AGL Upstream Investments Pty Ltd

Gloucester Gas Project

Hydrology study

21 March 2014

PARSONS BRINCKERHOFF

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Abbreviations

ADCP	Acoustic doppler current profiler
ANZECC	Australian and New Zealand Environment and Conservation Council
AGL	AGL Upstream Investments Pty Ltd
ARI	Average recurrence interval
BoM	Bureau of Meteorology
C1-C4 gases	Methane, ethane, propane, butane
CFU	Colony forming unit
CSG	Coal seam gas
DEM	Digital elevation model
DO	Dissolved oxygen
EC	Electrical conductivity
EMU	Entitlement management unit
EV	Environmental value
GFDA	Stage 1 gas field development area
GGP	Gloucester gas project
GRL	Gloucester Resources Limited
LOR	Limit of reporting
mAHD	Metres Australian height datum
MCW	MidCoast Water
NOW	NSW Office of Water
NTU	Nephelometric turbidity unit
PAH	Polycyclic aromatic hydrocarbons
R	Recommendation
RHCP	Rocky Hill Coal project
RFO	River flow objectives
SCPL	Stratford Coal Pty Ltd

SPM	Suspended particulate matter
BTEXN	Benzene, toluene, ethyl benzene, xylene and naphthalene
TN	Total nitrogen
TP	Total phosphorus
TPH	Total petroleum hydrocarbons
TRH	Total recoverable hydrocarbons
WAL	Water access licence
WQO	Water quality objective
WSP	Water sharing plan

Executive Summary

AGL Upstream Infrastructure Investments Pty Ltd is proposing to build the Gloucester gas project (GGP) which comprises several stages of development facilitating the extraction of Coal Seam Gas (CSG) from Gloucester Basin. The Stage 1 gas field development area (GFDA) is located approximately 100 km north of Newcastle, in the Gloucester Shire local government area in the Mid North Coast and Hunter regions of NSW. The GFDA lies in a narrow, south-north trending, elongated basin approximately 40 km long and 10 km wide, extending from Gloucester in the north to Stroud in the south.

The purpose of this report is to characterise surface water features across the Gloucester Basin particularly in the vicinity of the GFDA by reviewing surface hydrology and water quality information already collected and collecting additional data following a gap analysis. It is envisaged that this will help to further refine (and provide additional data for) the conceptual and numerical groundwater models for the Gloucester Basin.

The majority of the GFDA lies within the Avon River catchment (a sub-catchment of the Manning River catchment) and surface water flow is generally to the north. A very small portion of the southern GFDA lies within the Wards River catchment (a sub-catchment of the Karuah River catchment) which flows south and eventually into Port Stephens estuary. Water use in the Avon River catchment is predominately for irrigation, stock and domestic purposes. Water extraction from the Avon River and its tributaries represents less than 2% of the average annual flow from the Avon River sub-catchment.

The average flow contribution of the Avon River downstream to the Manning River flow at Killawarra was found to represent approximately 8% of the total river flow. For most of the time (99%) there was a small flow in the rivers and NSW Office of Water river flow objectives are being met. Based on water levels within the GFDA, a rapid response to rainfall events was recorded within the Avon River and Dog Trap Creek (except after extended dry periods) with large flow events occurring both in summer and winter. Water quality within the GFDA is typically within the desired range of performance indicators to satisfy water quality objectives for the Manning River catchment, although some exceedances above recommended maximums were recorded. Additional flow gauging and water quality sampling during two wet weather events was conducted so that monitoring was more representative of the full range of hydrological conditions.

A fluvial geomorphological assessment was undertaken to classify the watercourses within the GFDA based on the RiverStyles™ framework. Rivers and creeks within the GFDA are influenced by two major valley settings identified in the assessment; partly-confined and laterally confined valley settings. These valley settings result in three major classifications found within the GFDA; meandering rivers comprised typically of fine grained sediments; valley fill swamps and meadows characterised by discontinuous and poorly defined channels, and; bedrock controlled systems in partly confined valleys. A comparison to a previous geomorphological assessment has found that geomorphic condition within the GFDA is in a general poor to moderate state, however, recommended recovery actions would improve the general condition within the GFDA. Erosion potential was found to be greatest within the open drainage lines where nick points and a lack of vegetation cause bank instability. River cross-section surveys were conducted to record minimum creek bed elevations at 28 sites. These data will be utilised in the numerical groundwater model.

This hydrological study provides an indication of the hydrological baseline conditions found within the GFDA and wider Avon River sub-catchment. Additional investigations have been recommended that are necessary to further aid the understanding of hydrological conditions within the GFDA

1. Introduction

AGL Upstream Infrastructure Investments Pty Ltd (AGL) is proposing to build the Gloucester gas project (GGP) which comprises several stages of development facilitating the extraction of coal seam gas (CSG) from the Gloucester Basin. Concept plan and project approval (part 3A approval) for Stage 1 gas field development area (GFDA) was granted on 22 February 2011 under part 3A of the *Environmental Planning and Assessment Act (1979) (EP&A Act)*. In addition the project received approval under the *Environment Protection and Biodiversity Conservation Act (1999) (EPBC Act)* (EPBC Approval) on 11 February 2013.

AGL also holds Petroleum Exploration Licence 285, under the *Petroleum (Onshore) Act 1991*, covering the whole of the Gloucester Basin, approximately 100 km north of Newcastle, NSW.

This report characterises surface water features across the Gloucester Basin particularly in the vicinity of the GFDA and builds on surface hydrology and water quality information already collected by AGL and external sources. It is envisaged that this will help to further refine (and provide additional data for) the conceptual and numerical groundwater models for the Gloucester Basin.

1.1 Aims and objectives

This study aims to characterise the surface water environment, hydrology, fluvial geomorphology and surface water quality of the Gloucester Basin; primarily the Avon River catchment. Sensitive surface water features (species, habitats or water users) are also identified. This characterisation was achieved through the following activities:

- desktop review of existing data sources including AGL annual monitoring reports
- rapid geomorphological site reconnaissance with local surveying team
- additional hydrological and water quality monitoring in high flow conditions
- data reporting.

1.2 Approach

This section details the work that was conducted under each of the four headings in Section 1.1 in order to address the knowledge gaps identified in the independent peer review (3 May 2012) (SKM 2012), the initial Gloucester Basin modelling workshop (7 November 2012) and subsequent requirements of the numerical modelling.

1.2.1 Desktop review of existing data sources

An overview of land use, water management and drainage characteristics was conducted for the Manning and Karuah River Basins (Section 2.1). Delineation of the catchments that intersect the Gloucester Basin was completed using an existing digital elevation model (DEM). This informs a later comparison of the relative flow contribution from each sub-catchment. Strahler stream order classifications were applied to all watercourses within the GFDA. Strahler stream orders are presented in map format to allow a systematic understanding of creeks in the GFDA. Water quality objectives (WQOs) and river flow objectives (RFO's) for the Manning and Karuah basins were also reviewed, in order to gain an understanding of guidelines for maintenance of acceptable conditions.

A review and summary of available hydrological information, including surface water studies was carried out by Parsons Brinckerhoff to date, other impact assessments and publically available data (e.g. NSW Office of

Water [NOW]) was completed. A review of historic data was undertaken to help to elucidate the temporal trends and scale of variation in flow at the gauged sites and the influence of climate dynamics on these processes. Base-flow indexes for each sub-catchment were estimated, in order to identify the reliance of flow in each creek on groundwater inflow contributions. A comparison of hydrological data at each gauging station to the RFO’s was completed.

Existing GGP water quality data and water quality information obtained from various investigative studies to date was used to describe existing water quality characteristics of the local and regional catchments surrounding the GGP. Surface water quality has been compared against relevant WQO’s and discussed in relation to relevant water quality guidelines and targets. The following data sources have used in describing the existing water quality characteristics in this study:

- Avon Catchment Stream Salinity (DIPNR 2005c)
- Manning Catchment Water Quality Investigation (Thurtell 2007 and Thurtell 2009)
- State of Environment Reports (MidCoast Water 2011 - 2012)
- NSW Office of Water Data Request.
- Rocky Hill Coal Project Surface Water Assessment (WRM Water and Environment Pty Ltd 2013)
- Stratford Extension Project Surface Water Assessment (Gilbert and Associates Pty Ltd 2012).

A review of downstream sensitive water users was completed. This included ecologically sensitive areas and human water use. Water extraction in the region included licensed, unlicensed and basic landholder rights in the Lower North Coast unregulated and alluvial water source area. This includes an assessment of water use within the GFDA and the significance of these uses on downstream receptors. An evaluation of environmental water use is also included, in relation to the RFO’s descried in Section 2.1.5.

1.2.2 Rapid site reconnaissance with local surveying team

Selection of appropriate and accessible sites for a stream bed survey and rapid geomorphological walkover assessment involved a pre-site selection screening. Potential springs, refuge pools, wetlands and other potentially ecologically sensitive receptors were identified using aerial photography, and longitudinal profiles. Additional criteria were then reviewed to select a list of 28 locations within and surrounding the GFDA on the following watercourses:

- Avon River and unnamed tributaries
- Oaky Creek
- Waukivory Creek and unnamed tributaries
- Dog Trap Creek and unnamed tributaries
- Wards River
- Avondale Creek.

Selection of sites was informed by the desktop work described in Section 1.2.1. The walkover observations and subsequent classifications were conducted in accordance with the RiverStyles™ approach (Thompson *et al*. 2001), recognised Australia-wide as an effective, simple step-by-step procedure that ensures consistent and comparable results. It assesses river character and behaviour based on biophysical characteristics such as the planform, channel geometry and the surrounding assemblage of vegetation and landforms. Reference was made to a previous broader scale geomorphology classification, condition and recovery assessment to place these creek sites in the context of the larger Avon catchment (DIPNR 2005b). Channel cross-sections and bed elevations at all of the walkover site locations to supplement and ground-truth existing digital elevation data were also completed by a local surveying team (Calco). This assessment helps characterise specific creek types, identify sensitive creek stretches and elucidate the processes leading to channel recharge and loss (as the groundwater model calibration is sensitive to creek elevations).

1.2.3 Additional high flow site work

Flow gauging was conducted at four monitoring locations where automatic water level loggers have been deployed (site codes TSW01, TSW02, ASW01 and ASW02). A SonTek M9 river surveyor with an acoustic doppler current profiler (ADCP) system was used to measure 3-dimensional water velocity, depths and compute river discharge (see Section 3.1.1 for more details).

Site staff monitored weather forecast/rainfall conditions in order to mobilise and monitor during a significant flow event. Two flow events were captured on 27 and 28 June 2013. These data, along with previous survey data conducted in 21 June 2012, were used to construct a preliminary stage-discharge relationship for all the sites (see Section 3.1.1 for more details). If a strong correlation was found (r2 > 0.6) level records could be converted to discharges using the resulting regression equations from the stage-discharge relationship curves.

Collection and analysis of water quality samples were also completed during high flow events on 3 and 4 June 2013, and 27 and 28 June 2013 at the four monitoring locations. Field parameters (dissolved oxygen (DO), electrical conductivity (EC), pH, redox potential and temperature) were determined in situ using a calibrated handheld multi-parameter water quality meter.

Surface water samples for subsequent laboratory analysis were taken from the river bank using a telescopic sampler. The width of the major watercourses generally prohibited water samples collection from the thalweg, however, care was taken to ensure that the water samples collected were representative of observed water quality conditions at the time of sampling (e.g. avoidance of sampling in dead zones, close to discharges or in shallow water where the bed sediment could be disturbed). Samples were preserved and stored in the dark at 4ºC in accordance with laboratory guidelines and analysed for the following parameters at a NATA accredited laboratory within recommended holding times following appropriate chain of custody protocols.

Water samples collected during high flow sampling events were analysed for the following parameters:

- C1–C4 gases (methane, ethane, propane and butane)
- alkalinity and hardness (to interpret metals data)
- major anions and cations (calcium, chloride, magnesium, potassium, sodium and sulphate)
- metals (Arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, vanadium and zinc)
- nutrients (TN and TP)
- total recoverable hydrocarbons (TRH) / Benzene, toluene, ethylbenzene, xylene and naphthalene (BTEXN)
- total suspended solids.

1.2.4 Reporting

This report summarises the desktop review, field reconnaissance and additional site work in high flow conditions. Key elements of the hydrological report will feed directly into the further refinement of the conceptual groundwater model and inform the numerical model. Major gaps in knowledge or monitoring infrastructure across the entire model domain are identified. In particular, requirements for further work are identified in terms of spatial and temporal resolution. For example, long term monitoring to establish reference surface water quality conditions within the GFDA.

1.3 Site location description

The GFDA is located south to the south of Gloucester, in the Gloucester Shire local government area in the Mid North Coast and Hunter regions of NSW (Figure 1.1)The GFDA lies in a narrow, south-north trending, elongated basin approximately 40 km long and 10 km wide, extending from Gloucester in the north to Stroud in the south. The majority of the GFDA lies within the Avon River catchment (a sub-catchment of the Manning River catchment) and surface water flow is generally to the north.

A very small portion of the south-west GFDA (0.78 km^2 of the total GFDA area of 225 km^2) lies within the Wards River catchment, a sub-catchment of the Karuah River catchment which flows south and eventually into Port Stephens Estuary (Figure 1.2).

The GFDA is topographically enclosed to the west by the Bucketts Range and to the east by the Mograni Range. The area surrounding the GFDA is typically a modified catchment that has undergone clearance yet retains some natural riparian vegetation along the major water courses. Land use surrounding the GFDA is predominantly mining and agricultural, with beef and dairying the largest component, and a small number of timber mills and small-scale farming industry such as aqua-culture, olive groves, and vineyards now established (GC 2013).

The town of Gloucester is the major commercial centre in the area located towards the north of the GFDA (population 2,878, ABS 2011). The villages of Stratford and Craven are located towards the south-west of the GFDA (population 267, ABS 2011).

Stratford Coal Mine located approximately 2 km to the east of Stratford Village is an open cut coal mine which began operations in June 1995 (Yancoal 2010).

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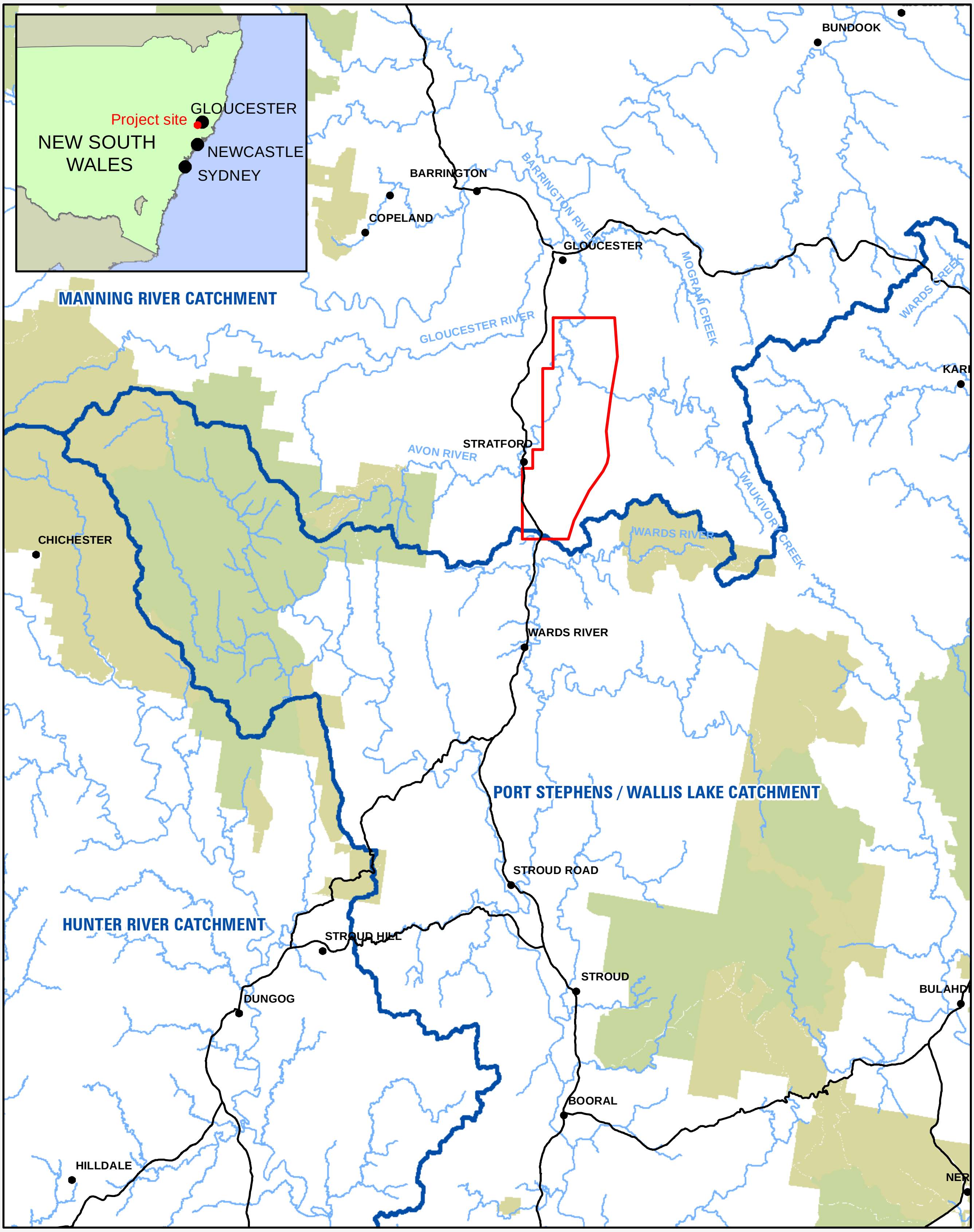

Stage 1 GFDA boundary
Catchment boundary
NSW State Forest
National Park, Nature Reserve or State Conservation Area
Towns
Rivers and streams
Major roads

N
0 10
Kilometres

Figure 1.1
Regional Location

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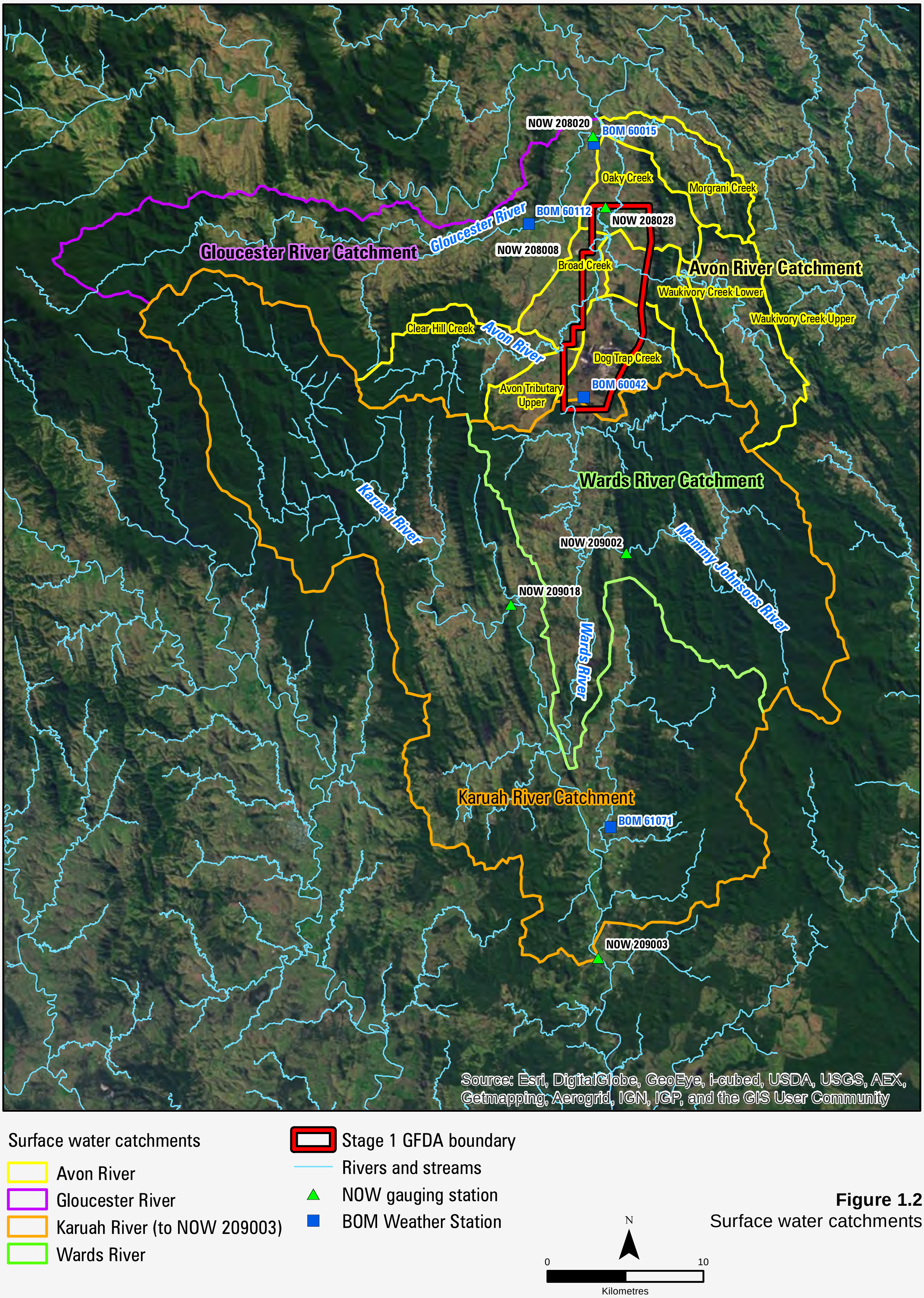

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Figure 1.2
Surface water catchments

2. Desktop review

Collation of existing catchment information for the Manning and Karuah River catchments relevant to the GFDA is included in this section. In particular the catchment network, hydrological conditions, water quality, downstream waters users and geomorphological conditions are reviewed.

2.1 Surface water catchment characterisation

A desktop review of the Manning and Karuah River catchments characteristics was undertaken and is summarised in the following sub-sections. Both catchments are categorised as unregulated (or uncontrolled) as there are no headwater storages.

2.1.1 Manning river catchment

The Manning River catchment is located on the NSW mid north coast. Bordered by:

- Hastings catchment in the north-east
- Macleay catchment in the north
- Namoi catchment in the north-west
- Hunter catchment in the south-west
- Karuah catchment in the south.

The Manning River Catchment area is approximately 8,420 km^2 (NOW 2013a). The major urban areas that lie within the Manning River catchment include Taree, Wingham and Gloucester (Figure 2.1).

The headwaters of the Manning River begin in the Northern Tablelands, a region of the Great Dividing Range and flow 250 km towards the coast, flowing south-east through a coastal floodplain to Taree where it splits in two channels. The southern arm flows into the Pacific Ocean at Old Bar, and the northern arm is joined by the Dawson and Lansdowne Rivers, flowing into the Pacific Ocean at Harrington (Figure 2.1).

The Manning River has an average annual discharge to the sea of 2,530,000 ML (DWE 2009b). The major tributaries of the Manning River catchment flow in a south-easterly direction through alluvial valleys before entering the Manning River which traverses the coastal riverine plains. In the lower reaches, the river is tidal and is often saline to Abbotts Falls (near Wingham). Much of the middle and lowers sections of the catchment are highly fertile due to the weathering of volcanic deposits in elevated areas. Approximately 22% of the catchment is heavily timbered and is managed by NSW State Forests. Most of the forested areas are located on relatively steep slopes (NOW 2013a).

Major industries relying on the rivers and estuarine resources of the catchment include dairy, oyster farming, coal mining, gravel extraction, manufacturing, agriculture, forestry and fisheries (Section 2.5) (NOW 2013a).

The majority of the GFDA lies within the Avon River catchment, which is part of the southern Manning River catchment. The Avon River meets the Gloucester River which then flows into the Manning River. Downstream along the Manning River is the river offtake for the Bootawa Dam and water treatment plant, operated by MidCoast Water (MCW). Water is pumped from the Manning River and stored in the off-river Bootawa Dam near Wingham before being treated at the Bootawa Water Treatment Plant (MCW 2013). The dam itself does not restrict flows in the Manning River; the Manning River catchment is classified as an unregulated system not controlled by dams or weirs.

2.1.2 Karuah river catchment

The Karuah River Basin is located on the lower north coast of New South Wales and has a catchment area of 4,480 km^2 (NOW 2013b). The catchment is bordered by the Manning River catchment in the north, and the Hunter River catchment in the south and west. The major town centres of the catchment include Port Stephens, Forster/Tuncurry, Bulahdelah, Karuah, Hawks Nest and Nelsons Bay (Figure 2.2).

The Karuah River flows south towards Port Stephens where it discharges into Port Stephens Estuary and subsequently, the Pacific Ocean. The river runs over a length of 90 km and rises in the Barrington Tops at an elevation of over 1,000 m. In the upper river reaches the valley floor is less than 1 km wide, surrounded by steep ridges. The mid-valley area is characterised by wide river valleys, up to 7 km wide. The lower river reaches are characterised by significant large water pools (DIPNR 2005c).

The Karuah River catchment includes large areas of State Forest and National Park Estate, coastal wetland and extensive stretches of natural waterways. Since the decline of the dairy industry, agricultural land use has been mainly beef cattle production. There are also a number of poultry farms in the catchment. Other major water users include Hunter Water Corporation, local councils, oyster farming and fishing industries (Section 2.5). Recreational fishing, linked with the prominent and fast growing tourism industry, is also a popular activity (NOW 2013b).

The Wards River catchment is a sub-catchment, situated to the north of the Karuah River catchment. The upper section of the Wards River is in forested land and is designated as an unregulated stream throughout its length.

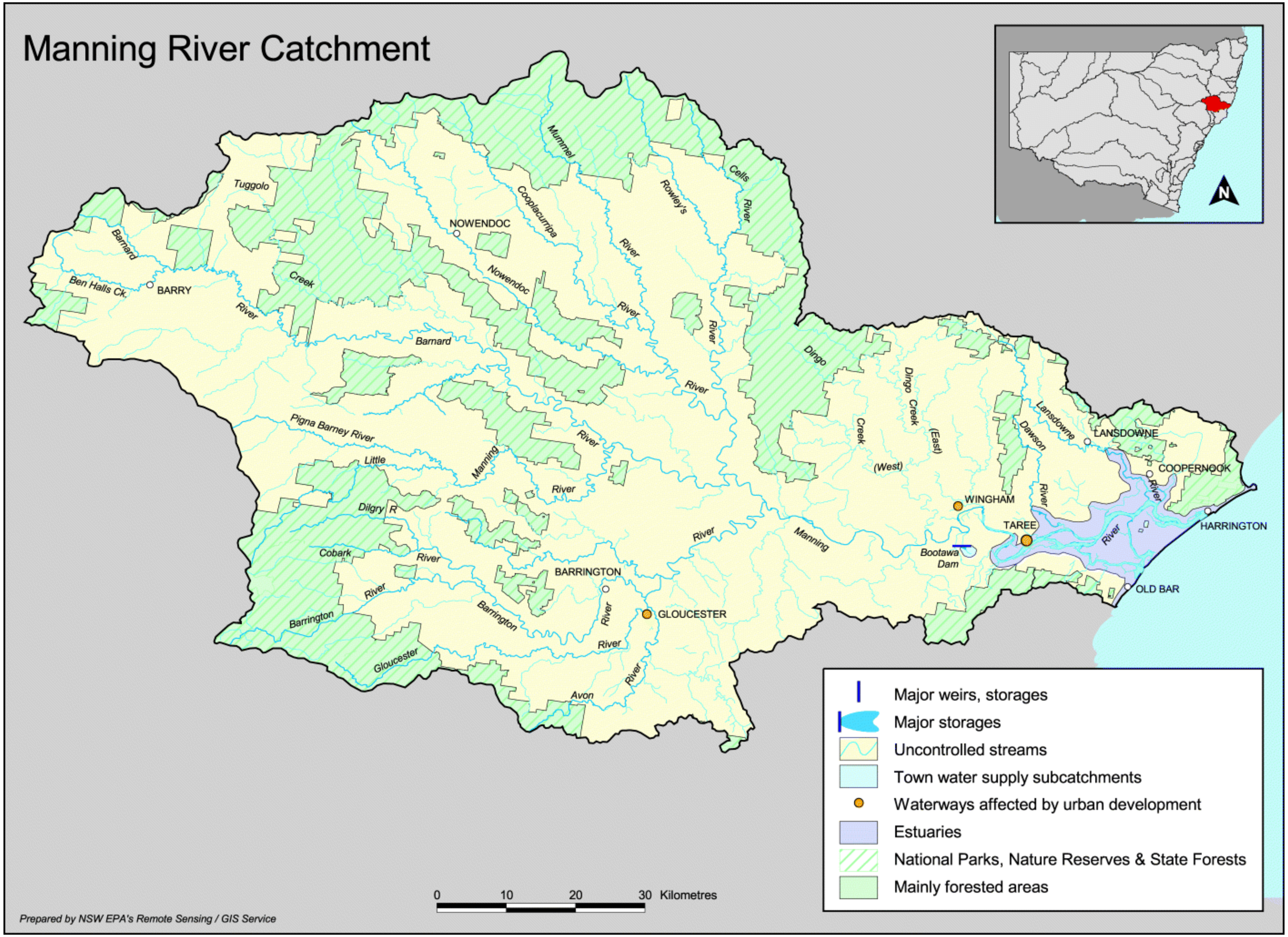

Figure 2.1 Manning River catchment

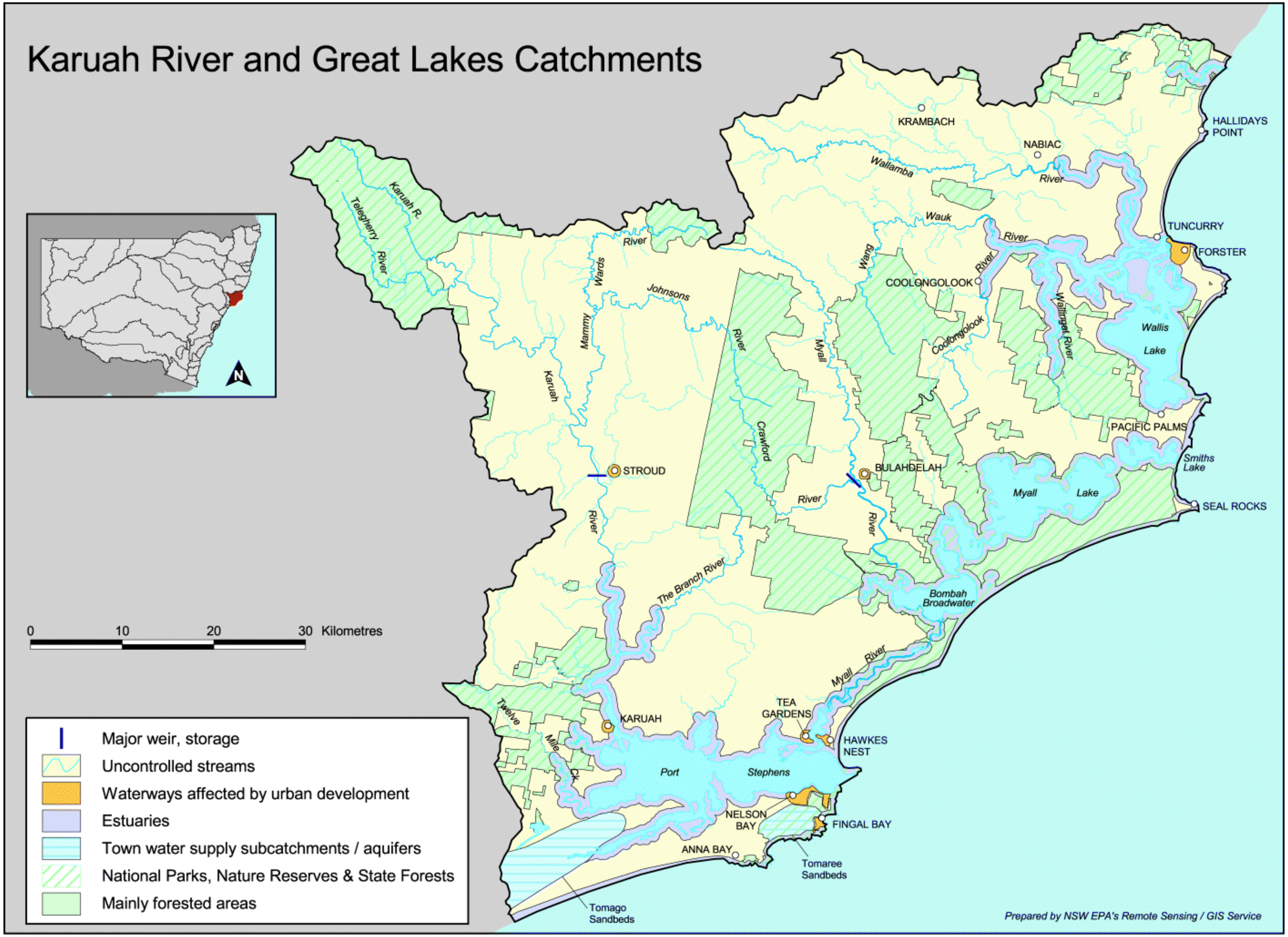

Figure 2.2 Karuah River catchment

2.1.3 Sub-catchment delineation of the Manning and Karuah catchments

Sub-catchments of the Manning and Karuah River catchments relevant to the GFDA were delineated using an existing digital elevation model (DEM), aerial photography and the blue line stream network supplied from NSW Department of Lands.

The Avon River catchment has been separated into sub-catchments for each of the main tributaries within the GFDA which include Dog Trap Creek, Waukivory Creek, Oaky Creek, Broad Creek and Mograni Creek (Figure 1.2). Table 2.1 summarises the sub-catchment areas and predominant land use type.

The Karuah River catchment has not been analysed in detail because it is a very small portion of the GFDA development area and therefore the impacts to the Wards River and Karuah River are expected to be negligible.

Table 2.1 Catchment characteristics

Catchment	Sub-catchment	Area (km^2)	Land use type
Avon River	Mograni Creek	34.3	Rural
	Oaky Creek	10.1	Rural
	Avon River near Oaky Creek	24.2	Rural
	Waukivory Creek Upper	59.4	Rural
	Waukivory Creek Lower	30.2	Rural (50%) Forest (50%)
	Dog Trap Creek	40.0	Rural
	Broad Creek	23.6	Rural
	Avon Tributary Upper	17.5	Rural
	Clear Hill Creek	51.6	Forest
Karuah River	Wards River	317.3	Forest (60%) Rural (40%)
	Karuah River	974.0	Forest (70%) Rural (30%)

Long section profiles of the main branches of creeks that dissect the GFDA are included in Appendix A.

2.1.4 Strahler stream order classifications

The Strahler stream classification system is a method of classifying waterways according to the number of tributaries associated with each waterway (Strahler 1957). Numbering begins at the top of a catchment where the headwaters of the system start. As the stream order increases the contributing catchment area and channel size also increase. Small tributaries at the top of the catchment are assigned as a first order streams. Where two first order streams join, the waterway downstream of the junction is referred to as a second order stream. Higher order streams are found in the lower parts of the catchment.

The Strahler classification system was applied to creeks within the GFDA. The GFDA covers a range of stream orders from first order to sixth order (Figure 2.3). A number of the streams which lie within the GFDA are first and second order streams, which represent minor tributaries of Dog Trap Creek, Waukivory Creek and Oaky Creek. Dog Trap Creek in the south-eastern area of the GFDA is a fourth order stream for most of its length but becomes a fifth order stream after the junction of a fourth order unnamed creek. Waukivory Creek is a fifth order stream within the GFDA and Oaky Creek in the north east corner of the GFDA is a fourth order stream. The Avon River enters the GFDA from the western boundary as a fifth order stream.

Further downstream it is joined by Dog Trap Creek and becomes a sixth order stream for the remainder of its length, the highest order stream within the GFDA. The Avon River is a major tributary of the Gloucester River which joins the Gloucester River approximately 12 km downstream of the Avon River junction with Dog Trap Creek.

In addition to Strahler stream orders, schedules for the streams are used in the Hunter Valley as a decision-making mechanism for the level of subsequent impact assessment required (DIPNR 2005a). Streams sub-schedules are defined as follows:

- schedule 1 streams comprise first and second order watercourses and are usually intermittent (streams showing evidence of permanent flow are schedule 2 streams)
- schedule 2 streams comprise primarily third order and higher streams, which drain into primary catchment rivers systems
- schedule 3 streams comprise major rivers and connected alluvial ground waters.

These schedules were designed for assessment of coal mining in the Hunter Valley and can be used as a guide to the significance of creeks in the Manning River catchment. Using this scheme, the Avon River is schedule 3. Dog Trap Creek, Waukivory Creek and Oaky Creek are schedule 2. There are some unnamed tributaries that are also schedule 2 and the streams that have been classified as Strahler order 1 and order 2 are schedule 1 streams.

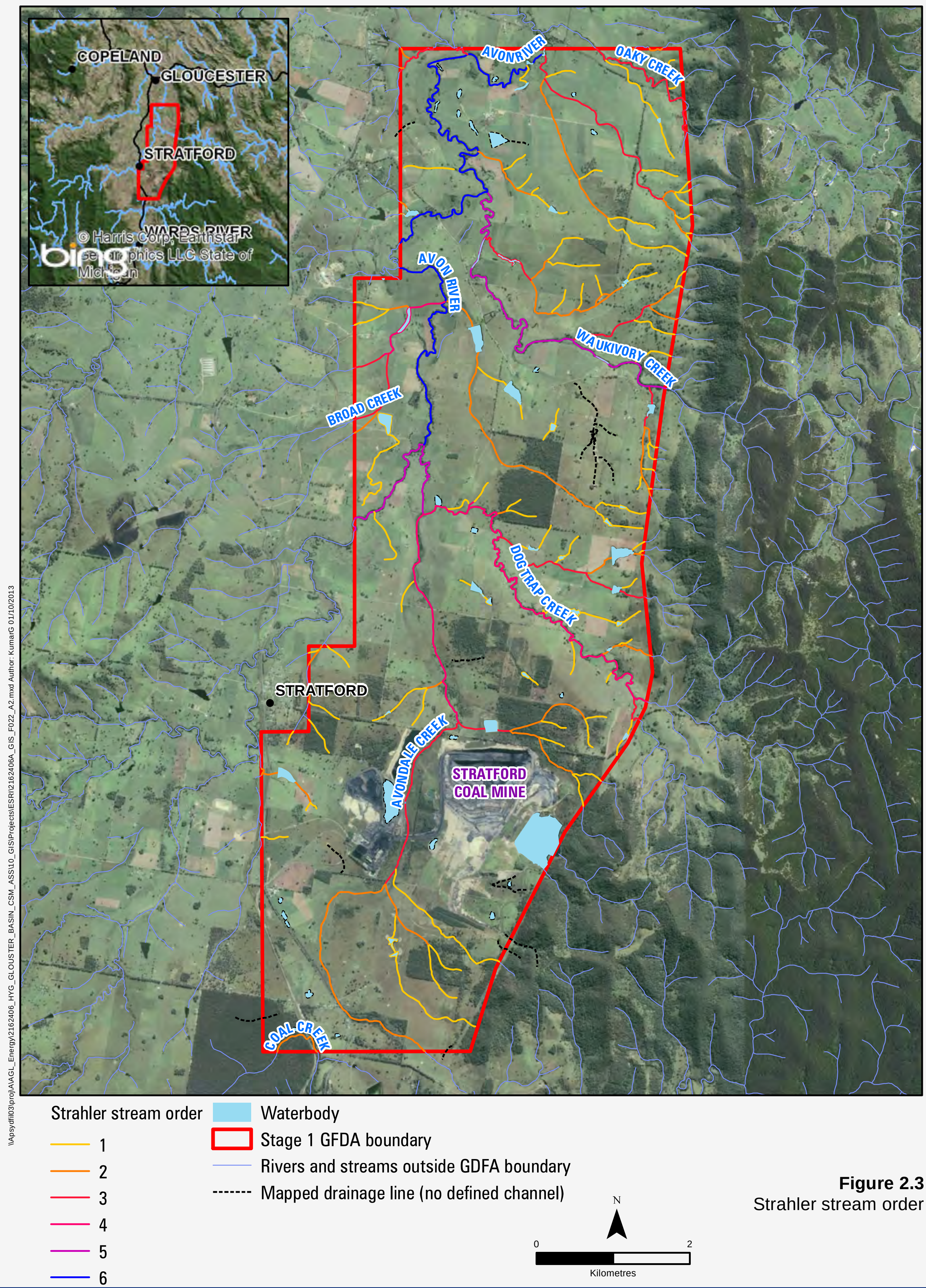

Figure 2.3
Strahler stream order

2.1.5 River flow objectives

The NSW government has developed specific RFOs for the Manning River and Karuah River catchments for the uncontrolled streams listed below (NSW Government 2006a & NSW Government 2006b):

- Protect pools in dry times – There should be no extraction from streams or wetlands in periods of no flow.
- Protect natural low flows – Share low flows between environment and water users. Protect very low flows (below the level exceeded on 95% of days with flow) and low flows (below the level exceeded on 80% of all days with flow). Environmental share is all the very low flows and 50–70% of the daily low levels.
- Protect important rises in water levels – No extraction of more than 30–50% of moderate to high flows on a daily basis.
- Maintain wetland and floodplain inundation – Management plans and actions for waterways need to include strategies to maintain, restore or mimic natural waterways and ensure adequate access for native fish to and from floodplain wetlands. Flooding patterns should not be altered without an environmental assessment.
- Mimic natural drying in temporary waterways – Identify any unregulated streams where unnatural flows have greatly reduced drying periods. Assess any potential short and long term environmental, economic and social effects of this change. Decide what if any action is appropriate to implement this objective in streams and wetlands.
- Maintain natural flow variability – Identify streams with unnatural flow variability and develop actions to mimic natural variability. Identify streams or development proposals with potential for flow variability problems and take early action.
- Manage groundwater ecosystems – Implement the state groundwater policy, identify streams and ecosystems that may depend on high groundwater levels and assess if impacts are related to changed recharge rates or excessive pumping, identify long term trends or changes in groundwater levels that are likely to threaten ecosystems or the quality of ground or surface water.
- Minimise effects of weirs and other structures – Implement the NSW Weirs Policy and take action to reduce the impacts on fish, other animals, plants and water quality of other structures that impede the two way movement in streams.

NSW Government (2006a and 2006b) has indicated that most streams in the Manning and Karuah River catchments are meeting the ‘mimic natural drying in temporary waterways’ objective, so this will not be reviewed. The objective to ‘minimise effects of weirs and other structures’ will not be reviewed in this report as there are no such structures built on these watercourses in the local catchment. The management of groundwater ecosystems has been discussed in the hydrogeological conceptual model of the Gloucester Basin (PB 2013a).

2.2 Water sharing plans

2.2.1 Lower North Coast water sharing plan

Water use in the Manning River Basin is governed by the water sharing plan (WSP) for the Lower North Coast unregulated and alluvial water sources (DWE 2009b). The Manning River Basin is known as an extraction management unit (EMU) for the purpose of managing annual extraction. The Manning River catchment is an unregulated river, without major storages or dams. The Manning EMU is comprised of 21 water sources (sub-catchments within the Manning River catchment).

Information on the WSP for the Lower North Coast unregulated and alluvial water sources includes a review of the following sources:

- Water Sharing Plan Lower North Coast unregulated and alluvial water sources - Guide (DWE 2009a).
- Water Sharing Plan Lower North Coast unregulated and alluvial water sources - Background document (DWE 2009b).
- Water source report cards from NOW (NOW 2013g).

Pumping rules in the Lower North Coast WSP commenced 1 August 2009, the rules listed in Table 2.2 come into effect in year 6 of the plan (i.e. from 1 August 2015), and until then existing water licences are in effect and the guidelines in the RFO's (Section 2.1.5) should be applied.

