are open.

It should be noted the flow estimates have not addressed catchment inflows from the Seaham Weir catchment and have not addressed the impact of downstream tide levels on flow to the weir pool during extreme high tides.

The daily probability distribution of weir pool outflows under two scenarios (with and without HWC extraction) is presented in Figure 8.5 calculated from daily flow records from 1 January 1999 to 30 September 2005. The figure highlights the impact of gate operation on downstream river flow with a distinct step between the days with and without gate openings. As part of the current assessment, 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 8.1.

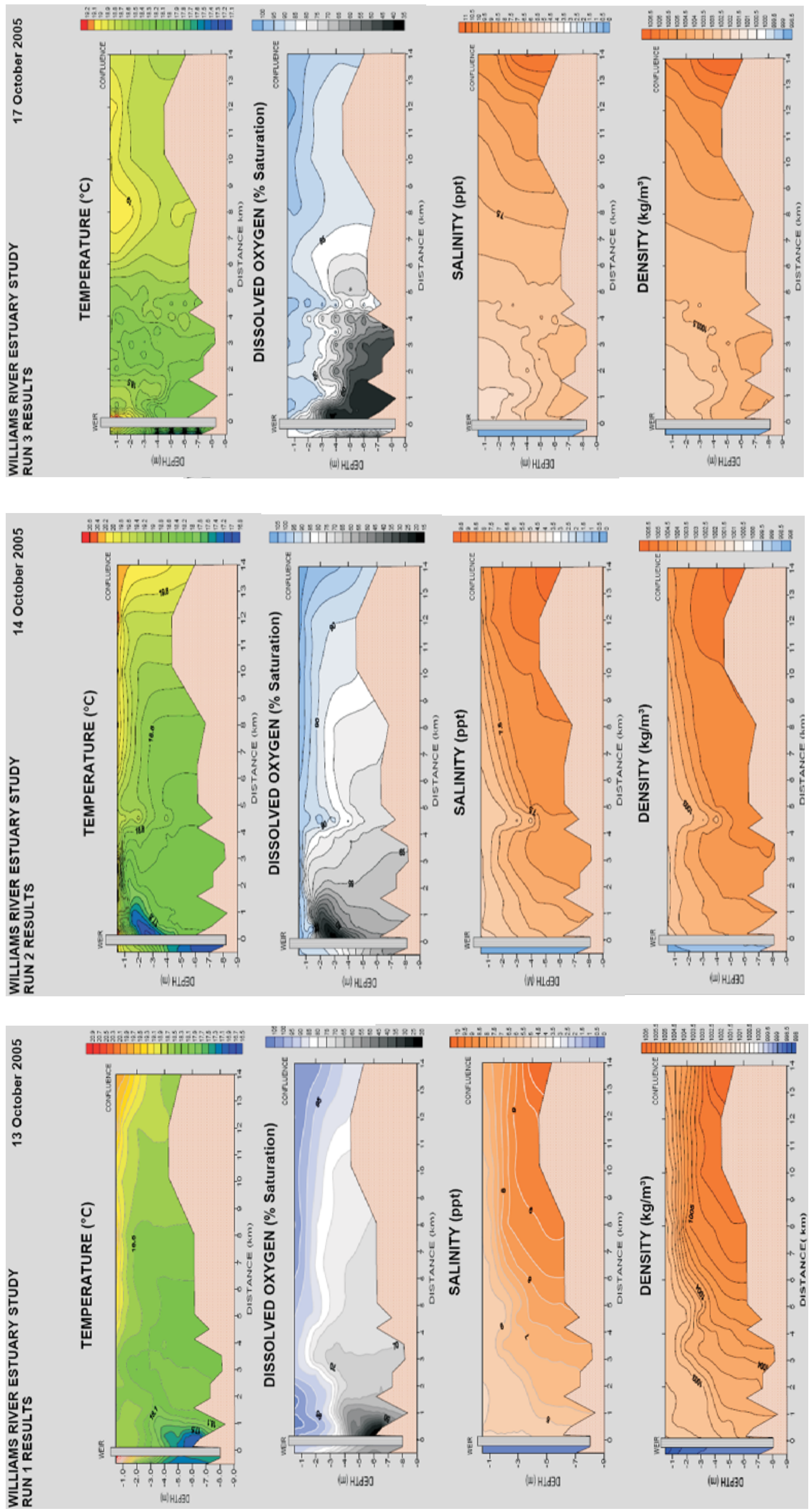


FIGURE 8.1 TEMPERATURE, DISSLOVED OXYGEN, SALINITY AND DENSITY PROFILING RESULTS OCTOBER 2005 (SOURCE SKM 2005)

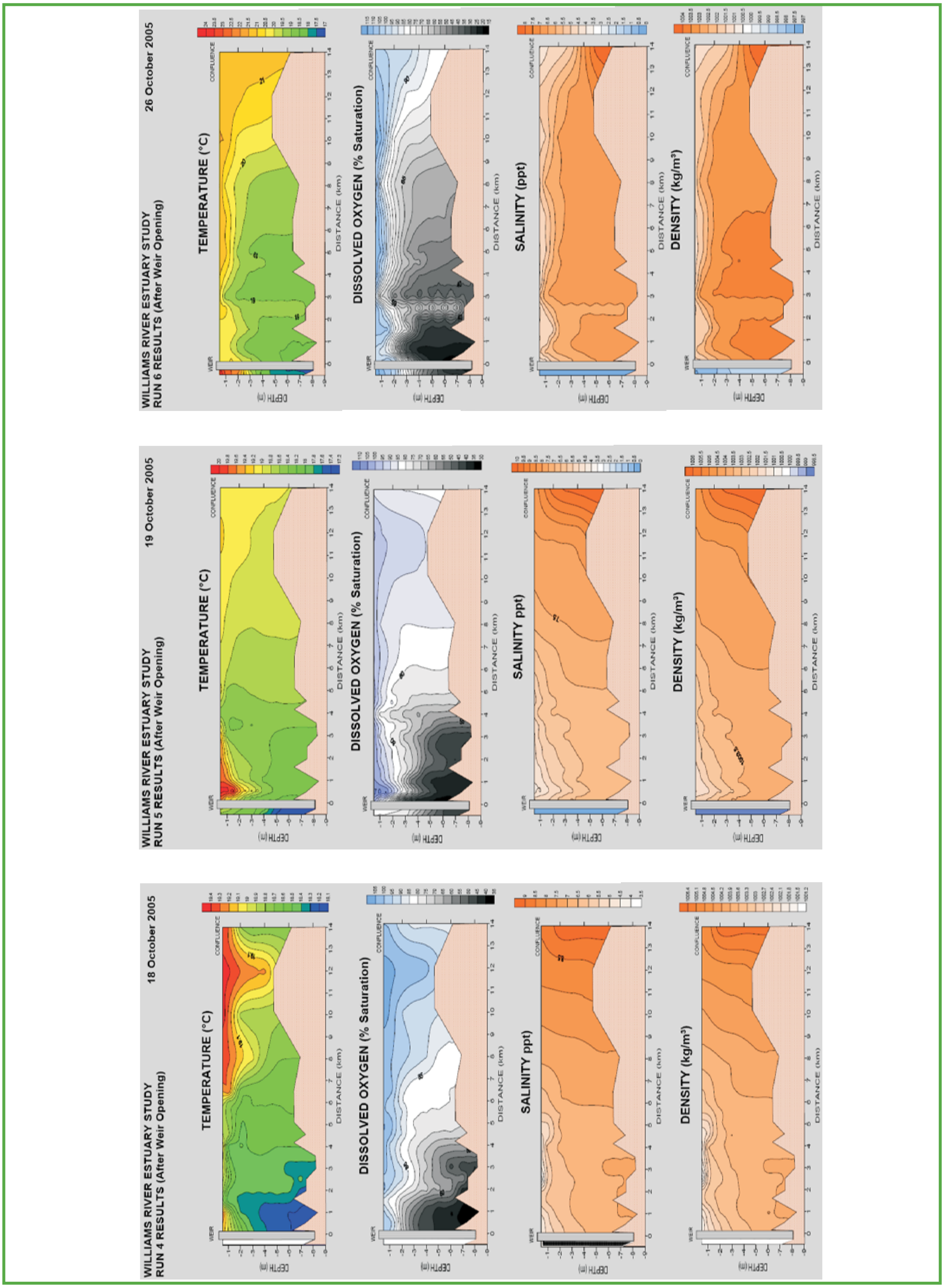


FIGURE 8.2 TEMPERATURE, DISSLOVED OXYGEN, SALINITY AND DENSITY PROFILING RESULTS OCTOBER 2005 (SOURCE SKM 2005)

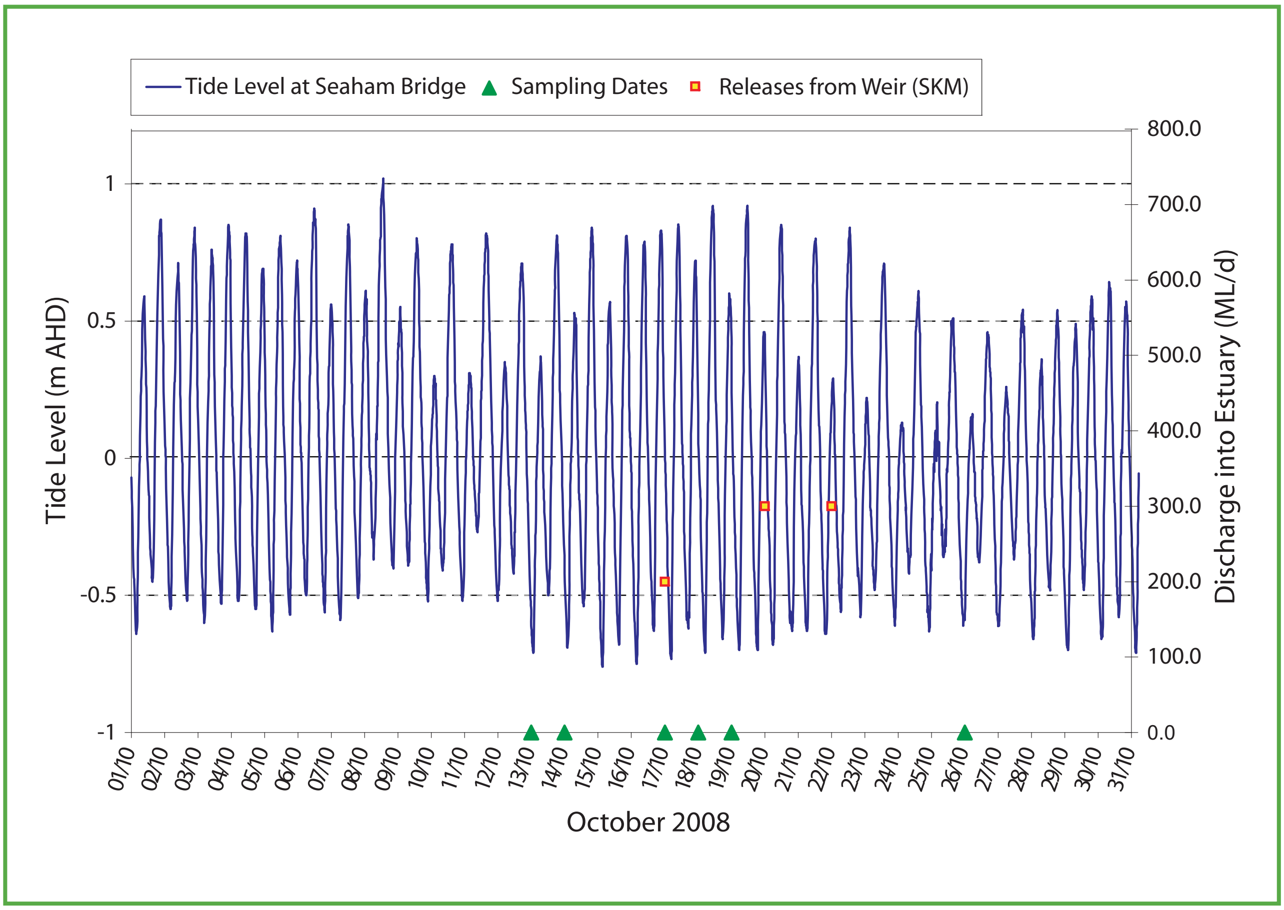
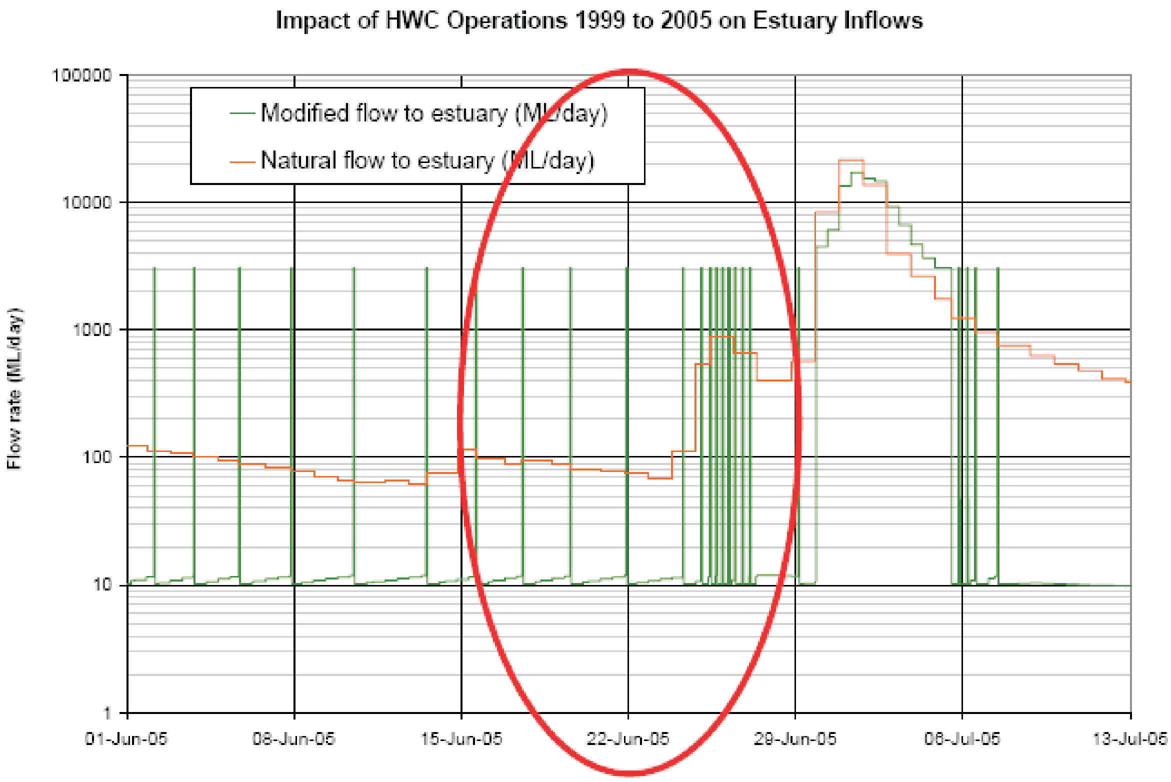


FIGURE 8.3 WILLIAMS RIVER ESTUARY TIDE LEVEL, RELEASES FROM SEAHAM WEIR AND SAMPLING DATA



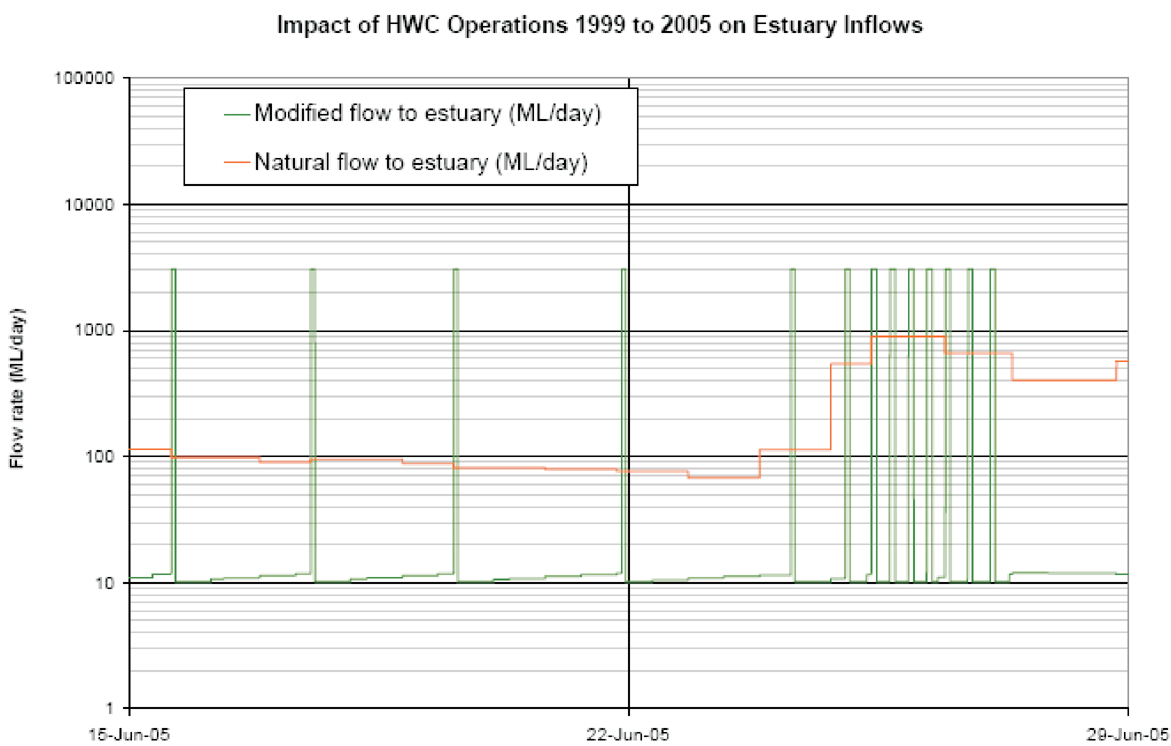


FIGURE 8.4 SEAHAM WEIR MODEL RESULTS (SOURCE HWC, 2006

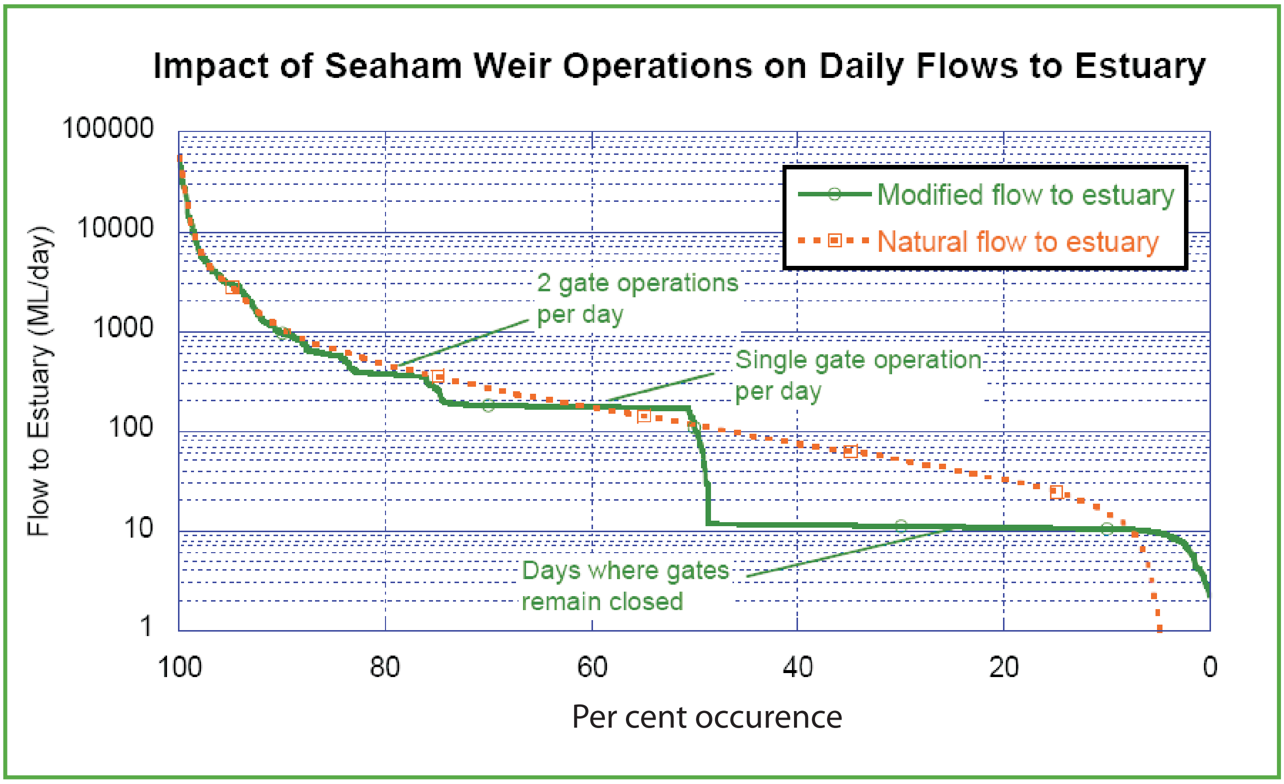


FIGURE 8.5 FLOW DURATION CURVE OF DAILY OUTFLOWS FROM SEAHAM WEIR (SOURCE HWC, 2006)

TABLE 8.1 STATISTICAL ANALYSIS OF SEAHAM WEIR FLOWS ML/D (1 JANUARY 1999 TO 12 FEBRUARY 2005)

STATISTIC	ALL DATA	SUMMER	AUTUMN	WINTER	SPRING
Minimum	2	2	10	10	2
95th percentile exceedence	9	8	11	10	6
90th percentile exceedence	10	9	11	11	10
80th percentile exceedence	11	11	22	11	10
50th percentile exceedence	173	165	316	174	11
20th percentile exceedence	394	366	1085	353	182
10th percentile exceedence	1008	606	3243	692	592
5th percentile exceedence	3027	1144	8919	1679	1387
Maximum	54554	5994	54554	31261	10365

These analyses show that close to 50 per cent of the time flow passing Seaham Weir is around 10 megalitres per day. The low flow estimate of around 10 megalitres per day comprises a component of flow through the fishway (~5 megalitres per day) and an additional ~5 megalitres per day derived as a loss from the weir. It is assumed that this loss actually flows over or through the weir pool. During the spring and summer months, when thermal heating is greatest, low flows passing the weir occur more than 20 per cent of the time. 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.

Statistical analysis was undertaken on Glen Martin flows for the period 1 January 1999 to 12 February 2005 to provide a long term context (1931-1977) of the estimates of flows past Seaham Weir. Statistics for Glen Martin 1999-2005 are shown in Table 8.2 and the long term statistics are shown in Table 2.4. The

TABLE 8.2 STATISTICAL ANALYSIS OF GLEN MARTIN ML/D (1 JAN 1999 TO 12 FEB 2005)

STATISTIC	ALL DATA	SUMMER	AUTUMN	WINTER	SPRING
Minimum	1.0	1.1	25.0	15.3	1.0
95th percentile exceedence	9.7	5.0	41.0	30.1	5.4
90th percentile exceedence	23.2	9.9	54.7	41.3	9.6
80th percentile exceedence	38.3	26.3	83.0	53.9	22.6
50th percentile exceedence	114.8	101.0	272.2	111.1	51.9
20th percentile exceedence	450.5	325.6	1017.4	319.3	223.6
10th percentile exceedence	938.4	572.2	2536.4	690.2	554.9
5th percentile exceedence	2096.6	1113.1	4990.1	1438.2	1209.8
Maximum	81905.9	10134.1	81905.9	55399.3	16132.3

statistics show that the 1999-2005 period experienced reduced flood flows. In the long term it is expected the estuary would receive more frequent flood flows and an increased occurrence of low flow.

8.2 Potential hydrology and water quality issues Reach 5

Downstream of Seaham Weir, reduced flows could lead to an increased number of days of saline ingress from the Hunter River estuary. The preliminary results from the hydrology model indicate there is relatively small change in the flow at Glen Martin. Assuming this low impact on flows also applies downstream then the estuarine salinity regime is expected to remain similar to existing conditions. Previous work in the estuary indicates the estuarine reach is strongly stratified by salt and temperature in the warmer months, particularly during periods of low river flow. In the following section an analysis of the relationship between flow past Seaham Weir and the salinity regime in the Williams River estuary below the weir provides an assessment of the likely impact of the dam on estuarine salinity.

8.3 Assessment of potential issues in Reach 5

The physical estuarine processes that determine transport and mixing within an estuary are complex. The transport and mixing processes within the Williams River Estuary are determined by physical form, tidal mixing, wind mixing, surface heating and cooling and freshwater flow. The prevailing and antecedent climatic conditions are extremely important in determining the salinity structure within an estuary.

8.3.1 Freshwater flows

The depth average salinity in the estuary is determined by a balance between downstream transport of salt by freshwater inflow events and upstream transport by tidal mixing, a reduction in freshwater flow by approximating 10 per cent will result in a small increase in the salinity near Seaham Weir.

A reduction in the volume of freshwater flow in the Williams River downstream of Seaham Weir would have marginal impact on salinity concentrations beyond the confluence of the Williams and Hunter River. Sanderson and Redden (2001) determined the median freshwater flow of the Hunter, Paterson and Williams rivers over 25 years as 716 megalitres per day. The median flow past Seaham Weir, as estimated by Hunter Water is 173 megalitres per day. The tidal prism of the Hunter River immediately downstream of the Williams River confluence is around 5,300 megalitres per day (Manly Hydraulics Laboratory 2003). As the freshwater flow from the Williams River accounts for less than 3 per cent of the total volume of water below the confluence of the Williams and Hunter Rivers the potential impact on salinity concentrations below the confluence of the rivers is expected to be negligible.

8.3.2 Tidal flows

The approximate bed level from Seaham Weir to the confluence of the Williams and Hunter River's, is depicted in Figure 8.6. The tidal prism, velocity and tidal excursion for the spring and neap tides were estimated at five points along the estuary and results are listed in Table 8.3 with the tidal excursion displayed in Figure 8.6.

TABLE 8.3 TIDAL PRISM, AVERAGE VELOCITY AND TIDAL EXCURSIONS DOWN THE WILLIAMS RIVER ESTUARY

DISTANCE FROM SEAHAM WEIR (km)	TIDAL PRISM SPRING (m^3)	TIDAL PRISM NEAP (m^3)	VELOCITY SPRING (m/s)	VELOCITY NEAP (m/s)	TIDAL EXCURSION SPRING (m)	TIDAL EXCURSION NEAP (m)
0.02	3,886	2,621	0.00	0.00	3	2
0.5	86,651	58,450	0.01	0.01	219	148
5	605,631	408,522	0.06	0.04	1403	946
10	1,245,996	840,475	0.13	0.09	2837	1914
14	1,802,866	1,216,106	0.17	0.12	3743	2525

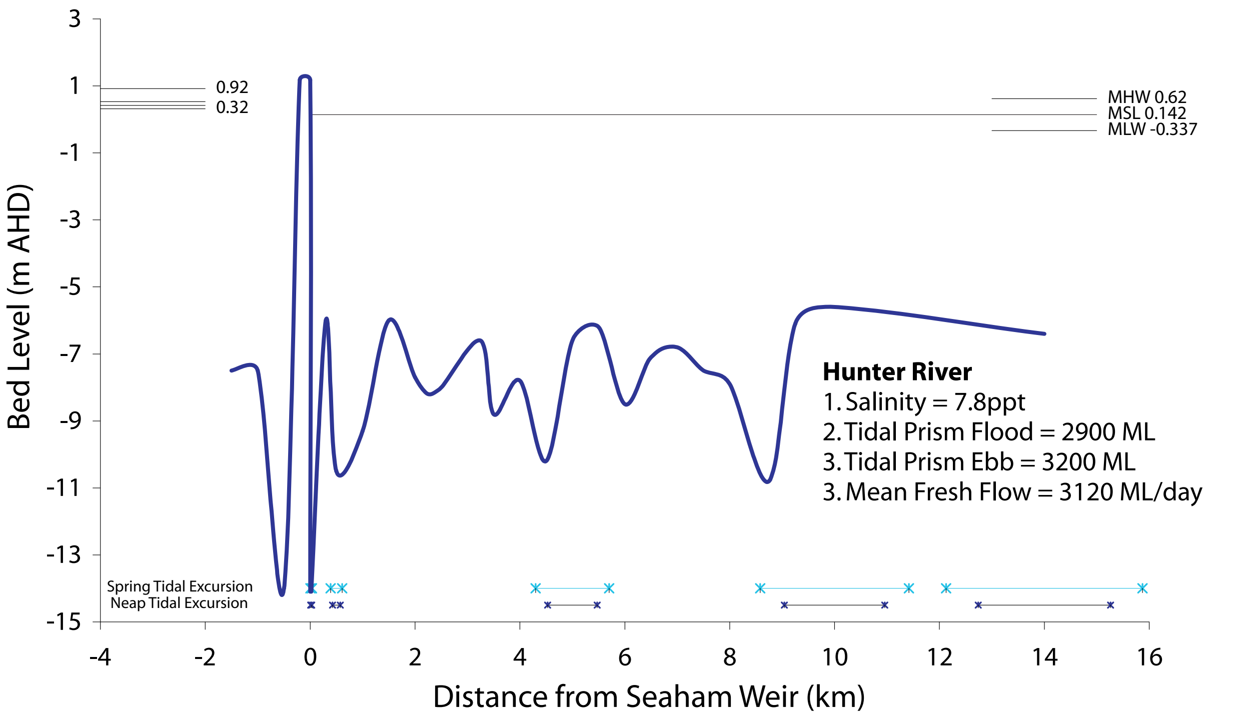


FIGURE 8.6 APPROXIMATE BED LEVEL AND TIDAL EXCURSION IN THE WILLIAMS RIVER

Tidal excursion is defined as the total distance travelled by a water particle over the tidal cycle. It represents the approximate distance travelled by a water particle during the rising or falling limb of the tide. Seaham Weir acts as a barrier to the tide. The tidal excursion increases along the estuary from zero at the weir over both the spring and neap tide cycle to about 3.5 kilometres at the confluence with the Hunter River. Similarly the tidal prism and average velocity show an increasing gradient downstream of the weir.

The tidal flows downstream of the weir will not be affected by the proposed Tillegra Dam. Rising sea levels will gradually increase the maximum water levels and consequently the frequency of weir over topping with upstream flow will increase.

8.3.3 Estuarine productivity

The physical, chemical and sediment (or biogeochemical) processes that influence biological productivity within estuaries are very complex. The input of nutrients and organic material to estuaries from river flows is important in driving estuarine foodwebs and is responsible for driving estuarine productivity (Pierson *et al* 2002). A general description of estuarine productivity of the Hunter River is described in the Hunter Estuary Processes Study (MHL 2003 see Figure 4.15 of this report).

The Hunter River catchment covers an area of 22,000km^2 and is one of the largest in NSW reaching further inland than any other catchment. The Hunter River Estuary covers a total waterway area of 26 km^2. The Hunter Estuary Wetlands RAMSAR site comprises Kooragang Nature Reserve (2,926 hectares) and Shortland Wetlands (45 hectares). These wetlands are located approximately 15 kilometres downstream of the Williams and Hunter Rivers confluence and are exposed to the general character of the lower Hunter River water of which the Williams River forms a relatively minor contribution.

Given the importance of nutrients and organic material in estuarine productivity an estimate of load reduction due to the construction and operation of Tillegra Dam was undertaken to determine if a significant change in productivity in the Hunter River estuary would be detectable. Sanderson and Redden (2001) analysed available total phosphorus data to derive empirical relationships between river flow and phosphorus concentrations in the Hunter, Paterson and Williams Rivers. These empirical relationships were utilised in the Hunter Estuary Processes Study (MHL 2003) to estimate nutrient fluxes at various points within the catchment, reproduced here in Table 8.4.

TABLE 8.4 MEAN AND GEOMETRIC MEAN LOADS INTO THE HUNTER RIVER ESTUARY (TONNES PER YEAR)

	NO_X		NH_3		TN[1]		TP	
	MEAN	GEO. MEAN	MEAN	GEO. MEAN	MEAN	GEO. MEAN	MEAN	GEO. MEAN
Hunter River	256	12	77	11	332	23	204	22
Paterson River	16	2	16	2	32	4	40	7
Williams River	35	2	24	2	59	4	62	7
Total	**307**	**16**	**117**	**15**	**424**	**31**	**307**	**36**

[1] TN estimate as the sum of NO_2 and NH_3 which is an underestimate as the organic nitrogen components of TN are not included
Source: MHL 2003

Further to information provided in Section 5.4.3 of the Water Quality and Hydrology Working Paper the phosphorus load at Tillegra Bridge was estimated as 6.4 t/year based on a mean annual flow of 94,439 ML/year (ANRA 2008). For the future scenario with 85 per cent of the mean annual flow being released from the dam the expected annual phosphorus load from the dam was estimated at around 2.7 t/year.

Given the minor total annual decrease in phosphorus load is approximately 1 per cent of the Hunter River load, it is unlikely that any changes to estuarine productivity detected near the RAMSAR sites could be attributed to the river impoundment and increased water use derived from the Tillegra project. Alterations to the natural nutrient loads and flow regime from the dam would be most apparent for the Williams River directly. In this regard, changes to the natural nutrient loads and flow regime will diminish with distance from the dam. Due to the large size of the both the Hunter River estuary and overall catchment approximately 100km downstream of the dam, impacts on estuarine productivity near the RAMSAR sites are not considered likely.

8.4 Potential mitigation measures for Reach 5

Only a small increase in salinity in the Williams River estuary is expected with a 10 per cent reduction in freshwater flow down the Williams River. As such, no mitigation and management would be required.

9. Conclusion

This investigation provides a characterisation of the existing Williams River system and highlights possible water quality and hydrology issues relating to the construction and operation of the proposed Tillegra Dam. The following has been noted:

- water quality in the Williams River is reasonably good although regular outbreaks of algal blooms occur in Seaham Weir Pool during the spring and summer
- flows within the Williams River have been regulated with the construction of Chichester Dam in the 1920s and Seaham Weir in the late 1960s. Over the last 77 years average flows at Tillegra and Glen Martin are around 260 megalitres per day and 880 megalitres per day, respectively
- the Williams River was characterised by 5 reaches from its upper headwaters to its confluence with the Hunter River. A number of potential key water quality and hydrology issues may arise with the construction of the proposed Tillegra Dam as tabulated below.

	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
Water Quality and Hydrology Issue	• NA	• Stratification • Algal blooms • Nutrient trapping	• Cold water pollution • Changes in river flow and quality	• Stratification • Algal blooms	• Potential saline ingress

- Preliminary results from the hydrology modelling of the post dam system indicate between 70 per cent and 80 per cent of historic average annual flow would pass the dam and between 75 per cent and 85 per cent of historic average annual flow would reach Glen Martin.