Table 2.2 Surface water pumping rules according to WSP - Rules summary sheet

Location	Cease to pump rules	Commence to pump rules
Avon River	Pumping must cease when there is no visible flow immediately downstream of the pump site or in or and out of the pumping pool.	None
Upper Manning River	Pumping must cease when there is no visible flow immediately downstream of the pump site or into and out of the pumping pool, and, the flow Manning River at Leslies Bridge is equal to or less than the 98%ile flow (which corresponds to 14 ML/day flow.	There is visible flow immediately downstream of the site or into and out of the pumping pool and the flow at Manning River at Leslies Bridge Gauge is equal to or greater than the 97%ile flow (which corresponds to 17 ML/day)
Bowmans River	Pumping must cease when there is no visible flow immediately downstream of the pump site or into and out of the pumping pool, and, the flow Gloucester River at Doon Ayre Gauge is equal to or less than the 98%ile flow (which corresponds to 27 ML/day.	There is visible flow immediately downstream of the site or into and out of the pumping pool and the flow at Gloucester River at Doon Ayre Gauge is equal to or greater than the 97%ile flow (which corresponds to 40 ML/day)
Lower Manning River	Pumping must cease when there is no visible flow immediately downstream of the pump site or into and out of the pumping pool, and, the flow at Manning River at Killawarra Gauge is equal to or less than the 98%ile flow (which corresponds to 98 ML/day.	There is visible flow immediately downstream of the site or into and out of the pumping pool and the flow at Manning River at Killawarra Gauge is equal to or greater than the 97%ile flow (which corresponds to 137 ML/day)

2.2.1.1 Licenced water use

Most of the flows in the Lower North Coast unregulated rivers are protected from extraction. The total volume of surface water licensed for extraction in the Manning EMU based on the WSP is 78,100 ML (DWE 2009b) whilst a review of the water source report cards shows that total surface water entitlement or share component (the amount of water an access licence holder is allocated in any year) within the Manning EMU is approximately 87,646 ML/year (NOW, 2013g). The discrepancy in these two extraction values results from the water source report cards covering a larger catchment area than the WSP. These values compare to an annual average flow in the Manning River of 2,530,000 ML. To be conservative, the larger extraction value will be used for the purposes of this study.

Licenced water users within the Manning EMU are predominately used for stock, domestic and irrigation purposes. Notable water users within the Manning EMU that hold water access licences for the extraction of water are provided in Figure 2.4 and include:

- Macquarie Generation
- MidCoast Water - Gloucester Water Treatment Plant
- MidCoast Water - Bootawa Dam Water Treatment Plant
- Agricultural users for irrigation, stock and domestic purposes.

The following section describes the major licensed water users and their usage requirements.

Macquarie Generation

Macquarie Generation is a major utility with a water access licence (WAL) entitlement of 20,000 ML/year from the Lower Barnard River water source. Macquarie Generation extracts water from the Barnard River at Barnard Weir and transfers water to the Hunter River system when required for the operation of the Bayswater and Liddell Power Stations. The Lower Barnard water source is located in the upper reaches of the Manning EMU and is not a downstream receiving catchment of the Avon water source. The flow regime and water quality within the Avon water source does not therefore, have an impact to water supply to Macquarie Generation.

MidCoast Water – Gloucester Water Treatment Plant

Town water supply to the townships of Gloucester and Barrington is maintained by MidCoast Water through the Gloucester Water Treatment Plant. A water entitlement of 576 ML/year operates for extraction from the Barrington River for treatment. The Barrington and Avon water sources form separate sub-catchments that discharge to the Gloucester River. The Barrington water source is located upstream from the confluence of the Barrington and Gloucester Rivers and is not a downstream receiving catchment of the Avon water source. The flow regime and water quality within the Avon water source does not therefore, have an impact to water supply to the Gloucester Water Treatment Plant.

MidCoast Water – Bootawa Dam Water Treatment Plant

MidCoast Water operates a water treatment plant for the supply of water to water customers in the local area under their Manning water supply scheme. A water entitlement of 12,500 ML/year operates for the extraction of water from the Lower Manning River water source. An additional 3,000 ML/year operates for extraction from the Manning River tidal pool. Water is extracted from the Manning River daily (water quality permitting) upstream of Wingham (between Wingham and Killawarra) for storage in the Bootawa Dam and subsequent treatment at the Bootawa Dam Water Treatment Plant. During times of high flow in the Manning River, water quality conditions in the river may prevent water extraction. The Bootawa Dam and water extraction point from the Manning River is located within the Lower Manning River Catchment, approximately 50 km downstream from the GFDA boundary on the Avon River.

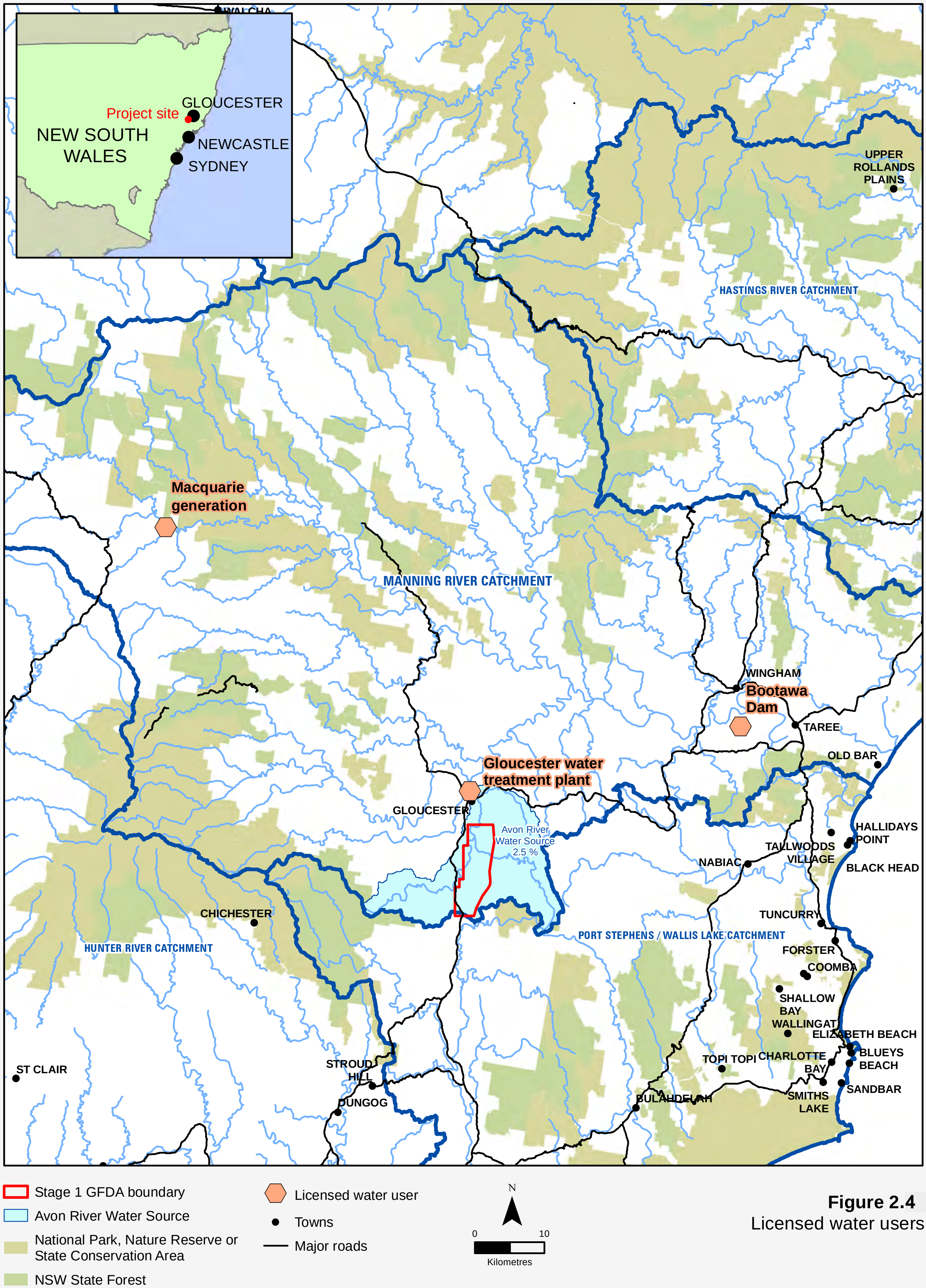

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Figure 2.4
Licensed water users

Agricultural users for irrigation, stock and domestic purposes

The WSP estimates that the share components of domestic and stock access licences (basic landowner rights) authorised to extract water from the Manning EMU total 98 ML/year. This represents the total volume or unit shares, with the actual volumes of water available at any time dependant on climate, access priority and the rules of the WSP. WALs and estimates of basic landholder rights for the water sources within the Manning EMU that are provided for in the WSP are summarised in Table 2.3.

Table 2.3 Water access licences and basic rights estimates within the Manning EMU

Water source	Total surface water entitlement (ML/year)	Basic landholder rights (ML/year)	Total	% use of EMU entitlement
Avon River	1,997	246	2,242	2.5
Bowman River	2,257	88	2,345	2.6
Cooplacurripa River	811	153	964	1.1
Dingo Creek	5,153	241	5,394	5.9
Lower Barnard River	31,369	194	31,562	34.6
Lower Barrington/Gloucester Rivers	**10,951**	**314**	**11,265**	**12.3**
Lower Manning River	**20,145**	**219**	**20,364**	**22.3**
Manning Estuary Tributaries	**2,849.5**	**1,077**	**3,926**	**4.3**
Manning River Tidal Pool	**0**	**69**	**69**	**0.1**
Mid Manning River	**632**	**95**	**727**	**0.8**
Myall Creek	57	77	134	0.1
Nowendoc River	1,158	259	1,417	1.6
Rowleys River	257	120	377	0.4
Upper Barnard River	274	139	413	0.5
Upper Barrington River	944	110	1,054	1.2
Upper Gloucester River	6,572	143	6,714	7.4
Upper Manning River	2,219	123	2,347	2.6
TOTAL	87,646	3,667	91,314	

(1) Note: bold water sources are downstream from GFDA

2.2.1.2 Water entitlements within the Avon River

Within the Avon River there are a total of 43 surface water licences with 1,997 ML/year in surface water entitlements (Table 2.3). Of this volume, 95% is used for irrigation purposes (DWE 2009c). To assess the contribution of the Avon River water source to the wider Manning EMU, the following information sources have been reviewed:

- total surface water entitlement provided by water source reports (DWE 2009c)
- basic landholder rights estimates provided by the WSP
- river flow information provided by NOW gauging stations
- downstream receiving water sources of the Avon River

- a concurrent period of flow data for all NOW stream gauges.

Full flow records are provided by NOW for varying time periods. For the purposes of flow data analysis in this study an assessment period was selected from 1 January 2005 to 27 May 2013 to determine a long term data series and mean annual flow at the NOW gauging stations (Table 2.4). This period was selected because it was a concurrent period for all the flow gauges and it included the most recent data at the time of reporting. All mean annual flows and peak water levels reported are based on this assessment period. NOW stream gauges are discussed further in Section 2.3.

Mean annual flow recorded at the NOW gauging stations at the Avon River (208028), and downstream gauging stations along the Gloucester River (208003) and Manning River (208004) is provided in Table 2.4. The sum of the volume of water entitlements (based on total water entitlements and basic landholder entitlements provided above in Table 2.4) have been compared to annual average flow at each gauging station to determine the water use requirements expressed as a percentage of mean annual flow at each NOW gauging station (Table 2.4). Further, the entitlements of the Avon River (2,242 ML/year) have been compared to mean annual flow at downstream gauging stations and expressed as a percentage of mean annual flow. Water entitlements from the Avon River represent less than 0.5% of mean annual flow downstream gauging stations at Doon Ayre (0.39%, station 208003) and Killawarra (0.16%, station 208004).

Table 2.4 Water extraction and contribution of the Avon River on downstream catchments

Gauging Station	Mean annual flow (ML/year)	Total water entitlement (ML/year)[1]	Total water entitlement (% of mean annual flow)	Avon River entitlement (% of downstream mean annual flow)
Avon River at D/S Waukivory Creek (208028)	110,099	2,242	2.0	N/A
Gloucester River at Doon Ayre (208003)	570,731	22,565	4.0	0.39
Manning River at Killawarra (208004)	1,421,406	81,924	5.8	0.16

(1) Total Water Extraction includes total water entitlement and water extracted under basic landholder rights

The Avon River sub-catchment at the Waukivory gauge represents a small portion in terms of both areas (3.5%) and average annual flow volume (8%) of the Manning River catchment at the Killawarra gauge. There is a slightly greater contribution to downstream flow compared to the area contribution as many of the sub-catchments to the north are heavily forested and runoff is less and evapotranspiration is greater in these forested areas.

Average annual rainfall across the Avon River catchment is of the order of 250,000 ML/year (derived from Parsons Brinckerhoff 2013b). Average annual flow at the Avon River gauging station (208028) is 110,099 ML/year (Table 2.4). Flows and entitlements from the Oaky Creek and Mograni Creek are included in the Avon River water source report cards however, these water bodies discharge to the Avon River downstream of the gauging station and are not accounted for by the Avon River (Waukivory) gauging station. Notwithstanding, a small portion of flows from the Avon water source are reserved for water extraction through water access licences and basic landholder rights. Based on total surface water entitlements and basic landholder rights to water flow within the Avon River water source of 2,242 ML/year, the maximum water extraction from the Avon River water source represents approximately 2% of the average annual flow at the Avon River gauging station. Taking additional flow into account from Oaky and Mograni Creeks, and the overland flow that is captured in numerous farm dams the maximum water extraction from the Avon River water source is less than 2% of the total flow.

The Gloucester River gauging station at Doon Ayre (208003) is located approximately 37 km downstream from the Avon River gauging station and receives flows from the Avon River, Bowman River, Lower Barrington/Gloucester Rivers and the Upper Gloucester Rivers water sources. Long term mean annual flow at the Doon Ayre gauging station is approximately 570,731 ML/year. Flows from the Avon River catchment represent approximately 19% of flows at this Gloucester River gauging station. Total surface water entitlements and basic landholder rights to water flows upstream of this gauging station account for approximately 22,565 ML/year. Therefore maximum water extraction upstream from this gauging station on the Gloucester River represents approximately 4% of the average annual flow. The increased portion is largely attributable to total water entitlements within the Lower Barrington/Gloucester Rivers water source that account for 10,951 ML/year.

Further downstream, the Manning River gauging station at Killawarra (208004) receives flows from the majority of water sources from within the Manning EMU (refer to Section 2.3 and Figure 2.1).

Average annual flow at the Killawarra Gauging Station on the Manning River located a further 35 km downstream of the Doon Ayre gauge is approximately 1,421,406 ML/year. Flows from the Avon River sub-catchment represent approximately 8% of the flows at the Killawarra gauging station.

2.2.2 Karuah River water sharing plan

A Karuah River WSP is due to be finalised in 2014 which will merge with the existing WSP for the Lower North Coast unregulated and alluvial water sources.

There are 64 WAL with 3,360 ML/year in water entitlements. Of this volume, about 3,000 ML was for irrigation, 320 ML for towns, 25 ML for stock and 100 ML for domestic and farming purposes (DWE 2004).

2.3 Existing stream flow monitoring network

2.3.1 Gauge locations

There are four NOW gauges within or downstream of the GFDA in the Manning River catchment (NOW 2013a) (Figure 1.2). The first NOW gauge is located on the Avon River on the northern boundary of the GFDA, with the second situated on the Gloucester River north of the GFDA. Another two NOW gauges are located downstream of the GFDA on the Gloucester River and Manning River. There is also a discontinued gauge on the Avon River close to its headwaters called Avon River below dam site

There are two NOW gauges in the Karuah River catchment downstream of the GFDA (NOW 2013b). Full flow records, catchment areas and locations of NOW gauges in the surrounding area are shown in Table 2.5 and Figure 1.2.

Table 2.5 NOW gauging station information

	Station number	Location	Full Flow record	Catchment area (km^2)
Manning River catchment	208018	Avon River below dam site #	03/08/1971-29/10/1985	26
	208028	Avon River D/S Waukivory Creek (402554.8E, 6454389N)	07/09/2004 – present	225
	208020	Gloucester River at Gloucester (401663.9E, 6458743N) #	05/04/2003 – present	253
	208003	Gloucester River at Doon Ayre (414578.9E, 6470683N) #	1/06/1945 – present	1,610
	208004	Manning River at Killawarra (434930.8E, 434930.8N) #	01/06/1945 – present	6,560

	Station number	Location	Full Flow record	Catchment area (km^2)
Karuah River catchment	209002	Mammy Johnsons River at Pikes Crossing (403804.8E, 6432089N) #	18/121967 – present	156
	209003	Karuah River at Booral (402004.7E, 6406089.1N) #	26/10/1968 – present	974
	209018	Karuah River at dam site (396404.8E, 642878934N) #	18/12/1979 – present	300

(1) Key: # - outside of Stage 1 GFDA

Figure 1.2 shows that only one of the NOW stream gauges (208028 on the Avon River) is located within the GFDA boundary, located on the northern edge. AGL has deployed additional gauges in the GFDA on the Avon River and on Dog Trap Creek, as detailed in Section 3.1.

2.3.2 Sub-catchment areas within the GFDA

The Avon River sub-catchment represents 3% of the Manning River catchment area to the Killawarra gauge (208004) (Table 2.5). The Wards River catchment represents 33% of the Karuah River catchment to the Karuah River at the Booral gauge (209003). The proportion of the GFDA within the Manning River and Karuah River catchments is less than 1% (Table 2.6).

Table 2.6 Portion of GFDA to catchment

Gauges with flow in GFDA	Total catchment area (km^2)	GFDA within catchment (km^2)	Proportion of total catchment
Avon River D/S Waukivory Creek	225	49.5	22.0%
Manning River at Killawarra	6,560	49.5	0.8%
Karuah River at Booral	974	0.78	0.1%

2.3.3 Sub-catchment flow contribution

A simple rational method calculation (Engineers Australia 2001) was undertaken to estimate the flow contribution for each of the smaller creek systems of the Avon River within the GFDA. Peak flows from the sub-catchments for a range of average recurrence interval (ARI) events were used (Appendix B).

Table 2.7 summarises the peak flows of the Avon River and its tributaries. The Waukivory Creek sub-catchment has the largest catchment area of all Avon River tributaries and is the largest contributing sub-catchment in terms of peak flow. This creek is followed closely by Dog Trap Creek, Mograni Creek and Clear Hill Creek, respectively. These three creeks have successively smaller catchment areas but also have steeper gradients than Waukivory Creek and the Avon River main channel. Mograni Creek and Clear Hill Creek lie outside of the GFDA boundary and therefore will not be affected by catchment changes that may take place within the GFDA. Changes to the catchment of Dog Trap Creek (which also includes the creek locally known as 'Avondale Creek') and/or Waukivory Creek have the potential to impact flows in the Avon River downstream of these creeks.

Table 2.7 Avon River sub-catchment peak flow estimates

Sub-catchment	Area (km^2)	% Area proportion (km^2)	100 year ARI peak flow (m^3/s)	50 year ARI peak flow (m^3/s)	20 year ARI peak flow (m^3/s)	10 year ARI peak flow (m^3/s)	5 year ARI peak flow (m^3/s)	2 year ARI peak flow (m^3/s)	1 year ARI peak flow (m^3/s)
Mograni Creek	34.3	12%	264.6	217.0	168.8	130.5	101.2	65.5	42.5
Oaky Creek	10.1	3%	100.3	82.4	64.3	49.8	38.7	25.2	16.4
Avon River near Oaky Creek	24.2	8%	200.6	164.6	128.2	99.1	77.0	49.9	32.4
Waukivory Creek	89.6	31%	566.2	463.6	359.9	277.5	214.7	138.4	89.6
Dog Trap Creek	40.0	14%	298.9	245.1	190.6	147.2	114.1	73.8	47.9
Broad Creek	23.6	8%	196.7	161.4	125.7	97.2	75.4	48.9	31.8
Avon Tributary Upper	17.5	6%	155.1	127.4	99.3	77.0	59.7	38.8	25.2
Clear Hill Creek	51.6	18%	365.7	299.7	233.0	179.8	139.3	90.0	58.3
Avon River total	290.9	n/a	1,439.5	1,176.6	910.7	700.5	540.4	346.2	223.6

Figure 2.5 highlights the proportion of the sub-catchments within the total Avon River catchment area. The main contributing sub-catchment is Waukivory Creek because it has the largest proportion of catchment area within the Avon River catchment. There was low variation in flow proportion contribution for the range of ARI events in Table 2.7. This shows that all the sub-catchments behave in a similar way to increasing rainfall intensity events. The rational method has been used to provide one numeric value for peak flow, a hydrograph for these events cannot be produced accurately. Hydrologic modelling should be undertaken to more accurately model floodplain storages and timing of peak flow events and for a more accurate breakdown on each sub-catchment contribution to flow (recommendation (R) 1).

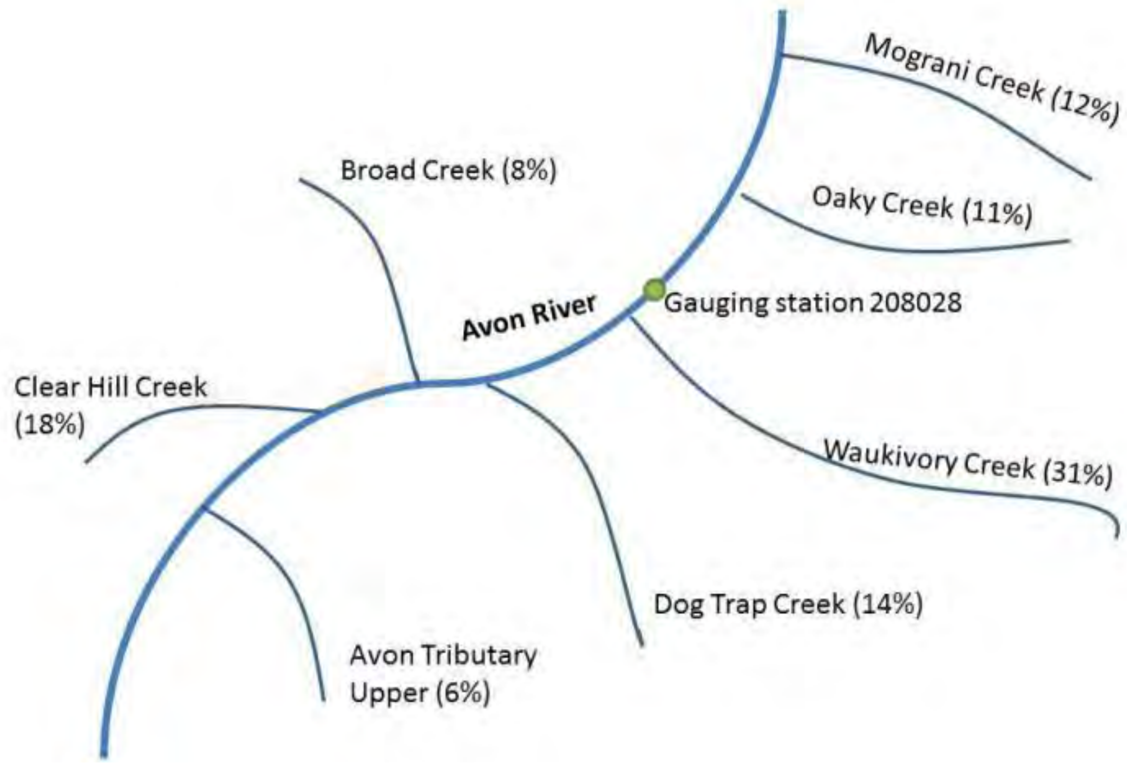

Figure 2.5 Proportion contribution to the Avon River

2.3.4 Temporal and spatial flow variation

There are three BoM rainfall gauges near the GFDA in the Avon River catchment. There is a BoM rainfall gauge in the southern Karuah River catchment (Figure 1.2). AGL has also installed a weather station that records total daily rainfall volume at its Tiedman property located between Stratford and Gloucester. Data from two of the BoM stations in the Avon River catchment, the one in the southern Karuah catchment and the AGL weather station were compared (Figure 2.6). The stations show similar temporal patterns and although the timing of the rainfall peaks differed slightly, the highest rainfalls generally occurred on the same day. There are no gaps in any of these data sets for January 2005 – January 2013 (BoM 2013).

The groundwater conceptual model (PB 2013a) used data from BoM at Gloucester Post Office (060015), however this hydrology report has analysed rainfall from BoM at Craven (060042) because the station is located in the headwaters of the Avon River catchment and was identified as providing a better representation of rainfall that would produce surface water runoff in the Avon River tributaries.

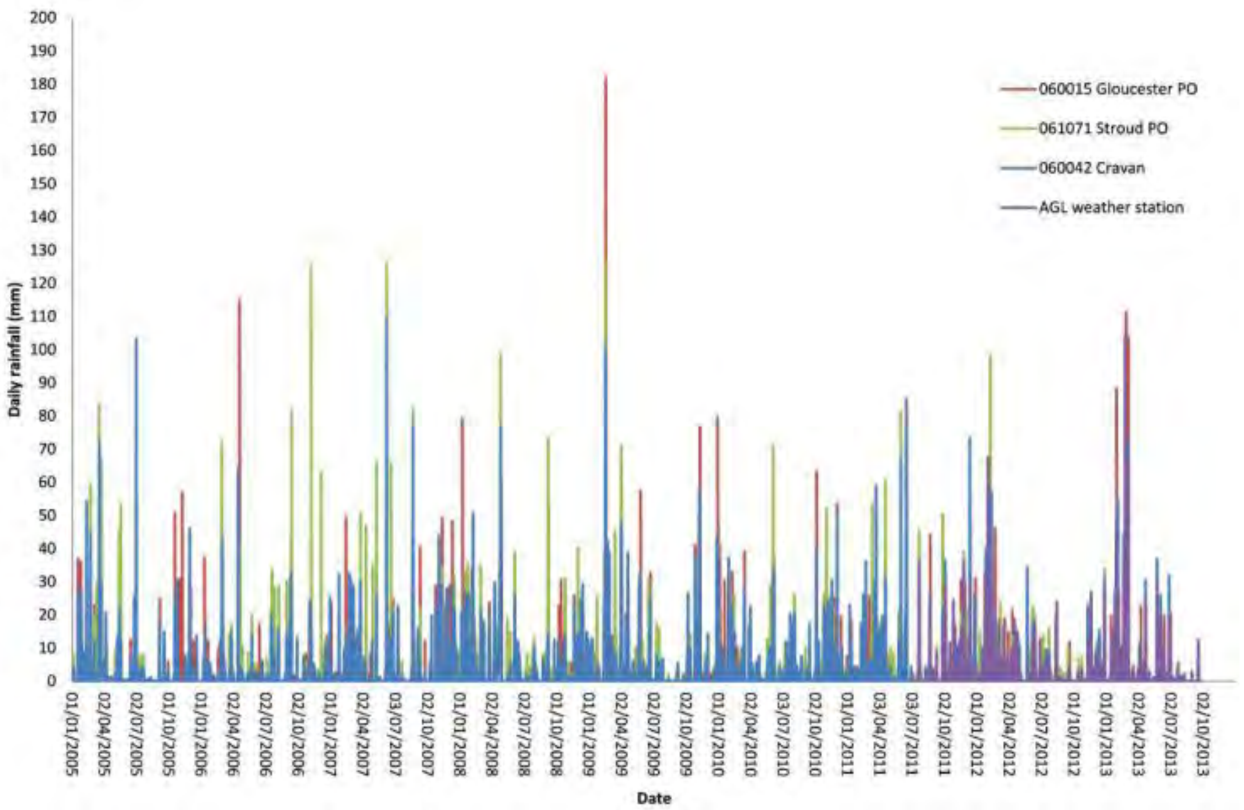

Figure 2.6 BoM rainfall comparison (BoM 2013)

2.3.4.1 NSW Office of Water flow gauges

Flow duration curves were developed for all of the NOW gauges (Appendix C). Figure 2.7 shows the flow duration curve developed for the Avon River (208028). Table 2.9 shows high flows which occur for 20% of days where the flow has been recorded; time without flow which is effectively zero flow; mean daily flow and mean annual flow.

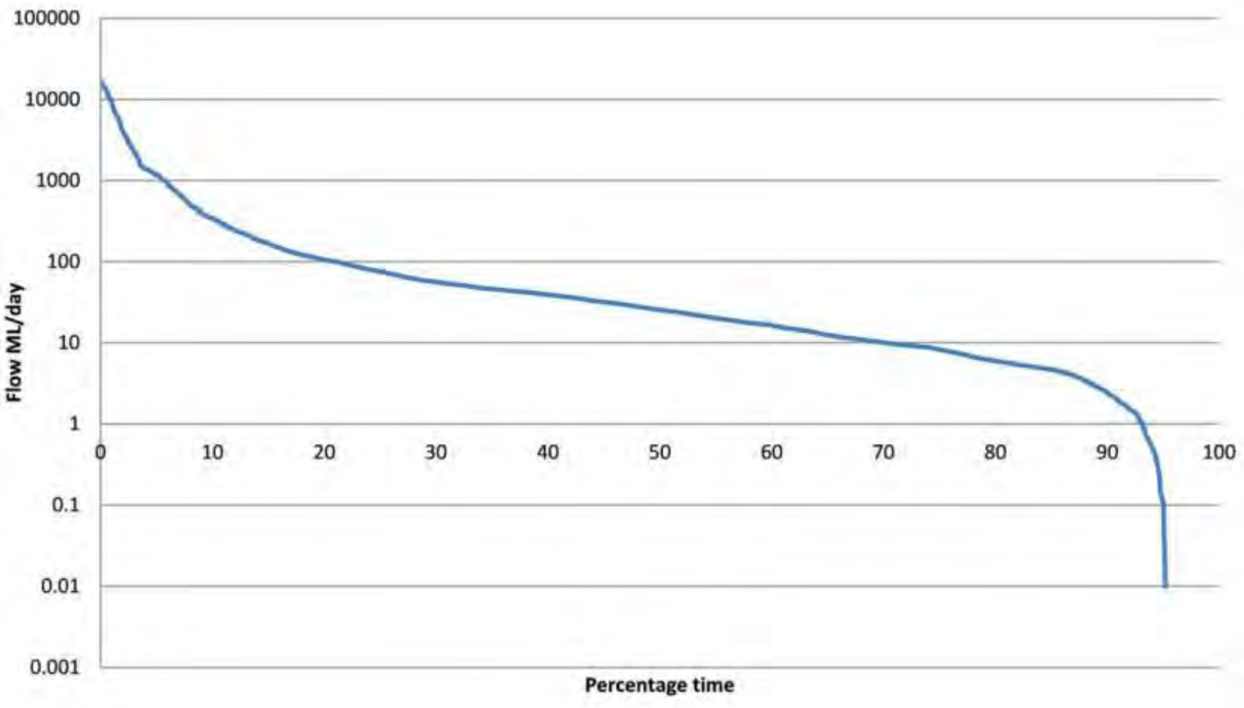

Figure 2.7 Avon River flow duration curve at GS 208028 (1 January 2005-27 May 2013)

The Avon River flow duration curve (Figure 2.7) and study period flow exceedance data (Table 2.9) indicate that there are small flows in the river most of the time (flow for 95% of the time). There is no flow past this gauge for less than 5% of the time, or on average 18 days per year. For a small portion of time (less than 1%) Avon River flow is above 10,000 ML/day. The Manning River downstream of the Avon River peak flow values are substantially above the peak flows of the Avon River (Table 2.9). There is flow most of the time in the Manning River (99% of the time). The Gloucester River at Gloucester (208020) has similar mean flows and high flow values to the Avon River (although local anecdotal evidence suggests that the Avon River has substantially less flow during dry periods than the Gloucester River); indicating that there are frequent short periods of high flows and longer periods of low flows. A similar trend was found for mean flows and high flows recorded for Gloucester River at Doon Ayre (208003).

The Karuah River catchment mean daily flows were all above the high flow value for each of the gauges, indicating there were short periods of high flows and long durations of medium to low flows.

Table 2.8 Flow exceedance data

	Station number	Location	High flows (occurring <20% of the days ML/day)	Time without flow (%)	Mean daily flow (ML/day)	Mean annual flow (ML/year)
Manning River catchment	208028	Avon River D/S Waukivory Creek (402554.8E, 6454389N)	104.8	<5%	301.6	110,099.3
	208020	Gloucester River at Gloucester (401663.9E, 6458743N)	246.6	<1%	238.3	86,975.1
	208003	Gloucester River at Doon Ayre (414578.9E, 6470683N)	1504.4	<1%	1563.6	570,730.6

	Station number	Location	High flows (occurring <20% of the days ML/day)	Time without flow (%)	Mean daily flow (ML/day)	Mean annual flow (ML/year)
	208004	Manning River at Killawarra (434930.8E, 434930.8N)	4037.8	<1%	3894.3	1,421,405.8
Karuah River catchment	209002	Mammy Johnsons River at Pikes Crossing (403804.8E, 6432089N)	50.4	<2%	116.3	42,449.3
	209003	Karuah River at Booral (402004.7E, 6406089.1N)	427.4	<1%	731.0	266,806.3
	209018	Karuah River at Dam Site (396404.8E, 642878934N)	238.4	<1%	334.6	122,119.2

(1) Note: Data 1 January 2005 – 27 May 2013

The mean daily flow on the Avon River at D/S Waukivory Creek for the study period 1 January 2005 to 27 May 2013 was 301.6 ML/day and in comparison the mean daily flow on Manning River at Killawarra was 3,894 ML/day, therefore the Avon River represents 8% of this total flow. Daily rainfall and flow were plotted for the period January 2005 – May 2013 to investigate temporal variation patterns (Figure 2.8 to 2.13).

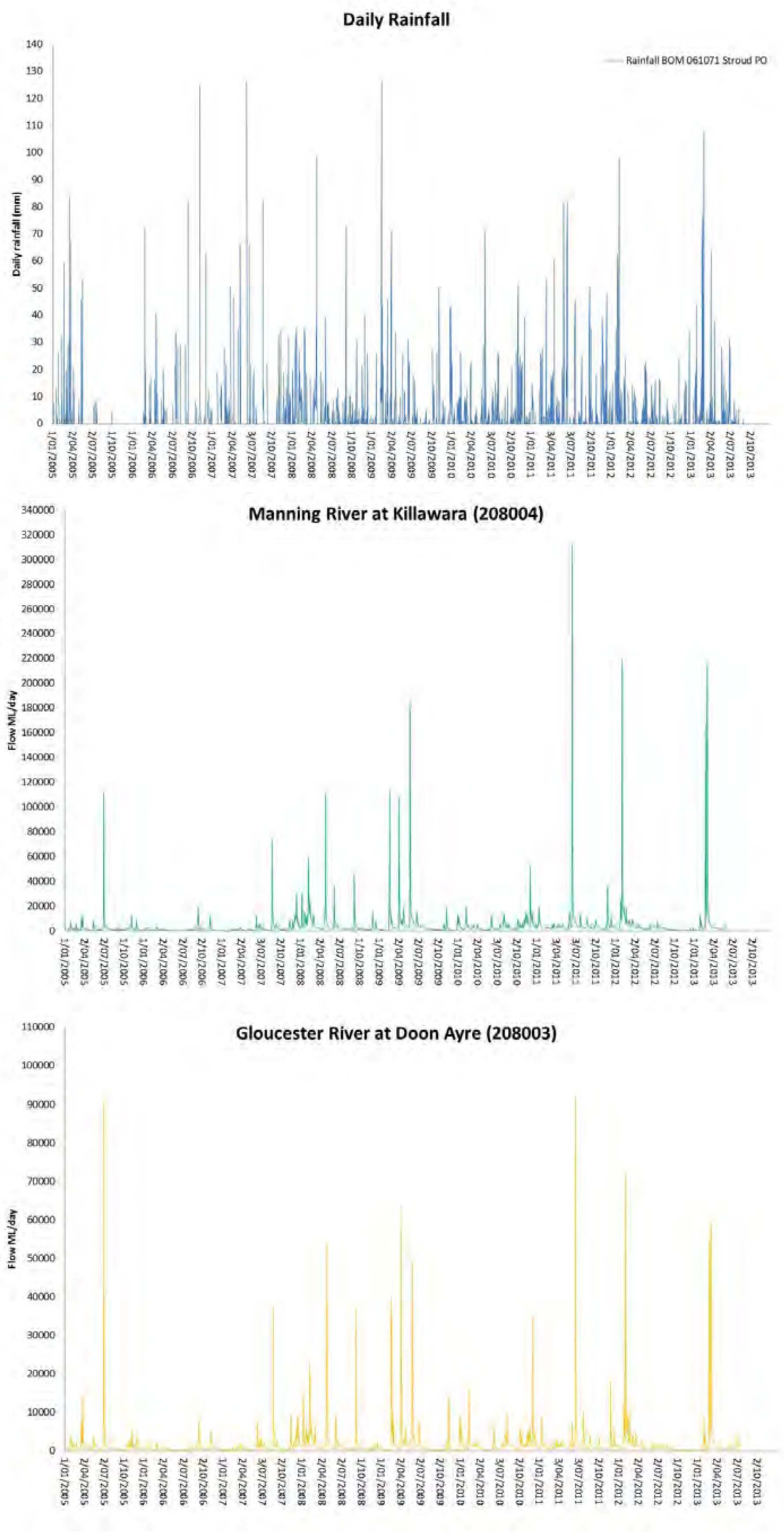

Figure 2.8 Rainfall (BoM 2013) and flow data in the Manning River Basin downstream (NOW 2013e

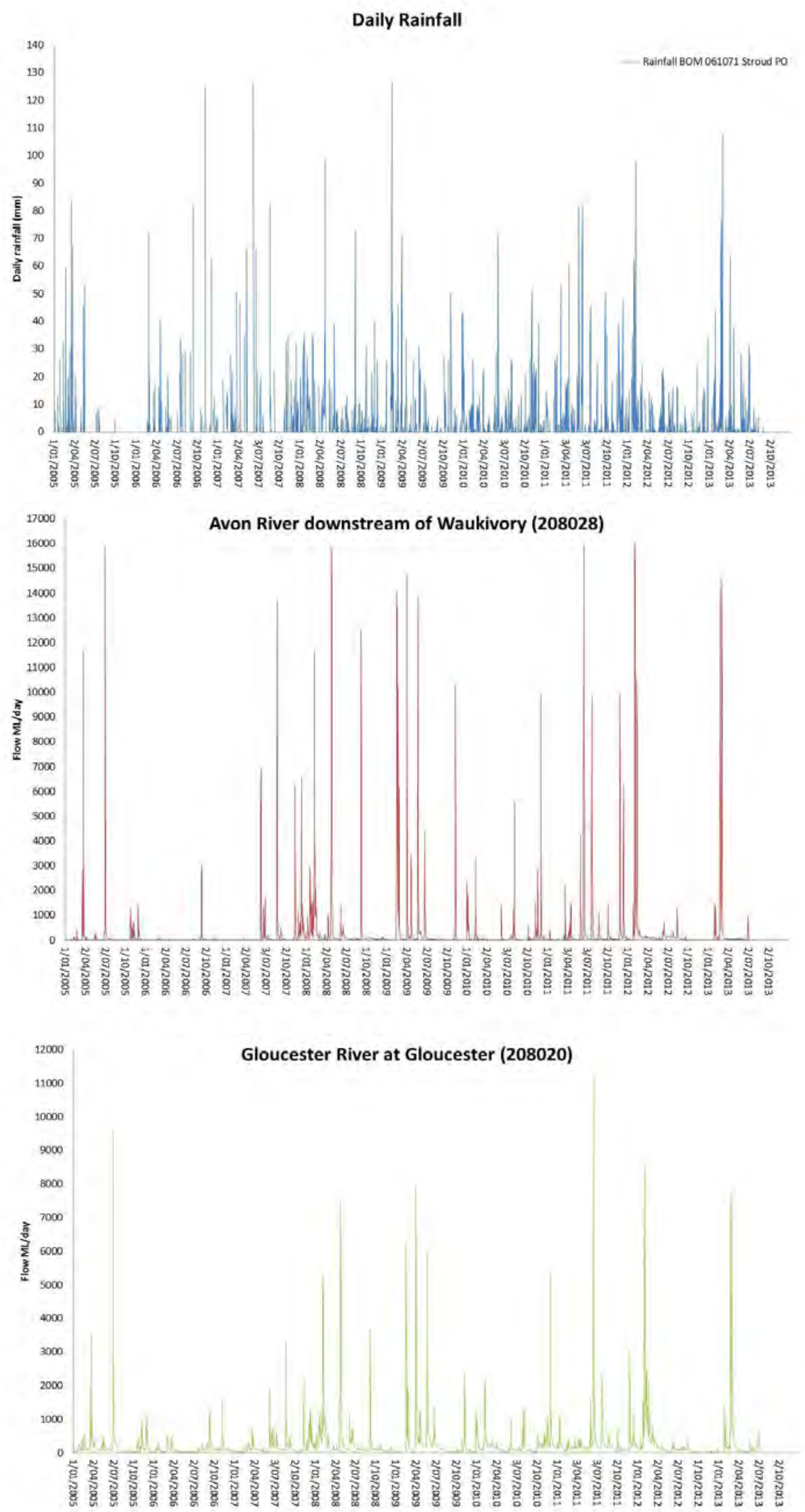

Figure 2.9 Rainfall (BoM) and flow data in the Avon River and Gloucester River catchments, sub-catchments of the Manning River catchment (NOW 2113e)

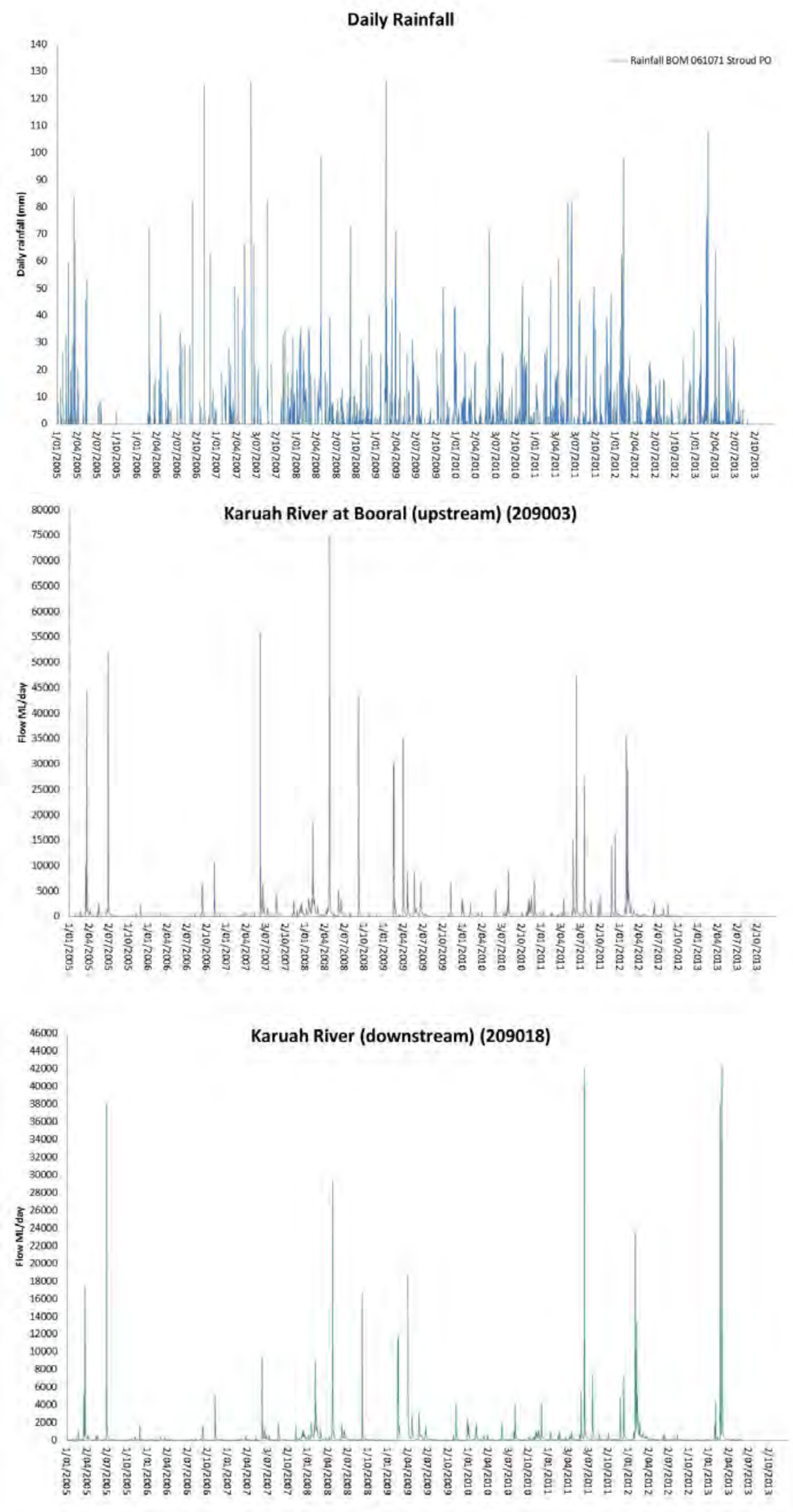

Figure 2.10 Rainfall (BoM) and flow data on the Karuah River in the Karuah River catchment (NOW 2103f)

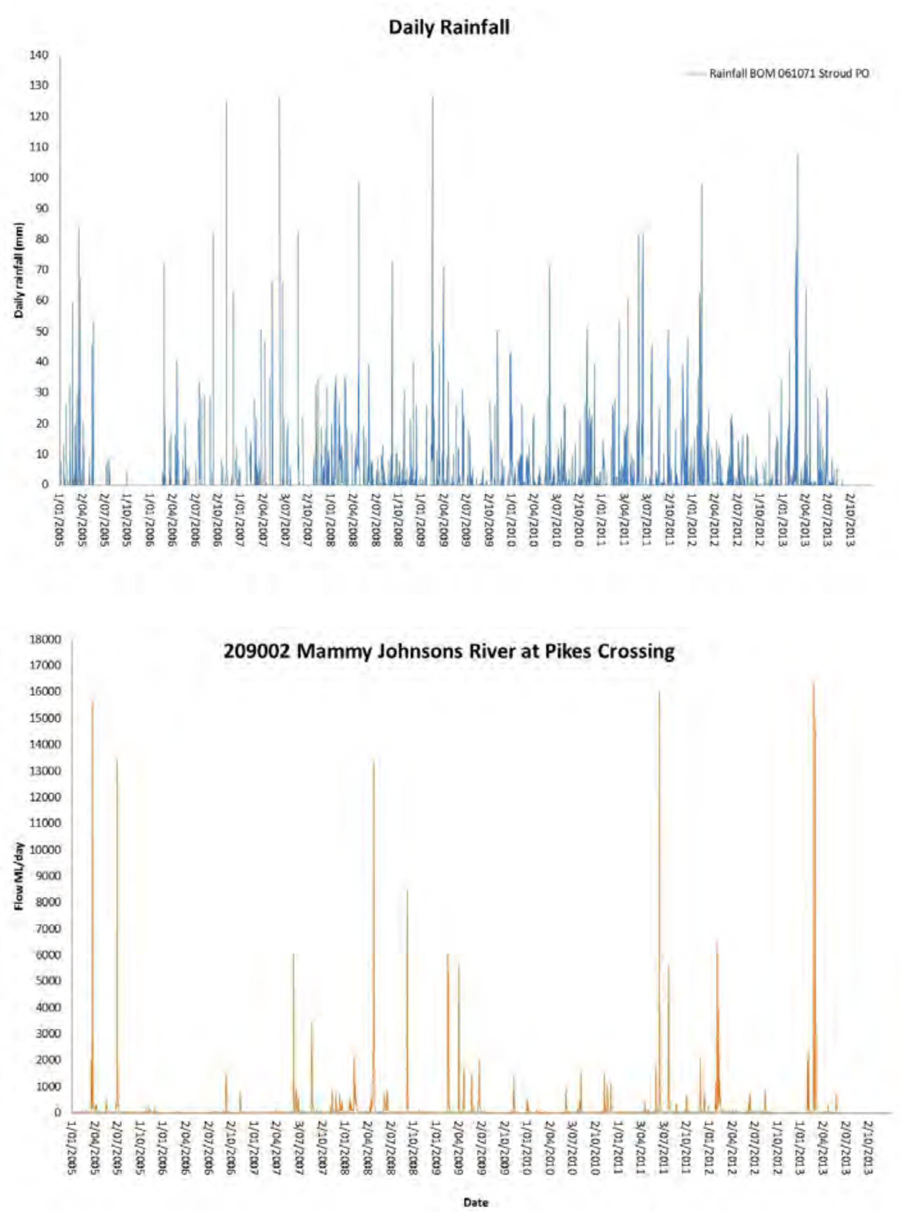

Figure 2.11 Rainfall (BoM 2013) and flow at Mammy Johnson River – Wards River sub-catchment of the Karuah River catchment (NOW 2013f)

The following observations have been made by studying the daily rainfall with the daily flow (Figure 2.8 to Figure 2.13 and flow duration curves (Appendix C).

Manning River catchment

- Flows were consistently higher on the Manning River at Killawarra with flows above 1,000 ML/day for 70% of the time. By comparison, the Gloucester at Doon Ayre had flows above 1,000 ML/day for 30% of the time and the Avon River at Waukivory had flows above 1,000 ML/day for 5% of the time.
- The peak flow rate occurs on the same day as the peak rainfall, indicating minimal lag time.
- High flows above 10,000 ML/day occurred for less than 0.5 % of the time at the Avon River at Waukivory, less than 1.5% of the time at Gloucester River at Doon Ayre and 5% of the time on the Manning River at Killawarra.

Avon River and Gloucester River at Gloucester

- During periods of high rainfall (>80 mm per day) the rivers both have a rapid increase in flow rate in less than 24 hours following rainfall events.
- The flows in the Gloucester River were consistently higher than those in the Avon River.
- The Avon River flows above 10,000 ML/day occurred for less than 0.5% of the time. For the Gloucester River flows above 10,000 ML/day occurred for less than 1.5% of the time. This indicates high magnitude, low duration events occurred in both these rivers.

Karuah River catchment

- Peak rainfall was higher in the Karuah River catchment (>120 mm/day) compared to the Manning River catchment.
- Not all peak rainfall events (above 80 mm/day) resulted in a peak flow event, unlike the Manning catchment. This is because the catchment has a high proportion of forested area (70%). This results in increased interception of rainfall and evapotranspiration by vegetation and therefore higher rainfall volumes are required for large flow events.
- Rainfall to runoff lag times is less than 24 hours.
- Downstream Karuah River and Mammy Johnson River have peak flows, occurring at the same time but upstream Karuah River has additional peak flow events, indicating that it is more responsive to rainfall events.
- Flows above 10,000 ML/day occur for less than 0.4% of the time on downstream Karuah River, less than 1% of the time upstream of the Karuah River and less than 0.15% of the time on Mammy Johnson River.

2.3.4.2 NOW gauges baseflow and baseflow index

Baseflow is the component of stream flow that is derived from groundwater discharge. Baseflow was calculated for this study and the water balance for Gloucester Basin (PB 2013b) using an approximate version of the sliding interval method (USGS 1996) for the seven NOW gauges (Table 2.9). The mean daily baseflow is the average baseflow over the downloaded time series period of 1 January 2005 – 27 May 2013. Baseflow index is the ratio of mean annual baseflow to mean annual flow. It shows the relative importance of groundwater flow contribution to the creek compared to inputs from rainfall and overland flow pathways.

Table 2.9 NOW gauging stations baseflow

	Station number	Location	Mean daily baseflow (ML/day)	Mean annual baseflow (ML/year)	Baseflow index (%)
Manning River catchment	208028	Avon River D/S Waukivory Creek 402554.8E, 6454389N	18.6	6,794.6	6%
	208020	Gloucester River at Gloucester 401663.9E, 6458743N	68.5	24,992.1	29%
	208003	Gloucester River at Doon Ayre 414578.9E, 6470683N	438.0	159,877.9	28%

	Station number	Location	Mean daily baseflow (ML/day)	Mean annual baseflow (ML/year)	Baseflow index (%)
	208004	Manning River at Killawarra 434930.8E, 434930.8N	1248.2	455,607.2	32%
Karuah River catchment	209002	Mammy Johnsons River at Pikes Crossing 403804.8E, 6432089N	6.8	2,497.5	7%
	209003	Karuah River at Booral 402004.7E, 6406089.1N	80.1	29,230.7	11%
	209018	Karuah River at Dam Site 396404.8E, 642878934N	52.4	19,122.7	16%

Flow duration curves and calculated average baseflow; indicate that there is potentially a groundwater contribution to the streams. The base flow index at Manning River and Gloucester River (at both Gloucester and Doon Ayre) is close to 30% (Table 2.9). The baseflow index for the Avon River (6%) and Mammy Johnsons River (6%) are relatively smaller compared to the Gloucester and Manning Rivers.

2.4 Existing water quality monitoring data

WQOs for uncontrolled streams apply to the GFDA and areas located within the Avon River catchment. The following section is a review of environmental values (EVs) and WQOs relevant to the Manning and Karuah catchments to assess against baseline water quality conditions.

2.4.1 Establishing water quality objectives

WQOs provided by NOW exist for distinct areas (or categories of streams) within the Manning River catchment and the Karuah River and Great Lakes catchment based on land use characteristics (NOW 2013c, and NOW 2013d). The following land use categories as described by NOW apply within the Manning and Karuah River catchments:

- town water supply sub-catchments
- mainly forested areas
- waterways affected by urban development
- uncontrolled streams
- estuaries.

The GFDA is positioned within the uncontrolled streams land use category within the Manning and Karuah River catchments. EVs are those values or uses of water that the community believes are important for a healthy ecosystem – for public benefit, welfare, safety or health (DEC 2006). The EVs that prescribe WQOs for uncontrolled streams within the Manning River catchment and Karuah River and Great Lakes catchments are provided in Figure 2.12 and Figure 2.13 respectively. WQOs apply to the various land uses within the catchment and provide target goals for water quality parameters depending on the environment and differing uses of water within a catchment. The WQOs are based on numeric measurable attributes of EVs to protect the uses of the environment within the catchment. In NSW, WQOs are the EVs and long-term goals and are not intended to be applied directly as regulatory criteria, limits or conditions (DEC 2006).

The WQOs for uncontrolled streams are the same in both catchments and are applicable to the GFDA. The EVs and objectives for uncontrolled streams within the Manning River and Karuah and Great Lakes catchments are provided in Table 2.10.

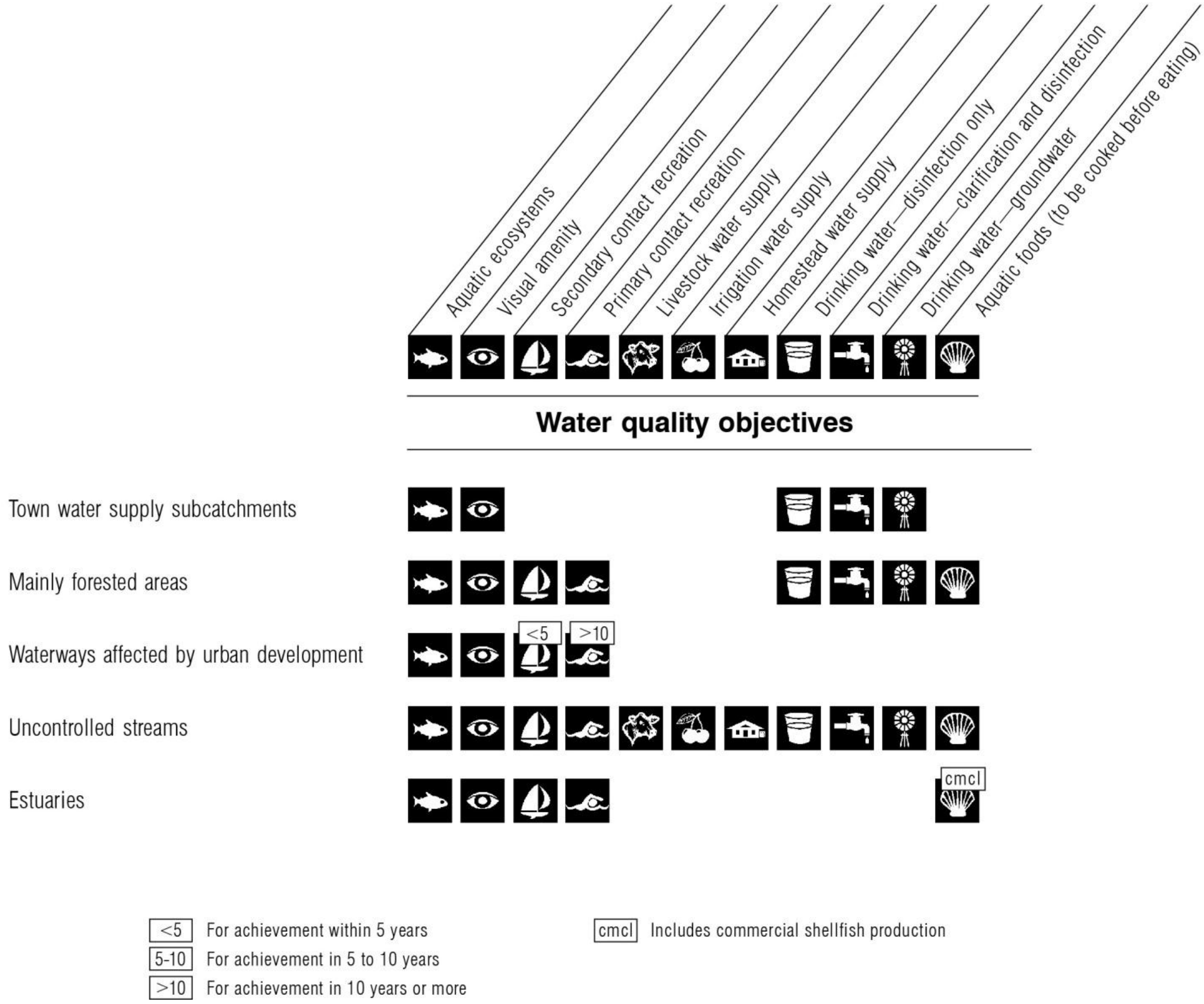

Figure 2.12 Manning River catchment WQOs

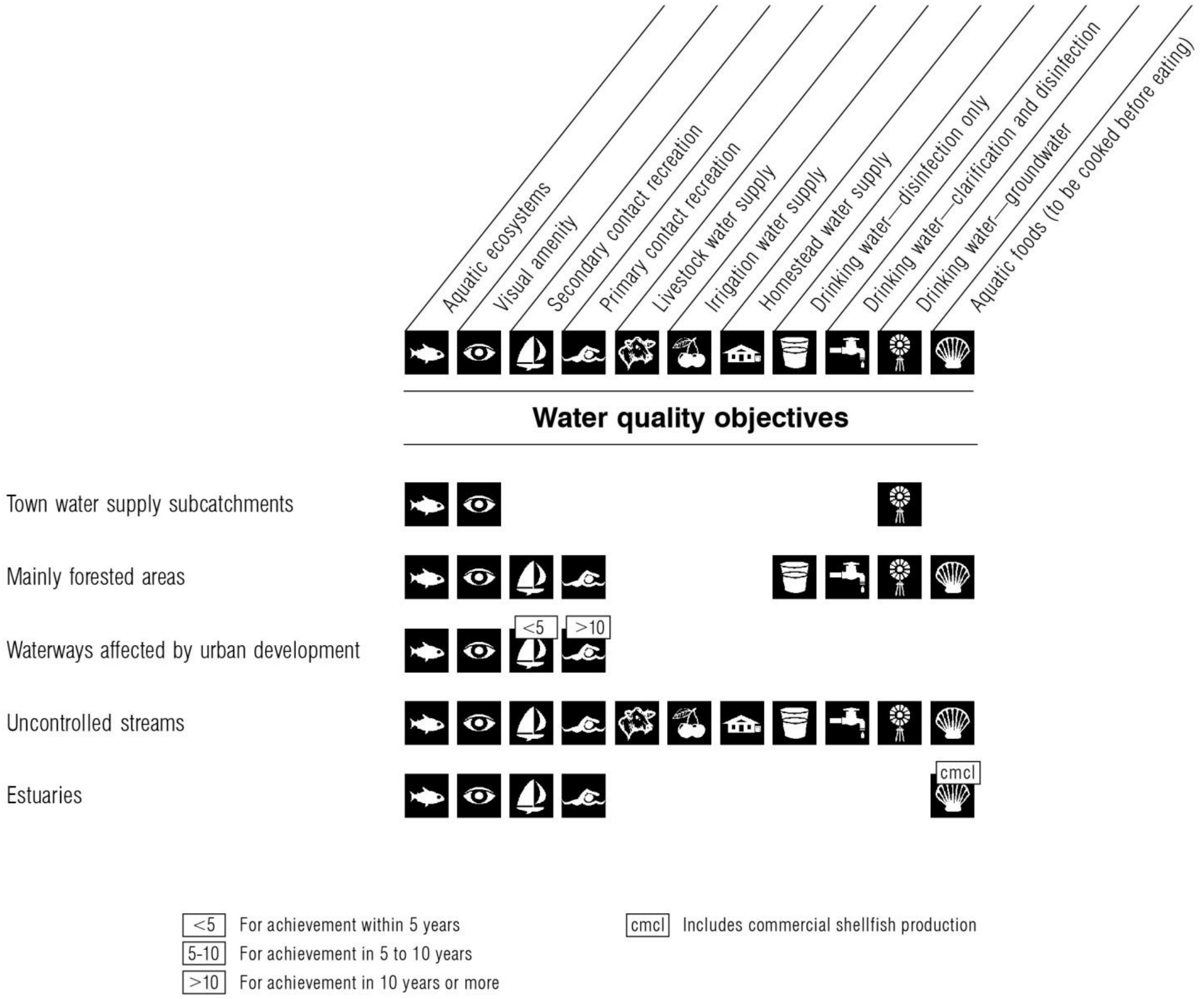

Figure 2.13 Karuah River catchment WQOs

Table 2.10 WQOs for the Manning River and Karuah River and Great Lakes catchments

Environmental values	Water quality objectives
Aquatic ecosystems	Maintaining or improving the ecological condition of water bodies and their riparian zones over the long term.
Visual amenity	Protect and improve aesthetic qualities of waters.
Secondary contact recreation	Maintaining or improving water quality for activities such as boating and wading, where there is a low probability of water being swallowed.
Primary contact recreation	Maintaining or improving water quality for activities such as swimming in which there is a high probability of water being swallowed.
Livestock water supply	Protecting water quality to maximise the production of healthy livestock.
Irrigation water supply	Protecting the quality of waters applied to crops and pasture.
Homestead water supply	Protecting water quality for domestic use in homesteads, including drinking, cooking and bathing.
Drinking water at point of supply – Disinfection only	Refers to the quality of drinking water drawn from the raw surface and groundwater sources before any treatment. A wide range of treatment technologies are available that enable the production
Drinking water at point of supply –	

Environmental values	Water quality objectives
Clarification and disinfection	of acceptable drinking water. All drinking water should comply with the Australian Drinking Water Guidelines (ADWG, 2011) at the point of use.
Drinking water at point of supply – Groundwater	
Aquatic foods (cooked)	Refers to protecting water quality so that it is suitable for the production of aquatic foods for human consumption and aquaculture activities.

The Australian and New Zealand Guidelines for fresh water quality (ANZECC 2000) guidelines advocate an 'issues-based' approach when assessing ambient water quality; when applying the guidelines in determining WQOs it is necessary to consider the desirable and appropriate EV based on local conditions and ecological or environmental processes that drive water quality.

Due to the lack of specific EVs or WQOs for the Avon River and Wards River sub-catchments, the following EVs are considered to be the most appropriate relating to uncontrolled streams within the GFDA:

- aquatic ecosystems
- visual amenity
- secondary contact recreation
- livestock water supply
- irrigation water supply.

The following are not considered likely EVs for these two sub-catchments based on land use, river morphology and known water quality:

- primary contact recreation
- homestead water supply
- drinking water – disinfection only
- drinking water – clarification and disinfection
- drinking water – groundwater
- aquatic foods (to be cooked before eating).

The guideline trigger values for physical and chemical stressors are provided in Section 3.3 of the ANZECC (2000) guidelines and derived from a number of historical data set across broad geographical regions. Additionally, the ANZECC (2000) guidelines provide trigger values for biological indicators and toxicants in Sections 3.2 and Sections 3.4 of the ANZECC (2000) guidelines, respectively. The Avon River catchment is predominately rural (Section 1.3) and ranges between 95 – 180 mAHD. As such, it is reasonable to characterise the Avon River catchment generically as a slightly to moderately disturbed, lowland (<150 mAHD) freshwater system.

The physical and chemical stressors to aquatic ecosystems in the Manning and Karuah River catchments along with example performance indicators and default trigger values for these stressors (based on the generic characterisation above) are shown in Table 2.11.

Table 2.11 Manning River and Karuah River catchment aquatic ecosystem stressors

Specific issue	Example performance indicators	Default trigger value [1]
Nuisance aquatic plants	Total phosphorus (TP) concentration [2]	25 µg/L
	Total nitrogen (TN) concentration [2]	350 µg/L

Specific issue	Example performance indicators	Default trigger value [1]
	Chlorophyll *a* [2]	3 µg/L
Lack of DO	DO Concentration	85 – 110 % saturation
Excess of suspended particulate matter (SPM)	SPM concentration [2]	6 – 50 NTU
Unnatural change in salinity	EC (salinity)	125 – 2,200 µS/cm
Unnatural change in temperature	Temperature	<20%ile baseline >80%ile baseline
Unnatural change in pH	pH	6.5 – 8.0
Poor optical properties	Turbidity [3]	6 – 50 NTU

(1) Default trigger values for physical and chemical stressors for south-east Australia for slightly disturbed systems.

(2) Values are for NSW east flowing coastal rivers.

(3) Ranges for SPM and turbidity are similar. Only turbidity (NTU) is reported by ANZECC (2000) guidelines (pp. 3.3-11). High values may be observed during high flow events.

Source: Adopted from tables 3.3.1 and 3.3.2 of the ANZECC (2000) guidelines

These ANZECC guidelines provide a generic indication of water quality in the local watercourses. The preferred approach would be to calculate site specific trigger values for each appropriate EV based on actual catchment water quality data. A minimum of two years of continuous monthly data at the reference site would be required to establish a valid site specific threshold taken at the 80th percentile. Exceedances of site specific trigger values are intended as early warning systems to alert managers of potential problems and are not intended to be an instrument of compliance.

2.4.2 Review of existing water quality data

Water quality data for the entire Manning River catchment have been sourced from readily available reports and relevant agencies including:

- Avon Catchment Stream Salinity (DIPNR 2005c).
- Manning Catchment Water Quality Investigation (Thurtell 2007).
- Determining locally derived water quality trigger values for the Manning Catchment 2008-09 (Thurtell 2009).
- State of Environment Reports (MidCoast Water 2011 - 2012).
- NSW Office of Water Data Request.
- Rocky Hill Coal Project Surface Water Assessment (WRM Water and Environment Pty Ltd 2013).
- Stratford Extension Project Surface Water Assessment (Gilbert and Associates Pty Ltd 2012).

These reports were reviewed and the purpose of this review was to collate information from third party sources and provide an indication of water quality conditions in the wider Manning River Catchment in order to gain understanding of potential impacts to downstream receptors. Water quality data focussing more directly on the GFDA area (including those data specifically collected as part of the GGP) are reported in Section 3.2. Water quality monitoring sites from these reports are provided in Figure 2.14

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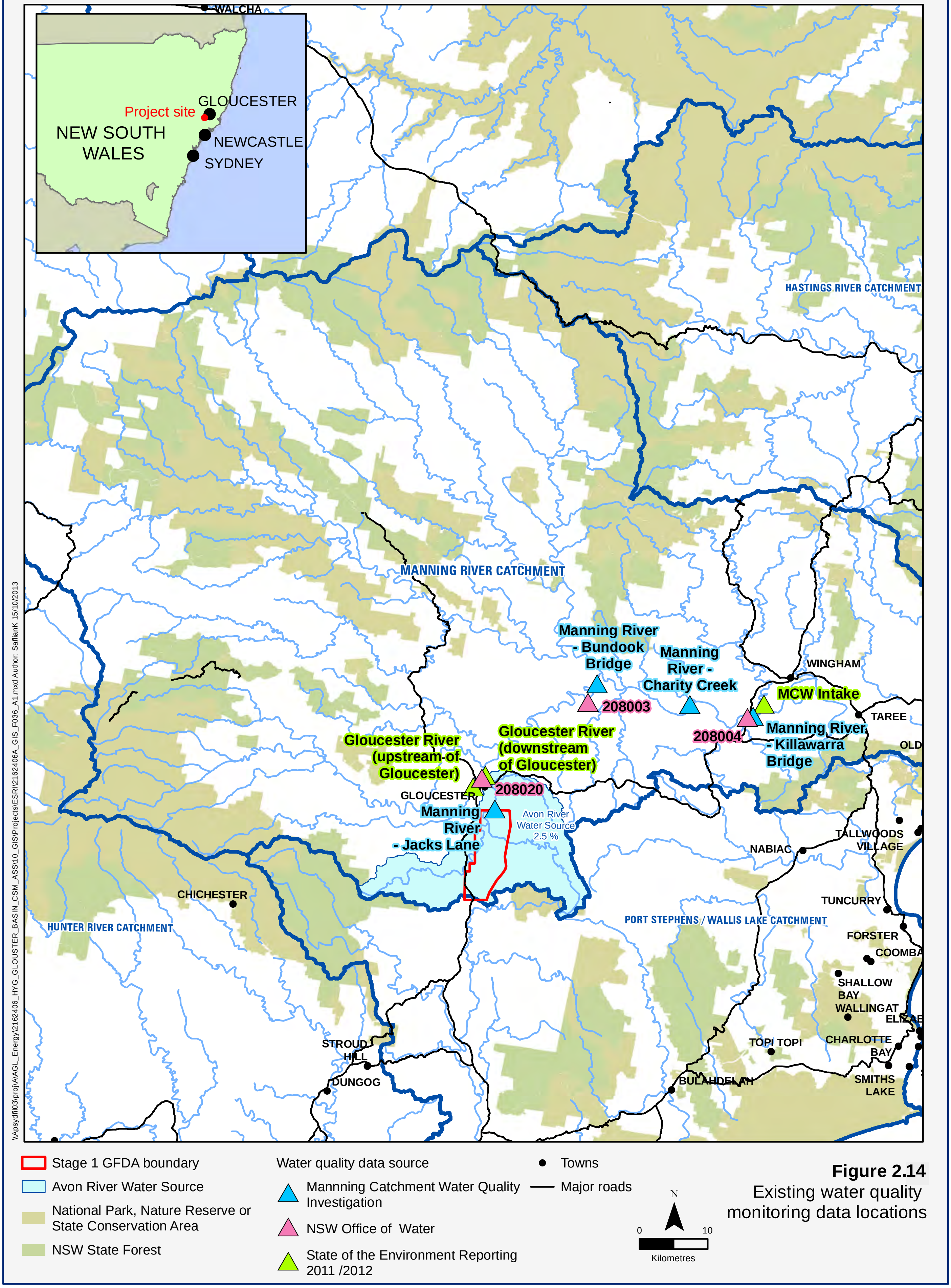


Figure 2.14
Existing water quality monitoring data locations

2.4.2.1 Avon catchment salinity assessment (DIPNR 2005c)

A rapid assessment of salinity (by measuring EC) and pH in the Avon River catchment was undertaken in 2004 to identify differences within and between streams of the Avon catchment (DIPNR 2005c).
Two sampling assessments were completed during dry periods (July 2004 and August 2004) at times of relatively low flow in the catchment to monitor salinity and were compared to historical data obtained from the Manning catchment community water quality program (Table 2.12).

Table 2.12 Salinity results from the Manning catchment community water quality program (1994–1997)

Catchment	EC (µS/cm)					No. samples
	Median	Minimum	25th percentile	75th percentile	Maximum	
Lower[1]	428	64	235	608	2,990	18
Mid[2]	390	95	271	478	942	32
Upper[3]	254	132	225	312	421	18

(1) Lower catchment – Avon River at Bucketts Way Bridge
(2) Mid catchment – Avon River at Wenham Cox Road
(3) Upper catchment – Avon River above junction of Morgan's Gully (west of Craven)

Source: Reproduced from Avon Catchment Salinity Assessment (DIPNR 2005c)

Historical data included in the salinity assessment indicates that EC generally is within the recommended thresholds provided by ANZECC guidelines and what is expected for the geology of this catchment. Maximum EC values in the lower catchment exceed ANZECC guidelines; however, these values are within the guidelines (125 – 2,200 µS/cm) in 75% of samples. A low level EC range was recorded in the upper catchment (132 – 421 µS/cm).

The salinity assessment recorded salinity at nine locations in July 2004 and 13 locations in August 2004 within the Avon catchment (Table 2.13 and Table 2.14 respectively).

Table 2.13 Salinity results recorded from July 2004 sampling (Avon catchment)

July 2004 sampling location	EC (µS/cm)
Avon River, Jacks Road	460
Oaky Creek, junction to Avon River, Jacks Road	1,160
Avon River, Fairbairns Lane near 'Birrico'	440
Waukivory Creek, Fairbairns Lane at 'Willandra'	524
Avon River, Wenham Cox Road near 'Glenview'	520
Avon River at Stratford (near Railway crossing)	551
Avon River at Deards Lane	338
Unnamed stream at 'Big Valley' with outflow to the Avon River	5,000
Unnamed stream to the Avon River at Mograni Creek Road near 'Dunbar'	1,160

Source: DIPNR 2005c

Table 2.14 Salinity results recorded from August 2004 sampling (Avon catchment)

August 2004 sampling location	EC (µS/cm)
Avon River, Mograni Creek Road near ‘Avon view’	1,360
Oaky Creek, Waukivory Creek Road	2,500
Oaky Creek junction to Avon River, Jacks Road	2,000
Avon River, Jacks Road	484
Avon River, Fairbairns Lane, near ‘Birrico’	620
Waukivory Creek, Fairbairns Lane near ‘Rochelle’	1,083
Waukivory Creek, Waukivory Creek Road near ‘Bracken Fells’	460
Dog Trap Creek, Wenham Cox Road near ‘Glenview’	818
Avon River at Wenham Cox Road	810
Cut off pond, Avon River, Deards Lane off Upper Avon Road near ‘Leama’	370
Clear Hill Creek, Upper Avon Road	1,900
Clear Hill Creek drainage line, 500 m west of Clear Hill Creek, Upper Avon Road	4,500
Avon River, Upper Avon River Road	232

Source: DIPNR 2005c

The results from samples collected during the salinity assessment have been summarised as follows:

- EC levels recorded in July 2004 range between 338 – 5,000 µS/cm:
  - the highest EC level (5,000 µS/cm was recorded at one location; an unnamed stream at ‘Big Valley’ with outflow to the Avon River
  - the next highest EC level (1,160 µS/cm) was recorded at two sites; the Oaky Creek junction to Avon River at Jacks Road, and; an unnamed stream to the Avon River at Mograni Creek Road near ‘Dunbar’.
- EC levels recorded in August 2004 range between 232 µS/cm– 4,500 µS/cm:
  - the highest EC level (4,500 µS/cm) was recorded at one location; Clear Hill Creek drainage line, 500 m west of Clear Hill Creek, Upper Avon Road
  - the next highest EC level (2,500 µS/cm) was recorded at Oaky Creek, Waukivory Creek Road.

The range of EC values recorded during the assessment were generally within recommended thresholds provided by ANZECC guidelines (125 – 2,200 µS/cm), however, exceedances were recorded in smaller tributaries of the Avon River above threshold values.

The report identified that parts of the Avon River catchment are inherently susceptible to salinity due to a combination of sedimentary geology that provides the predominant source of salt, large areas of sodic soils, and natural topography causing the migration of water and salt into the lower parts of the catchment. This assessment concluded that salt conditions observed appear to be a natural part of the Avon River catchment and salinity is not a major issue overall in the Avon, but is of local significance in some parts of the catchment relating to irrigation water salinity and salinity discharges associated with gully erosion.

Although high EC values have been recorded in the Avon River catchment, downstream of Gloucester, the higher flow volumes from the Gloucester River and Barrington River, have the ability to dilute salt loads from the Avon River (DIPNR 2005c).

A discrete water sample in August 2004 from an unnamed stream and mine outflow area to the Avon River at Wenham Cox Road recorded a single EC value of 7,800 µS/cm. This report is limited by discrete samples from two sampling events. Both events occurred during low flows when water residence time allows for potentially higher EC values. These water quality data therefore, represent times when water quality could be considered poorer compared to periods of high flow in the catchment.

2.4.2.2 Manning River catchment water quality investigation (Thurtell 2007)

A water quality investigation was undertaken within the Manning River catchment from January 2007 to December 2007 (Thurtell 2007). This review is focussed on sites within the Avon River catchment and downstream including:

- Avon River at Jacks Lane
- Gloucester River at Bundook Bridge
- Manning River at Charity Creek Bridge
- Manning River at Killawarra Bridge.

Discharge in the Manning River at Killawarra for the beginning of 2007 was less than average flows, calculated from the preceding eight years, but greater than average in the second half of the year, dominated by median to large ‘freshes’ towards the end of 2007.

Mean EC within the Avon River was found to be lower than 400 µS/cm with the highest recorded peak being no greater than 800 µs/cm. These results and downstream monitoring location data were within the ANZECC (2000) default trigger values (Table 2.11). Dilution of salts under increased flow was observed in the Avon River (Thurtell 2007). This finding is supported by more recent water quality results completed for the annual water monitoring reports (PB 2012a and PB 2013c).

The Avon River consistently reported elevated levels of total nitrogen (TN). There was no apparent relationship between discharge and TN during the sampling period. These results infer that elevated TN concentrations in the Avon River are not necessarily solely attributable to agricultural and mining surface runoff during rainfall events. All TN samples were above the Manning River WQOs with concentrations exceeding the default trigger value, 350 µg/L (Table 2.12). TN concentrations were more variable in the Manning River and were within WQOs in more than 80% of samples at Charity Creek, and 65% of samples at Killawarra Bridge. Concentrations of TN were greatly reduced as a result of dilution from other sub-catchments within the Manning River catchment.

Total phosphorus (TP) concentrations were much higher in the Avon River than elsewhere in the Manning River catchment. TP concentrations were unrelated to flow and no samples were reported below the WQOs; concentrations of TP in the Avon River exceeded the default trigger value, 25 µg/L (Table 2.9), in 100% of the samples collected during the study. Concentrations of TP within the Manning River at Charity Creek Bridge exceeded 25 µg/L in 45% of samples, while concentrations within the Manning River at Killawarra exceeded 25 µg/L in more than 70% of samples.

The author postulated that the lack of relationship between nutrient concentrations and discharge in the Avon River suggests that nutrient source was related to factors other than surface runoff.

2.4.2.3 Locally derived water quality trigger values (Thurtell 2009)

The purpose of this investigation (Thurtell 2009) was to suggest more regionally appropriate trigger values when assessing water quality within the Manning River catchment. The study did not consider water quality from within the Avon River and as such has not been considered further in this study when selecting WQO’s for the Avon River.

2.4.2.4 State of the environment reporting 2011/2012

State of the environment (SoE) reports has been prepared by MCW for the Manning River catchment since 2010. Water quality in the SoE report is aligned with the EV's and WQO's for the Manning River catchment (Section 2.4.1). Downstream from the Avon River catchment, a water quality monitoring site was located along a freshwater reach of the Manning River (upstream of Wingham near Kimbriki). No sites on the Avon River are reviewed and as a result these reports only provide a summary of water quality conditions for downstream receptors from the GGP.

Water quality results are presented in the SoE reports based on ranking criteria of compliance against each EV. All criteria must be met for a particular environmental objective to be met. Ranked results according to compliance against environmental objectives are provided in Table 2.15.

Table 2.15 MidCoast Water SoE 2011/12 water quality results for Manning River near Wingham

EV	Rank	% Criteria met
Aquatic ecosystem protection	Good	75 – 100%
Primary contact recreation	Fair	50 – 74%
Secondary contact recreation	Good	75 – 100%
Aquatic foods (Cooked)	Very poor	0 – 24%
Agricultural irrigation water supply	Good	75 – 100%
Livestock water supply	Good	75 – 100%
Drinking water	Fair	50 – 74%

Water quality results from the SoE report suggest that environmental objectives for the Manning River catchment for the protection of aquatic foods cannot be achieved throughout the catchment. This suggests that the WQOs for the protection of aquatic foods are not appropriate in sections of the Manning River catchment and that there are continuing issues with compliance for all EVs. This supports the decision to remove aquatic foods from the list of EV's most relevant to the GFDA (Section 2.4.1).

MidCoast Water applies average nutrient (TN and TP) concentrations at locations within the Manning River catchment to estimate base load nutrient levels (Table 2.16).

Table 2.16 MidCoast Water nutrient concentrations (SoE 2011/12)

Location	TN (µg/L)	TP (µg/L)
Manning River at MCW intake	222	31
Gloucester River (upstream of Gloucester)	230	30
Gloucester River (downstream of Gloucester)	287	60

Source: SoE 2012

TN concentrations are consistently within the recommended guidelines at the monitoring locations (350 µg/L); however, TP concentrations exceed recommended thresholds (25 µg/L) particularly downstream of Gloucester. The range of nutrient concentrations and the frequency that nutrient concentrations exceed desired guideline levels are not provided in SoE report.

2.4.2.5 NSW Office of Water

Water quality data was obtained from the NOW from established monitoring stations within the Manning River Basin (Table 2.17):

- 208003 – Barrington River upstream from the Manning River
- 208004 – Manning River upstream from Bootawa Dam
- 208020 – Gloucester River upstream from the Barrington River.

These sites are all downstream from the GFDA and thus only provide an indication of baseline water quality for potential downstream receptors for the GGP. The data obtained from these gauging stations has been summarised below in Table 2.17.

Table 2.17 Summary of water quality data obtained from NSW Office of Water

NOW Station	Parameter	Minimum	Maximum	Average	% Above WQOs*
Barrington (208003)	TP (mg/L)	0.006	0.066	0.045	87.5
	TN (mg/L)	0.17	0.22	0.195	0.0
	Turbidity (NTU)	0	38	3.78	0.0
	pH	6.80	9.33	7.30	1.2
	Faecal Coliform (CFU/100mL)	ND	ND	ND	ND
	Electrical Conductivity @25C (µs/cm)	63	485	137.91	0.0
	Chlorophyll-*a* (µg/L)	ND	ND	ND	ND
	DO (mg/L)	ND	ND	ND	ND
	DO (% saturation)	ND	ND	ND	ND
Gloucester (208020)	TP (mg/L)	0.010	0.344	0.039	57.7
	TN (mg/L)	0.05	2.4	0.311	25.4
	Turbidity (NTU)	1.08	183	6.87	1.4
	pH	6.00	8.60	7.19	11.1
	Faecal Coliform (CFU/100mL)	10	45,600	2438.05	100
	Electrical Conductivity @25C (µs/cm)	38.1	216.3	92.16	0.0
	Chlorophyll-*a* (µg/L)	ND	ND	ND	ND
	DO (mg/L)	ND	ND	ND	ND
	Dissolved Oxygen (% saturation)	ND	ND	ND	ND
Manning (208004)	TP (mg/L)	0	6	0.062	55.9
	TN (mg/L)	0.05	3.9	0.455	45.4
	Turbidity (NTU)	0	755	11.26	3.0
	pH	6.40	9.30	7.57	8.3
	Faecal Coliform (CFU/100mL)	8.0	2,500	177.11	100
	Electrical Conductivity @25C (µs/cm)	8.0	368	152.76	0.0
	Chlorophyll-*a* (µg/L)	0.00	0.07	0.01	0.0
	DO (mg/L)	7.54	11.11	9.32	ND
	DO (% saturation)	92	115.80	98.77	4.3

*For comparison purposes WQO's are listed in Table 2.11.

The following broad general observations can be made from the limited data at the Barrington River:

- TN concentrations were within WQOs in all samples
- TP concentrations exceeded WQOs in 87.5% of collected samples
- all recorded turbidity and EC values were within WQOs
- maximum pH levels (9.33) were elevated compared to WQOs.

A comprehensive data set was available from the Manning River gauging station (No. 208004) ranging from 1977–2013 for some water quality parameters. The following observations can be made from all available data obtained:

- average TN and TP concentrations exceeded guidelines
- maximum turbidity values (755 NTU) exceeded guidelines however, average turbidity values (11 NTU) and 80th percentile (8.8 NTU) were within guidelines
- minimum and maximum pH values (6.4 and 9.3 respectively) were outside of the WQO range, however average pH (7.57) and 80th percentile pH values (7.80) were within the WQOs
- EC was within recommended WQOs for average (153 µS/cm) and 80th percentile (175 µS/cm) recorded values
- chlorophyll-*a* and DO (mean 0.01 µg/L and 99% saturation respectively) were within the recommended WQOs.

The following observations have been made from the dataset available for the Gloucester River at Gloucester (No. 208020) from 1999 – 2007:

- maximum TP concentrations (344 µg/L) exceeded WQOs and TP concentrations were above WQOs in 58% of collected samples
- maximum TN concentrations (400 µg/L) exceeded WQOs and TN concentrations were above WQOs in 25% of collected sample.
- average TN and TP concentrations exceeded WQOs
- faecal coliforms exceeded WQOs in all collected samples
- EC was within the recommended WQOs for all collected samples (average 92 µS/cm)
- no data existed for Chlorophyll-*a* and DO.

Based on all water quality data available from the NOW, water quality within the lower Manning River generally meets the WQO's. Nutrient and faecal coliform concentrations and pH values however, are higher than the recommended values and do not meet WQOs for the protection of aquatic ecosystems.

2.4.2.6 Stratford extension project surface water assessment

The Stratford coal mining complex is an open cut coal mining operation located within the Stage 1 GFDA boundary and situated within the Avon River catchment (Figure 3.1). A surface water assessment was prepared for Stratford Coal Pty Ltd (SCPL) for the environmental impact statement for the continuation and extension of operations at the mining complex (Gilbert and Associates Pty Ltd 2012). A review of the surface water assessment was undertaken to further understand the local existing water quality characteristics.

This review focuses on the 10 surface water quality monitoring locations situated along the streams and rivers within the mining complex as follows:

- Avon River (two locations - W1 and W2)

- Dog Trap Creek (three locations – W3, W3A and W4)
- Avondale Creek and tributary (five locations – W5, W6, W8, W9 and W10 [with W10 being a tributary of Avondale Creek]).

Average EC concentrations were below recommended ANZECC guidelines (125 – 2,200 µS/cm) across all SCPL monitoring sites within the Avon River (W1 – 332 µS/cm and W2 – 387 µS/cm), Avondale Creek (W5 – 1671 µS/cm, W6 – 747 µS/cm, W8 – 786 µS/cm, W9 – 227 µS/cm and W10 – 617 µS/cm) and Dog Trap Creek (W3 – 419 µS/cm, W3A – 383 µS/cm and W4 – 608 µS/cm). Maximum EC concentrations within the Avon River monitoring locations were also recorded below the recommended ANZECC guidelines with no exceedances.

Maximum EC concentrations have been recorded above ANZECC guidelines within the Avondale Creek within three of the five Avondale Creek monitoring locations (W5 – 13,000 µS/cm, W6 – 5,200 µS/cm and W8 – 3,200 µS/cm) with the percent of samples exceeding recommended ANZECC guidelines in 23%, 5% and 2% of samples, respectively. Maximum EC concentrations above ANZECC guidelines within Dog Trap Creek were recorded in one of three monitoring locations (W4 – 3,090 µS/cm). Maximum EC concentrations exceeded recommended ANZECC guidelines in 2% of samples at monitoring location W4.

Maximum concentrations of TN and TP were recorded above recommended ANZECC guidelines at all monitoring locations across all water courses. Concentrations for both TN and TP exceeding the recommended ANZECC guidelines occurred in the majority of the total number of samples at each monitoring location.