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Appendix A

Sampling Sites

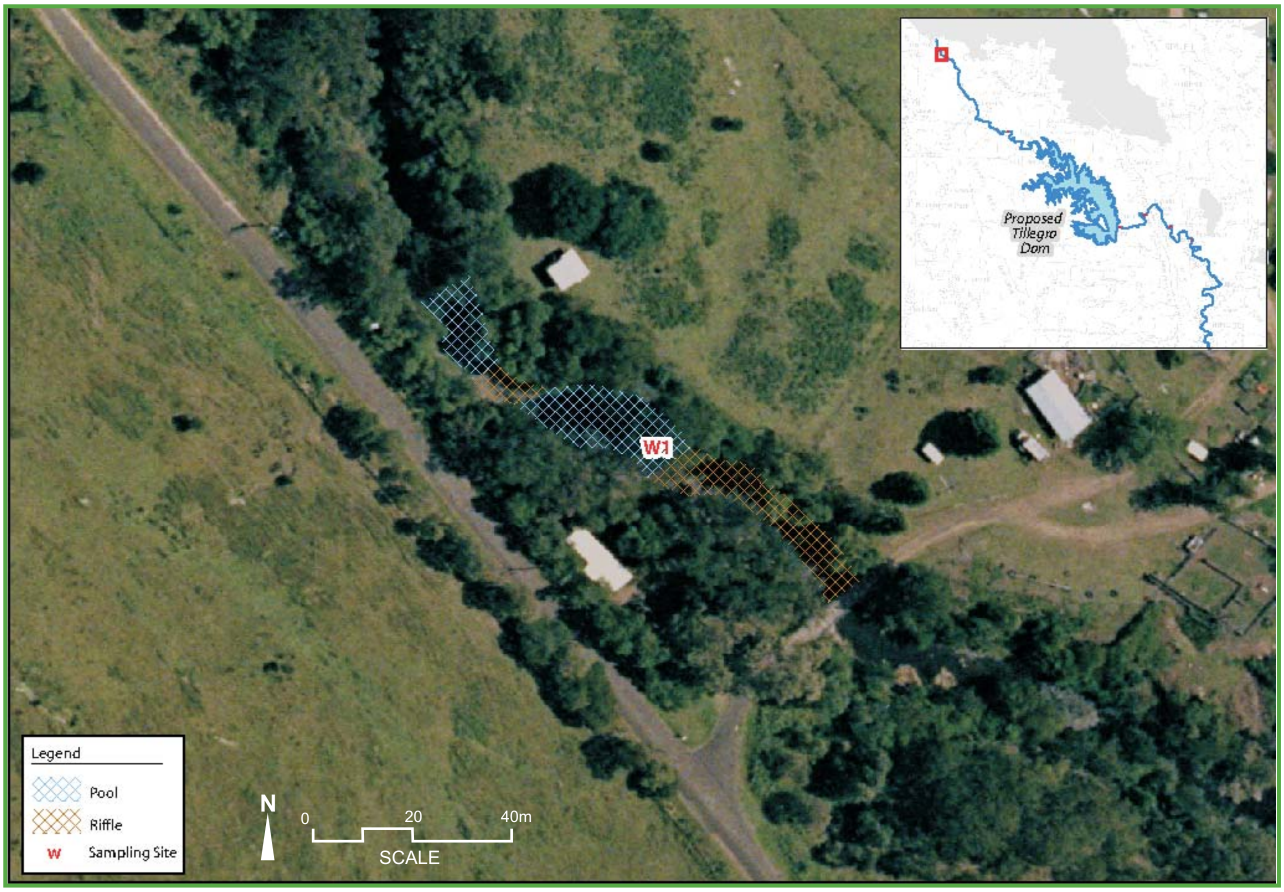

FIGURE A1 POOL AND RIFFLE SEQUENCE – SITE W1

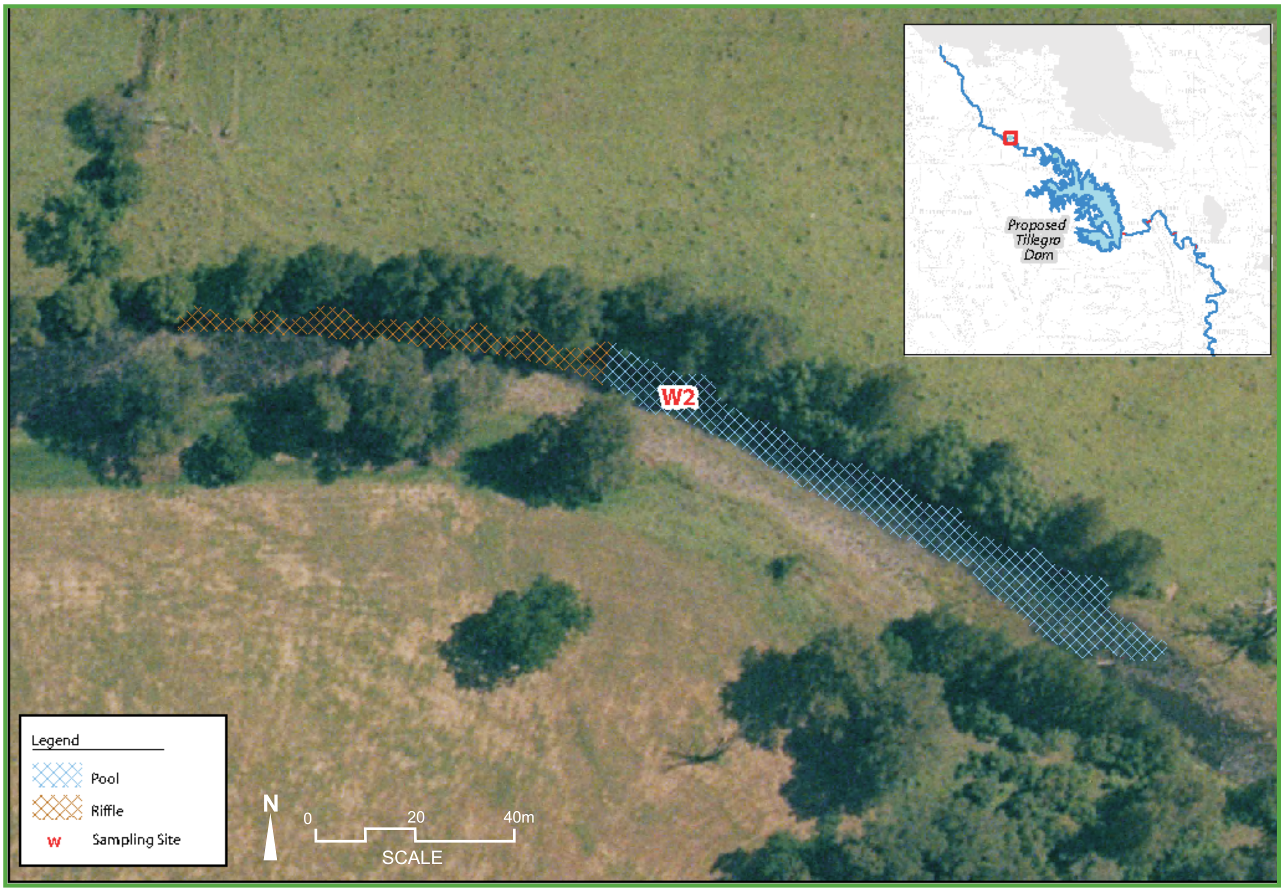

FIGURE A2 POOL AND RIFFLE SEQUENCE – SITE W2

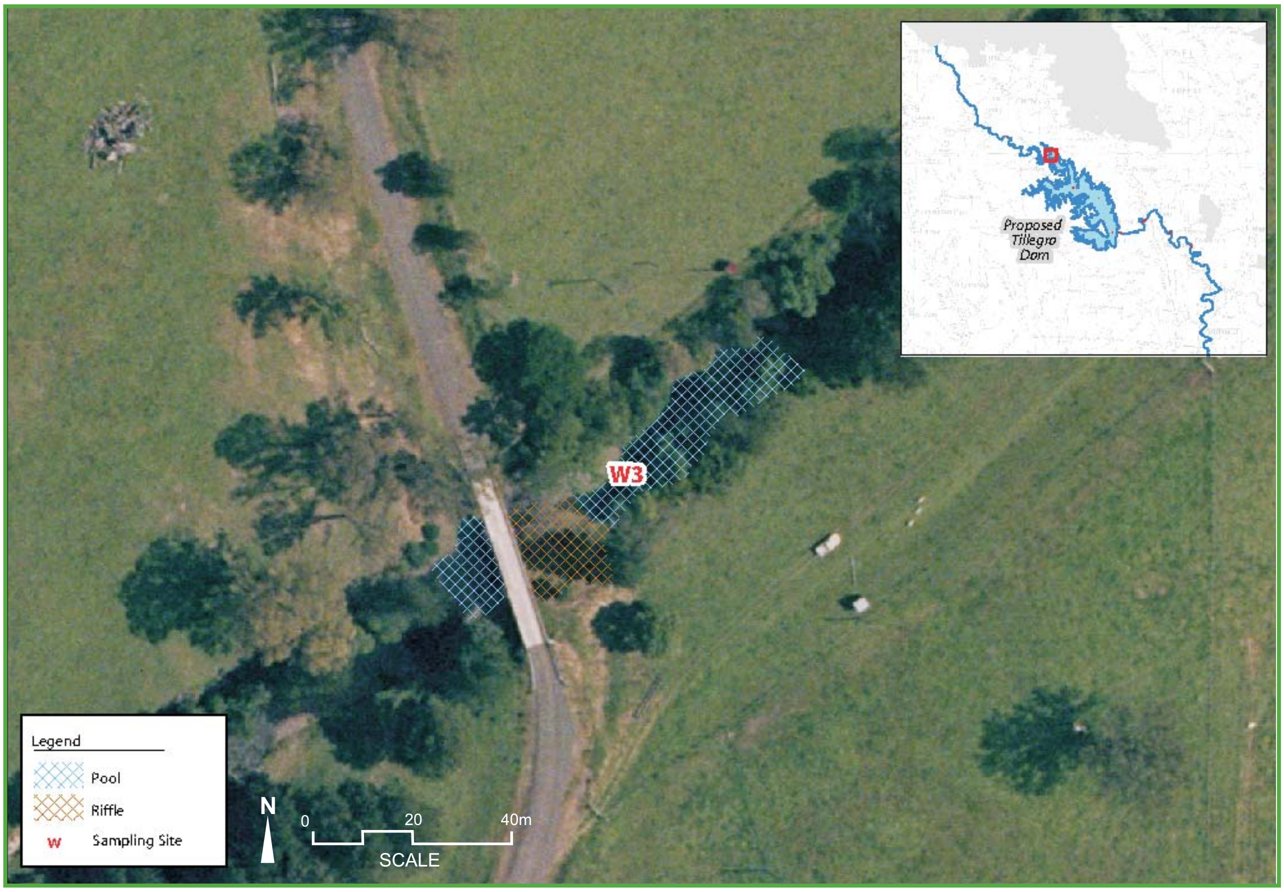

FIGURE A3 POOL AND RIFFLE SEQUENCE – SITE W3

FIGURE A4 POOL AND RIFFLE SEQUENCE – SITE W4

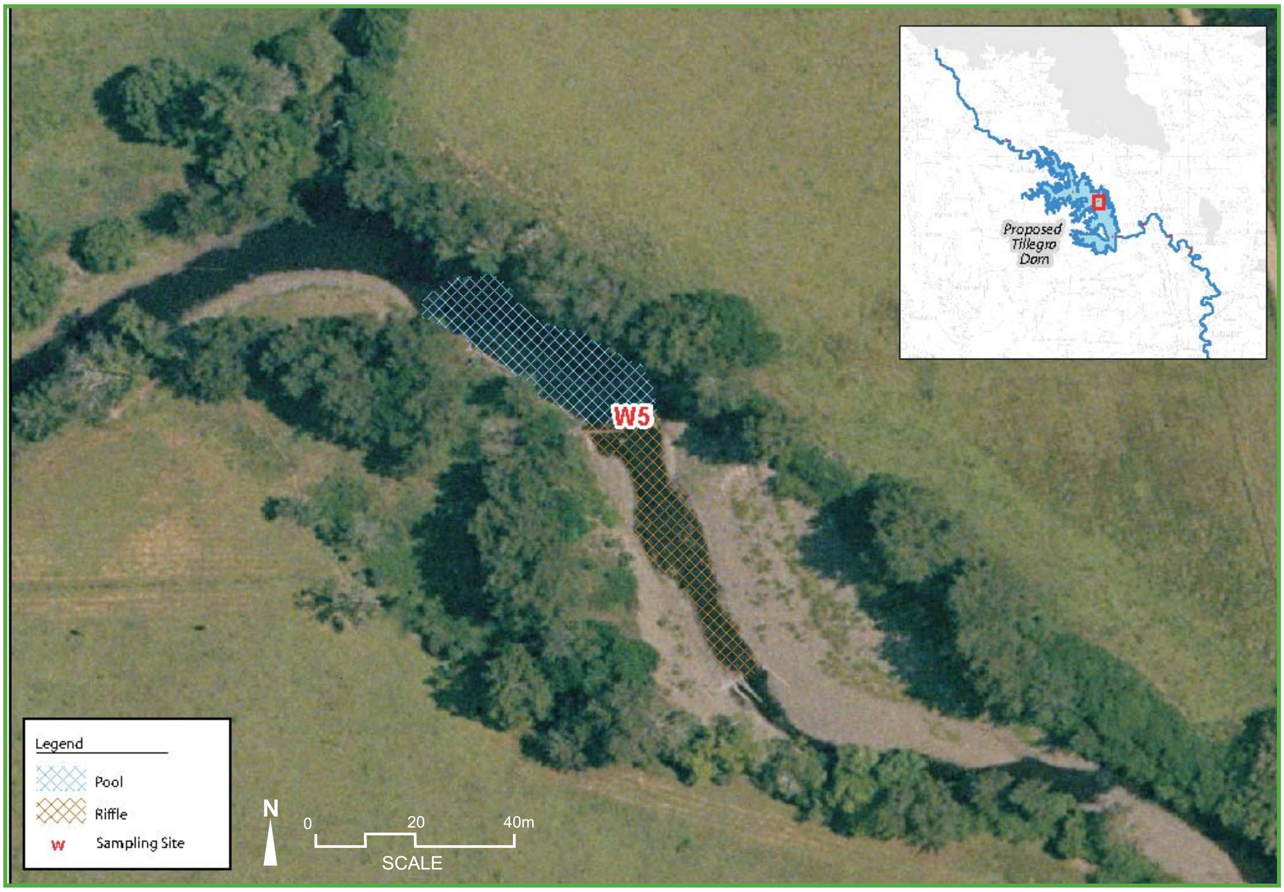

FIGURE A5 POOL AND RIFFLE SEQUENCE – SITE W5

FIGURE A6 POOL AND RIFFLE SEQUENCE – SITE W6

FIGURE A7 POOL AND RIFFLE SEQUENCE – SITE W7

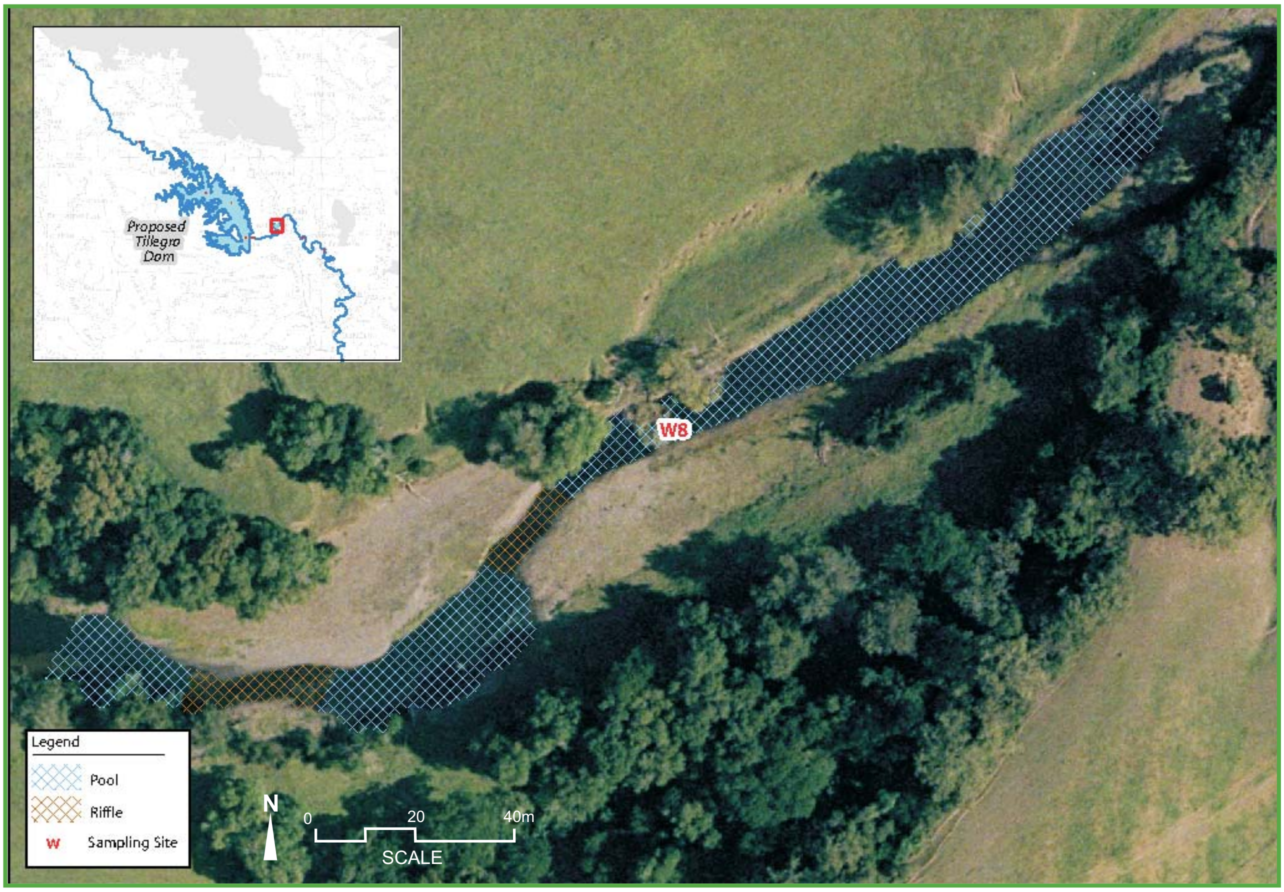

FIGURE A8 POOL AND RIFFLE SEQUENCE – SITE W8

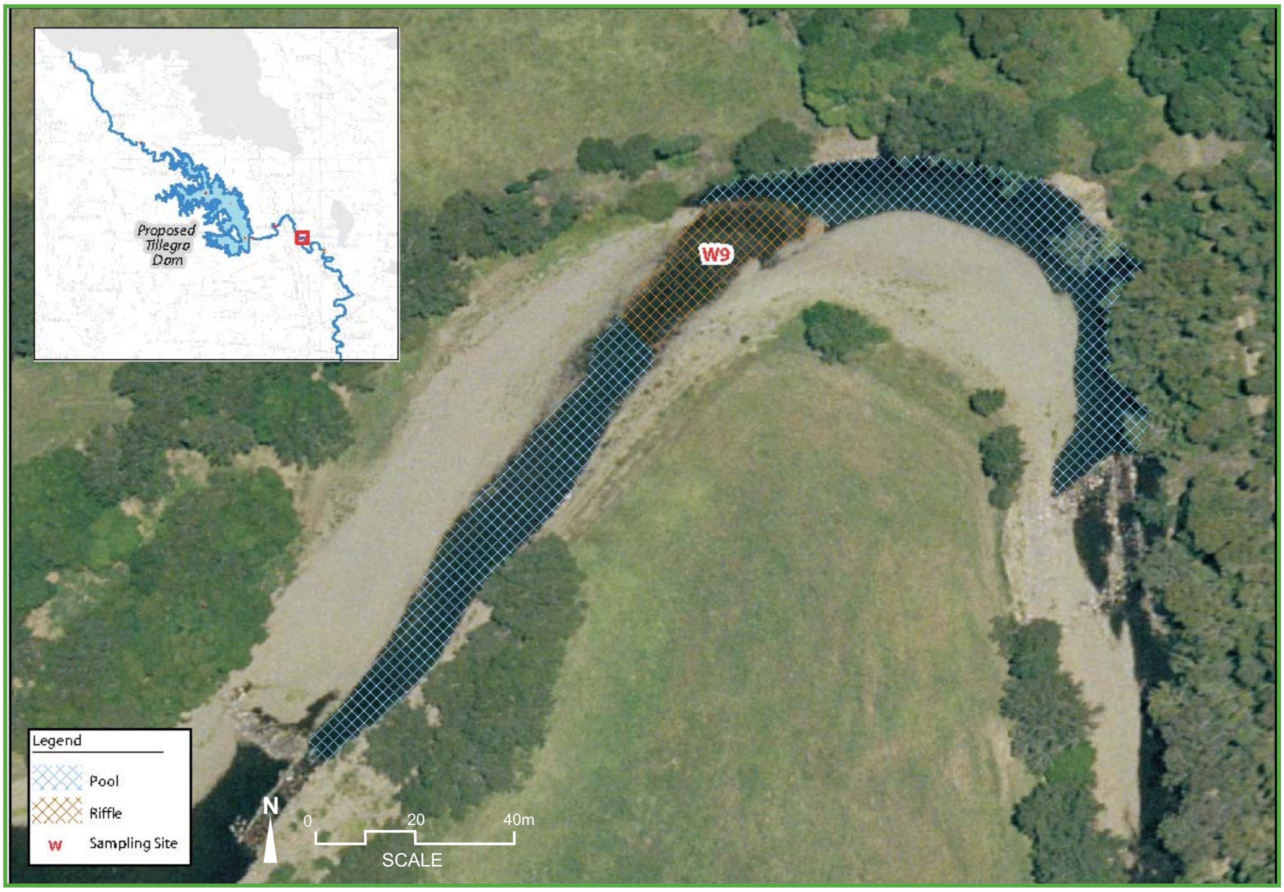

FIGURE A9 POOL AND RIFFLE SEQUENCE – SITE W9

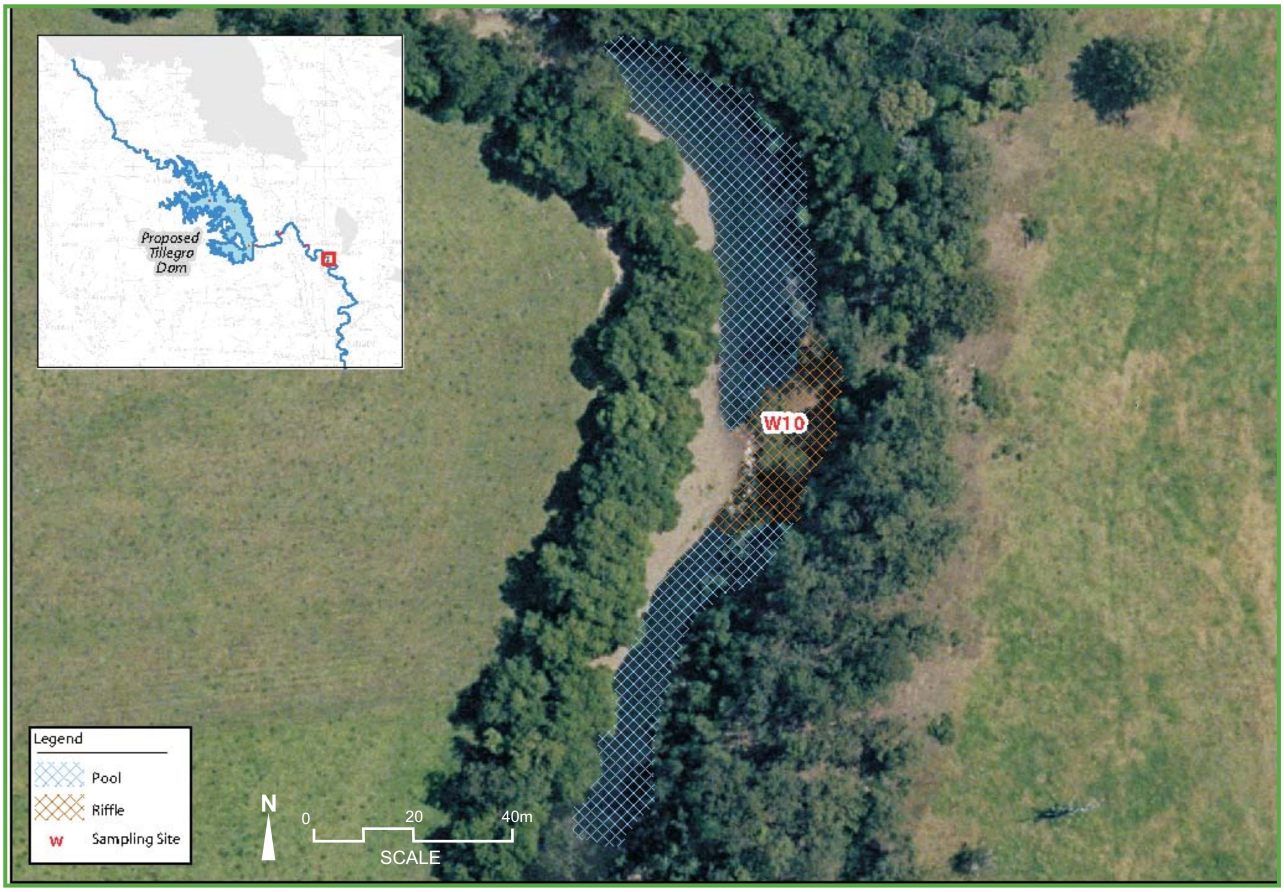

FIGURE A10 POOL AND RIFFLE SEQUENCE – SITE W10

Appendix B

Water Quality Sampling Results

Table B1: Location of water quality sampling site and variables analysed.

Site	Easting	Northing	Variables analysed
W1	361880	6439807	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity), Metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al), Nutrients (TN, TP, NOx, PO43-), Organochlorine Pesticides, Anions (Cl, SO4), Suspended Solids
W2	367296	6432547	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity) Metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al), Nutrients (TN, TP, NOx, PO43-), Organochlorine Pesticides, Anions (Cl, SO4), Suspended Solids
W3	371023	6430879	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity)
W4	372888	6427766	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity) Metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al), Nutrients (TN, TP, NOx, PO43-), Organochlorine Pesticides, Anions (Cl, SO4), Suspended Solids
W5	374949	6426790	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity)
W6	376149	6423500	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity) Metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al), Nutrients (TN, TP, NOx, PO43-), Organochlorine Pesticides, Anions (Cl, SO4), Suspended Solids, Chlorophyll-a
W7	376699	6423457	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity)
W8	378599	6424587	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity) Metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al), Nutrients (TN, TP, NOx, PO43-), Organochlorine Pesticides, Anions (Cl, SO4), Suspended Solids, Faecal coli forms
W9	380808	6423576	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity) Metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al), Nutrients (TN, TP, NOx, PO43-), Organochlorine Pesticides, Anions (Cl, SO4), Suspended Solids, Faecal coli forms, Chlorophyll-a
W10	382601	6422320	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity) Metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al), Nutrients (TN, TP, NOx, PO43-), Organochlorine Pesticides, Anions (Cl, SO4), Suspended Solids, Chlorophyll-a
W11	383704	6406824	Metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al), Nutrients (TN, TP, NOx, PO43-), Organochlorine Pesticides, Anions (Cl, SO4), Suspended Solids, Faecal coli forms, Chlorophyll-a
W12	387245	6397027	Metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al), Nutrients (TN, TP, NOx, PO43-), Organochlorine Pesticides, Anions (Cl, SO4), Suspended Solids, Faecal coli forms, Chlorophyll-a
SWP-T SWP-B	382093	6385747	Physio-chemical measurements (Temp, Conductivity, Salinity, pH, ORP, DO, turbidity, alkalinity) Metals (As, Cd, Cr, Cu, Pb, Hg, Fe, Mn, Zu, Al), Nutrients (TN, TP, NOx, PO43-), Organochlorine Pesticides, Anions (Cl, SO4), Suspended Solids, Faecal coli forms, Chl-a