Cadmium, chromium, copper and lead concentrations across the Avon River monitoring locations were found to exceed the ANZECC recommended guidelines for the protection of aquatic ecosystems. The frequency at which concentrations exceeded desired guideline levels were recorded as follows:

- Cadmium — 7% at W1 and 11% at W2
- Chromium — 17% at W1 and 20% at W2
- Copper — 8% at W1 and 27% at W2
- Lead — 16% at W1 and 27% at W2.

Cadmium, chromium, copper, lead and manganese concentrations were found to exceed guidelines within Avondale Creek and Dog Trap Creek. The frequency at which concentrations exceeded desired guideline levels were recorded as follows:

- Copper — 72% at W9, 30% at W6, 29% at W8, and 29% at W5
- Chromium — 56% at W9, 10% at W6, 14% at W8 and 17% at W5
- Cadmium — 10% at W6 and 7% at W8
- Lead — 17% at W6 and 18% at W5
- Manganese — 9% at W8 and 9% at W5.

It is not clear from the report if the samples recording exceedances were collected during event sampling or routine monthly sampling.

These water quality results are generally consistent with the water quality data recorded for the GGP water quality monitoring program.

2.4.2.7 Rocky Hill coal project surface water assessment

A surface water assessment was prepared for Gloucester Resources Limited (GRL) for the for the proposed open cut mining operations for the Rocky Hill coal project (RHCP) (WRM Water and Environment Pty Ltd

2013). A review of the surface water assessment was undertaken to further understand the local existing water quality characteristics.

A baseline surface water quality monitoring program commenced for the RHCP in July 2010 as part of the assessment. This review has focussed on the water quality monitoring locations along the following watercourses:

- Avon River – two sites
- Oaky Creek – one site
- Waukivory Creek – three sites
- Mine area – five sites.

Median EC concentrations within the Avon River and Waukivory Creek monitoring locations were within recommended ANZECC guidelines (ranging from 357 – 400 µS/cm and 364 – 378 µS/cm respectively). Median concentrations of EC within Oaky Creek were generally lower (328 µS/cm), while EC concentrations within the mine area were highly variable (ranging from 132 – 1,446 µS/cm), most likely as a result of the ephemeral nature of these watercourses.

Median TN and TP concentrations were recorded above recommended ANZECC guidelines at all water quality monitoring locations.

Levels of pH were found to be neutral across Avon River, Oaky Creek and the mine area monitoring locations with neutral to slightly alkaline conditions found within Waukivory Creek. Median concentrations of metals above recommended guidelines for the protection of 95% of species were found within some monitoring locations. The most common exceedances were for cadmium, copper, chromium, lead and zinc.

These water quality results are generally consistent with the water quality data recorded for the GGP water quality monitoring program.

2.5 Sensitive downstream users

This sub-section contains a review of sensitive water users downstream from the GFDA. This includes aquatic ecosystem use and raw water extraction for potable water supply.

2.5.1 Aquatic ecosystem use

The Manning and Karuah River catchments do not contain ‘inland wetlands’ of national significance in terms of protection (DSEWPC 2011). The Karuah River catchment does contain a RAMSAR designated coastal zone wetland – Myall Lakes – a series of fresh, saline and brackish water bodies of differing depths and associated vegetation types. However, the main freshwater inputs to this wetland are from the Myall River and Crawford River, which are not hydrologically connected to creeks that drain the GFDA into the Karuah River. The Karuah River catchment also contains the Port Stephens Estuary and Wallis Lake, which are both classified as nationally important wetlands (DoE 2013). The GFDA is approximately 40 km from the upstream boundary of the Port Stephens Estuary designated wetland area. Wallis Lake is not hydrologically connected to the GFDA, with the main freshwater inputs from Wallamba River, Wang Wauk River and Walling at River (NOW 2011).

Aquatic habitats within the GFDA have been identified in Section 4.7.

2.5.2 Raw water for potable water supply

There are no raw water supply offtakes for potable water supplies in the Avon River catchment. There are two river offtakes downstream of the Avon River sub-catchment within the broader Manning River catchment:

- The Barrington River offtake for the Gloucester water supply (operated by MidCoast Water) is situated upstream of the confluence between the Gloucester River and the Avon River. Being on a tributary of the Avon River (and upstream) there is no direct effect on this adjacent catchment from flows originating from the Avon River sub-catchment.
- The Manning River offtake for the Manning water supply (which is situated on the Manning River about 50 km downstream from the GFDA boundary on the Avon River) is operated by MidCoast Water and serves areas such as Taree, Wingham, Forster, Tuncurry, Pacific Palms, Nabiac, Dyers Crossing, Harrington, Coopernook, Hallidays Point and Lansdowne. Flows from the Avon River sub-catchment flow past this offtake but (on average) the Avon River flows represent 8% of the total flow at the Killawarra gauging station (Section 2.2.1.2).

The Karuah River is regulated at Stroud by a weir structure; however, there are no known water supply offtakes for potable water supplies in the Karuah River catchment.

3. Project surface water

AGL established an extensive water monitoring network across the GFDA in 2011/12 and this is being further expanded across the whole of the Gloucester Basin. In this section, the AGL surface water data that has been collected since 2011 plus additional data collected as part of this study for the GFDA (to October 2013) are discussed. The discussion addresses some of the knowledge gaps highlighted in Section 2.

Additional discussion of the surface water data and trends is provided in the original Phase 2 investigations (PB 2012), and the 2012 and 2013 annual water monitoring reports (PB 2012a and PB 2013c respectively).

3.1 Project stream gauges

A surface water quality and stream gauging monitoring network was established for surface water investigations for the Stage 1 GFDA of the GGP in 2011 (Figure 3.1.

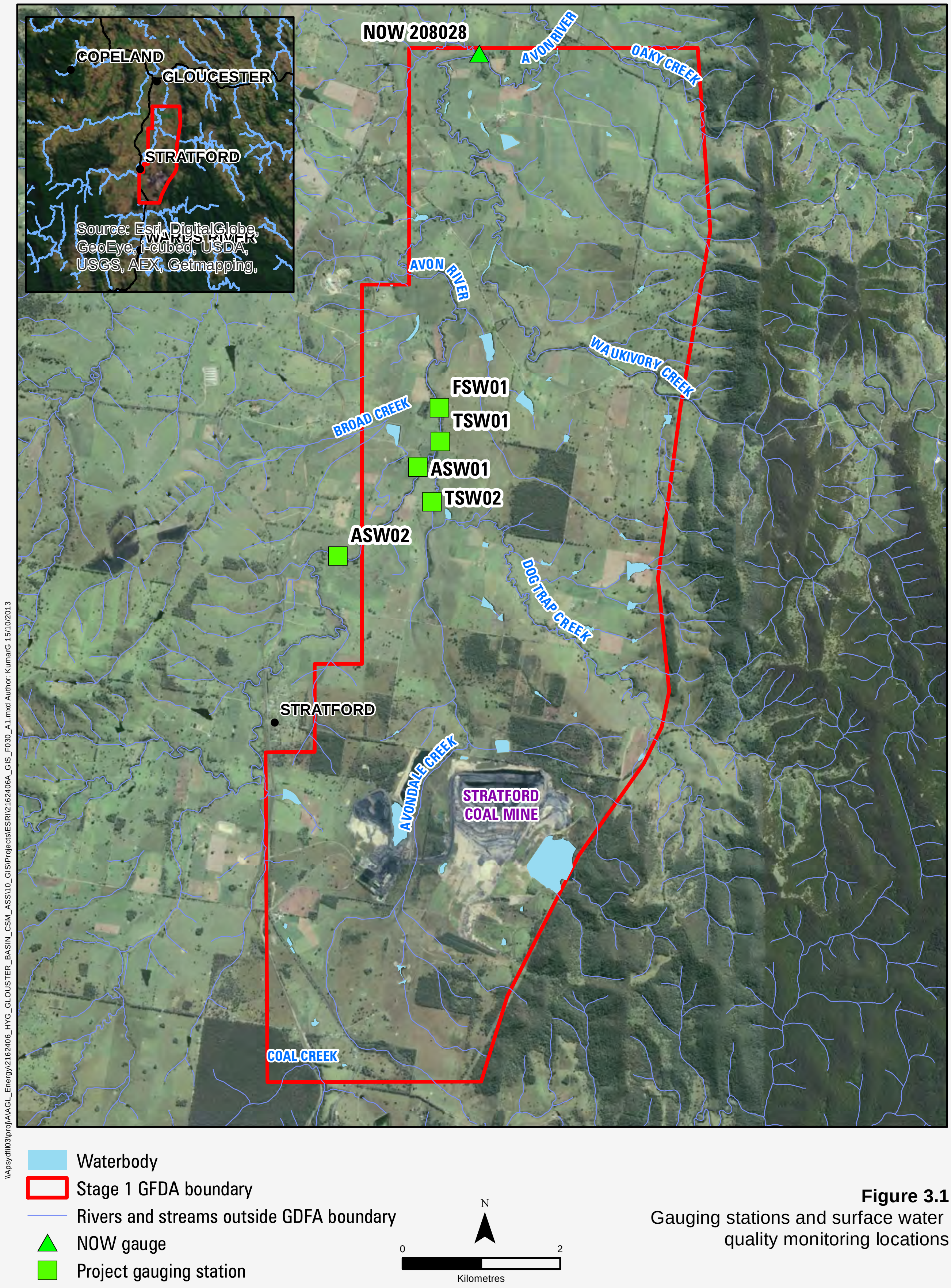


Figure 3.1
Gauging stations and surface water quality monitoring locations

A total of four stream gauges have been deployed (Table 3.1) as part of the phase 2 investigations (Parsons Brinckerhoff 2012a) as follows:

- TSW01 – located on the Avon River within the Tiedman property, 0.3 km downstream of the confluence with Dog Trap Creek
- TSW02 – located on Dog Trap Creek within the Tiedman property, 0.4 km upstream of the confluence with the Avon River
- ASW01 – located on the Avon River within the Atkins property, 0.1 km upstream of the confluence with Dog Trap Creek
- ASW02 – 1.7 km upstream of the confluence with Dog Trap Creek on the Avon River within the Atkins property.

Each location is equipped with a water level and salinity data logger to collect automatic data for this part of the Avon River sub-catchment. Water level and salinity data is collected at 15 minute intervals.

An additional site (FSW01 located approximately 0.2 km downstream from TSW01 on the Avon River) was included in the local surface water quality monitoring network as part of the Tiedman Irrigation Trial monitoring network in 2012. Occasional water quality data has been collected at this site.

Table 3.1 AGL stream gauges – Stage 1 GFDA

Stream gauge	Stream location	Water level record duration	Catchment area (km^2)
TSW01	Avon River	23/03/2011 – present	117.3
TSW02	Dog Trap Creek	04/04/2012 – present	40.2
ASW01	Avon River	23/03/2011 – present	77.0
ASW02	Avon River	23/03/2011 – present	75.8

All stream gauges on the Avon River and Dog Trap Creek show sharp increases in water level in response to rainfall and flood events, and relatively steep recession curves (Figure 3.2). This is characteristic of rapid runoff responses from a relatively small upstream catchment with limited flood plain and low groundwater baseflow contributions. Stream levels decrease over several weeks following large rainfall events to a relatively consistent baseflow level that represents a small baseflow component in the Avon River.

During the monitoring period, anomalously low rainfall occurred in the Spring of 2012 (September and October 2012). This resulted in a period of ‘no flow’ or very low flow, when the Avon River was characterised by multiple disconnected pools from September 2012 to January 2013 (Figure 3.2). Rainfall occurred in November 2012 however it was not until the high rainfall events in January and February 2013 that there were increased flows in the Avon River and Dog Trap Creek and corresponding sharp increases in river water levels.

Similar conditions prevailed in the Spring of 2013 and have continued through the Summer of 2013/14.

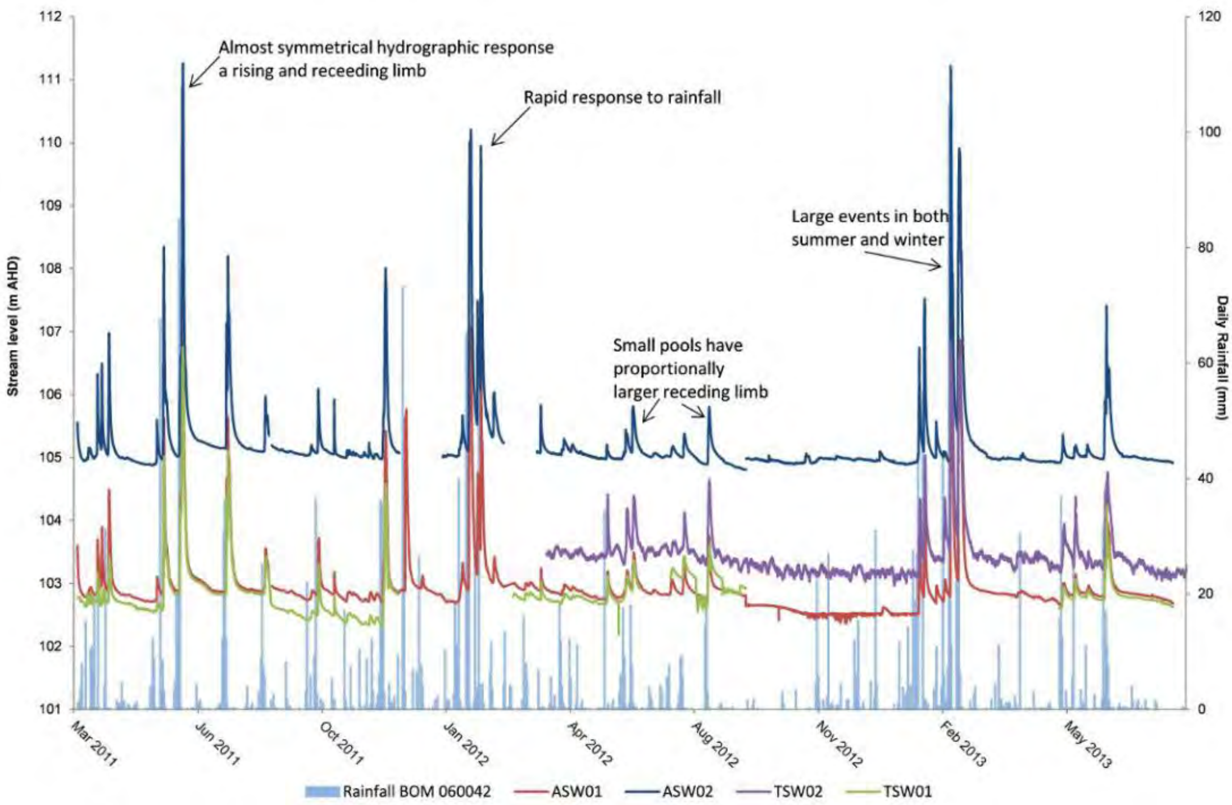
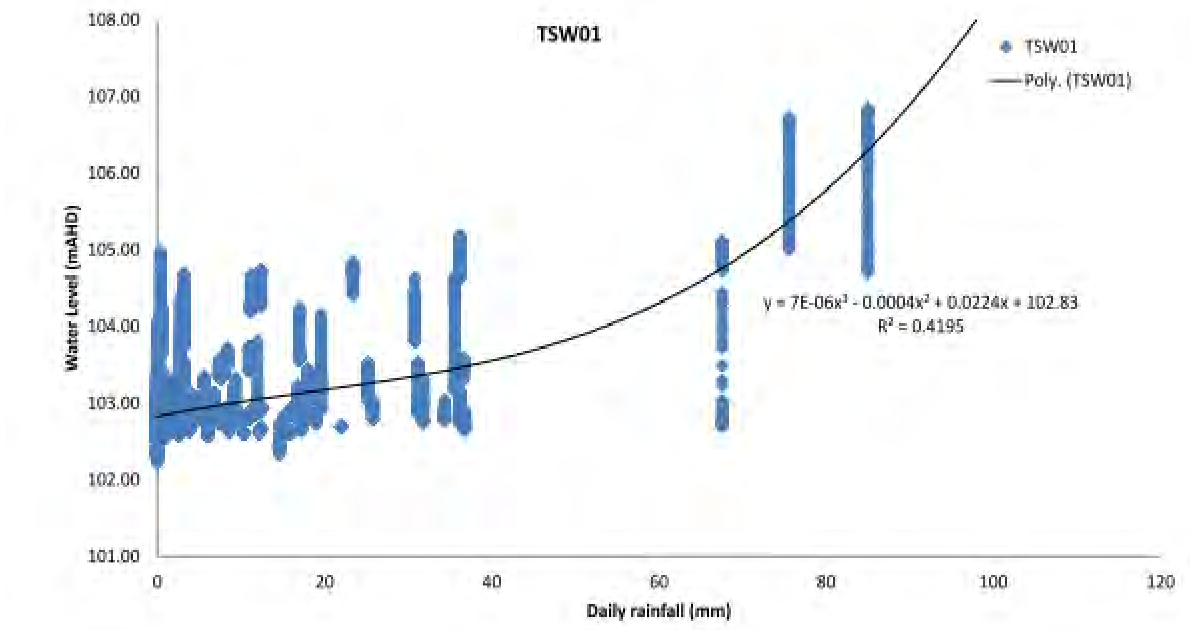
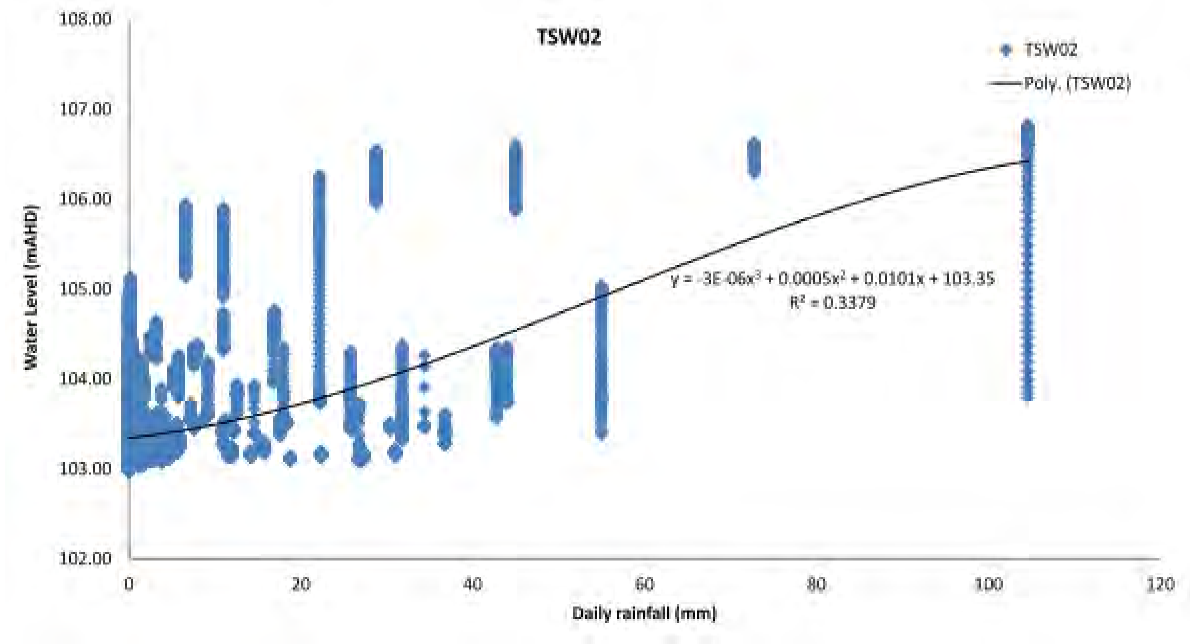


Figure 3.2 Avon River and Dog Trap Creek stream level data and rainfall

Scatter graphs were plotted for the four loggers to determine the relationship between rainfall and water level (Figure 3.3). The correlation was found to be poor. The coefficient of determination (r2) highest value was 0.58 at ASW02; suggesting that factors other than rainfall peak influence water level, such as ponded water after a rainfall event, antecedent soil moisture, the ability of the catchment to soak up small rainfall events and larger events after extended dry periods such as November 2012. A more robust comparison between rainfall and flow should be completed (R2) once stage-discharge curves are constructed (Section 3.1.2).


TSW01
TSW01
Poly. (TSW01)
y = 7E-06x³ - 0.0004x² + 0.0224x + 102.83
R² = 0.4195
Water Level (mAHD)
108.00
107.00
106.00
105.00
104.00
103.00
102.00
101.00
0
20
40
60
80
100
120
Daily rainfall (mm)


TSW02
TSW02
Poly. (TSW02)
y = -3E-06x³ + 0.0005x² + 0.0101x + 103.35
R² = 0.3379
Water Level (mAHD)
108.00
107.00
106.00
105.00
104.00
103.00
102.00
0
20
40
60
80
100
120
Daily rainfall (mm)

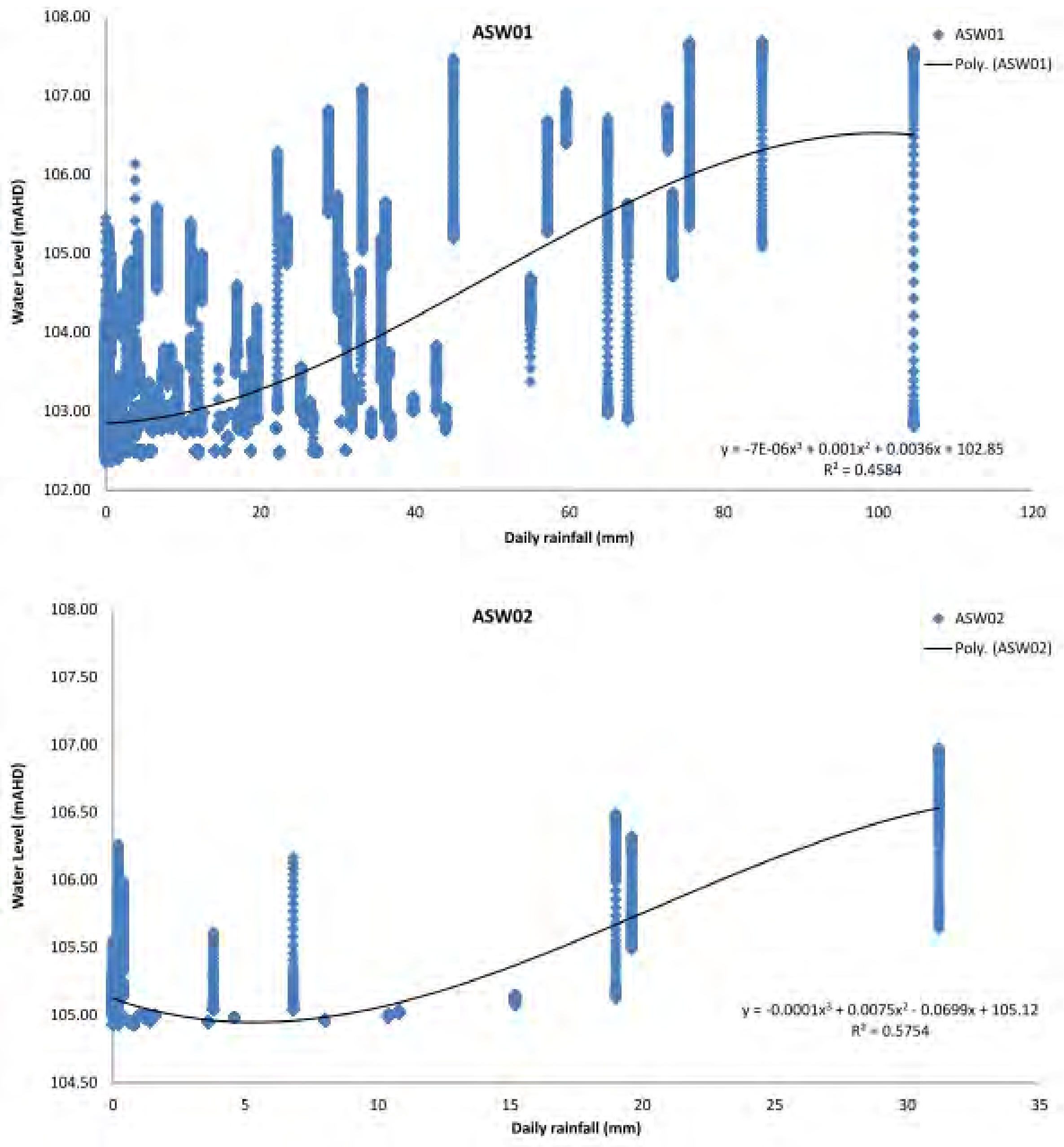


Figure 3.3 Scatter plot of the four loggers and their relation to rainfall and water level

3.1.1 Sub-catchment flow contribution

The flow to each of the AGL deployed gauges was also estimated using the rational method (Section 2.3.3) and catchment area to the gauge (Appendix B). The peak flow estimates for a range of ARI events are shown in Table 3.2. These peak flows can be used to approximate the ARI of the flow records taken on site (Section 3.1.1). It is noted that a more detailed flood frequency analysis should be undertaken to more accurately estimate the ARI of the flow events captured (R3), however there is no long term gauged flow data in the smaller tributaries available and, therefore, these numbers have been used as a guide for approximation purposes until more data becomes available

Table 3.2 Peak flow estimates to all stream gauges within the Stage 1 GFDA

Gauge location	Area to gauge (km^2)	100 year ARI peak flow (m^3/s)	50 year ARI peak flow (m^3/s)	20 year ARI peak flow (m^3/s)	10 year ARI peak flow (m^3/s)	5 year ARI peak flow (m^3/s)	2 year ARI peak flow (m^3/s)	1 year ARI peak flow (m^3/s)
NOW gauge 208028	225.0	1174.2	960.0	743.6	572.3	441.7	283.4	183.1
TSW01	117.3	700.8	573.6	445.0	342.9	265.2	170.6	110.4
TSW02	40.2	300.1	246.0	191.3	147.8	114.6	74.1	48.1
ASW01	77.0	502.1	411.3	319.4	246.3	190.7	123.0	79.6
ASW02	75.8	495.9	406.2	315.4	243.3	188.3	121.5	78.6

3.1.2 Stage discharge relationship

In order to convert the recorded river water levels into flows, a stage-discharge relationship must be developed for each of the sites.

A SonTek M9 river surveyor with an ADCP system was used to measure 3-dimensional water velocity, channel cross section area, channel depths and compute river flows. The ADCP was deployed on two consecutive days during a high flow rain event on 27 – 28 June 2013 (where >15 mm at the AGL Tiedman property weather station is likely to result in water levels at the stream gauges above the 20th percentile). The ADCP was deployed at Stage 1 GFDA stream gauges considering representative flow at three locations:

- TSW01 (two measurements on 27 June and three measurements on 28 June)
- TSW02 (two measurements on 27 June and two measurements on 28 June)
- ASW01 (three measurements on 28 June)
- wet and muddy conditions prohibited access to ASW02. Using the tethered deployment method, the ADCP was mounted on a floating platform and secured to a tag line (or cableway) perpendicular to channel flow.

The position of the tag line and cross section for measurement considered the suitability of the flow conditions at each location. Measurement locations chosen (where possible) were characteristic of the channel form at each monitoring location, were not obstructed by debris in the channel, consisted of apparent uniform (non-turbulent) flow and repeatability of the tag line position.

Post measurement review and data processing was undertaken using SonTek river surveyor live software (version 3.6.0.3384) to report on the calculated discharge and assess the quality of the data. The discharge measurement summaries at each location are provided (Appendix D).

Using the discharge measurement summaries and the recorded water level from the loggers, it was possible to plot a water level versus flow scatter plot for these events (Appendix D). However, due to the limited flow records at the gauging locations to date (three at ASW01, TSW01, TSW02 and none at ASW02 as of September 2013) there is insufficient flow data to establish a trend line for stage versus discharge.

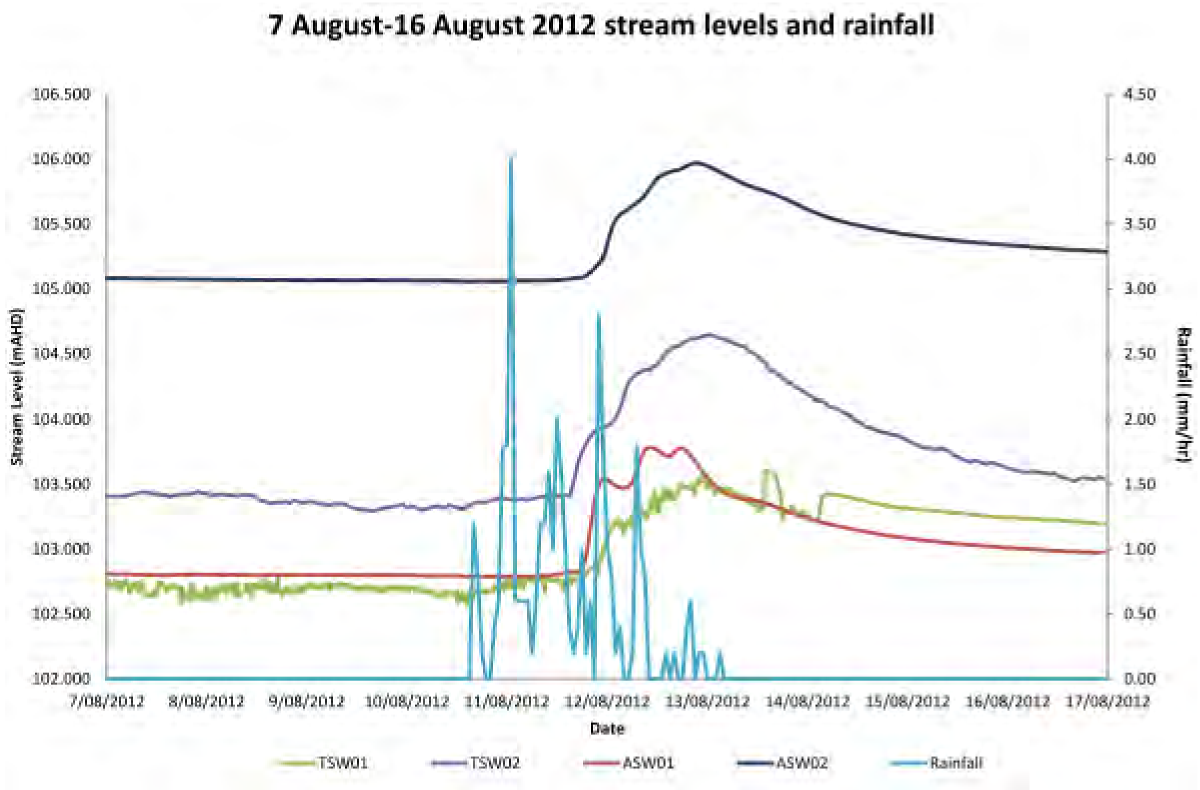
Flow water level data recorded on ASW02 was limited due to a high flow event when access was not possible and a water logger malfunction at TSW01. Once more stream flow data is captured for a range of high and low flow events it may be possible to calculate a reliable stage-discharge relationship for the gauge cross sections and convert the recorded water level from the loggers into a stream flow time series. It is expected that five further flow measurements would be required at each site including one low flow, three intermediate flows and one high flow event (R4). Refer to Appendix D for further detail on stage-discharge relationships.

3.1.3 Lag time

Flow at the NOW stream gauges on the Avon River and Mammy Johnson River for the rainfall event from 7 – 16 August 2012 found peak flows were on the 12 August, the same day as the peak rainfall. This is reasonable because these gauges are located high in their respective catchments and close to the rainfall stations. Flows in the Gloucester River at Gloucester, Karuah River downstream, Karuah River upstream and Gloucester River at Doon Ayre peak flow occurred on the 13 August, a day after the peak rainfall. In the Manning River at Killawarra, the peak flow was on 14 August, two days after the rainfall event.

Typical storm responses from the stream gauge loggers are shown over two periods when normal conditions prevailed across the catchment; 7 – 16 August 2012 and 4 – 15 June 2012 (Figure 3.4). Peak water level occurred approximately 40 hours after the first peak rainfall event for the August event. For the June event, the water level began to increase after the peak rainfall on the 6 June and then the water level peaked just after the rainfall on the 7 June. Rainfall data and water level data recorded at the AGL loggers was a mixture of hourly and 15 minute data. Data indicates that there was frequently a lag of 24 hours or more between rainfall and runoff.

All four loggers have a similar lag and duration. However, the magnitude of the peak water level varied. The high water levels at TSW02 and ASW02 are a result of confined channels and steep banks, compared to the cross sections of ASW01 and TSW01 which have larger bank width with greater hydrologic capacity (Appendix D).



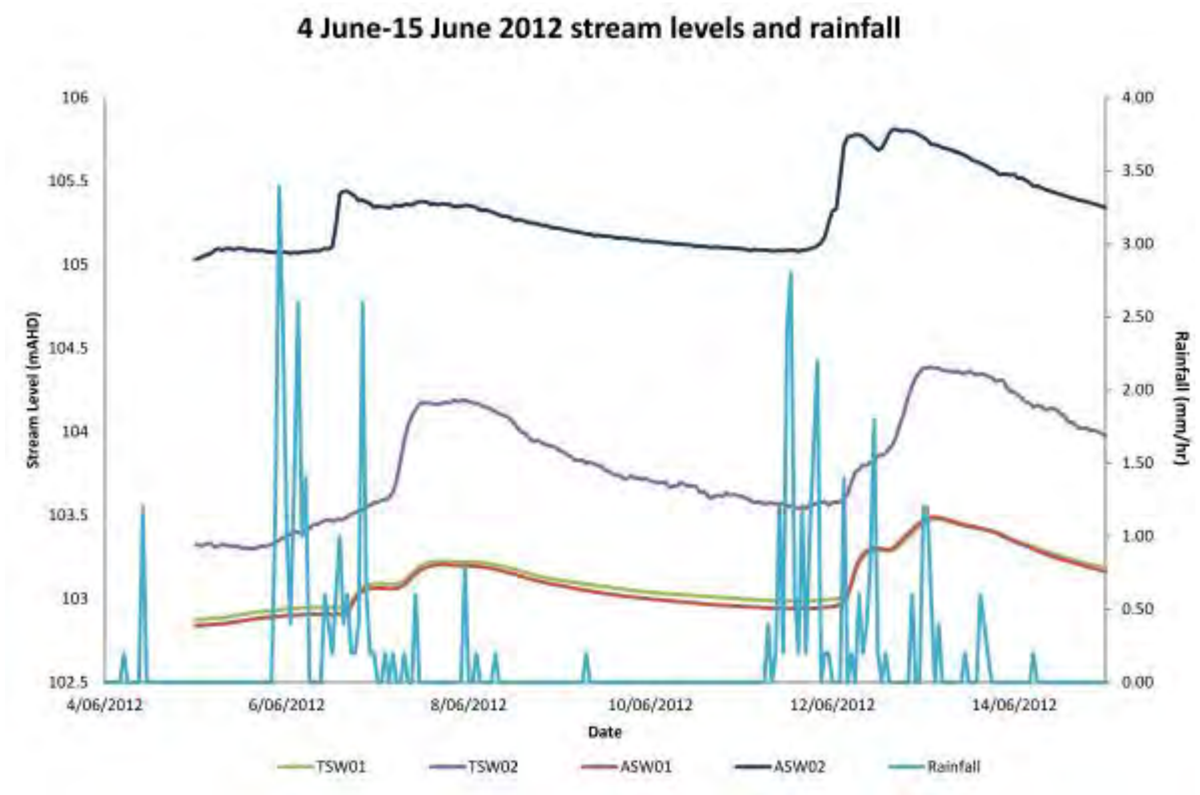


Figure 3.4 Specific rainfall event for water level gauges

The main observations from analysis of a June 2012 rainfall event, summarised in Table 3.3 and Figure 3.4 are:

- there was a two day lag between peak rainfall as recorded at the AGL rainfall station (at Tiedman) and peak water level at the NOW Avon River at Waukivory (208028) flow gauge
- TSW01, TSW02 and ASW01 all had a plateau style peak that lasted for 12 – 16 hours. This extended duration indicates that water was stored in the channel at these sites, possibly by a control point/structure downstream
- ASW02 had a short peak water level, and then fell to 105.358 mAHD at 11pm, 6 June. The water level remained around this level until 11pm, 7 June. The short rising limb was a result of the rapid delivery of water into the confined channel and the long falling limb was due to the larger storage capacity at this point
- All peak water levels at the AGL loggers occurred before the peak flow event on the Avon River at Waukivory because TSW01, TSW02, ASW01 and ASW02 are located upstream of the Avon River gauge.

Table 3.3 June 6 rainfall and peak water level event

Station/gauge	Monitoring	Date of peak	Peak level
AGL rainfall gauge	Daily rainfall	6 June 2012	14.8 mm
AGL rainfall gauge	Hourly rainfall	11pm 5 June 2012	3.4 mm
NOW gauge Avon River 208028	Daily peak water level	9 June 2012	1.549 m
TSW01	Water level (mix of hourly and 15 minute data)	Start 12:15pm 7 June End 4:00am 8 June	103.211 mAHD
TSW02	Water level (mix of hourly and 15 minute data)	Start 11:00am 7 June End 3:00am 8 June	104.165 mAHD
ASW01	Water level (mix of hourly and 15 minute data)	Start 2:00pm 7 June End 2:00am 8 June	103.194 mAHD
ASW02	Water level (mix of hourly and 15 minute data)	Start 3:00pm 6 June End 3:15pm 6 June	105.411 mAHD

3.2 Project surface water quality

The automatic monitoring of groundwater and surface water levels is part of AGL's ongoing monitoring investigations. The objective of the surface water component of the monitoring program is to provide information on surface water level and water quality behaviour and trends, and assess connectivity between the deep water bearing zones, shallow alluvial aquifers, and stream flow.

Surface water quality sampling has been undertaken at multiple times as part of the GGP. The dataset used to describe the baseline local surface water quality conditions in this section has been compiled from the following investigations:

- GGP groundwater monitoring program 2012 annual report
- GGP groundwater monitoring program 2013 annual report
- Tiedman irrigation trial water quality monitoring between August 2011 – November 2013
- event sampling undertaken in June 2013 during two high flows.

Surface water quality samples have been collected at monitoring sites TSW01, TSW02, ASW01, ASW02 and FSW01 Table 3.4). Surface water sampling commenced at TSW01, ASW01 and ASW02 in April 2011 and commenced at TSW02 in December 2011. Water samples for the GGP project have been collected at these locations as shown in Table 3.4.

Table 3.4 Summary of project surface water sampling

	Date	ASW01	ASW02	TSW01	TSW02	FSW01
Irrigation Trial (PB 2013d)	25 November 2011	Y	N	Y	N	N
	6 – 7 December 2013	Y	N	Y	Y	N
	29 February 2012	Y	N	Y	Y	Y
	18 – 19 June 2012	Y	N	Y	Y	Y
	10 – 11 September 2012	Y	N	Y	Y	Y
	6 & 8 May 2013	Y	N	Y	Y	N
	13 August 2013	Y	N	Y	Y	N
	12 November 2013	Y	N	Y	N	Y
High Flow sampling	3 June 2013	Y	Y	Y	Y	N
	4 June 2013	Y	Y	Y	Y	N
	27 June 2013	Y	Y	Y	Y	N
	28 June 2013	Y	N	Y	Y	N
Annual monitoring	7 – 8 April 2011	Y	Y	Y	N	N
	20 – 21 June 2013	Y	Y	Y	Y	N

Access restrictions caused by inclement weather and a boggy paddock on 27 – 28 June 2013 precluded sampling at stream gauge ASW02; and an alternative water quality samples on 27 June 2013 were collected from the Avon River culvert at Wenham Cox Road, approximately 1.3 km upstream from the ASW02 site (no samples were collected on 28 June 2013 from ASW02).

3.2.1 Water quality guidelines

Assessment of surface water quality has considered the Manning River catchment WQOs derived from ANZECC default trigger values for physical and chemical stressors for south-east Australia for slightly disturbed systems (Section 2.4.1). The values represent recommended low-risk trigger value to assess water quality. Site specific analysis of longer term water monitoring data would be required to compare water quality parameters against more appropriate criteria applicable to the GFDA as previously discussed in Section 2.4.1 (R5).

The water quality parameters analysed during the monitoring period vary between the different surface water sampling tasks (which were project specific), nonetheless, spatial and temporal variability at the four AGL monitoring sites has been sufficiently captured to describe the general water quality conditions under a variety of flow conditions (Section 3.2).

3.2.2 Additional high flow site work

High flow sampling was undertaken during the reporting period to target flow conditions to understand water quality response to rainfall. Existing surface water monitoring sites (ASW01, ASW02 TSW01 and TSW02) were used in the collection of flow and water quality data.

High flow sampling is determined by the NOW gauges to be the flow rate that occurred for only 20% of the time, therefore the level would be above the 20th percentile flow. It was assumed that the top 20th percentile water levels recorded from the AGL loggers would represent the 20th percentiles flows. Predicted water levels from background research at the 20th percentile level for each monitoring site are shown in Table 3.5.

Table 3.5 20th percentile water level at AGL water level gauges

20th percentile water level (mAHD)			
TSW01	TSW02	ASW01	ASW02
103.009	103.475	102.974	105.226

High flow sampling undertaken in June 2013 adopted a targeted approach to collect water quality samples under high flow conditions. Four water quality samples were collected during two separate high flow events in June (the first taking place over 3 and 4 June and the second taking place over 27 and 28 June (Figure 3.5).

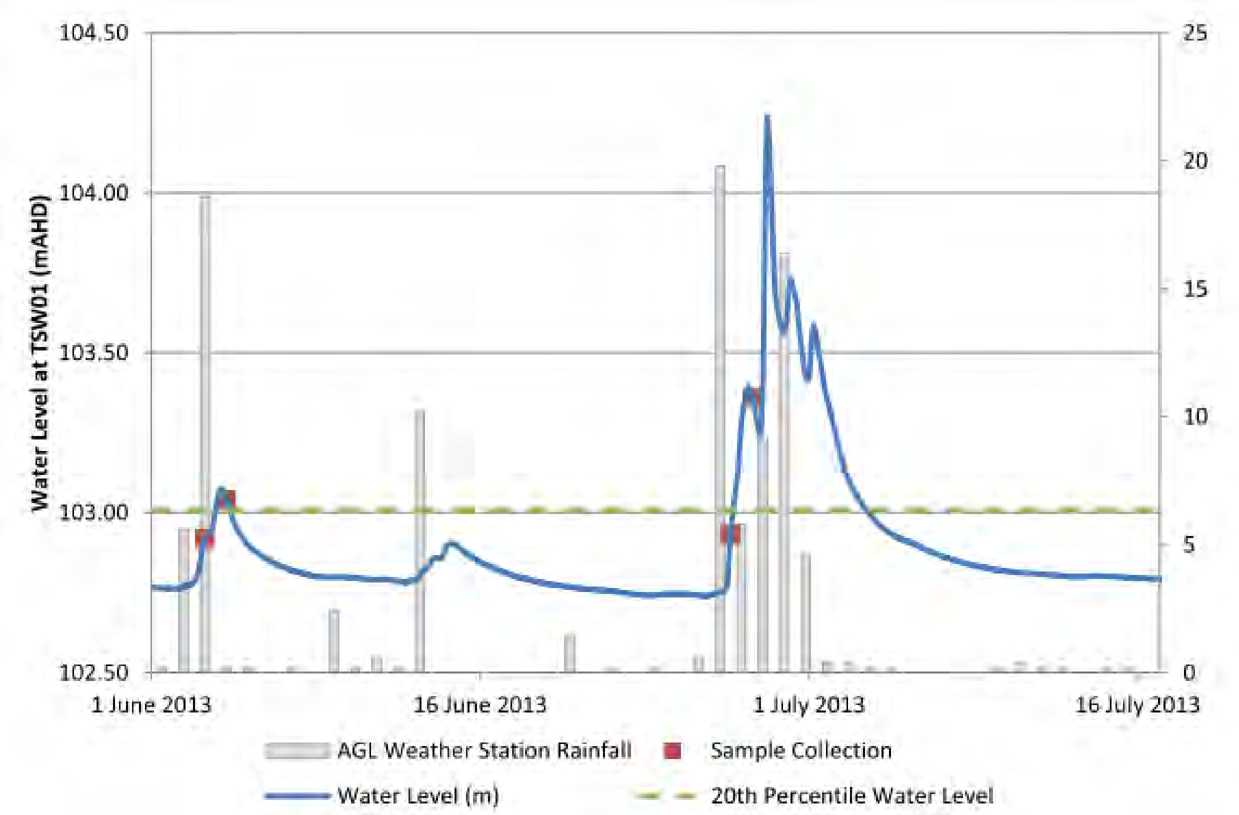


Figure 3.5 Surface water quality sample collection time and water levels at TSW01 under high flow conditions

Water quality sampling during the monitoring period has been conducted under a range of conditions including prolonged dry periods and high flow events. With the exception of the targeted high flow monitoring round, water samples have generally been taken in periods of low or normal flow (Figure 3.6).

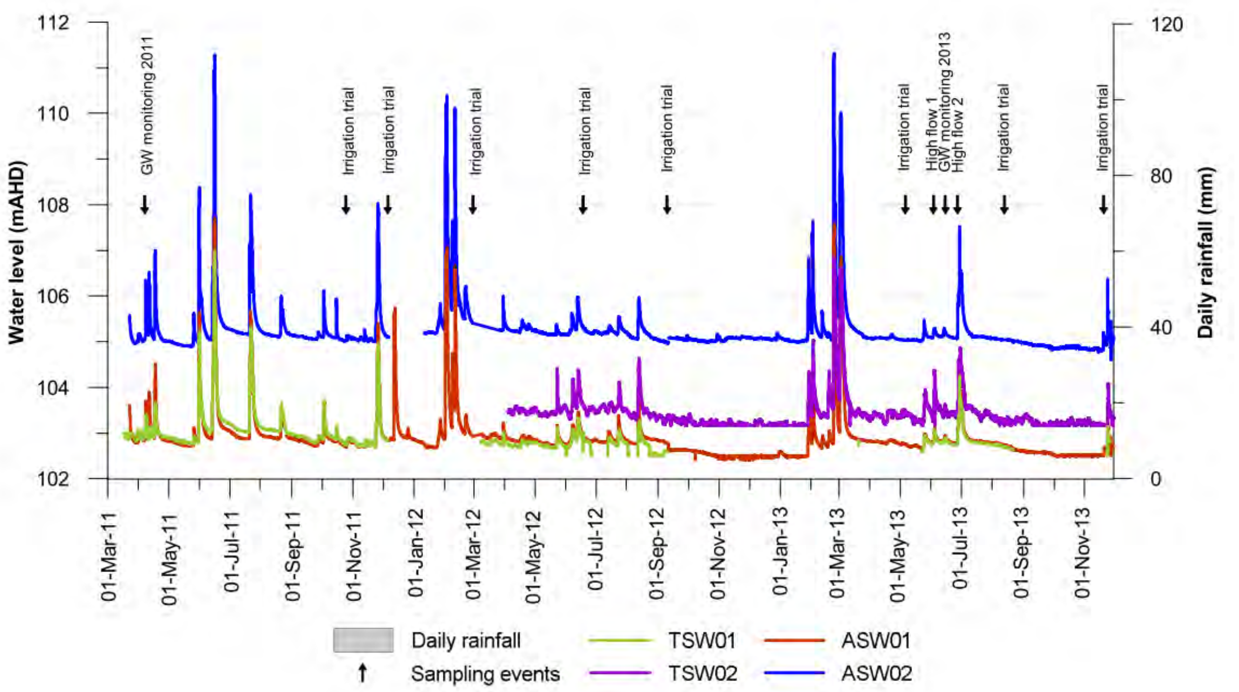


Figure 3.6 Water quality samples collected during the GGP (April 2011 – August 2013

3.2.3 Field parameters

The pH measured during the monitoring period is predominately neutral (average 7.1; minimum 5.9; maximum 7.9) and within the recommended range of 6.5 – 8.0 as provided by the ANZECC (2000) guidelines. Some slightly acidic pH values were noted at ASW01 (5.9), TSW01 (6.3) and TSW02 (6.1) during the monitoring period, however, the median reported values (7.1) and majority of samples are within the recommended range (6.5 – 8.0).

Temperature shows a typical seasonal response with warmer water recorded in the summer months, and cooler water recorded in the winter months. Temperature measurements ranged from a minimum of 10.2°C in June to a maximum of 27.9°C in February.

DO levels (% saturation) vary over the duration period of the monitoring period between the monitoring sites (average 73.5; minimum 14.0; maximum 150.1). Concentrations below the recommended 85% saturation level were noted in more than half of the total samples collected during the monitoring period. The analysis has not considered the time samples were obtained or potential diurnal effects on dissolved oxygen concentrations. Generally, turbid conditions observed in the main channel and lack of in stream vegetation could explain low DO concentrations. In addition, sampling of stagnant/slow flowing pools and water with limited opportunity for air – water exchange of oxygen will have led to low DO levels observed during the irrigation trial monitoring program (mostly pre-irrigation sampling events).

3.2.4 Electrical conductivity

Automatic and grab EC measurements have been recorded at the surface water monitoring sites during the monitoring period to assess salinity trends.

The average EC range of grab sample measurements varies slightly between the surface water monitoring sites with the lowest average EC grab sample reported at ASW02 (300 µS/cm) and the highest average grab sample at TSW02 (600 µS/cm). The highest EC grab sample level was recorded at TSW02 (848 µS/cm); this measurement was taken following high rainfalls in February 2012.

Automatic EC loggers have been deployed at stream gauge locations (ASW01, ASW02, TSW01 and TSW02). These data has been summarised in Table 3.6.

Continuous recorded EC levels vary between the stream gauge locations. The highest median EC level and highest maximum was recorded at TSW01 (442.8 µS/cm and 2,323.4 µS/cm, respectively). The lowest median EC level was recorded at ASW02 (231.2 µS/cm) and the lowest maximum was recorded at ASW01 (1,105.5 µS/cm). Median EC levels showed an increasing trend along the downstream gradient of the Avon River (median EC at ASW02 < ASW01 < TSW01). While percentile statistics showed a decrease in EC levels between ASW02 and ASW01, the recorded EC levels across all percentile statistics increased between ASW02 and TSW01.

TSW02 (located on Dog Trap Creek, a tributary of the Avon River), showed a higher median EC level than ASW01 and ASW02 (295.0 µS/cm), however, the maximum median (1900 µS/cm) was lower than the downstream stream gauge TSW01 (2324.4 µS/cm). EC levels across all percentile statistics were greatest at TSW02, suggesting that TSW02 generally has more frequent spikes in EC levels.

Table 3.6 Automatic EC summary statistics

Stream gauge	EC (µS/cm)						Data range
	Median	MIN	MAX	PERCENTILE			
				90th	95th	99th	
AWS01	276.5	0.0	1105.5	465.0	506.1	688.1	23/3/2011 – 27/11/2013
ASW02	231.2	0.0	1230.4	471.6	669.3	815.9	23/3/2011 – 26/11/2013
TSW01	442.8	0.1	2323.4	621.5	683.5	860.0	23/3/2011 – 26/11/2013
TSW02	295.0	0.0	1,900.0	640.0	750.0	1,103.9	4/4/2012 – 2/12/2013

Six mechanisms are expected to influence stream salinity (EC) levels:

1. local catchment geology and derived soils
2. input of ion-rich groundwater during baseflow conditions
3. input of ion-rich surface runoff in ‘first flush’ waters immediately after a high rainfall event
4. dilution of salinity during peak flows
5. gradual stagnation/evaporation of pooled water in channels during extended dry periods
6. input of discharge waters with elevated salinity from different land uses e.g. Gloucester Sewage Treatment Plant.

The Avon River monitoring sites (ASW01, ASW02 and TSW01) generally reported lower EC measurements than Dog Trap Creek (TSW02) during the monitoring period. An increasing downstream gradient in EC along the Avon River is apparent between sites ASW02 and TSW01. The confluence of Dog Trap Creek and the Avon River is upstream of TSW01 and downstream of ASW01 and ASW02. The increased EC at TSW01 is most likely attributed to the discharges from Dog Trap Creek being higher in EC than the receiving waters of the Avon River.

ANZECC guidelines recommend EC default trigger values between the range of 125 – 2,200 µS/cm for lowland rivers (<150 m altitude) and a typical range of 200 – 300 µS/cm for NSW coastal rivers. While EC is generally higher than the expected range for NSW coastal rivers, discrete measured values of EC recorded over the sampling period are all below the maximum ANZECC EC trigger value (2,200 µS/cm) with no measured exceedances. Despite elevated concentrations of EC in Dog Trap Creek, downstream mixing with the Avon River (water with lower EC concentrations) is evident as total concentration of EC is reduced at TSW01.

An inverse relationship between EC and rainfall has been previously demonstrated (PB 2012a; and Thurtell 2007) and EC increases under periods of low rainfall.

Automatic EC logging shows that in general, EC sharply decreases after rainfall events as relatively fresh runoff is routed into streams. An initial short-lived dip caused by input of low ionic content rainwater directly to the channel followed by a spike (sudden transient increase) in EC is often seen in the initial runoff phase as readily dissolvable salts are flushed from the ground surface and shallow soils of the catchment area. After the initial EC spike and subsequent reduction in EC levels, the EC then gradually increases as flow decreases during periods of recession and groundwater baseflow starts to become a more dominant component of flow. Evaporative concentration of salts may also be taking place in residual and connected pools. A typical EC response during and immediately following a rainfall event at TSW01 is shown in Figure 3.7.

A comparison of EC between automatic logging data obtained from the AGL stream gauges (Table 3.6) and the downstream NOW monitoring station (208004) at Killawarra shows a downstream decline in EC. The NOW Killawarra monitoring station (Section 2.4.2.5) shows an average EC of 153 µS/cm and a recorded maximum of 368 µS/cm. Median and maximum EC recorded at the AGL gauges is greater than the downstream levels demonstrating a decline in EC along a downstream gradient, contrasting with the smaller spatial-scale results reported earlier in the section from ASW01, ASW02 and TSW01 where EC increased with distance downstream. The decreasing trend is most likely due to dilution afforded by the larger catchment area at the Killawarra site or because the automatic loggers recorded data during extreme events that were not captured by the routine grab sample NOW programme.

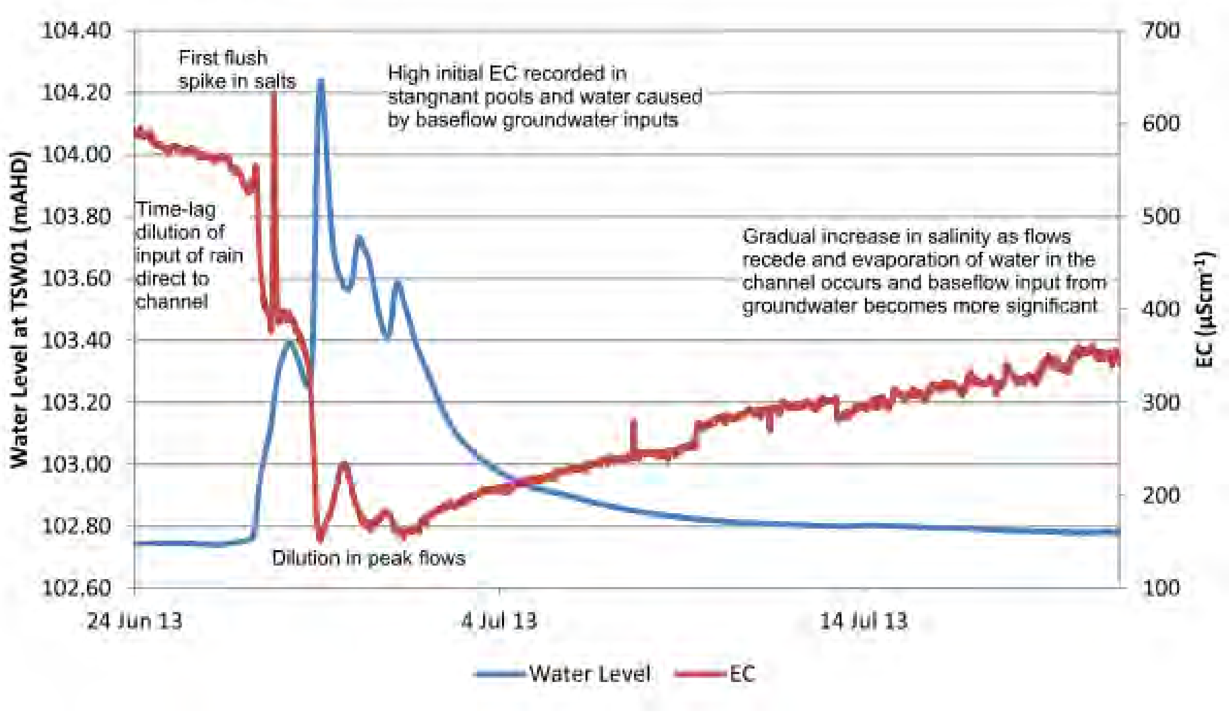


Figure 3.7 Typical EC response to a rain event on the Avon River at TSW01

3.2.5 Additional analysis

Ammonia

Ammonia results have been reported as ammonia (as N). This represents the sum of NH_{4+} and NH_3 species in the sample i.e. total ammonia. ANZECC guidelines provide a recommended concentration of 10 µg/L for recreational water quality, secondary contact (Section 2.4.1). Ammonia as N has been reported for the 2011 and 2013 groundwater sampling events and all irrigation trial monitoring events. Ammonia concentrations over the duration of the sampling period have been found in concentrations ranging from 10 – 60 µg/L among monitoring sites (TSW01, TSW02, ASW01 and ASW02). Ammonia concentrations of 60 - 220 µg/L were recorded at FSW01 as part of the irrigation trial.

Nutrients

Records of TN concentrations (µg/L) are only available for the high flow conditions captured over two monitoring events in June 2013. Concentrations of TN range between 200 µg/L (recorded at ASW01 and TSW01) and 1,300 µg/L (recorded along the Avon River at TSW01 and Dog Trap Creek at TSW02). Minimum concentrations below the recommended maximum criteria (<350 µg/L) were found at all monitoring locations along the Avon River. Concentrations at Dog Trap Creek (TSW02) showed a higher range of TN during the high flow sampling event (800 – 1,300 µg/L). These data represent a snapshot of TN concentrations during a high flow event. Additional sampling would be required to determine more accurate TN baseline conditions for the local area for a range of flow conditions (R6).

Nitrates as N and nitrites as N have been reported in six sampling rounds between April 2011 and September 2013 as part of the irrigation trial. Nitrate and nitrite do not have a trigger value in the ANZECC aquatic ecosystem or I\irrigation guidelines but concentration recommendations are provided in the ANZECC guidelines for livestock drinking water quality. Nitrate concentrations less than 400 mg/L in livestock drinking water are not considered harmful while concentrations of nitrite exceeding 30 mg/L may be hazardous to animal health.

Inorganic nitrogen compounds (NOx) and organic nitrogen (TKN) were measured in the August 2013 sampling event for the irrigation program. As a rough guide the two analytes have been combined to estimate TN during this sampling event. At monitoring sites TSW01 and TSW02, concentrations exceeded default livestock drinking water trigger values (530 µg/L and 830 µg/L, respectively). Concentrations at ASW01 (320 µg/L) were below recommended maximum at the time of sampling.

Observed variability in TN concentrations across the high flow and irrigation trial sampling events do not show any discerning relationships in TN concentrations between sampling locations. Further, variability in these data does not currently suggest a response in TN concentration to flow conditions as found in a previous study (Thurtell 2007).

TP concentrations have been reported consistently over the duration of the sampling period and data are available for comparison from all monitoring events. Concentrations of TP exceed recommended WQOs for the majority of collected samples. Some values below recommended maximum concentrations have been recorded during high flow sampling in June 2013 and again during the irrigation trial monitoring events. Values below the recommended maximum concentrations appear anomalous and highly variable between sites and flow conditions. Concentrations of TP recorded in samples from the high flow event on 27 June 2013 were all within the recommended guideline values. This suggests a potential flushing response under high flow conditions; however, this is not consistent with sample results obtained from the subsequent day or high flow events earlier in June where TP concentrations exceeded guidelines. A series of samples collected through representative hydrograph events are recommended to understand TP dynamics and quantify the impact of increased rainfall and flows on concentrations (R6).

There does not appear to be a relationship between TP concentrations and the monitoring sites with a highly variable range of TP across all monitoring sites. All sites reported concentrations below detectable limits at various stages over the sampling period. The maximum concentrations were reported at ASW01 (300 µg/L) and ASW02 (240 µg/L) during the 2011 groundwater monitoring event.

Hardness

Total water hardness (CaCO3 mg/L) has been analysed throughout the monitoring period (with the exception of the 2011 and 2013 groundwater monitoring rounds and the October 2011 Irrigation monitoring). Water hardness categories (mg/L $CaCO^3$) are provided by the ANZECC (2000) guidelines to derive a hardness-modified trigger value for some metals as this affects toxicity. The GPP has potential to indirectly affect hardness levels in surface waters via changes to ground-surface water interaction. The following hardness categories (measured as mg/L $CaCO^3$) have been recorded during the sampling period as follows; soft (0 – 59), moderate (60 – 119), and hard (120 – 179). Water hardness shows some variability over the duration of sampling period within and between the monitoring locations.

Median water hardness was found to be moderate (60 – 119) for the sum of all monitoring locations. Monitoring site TSW01 is located on the Avon River downstream from the confluence of Dog Trap Creek and influenced by downstream mixing between the two water bodies. Monitoring site TSW02 is upstream of the confluence on Dog Trap Creek while ASW01 is upstream of the confluence on the Avon River. Site TSW02 showed the greatest variability in water hardness between sites with a median of 84 mg/L and a range between 22 mg/L (soft) and 128 mg/L (hard). The majority of samples measured at TSW02 were towards the upper range of the moderate category of water hardness. Monitoring site ASW01 recorded a median water hardness of 72 mg/L (moderate) with the majority of samples below the median. Site TSW01 shows a median water hardness of 70.5 mg/L similar to ASW01, with the majority of samples recorded above the median.

This high variability between sampling events and site locations demonstrates that site specific metal conversions are required.

Dissolved metals

A total 21 dissolved metal species have been analysed over the duration of the monitoring period to determine background concentrations and, where possible, have been compared to ANZECC (2000) trigger values. Default trigger values provided by the ANZEC (2000) guidelines are to be applied to soft category waters. Where water hardness is categorised moderate and above (i.e. ≥ 60 mg/L $CaCO^3$), a calculation to the default trigger values has been applied to correct for water hardness as recommended by the ANZECC (2000) guidelines. This calculation provides site specific trigger values for metals.

A summary of the metal analysis is provided below in Table 3.7 and the complete dataset is included in Appendix E.

Table 3.7 Comparison of metal concentrations against ANZECC (2000) triggers values

Dissolved metals	No. samples	No. samples above detectable limits	ANZECC trigger values (mg/L)	No. samples exceeding guidelines	MIN (mg/L)	MAX (mg/L)
Aluminium (pH>6.5)	27	25	0.055	14	<0.01	1.570
Arsenic (As V)	45	4	0.013	0	<0.001	0.002
Barium	42	42	1.0	0	0.033	0.261
Beryllium	42	0	ID	-	0	0.000
Boron	27	1	0.37	0	<0.05	0.06
Bromine	27	23	-	-	<0.1	0.5
Cadmium	45	6	**0.00054**	1	<0.0001	0.0006
Cobalt	42	3	ID	-	<0.001	0.002
Chromium	25	9	0.001	4	<0.001	0.006
Copper	38	27	**0.0035**	11	<0.001	0.007
Iron	27	27	ID	-	0.09	1.44
Manganese	42	42	1.9	0	0.018	0.586
Molybdenum	27	1	ID	-	<0.001	0.001
Nickel	45	30	**0.011**	0	<0.001	0.010
Lead	45	3	**0.0136**	0	<0.001	0.001
Selenium	27	0	0.011 (total)	0	<0.01	<0.01
Strontium	27	27	-	-	0.07	0.573
Vanadium	42	0	ID	-	<0.01	<0.01
Zinc	45	40	**0.02**	26	<0.005	0.189
Mercury (inorganic)	18	0	0.0006	0	<0.0001	<0.0001
Uranium	27	0	ID	-	<0.001	<0.001

(1) **Bold** trigger values for 95% level of protection have been corrected for moderate water hardness

For the majority of dissolved metal species, the maximum concentrations were below ANZECC (2000) trigger values. In the majority of samples analysed, metals are not found in concentrations above the limit of reporting (LOR).

Concentrations of zinc showed the greatest number of occurrences exceeding trigger values. Zinc concentrations ranged from <0.005 mg/L to 0.189 mg/L and exceedances were noted in 26 out of 45 samples over the monitoring period above the recommended guideline (0.02 mg/L). Concentrations of copper, chromium and cadmium were also greater than the recommended guidelines on occasion although, not as frequently as zinc. Copper concentrations exceeded guidelines (0.0035 mg/L) in 11 out of 38 samples with a maximum concentration of 0.007 mg/L. Chromium concentrations exceeded guidelines in 4 out of 25 samples with a maximum concentration of 0.006 mg/L and cadmium exceeded guidelines on one occasion in 45 samples.

Of the 21 dissolved metal species analysed, ANZECC (2000) guideline trigger values do not exist or there is insufficient data available to determine trigger values of eight species (beryllium, bromine, cobalt, iron, molybdenum, strontium, vanadium and uranium). Metals that did not exceed guidelines in any samples include arsenic (As V), barium, boron, manganese, nickel, lead, selenium and mercury.

Major cations

A high level analysis of the ionic composition of the surface, groundwater and rainwater samples was completed. Samples were consistently dominated by sodium across all sampling locations. Surface water, alluvial and shallow rock samples were similar in composition (sodium ranging between 60–70% composition). Interburden and coal formation waters showed a much greater composition of sodium ions (99 and 80% respectively). Other major cations (Ca^{+2}, Mg^{+2}, K^{+}) were recorded in the water samples in much smaller abundance but the composition ratio is similar at most sites, with the exception of deeper groundwater sites where sodium cations dominate.

Rainwater composition in the Barrington Tops and nearby Dorrigo (Post *et al* 1991) showed a similar ionic composition to surface water, alluvial and shallow rock (dominated by sodium and chloride ions).
This comparison suggests that surface water composition within the Avon River catchment is predominately influenced by rainfall composition. This observation is supported by the short duration peaks in water level recorded following peak rainfall events and the noted low baseflow contribution (Section 3.1).

Hydrocarbons and other compounds

A number of hydrocarbon water quality indicators sampled over the monitoring period were below the LOR. During the monitoring period these indicators were not detected in concentrations to which accurate detection by the laboratory can be achieved. These indicators include total petroleum hydrocarbons (TPH), total recoverable hydrocarbons (TRH), phenolic compounds, poly aromatic hydrocarbons (PAH), and BTEXN. It is reasonable to consider that these indicators are not cause for concern in the local water-bodies surrounding the GFDA and have not been further considered in this report.

Hydrocarbon gases were analysed during the high flow sampling events in June 2013. With the exception of methane, hydrocarbon gases (ethane, ethane, propene, propane, butane and butane) were found to be below detectable limits. Dissolved methane was detected at three sites (ASW01, ASW02 [Wenham Cox Road culvert] and TSW01) during high flow sampling (27 – 28 June 2012) with the maximum concentration of methane detected (23 µg/L) found at ASW01. Dissolved methane was also detected at ASW01 and ASW02 (21 June 2013). There are no catchment specific appropriate guidelines to compare to the recorded methane concentrations.

4. Geomorphological classification of surface water systems

4.1 Objectives and methodology

A desktop survey was undertaken as a precursor to site investigations to identify local watercourses and tributaries and to identify representative locations suitable for assessment. Assessments were completed at a total of 28 assessment sites, with 24 sites located within the GFDA boundary and four additional sites located outside of the development area. This survey information was also collected to assist with the numerical modelling.

The assessments were undertaken in August 2013 and September 2013 within the following watercourses:

- Avon River
- Avondale Creek
- Dog Trap Creek
- Oaky Creek
- Tiedman Gully
- Waukivory Creek
- GRL north (an unnamed drainage line to the north of the GRL property)
- GRL south (an unnamed drainage line to the north of the GRL property).

The survey was undertaken during a period of relatively low rainfall. Rainfall recorded at the AGL Tiedman property weather stations in the preceding months, recorded 14.6 mm, 7.0 mm and 13.0 mm in July, August and September, respectively. Generally, winter months record lower rainfall than summer months. Monthly recorded rainfall from the Tiedman property weather station is shown in Figure 4.1. Flow in the creek can be attributed to a 12.6 mm rainfall event prior to the survey on 17 September 2013.

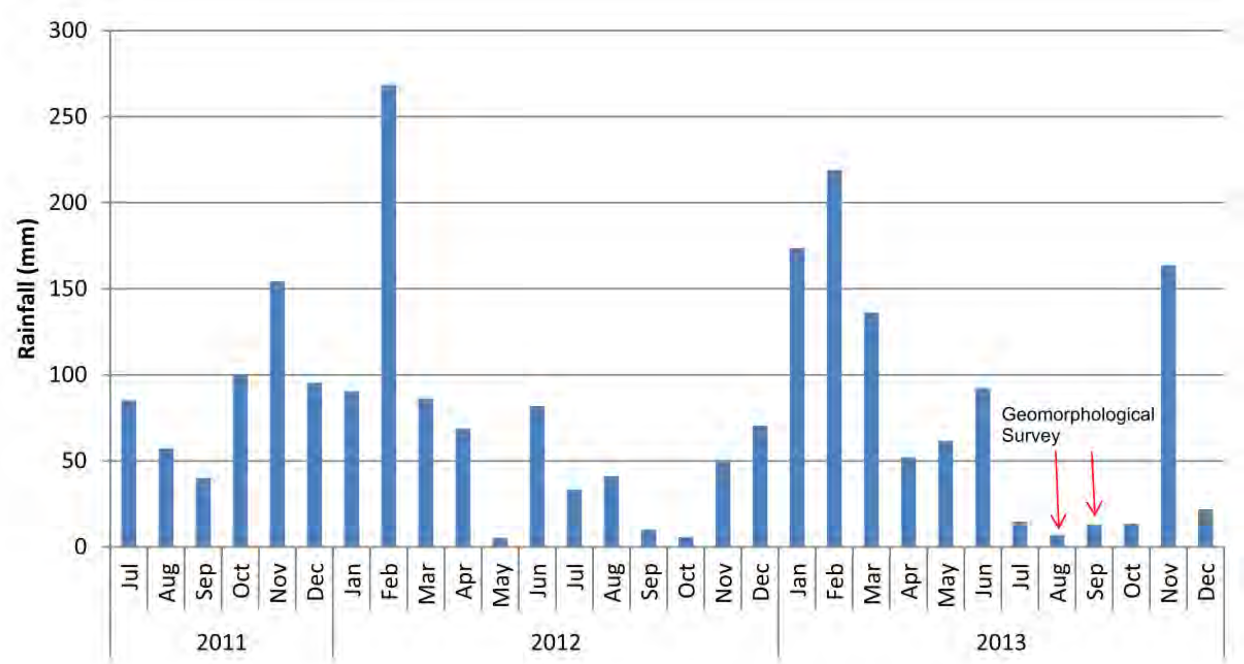


Figure 4.1 Tiedman property weather station monthly rainfall

The study area and assessment locations including river bed elevation (mAHD) are provided in Table 4.1 and Figure 4.2. Cross section river bed surveys are included in Appendix F.

Table 4.1 Fluvial geomorphology survey data

Site	Survey date and approximate time	Elevation (mAHD)		Coordinates	
		Creek bed	Water level	X	Y
ADC01	13/08/2013 15:50	105.5	106.5	401940	6447207
ADC02	3/09/2013 9:35	122.2	122.5	400812	6443385
ADC03	3/09/2013 8:50	129.0	129.0	400762	6441996
AR01	13/08/2013 14:30	86.5	87.7	403552	6456549
AR02	9/08/2013 14:15	89.6	89.6	403346	6454630
AR03	9/08/2013 14:50	93.1	94.0	402231	6453325
AR04	13/08/2013 14:40	101.3	101.5	401995	6450895
ASW01	6/08/2013 15:00	101.5	102.6	401726	6449118
ASW02	13/08/2013 15:30	104.3	104.8	400710	6447961
DTC01	8/08/2013 10:30	102.6	102.8	401912	6448980
DTC02	8/08/12013 12:30	108.0	108.4	402776	6448310
DTC03	3/09/2013 10:20	115.7	116.0	403140	6447180
DTC04	3/09/2013 11:05	134.2	134.7	404612	6445978

Site	Survey date and approximate time	Elevation (mAHD)		Coordinates	
		Creek bed	Water level	X	Y
GRL01	9/08/2013 15:10	96.5	97.0	403509	6453678
GRL02	9/08/2013 11:45	117.0	117.2	404280	6452233
GRL03	13/08/2013 12:05	99.3	100.1	402786	6451803
GRL04	9/08/2013 11:55	111.1	111.2	404158	6451074
OC01	9/08/2013 10:50	106.9	107.2	404817	6454017
OC02	8/08/2013 14:30	97.5	97.9	404070	6454482
TSW01	6/08/2013 14:25	101.8	102.6	401978	6449408
TSW02	6/08/2013 15:50	103.1	103.4	401919	6448738
TT01	19/08/2013 12:20	100.1	100.2	402237	6451101
TT02	8/08/2013 10:50	114.2	114.3	402699	6449389
TT03	8/08/2013 11:05	121.9	-	403305	6448955
WC01	13/08/2013 11:10	97.3	97.5	402736	6452151
WC02	9/08/2013 12:20	103.4	103.7	403635	6450578
WC03	9/08/2013 12:40	108.1	108.2	404975	6449998
WR01	13/08/2013 15:05	87.3	87.5	400588	6439835

4.2 Site selection

A desktop assessment was undertaken to guide selection of the most appropriate assessment sites for the geomorphology assessment. The assessment sites were chosen based on the following selection criteria as they provided:

- spatial representation over the GFDA and nominated watercourses
- GFDA boundary points where tributaries enter and exit the project area
- existing project surface water monitoring sites
- ease of access and landholder titles
- upstream and downstream points to determine longitudinal river gradients
- disturbed locations that warranted further investigation
- underlying geology
- representative sites were chosen to ensure the variety of selection criteria were captured in the assessment. Predominately the sites selected were within the Avon River catchment, with one site (WR01) located within the Wards River catchment.

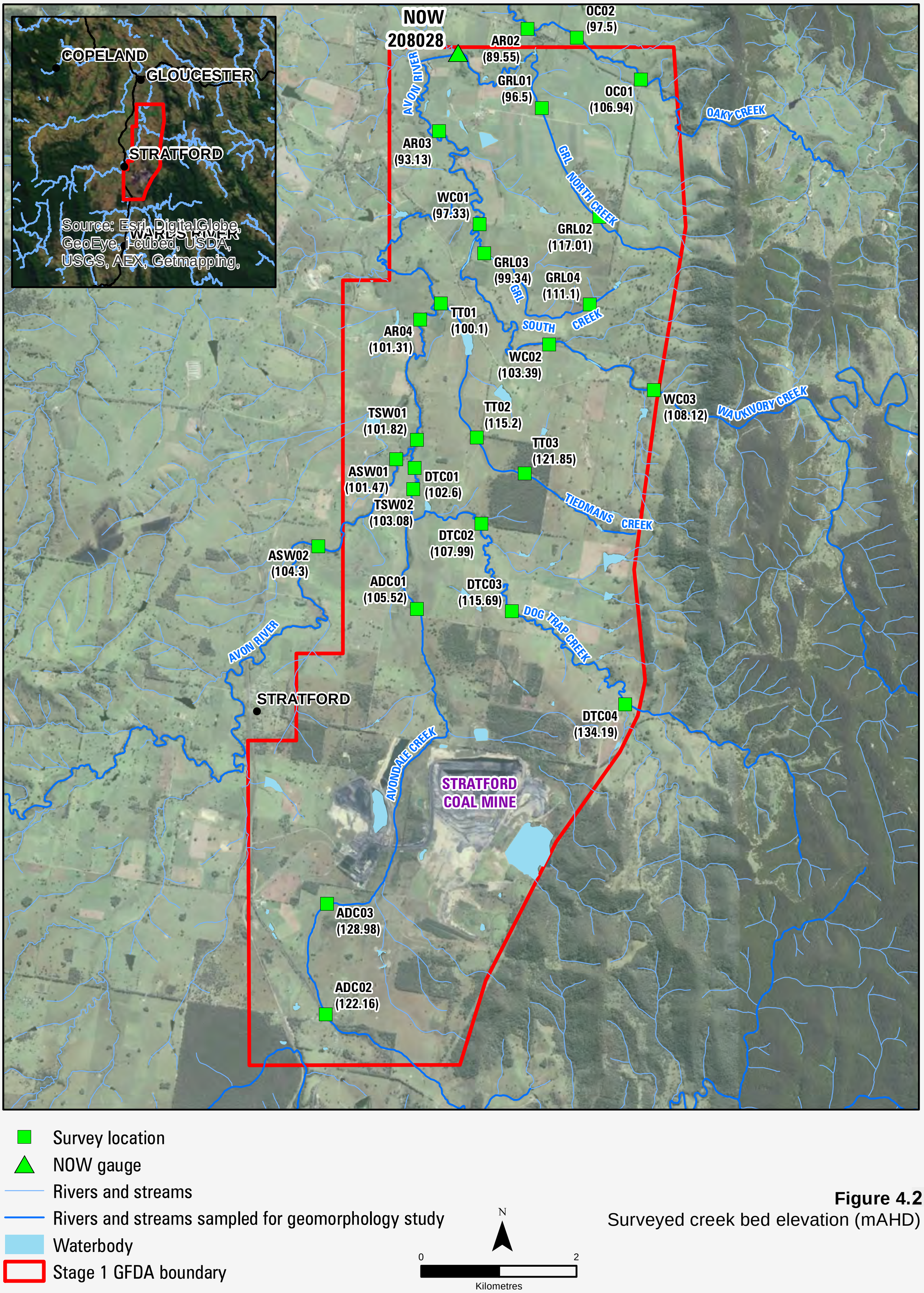


Figure 4.2
Surveyed creek bed elevation (mAHD)

\\Apsydfil03\proj\A\AGL_Energy\2162406_HYG_GLOUSTER_BASIN_CSM_ASS\10_GIS\Projects\ESRI\2162406A_GIS_F034_A1.mxd Author: SaflianK 15/10/2013

4.3 Geomorphological conditions

A baseline geomorphology review was conducted to provide a snapshot of the current geomorphic conditions and capture the various channel types and characterise the main watercourses within the GFDA boundary. RiverStyles™ classification (Brierly and Fryirs 2005) was used to describe the main channel types identified in the assessment based on valley setting, channel continuity, river planform, geomorphic units and bed material texture.

- The main drainage channel in the study area is the Avon River; the planform characteristics are generally a low-gradient, entrenched single macrochannel. Geomorphic units generally comprised of continuous reaches, erodible banks, shallow bars and submerged trees. The river bed was composed of moderately compacted silt and fine sand suggesting relative bed stability. Although deeply entrenched the Avon River exhibited high connectivity to the floodplain and is known to overtop under flood conditions. The Avon River is generally devoid of instream vegetation growing within the channel but riparian vegetation growth was abundant.
- Main tributaries of the Avon River (Waukivory Creek, Oaky Creek and Dog Trap Creek) generally portrayed similar deeply entrenched single macrochannel characteristics. A greater occurrence of boulders resulting in pool and riffle water features was observed as well as a greater occurrence of instream vegetation and fallen trees and debris within the channel. Flows are generally ephemeral with discontinuous pooled reaches at times of low flow. Larger sized particles such as gravels, cobbles and boulders are generally found in the waterways running east to west (Oaky Creek, Dog Trap Creek and Waukivory Creek). These waterways drain the mountain range to the east of the GFDA and are likely to experience higher velocities as a result of increased slopes from the adjacent hilly landscape.
- Smaller tributaries included open drainage channels with high connectivity to open grazing farmland with very low sinuosity. Riparian strips along these channels were generally poor to non-existent as these reaches have been subject to land clearing for grazing purposes. These open channels were composed predominately of finer grained materials such as sands, silt and clays.
- A braided reach was observed at Wards River comprising secondary high flow drainage paths.
  The major geomorphic features were comprised of a boulder/gravel riverbed with cut banks, indicating strong lateral migration potential, and high connectivity to the surrounding flood plain.

The geomorphic functions of the major channel types portrayed different characteristics spatially within the study area. River bed composition of the Avon River is generally a finer grained sediment (clay to fine sand) suggesting that flow velocities are generally low and the Avon River functions as a conveying system of finer grained materials (Figure 4.3). Evidence of erosion and undercut banks suggests that the Avon River also supplies sediment further downstream of the catchment.

The banks of the open drainage channels were generally fine grained materials (Figure 4.3), predominately covered with grass with poor riparian coverage. While the river beds of these water courses offer some compaction characteristics, under high flow velocities, these systems would erode and supply sediment downstream. These water courses are all located within open grazing paddocks. Direct access to the waterbodies would increase erosion potential caused from cattle crossing and accessing the creeks and creek crossings.

The low-moderate sinuosity stretches observed will act as a conveyance stretch, storing sediments in-between events and supplying them to downstream reaches during high flow conditions. They will probably not provide material in-situ as the channel is relatively stable. Conversely, the meander bends will provide new material to the channel during high flow events, due to erosion on the apex of the curve facing highest water velocities.

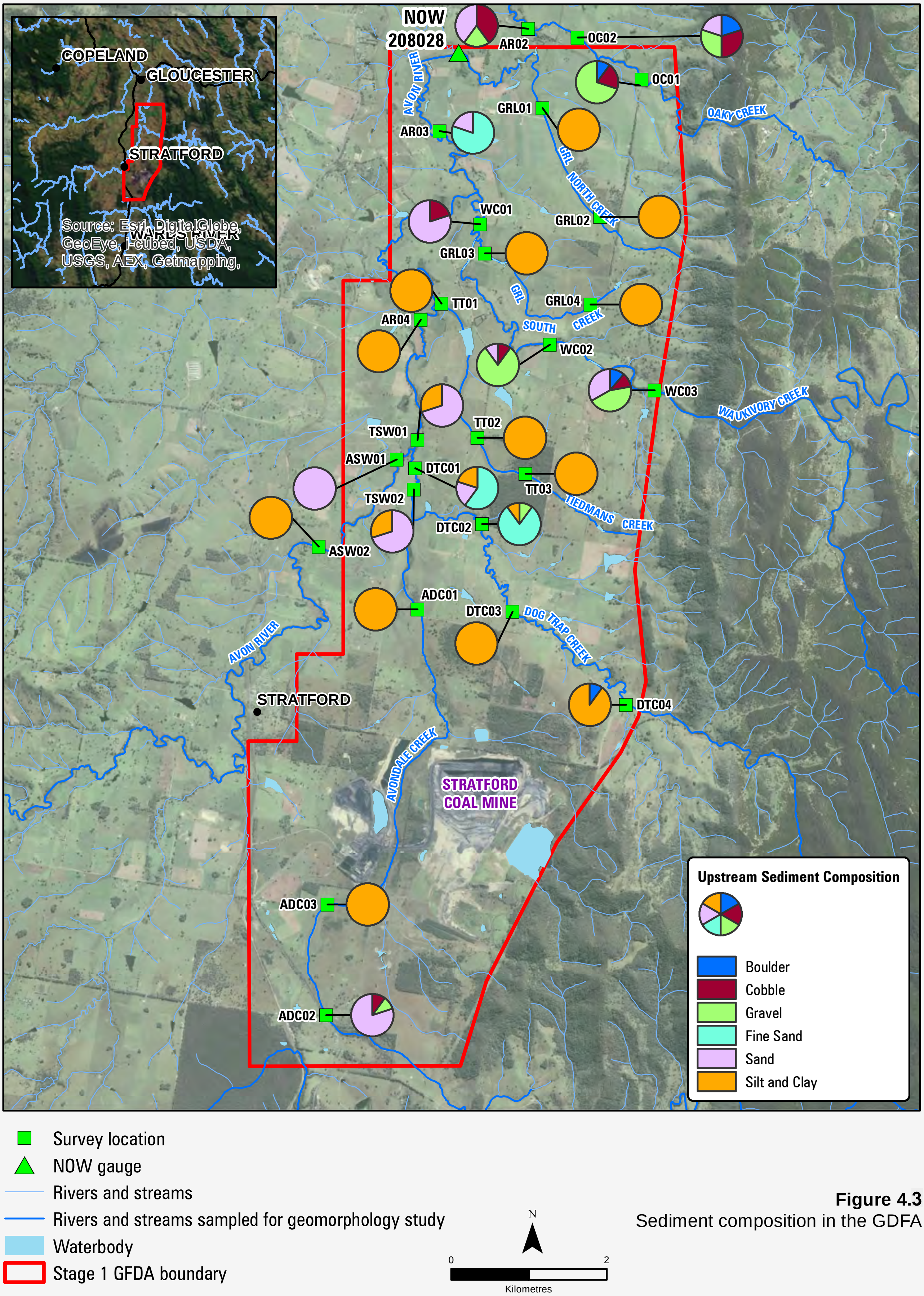


Figure 4.3
Sediment composition in the GDFA

4.4 Sinuosity and gradient

Sinuosity and gradient have been assessed to assist in the characterisation of major courses. The sinuosity calculations have been provided below in Table 4.2 and long profiles have been included in Appendix A.

Table 4.2 Sinuosity calculations

	Blue line network length (m)	Straight length (m)	Sinuosity	Description
Avon River	29,070	21,645	1.34	Meandering
Dog Trap Creek	11,940	7,838	1.52	Meandering
Avondale Creek	13,648	7,341	1.86	Meandering
Tiedman Gully	4,644	3,812	1.22	Low
Waukivory Creek	15,662	10,344	1.51	Meandering
GRL (south)*	4,467	2,455	1.82	Meandering
GRL (north)*	3,790	3,259	1.16	Low
Oaky Creek	7,542	4,609	1.64	Meandering

(1) * See Section 4.1 for locations

Sinuosity is considered low if the degree of calculated sinuosity is between 1.06 and 1.30 and meandering between 1.31 and 3.0 (Brierly and Fryirs 2005). Meandering sinuosity is irregular in all major watercourses within the GFDA confined by a single continuous channel. Open drainage lines within farming paddocks sometimes show no defined or a discontinuous channel and low sinuosity. Tiedman Gully and the northern drainage channel on the GRL property are considered to have low sinuosity, while the remaining water courses are considered meandering (high sinuosity). Typically erosion zones are likely to occur on steep/vertical down gradient sections and deposition zones will occur on flat reaches with little to no downfall.

4.5 Characterisation and classification of major watercourses

The GFDA boundary represents a transition from rounded foothills at the base of the Mograni Range to lowland plains along the valley floor of the Avon River catchment. This results in two major valley settings for the classification of the watercourses using the RiverStyles™ framework as follows:

- partly-confined valley setting – characterised by discontinuous connectivity to the floodplain. This is typical of the upstream reaches that drain the Mograni Range such as upstream reaches of Dog Trap Creek and Waukivory Creek
- laterally confined valley setting – characterised by continuous connection to floodplains along both channel banks. This is typical of the Avon River and the downstream reaches of the main tributaries (Dog Trap Creek, Waukivory Creek, Avondale Creek and Oaky Creek).

When assessing the valley setting, sinuosity and planform the following classifications have been described within the GFDA:

- meandering fine grained – this classification represents the meandering, laterally stable reaches of the Avon River and downstream reaches of Dog Trap Creek, Waukivory Creek the southern GRL tributary of the Avon River and Oaky Creek

- valley fill (swamp, swampy meadow) – this classification represents the discontinuous and poorly defined channels typical of the upper reaches of open drainage lines draining open farmland as found at Tiedman Gully and the northern GRL drainage channel
- Bedrock controlled discontinuous floodplain – this classification represents the uppermost reaches of the major tributaries of the Avon River set in a partly confined valleys. This is typical of the upstream reaches of Oaky Creek, Waukivory Creek and Dog Trap Creek at the base of the Mograni Range.

All assessments sites showed some connectivity to the floodplain. The upper reaches of the major tributaries are discontinuous; however, connectivity was recorded at all assessment sites. The Avon River is deeply entrenched resulting in containment under the majority of flow conditions. Although deeply entrenched, connectivity to the floodplain is evident at all locations.