Table B2: Physio-chemical results

Site	Sample Date	Replicate	Temperature (^0C)	Conductivity (mS/cm)	Conductivity (µS/cm)	Salinity (ppt)	pH	ORP	DO (%sat'n)	DO (mg/L)	Turbidity Average[C] (ntu)	Alkalinity (mg/L)
Guideline		Upland[A]	n/a	0.03-.35	30 - 350		6.5-8	n/a	90-110		2-25	*n/a*
Guideline		Lowland[B]	n/a	0.125-2.2	125 - 2200		6.5-8	n/a	85-110		6-50	n/a
W1	26/11/07	1	17.15	0.06	73	0.03	6.15	470	92.6	8.9	6.70	20
		2	17.13	0.06	77	0.03	6.45	488	89.7	8.6	2.77	
		Mean	*17.14*	*0.06*	*75.00*	*0.03*	*6.30*	*479.00*	*91.15*	*8.75*	*4.73*	*20.00*
W2	27/11/07	1	20.21	0.09	118	0.05	6.71	535	90.2	8.1	3.57	26
		2	20.31	0.09	118	0.05	6.85	534	88.1	8.0	3.43	
		Mean	*20.26*	*0.09*	*118.00*	*0.05*	*6.78*	*534.50*	*89.15*	*8.05*	*3.50*	*26.00*
W3	26/11/07	1	22.23	0.07	102	0.03	6.65	451	82.2	7.1	10.30	31
		2	22.19	0.07	102	0.03	6.84	460	81.4	7.1	9.87	
		Mean	*22.21*	*0.07*	*102.00*	*0.03*	*6.75*	*455.50*	*81.80*	*7.10*	*10.08*	*31.00*
W4	28/11/07	1	21.58	0.09	123	0.07	6.88	468	80.9	7.1	3.73	28
		2	21.66	0.09	123	0.07	6.90	475	80.6	7.1	4.40	
		Mean	*21.62*	*0.09*	*123.00*	*0.07*	*6.89*	*471.50*	*80.75*	*7.10*	*4.07*	*28.00*
W5	27/11/07	1	21.43	0.11	125	0.05	6.65	485	73.3	6.5	15.67	32
		2	21.43	0.11	125	0.05	6.89	490	73.8	6.5	12.30	
		Mean	*21.43*	*0.11*	*125.00*	*0.05*	*6.77*	*487.50*	*73.55*	*6.50*	*13.98*	*32.00*
W6	27/11/07	1	24.09	0.10	117	0.05	6.79	522	84.1	7.1	11.77	35
		2	24.10	0.10	117	0.05	6.98	520	81.6	6.8	10.83	
		Mean	*24.10*	*0.10*	*117.00*	*0.05*	*6.89*	*521.00*	*82.85*	*6.95*	*11.30*	*35.00*
W7	3/12/07	1	22.44	0.11	105	0.05	6.42	456	76.1	6.6	23.03	30
		2	22.41	0.11	105	0.05	6.92	466	75.9	6.6	23.50	
		Mean	*22.43*	*0.11*	*105.00*	*0.05*	*6.67*	*461.00*	*76.00*	*6.60*	*23.27*	*30.00*
W8	3/12/07	1	23.02	0.10	117	0.05	7.02	461	70.6	6.1	24.23	32
		2	23.00	0.10	117	0.05	7.11	467	70.3	6.0	21.57	
		Mean	*23.01*	*0.10*	*117.00*	*0.05*	*7.07*	*464.00*	*70.45*	*6.05*	*22.90*	*32.00*
W9	4/12/07	1	20.85	0.07	83	0.03	7.40	454	67.4	6.0	50.93	33
		2	20.87	0.07	96	0.03	7.40	461	68.5	6.1	52.37	
		Mean	*20.86*	*0.07*	*89.50*	*0.03*	*7.40*	*457.50*	*67.95*	*6.05*	*51.65*	*33.00*
W10	4/12/07	1	21.68	0.03	55	0.01	7.33	476	72.5	6.4	43.83	38
		2	21.62	0.03	55	0.01	7.33	479	71.9	6.3	45.37	
		Mean	*21.65*	*0.03*	*55.00*	*0.01*	*7.33*	*477.50*	*72.20*	*6.35*	*44.60*	*38.00*

[A]ANZECC guidelines for SE Australian slightly disturbed ecosystems–Upland River (>150m altitude). [B]ANZECC guidelines for SE Australian slightly disturbed ecosystems– Low land River (<150m altitude). [C]Turbidity is an average of 3 field measurements

Table B3: Seaham Weir physio-chemical profile results

Depth (m)	Temperature (^{0}C)	Conductivity (mS/cm)	Conductivity (µS/cm)	Salinity (ppt)	pH	ORP	DO (%sat'n)	DO (mg/L)	Turbidity average[C] (ntu)
Guideline[A]	n/a	0.002-0.003	20-30	n/a	6.5-8	n/a	90-110	n/a	1-20
0.5	26.45	0.214	213	0.1	7.26	450	72.8	5.8	4.73
1	25.87	0.213	213	0.1	7.26	456	69	5.6	5.53
1.5	25.74	0.213	213	0.1	7.25	462	65.8	5.4	4.53
2	25.49	0.213	213	0.1	7.25	467	66.5	5.5	4.23
2.5	25.23	0.213	213	0.1	7.17	473	56.2	4.8	4.33
3	24.76	0.212	211	0.1	7.09	476	42.8	3.5	4.20
3.5	24.17	0.208	207	0.1	7.03	480	30.6	2.6	4.47
4	23.48	0.212	214	0.1	6.98	481	17.6	1.5	6.00
4.5	22.89	0.228	227	0.11	6.94	418	7.2	0.6	8.00
5	21.41	0.258	258	0.12	7.02	280	2	0.2	16.17
5.5	20.95	0.265	266	0.13	6.98	241	1.4	0.1	17.20
6	20.59	0.271	271	0.13	7	217	1.2	0.1	17.33
6.5	20.39	0.273	274	0.13	7.05	193	1.3	0.1	15.97
7	19.95	0.276	276	0.13	7.06	149	0.9	0.1	13.83
7.5	19.89	0.277	276	0.13	7.08	134	0.9	0.1	14.00
8	19.84	0.277	277	0.13	7.09	125	0.9	0.1	13.13

[A]ANZECC guidelines for SE Australian slightly disturbed ecosystems–Lakes and Reservoirs, [C]Turbidity is an average of 3 field measurements

Table B4: Laboratory Results

Site	Replicate	Faecal Coliform Count units/100ml	Chlorophyll a mg/L	Chloride mg/L	Nitrogen Total mg/L	Nox mg/L	Sulphate mg/L	Suspended Solids mg/L	Total Kjeldahl Nitrogen mg/L	Phosphorus total mg/L
Guideline	Upland[A]	150[D]	na	n/a	0.250	0.015	n/a	n/a	n/a	0.020
Guideline	Lowland[B]	150[D]	0.003[E]	n/a	0.350[E]	0.040	n/a	n/a	n/a	0.025[E]
Guideline	Lake & Reservoir[C]	150[D]	0.005	n/a	0.350	0.010	n/a	n/a	n/a	0.010
W1	1	na	na	9.1	0.13	0.02	3.6	10	0.11	<0.05
W1	2	na	na	9.2	0.14	0.02	3.4	4	0.11	0.07
	Mean			*9.15*	*0.135*	*0.02*	*3.5*	*7*	*0.11*	
W2	1	na	na	5.8	<0.05	0.02	2.3	2	<0.05	<0.05
W2	2	na	na	5.8	<0.05	0.02	2.3	5	<0.05	0.05
	Mean			*5.8*		*0.02*	*2.3*	*3.5*		
W4	1	na	na	11	0.17	0.03	4.1	<2	0.14	0.07
W4	2	na	na	11	0.22	0.03	4.1	<2	0.18	0.058
	Mean			*11*	*0.195*	*0.03*	*4.1*		*0.16*	*0.064*
W6	1	na	<0.001	13	0.15	0.04	4.6	11	0.1	0.073
W6	2	na	<0.001	13	0.21	0.04	4.6	14	0.17	0.072
	Mean			*13*	*0.18*	*0.04*	*4.6*	*12.5*	*0.135*	*0.073*
W8	1	2400	na	13	0.39	0.05	4.3	22	0.35	0.094
W8	2	3500	na	13	0.28	0.05	4.4	20	0.23	0.08
	Mean	*2950*		*13*	*0.335*	*0.05*	*4.35*	*21*	*0.29*	*0.087*
W9	1	1100	0.002	10	0.19	0.03	3.4	12	0.16	<0.05
W9	2	700	<0.001	10	0.25	0.03	3.2	12	0.22	0.054
	Mean	*900*		*10*	*0.22*	*0.03*	*3.3*	*12*	*0.19*	
W10	1	na	<0.001	10	0.3	0.04	3.1	13	0.26	0.074
W10	2	na	<0.001	11	0.29	0.04	3.3	13	0.25	0.073
	Mean			*10.5*	*0.295*	*0.04*	*3.2*	*13*	*0.255*	*0.074*
W11	1	2400	<0.001	12	0.460	0.05	3.1	29	0.41	0.11
W11	2	3500	<0.001	12	0.510	0.05	4.1	33	0.46	0.11
	Mean	*2950*		*12*	*0.485*	*0.05*	*3.6*	*31*	*0.435*	*0.11*
W12	1	270	<0.001	18	1.2	0.12	4.6	49	1.1	0.1
W12	2	1300	<0.001	18	0.4	0.06	4.7	39	0.33	0.079
	Mean	*785*		*18*	*0.8*	*0.09*	*4.65*	*44*	*0.715*	*0.090*
SWP-S	1	<20	0.019	30	0.25	<0.01	5.9	6	0.25	0.084

Site	Replicate	Faecal Coliform Count units/100ml	Chlorophyll a mg/L	Chloride mg/L	Nitrogen Total mg/L	Nox mg/L	Sulphate mg/L	Suspended Solids mg/L	Total Kjeldahl Nitrogen mg/L	Phosphorus total mg/L
Guideline	Upland[A]	150[D]	na	n/a	0.250	0.015	n/a	n/a	n/a	0.020
Guideline	Lowland[B]	150[D]	0.003[E]	n/a	0.350[E]	0.040	n/a	n/a	n/a	0.025[E]
Guideline	Lake & Reservoir[C]	150[D]	0.005	n/a	0.350	0.010	n/a	n/a	n/a	0.010
SWP-S	2	<20	0.017	29	0.31	<0.01	5.9	6	0.31	0.073
	Mean		*0.018*	*29.5*	*0.28*		*5.9*	*6*	*0.28*	*0.079*
SWP-B	1	<20	<0.001	42	0.49	0.09	6.3	19	0.4	0.29
SWP-B	2	<20	0.002	40	0.4	0.07	6.4	16	0.33	0.23
	Mean			*41*	*0.445*	*0.08*	*6.35*	*17.5*	*0.365*	*0.26*

[A]ANZECC guidelines for SE Australian slightly disturbed ecosystems–Upland River (>150m altitude).
[B]ANZECC guidelines for SE Australian slightly disturbed ecosystems– Low land River (<150m altitude).
[C]ANZECC guidelines for SE Australian slightly disturbed ecosystems–Lakes and Reservoirs,
[D]Primary contact recreational value
[E]Values for NSW and Vic east flowing coastal rivers

Table B5: Laboratory Results - Metals

Site	Replicate	Arsenic total mg/L	Cadmium total mg/L	Chromium total mg/L	Copper total mg/L	Lead total mg/L	Mercury total mg/L	Zinc total mg/L
Guideline[A]		0.013	0.0002	0.001	0.0014	0.0034	0.00006	0.008
W1	1	<0.001	<0.001	0.001	0.002	<0.001	<0.0001	0.019
W1	2	<0.001	<0.001	0.001	0.001	<0.001	<0.0001	0.019
	Mean			*0.001*	*0.002*			*0.019*
W2	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	0.015
W2	2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	0.016
	Mean							*0.016*
W4	1	<0.001	<0.001	0.001	0.001	<0.001	<0.0001	0.017
W4	2	<0.001	<0.001	0.001	0.001	<0.001	<0.0001	0.02
	Mean			*0.001*	*0.001*			*0.019*
W6	1	<0.001	<0.001	<0.001	0.002	<0.001	<0.0001	0.027
W6	2	<0.001	<0.001	0.001	0.002	<0.001	<0.0001	0.015
	Mean			*0.001*	*0.002*			*0.021*
W8	1	<0.001	<0.001	0.001	0.002	<0.001	<0.0001	0.016
W8	2	<0.001	<0.001	0.001	0.002	<0.001	<0.0001	0.018
	Mean			*0.001*	*0.002*			*0.017*
W9	1	<0.001	<0.001	<0.001	0.001	<0.001	<0.0001	0.016
W9	2	<0.001	<0.001	<0.001	0.001	<0.001	<0.0001	0.02
	Mean				*0.001*			*0.018*
W10	1	<0.001	<0.001	<0.001	0.001	<0.001	<0.0001	0.014
W10	2	<0.001	<0.001	<0.001	0.001	<0.001	<0.0001	0.011
	Mean				*0.001*			*0.013*
W11	1	<0.001	<0.001	0.001	0.002	<0.001	<0.0001	0.014
W11	2	0.001	<0.001	0.001	0.002	<0.001	<0.0001	0.017
	Mean	*0.001*		*0.001*	*0.002*			*0.016*
W12	1	0.001	<0.001	0.001	0.002	<0.001	<0.0001	0.024
W12	2	0.001	<0.001	0.001	0.002	<0.001	<0.0001	0.016
	Mean	*0.001*		*0.001*	*0.002*			*0.02*
SWP-S	1	0.001	<0.001	<0.001	0.001	<0.001	0.0002	0.011
SWP-S	2	0.001	<0.001	<0.001	0.001	<0.001	0.0002	0.014

Site	Replicate	Arsenic total mg/L	Cadmium total mg/L	Chromium total mg/L	Copper total mg/L	Lead total mg/L	Mercury total mg/L	Zinc total mg/L
Guideline[A]		0.013	0.0002	0.001	0.0014	0.0034	0.00006	0.008
	Mean	*0.001*			*0.001*		*0.0002*	*0.013*
SWP-B	1	0.002	<0.001	<0.001	0.001	<0.001	0.0002	0.019
SWP-B	2	0.002	<0.001	<0.001	0.001	<0.001	<0.0001	0.012
	Mean	*0.002*			*0.001*			*0.016*

[A] ANZECC guidelines for slightly disturbed systems.

Table B6: Laboratory Results – Pesticides

Pesticides	Units	Detection Limit
HCB	µg/L	<0.01
Heptachlor	µg/L	<0.01
Heptachlor epoxide	µg/L	<0.01
Aldrin	µg/L	<0.01
gamma-BHC (Lindane)	µg/L	<0.01
alpha-BHC	µg/L	<0.01
beta-BHC	µg/L	<0.01
delta-BHC	µg/L	<0.01
trans-Chlordane	µg/L	<0.01
cis-Chlordane	µg/L	<0.01
Oxychlordane	µg/L	<0.01
Dieldrin	µg/L	<0.01
p,p-DDE	µg/L	<0.01
p,p-DDD	µg/L	<0.01
p,p-DDT	µg/L	<0.01
Endrin	µg/L	<0.01
Endrin Aldehyde	µg/L	<0.01
Endrin Ketone	µg/L	<0.01
alpha-Endosulfan	µg/L	<0.01
beta-Endosulfan	µg/L	<0.01
Endosulfan Sulfate	µg/L	<0.01
Methoxychlor	µg/L	<0.01

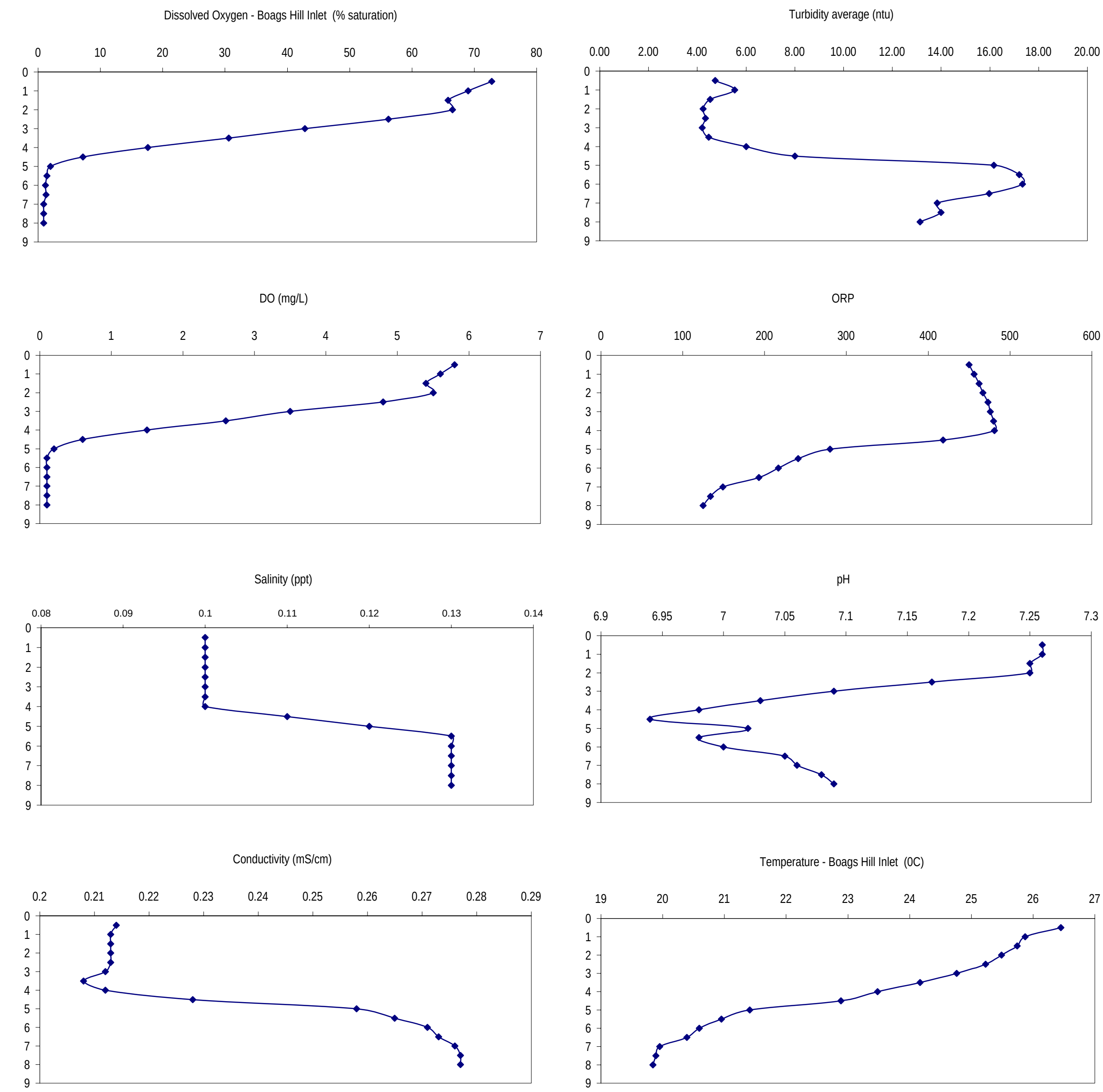

Figure B1: Water Quality Profiles, Boags Hill, Seaham Weir Pool

Appendix C

Pool/riffle bed level and percentiles

Table C1 **Historic Percentiles for flow, water height, wetted perimeter and velocity at site W7**

	Site	**W7 Riffle**			
	Variable	**Discharge ML/Day**			
	Flow	**Tillegra**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0	0	0	0	0
5	1.9	0.0	4.2	10.1	1.5
10	7.4	2.2	13.4	14.7	5.9
15	12.2	5.1	18.9	17.5	9.2
20	15.9	9.3	24.4	22.0	11.8
25	19.7	13.5	29.7	24.8	14.6
50	46.5	41.5	67.3	49.4	32.8
75	125.7	136.4	193.3	119.1	79.9
80	170.8	190.7	271.2	156.8	103.2
85	250.9	279.2	387.4	213.7	144.1
90	416.0	495.8	611.1	333.4	233.1
95	914.5	1099.5	1290.2	740.4	530.6

	Site	**W7 Riffle**			
	Variable	**Water height (m) above bed**			
	Flow	**Tillegra**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0	0	0	0	0
5	0.06	0.00	0.07	0.11	0.06
10	0.09	0.06	0.12	0.13	0.08
15	0.12	0.08	0.15	0.14	0.10
20	0.14	0.10	0.16	0.16	0.12
25	0.15	0.13	0.17	0.16	0.13
50	0.20	0.20	0.24	0.21	0.18
75	0.30	0.31	0.35	0.30	0.26
80	0.34	0.35	0.40	0.32	0.28
85	0.39	0.41	0.46	0.37	0.32
90	0.47	0.51	0.55	0.44	0.38
95	0.65	0.69	0.74	0.60	0.52

	Site	**W7 Riffle**			
	Variable	**Wetted Perimeter (m)**			
	Flow	**Tillegra**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.0	0.0	0.0	0.0	0.0
5	1.6	0.0	2.0	2.8	1.5
10	2.5	1.7	3.2	3.3	2.3
15	3.1	2.2	3.7	3.6	2.8
20	3.5	2.8	4.1	4.0	3.0
25	3.8	3.2	4.4	4.1	3.3
50	5.3	5.1	6.2	5.4	4.6
75	8.4	8.7	10.2	8.2	6.8
80	9.7	10.2	11.9	9.3	7.7
85	11.5	12.0	13.8	10.7	8.9
90	14.2	15.3	16.7	12.9	11.1
95	19.8	21.3	22.7	18.1	15.8

	Site	**W7 Riffle**			
	Variable	**Average Velocity (m/s)**			
	Flow	**Tillegra**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.00	0.00	0.00	0.00	0.00
5	0.52	0.00	0.61	0.74	0.49
10	0.69	0.53	0.78	0.79	0.66
15	0.76	0.64	0.83	0.82	0.72
20	0.81	0.72	0.87	0.86	0.76
25	0.84	0.78	0.91	0.88	0.79
50	1.00	0.98	1.08	1.02	0.93
75	1.21	1.23	1.31	1.20	1.11
80	1.28	1.30	1.39	1.26	1.17
85	1.37	1.40	1.49	1.33	1.24
90	1.51	1.57	1.63	1.45	1.35
95	1.76	1.82	1.88	1.69	1.59