The implications of the valley setting identified above influence flow velocity along the downstream gradient. Water velocities draining the steeper elevated areas are greater than flow velocities in the lowland plains. Reaches with higher velocities are more prone to erosion and act as a supply source for medium – fine grained sediment downstream. Downstream reaches with lower velocities would function as gradual deposition zones under low velocity conditions and potential sedimentation of the major channel could occur overtime. Deposited sediments in these reaches would be again mobilised further downstream during storm events.

Groundwater and surface water interaction is possible in creeks and rivers through gaining or losing processes. Gaining systems are recharged by groundwater flows and conversely, losing systems lose surface water flow through the alluvium or cracked bedrock. Gaining streams are most likely to occur along the valley floor where groundwater levels are high and groundwater discharges from alluvial or shallow fractured rock groundwater systems to provide baseflows to perennial streams. Losing streams are most likely to occur in up gradient areas where streams flow over fractured rock and there is a loss of flow to the water table. Bedrock controlled systems are only a small portion of the watercourses identified in the geomorphology assessment. The classification of the majority of the GFDA is comprised of meandering fine grained and valley fill systems.

4.6 Sediment characteristics and transport

The relationship between sediment size and the velocity regime causing erosion, transportation and deposition of channel material was generated using a Hjulström curve (Figure 4.4). Known velocities (cm/s) measured during high flow monitoring at sites TSW01, TSW02 and ASW01 have been compared to the approximate median sediment particle size determined by geomorphology field investigations (Figure 4.3).

Only the monitoring site where velocity has been measured has been considered in Hjulström curve (TSW01, TSW02 and ASW01). Where velocities are unknown it is not possible to generate a relationship between velocity and sediment particle size and velocities at all geomorphology assessment sites cannot be determined with reasonable accuracy.

Velocity measurements were taken over two days at TSW01 and TSW02 and once at ASW01 as part of the high flow sampling. Measured channel velocities were greater on the second day of monitoring at all monitoring sites. The channel width at TSW02 was considerably narrower with a lower hydraulic capacity than TSW01 and ASW01. The wider channels, (TSW01 and ASW01) with greater hydraulic capacity, do not concentrate flow resulting in lower flow velocities.

Particle sizes at the monitoring sites were composed predominately of fine grained material such as clay/silt and fine sand sediment particles (generally <1 mm). The velocities measured under the high flow event observed at the time of sampling were unlikely to cause erosion at sites TSW01 and ASW01 but would convey non-cohesive particles and export them from the channel reach. The measured velocities at TSW02 were higher and velocities measured on the second day of monitoring were likely to cause erosion of fine particles. The measured velocities at the time of sampling were representative of high flow conditions (see Section 1.2.3) and were sufficient to transport unconsolidated and suspended material downstream.

It is important to note that the Hjulström curve tests resistance to transport for un-cohesive sediments in the channel not bank sediments with compaction. Figure 4.4 presents an accurate representation of observed conditions at the monitoring sites.

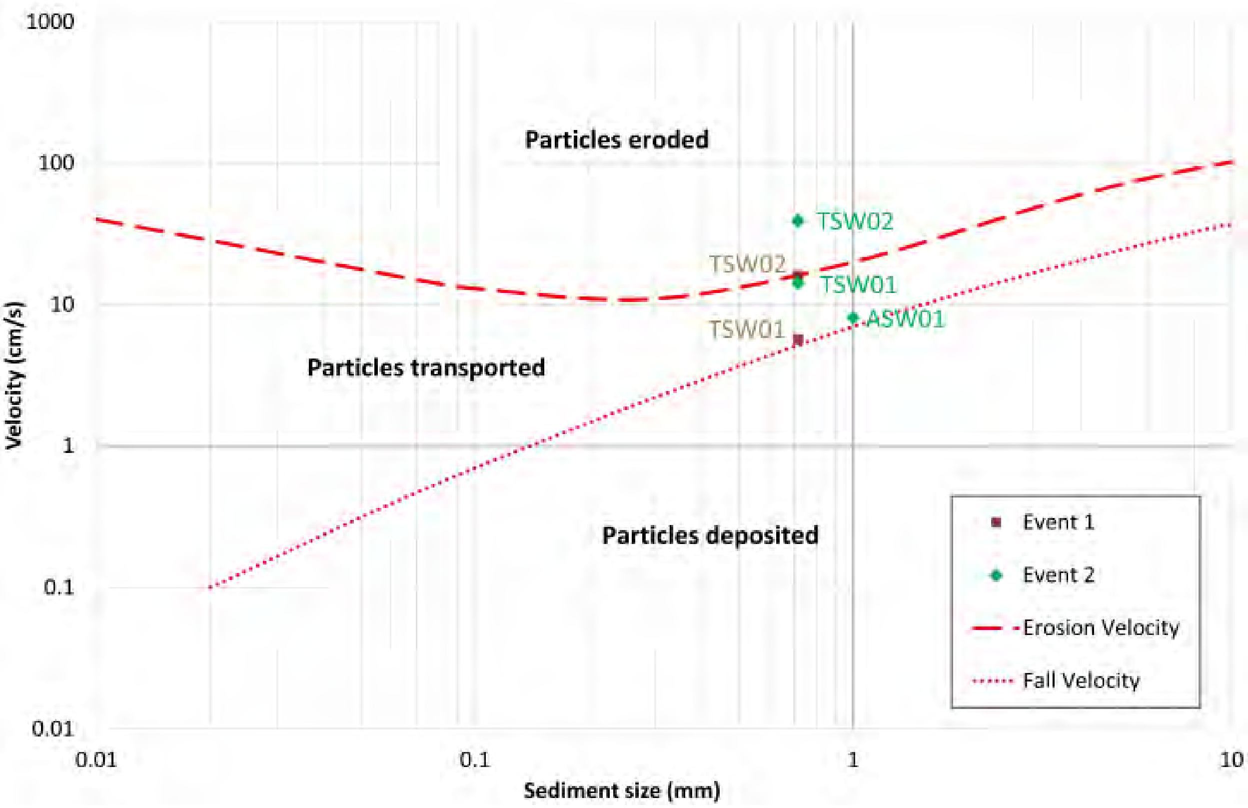


Figure 4.4 Hjulström diagram and sediment entrainment at study locations

Open channel drainage lines draining open farm paddocks were poorly vegetated and provided unrestricted access to grazing cattle resulting in erosion of banks and unconsolidated river beds prone to erosion. The lack of stability in these drainage lines results in a supply of sediment to the major waterways (such as the Avon River). Velocities were not known at these assessment sites, however, given the fine grain sized sediment composition, low velocities would generally cause erosion and transportation in these areas.

Main tributaries to the Avon River draining the Mograni Range to the east (Oaky Creek, Waukivory Creek, Dog Trap Creek) contain a greater composition of larger sized particles such as gravel, cobbles and boulders. These assessment sites are characteristic of waterways with higher flow velocities as shown by larger sediment sizes. Increased velocities at these assessment sites have a greater erosion and transportation potential as a result of higher velocities. Higher velocities also have the potential to transport larger, heavier particles. This was evident at site AR02 along the Avon River. This site is located downstream of the confluence of Oaky Creek and sediment composition was uncharacteristic of the other Avon River sites. This is most likely the result of high velocity flows from Oaky Creek supplying coarse sediments to the Avon River.

4.7 Sensitive habitats

Geomorphic processes determine the character and distribution of channel form and introduce different ranges of habitat availability in different settings at different flow stages (Brierley and Fryirs 2005).

The environmental properties of any given habitat within a stream system will determine the types of macro-invertebrate communities found there (Parsons *et al* 2002).

Previous studies (Alison Hunt and Associates 2012) identified the importance of permanent water resources and intermittently wet drainage lines as important habitat for amphibians, waterbirds and freshwater vertebrates and invertebrates. Two species of frog; Green and Golden Bell Frog (*Litoria aurea)* and Giant Barred Frog (*Mixophyes iterates*) have the potential to inhabit the area but have never been found in surveys. Both species are listed under the *Environmental Protection and Biodiversity Conservation Act 1999* and the *NSW Threatened Species Conservation Act 1995*.

A number of aquatic habitats have been identified from the geomorphology assessment including runs and riffles, continuous and discontinued pools among a variety of substrates and different physical conditions. The diversity of features and conditions found among the assessment sites provide substrate for aquatic habitat for macro-invertebrate assemblages.

The assessment locations exhibit different fluvial connectivity characteristics to upstream and downstream locations based on physical conditions and geomorphic features (such as narrowing channels and shallow creek beds that can dry out during times of low flow). Table 4.2 provides a description on flow characteristics during the time of assessment and fluvial connectivity characteristics to upstream and downstream locations.

Table 4.3 Flow characteristics and hydraulic connectivity of geomorphological assessment locations

Location	Hydraulic connectivity	Description and flow characteristics
AR01	Connected	This location is well connected upstream and downstream. Flow at the time of assessment was scarcely perceptible.
AR02	Limited connectivity	This location is predominately characterised by a refuge pool with scarcely perceptible flow. Upstream connectivity is restricted by a narrow chute with rippled flow, similarly, downstream connectivity is restricted by an shallow riffle, with a small free fall.
AR03	Connected	This location is well connected upstream and downstream. Flow was scarcely perceptible at the time of assessment.
AR04	Limited connectivity	Flow upstream at this location is constricted by a riffle, flowing into pools of standing water with scarcely perceptible flow. Downstream is well connected to further pools with scarcely perceptible flow.
TSW01	Connected	This location is well connected upstream and downstream with scarcely perceptible flow at the time of assessment.
TSW02	Limited connectivity	At the time of assessment, flows at this site were scarcely perceptible, and constricted by a narrow channel and vegetation. It is known that when flows cease at this location, unconnected pools form.
ASW01	Limited connectivity	Upstream flow is constricted by a narrow chute, flowing into a pool of standing water with smooth surface flow. Flows within the deeper pooled sections are scarcely perceptible. Downstream at this location the channel narrows, but the depth of the channel allows for does not restrict downstream connectivity.
ASW02	Connected	This location is well connected upstream and downstream. Flow was scarcely perceptible at the time of assessment.
WC01	Limited connectivity	This site is predominately characterised by a pool of standing water with smooth surface flow. Upstream and downstream connectivity is restricted by chutes and riffles.
WC02	Limited connectivity	Upstream flow is constricted by gravel bar and riffle. Flows give way to a pool constricted in the middle by narrowing of the river bank. Smooth surface flow in shallow sections give way to scarcely perceptible flow in the deeper sections of the channel. Downstream flows are well connected.

Location	Hydraulic connectivity	Description and flow characteristics
WC03	Limited connectivity	Upstream flow is constricted by a riffle flowing into pooled water with scarcely perceptible flow. Downstream flow is well connected.
DTC01	Limited connectivity	Upstream and downstream connectivity was constricted by a series of riffles, shallow bars and fallen trees. Flows within pooled sections are scarcely perceptible.
DTC02	Connected	This location is well connected upstream and downstream. Flow was scarcely perceptible at the time of assessment.
DTC03	Limited connectivity	Upstream flow is well connected. Flows at the time of survey were scarcely perceptible in pooled sections. Downstream, flows are constricted by a causeway and chute flowing to a narrow free fall section and series of smaller ponded sections.
DTC04	Not connected	Flows upstream are constricted by an exposed causeway. Flows downstream are constricted by exposed boulders. No flows were observed in the pooled section at the time of assessment.
WR01	Limited connectivity	Upstream sections are comprised of pools with scarcely perceptible flow. The channel is braided and forked in sections which lead to unconnected flows in some channels during low flow. Flows in the main channel are constricted by ripples and chutes with some free fall. Downstream pooled sections are well connected.
GRL01	Not connected	At the time of assessment standing pooled water was recorded. Upstream and downstream of this location were dry.
GRL02	Not connected	At the time of assessment standing pooled water was recorded. Upstream and downstream of this location were dry.
GRL03	Dry	At the time of assessment this location was dry.
GRL04	Not connected	At the time of assessment standing pooled water was recorded. Upstream and downstream of this location were dry and not connected.
ADC01	Connected	This location is well connected upstream and downstream. Flow was scarcely perceptible at the time of assessment.
ADC02	Not connected	At the time of assessment standing pooled water was observed. Upstream and downstream of this location were dry and not connected.
ADC03	Not connected	At the time of assessment standing pooled water was observed. Upstream and downstream of this location were dry and not connected.
OC01	Limited connectivity	Upstream and downstream at this location was constricted by low flowing riffles and chutes. Flows in pooled water in deeper sections was scarcely perceptible
OC02	Limited connectivity	Upstream and downstream at this location was constricted by low flowing riffles and chutes. Flows in pooled water in deeper sections were scarcely perceptible. The pooled section was divided by a small hydraulic jump (approx. 0.2 m).
TT01	Not connected	At the time of assessment standing pooled water was observed. Upstream and downstream of this location were dry and not connected.
TT02	Not connected	At the time of assessment standing pooled water was observed. Upstream and downstream of this location were dry and not connected.
TT03	Dry	At the time of assessment this location was relatively dry with some soft, muddy patches.

Depth to groundwater has been interpreted based on a conceptual understanding and the preliminary numerical model prepared for the water balance (PB 2013b). Potential spring locations could exist where the interpreted depth to groundwater is in close proximity to the ground surface elevation and where river and creek channels exist. Spring location potential can be interpreted from Figure 4.5. No spring locations were identified during field assessments. A number of wetland areas were identified during the assessment, these areas are disconnected from rivers and creeks and provide potential habitat for aquatic vegetation and macro-invertebrates. Wetland areas identified from field based activities and a rapid desktop survey using aerial photography are provided in Figure 4.5.

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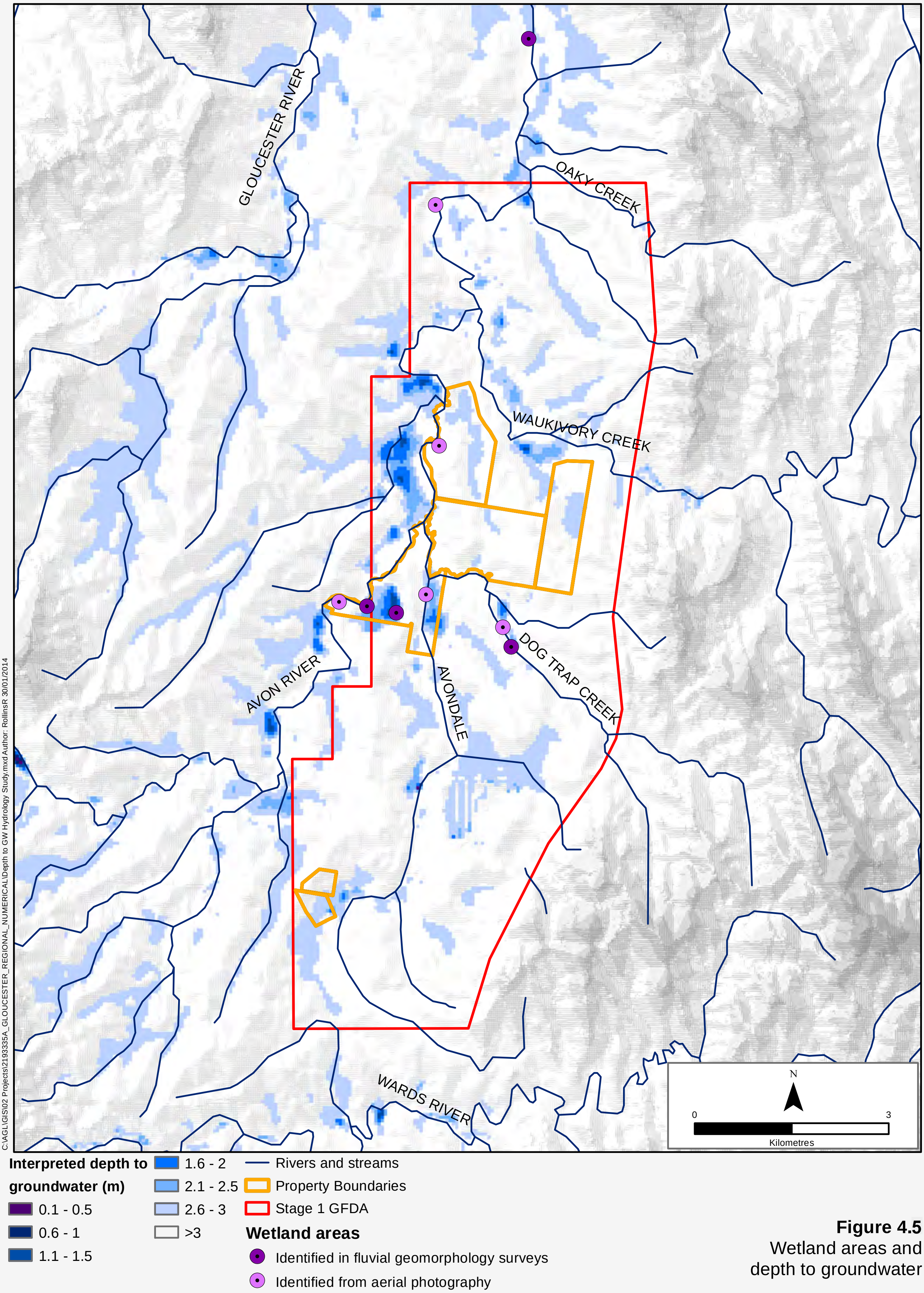

Figure 4.5
Wetland areas and depth to groundwater

The following photos are representative of the variety of habitats found from site assessments.

Photo 4.1 The majority of the Avon River is a series of continuous pools characterised by fine grained substrate, woody debris, fallen trees and steep vertical banks

Photo 4.2 Upstream reaches of the Waukivory River and Oaky Creek have a series of pools interconnected by riffle reaches. Coarse grained substrate comprised of cobbles and boulders were found in these areas

Photo 4.3 A number of isolated pools not connected to the main channels were observed during the study

Photo 4.4 A number of laterally unconfined drainage lines found within the farm paddocks are highly connected to the floodplain. These reaches are characterised by disconnected pools and intermittent flow

Photo 4.5 High erosion potential exists along some reaches of Oaky Creek where high energy velocities are likely

4.8 Comparison to previous studies

A broad scale geomorphology classification (DIPNR 2005b) identified three broad scale valley settings within the Avon River catchment:

- confined valley settings
- partially confined valley settings
- laterally unconfined valley settings.

Confined valley settings were found at the headwaters in the upstream areas of the catchment. The GFDA lies in the lower floodplains of the catchment where partially confined and laterally unconfined valley settings are present.

Generally, geomorphic condition was found to be in moderate condition in the mid and lower reaches of the catchment and poor towards the south of the catchment. Moderate condition reaches were defined as areas were degradation is recoverable by re-vegetation or small scale bed control works. Poor reaches are typically dominated by over-widened stream channels and significant erosion of the bed and banks.
The geomorphic condition of the Avon River and Waukivory Creek within the GFDA were found to be in moderate condition. Dog Trap Creek, Oaky Creek and Avondale Creek were found to be in poor condition.

The Avon River is subject to a variety of land management pressures that determines resilience or fragility when subjected to damaging impacts. A majority of the Avon River sub-catchment was classified as medium fragility where damage only occurs when a high threshold of damaging impact is exceeded (such as a catastrophic flood, mobilisation of a sediment slug or vegetation clearing). These areas were generally found among the low sinuosity and meandering fine grained river styles (Section 4.5). High fragility, where there is a low threshold to damaging impact (such as vegetation clearing alone), was found among the valley fill river styles. The headwaters and the gorge sections of the upper catchment were found to have a low fragility with only minor alteration to bedform regardless of the level of impact.

Recovery potential is determined by sensitivity to adjustment (such as erosion or sedimentation) and changing flow characteristics, or flow regime. Vegetation, woody debris, and upstream seed sources are all considered important components in recovery potential. Geomorphic recovery potential within the Avon River catchment (with a GFDA focus) and recommended actions required to maintain or improve geomorphic conditions are provided in Table 4.4.

Table 4.4 Geomorphic recovery potential and recommended actions to improve or maintain conditions

	Geomorphic recovery potential	Actions required
Avon River	Moderate	Ensure rehabilitation is occurring along upstream reaches. Plan revegetation, weed management and bed raising structures e.g. large woody debris and bed controls.
Oaky Creek	Moderate	Ensure rehabilitation is occurring along upstream reaches. Plan revegetation, weed management and bed raising structures e.g. large woody debris and bed controls.
Waukivory Creek	High	Ensure rehabilitation is occurring in upstream reaches, fence and revegetate and install large woody debris or bed controls in this reach and target weed management.

	Geomorphic recovery potential	Actions required
Dog Trap Creek	Low	Ensure extensive rehabilitation has or is occurring upstream and in this reach, including bed raising structures, bank erosion control structures to reduce rates of change before vegetation can be established or large woody debris installed.
Avondale Creek	Low	Ensure extensive rehabilitation has or is occurring upstream and in this reach, including bed raising structures, bank erosion control structures to reduce rates of change before vegetation can be established or large woody debris installed.

5. Conclusions and recommendations

The purpose of this report was to characterise surface water features in the vicinity of the GFDA by reviewing surface hydrology and water quality information already collected and collecting additional data following a gap analysis.

The main findings from the report are:

- The GFDA lies mainly within the Avon River catchment, a sub-catchment of the Manning River catchment). A small portion of the southern GFDA lies within the Wards River catchment (a sub-catchment of the Karuah River catchment).
- Water use in the Avon River catchment is predominately for irrigation, stock and domestic purposes. Water extraction from the Avon River and its tributaries represents less than 2% of the average annual flow from the Avon River sub-catchment.
- The average flow contribution of the Avon River downstream to the Manning River flow at Killawarra was found to represent approximately 8% of the total river flow.
- A rapid water level response to rainfall events was recorded within the Avon River and Dog Trap Creek (except after extended dry periods) with large flow events occurring both in summer and winter.
- Water quality within the GFDA is typically within the desired range of performance indicators to satisfy WQOs for the Manning River catchment, although some exceedances above recommended maximums were recorded. Water chemistry composition and flow dynamics suggest that baseflow contribution from groundwater sources to the Avon River catchment is low.
- Additional flow gauging and water quality sampling during two wet weather events was conducted so that monitoring was more representative of the full range of hydrological conditions. Different water quality results were recorded during these high flow events, compared to baseflow monitoring. (i.e. dissolved metal concentrations are generally lower during high flow sampling events than routine monitoring conducted during lower flows).
- Creeks within the GFDA have three RiverStyles™ geomorphological classifications: 'meandering rivers comprised typically of fine grained sediments'; 'valley fill swamps and meadows characterised by discontinuous and poorly defined channels', and' bedrock controlled systems in partly confined valleys'. Geomorphological condition within the GFDA is in a general poor to moderate state.
- Creek bed profile depths of between 86.22 and 134.36 mAHD were recorded at 28 representative sites.
- Hydrologically disconnected refuge pools which might provide aquatic ecological habitat during low flow periods and wetland areas have been identified within the GFDA.
- No springs were identified during the site walkover.

The following additional investigations are recommended to further understand hydrological conditions within the GFDA:

- R1: Hydrologic modelling should be undertaken to more accurately model floodplain storages and timing of peak flow events and for a more accurate breakdown on each sub-catchment contribution to flow
- R2: A rainfall versus runoff comparison should be conducted, following completion of a stage-discharge relationship (see R4).

- R3: A more detailed flood frequency analysis should be undertaken to more accurately estimate the ARI of the flow events captured by the AGL gauges.
- R4: Additional flow gauging is required at the four AGL stream gauge sites with water level loggers so a rating curve can be developed and flows calculated. It is estimated that at least 5 more events need to be captured.
- R5: Develop specific target thresholds for Avon River water quality based on continuing water quality baseline monitoring as some analytes are above the current ANZECC freshwater guidelines.
- R6: Additional water quality monitoring should be conducted to assess the influence of flow conditions on nutrient conditions in local creeks.

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Appendix A

Long section profiles

A1. Long section profiles

Long profiles of the local creeks were plotted based on draping the main river channel over the 2 m contour data from NSW Department of Lands.

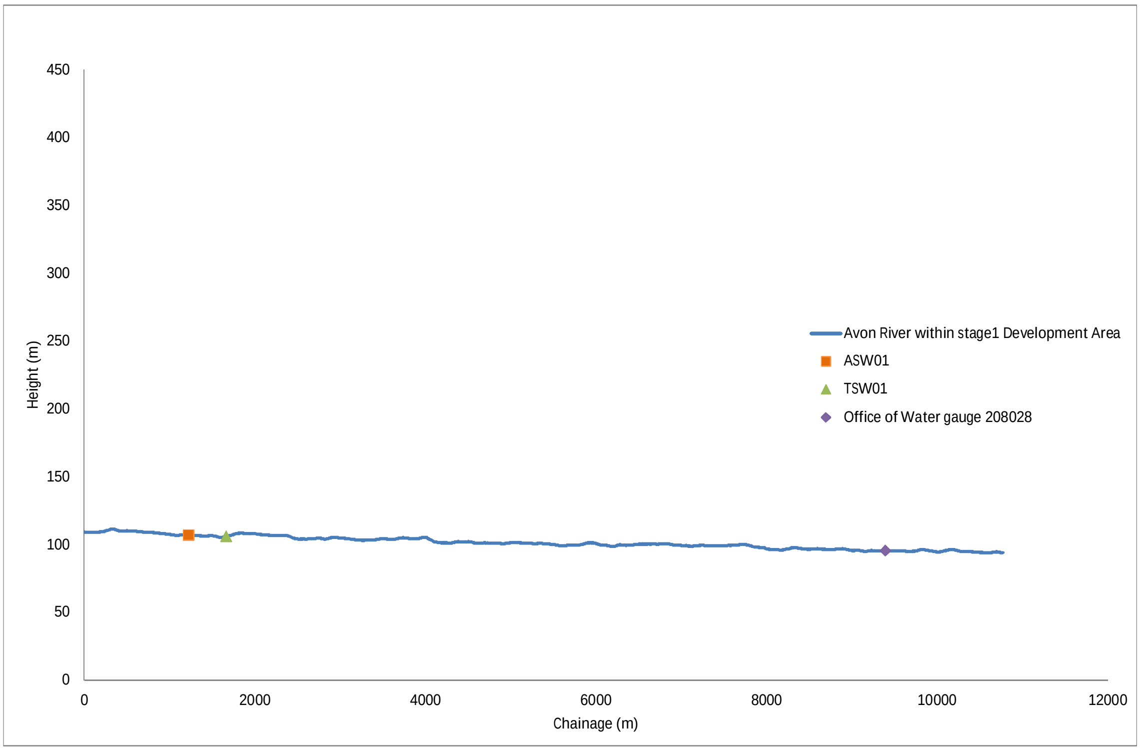


Figure D.1 Avon River long profile

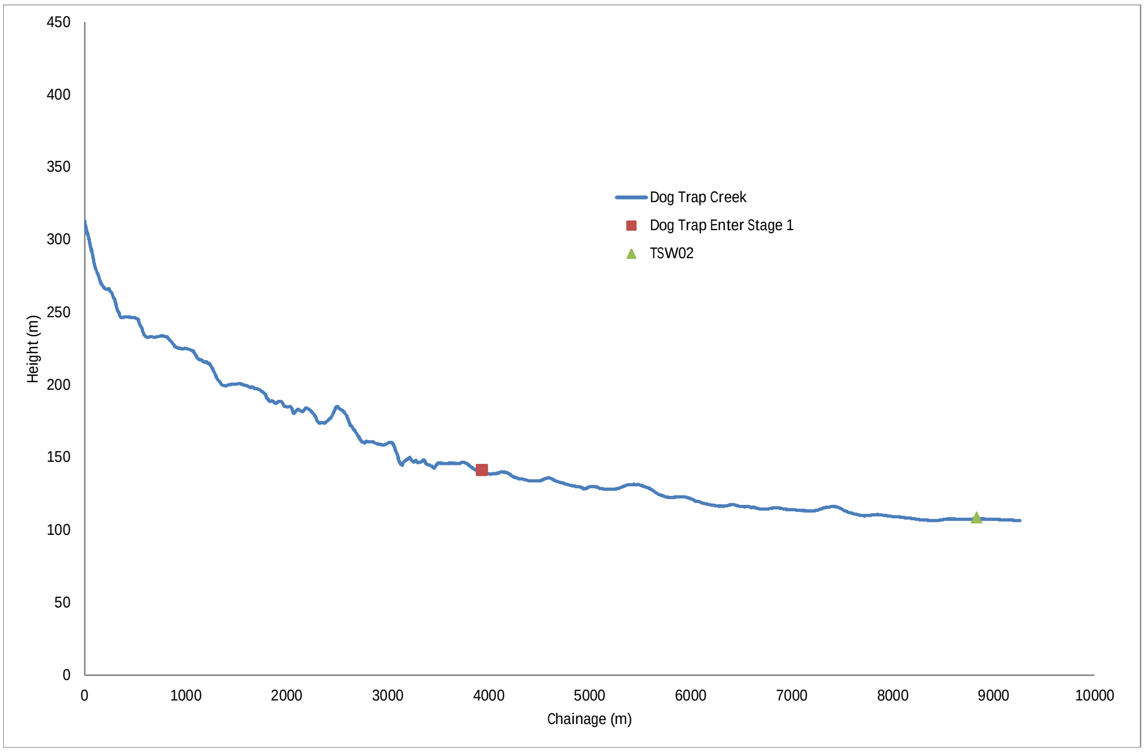


Figure D.2 Dog Trap Creek long profile

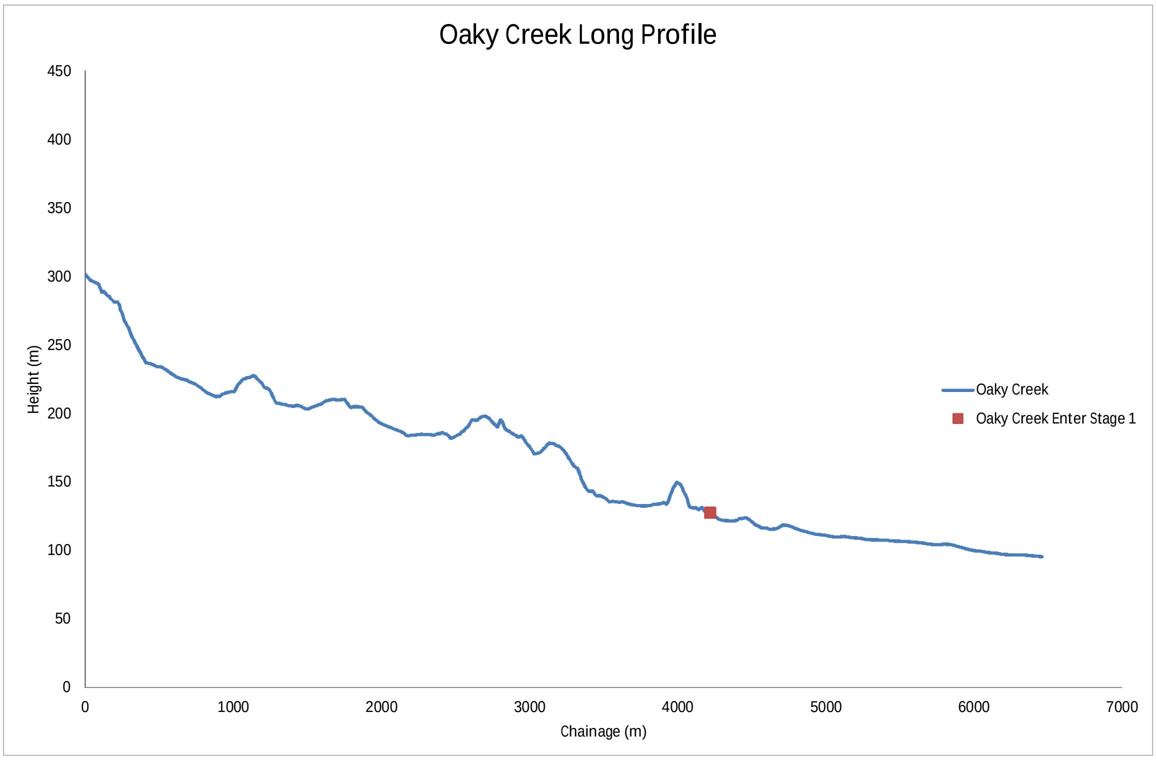


Figure D.3 Oaky Creek long profile

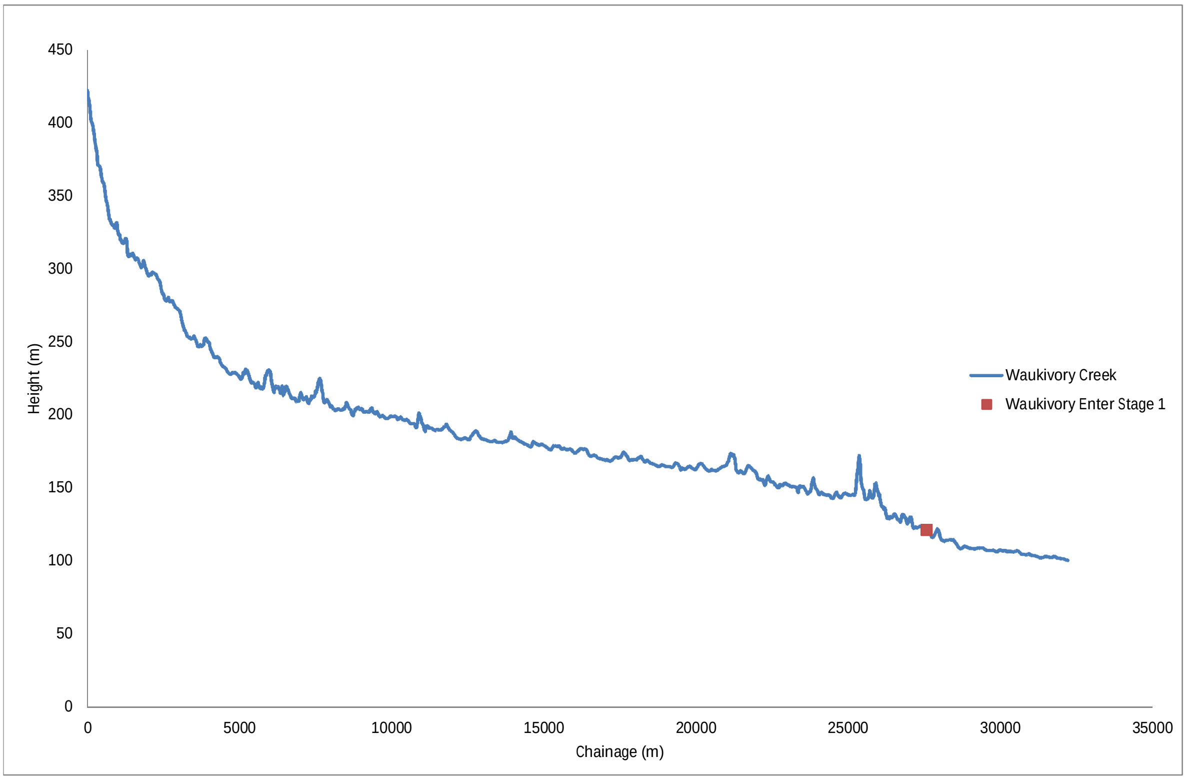


Figure D.4 Waukivory Creek long profile

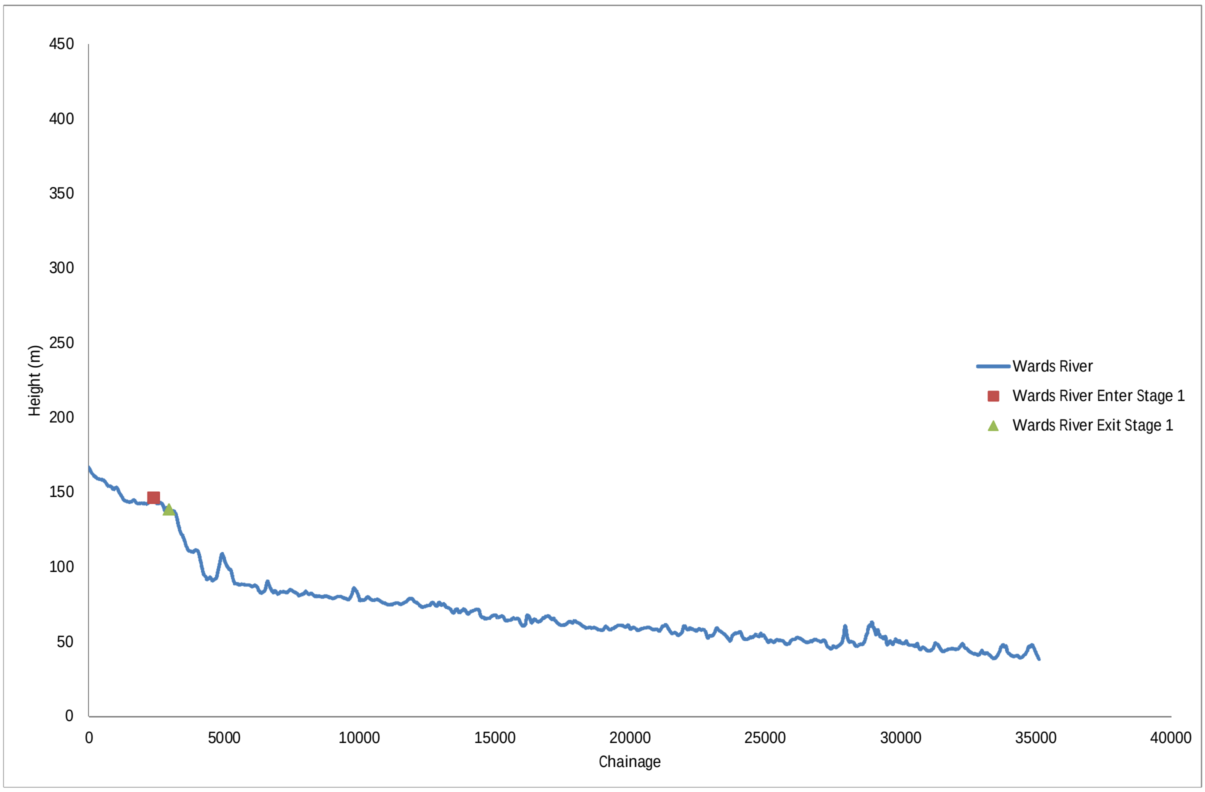


Figure D.5 Ward River long profile

Appendix B

Rational method calculations

B1. Rational method calculations

The rational method is used to calculate runoff for rural catchments in eastern NSW. The detailed methodology is described in AR&R, Volume 1, Book IV (Engineers Australia, 2001). A summary of the parameters used in the rational method calculation are presented below.

The basic rational method equation is:

Q= C.I.A.

where

Q is the peak flow

C is the coefficient of discharge. It is a dimensionless number found by multiplying the 10 year C value which by the Frequency Factors for the given ARI event found in Table 1.1 of AR&R Vol 1, Book 4.

The C_{10} coefficient was found to be 0.55 from Figure 6.1, AR&R Vol 2.

I is the average rainfall intensity (mm/h) for a specified ARI and design duration (t_c) - calculated using the following equation

$$t_c = 0.76.A^{0.38}$$

where

A is the catchment area. This was found using contour data and aerial photography to delineate local sub-catchment areas of the Avon River and the catchment at each gauge of interest.

A catchment map is shown in Figure 1.2. Catchment area and catchment slope are shown in Table A.1. The rational method makes and adjustment for slope of the catchment.

Table A.1 Sub-catchment areas and catchment slopes used in the calculation

Sub- catchment	Area km^2	Slope (%)
Mograni Creek	34.3	2.31
Oaky Creek	10.1	3.19
Avon River near Oaky Creek	24.2	0.94
Waukivory Creek	89.6	1.00
Dog Trap Creek	40	2.23
Broad Creek	23.6	1.25
Avon Tributary Upper	17.5	0.82
Clear Hill Creek	51.6	4.04
Avon River total	290.9	0.94

Appendix C

Flow duration curves

C1. Flow duration curves

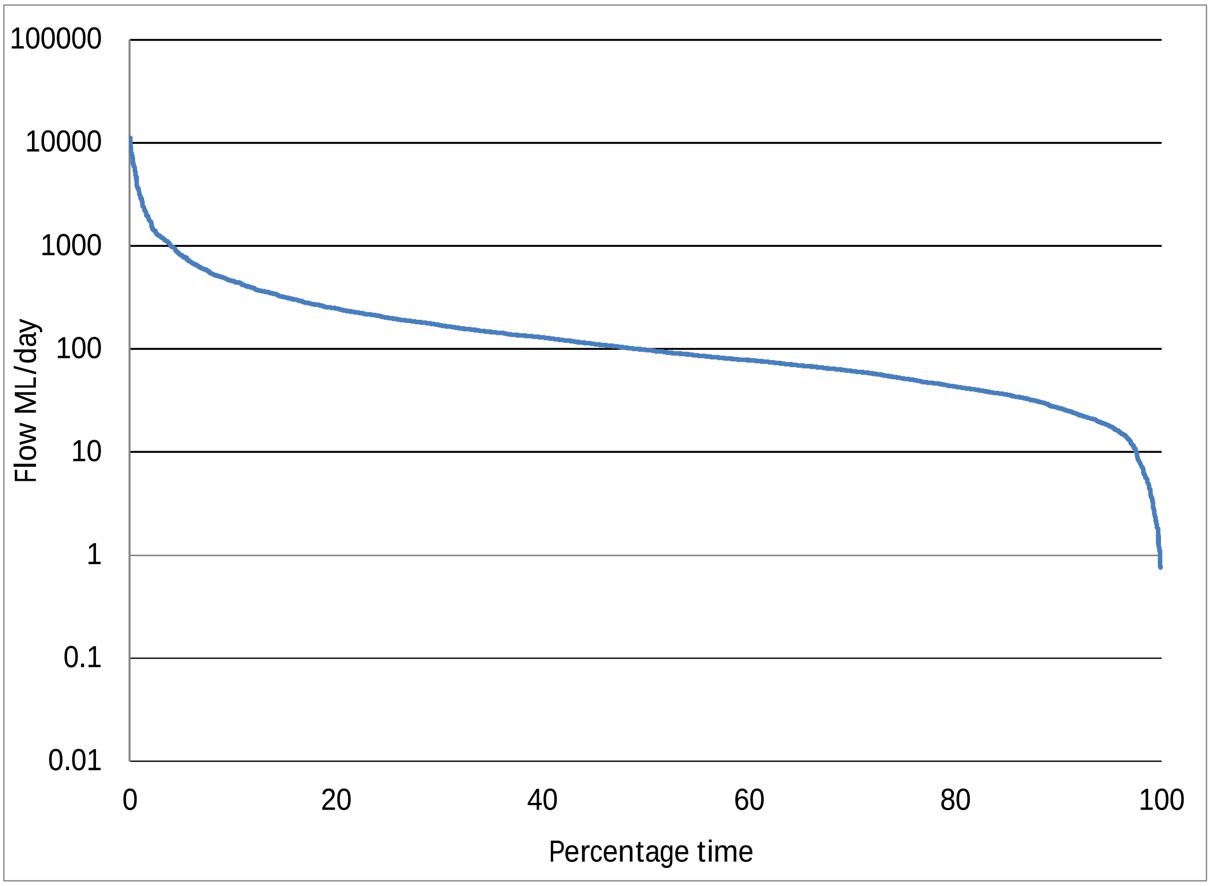


Figure B.1 Gloucester River (NOW #208020) Flow Duration Curve

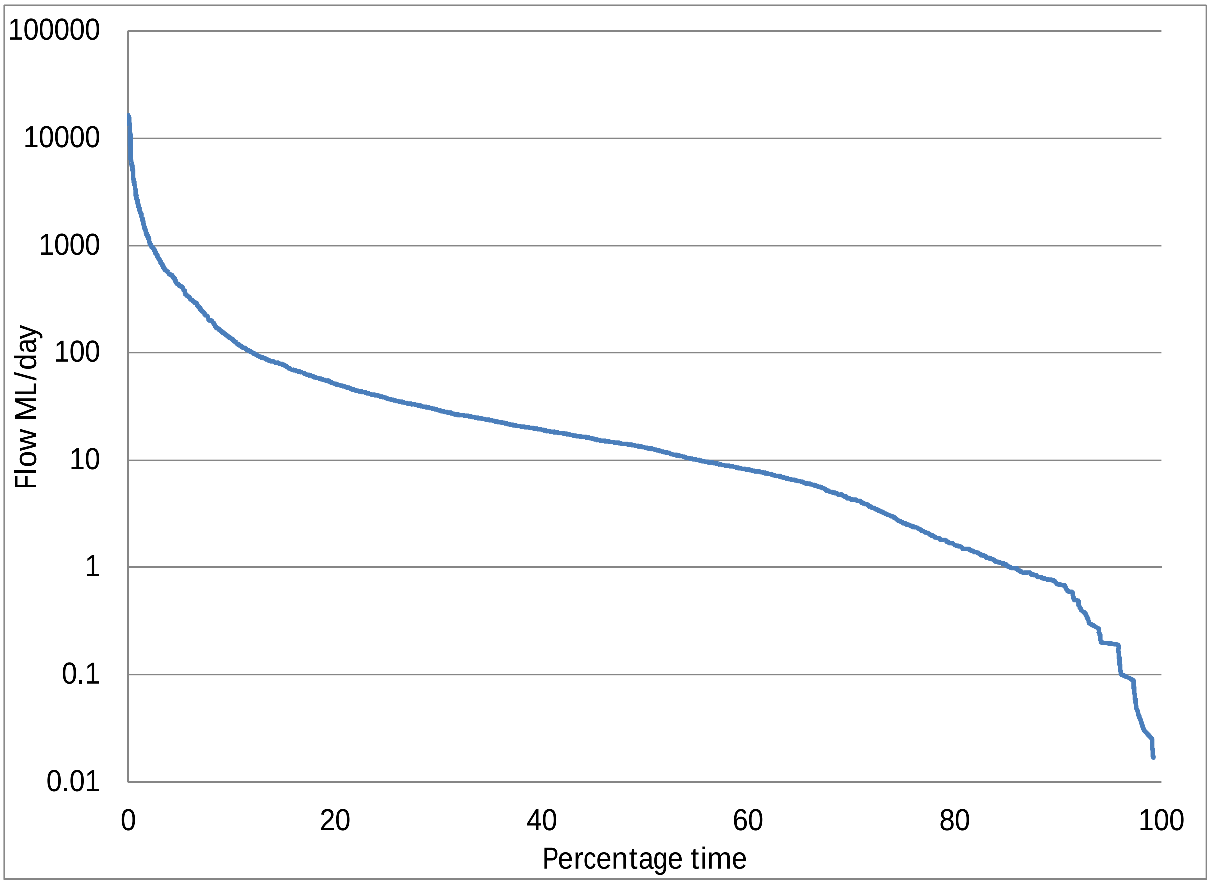


Figure B.2 Mammy Johnsons River (NOW #209002) Flow Duration Curve

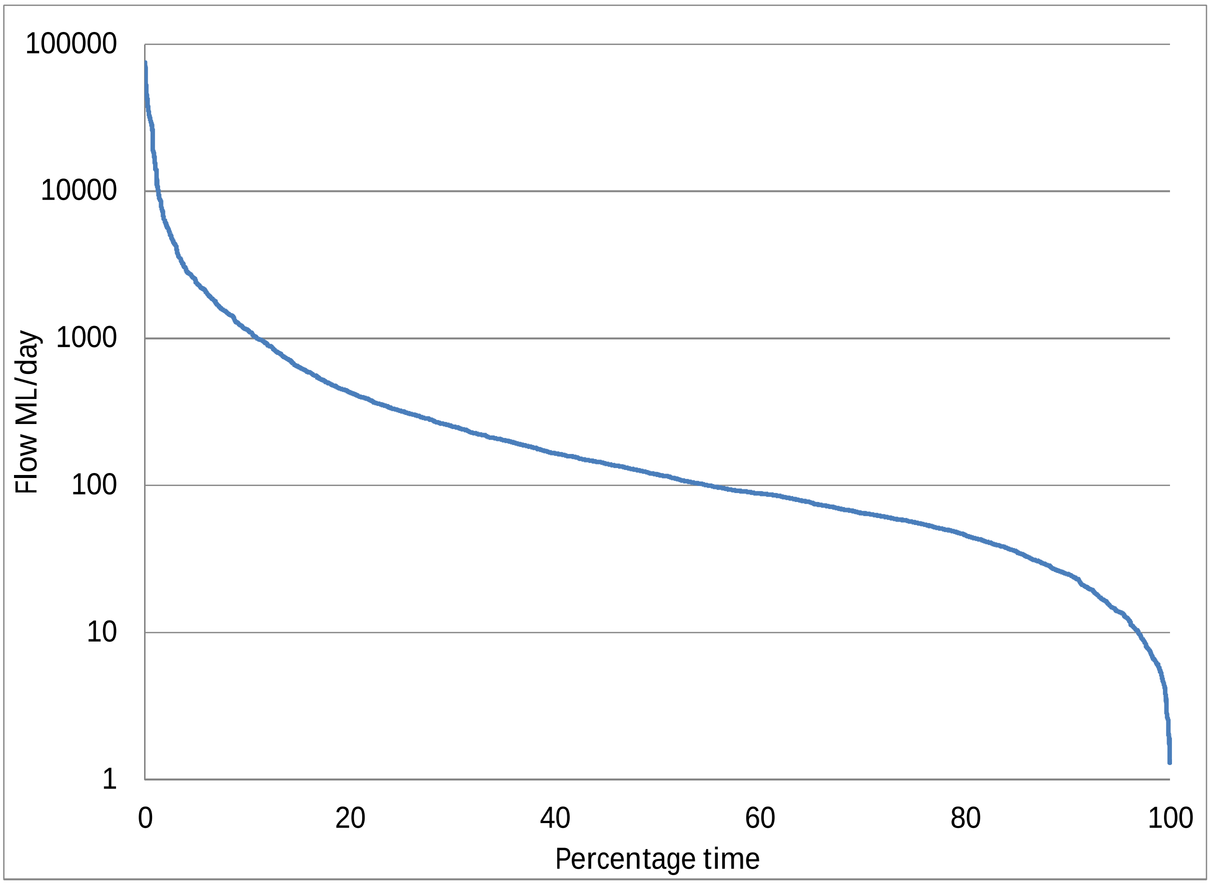


Figure B.3 Upstream Karuah River (NOW #209003) Flow Duration Curve

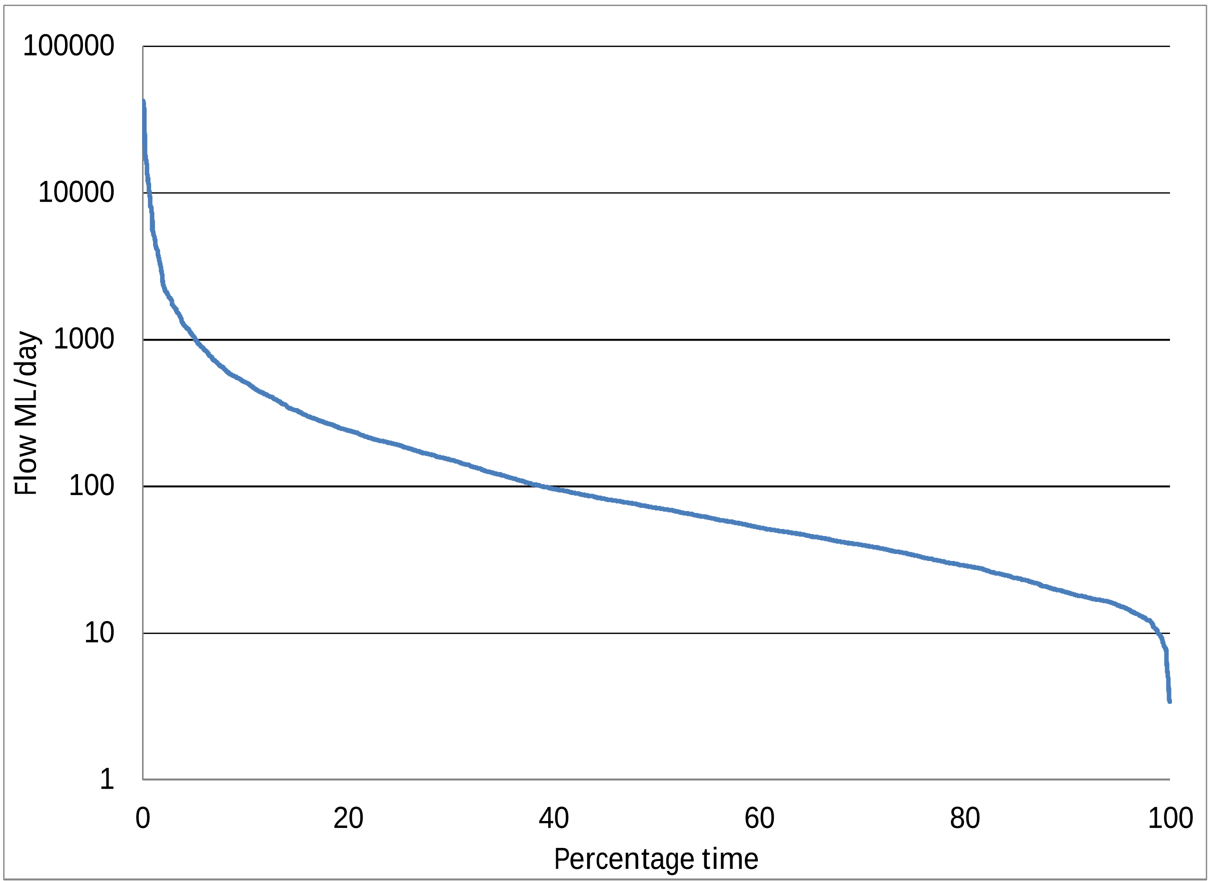


Figure B.4 Downstream Karuah River (NOW #209018) Flow Duration Curve

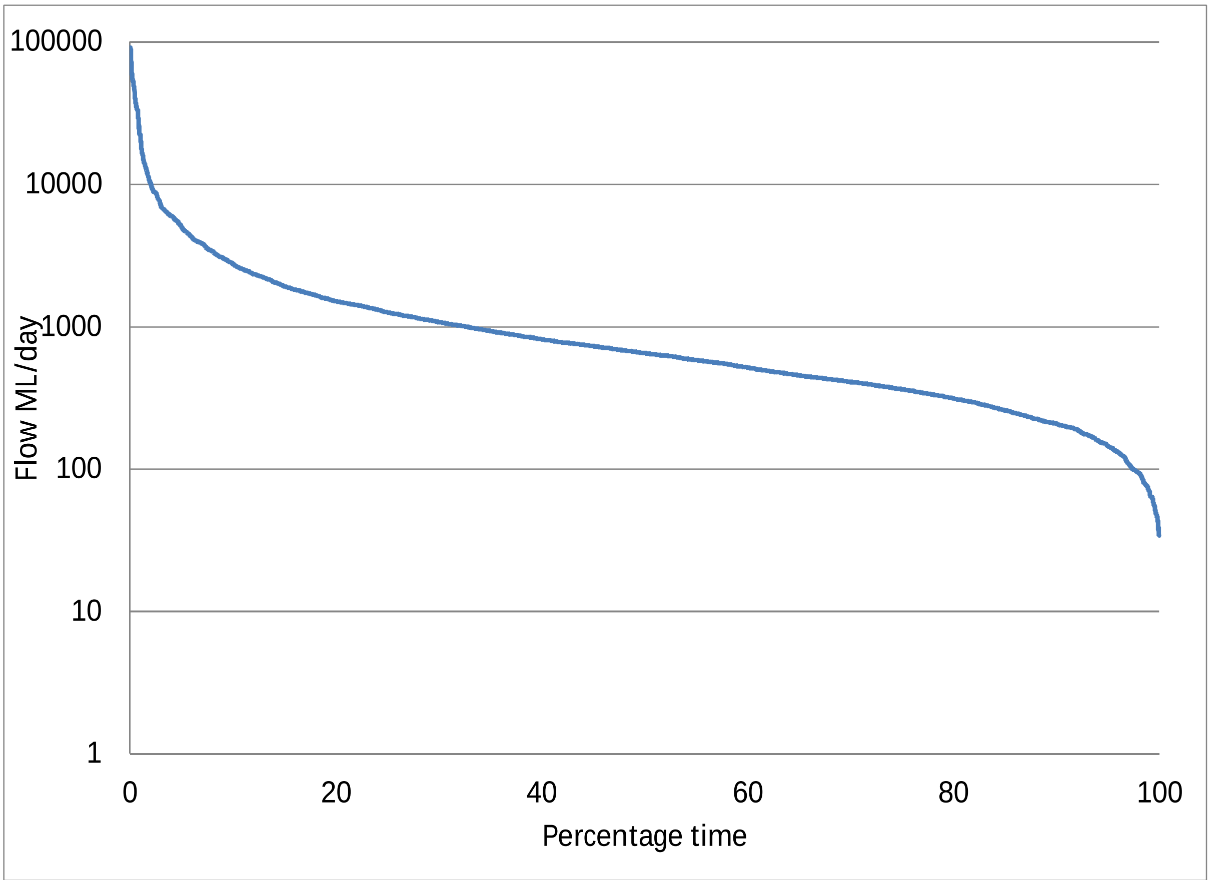


Figure B.5 Gloucester at Doon Ayre (NOW #208003) Flow Duration Curve

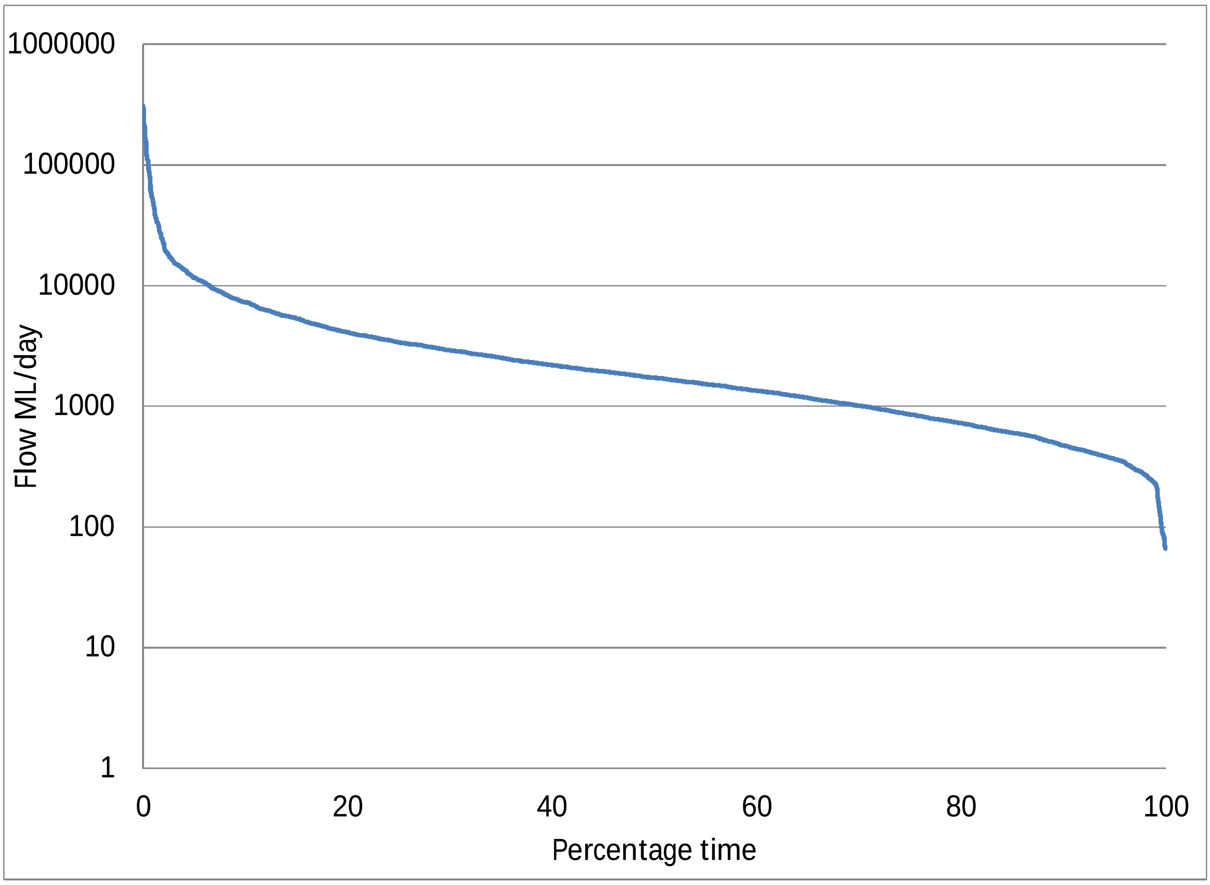


Figure B.6 Manning at Killawara (NOW #208004) Flow Duration Curve

Appendix D

Discharge measurement summaries

Discharge Measurement Summary

Date Measured: Thursday, June 27, 2013

Site Information

Site Name	TSW01
Station Number	
Location	

Measurement Information

Party	
Boat/Motor	
Meas. Number	

System Information

System Type	RS-M9
Serial Number	2043
Firmware Version	3.00
Software Version	3.6.0.3384

System Setup

Transducer Depth (m)	0.08*
Salinity (ppt)	0.0
Magnetic Declination (deg)	12.0

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Vertical Bank
Depth Reference	Vertical Beam*	Right Method	Vertical Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width	7.564
Area	10.845
Mean Speed	0.057
Total Q	0.616
Maximum Measured Depth	2.326
Maximum Measured Speed	0.735

Measurement Results

Tr		Time			Distance				Mean Vel		Discharge							%
#		Time	Duration	Temp.	Track	DMG	Width	Area	Boat	Water	Left	Right	Top	Middle	Bottom	Total	MBTotal	Measured
1	L	10:05:13 AM	0:11:19	11.2	15.14	6.57	7.368	9.908	0.022	0.057	0.00	0.03	0.07	0.38	0.09	0.569	--	66.5
2	R	10:26:55 AM	0:09:33	11.1	12.28	7.16	7.759	11.781	0.021	0.056	0.00	0.02	0.04	0.46	0.14	0.663	--	70.1
			Mean	11.1	13.71	6.86	7.564	10.845	0.022	0.057	0.00	0.02	0.05	0.42	0.12	0.616	0.000	68.3
			Std Dev	0.0	1.43	0.30	0.196	0.936	0.000	0.001	0.00	0.01	0.01	0.04	0.02	0.047	0.000	1.8
			COV	0.0	0.104	0.043	0.026	0.086	0.020	0.010	-1.366	0.330	0.203	0.100	0.196	0.076	0.000	0.026

Exposure Time: 0:20:52

Tr1=20130627100512r_MissingSamples.rivr-Locked; Tr2=20130627102654.riv-Locked;

Comments

Tr1=20130627100512r_MissingSamples.rivr - ; Tr2=20130627102654.riv - ;

Compass Calibration

Passed Calibration

Calibration duration = 66 seconds
M12.00 = Magnetic influence is acceptable
Q9 = Magnetic field is uniform
H9 = Complete horizontal rotation
V9 = High pitch/roll

Recommendation(s):
Avoid any changes to the instrument setup or its orientation to the magnetic influences detected during the compass calibration.

Measurements should be made in locations with similar magnetic influences as the location of the compass calibration.

System Test

System Test: PASS

Parameters and settings marked with a * are not constant for all files.

Report generated using SonTek RiverSurveyor Live v3.6.0.3384

Discharge Measurement Summary

Date Measured: Friday, June 28, 2013

Site Information

Site Name	ASW01
Station Number	
Location	

Measurement Information

Party	
Boat/Motor	
Meas. Number	

System Information

System Type	RS-M9
Serial Number	2043
Firmware Version	3.00
Software Version	3.6.0.3384

System Setup

Transducer Depth (m)	0.08
Salinity (ppt)	0.0
Magnetic Declination (deg)	12.0

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Vertical Bank
Depth Reference	Vertical Beam	Right Method	Vertical Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width	8.390
Area	13.488
Mean Speed	0.081
Total Q	1.089
Maximum Measured Depth	2.603
Maximum Measured Speed	0.878

Measurement Results

Tr		Time			Distance				Mean Vel		Discharge							%
#		Time	Duration	Temp.	Track	DMG	Width	Area	Boat	Water	Left	Right	Top	Middle	Bottom	Total	MBTotal	Measured
2	L	10:27:20 AM	0:03:22	13.5	12.44	6.94	8.441	15.314	0.062	0.086	0.00	0.02	0.12	0.83	0.36	1.322	--	62.4
3	L	10:31:25 AM	0:02:49	13.5	10.97	7.11	8.607	11.111	0.065	0.085	0.00	0.11	0.09	0.61	0.14	0.944	--	64.0
4	L	10:34:53 AM	0:02:47	13.4	8.17	6.62	8.123	14.039	0.049	0.071	-0.01	0.07	0.09	0.66	0.18	1.001	--	65.3
			Mean	13.5	10.53	6.89	8.390	13.488	0.058	0.081	0.00	0.07	0.10	0.70	0.22	1.089	0.000	63.9
			Std Dev	0.0	1.77	0.20	0.201	1.760	0.007	0.007	0.00	0.04	0.01	0.09	0.09	0.167	0.000	1.2
			COV	0.0	0.168	0.029	0.024	0.130	0.118	0.084	-0.984	0.552	0.148	0.133	0.422	0.153	0.000	0.019

Exposure Time: 0:08:58

Tr2=20130628102718.riv; Tr3=20130628103123.riv; Tr4=20130628103451.riv;

Comments

Tr2=20130628102718.riv - ; Tr3=20130628103123.riv - ; Tr4=20130628103451.riv - ;

Compass Calibration

Passed Calibration

Calibration duration = 66 seconds
M12.00 = Magnetic influence is acceptable
Q9 = Magnetic field is uniform
H9 = Complete horizontal rotation
V9 = High pitch/roll

Recommendation(s):
Avoid any changes to the instrument setup or its orientation to the magnetic influences detected during the compass calibration.

Measurements should be made in locations with similar magnetic influences as the location of the compass calibration.

System Test

System Test: PASS

Parameters and settings marked with a * are not constant for all files.

Report generated using SonTek RiverSurveyor Live v3.6.0.3384

Discharge Measurement Summary

Date Measured: Friday, June 28, 2013

Site Information

Site Name	TSW01
Station Number	
Location	

Measurement Information

Party	
Boat/Motor	
Meas. Number	

System Information

System Type	RS-M9
Serial Number	2043
Firmware Version	3.00
Software Version	3.6.0.3384

System Setup

Transducer Depth (m)	0.08
Salinity (ppt)	0.0
Magnetic Declination (deg)	12.0

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Vertical Bank
Depth Reference	Vertical Beam*	Right Method	Vertical Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width	9.237
Area	17.528
Mean Speed	0.142
Total Q	2.493
Maximum Measured Depth	2.641
Maximum Measured Speed	1.286

Measurement Results

Tr		Time			Distance				Mean Vel		Discharge							%
#		Time	Duration	Temp.	Track	DMG	Width	Area	Boat	Water	Left	Right	Top	Middle	Bottom	Total	MBTotal	Measured
1	L	9:31:01 AM	0:04:35	13.3	12.11	8.75	9.750	18.181	0.044	0.142	0.00	0.12	0.26	1.79	0.41	2.581	--	69.4
3	L	9:42:11 AM	0:03:59	13.2	10.25	8.03	9.026	17.297	0.043	0.138	0.04	0.05	0.25	1.68	0.38	2.393	--	70.0
4	L	9:46:53 AM	0:03:08	13.2	9.47	7.94	8.936	17.106	0.050	0.146	0.00	0.03	0.26	1.78	0.43	2.503	--	71.1
			Mean	13.2	10.61	8.24	9.237	17.528	0.046	0.142	0.02	0.07	0.26	1.75	0.40	2.493	0.000	70.2
			Std Dev	0.0	1.11	0.36	0.365	0.468	0.003	0.003	0.02	0.04	0.01	0.05	0.02	0.077	0.000	0.7
			COV	0.0	0.105	0.044	0.039	0.027	0.072	0.023	1.403	0.562	0.029	0.030	0.051	0.031	0.000	0.010

Exposure Time: 0:11:42

Tr1=20130628093101.riv; Tr3=20130628094211.riv; Tr4=20130628094653.riv;

Comments

Tr1=20130628093101.riv - ; Tr3=20130628094211.riv - ; Tr4=20130628094653.riv - ;

Compass Calibration

Passed Calibration

Calibration duration = 66 seconds
M12.00 = Magnetic influence is acceptable
Q9 = Magnetic field is uniform
H9 = Complete horizontal rotation
V9 = High pitch/roll

Recommendation(s):
Avoid any changes to the instrument setup or its orientation to the magnetic influences detected during the compass calibration.

Measurements should be made in locations with similar magnetic influences as the location of the compass calibration.

System Test

System Test: PASS

Parameters and settings marked with a * are not constant for all files.

Report generated using SonTek RiverSurveyor Live v3.6.0.3384

Discharge Measurement Summary

Date Measured: Friday, June 28, 2013

Site Information

Site Name	TSW02
Station Number	
Location	

Measurement Information

Party	
Boat/Motor	
Meas. Number	

System Information

System Type	RS-M9
Serial Number	2043
Firmware Version	3.00
Software Version	3.6.0.3384

System Setup

Transducer Depth (m)	0.08
Salinity (ppt)	0.0
Magnetic Declination (deg)	12.0

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Vertical Bank
Depth Reference	Bottom-Track*	Right Method	Vertical Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width	4.543
Area	3.314
Mean Speed	0.392
Total Q	1.297
Maximum Measured Depth	1.407
Maximum Measured Speed	1.035

Measurement Results

Tr		Time			Distance				Mean Vel		Discharge							%
#		Time	Duration	Temp.	Track	DMG	Width	Area	Boat	Water	Left	Right	Top	Middle	Bottom	Total	MBTotal	Measured
2	R	11:48:55 AM	0:01:49	13.9	8.03	4.03	5.033	4.150	0.074	0.391	0.02	0.05	0.29	0.85	0.41	1.623	--	52.7
3	R	11:51:08 AM	0:01:51	13.9	8.43	3.05	4.052	2.477	0.076	0.392	0.01	0.04	0.20	0.54	0.17	0.971	--	55.6
			Mean	13.9	8.23	3.54	4.543	3.314	0.075	0.392	0.02	0.05	0.24	0.70	0.29	1.297	0.000	54.1
			Std Dev	0.0	0.20	0.49	0.490	0.837	0.001	0.001	0.00	0.00	0.04	0.16	0.12	0.326	0.000	1.5
			COV	0.0	0.024	0.138	0.108	0.253	0.015	0.001	0.241	0.071	0.175	0.226	0.405	0.251	0.000	0.027

Exposure Time: 0:03:40

Tr2=20130628114854.riv; Tr3=20130628115108.riv;

Comments

Tr2=20130628114854.riv - ; Tr3=20130628115108.riv - ;

Compass Calibration

Passed Calibration

Calibration duration = 66 seconds
M12.00 = Magnetic influence is acceptable
Q9 = Magnetic field is uniform
H9 = Complete horizontal rotation
V9 = High pitch/roll

Recommendation(s):
Avoid any changes to the instrument setup or its orientation to the magnetic influences detected during the compass calibration.

Measurements should be made in locations with similar magnetic influences as the location of the compass calibration.

System Test

System Test: PASS

Parameters and settings marked with a * are not constant for all files.

Report generated using SonTek RiverSurveyor Live v3.6.0.3384

Discharge Measurement Summary

Date Measured: Thursday, June 27, 2013

Site Information

Site Name	TSW02
Station Number	
Location	

Measurement Information

Party	
Boat/Motor	
Meas. Number	

System Information

System Type	RS-M9
Serial Number	2043
Firmware Version	3.00
Software Version	3.6.0.3384

System Setup

Transducer Depth (m)	0.08
Salinity (ppt)	0.0
Magnetic Declination (deg)	12.0

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Vertical Bank
Depth Reference	Bottom-Track	Right Method	Vertical Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width	2.495
Area	1.187
Mean Speed	0.161
Total Q	0.191
Maximum Measured Depth	0.617
Maximum Measured Speed	0.433

Measurement Results

Tr		Time			Distance				Mean Vel		Discharge							%
#		Time	Duration	Temp.	Track	DMG	Width	Area	Boat	Water	Left	Right	Top	Middle	Bottom	Total	MBTotal	Measured
2	L	12:00:26 PM	0:02:10	12.5	3.20	1.94	2.542	1.155	0.025	0.167	0.02	0.00	0.05	0.10	0.03	0.193	--	49.9
3	R	12:07:01 PM	0:03:24	12.4	3.02	1.85	2.449	1.218	0.015	0.155	0.01	0.00	0.05	0.09	0.03	0.189	--	49.0
			Mean	12.5	3.11	1.90	2.495	1.187	0.020	0.161	0.02	0.00	0.05	0.09	0.03	0.191	0.000	49.5
			Std Dev	0.1	0.09	0.05	0.046	0.032	0.005	0.006	0.00	0.00	0.00	0.00	0.00	0.002	0.000	0.5
			COV	0.0	0.029	0.024	0.019	0.027	0.249	0.037	0.099	1.000	0.007	0.020	0.009	0.011	0.000	0.009

Exposure Time: 0:05:34

Tr2=20130627120025.riv; Tr3=20130627120700.riv;

Comments

Tr2=20130627120025.riv - ; Tr3=20130627120700.riv - ;

Compass Calibration

Passed Calibration

Calibration duration = 66 seconds
M12.00 = Magnetic influence is acceptable
Q9 = Magnetic field is uniform
H9 = Complete horizontal rotation
V9 = High pitch/roll

Recommendation(s):
Avoid any changes to the instrument setup or its orientation to the magnetic influences detected during the compass calibration.

Measurements should be made in locations with similar magnetic influences as the location of the compass calibration.

System Test

System Test: PASS

Parameters and settings marked with a * are not constant for all files.

Report generated using SonTek RiverSurveyor Live v3.6.0.3384

Appendix E

Water quality data

NAME AND DATE					HIGH FLOW MONITORING ROUND 1								HIGH FLOW MONITORING ROUND 2						
					ASW01	ASW02	TSW01	TSW02	ASW01	ASW02	TSW01	TSW02	ASW01	ASW02 (Bridge)	TSW01	TSW02	ASW01	TSW01	TSW02
Sample date					3/06/2013	3/06/2013	3/06/2013	3/06/2013	4/06/2013	4/06/2013	4/06/2013	4/06/2013	27/06/2013	27/06/2013	27/06/2013	27/06/2013	28/06/2013	28/06/2013	28/06/2013
Analyte		Units	LOR	ANZECC 2000 Guidelines	Avon River	Avon River	Dog Trap Creek	Dog Trap Creek	Avon River	Avon River	Dog Trap Creek	Dog Trap Creek	Avon River	Avon River	Dog Trap Creek	Dog Trap Creek	Avon River	Dog Trap Creek	Dog Trap Creek
Field Parameters																			
pH		pH units	0.01	6.5 - 8.0*	6.95	6.89	6.28	6.65	7.41	7.41	6.3	7.41	7.01	7.04	7.89	6.09	6.47		6.22
Conductivity		µS/cm	1	125 - 2200*	380	371	502	668	340	340	577	581	369	219	461	507	228	385	496
Total Dissolved Solids		mg/L	1	-	0.247	0.241	0.326	0.434	0.221	0.221	0.375	0.377	0.24	0.142	0.3	0.329	0.148	0.25	0.323
Temperature		degC	0.01	-	11.97	12.34	12.5	13.51	11.79	11.79	10.44	10.58	10.45	11.99	10.15	11.34	12.51	12.27	12.76
Dissolved Oxygen		%	0.1	85 - 110	64.8	81.8	76.1	74.4	92.1	92.1	58.1	63.2	58.2	68.1	102.1	61.3	48.5	43.7	42.3
Dissolved Oxygen		mg/L	0.01	-	6.97	8.69	8.1	7.71	9.95	9.95	6.45	7.02	6.49	7.33		6.69	5.16	4.67	4.48
Oxidation/Reduction Potential (ORP)		no units	0.1	-	-78.6	-73.2	-13.6	-58.5	-75.2	-75.2	20.9	-69	-26.7	-27.2	-17.6	-22.8	-91.1	-84.6	-82.5
Turbidity (NTU)		NTU	-	6 - 50															
Laboratory Analysis																			
Suspended Solids (SS)		mg/L	5	-	12	16	21	18	<5	<5	14	13	27	134	8	13	28	37	9
Total Hardness as CaCO3		mg/L	1	-	76	70	98	127	72	63	101	105	56	75	67	22	31	57	68
Silica		mg/L	0.1	-															
Fluoride		mg/L		-															
Sulfur		mg/L		-															
Sulfate as SO4 - Turbidimetric		mg/L	1	-	11	12	48	103	12	12	83	89	12	29	20	8	16	37	50
Chloride		mg/L	1	-	75	73	95	128	76	71	120	124	73	109	95	45	47	80	106
Alkalinity																			
Hydroxide Alkalinity as CaCO3		mg/L	1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3		mg/L	1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as CaCO3		mg/L	1	-	65	58	54	30	61	56	18	13	53	26	56	48	29	24	10
Total Alkalinity as CaCO3		mg/L	1	-	65	58	54	30	61	56	18	13	53	26	56	48	29	24	10
Dissolved Major Cations																			
Calcium		mg/L	1	-	14	13	16	18	14	12	14	14	11	12	12	4	6	8	9
Magnesium		mg/L	1	-	10	9	14	20	9	8	16	17	7	11	9	3	4	9	11
Sodium		mg/L	1	-	50	49	63	87	50	49	79	82	50	60	66	30	28	51	63
Potassium		mg/L	1	-	3	3	8	8	4	4	6	6	3	6	3	5	5	5	5
Dissolved Metals																			
Aluminium		mg/L	0.01	0.055															
Arsenic		mg/L	0.001	0.013 (as V)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium		mg/L	0.001	1.0	0.048	0.056	0.072	0.107	0.055	0.048	0.076	0.075	0.06	0.052	0.11	0.09	0.057	0.07	0.066
Beryllium		mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron		mg/L	0.05	0.37															
Bromine		mg/L	0.1	-															
Cadmium	H	mg/L	0.0001	**0.0005**	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt		mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium		mg/L	0.001	**0.0025**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.001	0.001
Copper	H	mg/L	0.001	**0.0035**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.003	0.003	0.002	0.003	0.002	0.002
Iron		mg/L	0.05	ID															
Manganese		mg/L	0.001	1.9	0.036	0.033	0.046	0.048	0.018	0.02	0.048	0.024	0.07	0.072	0.062	0.067	0.035	0.043	0.037
Molybdenum		mg/L	0.001	ID															
Nickel	H	mg/L	0.001	**0.011**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.003	0.002	0.002	0.002	0.002	0.002
Lead	H	mg/L	0.001	**0.0136**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.001
Selenium		mg/L	0.01	0.011 (total)															
Strontium		mg/L	0.001	-															
Vanadium		mg/L	0.01	ID	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc		mg/L	0.005	**0.020**	<0.005	<0.005	<0.005	0.006	<0.005	<0.005	0.006	0.009	0.018	0.064	0.043	0.046	0.029	0.04	0.054
Mercury	M	mg/L	0.0001	0.0006	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Uranium		mg/L	0.001	ID															
Nutrients																			
Ammonia as N (NH3 + NH4+)		mg/L	-	-															
Nitrite + Nitrate as N (NOx)		mg/L	0.01	0.04	0.04	<0.01	0.12	0.11	<0.01	0.05	0.06	0.07	0.02	0.06	0.02	0.33	0.02	0.04	0.04
Total Kjeldahl Nitrogen (TKN) as N		mg/L	0.1	-	0.2	0.3	1.2	1.2	0.3	0.5	0.7	0.8	0.3	1.1	0.2	0.5	1.1	1	0.9
Total Nitrogen as N (TKN + NOx)		mg/L	0.1	0.35*	0.2	0.3	1.3	1.3	0.3	0.6	0.8	0.9	0.3	1.2	0.2	0.8	1.1	1	0.9
Total Phosphorus as P		mg/L	0.01	0.025*	0.05	0.02	0.02	0.1	0.07	<0.01	0.06	<0.01	<0.01	<0.01	0.01	<0.01	0.06	0.12	<0.01
Reactive Phosphorous		mg/L	0.01	-	0.2	0.3	1.2	1.2	0.3	0.5	0.7	0.8	0.3	1.1	0.2	0.5	1.1	1	0.9
Total Organic Carbon		mg/L																	
Nitrite as N		mg/L	0.01	-															
Nitrate as N		mg/L	0.01	0.7															
Ionic Balance																			
Total Anions		meq/L	0.01	-	3.64	3.47	4.76	6.35	3.61	3.37	5.47	5.61	3.37	4.2	4.22	2.39	2.24	3.51	4.23
Total Cations		meq/L	0.01	-	3.77	3.6	4.9	6.53	3.72	3.49	5.61	5.82	3.38	4.27	4.29	1.88	1.97	3.49	4.22
Ionic Balance		%	0.01	-	1.74	1.82	1.42	1.38	1.41	1.73	1.18	1.8	0.11	0.81	0.83			0.3	0.11

NAME AND DATE				HIGH FLOW MONITORING ROUND 1								HIGH FLOW MONITORING ROUND 2						
				ASW01	ASW02	TSW01	TSW02	ASW01	ASW02	TSW01	TSW02	ASW01	ASW02 (Bridge)	TSW01	TSW02	ASW01	TSW01	TSW02
Sample date				3/06/2013	3/06/2013	3/06/2013	3/06/2013	4/06/2013	4/06/2013	4/06/2013	4/06/2013	27/06/2013	27/06/2013	27/06/2013	27/06/2013	28/06/2013	28/06/2013	28/06/2013
Analyte	Units	LOR	ANZECC 2000 Guidelines	Avon River	Avon River	Dog Trap Creek	Dog Trap Creek	Avon River	Avon River	Dog Trap Creek	Dog Trap Creek	Avon River	Avon River	Dog Trap Creek	Dog Trap Creek	Avon River	Dog Trap Creek	Dog Trap Creek
C1 - C4 Hydrocarbon Gases																		
Methane	µg/L	10	65 000^	<10	<10	<10	<10	<10	<10	<10	<10	23	20	12	<10	13	10	<10
Ethene	µg/L	10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Ethane	µg/L	10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Propene	µg/L	10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Propane	µg/L	10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Butene	µg/L	10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Butane	µg/L	10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
BTEXN																		
Benzene	µg/L	1	950	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Toluene	µg/L	2	ID	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ethylbenzene	µg/L	2	ID	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
meta- & para-Xylene	µg/L	2	ID	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
ortho-Xylene	µg/L	2	350	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Total Xylenes	µg/L	2	-	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Sum of BTEX	µg/L	1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Naphthalene	µg/L	5	16	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Total Petroleum Hydrocarbons																		
C6 - C9 Fraction	µg/L	20	ID	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
C10 - C14 Fraction	µg/L	50	ID	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C15 - C28 Fraction	µg/L	100	ID	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
C29 - C36 Fraction	µg/L	50	ID	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
C10 - C36 Fraction (sum)	µg/L	50	-	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50
Total Recoverable Hydrocarbons																		
C6 - C10 Fraction	µg/L	20	ID	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
C6 - C10 Fraction minus BTEX	µg/L	20	ID	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
>C10 - C16 Fraction	µg/L	100	ID	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C16 - C34 Fraction	µg/L	100	ID	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C34 - C40 Fraction	µg/L	100	ID	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
>C10 - C40 Fraction (sum)	µg/L	100	-	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Phenolic compounds																		
Phenol	µg/L	1	320															
2-Chlorophenol	µg/L	1	490															
2-Methylphenol	µg/L	1	-															
3-&4-Methylphenol	µg/L	2	-															
2-Nitrophenol	µg/L	1	ID															
2.4-Dimethylphenol	µg/L	1	ID															
2.4-Dichlorophenol	µg/L	1	160															
2.6-Dichlorophenol	µg/L	1	ID															
4-Chloro-3-Methylphenol	µg/L	1	-															
2.4.6-Trichlorophenol	µg/L	1	20															
2.4.5-Trichlorophenol	µg/L	1	ID															
Pentachlorophenol	µg/L	2	ID															
Polycyclic aromatic hydrocarbons																		
Acenaphthylene	µg/L	1	-															
Acenaphthene	µg/L	1	-															
Fluorene	µg/L	1	-															
Phenanthrene	µg/L	1	ID															
Anthracene	µg/L	1	ID															
Fluoranthene	µg/L	1	ID															
Pyrene	µg/L	1	-															
Benz(a)anthracene	µg/L	1	-															
Chrysene	µg/L	1	-															
Benzo(b)fluoranthene	µg/L	1	-															
Benzo(k)fluoranthene	µg/L	1	-															
Benzo(a)pyrene	µg/L	0.5	ID															
Indeno(1.2.3.cd)pyrene	µg/L	1	-															
Dibenz(a.h)anthracene	µg/L	1	-															
Benzo(g.h.i)perylene	µg/L	1	-															
Sum of polycyclic aromatic hydrocarbons	µg/L	0.5	-															
Benzo(a)pyrene TEQ (WHO)	µg/L	0.5	-															

Guideline values

ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems.

* ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems, South-East Australia, low lying river ecosystems

^ Toxicant guideline for the protection of aquaculture species

< This result is below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit) and therefore has an unacceptable level of uncertainty. Hence the data should only be used as an indicator of true concentration.