	Site	**W7 Pool**			
	Variable	**Discharge ML/Day**			
	Flow	**Tillegra**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.0	0.0	0.0	0.0	0.0
5	1.9	0.0	4.2	10.1	1.5
10	7.4	2.2	13.4	14.7	5.9
15	12.2	5.1	18.9	17.5	9.2
20	15.9	9.3	24.4	22.0	11.8
25	19.7	13.5	29.7	24.8	14.6
50	46.5	41.5	67.3	49.4	32.8
75	125.7	136.4	193.3	119.1	79.9
80	170.8	190.7	271.2	156.8	103.2
85	250.9	279.2	387.4	213.7	144.1
90	416.0	495.8	611.1	333.4	233.1
95	914.5	1099.5	1290.2	740.4	530.6

	Site	**W7 Pool**			
	Variable	**Water height (m) above bed**			
	Flow	**Tillegra**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	1.44	1.44	1.44	1.44	1.44
5	1.45	1.44	1.47	1.51	1.45
10	1.49	1.46	1.53	1.53	1.49
15	1.52	1.48	1.56	1.55	1.50
20	1.54	1.50	1.58	1.57	1.52
25	1.56	1.53	1.59	1.58	1.53
50	1.63	1.62	1.67	1.64	1.60
75	1.75	1.76	1.82	1.74	1.69
80	1.80	1.82	1.89	1.79	1.72
85	1.87	1.89	1.97	1.84	1.77
90	1.98	2.03	2.08	1.93	1.86
95	2.20	2.26	2.33	2.14	2.05

	Site	**W7 Pool**			
	Variable	**Wetted Perimeter (m)**			
	Flow	**Tillegra**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	13.2	13.2	13.2	13.2	13.2
5	13.3	13.2	13.4	13.5	13.3
10	13.5	13.4	13.6	13.6	13.4
15	13.5	13.4	13.6	13.6	13.5
20	13.6	13.5	13.7	13.7	13.5
25	13.6	13.6	13.7	13.7	13.6
50	13.9	13.8	14.0	13.9	13.8
75	14.4	14.6	15.2	14.4	14.1
80	14.9	15.2	15.9	14.8	14.2
85	15.8	16.0	16.5	15.4	14.6
90	16.7	16.9	17.2	16.3	15.7
95	18.0	18.9	20.5	17.5	17.0

	Site	**W7 Pool**			
	Variable	**Average Velocity (m/s)**			
	Flow	**Tillegra**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.01	0.00
10	0.00	0.00	0.01	0.01	0.00
15	0.01	0.00	0.01	0.01	0.01
20	0.01	0.01	0.01	0.01	0.01
25	0.01	0.01	0.01	0.01	0.01
50	0.03	0.02	0.04	0.03	0.02
75	0.07	0.08	0.11	0.07	0.05
80	0.10	0.11	0.15	0.09	0.06
85	0.14	0.15	0.20	0.12	0.09
90	0.21	0.25	0.30	0.18	0.13
95	0.41	0.47	0.53	0.35	0.26

Table C2 **Historic Percentiles for flow, water height, wetted perimeter and velocity at site W8**

Site	W8 Riffle				
Variable	Discharge ML/Day				
Flow	Tillegra				
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0	0	0	0	0
5	1.9	0.0	4.2	10.1	1.5
10	7.4	2.2	13.4	14.7	5.9
15	12.2	5.1	18.9	17.5	9.2
20	15.9	9.3	24.4	22.0	11.8
25	19.7	13.5	29.7	24.8	14.6
50	46.5	41.5	67.3	49.4	32.8
75	125.7	136.4	193.3	119.1	79.9
80	170.8	190.7	271.2	156.8	103.2
85	250.9	279.2	387.4	213.7	144.1
90	416.0	495.8	611.1	333.4	233.1
95	914.5	1099.5	1290.2	740.4	530.6

Site	W8 Riffle				
Variable	Water height (m) above bed				
Flow	Tillegra				
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0	0	0	0	0
5	0.03	0.00	0.04	0.06	0.03
10	0.05	0.03	0.07	0.07	0.04
15	0.06	0.04	0.08	0.08	0.06
20	0.07	0.06	0.09	0.08	0.06
25	0.08	0.07	0.11	0.09	0.07
50	0.15	0.14	0.16	0.15	0.11
75	0.19	0.19	0.22	0.19	0.16
80	0.21	0.22	0.25	0.20	0.18
85	0.24	0.25	0.27	0.23	0.20
90	0.28	0.30	0.33	0.26	0.23
95	0.39	0.43	0.46	0.36	0.31

Site	W8 Riffle				
Variable	Wetted Perimeter (m)				
Flow	Tillegra				
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.0	0.0	0.0	0.0	0.0
5	3.4	0.0	3.5	4.1	3.3
10	3.8	3.4	4.3	4.3	3.7
15	4.2	3.6	4.5	4.4	4.0
20	4.3	4.0	5.4	4.8	4.2
25	4.5	4.3	7.6	5.5	4.3
50	16.9	14.4	21.8	17.9	9.3
75	22.6	22.7	22.8	22.6	22.5
80	22.8	22.8	23.0	22.7	22.5
85	23.0	23.1	23.3	22.9	22.7
90	23.3	23.4	23.5	23.2	23.0
95	23.6	23.7	23.8	23.5	23.4

Site	W8 Riffle				
Variable	Average Velocity (m/s)				
Flow	Tillegra				
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.00	0.00	0.00	0.00	0.00
5	0.37	0.00	0.53	0.56	0.32
10	0.55	0.39	0.63	0.67	0.55
15	0.59	0.55	0.68	0.68	0.56
20	0.68	0.56	0.69	0.69	0.58
25	0.69	0.63	0.71	0.70	0.67
50	0.77	0.76	0.78	0.77	0.75
75	0.83	0.84	0.93	0.82	0.81
80	0.89	0.92	1.05	0.87	0.81
85	1.02	1.06	1.21	0.96	0.85
90	1.25	1.34	1.44	1.14	0.99
95	1.65	1.74	1.83	1.54	1.37

Site	W8 Pool				
Variable	Discharge ML/Day				
Flow	Tillegra				
Percentiles					
Min	0.0	0.0	0.0	0.0	0.0
5	1.9	0.0	4.2	10.1	1.5
10	7.4	2.2	13.4	14.7	5.9
15	12.2	5.1	18.9	17.5	9.2
20	15.9	9.3	24.4	22.0	11.8
25	19.7	13.5	29.7	24.8	14.6
50	46.5	41.5	67.3	49.4	32.8
75	125.7	136.4	193.3	119.1	79.9
80	170.8	190.7	271.2	156.8	103.2
85	250.9	279.2	387.4	213.7	144.1
90	416.0	495.8	611.1	333.4	233.1
95	914.5	1099.5	1290.2	740.4	530.6

Site	W8 Pool				
Variable	Water height (m) above bed				
Flow	Tillegra				
Percentiles					
Min	0.77	0.77	0.77	0.77	0.77
5	0.78	0.77	0.80	0.83	0.78
10	0.81	0.79	0.84	0.85	0.80
15	0.84	0.80	0.87	0.86	0.82
20	0.86	0.82	0.88	0.88	0.84
25	0.87	0.85	0.89	0.88	0.85
50	0.92	0.91	0.93	0.92	0.90
75	0.98	0.98	1.02	0.97	0.94
80	1.00	1.02	1.06	0.99	0.96
85	1.05	1.06	1.11	1.03	0.99
90	1.13	1.16	1.21	1.09	1.04
95	1.31	1.37	1.43	1.26	1.17

Site	W8 Pool				
Variable	Wetted Perimeter (m)				
Flow	Tillegra				
Percentiles					
Min	19.1	19.1	19.1	19.1	19.1
5	19.2	19.1	19.4	19.7	19.2
10	19.6	19.2	19.9	20.0	19.5
15	19.8	19.4	20.1	20.1	19.7
20	20.0	19.7	20.2	20.2	19.8
25	20.1	19.9	20.3	20.2	20.0
50	20.4	20.4	20.5	20.4	20.3
75	20.6	20.6	20.7	20.6	20.5
80	20.7	20.7	20.8	20.6	20.5
85	20.8	20.8	21.2	20.7	20.6
90	21.3	21.6	22.1	21.0	20.7
95	23.2	24.2	25.8	22.6	21.8

Site	W8 Pool				
Variable	Average Velocity (m/s)				
Flow	Tillegra				
Percentiles					
Min	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.01	0.00
10	0.00	0.00	0.01	0.02	0.00
15	0.01	0.00	0.02	0.02	0.01
20	0.02	0.01	0.02	0.02	0.01
25	0.02	0.01	0.03	0.02	0.02
50	0.04	0.03	0.05	0.04	0.03
75	0.10	0.10	0.14	0.09	0.06
80	0.12	0.13	0.18	0.11	0.08
85	0.17	0.19	0.24	0.15	0.11
90	0.26	0.30	0.35	0.22	0.16
95	0.47	0.53	0.59	0.41	0.31

Table C3 **Historic Percentiles for flow, water height, wetted perimeter and velocity at site W9**

	Site	W9 Riffle			
	Variable	**Discharge ML/Day**			
	Flow	**Tillegra + Chichester**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	2.2	2.2	4.4	9.0	3.1
5	15.5	14.0	18.4	24.3	14.9
10	21.4	15.7	27.4	28.7	19.7
15	26.2	19.0	33.8	31.8	23.1
20	30.3	23.3	41.0	36.0	25.7
25	34.2	27.6	49.2	39.4	28.6
50	72.7	68.5	144.8	73.7	47.7
75	256.3	275.4	411.2	229.8	129.9
80	341.5	371.9	553.2	297.0	176.7
85	492.0	560.1	832.1	407.7	259.3
90	843.6	1006.6	1399.3	656.6	427.9
95	1837.5	2170.9	2661.3	1407.6	955.4

	Site	W9 Riffle			
	Variable	**Water height (m) above bed**			
	Flow	**Tillegra + Chichester**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.01	0.01	0.01	0.03	0.01
5	0.04	0.03	0.04	0.05	0.04
10	0.04	0.04	0.05	0.05	0.04
15	0.05	0.04	0.06	0.06	0.04
20	0.05	0.04	0.07	0.06	0.05
25	0.06	0.05	0.08	0.07	0.05
50	0.09	0.09	0.14	0.09	0.08
75	0.17	0.18	0.22	0.16	0.13
80	0.20	0.21	0.26	0.19	0.15
85	0.25	0.26	0.31	0.22	0.17
90	0.32	0.34	0.41	0.28	0.23
95	0.48	0.52	0.58	0.41	0.33

	Site	W9 Riffle			
	Variable	**Wetted Perimeter (m)**			
	Flow	**Tillegra + Chichester**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	7.9	7.9	7.9	9.5	7.9
5	11.2	10.9	11.7	12.5	11.1
10	12.1	11.2	12.9	13.1	11.8
15	12.7	11.7	13.7	13.5	12.3
20	13.3	12.3	14.4	13.9	12.7
25	13.7	12.9	15.0	14.3	13.1
50	16.0	15.8	20.3	16.0	15.0
75	23.0	23.5	26.6	22.5	19.3
80	25.1	25.8	27.9	24.0	21.3
85	27.7	27.9	28.6	26.5	23.1
90	28.6	28.9	29.7	28.2	26.9
95	32.4	34.1	35.8	29.8	28.8

	Site	W9 Riffle			
	Variable	**Average Velocity (m/s)**			
	Flow	**Tillegra + Chichester**			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.31	0.31	0.50	0.50	0.44
5	0.57	0.53	0.60	0.62	0.55
10	0.61	0.57	0.62	0.63	0.61
15	0.62	0.61	0.63	0.63	0.62
20	0.63	0.62	0.64	0.63	0.62
25	0.63	0.63	0.65	0.64	0.63
50	0.81	0.78	0.88	0.81	0.65
75	1.11	1.13	1.23	1.06	0.88
80	1.18	1.20	1.32	1.15	0.90
85	1.27	1.32	1.49	1.23	1.11
90	1.50	1.58	1.76	1.38	1.24
95	1.88	1.94	1.99	1.76	1.56

	Site	W9 Pool			
	Variable	**Discharge ML/Day**			
	Flow	**Tillegra + Chichester**			
Percentiles					
Min	2.2	2.2	4.4	9.0	3.1
5	15.5	14.0	18.4	24.3	14.9
10	21.4	15.7	27.4	28.7	19.7
15	26.2	19.0	33.8	31.8	23.1
20	30.3	23.3	41.0	36.0	25.7
25	34.2	27.6	49.2	39.4	28.6
50	72.7	68.5	144.8	73.7	47.7
75	256.3	275.4	411.2	229.8	129.9
80	341.5	371.9	553.2	297.0	176.7
85	492.0	560.1	832.1	407.7	259.3
90	843.6	1006.6	1399.3	656.6	427.9
95	1837.5	2170.9	2661.3	1407.6	955.4

	Site	W9 Pool			
	Variable	**Water height (m) above bed**			
	Flow	**Tillegra + Chichester**			
Percentiles					
Min	0.32	0.32	0.33	0.34	0.33
5	0.36	0.35	0.37	0.38	0.35
10	0.37	0.36	0.38	0.38	0.37
15	0.38	0.37	0.39	0.39	0.38
20	0.39	0.38	0.40	0.39	0.38
25	0.39	0.38	0.41	0.40	0.38
50	0.45	0.44	0.51	0.45	0.41
75	0.60	0.62	0.70	0.59	0.50
80	0.66	0.67	0.77	0.63	0.54
85	0.74	0.77	0.88	0.69	0.61
90	0.89	0.94	1.05	0.81	0.70
95	1.16	1.24	1.34	1.06	0.93

	Site	W9 Pool			
	Variable	**Wetted Perimeter (m)**			
	Flow	**Tillegra + Chichester**			
Percentiles					
Min	17.9	17.9	18.0	18.1	18.0
5	18.3	18.2	18.4	18.5	18.3
10	18.4	18.3	18.6	18.6	18.4
15	18.6	18.4	18.7	18.7	18.5
20	18.6	18.5	18.8	18.7	18.5
25	18.7	18.6	19.0	18.8	18.6
50	19.4	19.3	20.2	19.4	19.0
75	21.3	21.5	22.4	21.1	20.1
80	22.0	22.2	23.2	21.6	20.6
85	22.9	23.3	24.6	22.4	21.3
90	24.7	25.3	25.8	23.8	22.5
95	26.5	27.5	29.8	25.8	25.1

	Site	W9 Pool			
	Variable	**Average Velocity (m/s)**			
	Flow	**Tillegra + Chichester**			
Percentiles					
Min	0.00	0.00	0.01	0.02	0.00
5	0.03	0.03	0.04	0.05	0.03
10	0.04	0.03	0.05	0.05	0.04
15	0.05	0.04	0.06	0.06	0.05
20	0.06	0.05	0.07	0.06	0.05
25	0.06	0.05	0.08	0.07	0.05
50	0.12	0.11	0.18	0.12	0.08
75	0.27	0.29	0.38	0.26	0.17
80	0.33	0.35	0.46	0.30	0.21
85	0.43	0.46	0.57	0.38	0.28
90	0.58	0.63	0.76	0.50	0.39
95	0.88	0.95	1.04	0.76	0.61

Table C4 **Historic Percentiles for flow, water height, wetted perimeter and velocity at Glen Martin**

	Site	Glen Martin Riffle			
	Variable	Discharge ML/Day			
	Flow	Glen Martir			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.0	0.0	0.0	0.0	0.0
5	0.4	0.0	6.6	15.3	0.5
10	9.8	0.2	19.8	28.1	6.6
15	18.7	5.1	32.5	37.3	12.4
20	27.5	12.1	48.2	48.5	18.4
25	36.6	19.0	63.6	58.5	25.1
50	116.0	86.1	226.1	136.7	63.8
75	449.6	441.8	705.1	429.7	219.4
80	610.3	622.2	944.1	577.2	318.8
85	894.5	938.0	1381.6	834.5	502.1
90	1494.1	1598.5	2143.6	1428.5	804.5
95	3165.8	3354.4	4649.9	3073.2	1787.8

	Site	Glen Martin Riffle			
	Variable	Water height (m) above bed			
	Flow	Glen Martir			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.00	0.00	0.00	0.00	0.00
5	0.02	0.00	0.10	0.13	0.03
10	0.11	0.02	0.14	0.16	0.10
15	0.14	0.10	0.17	0.18	0.12
20	0.16	0.11	0.20	0.20	0.14
25	0.18	0.14	0.21	0.21	0.15
50	0.25	0.23	0.34	0.27	0.21
75	0.46	0.46	0.61	0.45	0.34
80	0.56	0.56	0.70	0.53	0.40
85	0.68	0.69	0.78	0.66	0.49
90	0.80	0.82	0.91	0.79	0.65
95	1.05	1.07	1.21	1.04	0.85

	Site	Glen Martin Riffle			
	Variable	Wetted Perimeter (m)			
	Flow	Glen Martir			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.0	0.0	0.0	0.0	0.0
5	0.4	0.0	3.4	4.7	0.5
10	4.0	0.3	5.3	6.1	3.4
15	5.1	3.1	6.5	6.9	4.3
20	6.0	4.3	7.5	7.6	5.1
25	6.9	5.2	7.7	7.7	5.8
50	8.2	7.9	9.3	8.4	7.7
75	10.8	10.7	18.1	10.6	9.2
80	14.4	14.9	23.1	13.2	10.0
85	22.3	23.0	26.0	21.2	11.3
90	26.5	27.2	29.7	26.2	20.6
95	32.0	32.3	34.3	31.8	28.3

	Site	Glen Martin Riffle			
	Variable	Average Velocity (m/s)			
	Flow	Glen Martir			
	All data	Summer	Autumn	Winter	Spring
Percentiles					
Min	0.00	0.00	0.00	0.00	0.00
5	0.32	0.00	0.57	0.76	0.42
10	0.65	0.22	0.82	0.84	0.58
15	0.81	0.57	0.84	0.84	0.70
20	0.84	0.70	0.86	0.86	0.81
25	0.84	0.82	0.95	0.90	0.83
50	1.17	1.07	1.40	1.23	0.95
75	1.65	1.65	1.71	1.65	1.39
80	1.69	1.69	1.73	1.69	1.55
85	1.72	1.73	1.85	1.72	1.67
90	1.89	1.91	2.02	1.87	1.72
95	2.23	2.27	2.51	2.21	1.95

	Site	Glen Martin Pool			
	Variable	Discharge ML/Day			
	Flow	Glen Martir			
Percentiles					
Min	0.0	0.0	0.0	0.0	0.0
5	0.4	0.0	6.6	15.3	0.5
10	9.8	0.2	19.8	28.1	6.6
15	18.7	5.1	32.5	37.3	12.4
20	27.5	12.1	48.2	48.5	18.4
25	36.6	19.0	63.6	58.5	25.1
50	116.0	86.1	226.1	136.7	63.8
75	449.6	441.8	705.1	429.7	219.4
80	610.3	622.2	944.1	577.2	318.8
85	894.5	938.0	1381.6	834.5	502.1
90	1494.1	1598.5	2143.6	1428.5	804.5
95	3165.8	3354.4	4649.9	3073.2	1787.8

	Site	Glen Martin Pool			
	Variable	Water height (m) above bed			
	Flow	Glen Martir			
Percentiles					
Min	1.74	1.74	1.74	1.74	1.74
5	0.92	1.74	1.76	1.80	1.74
10	1.78	1.74	1.82	1.84	1.76
15	1.82	1.75	1.85	1.86	1.79
20	1.84	1.79	1.88	1.88	1.82
25	1.86	1.82	1.90	1.89	1.83
50	1.97	1.93	2.09	1.99	1.90
75	2.27	2.26	2.42	2.25	2.08
80	2.37	2.38	2.50	2.35	2.17
85	2.49	2.50	2.64	2.47	2.30
90	2.67	2.70	2.82	2.65	2.46
95	3.04	3.07	3.31	3.02	2.74

	Site	Glen Martin Pool			
	Variable	Wetted Perimeter (m)			
	Flow	Glen Martir			
Percentiles					
Min	38.2	38.2	38.2	38.2	38.2
5	38.2	38.2	38.2	38.3	27.1
10	38.2	38.2	38.3	38.4	38.2
15	38.3	38.2	38.4	38.4	38.3
20	38.4	38.3	38.5	38.5	38.3
25	38.4	38.3	38.5	38.5	38.4
50	38.7	38.6	39.0	38.8	38.5
75	39.4	39.4	39.8	39.4	39.0
80	39.7	39.7	40.0	39.6	39.2
85	40.0	40.0	40.3	39.9	39.5
90	40.4	40.5	40.8	40.3	39.9
95	41.3	41.4	41.9	41.2	40.6

	Site	Glen Martin Pool			
	Variable	Average Velocity (m/s)			
	Flow	Glen Martir			
Percentiles					
Min	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.01	0.01	0.00
25	0.00	0.00	0.02	0.01	0.00
50	0.02	0.02	0.05	0.03	0.02
75	0.08	0.08	0.11	0.08	0.04
80	0.10	0.11	0.14	0.10	0.06
85	0.14	0.14	0.20	0.13	0.09
90	0.21	0.22	0.28	0.20	0.13
95	0.38	0.40	0.50	0.37	0.25

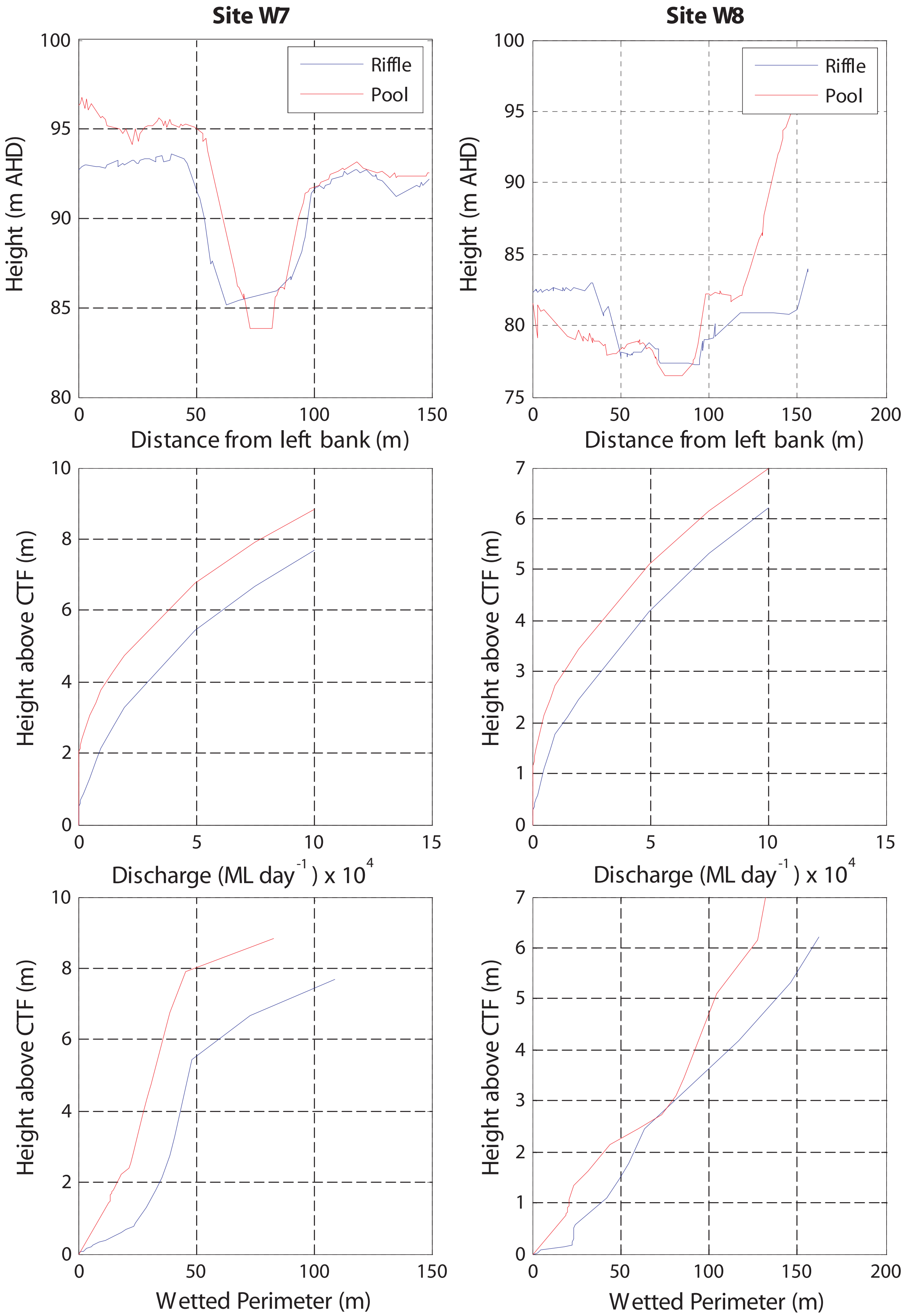

Figure C1 W7 and W8 pool and riffle bed levels discharge verses height and wetted perimeter verses height

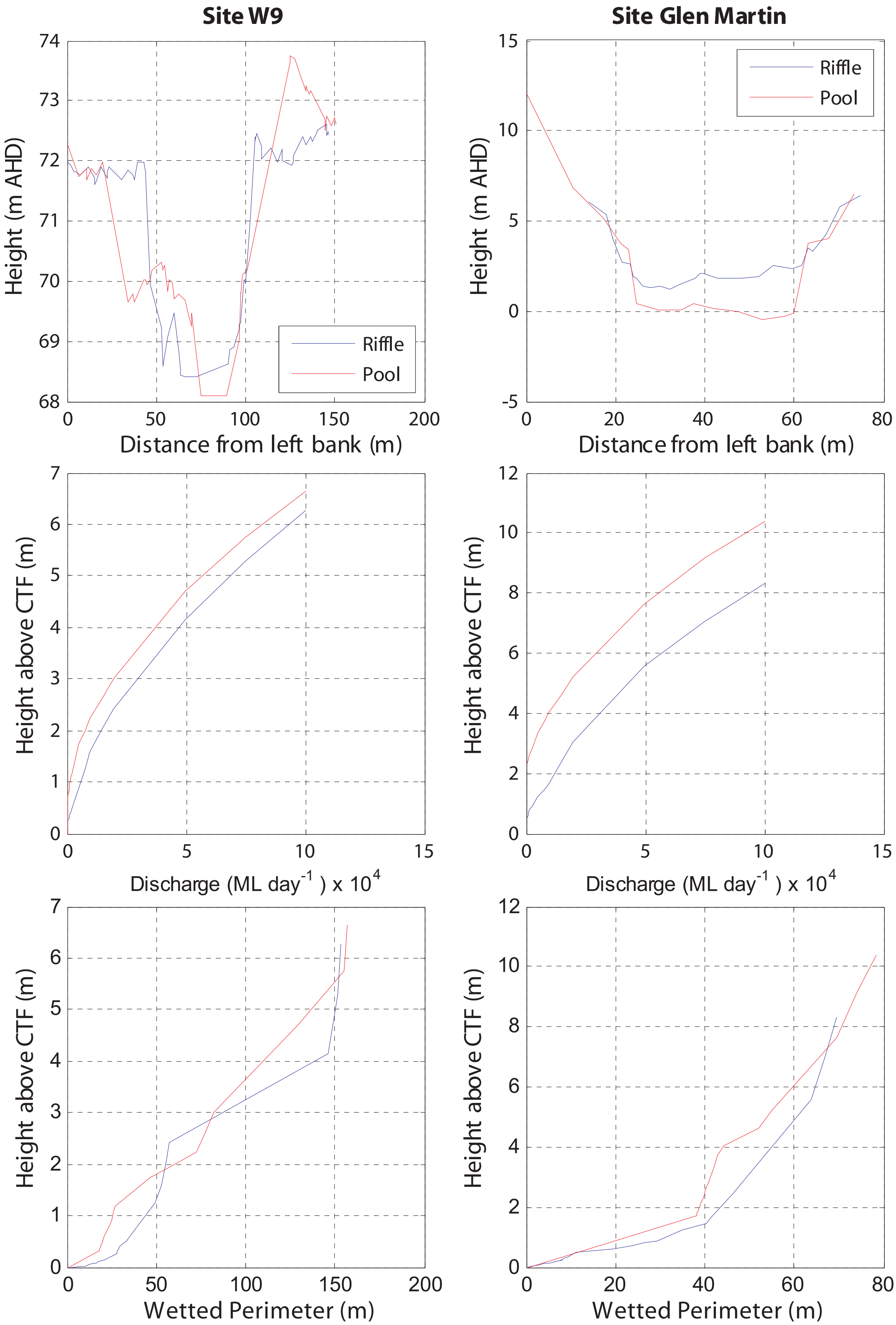

Figure C2 W7 and W8 pool and riffle bed levels discharge verses height and wetted perimeter verses height

Appendix D

Glennies Creek Catchment Characteristics

Glennies Creek Dam and the associated water storage, Lake St Clair, are located approximately 35 kilometres west of the proposed Tillegra Dam Site. Due to comparable size and location, Glennies Creek Dam was used as a model to make predictions about the likely water quality and stratification tendencies of the proposed Tillegra Dam. Information regarding the climate, catchment, dam characteristics, thermal behaviour, water quality and environmental flow provisions for Glennies Creek Dam are provided below.

Climate

The nearest appropriate site for climate data was Lostock Dam, located 15 kilometres east of Glennies Creek Dam and at a similar elevation. Climate statistics for this site are as follows:

- annually, the site receives 949 millimetres of rain from 132 rain days. The highest annual rainfall on record is 1329.6 millimetres and highest daily rainfall was 155 millimetres on 8 June 2007
- mean daily solar exposure is 16.6MJ/m^2 which typically peaks in January and is lowest in June
- daily evaporation is on average 4.4 millimetres
- mean maximum daily temperature varies from 29.2 degrees Celsius in January to 16.4 degrees Celsius in July.

Catchment

Glennies Creek Dam has a catchment of 23,300 hectares which is predominantly used for agricultural or conservation purposes. The reservoir has two major tributaries, Fal Brook and Carrow Brook, which provide 33 per cent and 22 per cent of inflow, respectively. Both waterways have their headwaters on the slopes of Mount Royal, north of the reservoir.

Dam characteristics

Glennies Creek Dam is a 67 metre high, 550 metre long concrete faced dam with a rock fill embankment. The reservoir has a capacity of 283 gigalitres and is used for water supply to the town of Singleton via pipeline and irrigation. The spillway has a capacity of 637 m^3/s but as of 2003 no spill had been recorded thus high flows are not experienced downstream of the dam.

According to ANCOLD records, there is no hydro-power infrastructure currently associated with the dam. State Water indicated in the 2005 Annual Report that there were plans to install hydro facilities which had been delayed due to recent low rainfall.

An incomplete record of storage releases, reservoir level and stream flow was available for Glennies Creek dam and downstream sites. This data indicates the average 24 storage release from the reservoir is less than 100 megalitres and the maximum release was 626 megalitres. High releases typically occurred over the summer period (late November to February) while releases in winter were significantly less.

Since mid 2001 the water level in the dam has been steadily declining with the only significant increase occurring in 2007 following a significant precipitation event on 8 June. This correlates to a decline in rainfall.

Flows recorded downstream of Glennies Creek Dam at The Rocks show that stream flow closely reflects the dam releases. However, in 2004 despite releases from the dam, Glennies Creek ceased to flow for several periods of around 7 days.

Thermal stratification behaviour

The reservoir stratifies annually, starting in late August and destratifying in early May. The effects of stratification include lower dissolved oxygen and higher iron and manganese levels within the deep waters of the reservoir. Large differences in surface and bottom water temperatures of up to 14 degrees Celsius have been recorded in Lake St Clair.

Blue-green algae can take advantage of stratified conditions if other requirements are also available. The presence of an algal bloom in a stratified storage can influence decisions to use a deeper intake to minimize the risk of releasing algal cells at the cost of releasing colder water.

Water quality

Typical conditions in the reservoir include pH concentrations slightly above neutral, low turbidity and moderate concentrations of nutrients, especially phosphorus and nitrogen. Particularly high total phosphorous concentrations have been recorded at sites where cattle have access to the foreshore areas of Lake St Clair.

Elevated concentrations of total iron and total manganese have also been recorded in the dam. Measurements from the late 1980's indicated that during a typical year in which Lake St Clair stratifies, manganese levels recorded in the deep waters over summer are unacceptable for drinking water.

Frequent blue-green algal blooms have been observed in Lake St Clair since construction of the dam. A major cyanobacterial bloom occurred in the reservoir in November 1998 following a large storm event and the recreation area was closed in response. Decreased vegetation cover and the limited storage capacity were considered contributing factors.

Environmental flow provisions

Under the Water Sharing Plan for the Hunter Regulated River Water Source, at the start of each year, 5000 megalitres (nominal) is reserved in an environmental contingency allowance account. Releases from the environmental contingency allowance can occur as part of the management of downstream water quality problems, including blue-green algae or diatom blooms. Any volume remaining in the environmental contingency allowance account at the end of a water year is to be forfeited from the account.

Domestic and stock rights can be restricted for environmental protection purposes and total extractions from each river are restricted to no more than 50 per cent of total flow during periods when supplementary water access licences may take water.

Under the Plan, maximum flow in Glennies Creek is limited to 5000 megalitres per day due to channel constraints.

Cold water pollution

Frequent algal blooms in Lake St Clair result in water releases from deeper in the dam, below the thermocline. The release of unseasonably cold water from deep layers of thermally stratified reservoirs during warmer months can pose a serious threat to the survival of aquatic fauna in downstream waterways.

Measurements in Glennies Creek one kilometres downstream of the dam show a reduced temperature range (typically 13-17 degrees Celsius) whereas 20 kilometres downstream of the dam the temperature range is much greater (typically 10-28 degrees Celsius). However, due to low discharges the impacts of cold water pollution is localised to within 20 kilometres of the dam and the Glennies Creek Dam has been assessed to have a medium level cold water potential, similar to that of nearby Lostock Dam.

A Cold Water Pollution Mitigation Working Group made recommendations to amend dam operating protocols to minimize cold water pollution effects.

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Appendix E

Subterranean Flows

This Appendix provides a coarse estimate of subterranean (below creek bed level) flows at the Tillegra site.

Groundwater flow beneath the river bed may be estimated from Darcy's law as follows:

$$Q = A * K * \frac{dh}{dx}$$

Where: Q = discharge through the soil/rock matrix (m3/s)
A = cross sectional area of the aquifer (square metres)
K = hydraulic conductivity (metres per second)
$\frac{dh}{dx}$ = hydraulic gradient or water pressure gradient along the direction of flow

Application of this law to the Tillegra site assumes the pervious river bed material may be treated as an unconfined aquifer.

The Williams River is underlain by impervious bedrock with an overlying gravel layer supporting the river. The depth of this riverbed gravel is unknown but estimates provided by HWC suggest thicknesses of between 1 and 15 metres below the surface.

The cross sectional area may be approximated as a rectangular section with the riverbed width of 50 to 100 metres and sediment depth ranging from 1 to 15 metres. Based on these estimate the cross sectional area of the below bed aquifer could be between 50 and 1500 square metres.

The hydraulic gradient, dh/dx may be approximated by the gradient of the bed slope which is about 1 in 500 (Land and Water Australia, 2008).

The hydraulic conductivity (K) varies widely with varying soil types. Hydraulic conductivity is a measure of how fast water will travel through the soil (ie. porosity of the soil) and is directly related to grain size. Recent site inspections suggest the surface of the riverbed is covered with medium sized pebbles as large as 100mm in diameter grading down to gravel and sand (<1 millimetre). Clays or silts could exist on the bottom of this permeable bed, however, due to their very small hydraulic conductivity values, can be neglected. Medium Sand (0.25-0.5 millimetres diameter), coarse sand (0.5-2 millimetres diameter) and gravel (2-64 millimetres diameter) have hydraulic conductivity ranges 5-20, 20-100, and 100-1000 meters per day respectively (Connected Water, 2008).

The bed flow estimates for the upper and lower ranges for both area and hydraulic conductivity gives the estimates shown in the table below.

A	K	dh/dx	Q (m^3/day)	Q (ML/day)
1500	1000	0.002	3000	3
1500	5	0.002	15	0.015
50	5	0.002	0.5	0.0005
50	1000	0.002	100	0.1

From online research, little information is available on the dimensions or soil makeup of the Williams River soil bed. There are no available borehole test data from the Williams River itself so there is still doubt as to the cross-sectional area and hydraulic conductivity of the river bed. However, a study done in 2005 on the permeability of the soil makeup in the Murrumbidgee River region (University of Wollongong, 2008a) could give an approximation of general riverbed makeup of rivers in NSW. This study contains borehole log data from an area approximately 2,500 square kilometre in the fork between the Murrumbidgee River and Yanco Creek (University of Wollongong, 2008b).

Since none of these borehole tests were done in the Murrumbidgee River itself, these values are not a true representation of flow beneath the river. Most likely the soil beneath the actual river has a higher permeability as some of the clays and silts which decrease permeability on dry land are washed downstream. As there is no way of calculating this difference an assumption that the hydraulic conductivity of the river bed is approximately twice that of the values calculated from the borehole data collected adjacent to the river was made. Since hydraulic conductivity is directly proportional to flow it gives a final flow value in the order of 200 to 300 kilolitres per day (0.2 - 0.3 megalitres per day).

The estimates vary from ~ 10-4 to 3 megalitres per day depending on the assumed values of the cross section area and hydraulic conductivity. Given the geology of the area it is likely that the bed of the Williams River is formed by fluvial bed load transport intersecting with rock outcrops that make up natural weirs and riffle sections. At these sections the subterranean flows is likely to be impeded and hence the cross section area of flowing groundwater would be small. On this basis it is likely that average ssubterranean flow along an extended (say kilometres) reach of river would be small and insignificant. There may exist, however, localised pools where subterranean aquifers may connect to aquifers downstream that could support flow from one pool to a point further downstream. This situation has been found to occur in streams along the Great Dividing Range. These flows are generally small and only noticeable during drought periods.

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Appendix F

Hydrodynamic Modelling of Proposed Tillegra Dam

Table of Contents

1. Introduction

1.1 Scope of work

In November 2006 the NSW Government announced a package of works to secure the water future of the lower Hunter and the Central Coast regions for at least the next 60 years. This includes the construction of a 450 gigalitre dam at Tillegra that will approximately double the existing water storage capacity of the Lower Hunter region.

The proposed Tillegra storage is similar in size, volume and depth to the Glennies Creek storage (Lake St Clair) some 30 kilometres to the west. Therefore, monitoring and specialist studies in Lake St Clair form a good indication of the likely behaviour of water quality in the proposed Tillegra storage.

The University of Western Australia, Centre for Water Research (CWR) monitored and studied stratification and water quality in the Glennies Creek storage in the early 1990's (Wright et al 1990 and Schladow, 1991). CWR installed an extensive data collection network on the Glennies Creek reservoir which included meteorological stations, water column profiling and inflow/outflow monitoring. Numerical modelling using the DYRESM package was undertaken to assist in the design of an aeration system to combat stratification and the model was also used for performance monitoring once the destratification system was installed.

For this study the one-dimensional hydrodynamic model DYRESM-CAEDYM (DYnamic REServoir Simulation Model – Computational Aquatic Ecosystem DYnamic Model) was used to study the effects of stratification in the proposed Tillegra Dam. The overall modelling philosophy is to build a robust demonstration model that may be refined at a later stage to design intake structures suited to a range of design conditions. The modelling in this study was undertaken in four distinctive stages:

- calibration of a 1990-1991 Glennies Creek storage DYRESM-CAEDYM model, using the validated DYRESM model results. The model was run using Glennies Creek and Warragamba Dam meteorological data
- validation of the Glennies Creek storage DYRESM-CAEDYM models to 2001-2002 thermocline recordings
- application of the DYRESM-CAEDYM model to the proposed Tillegra storage between 1 July 1990 and 30 June 1991

Available Glennies Creek meteorological data, covering an 8 month time period was used initially and results showed a reasonable comparison using the same period of data from Warragamba Dam. Therefore, to gain a reasonable depiction of the annual heat flux cycle at the proposed Tillegra Dam long term data from Warragamba Dam was applied to the model.

This study compares the hydrodynamic processes in Glennies Creek storage with the proposed Tillegra storage.

1.2 Surface heat flux

The overall heat flux in a reservoir is dictated by the surface heat transfers. A change in heat is representative of an energy change in the system which is driven largely by external forces. The total surface heat flux (Q_{tot}) of a reservoir is influenced by a series of heat exchanges as shown in Equation (1).

$$Q_{tot} = Q_{an} + Q_{sn} - Q_{br} - Q_{ev} - Q_{co} \qquad (1)$$

A reservoir gains heat through atmospheric radiation (Q_{an}) and solar radiation (Q_{sn}). A reservoir losses heat through back radiation (Q_{br}), evaporation (Q_{ev}) and convection (Q_{co}). The balance of these heating and cooling processes results in the total surface heat flux (Q_{tot}) of a reservoir. Refer to Appendix F1 for a detailed analysis of surface heat flux.

Solar radiation is the dominant force controlling the total surface heat flux in a reservoir. During summer when there is increased solar radiation the surface waters heat at a faster rate than they can loose heat through back radiation, evaporation and convection. During winter there is less solar radiation reaching the water body, but the energy loss through back radiation, evaporation and convection remain constant. This results in an overall temperature drop in the surface waters during the winter months. This heating and cooling process leads to stratification in reservoirs and lakes.

The stratification cycle generally occurs on an annual basis. During the summer months warmer weather results in the heating of surface water. Turbulent atmospheric conditions, such as wind and precipitation, induce mixing within the top layer of water (epilimnion). The warmer top layer continues to heat over the summer months increasing the temperature difference between the epilimnion and hypolimnion (colder bottom layer). The warmer, less dense water effectively floats on top of the cold denser water. During the autumn and winter months the temperature of the eplimnion drops as the atmosphere starts to cool. As the surface water cools, it gets ‘heavier’ and starts to drop down into thermocline, creating a mixing effect between layers. With continued cooling stratification weakens and ultimately the reservoir may become completely mixed and the temperature becomes uniform with depth.

2. Model overview

DYRESM-CAEDYM is a quasi-one dimensional hydrodynamic model used to predict the thermal structure and mixing processes in small to medium sized lakes and reservoirs (CWR, 2008). This model is based on a Lagrangian layer scheme, where the reservoir response to mixing processes is induced by meteorological conditions, inflows and outflows. Mixed layer deepening is modelled as convective overturn resulting from surface cooling, wind mixing, induced shear and billowing in the pycnocline. Turbulent transport in the hypolimnion (bottom layers) is modelled as diffusion-like processes.

CAEDYM is an aquatic ecological model that is 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 variables, parameters and coefficients used in the simulation of reservoir water quality and ecosystems. The coefficients and parameter values used in the standard CAEDYM distribution were adopted for application to the Tillegra storage.

2.1 Glennies Creek storage

Glennies Creek Dam is a 67 metres high, concrete faced, rock fill embankment dam located on Glennies Creek near Singleton, New South Wales. Glennies Creek is a tributary of the Hunter River in the foothills of the Barrington Tops National Park. The reservoir, referred to as Lake St Clair, is up to 16 kilometres long, has a capacity of 283 gigalitres and a surface area of 1,538 hectares.

Glennies Creek storage is located approximately 30 kilometres west of the proposed Tillegra Dam. The Glennies Creek storage is of similar size, depth, volume and meteorological characteristics to the proposed Tillegra Dam and as such, previous studies by CWR of the Glennies Creek storage (Wright et al, 1990 and Schladow, 1991) have been utilised to create and validate a model for the proposed Tillegra Dam. Characteristics of the Glennies Creek storage are summarised in Table F1.

Table F1 Glennies Creek storage – elevation levels and storage capacities

	Elevation (m R.L)	Surface area (Ha)	Storage volume (ML)
Zero storage	130.5	0	0
Offtake level (after 05/1989)	180.48	1,256	199,690
FSL	186.00	1,540	283,370

2.1.1 Meteorological and other recorded information

The report 'Glennies Creek Reservoir Destratification Project – Progress Report' (Wright et al 1990) provides information about the reservoir's thermal loading. The report outlines available data from the storage which includes:

- high resolution meteorological data (commenced July 1989) including wind speed, wind direction, rainfall, relative humidity, air temperature, surface water temperature and radiation
- UNIDATA meteorological data (commenced April 1989) including wind speed, wind direction and thermistor chain data
- profiling data (commenced February 1989) including conductivity, temperature and dissolved oxygen
- inflow gauging data - two permanent inflow gauging stations commenced recording discharges at Fal Brook (station 21023) and on Carrow Brook (station 210114) in November 1989. Temporary stations on Carrow Brook and Babuc Creek commenced recording in April 1989. Inflow volumes to the reservoir are comprised of 33 per cent from Fal Brook, 24 per cent from Carrow Brook and 36 per cent from small creeks and direct runoff.

- the outflows for Glennies Creek storage comprise daily records of discharge valve settings, downstream river gauging, volume of water supplied for domestic use in Singleton and any overflow through the spillway.

Limited data from the above CWR investigations were available in a useable format for this study. Meteorological data from the high resolution weather station was available for an 8 month period in 1990-1991.

2.1.2 Lake temperature data

Thermal data for Lake St Clair was collected by State Water over the 2001-2002 year. Unfortunately, this information is not accompanied by local measurements of meteorological variables: radiation, air temperature, humidity, wind, inflow or water level measurement and therefore cannot be used for model calibration. The data can, however, provide an indication of the annual stratification cycle in the reservoir at a similar water level and discharge volume to the 1990-1991 period. Figure F1 shows the heating and cooling process in the Glennies Creek storage over 2001-2002.

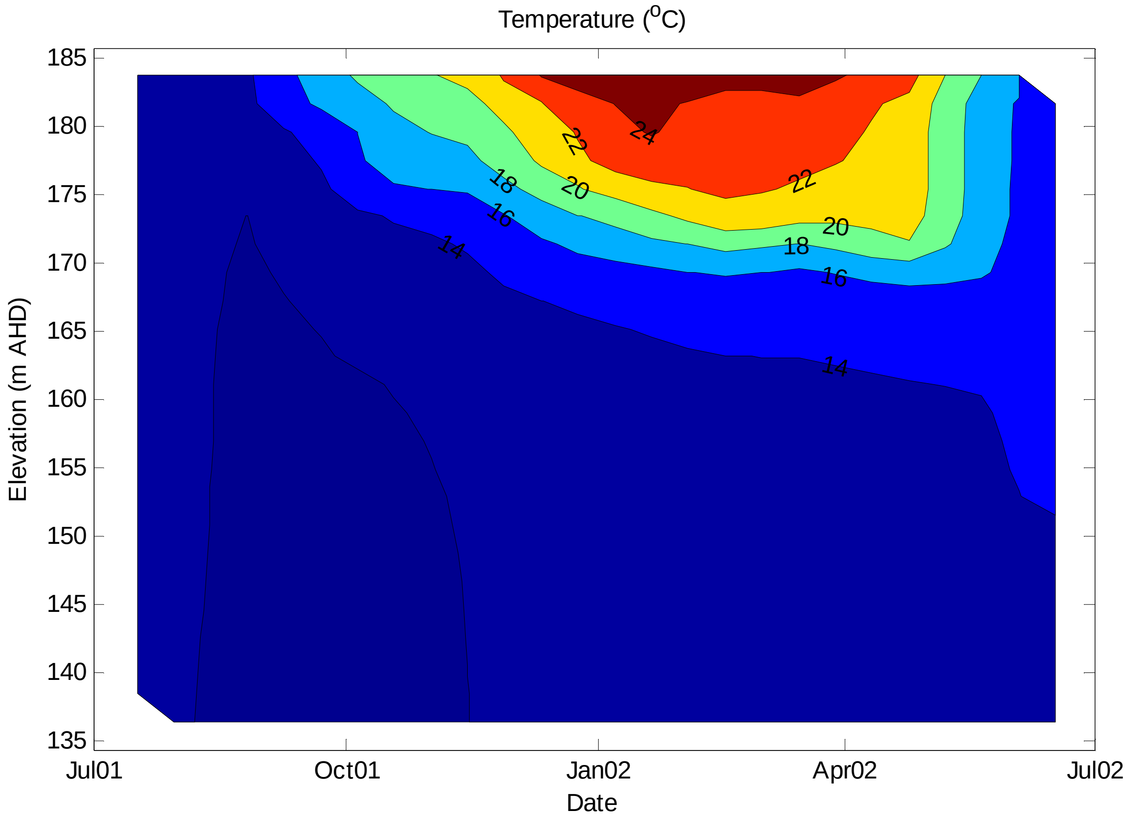

Figure F1 2001-2002 temperature contours versus time

Figure F1 shows the Glennies Creek storage typically stratifies during spring and summer with cooling during autumn and winter when the storage becomes mixed from surface to bottom. The change in temperature from top to bottom is often characterised by a rapid change at a depth that is referred to as the thermocline. The depth of the thermocline increases as surface heating progresses through spring and summer, reaching about 15 to 20 metres at a maximum. The thermally mixed surface layer during summer generally extends over 5 to 10 metres depth. Surface (epilimnic) temperatures range from about 14 degrees Celsius in July to about 24 degrees Celsius in February. The bottom (hypolimnic) temperatures vary less than the surface temperatures and range from the winter minimum of about 11 degrees Celsius in August to about 13 degrees Celsius in May following complete mixing of the summer stratification

2.1.3 Previous modelling (CWR)

CWR in the early 1990's used DYRESM to predict the thermal structure and mixing in the Glennies Creek storage (Wright et al 1990 and Schladow, 1991). The heat exchange at the surface is modelled in one dimension and thus represents a simplification of the surface of the reservoir. Also the model represents principally heat exchange across layers as a diffusion process, while it is likely that this heat exchange is principally induced by turbulent mixing and baroclinic processes. The thermocline gradient would be significantly 'smoothed-out' by the DYRESM diffusion modelling.

The model was calibrated and validated using the data collected by CWR. DYRESM represents the most advanced stratification model available at the time of writing that replicates satisfactorily the 1990-1991 thermocline build-up. Figure F2 shows the DYRESM model results for January 1991 for the CWR model run. Surface waters are relatively uniform in temperature to a depth of around 7 metres, approximately 25ºC ±1ºC. The thermocline sits around 12 metres below the lake surface where temperatures drop to 14ºC ±2ºC.

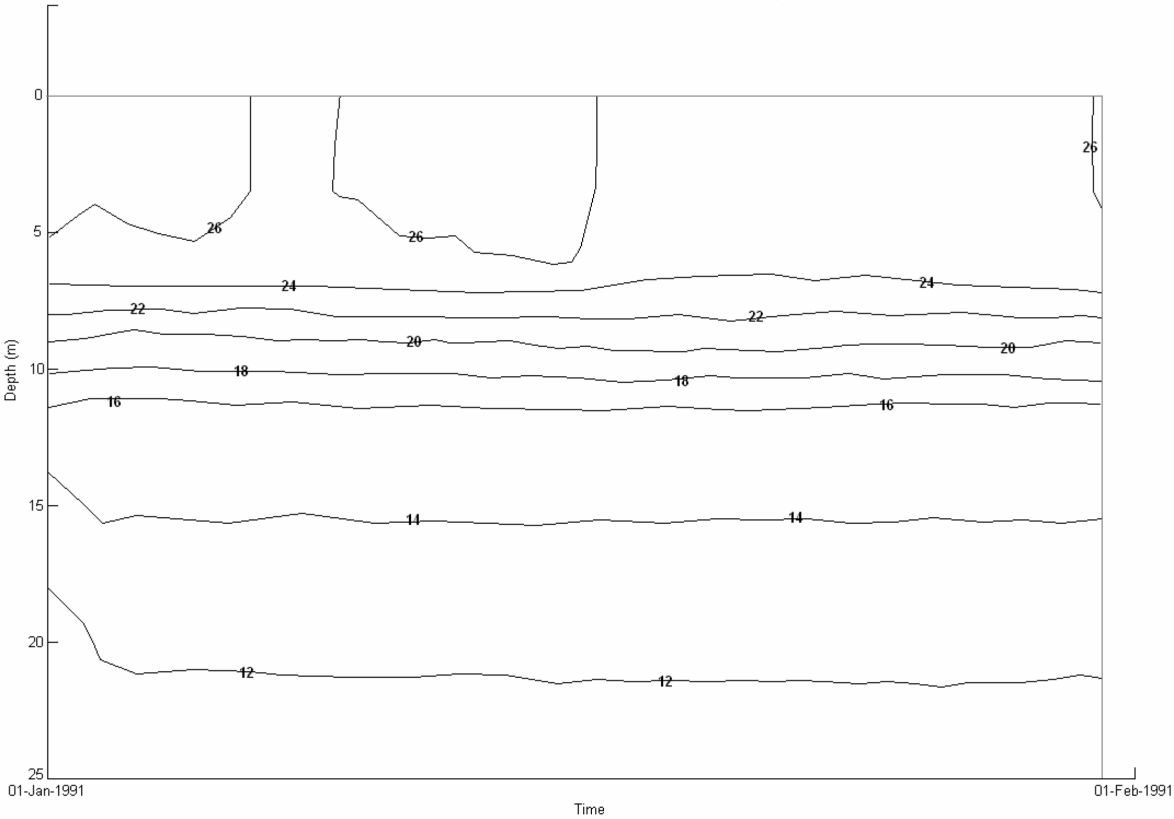

Figure F2 Glennies Creek Stratification model (January 1991)

2.2 Proposed Tillegra Dam

Tillegra was first proposed for a dam during the 1950s due to its large catchment area, adequate rainfall and limited environmental impacts. Tillegra Dam is proposed to be used as a drought storage and operated between 90 and 100 per cent of FSL, outside of drought periods. During droughts, water would be delivered to Grahamstown Dam by controlled releases into the Williams River. HWC has developed a hydrological model for future demand scenarios which are based on observed inflows from 1931 to 2007. The model assumes a continued maximum environmental flow release of 14 megalitres per day from Chichester Dam.

At FSL the proposed reservoir will cover 2,100 hectares of farmland, will have a maximum depth of 72.5 metres and will have a storage capacity of 450 gigalitres. A concrete faced rockfill dam design has been recommended for the proposed Tillegra Dam. Characteristics of the proposed Tillegra Dam are summarised in Table F2.

Table F2 Tillegra Dam storage – approximate elevation levels and storage capacities

	Elevation(m R.L)	Surface area (Ha)	Storage volume (GL)
Zero storage	78.00	0	0
FSL	150.50	2,100	450

3. Model set-up

The DYRESM-CAEDYM model has the ability to model a large array of possible state variables in a dynamic water body. The model uses daily averaged forcing data and considerably simplifies the reservoir hydrodynamic, turbulence level and boundary layers. Hence, data for a large range of daily variables is required in the DYRESM-CAEDYM input files.

3.1 Model input overview

DYRESM-CAEDYM requires a variety of input data to simulate heat flux to and from the reservoir and mixing within the reservoir. For both the Glennies Creek and the proposed Tillegra Dam storage simulations the required meteorological data have been sourced from a variety of locations. Data has been collated and used during this investigation. The source of data for Glennies Creek and Tillegra Dam model simulations are highlighted in Table F3.

Table F3 DYRESM-CAEDYM input data

Input Data	Glennies Creek Data Source	Proposed Tillegra Data Source
Physical Data	CWR Destratification Reports (Wright et al 1990, Schladow, 1991)	Proposed Tillegra Dam Design
Lake Morphology	CWR Destratification Reports (Wright et al 1990, Schladow, 1991)	Tillegra LiDAR Information
Meteorological Data	CWR DYRESM Model (1990-1991) Warragamba Dam (1990-1991)	Warragamba Dam (1990-1991)
Inflow Data		
- Volume	CWR DYRESM Model (1990-1991)	HWC Hydrology Model 1931-2007 (1990-1991)
- Other Parameters	CWR DYRESM Model (1990-1991)	HWC Tillegra Bridge Measurements (1987-2007)
Initial Profile Data	CWR DYRESM Model (1990-1991)	CWR DYRESM Model (1990-1991)
Outflow Data	CWR DYRESM Model (1990-1991)	HWC Hydrology Model 1931-2007 (1990-1991)

Available data was not always in an appropriate time step or time period, and hence adjustment was required for this study. Care must be taken to ensure all data input is correct, and that correct units are used. The data used by CWR to create the DYRESM model for Glennies Creek spans the period from 3 August 1990 to 11 April 1991. To simulate a full year stratification cycle data collected from Warragamba Dam was applied for the period 1 July 1990 to 30 June 1991. Warragamba Dam meteorological data showed a reasonable comparison with the Glennies Creek data for the same time period, August 1990 to April 1991.

The model was initially set up for the Glennies Creek Storage as reported by CWR (Wright et al 1990 and Schladow, 1991). Model inputs were then adjusted to simulate the proposed Tillegra Storage. A detailed summary of the data files used in the DYRESM-CAEDYM model is given in Appendix F2.

3.2 Physical data and lake morphology

The physical data required for DYRESM-CAEDYM modelling includes information regarding the physical characteristics of the dam structure and lake. Information required includes:

- latitude
- number of inlets/outlets
- reservoir hypsographic information
- dam base and crest elevations

For the Glennies Creek model, all physical and lake morphology data was provided by State Water as reported in Wright et al (1990) and Schladow (1991). For the proposed Tillegra Dam, physical characteristics were obtained from the proposed dam design:

- dam base at 86 metres AHD
- dam wall crest at 152.5 metres AHD
- one inflow structure from the Williams River
- one outlet structure at varying depths

The Tillegra hypsographic information was derived from LIDAR terrain information provided by HWC.

3.3 Meteorological data

The local meteorological conditions determine the heat flux to a reservoir. The Glennies Creek model was originally run using the CWR DYRESM model data. As the data did not span an annual stratification cycle, an alternate set of suitable meteorological data was required to simulate the yearly cycle at Tillegra. Meteorological data from Warragamba Dam was utilised as the data showed a reasonable comparison of the heat flux calculated using the original CWR data.

The input meteorological data file for the model contains all the atmospheric data for the simulation period. The DYRESM data inputs are the average values over the time step used for calculation. The model was set up to run with daily averages. The data required for model input is outlined in Table F4.

Table F4 Meteorological data required by DYRESM

Variable	Measured by	Unit
Short wave radiation indicator	Average of the total short wave radiation	W/m^2 (= $J/m^2/sec$)
Long wave radiation indicator	Cloud cover	Fraction (valid range [0,1])
Temperature	Daily average air temperature	°C
Average vapour pressure	Daily average vapour pressure	hPa
Average wind speed	Daily average wind speed	m/s
Rain	Total precipitation	mm

3.4 Inflow data

The inflow file represents the characteristic creek/streams flowing into the reservoir and must be available for the entire simulation period. Inflows influence the water balance and heat content of the reservoir, and also influence mixing. The Glennies Creek inflow files were extracted from the CWR DYRESM information. The Glennies Creek model included five inflows into the reservoir.

Inflow data for the proposed Tillegra Dam was collated from a variety of sources. Discharge to the proposed Tillegra Dam was extracted from Tillegra gauge records. As this site does not record temperature, inflow temperatures, where possible, were extracted from the corresponding dates for Glennies Creek inflows. Inflow concentrations of chemical and biological parameters were taken as the average levels (between 1987 and 2007) from HWC measurements at the Tillegra Bridge site.

3.5 Initial profile

The initial profile provides DYRESM the starting point for modelling. The simulation starts at midnight on the first simulation day (i.e. midnight the day before). The initial profile is specified at the deepest point of the reservoir and inputs of temperature and salinity are required. The Glennies Creek model was based on initial temperature profiles collected in the reservoir in late winter when the reservoir was almost fully mixed. The same temperature profile was adopted for the proposed Tillegra Dam.

3.6 Withdrawal data

Withdrawal data is the volume of water discharged from the modelled dam. The temperature of the discharge depends on the level of the outlet (specified as part of the physical data). The withdrawal data for the Glennies Creek model was provided with the CWR DYRESM model inputs data. For the proposed Tillegra Dam it was assumed there were no withdrawals and only spillway overflows could occur. The initial water level was set to 90 per cent full and the 200-2001 dry period selected for the simulation period. During this period there were no significant inflows and hence no overtopping of the spillway. This period was considered to highlight the maximal stratification due to thermal inputs that the reservoir is likely to experience.

4. Model verification

4.1 Glennies Creek model results (1990-1991)

The DYRESM-CAEDYM model for the proposed Tillegra Dam was verified using the previous model of Lake St Clair reported in Wright et al (1990) and Schladow (1991). The CWR model simulated the heat flux in Glennies Creek during January 1991, as shown in Figure F2 for the reservoir with no artificial mixing. This model showed the thermocline at around 12 metres depth.

The present Lake St Clair model showed good agreement with the results with a similar stratification during January as highlighted in Figure F2. When the Warragamba data was substituted, and the modelling period extended to a full year, the heat flux and stratification was also similar to the CWR model. The model showed a similar mixing layer of 12 metres during the summer months with the hypolimnion extending from 12 metres to the bottom at a uniform temperature of 12 degrees Celsius.

The use of meteorological data from Warragamba Dam provided a reasonable representation of the Glennies Creek heat flux in 1990-1991.

4.2 Glennies Creek thermal data (2001-2002)

Thermal profile data collected during 2001-2002 in Lake St Clair is shown in Figure F1. These data provide an estimate of the heat content in Lake St Clair. These results show surface heating in the reservoir begins around September, reaching a maximum in February with the depth of the thermocline extending to around 20 metres. As the reservoir cools, complete mixing occurs and uniform temperatures throughout the water column result in July and August.

The results for the Glennies Creek model using Warragamba meteorological input data show similar stratification over summer similar to the 2001-2002 thermal measurements. The modelled maximum surface temperatures are similar to those measured during 2001-2002. The thermocline extends between 7 and 15 metres below the surface level during the period of maximum temperatures.

5. Tillegra Dam model results

Results from the DYRESM-CAEDYM modelling of the proposed Tillegra Dam are provided in Figures F3 to F5.

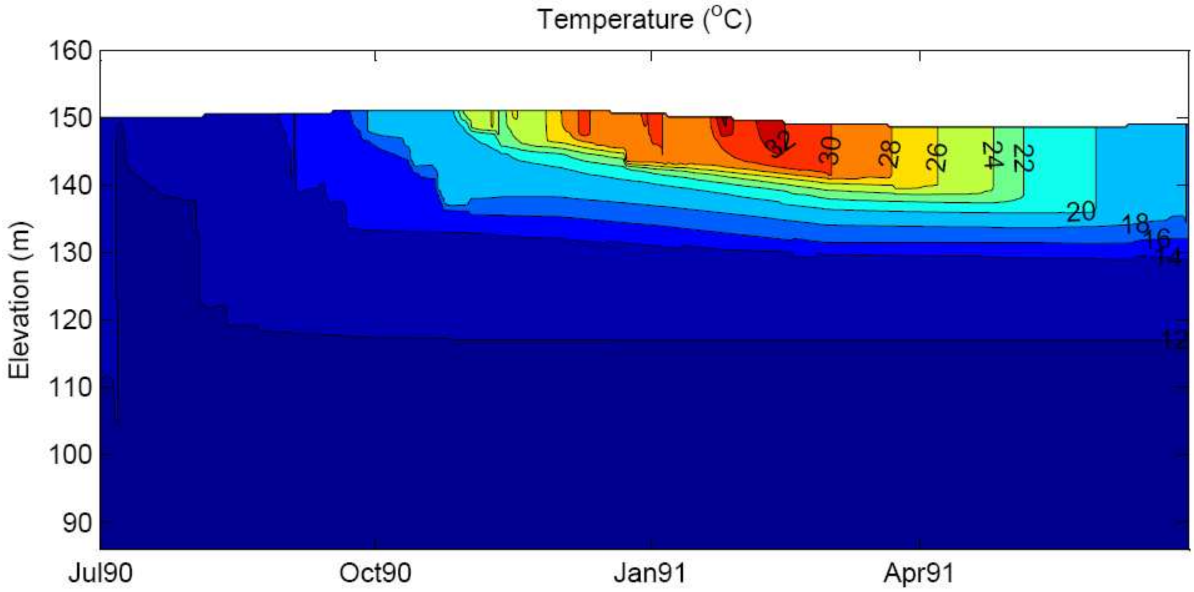

Figure F3 Temperature contours for the proposed Tillegra Dam versus time (1990-1991)

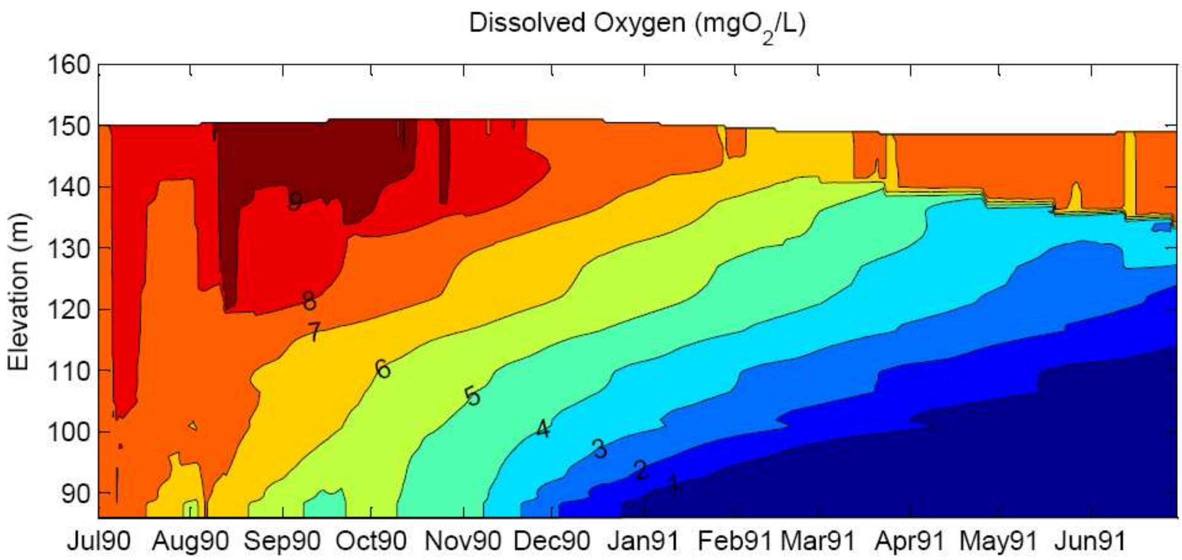

Figure F4 Dissolved oxygen contours for the proposed Tillegra Dam versus time (1990-1991)

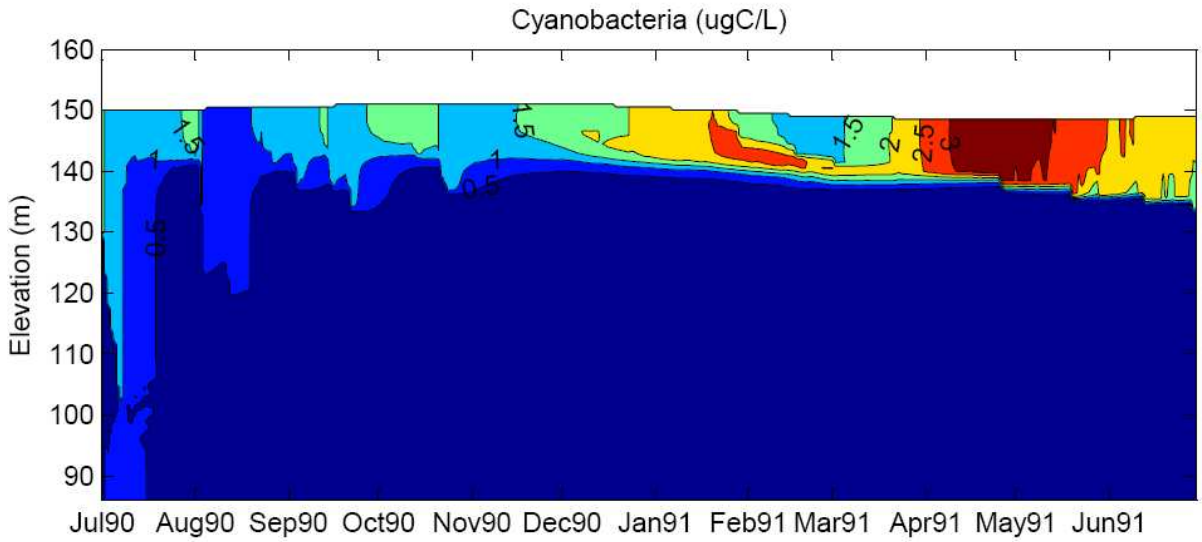

Figure F 5 Cyanobacteria contours for the proposed Tillegra Dam versus time (1990-1991)

6. Discussion

6.1 Stratification

Figure F3 shows that the proposed Tillegra Dam is likely to stratify during the spring and summer months and become well mixed in late winter as the reservoir cools. In some years a weak stratification may persist through the winter as suggested for the Tillegra simulation at the end of the model run at the end of June. It is likely this will become completely mixed during colder periods in July and August. The depth of the thermocline increases as surface heating progresses reaching about 20 metres at a maximum. Surface (epilimnic) temperatures range from about 32 degrees Celsius in February to about 14 degrees Celsius in July. The bottom (hypolimnic) temperatures vary less than the surface temperatures and range from 10 to 12 degrees Celsius.

During the dam filling phase it is suggested that stratification of the storage would develop on an annual basis once mean depth was greater than about 10 metres.

6.2 Water quality

6.2.1 Dissolved oxygen

The modelled dissolved oxygen concentration profiles at the proposed Tillegra Dam are displayed in Figure F4. Concentrations in the waters above the thermocline meet the ANZECC (2000) guidelines of 80 to 110 per cent saturation (~>6mgDO/L) in the surface mixed layer to about 8 metres depth for the simulated year. The dissolved oxygen concentration in deeper waters declines during the summer months leading to conditions favourable to the release of nutrients, iron and manganese from the sediments as currently occurs at Lake St Clair.

6.2.2 Blue-green algae

The water quality model results for cyanobacteria (Figure F5) 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 whether they are likely to exceed guidelines.

6.3 Outlet level issues

Management of the releases to meet relevant downstream water quality objectives are proposed to be achieved by release of surface water from the dam. HWC propose to install a multi-level off take at Tillegra Dam which will enable warmer, well oxygenated surface water to be released to the Williams River. The benefits of this approach, compared to a water release from the bottom of the reservoir, are assessed below to demonstrate the benefits to downstream aquatic life.

The key water quality criteria considered to be relevant to demonstrate the benefits of the proposed offtake to downstream aquatic life are temperature, dissolved oxygen and blue-green algae.

The aim of the surface release is to mimic the dam inflow temperatures and dissolved oxygen and to have blue green algae levels in the river which meet the NH&MRC guidelines for recreational use. These measures are expected to protect downstream aquatic life, including fish-spawning and larval development. This assumes that the biological requirements of the fish and other aquatic life are adapted to the natural seasonal variation in the Williams River temperatures.

<u>Expected downstream temperatures</u>

It is expected that the proposed Tillegra Dam will stratify during summer and become mixed during winter following autumn cooling. The warm surface layer during summer generally extends over 5 to 10 metres. Winter temperatures in this depth range also tend to be warmer than in the deeper waters. It is proposed that surface water from the 5 to 10 metre layer would be released.

A release from the 5 to 10 metres depth range should not cause a significant effect on the downstream temperatures or on the spawning success of fish in the Williams River.

Expected downstream dissolved oxygen concentrations

Dissolved oxygen concentrations in the waters above the thermocline meet the ANZECC (2000) guidelines of 80 to 110 per cent saturation in the thermally mixed surface layers to about 8 metres depth.

The CAEDYM model results for the proposed Tillegra Dam Storage show a decrease in dissolved oxygen with depth, even during winter. It is proposed that surface releases from the dam be facilitated by an appropriate multi-level intake infrastructure. The available water quality data indicates a release from the 5 to 8 metres depth range in Tillegra Dam would be expected to give similar downstream dissolved oxygen concentrations as presently occur upstream of the dam. During the short period of well mixed conditions in July and August releases from any depth would provide similar quality water to the inflow quality.

Expected downstream blue-green algae concentrations

The depth at which releases could be expected to avoid significant releases of blue-green algae to the Williams River should be selected to avoid releases above the NH&MRC recreational guidelines of 50,000 cells per millilitre. The coarse sensitivity of the model means the magnitude of blooms and whether they exceed recreational guidelines can not be determined. A depth estimate of around 6 metres may be used to obtain cyanobacteria below guideline levels.

Release depth

From the above examination of the available profile data, releases of acceptable levels of temperature and dissolved oxygen, as well as blue-green algae to meet the NH&MRC guidelines is expected to be achieved by a multi-level intake structure set at around 6 to 8 metres below the surface most of the year.

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Appendix F1 – Heat flux estimates

Meteorological data can be used to determine the surface heat flux of a reservoir. There are five main forces causing heat flux in a free surface water body, such as:

- Solar radiation
- Atmospheric radiation
- Back radiation
- Evaporative forces
- Convective forces

The total heat flux in a water body is the sum of above fluxes, calculated using equation (2).

$$Q_{tot} = Q_{an} + Q_{sn} - Q_{br} - Q_{ev} - Q_{co} \tag{2}$$

F1.1 Heat flux due to solar radiation (Q_{sn})

Heat flux due to solar radiation is induced by short-wave radiation from the sun that reaches the water body, heating or cooling the body's surface temperature. In the absence of direct measurements it may be calculated using the lakes geographical position on the earth's surface, local time and the fraction of cloud covering the sky on that day.

$$\delta = \frac{23.5\pi}{180}\cos\left(\frac{(172 - DN)\pi}{180}\right) \tag{3}$$

$$\sin(\gamma) = \sin(\delta)\sin(\varphi) - \cos(\delta)\cos(\varphi)\cos\left(\frac{(12 - hr)\pi}{180}\right) \tag{4}$$

Equation (3) and (4) are used to calculate the earth tilting angle (δ) and solar elevation angle (γ) respectively. This factor represents the angle of the solar radiation hitting the lake. *DN* is the day number in the year (1 January = 1, 31 December = 365), *hr* is the hour of the day that the sample was taken and φ is the latitude of the reservoir.

$$if \begin{cases} \sin(\gamma) > 0, & Q_{sc} = 0.76S\sin(\gamma) \\ \sin(\gamma) \le 0, & Q_{sc} = 0 \end{cases} \tag{5}$$

Where *S* is the solar constant. The incoming short-wave solar radiation through clear sky at ground level is about 0.76 of the flux incident at the top of the atmosphere (DELFT3D). At a certain angle, the solar radiation reflects off the atmosphere (hence $Q_{sc} = 0$) as in (5).

From there, using the albedo reflection coefficient (β), the flux due to solar radiation can be determined using equation (6), where F_c is the percentage of sky covered by clouds.

$$Q_{sn} = (1 - \beta)Q_{sc}(1.0 - 0.4F_c - 0.38F_c^{\,2}) \tag{6}$$

F1.2 Heat flux due to atmospheric radiation (Q_{an})

Heat flux due to atmospheric radiation is primarily caused by the emission of absorbed solar radiation by water vapour, carbon dioxide and ozone in the atmosphere (DELFT3D). Stefan-Boltsmann's law is used to determine the amount of atmospheric radiation that reaches the earth's surface. Hence, the heat flux due to atmospheric radiation is calculated using equation (7).

$$Q_{an} = (1-r)\varepsilon\sigma\overline{T}_a^{\,4}(1.0 + 0.17F_c^{\,2}) \quad (7)$$

Where *r* is the reflection coefficient, ε is the emissivity of atmosphere, σ is the Stefan-Boltamann's constant (J/m^2sK^4) and $\overline{T}_a$ is the air temperature in degrees Kelvin.

F1.3 Heat flux due to back radiation (Q_{br})

Water acts as a near black body; hence the heat radiated back by the water can also be described by the Stefan-Boltzmann's law of radiation, corrected by the before mentioned reflection coefficient (*r*) and emissivity coefficient (ε).

$$Q_{br} = (1-r)\varepsilon\sigma\overline{T}_s^{\,4} \quad (8)$$

Where $\overline{T}_s$ is the water surface temperature in degrees Kelvin.

F1.4 Evaporative heat flux (Q_{ev})

Evaporation is an energy exchange process that takes place at the interface between water and air. It is largely driven by the meteorological conditions of the area and responsible for the cooling of water temperatures. The evaporative heat flux was calculated as in equation (9).

$$Q_{ev} = L_v c_E U q_s (1 - r_{hum}) \quad (9)$$

Where L_v is the latent heat of evaporation constant and c_E is the specific heat of water at a constant pressure. U represents the wind speed in m/s, q_s is the saturated specific gravity of the air in kg/kg and r_{hum} is the relative humidity as a percentage.

F1.5 Convective heat flux (Q_{co})

Assuming a turbulent exchange of heat between the air-water interface equals the turbulent exchange of mass (DELFT3D), the heat flux due to convective forces can be related to the evaporative heat flux through equation (10).

$$Q_{co} = R_b Q_{ev} \quad (10)$$

Where $R_b = \gamma \dfrac{T_s - T_a}{e_s - e_a}$ (11)

And $e_s - e_a = (1 - r_{hum})23.38e^{18.1 - \frac{5303.3}{\overline{T}_a}}$ (12)

Where γ is the Bowen constant and T_a is the air temperature in degrees Celsius while $\overline{T}_a$ is the air temperature in degrees Kelvin.

Appendix F2 – DYRESM-CAEDYM file specification

DYRESM-CAEDYM input files for the proposed Tillegra Dam include:

- DYRESM Configuration File
- CAEDYM Configuration File
- DYRESM Parameters File
- CAEDYM Parameters File
- physical Data and Lake Morphology File
- meteorological Data
- inflows File
- initialisation File
- initial Profile File
- withdrawals File

F2.1 DYRESM Configuration File (.cfg)

The DYRESM configuration file contains the configuration information for a particular simulation. It contains information regarding the start time and length of the model. The data needed to run the model was for a range of different time steps and date ranges. Hence, an arbitrary start date was set to base the simulation. The majority of the data required was available between 1 July 1990 and 31 June 1991, a total of 365 days. This period was adopted and any missing data was retrieved from corresponding dates in different years.

This configuration file also determines the type of DYRESM model to run. There are switches to control whether CAEDYM is run, whether there is destratification occurring and what output parameters are necessary. The level of detail of the investigation, controlled by the layer thickness boundary conditions and the simulation time step are also contained in this file.

F2.2 CAEDYM Configuration File (.con)

The CAEDYM simulation file contains information controlling how CAEDYM is run in the model. There are also a number of switches that control the type of biological, chemical and nutrient simulation to run. The CAEDYM configuration file was left untouched from the example cases.

F2.3 Parameters File (.dat and .par)

The DYRESM (.dat) and CAEDYM (.par) parameters files were left unchanged from the DYRESM-CAEDYM example models. They contain the parameters and coefficients used for the lake simulation.

F2.4 Physical Data and Lake Morphology (.stg)

This file contains a description of the morphometric characteristics of the water body. The latitude of Tillegra Dam, the nature and number of inflowing streams and outlet level are all detailed in this file. The model was run with one outlet structure and one inflow from an upstream catchment. The half-angle slope and drag coefficients for the inflow stream were all adopted from the previous Glennies Creek studies.

The file also contains the hypsographic information outlining the lake surface area (square metres) and volume (cubic metres) at the water depths (metres). The hypsographic information is derived from LIDAR terrain information, Tillegra observations and estimates of typical withdrawal releases. The proposed Tillegra Dam dimensions are set out in this file, with the base and crest elevations at 86 metres and 152.5 metres above sea level, respectively.

F2.5 Meteorological Data (.met)

The largest contributor to heat flux in a reservoir is the local meteorological conditions. As the meteorological data recovered at the reservoir (1990-1991 UNIDATA) is of a shortened time period, appropriate substitute data was implemented to run the model. This data covering an 8 month period was used initially and results showed a reasonable comparison with meteorological data of the same time from Warragamba. The Warragamba data covers a much longer date range and hence was utilised in modelling the proposed Tillegra Dam.

The meteorological data file contains all the atmospheric data for the simulation period. To simulate a full year seasonal cycle, long term data from Warragamba was applied to the model. The DYRESM data inputs are to be the average values over the timestep used for calculation. The model was set up to run with daily calculations, hence meaning the input data must be daily averages. The data required is outline in Table F2.1

Table F2.1 Meteorological data required by DYRESM

Variable	Measured By	Unit
Short wave radiation indicator	Average of the total short wave radiation	W/m^2 (= J/m^2/sec)
Long wave radiation indicator	Cloud cover	Fraction (valid range [0,1])
Temperature	Daily average air temperature	°C
Average vapour pressure	Daily average vapour pressure	hPa
Average wind speed	Daily average wind speed	m/s
Rain	Total precipitation	mm

The meteorological data is the key component in the heating and cooling of a water body. It is therefore imperative that this data be accurate otherwise the results will be inconclusive.

B.5.1 Short wave radiation indicator

The net short wave radiation (J/m^2/sec) is a meteorological condition needed to run DYRESM. It is the prominent force in the heating of surface water in water bodies. The Warragamba data provided was the total short wave (or solar) radiation reaching the earths surface. As the model calculation time step is one day, the total short wave radiation was averaged over the entire 24 hours to obtain the relevant data for use in DYRESM.

B.5.2 Long wave radiation indicator

DYRESM uses one of three alternate methods to indicate the amount of long wave radiation reaching the earth’s surface. They are the measured average incident long wave radiation (J/m^2/sec), the measured average net long wave radiation (J/m^2/sec) or the observed average amount of sky covered by clouds. The only data of this nature available from Warragamba was the observed cloud cover records taken at 9 am and 3 pm. The cloud cover inputted in DYRESM was the average of these two values and does not necessarily represent the daily average.

B.5.3 Air temperature

Temperature is another factor largely related to the surface temperature in the reservoir. The data available for Warragamba were measured at 9am and 3pm every day and represented the average dry-bulb air temperature between the gauge times. For example, the 9 am values are the average values between 4 pm and 9 am and the 3 pm values are the average between 10 am and 3 pm.

The values implemented in the proposed Tillegra Dam model were the average of these two daily values.

B.5.4 Average vapour pressure

Vapour pressure is the pressure exerted by the moisture in the air on the atmosphere. The average water vapour pressure required for DYRESM is the daily average in hectopascals (hPa). For this study it was derived from relative humidity and dry-bulb temperatures using equation (13).

$$e_a = r_{hum} \times e^{2.303\left(\left(\frac{7.5T_a}{T_a+237.3}\right)+0.7858\right)} \quad (13)$$

Where e_a = vapour pressure [hPa]
r_{hum} = relative humidity [%]
T_a = dry buld air temperature [°C]

B.5.5 Average wind speed

The DYRESM wind parameters affect the surface turbulent mixing. The average wind speeds at Warragamba are measured 10 metres above the ground at 9 am and 3 pm daily. The value given is the average wind speed for the 10 minutes leading up to the gauge time. The values inputted into DYRESM were the average of these 2 wind speeds, converted from kilometres per hour to metres per second. These values are not necessarily representative of the daily average wind speeds.

B.5.6 Rain

Rain can have a cooling effect on surface temperatures and add to the mixing of the upper layers. The values inputted into DYRESM were the daily totals taken from the Warragamba meteorological data measured in millimetres.

B.6 Inflows File (.inf)

The inflow file represents the nature and characteristics of inflowing streams into the catchment. The inflows must occur for the entire simulation period. This influences the heat content of the reservoir, in particular the surface layer mixing. There is one inflow characterised in this file, consistent with that outlined in the physical characteristics and lake morphology file. The information includes physical characteristics (temperature, salinity etc) as well as chemical and biological levels.

The only available inflow data specific to Tillegra Dam is the inflow volumes determined from LIDAR terrain information, observations and estimates. Therefore the inflow volumes for the study period were collated with corresponding characteristic values for the Glennies Creek inflows used by CWR. The inflow temperatures were taken from corresponding dates in the CWR DYRESM model data. The inflow levels of chemical and biological parameters were taken as the average levels (between 1987 and 2007) from State Water Meaurements at the Tillegra Bridge site.

B.7 Initialisation File (.int)

The initialisation profile contains the depth profiles of the various physical, biological and chemical levels in the reservoir. All characteristics that are being modelled must have an initial profile. This provides the model with a base to start the calculations from. There was no data regarding any of these depth profiles, so average values were taken from corresponding times during the year in DYRESM-CAEDYM tutorial examples.

B.8 Initial Profile (.pro)

This file contains the initial vertical profile of the water temperature and salinity. Like the initialisation file, the initial profile provided DYRESM the starting point needed to base the continuing calculations from. The initial profile must be specified at the deepest point of the reservoir. The initial values for the simulation in this file are for the start of the first simulation day (i.e. midnight the day before). The DYRESM data supplied by CWR contained a number of measurements taken from CTD profiles taken through the UNIDATA period (1990-1991). The temperature profile for the 1 July 1990 was adopted for analysing the proposed Tillegra Dam.

B.9 Withdrawals File (.wdr)

This file contains daily withdrawal rates from the proposed Tillegra dam in cubic metres. Depending on the depth of the outlet, these volumes can have a large affect on the stratification and the mixing layer. There is one outflow in this file, corresponding with that stipulated in the physical data and Lake Morphology file. The withdrawal rates used for the model were estimated using LIDAR terrain information, observations and estimate of withdrawal releases.