Calculated Ammonium values have been derived from Ammonia as N

TKN values for August 2013 Irrigation monitoring have been estimated as the sum of NOx and TKN

Calculated nitrite and nitrate values have been determined using Nitrite as N and Nitrate as N values. ANZECC guidelines for nitrate and nitrite are for livestock drinking water quality

Bold ANZECC values have been corrected for moderate water hardness

ANZECC 2000 guidelines

Values below LOR no guidelines exist
Values within guidliens
Values exceed guidelines
No guidelines to compare detected values

NAME AND DATE					GROUNDWATER MONITORING ROUND			GROUNDWATER MONITORING ROUND				IRRIGATION MONITORING		IRRIGATION MONITORING			IRRIGATION MONITORING			
					TSW01	ASW01	ASW02	ASW01	ASW02	TSW01	TSW02	TSW01	ASW01	TSW01	TSW02	ASW01	TSW01	TSW02	ASW01	FSW01
Sample date					**7/04/2011**	**8/04/2011**	**8/04/2011**	**21/06/2013**	**21/06/2013**	**20/06/2013**	**20/06/2013**	**25/10/2011**	**25/10/2011**	**6/12/2011**	**6/12/2011**	**7/12/2011**	**29/02/2012**	**29/02/2012**	**29/02/2012**	**29/02/2012**
Analyte		**Units**	**LOR**	**ANZECC 2000 Guidelines**	**Dog Trap Creek**	**Avon River**	**Avon River**	**Avon River**	**Avon River**	**Dog Trap Creek**	**Dog Trap Creek**	**Avon River**	**Avon River**	**Avon River**	**Dog Trap Creek**	**Avon River**	**Avon River**	**Dog Trap Creek**	**Avon River**	**Avon River**
Field Parameters																				
pH		pH units	0.01	6.5 - 8.0*	7.38	6.82	6.62	7.42	7.26	7.06	6.95	7.21	6.95	7.33	7.51	7.9	6.75	7.81	5.88	6.97
Conductivity		µS/cm	1	125 - 2200*	324	161	158					588	291	297	567	271	509	848	421	481
Total Dissolved Solids		mg/L	1	-	236	199	192	306	242	342	326			0.318	0.368	0.176	0.331	0.552	0.274	0.312
Temperature		degC	0.01	-	18.66	19.02	18.06					20.56	20.75	18.28	19.52	17.22	25.59	26.23	22.95	27.86
Dissolved Oxygen		%	0.1	85 - 110	60.6	54.2	66					104.2	55.8	68.9	108.7	72.5	94.2	135	115.4	121.5
Dissolved Oxygen		mg/L	0.01	-	5.62	14.7	6.22							-	-	-	-	-	-	-
Oxidation/Reduction Potential (ORP)		no units	0.1	-	-80.4	15	139.9					-122	-114.7	-113.3	-175.6	-123.6	15.3	-19.2	28.7	12.9
Turbidity (NTU)		NTU	-	6 - 50																
Laboratory Analysis																				
Suspended Solids (SS)		mg/L	5	-																
Total Hardness as CaCO3		mg/L	1	-										56	73	56				
Silica		mg/L	0.1	-	17.8	22.1	22.1	12.7	13.1	10.1	7.34									
Fluoride		mg/L		-				0.1	0.1	<0.1	<0.1			0.1	0.1	0.1				
Sulfur		mg/L		-										2	2	2				
Sulfate as SO4 - Turbidimetric		mg/L	1	-	18	<1	<1	14	10	44	55	11	2	6	4	6	7	15	6	7
Chloride		mg/L	1	-	56	24	24	135	84	145	140	76	46	46	75	44	45	81	36	42
Alkalinity																				
Hydroxide Alkalinity as CaCO3		mg/L	1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3		mg/L	1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as CaCO3		mg/L	1	-	52	30	29	64	57	41	22	68	58	60	70	51	56	97	46	53
Total Alkalinity as CaCO3		mg/L	1	-	52	30	29	64	57	41	22	68	58	60	70	51	56	97	46	53
Dissolved Major Cations																				
Calcium		mg/L	1	-	12	5	5	15	14	16	15	12	12	11	11	11	11	16	10	11
Magnesium		mg/L	1	-	8	3	3	11	9	14	16	10	7	7	11	7	8	16	6	7
Sodium		mg/L	1	-	38	17	16	83	49	86	80	49	32	34	50	30	34	55	27	31
Potassium		mg/L	1	-	4	7	7	3	3	4	5	4	4	3	2	3	3	3	2	2
Dissolved Metals																				
Aluminium		mg/L	0.01	0.055	0.02	0.66	0.17	0.29	1.57	0.13	0.04	0.02	0.02	0.13	0.03	0.14	0.07	<0.01	0.19	0.13
Arsenic		mg/L	0.001	0.013 (as V)	<0.001	0.002	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium		mg/L	0.001	1.0	0.044	0.053	0.045	0.087	0.144	0.097	0.261	0.045	0.049	0.047	0.036	0.05	0.041	0.048	0.033	0.036
Beryllium		mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Boron		mg/L	0.05	0.37	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Bromine		mg/L	0.1	-	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.1	<0.1	0.1	0.2	0.1	<0.1	0.1	<0.1	<0.1
Cadmium	H	mg/L	0.0001	**0.0005**	0.0006	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	0.0004	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001
Cobalt		mg/L	0.001	ID	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001
Chromium		mg/L	0.001	**0.0025**				0.001	0.006	0.001	<0.001			0.004	0.003	0.003				
Copper	H	mg/L	0.001	**0.0035**	0.003	0.003	0.007					0.004	0.004				0.001	0.003	0.001	0.004
Iron		mg/L	0.05	ID	0.26	1.37	0.77	0.7	1.44	0.38	0.18	0.26	0.4	0.44	0.09	0.77	0.3	0.2	0.43	0.31
Manganese		mg/L	0.001	1.9	0.046	0.035	0.031	0.037	0.07	0.06	0.061	0.163	0.2	0.065	0.043	0.109	0.077	0.586	0.058	0.093
Molybdenum		mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	H	mg/L	0.001	**0.011**	0.002	0.002	0.003	0.002	0.01	<0.001	<0.001	0.001	0.001	0.002	0.002	0.003	0.001	0.002	0.001	<0.001
Lead	H	mg/L	0.001	**0.0136**	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Selenium		mg/L	0.01	0.011 (total)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strontium		mg/L	0.001	-	0.16	0.115	0.07	0.295	0.364	0.28	0.573	0.168	0.16	0.158	0.164	0.15	0.142	0.208	0.139	0.092
Vanadium		mg/L	0.01	ID	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc		mg/L	0.005	**0.020**	0.027	0.017	0.031	0.046	0.177	0.079	0.153	0.027	0.026	0.189	0.063	0.042	0.01	0.028	0.031	0.042
Mercury	M	mg/L	0.0001	0.0006																
Uranium		mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nutrients																				
Ammonia as N (NH3 + NH4+)		mg/L	-	-	0.03	0.02	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.06	0.01	0.05	0.06	0.01	0.06	0.14
Nitrite + Nitrate as N (NOx)		mg/L	0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	0.1									
Total Kjeldahl Nitrogen (TKN) as N		mg/L	0.1	-																
Total Nitrogen as N (TKN + NOx)		mg/L	0.1	0.35*																
Total Phosphorus as P		mg/L	0.01	0.025*	0.08	0.3	0.24	0.02	<0.01	0.03	<0.01	0.21	0.17	0.14	0.1	0.17	0.05	0.06	0.04	0.04
Reactive Phosphorous		mg/L	0.01	-	0.06	0.15	0.16	<0.01	<0.01	<0.01	<0.01	0.04	0.06	0.02	0.04	0.06	0.02	0.04	0.01	0.02
Total Organic Carbon		mg/L			9	22	31	5	4	6	6	17	12	5	10	12	8	14	6	8
Nitrite as N		mg/L	0.01	-	0.03	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrate as N		mg/L	0.01	0.7	0.03	0.02	<0.01	<0.01	<0.01	0.05	0.1	<0.01	0.03	0.09	0.06	0.03	0.05	0.02	0.06	0.06
Ionic Balance																				
Total Anions		meq/L	0.01	-	2.99	1.29	1.26	5.38	3.72	5.83	5.53									
Total Cations		meq/L	0.01	-	3.08	1.43	1.37	5.34	3.65	5.79	5.67									
Ionic Balance		%	0.01	-	1.4			0.36	0.95	0.28	1.23									

NAME AND DATE				GROUNDWATER MONITORING ROUND			GROUNDWATER MONITORING ROUND				IRRIGATION MONITORING		IRRIGATION MONITORING			IRRIGATION MONITORING			
Sample date				TSW01	ASW01	ASW02	ASW01	ASW02	TSW01	TSW02	TSW01	ASW01	TSW01	TSW02	ASW01	TSW01	TSW02	ASW01	FSW01
				7/04/2011	8/04/2011	8/04/2011	21/06/2013	21/06/2013	20/06/2013	20/06/2013	25/10/2011	25/10/2011	6/12/2011	6/12/2011	7/12/2011	29/02/2012	29/02/2012	29/02/2012	29/02/2012
Analyte	Units	LOR	ANZECC 2000 Guidelines	Dog Trap Creek	Avon River	Avon River	Avon River	Avon River	Dog Trap Creek	Dog Trap Creek	Avon River	Avon River	Avon River	Dog Trap Creek	Avon River	Avon River	Dog Trap Creek	Avon River	Avon River
C1 - C4 Hydrocarbon Gases																			
Methane	µg/L	10	65 000^				14	15	<10	<10									
Ethene	µg/L	10	-				<10	<10	<10	<10									
Ethane	µg/L	10	-				<10	<10	<10	<10									
Propene	µg/L	10	-				<10	<10	<10	<10									
Propane	µg/L	10	-				<10	<10	<10	<10									
Butene	µg/L	10	-				<10	<10	<10	<10									
Butane	µg/L	10	-				<10	<10	<10	<10									
BTEXN																			
Benzene	µg/L	1	950	<1	<1	<1	<1	<1	<1	<1	<1	<1							
Toluene	µg/L	2	ID	<5	<5	<5	<2	<2	<2	<2	<5	<5							
Ethylbenzene	µg/L	2	ID	<2	<2	<2	<2	<2	<2	<2	<2	<2							
meta- & para-Xylene	µg/L	2	ID	<2	<2	<2	<2	<2	<2	<2	<2	<2							
ortho-Xylene	µg/L	2	350	<2	<2	<2	<2	<2	<2	<2	<2	<2							
Total Xylenes	µg/L	2	-				<2	<2	<2	<2	<2	<2							
Sum of BTEX	µg/L	1	-				<1	<1	<1	<1	<1	<1							
Naphthalene	µg/L	5	16	<1.0	<1.0	<1.0	<5	<5	<5	<5	<5	<5							
Total Petroleum Hydrocarbons																			
C6 - C9 Fraction	µg/L	20	ID	<20	<20	<20	<20	<20	<20	<20	<20	<20							
C10 - C14 Fraction	µg/L	50	ID	<50	<50	<50	<50	<50	<50	<50	<50	<50							
C15 - C28 Fraction	µg/L	100	ID	<100	<100	<100	<100	<100	<100	<100	<100	<100							
C29 - C36 Fraction	µg/L	50	ID	<50	<50	<50	<50	<50	<50	<50	<50	<50							
C10 - C36 Fraction (sum)	µg/L	50	-	<50	<50	<50	<50	<50	<50	<50	<50	<50							
Total Recoverable Hydrocarbons																			
C6 - C10 Fraction	µg/L	20	ID				<20	<20	<20	<20	<20	<20							
C6 - C10 Fraction minus BTEX	µg/L	20	ID				<20	<20	<20	<20	<20	<20							
>C10 - C16 Fraction	µg/L	100	ID				<100	<100	<100	<100	<100	<100							
>C16 - C34 Fraction	µg/L	100	ID				<100	<100	<100	<100	<100	<100							
>C34 - C40 Fraction	µg/L	100	ID				<100	<100	<100	<100	<100	<100							
>C10 - C40 Fraction (sum)	µg/L	100	-				<100	<100	<100	<100	<100	<100							
Phenolic compounds																			
Phenol	µg/L	1	320	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
2-Chlorophenol	µg/L	1	490	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
2-Methylphenol	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
3-&4-Methylphenol	µg/L	2	-	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0									
2-Nitrophenol	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
2.4-Dimethylphenol	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
2.4-Dichlorophenol	µg/L	1	160	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
2.6-Dichlorophenol	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
4-Chloro-3-Methylphenol	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
2.4.6-Trichlorophenol	µg/L	1	20	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
2.4.5-Trichlorophenol	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Pentachlorophenol	µg/L	2	ID	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0									
Polycyclic aromatic hydrocarbons																			
Acenaphthylene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Acenaphthene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Fluorene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Phenanthrene	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Anthracene	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Fluoranthene	µg/L	1	ID	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Pyrene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Benz(a)anthracene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Chrysene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Benzo(b)fluoranthene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Benzo(k)fluoranthene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Benzo(a)pyrene	µg/L	0.5	ID	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5									
Indeno(1.2.3.cd)pyrene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Dibenz(a.h)anthracene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Benzo(g.h.i)perylene	µg/L	1	-	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0									
Sum of polycyclic aromatic hydrocarbons	µg/L	0.5	-				<0.5	<0.5	<0.5	<0.5									
Benzo(a)pyrene TEQ (WHO)	µg/L	0.5	-				<0.5	<0.5	<0.5	<0.5									

Guideline values

ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater a

* ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater

^ Toxicant guideline for the protection of aquaculture species

< This result is below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit) and therefor

Calculated Ammonium values have been derived from Ammonia as N

TKN values for August 2013 Irrigation monitoring have been estimated as the sum of NOx and TKN

Calculated nitrite and nitrate values have been determined using Nitrite as N and Nitrate as N values. ANZECC gu

Bold ANZECC values have been corrected for moderate water hardness

ANZECC 2000 guidelines

Values below LOR no guidelines exist
Values within guidliens
Values exceed guidelines
No guidelines to compare detected values

NAME AND DATE					IRRIGATION MONITORING				IRRIGATION MONITORING				IRRIGATION MONITORING			IRRIGATION MONITORING		
					TSW01	**TSW02**	**ASW01**	**FSW01**	**TSW01**	**TSW02**	**ASW01**	**FSW01**	**TSW01**	**TSW02**	**ASW01**	**ASW01**	**TSW02**	**TSW01**
Sample date					**18/06/2012**	**18/06/2012**	**19/06/2012**	**19/06/2012**	**10/09/2012**	**10/09/2012**	**11/09/2012**	**10/09/2012**	**6/05/2013**	**6/05/2013**	**8/05/2013**	**13/08/2013**	**13/08/2013**	**13/08/2013**
Analyte		**Units**	**LOR**	**ANZECC 2000 Guidelines**	**Avon River**	**Dog Trap Creek**	**Avon River**	**Avon River**	**Avon River**	**Dog Trap Creek**	**Avon River**	**Avon River**	**Avon River**	**Dog Trap Creek**	**Avon River**	**Avon River**	**Dog Trap Creek**	**Avon River**
Field Parameters																		
pH		pH units	0.01	6.5 - 8.0*	7.2	7.53	7.3	7.24	7.52	7.4	7	7.35	7.59	7.11	7.29	7.46	7.56	7.53
Conductivity		µS/cm	1	125 - 2200*	327	530	218	284	543	650	383	402	454	371	397	413	628	440
Total Dissolved Solids		mg/L	1	-	0.214	0.345	0.142	0.185	353	0.423	249	261	na	242	na	279	325	228
Temperature		degC	0.01	-	11.53	13.17	8.69	10.96	16.59	21.08	15.64	16.58	15.29	16.95	12.49	12.5	15.01	13.42
Dissolved Oxygen		%	0.1	85 - 110	51.6	51.7	46.1	44.7	150.1	99.6	96.3	91.3	104.3	92	48.3	14	21.6	18.6
Dissolved Oxygen		mg/L	0.01	-	-	-	-	-	14.28	8.79	9.52	8.87	-	8.87	5.15	1.48	2.17	1.91
Oxidation/Reduction Potential (ORP)		no units	0.1	-	-7.6	-10.6	18.6	20.2	-63.2	-75.2	91.1	-16.3	-156.1	-95.1	-94	1938	49.7	-10
Turbidity (NTU)		NTU	-	6 - 50												6.9	4.4	4.5
Laboratory Analysis																		
Suspended Solids (SS)		mg/L	5	-												4	3	4
Total Hardness as CaCO3		mg/L	1	-	51	64	43	58	89	128	80	89				74	95	74
Silica		mg/L	0.1	-												14.2	1.8	11.6
Fluoride		mg/L		-	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	<0.1	<0.1
Sulfur		mg/L		-	4	6	2	4	4	36	4	4						
Sulfate as SO4 - Turbidimetric		mg/L	1	-	17	27	8	17	14	124	10	14	31	48	8	8	27	12
Chloride		mg/L	1	-	53	80	35	56	88	152	69	84	72	48	72	74	132	82
Alkalinity																		
Hydroxide Alkalinity as CaCO3		mg/L	1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3		mg/L	1	-	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as CaCO3		mg/L	1	-	38	42	43	43	81	<1	88	71	50	40	74	80	76	74
Total Alkalinity as CaCO3		mg/L	1	-	38	42	43	43	81	<1	88	71	50	50	74	80	76	74
Dissolved Major Cations																		
Calcium		mg/L	1	-	9	9	9	10	16	20	17	16	12	7	16	13	15	13
Magnesium		mg/L	1	-	7	10	5	8	12	19	11	12	9	8	9	10	14	10
Sodium		mg/L	1	-	35	52	25	38	54	91	44	48	52	53	45	53	81	54
Potassium		mg/L	1	-	4	4	3	4	5	6	4	5	2	2	3	3	6	3
Dissolved Metals																		
Aluminium		mg/L	0.01	0.055	0.19	0.04	0.34	0.46	<0.01	0.04	0.02	0.01	0.05	0.07	0.02			
Arsenic		mg/L	0.001	0.013 (as V)	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium		mg/L	0.001	1.0	0.039	0.037	0.036	0.068	0.05	0.078	0.061	0.05	0.05	0.038	0.044			
Beryllium		mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			
Boron		mg/L	0.05	0.37	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05			
Bromine		mg/L	0.1	-	0.1	0.2	0.1	0.2	0.3	0.5	0.3	0.2	0.4	0.2	0.3			
Cadmium	H	mg/L	0.0001	**0.0005**	<0.0001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt		mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002			
Chromium		mg/L	0.001	**0.0025**												<0.001	<0.001	<0.001
Copper	H	mg/L	0.001	**0.0035**	0.005	0.005	0.007	0.003	0.004	0.005	0.005	0.003	0.005	0.002	<0.001	<0.001	<0.001	0.001
Iron		mg/L	0.05	ID	0.4	0.09	0.72	0.79	0.13	0.18	0.85	0.09	0.45	0.26	0.71			
Manganese		mg/L	0.001	1.9	0.035	0.034	0.037	0.096	0.137	0.373	0.194	0.112	0.106	0.083	0.078			
Molybdenum		mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001			
Nickel	H	mg/L	0.001	**0.011**	0.001	0.001	0.001	0.001	<0.001	0.002	0.001	<0.001	0.003	0.004	0.001	<0.001	0.002	<0.001
Lead	H	mg/L	0.001	**0.0136**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Selenium		mg/L	0.01	0.011 (total)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			
Strontium		mg/L	0.001	-	0.125	0.145	0.122	0.202	0.27	0.482	0.34	0.172	0.249	0.191	0.23			
Vanadium		mg/L	0.01	ID	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			
Zinc		mg/L	0.005	**0.020**	0.024	0.03	0.023	0.033	0.027	0.052	0.057	0.028	0.013	0.006	0.009	0.021	0.015	0.007
Mercury	M	mg/L	0.0001	0.0006												<0.0001	<0.0001	<0.0001
Uranium		mg/L	0.001	ID	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			
Nutrients																		
Ammonia as N (NH3 + NH4+)		mg/L	-	-	0.04	0.06	0.04	0.06	<0.01	0.06	0.02	0.22	<0.01	<0.01	0.02	0.01	0.01	0.01
Nitrite + Nitrate as N (NOx)		mg/L	0.01	0.04												0.02	0.01	0.03
Total Kjeldahl Nitrogen (TKN) as N		mg/L	0.1	-												0.3	0.8	0.5
Total Nitrogen as N (TKN + NOx)		mg/L	0.1	0.35*												*0.32*	*0.83*	*0.53*
Total Phosphorus as P		mg/L	0.01	0.025*	0.06	0.08	0.05	0.09	<0.01	0.08	<0.01	0.06	0.1	0.07	<0.01	0.02	0.03	0.03
Reactive Phosphorous		mg/L	0.01	-	0.02	0.05	0.01	0.02	<0.01	0.03	0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01
Total Organic Carbon		mg/L			13	12	14	13	9	9	7	9	9	12	3	5	9	5
Nitrite as N		mg/L	0.01	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nitrate as N		mg/L	0.01	0.7	0.06	0.14	0.02	0.11	<0.01	<0.01	0.02	<0.01	0.02	<0.01	<0.01	0.02	0.01	0.03
Ionic Balance																		
Total Anions		meq/L	0.01	-												3.85	5.8	4.04
Total Cations		meq/L	0.01	-												3.85	5.58	3.9
Ionic Balance		%	0.01	-												<0.01	2	1.83

NAME AND DATE					IRRIGATION MONITORING				IRRIGATION MONITORING				IRRIGATION MONITORING			IRRIGATION MONITORING		
					TSW01	TSW02	ASW01	FSW01	TSW01	TSW02	ASW01	FSW01	TSW01	TSW02	ASW01	ASW01	TSW02	TSW01
Sample date					18/06/2012	18/06/2012	19/06/2012	19/06/2012	10/09/2012	10/09/2012	11/09/2012	10/09/2012	6/05/2013	6/05/2013	8/05/2013	13/08/2013	13/08/2013	13/08/2013
Analyte		Units	LOR	ANZECC 2000 Guidelines	Avon River	Dog Trap Creek	Avon River	Avon River	Avon River	Dog Trap Creek	Avon River	Avon River	Avon River	Dog Trap Creek	Avon River	Avon River	Dog Trap Creek	Avon River
C1 - C4 Hydrocarbon Gases																		
Methane		µg/L	10	65 000^														
Ethene		µg/L	10	-														
Ethane		µg/L	10	-														
Propene		µg/L	10	-														
Propane		µg/L	10	-														
Butene		µg/L	10	-														
Butane		µg/L	10	-														
BTEXN																		
Benzene		µg/L	1	950					<1	<1	<1	<1	<1	<1	<1			
Toluene		µg/L	2	ID					<2	<2	<2	<2	<2	<2	<2			
Ethylbenzene		µg/L	2	ID					<2	<2	<2	<2	<2	<2	<2			
meta- & para-Xylene		µg/L	2	ID					<2	<2	<2	<2	<2	<2	<2			
ortho-Xylene		µg/L	2	350					<2	<2	<2	<2	<2	<2	<2			
Total Xylenes		µg/L	2	-					<2	<2	<2	<2	<2	<2	<2			
Sum of BTEX		µg/L	1	-					<1	<1	<1	<1	<1	<1	<1			
Naphthalene		µg/L	5	16					<5	<5	<5	<5	<5	<5	<5			
Total Petroleum Hydrocarbons																		
C6 - C9 Fraction		µg/L	20	ID					<20	<20	<20	<20	<20	<20	<20			
C10 - C14 Fraction		µg/L	50	ID					<50	<50	<50	<50	<50	<50	<50			
C15 - C28 Fraction		µg/L	100	ID					<100	<100	<100	<100	<100	<100	<100			
C29 - C36 Fraction		µg/L	50	ID					<50	<50	<50	<50	<50	<50	<50			
C10 - C36 Fraction (sum)		µg/L	50	-					<50	<50	<50	<50	<50	<50	<50			
Total Recoverable Hydrocarbons																		
C6 - C10 Fraction		µg/L	20	ID					<20	<20	<20	<20	<20	<20	<20			
C6 - C10 Fraction minus BTEX		µg/L	20	ID					<20	<20	<20	<20	<20	<20	<20			
>C10 - C16 Fraction		µg/L	100	ID					<100	<100	<100	<100	<100	<100	<100			
>C16 - C34 Fraction		µg/L	100	ID					<100	<100	<100	<100	<100	<100	<100			
>C34 - C40 Fraction		µg/L	100	ID					<100	<100	<100	<100	<100	<100	<100			
>C10 - C40 Fraction (sum)		µg/L	100	-					<100	<100	<100	<100	<100	<100	<100			
Phenolic compounds																		
Phenol		µg/L	1	320									<1.0	<1.0	<1.0			
2-Chlorophenol		µg/L	1	490									<1.0	<1.0	<1.0			
2-Methylphenol		µg/L	1	-									<1.0	<1.0	<1.0			
3-&4-Methylphenol		µg/L	2	-									<2.0	<2.0	<2.0			
2-Nitrophenol		µg/L	1	ID									<1.0	<1.0	<1.0			
2.4-Dimethylphenol		µg/L	1	ID									<1.0	<1.0	<1.0			
2.4-Dichlorophenol		µg/L	1	160									<1.0	<1.0	<1.0			
2.6-Dichlorophenol		µg/L	1	ID									<1.0	<1.0	<1.0			
4-Chloro-3-Methylphenol		µg/L	1	-									<1.0	<1.0	<1.0			
2.4.6-Trichlorophenol		µg/L	1	20									<1.0	<1.0	<1.0			
2.4.5-Trichlorophenol		µg/L	1	ID									<1.0	<1.0	<1.0			
Pentachlorophenol		µg/L	2	ID									<2.0	<2.0	<2.0			
Polycyclic aromatic hydrocarbons																		
Acenaphthylene		µg/L	1	-									<1.0	<1.0	<1.0			
Acenaphthene		µg/L	1	-									<1.0	<1.0	<1.0			
Fluorene		µg/L	1	-									<1.0	<1.0	<1.0			
Phenanthrene		µg/L	1	ID									<1.0	<1.0	<1.0			
Anthracene		µg/L	1	ID									<1.0	<1.0	<1.0			
Fluoranthene		µg/L	1	ID									<1.0	<1.0	<1.0			
Pyrene		µg/L	1	-									<1.0	<1.0	<1.0			
Benz(a)anthracene		µg/L	1	-									<1.0	<1.0	<1.0			
Chrysene		µg/L	1	-									<1.0	<1.0	<1.0			
Benzo(b)fluoranthene		µg/L	1	-									<1.0	<1.0	<1.0			
Benzo(k)fluoranthene		µg/L	1	-									<1.0	<1.0	<1.0			
Benzo(a)pyrene		µg/L	0.5	ID									<0.5	<0.5	<0.5			
Indeno(1.2.3.cd)pyrene		µg/L	1	-									<1.0	<1.0	<1.0			
Dibenz(a.h)anthracene		µg/L	1	-									<1.0	<1.0	<1.0			
Benzo(g.h.i)perylene		µg/L	1	-									<1.0	<1.0	<1.0			
Sum of polycyclic aromatic hydrocarbons		µg/L	0.5	-														
Benzo(a)pyrene TEQ (WHO)		µg/L	0.5	-														

Guideline values

ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater a

* ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater

^ Toxicant guideline for the protection of aquaculture species

< This result is below the Minimum Detectable Activity (MDA) and Limit of Quantification (Quant Limit) and therefor

Calculated Ammonium values have been derived from Ammonia as N

TKN values for August 2013 Irrigation monitoring have been estimated as the sum of NOx and TKN

Calculated nitrite and nitrate values have been determined using Nitrite as N and Nitrate as N values. ANZECC gui

Bold ANZECC values have been corrected for moderate water hardness

ANZECC 2000 guidelines

Values below LOR no guidelines exist
Values within guidlienes
Values exceed guidelines
No guidelines to compare detected values

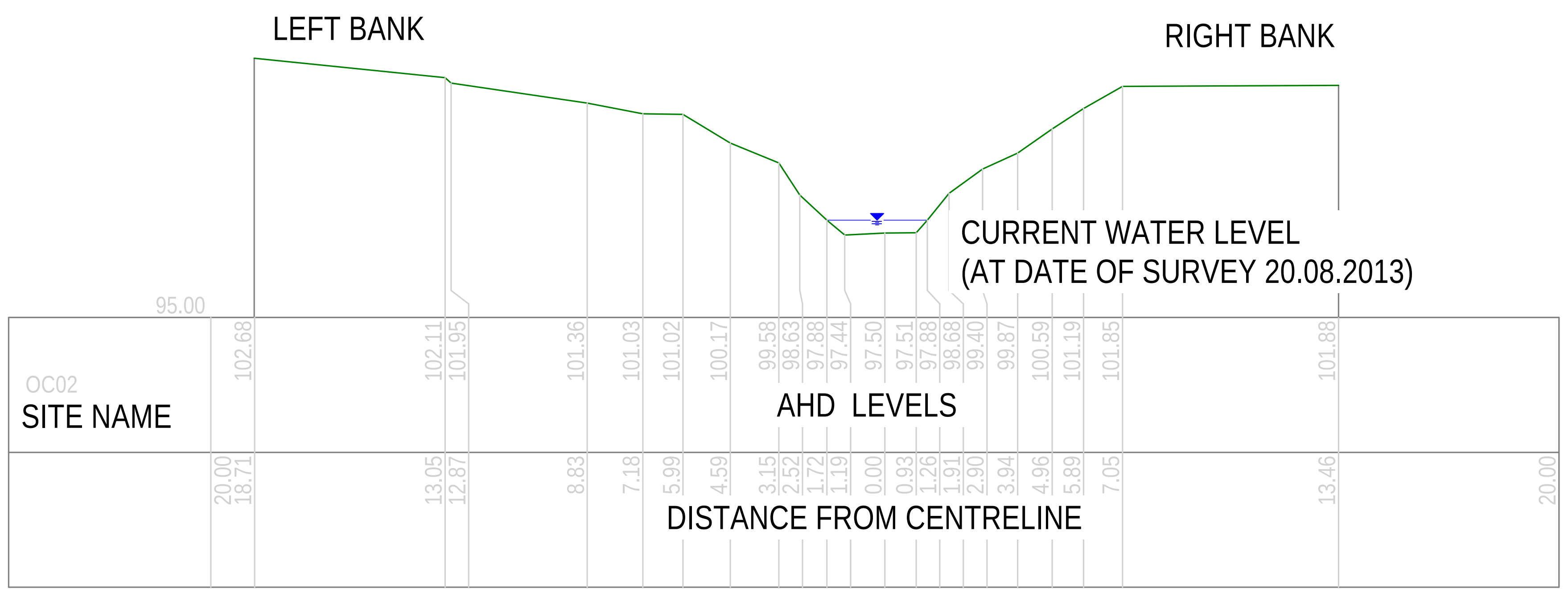
Appendix F

Riverbed survey cross sections

HYDROLOGY STUDY
OF THE GLOUCESTER BASIN
SITE CROSS SECTIONS

SHT 1 - WC01, WC02, WC03
SHT 2 - TSW01, TSW02, ASW01, ASW02
SHT 3 - ADC01, ADC02, ADC03, DTC01, DTC02, DTC03, DTC04
SHT 4 - AR01, AR02, AR03, AR04, OC01, OC02
SHT 5 - TT01, TT02, TT03
SHT 6 - GRL01, GRL02, GRL03, GRL04
SHT 7 - WR01

TYPICAL CROSS SECTION



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PROJECT - HYDROLOGY STUDY OF THE GLOUCESTER BASIN

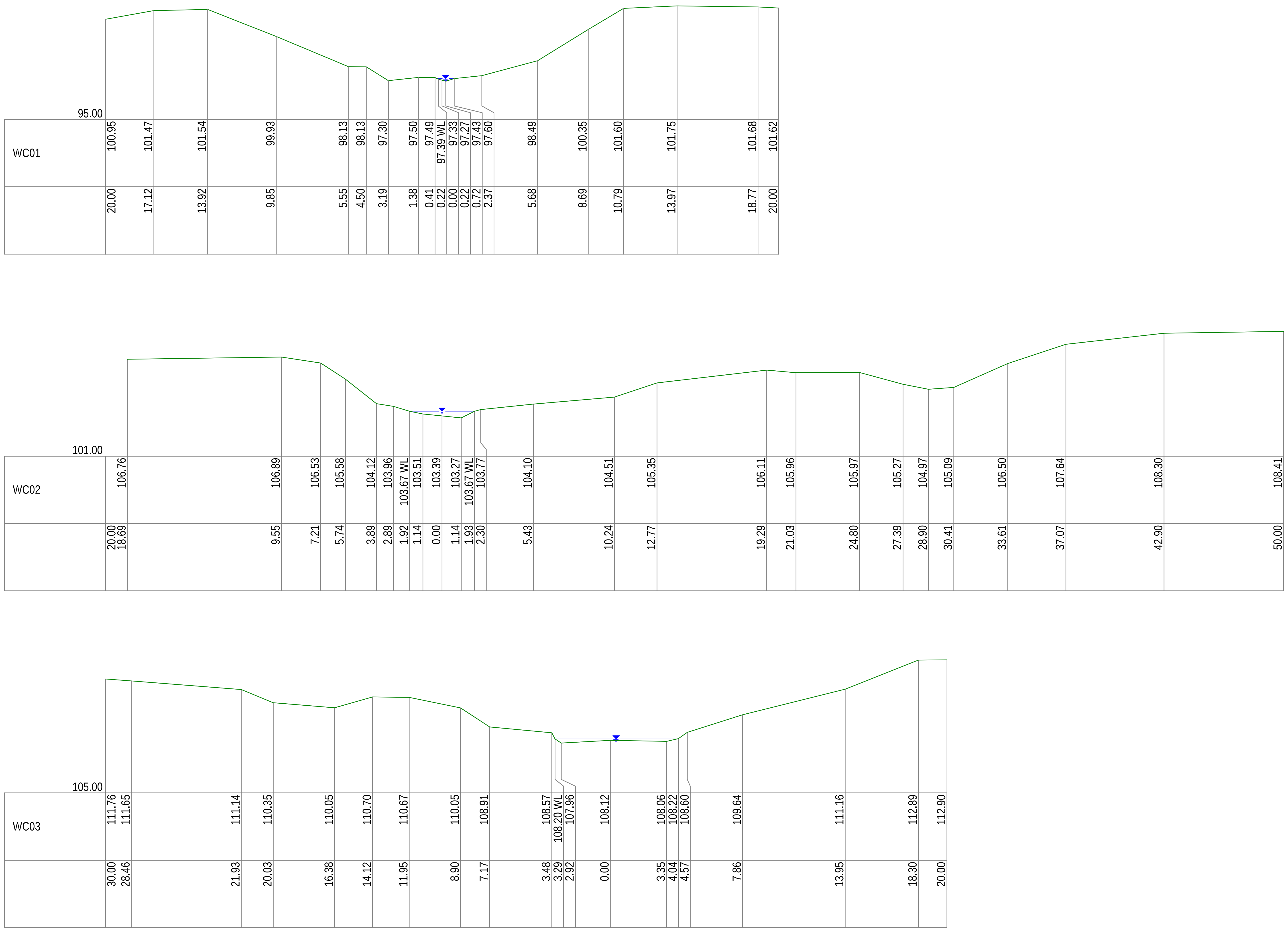
CLIENT - AGL UPSTREAM INVESTMENTS P/L

SITE CROSS SECTIONS

JOB No. 2456 _4

DWG No. DWG2456 _4

AMENDMENTS	DATE	BY	AMENDMENTS	DATE	BY



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CLIENT - AGL UPSTREAM INVESTMENTS P/L

SITE CROSS SECTIONS

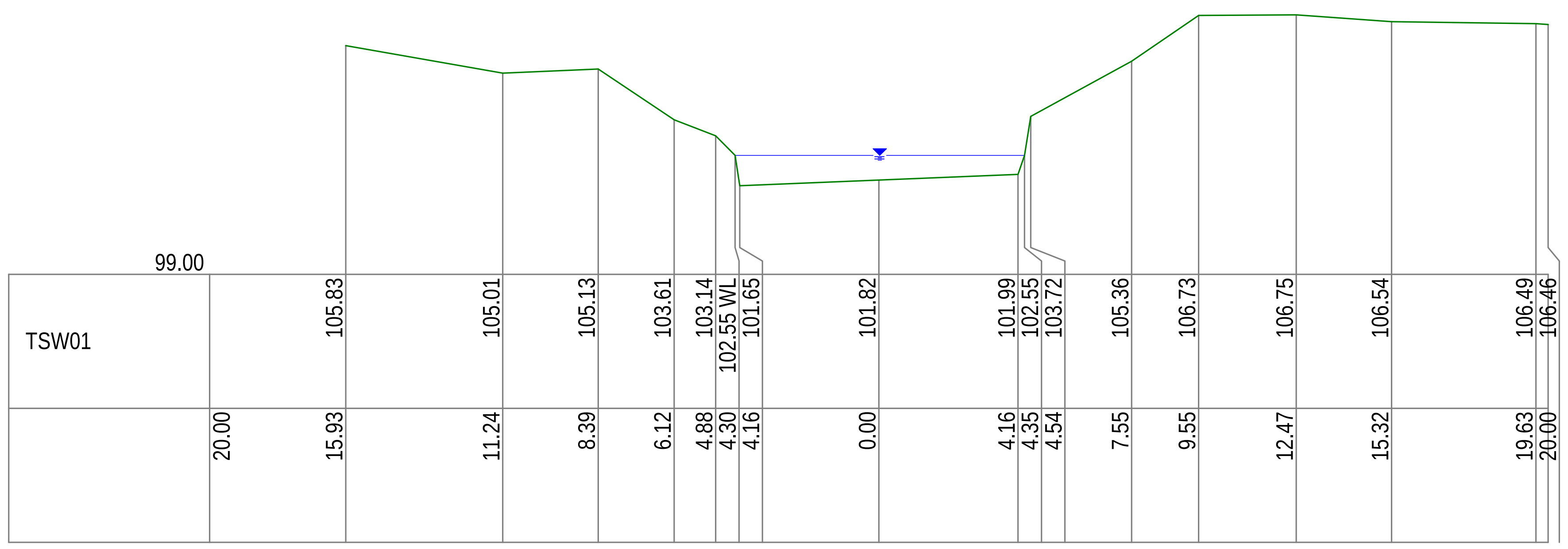
SHEET 1

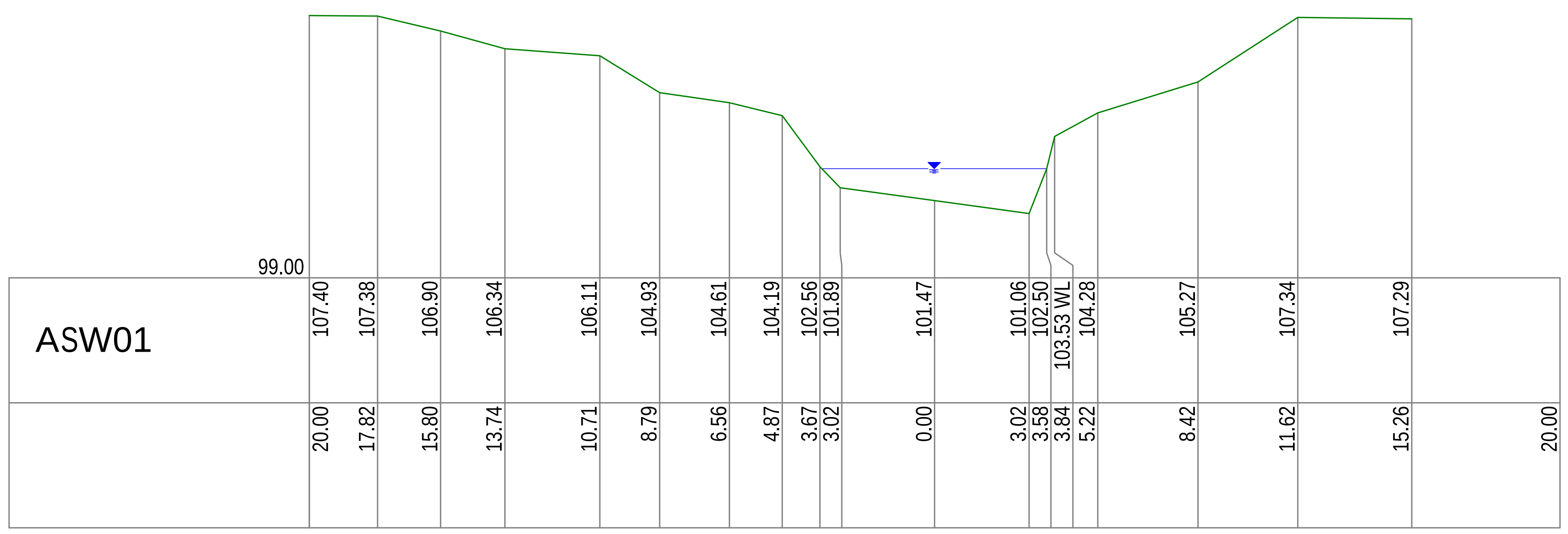
SCALE - AS SHOWN
DATUM - AHD
DATE - 4/09/2013

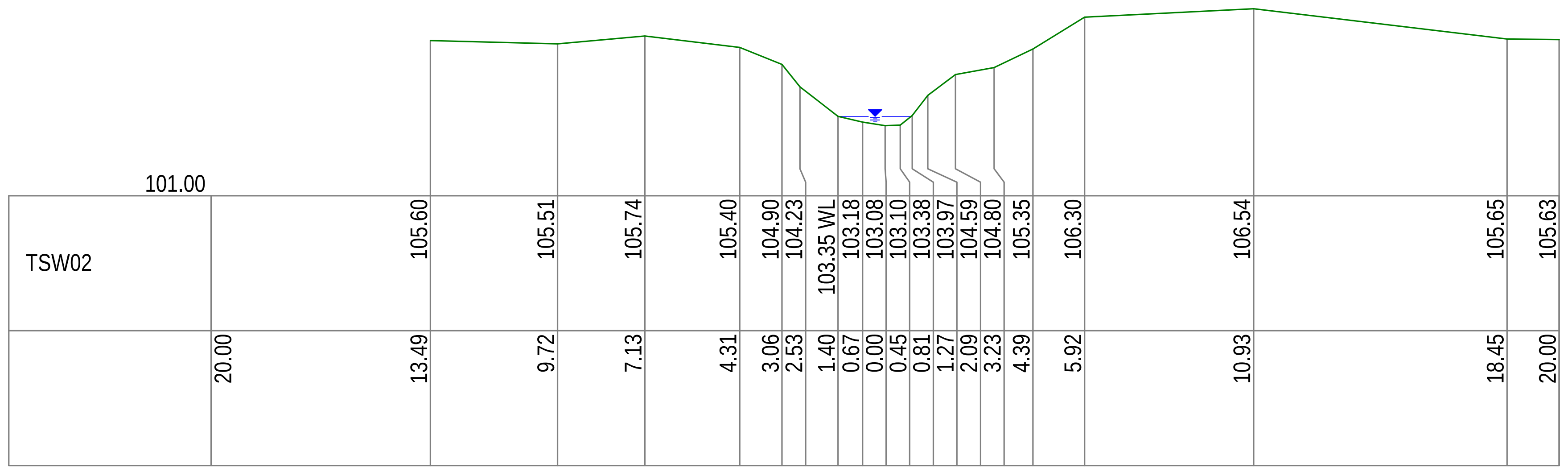
JOB No. 2456 _4

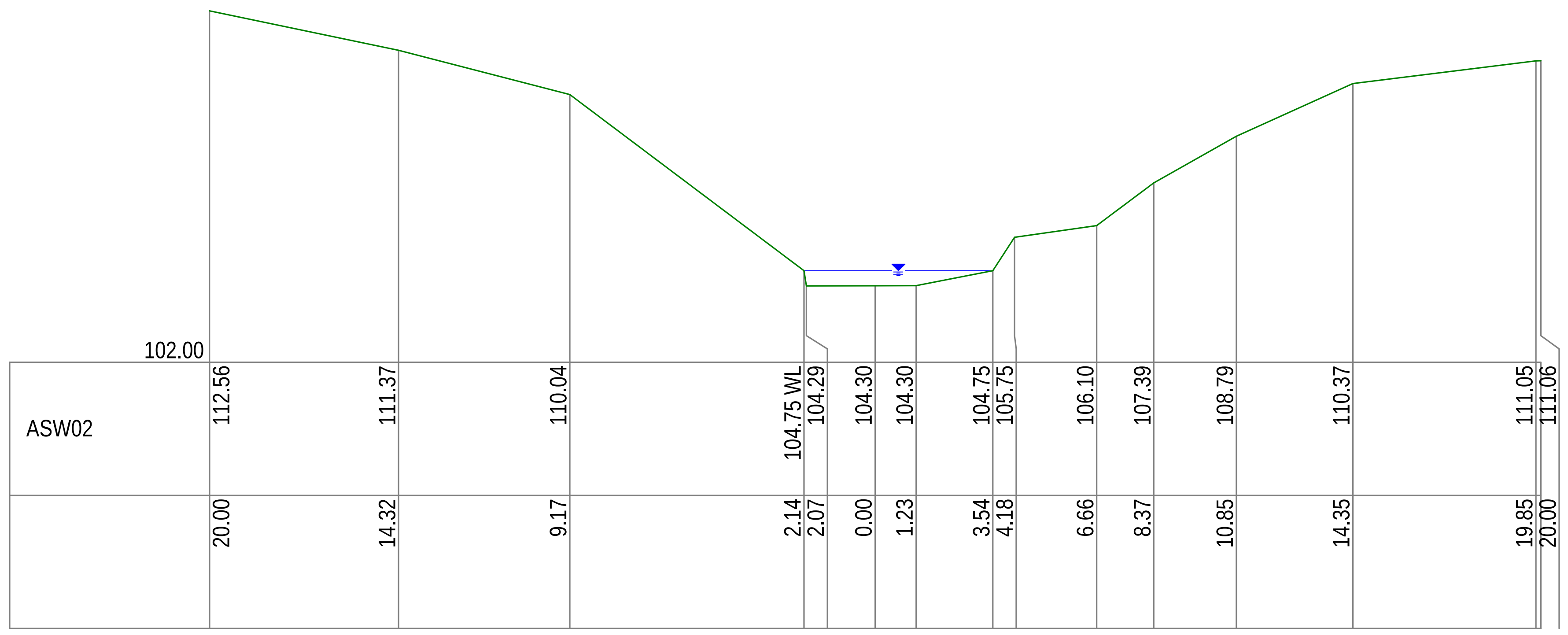
DWG No. DWG2456 _4

AMENDMENTS	DATE	BY	AMENDMENTS	DATE	BY









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CLIENT - AGL UPSTREAM INVESTMENTS P/L

SITE CROSS SECTIONS

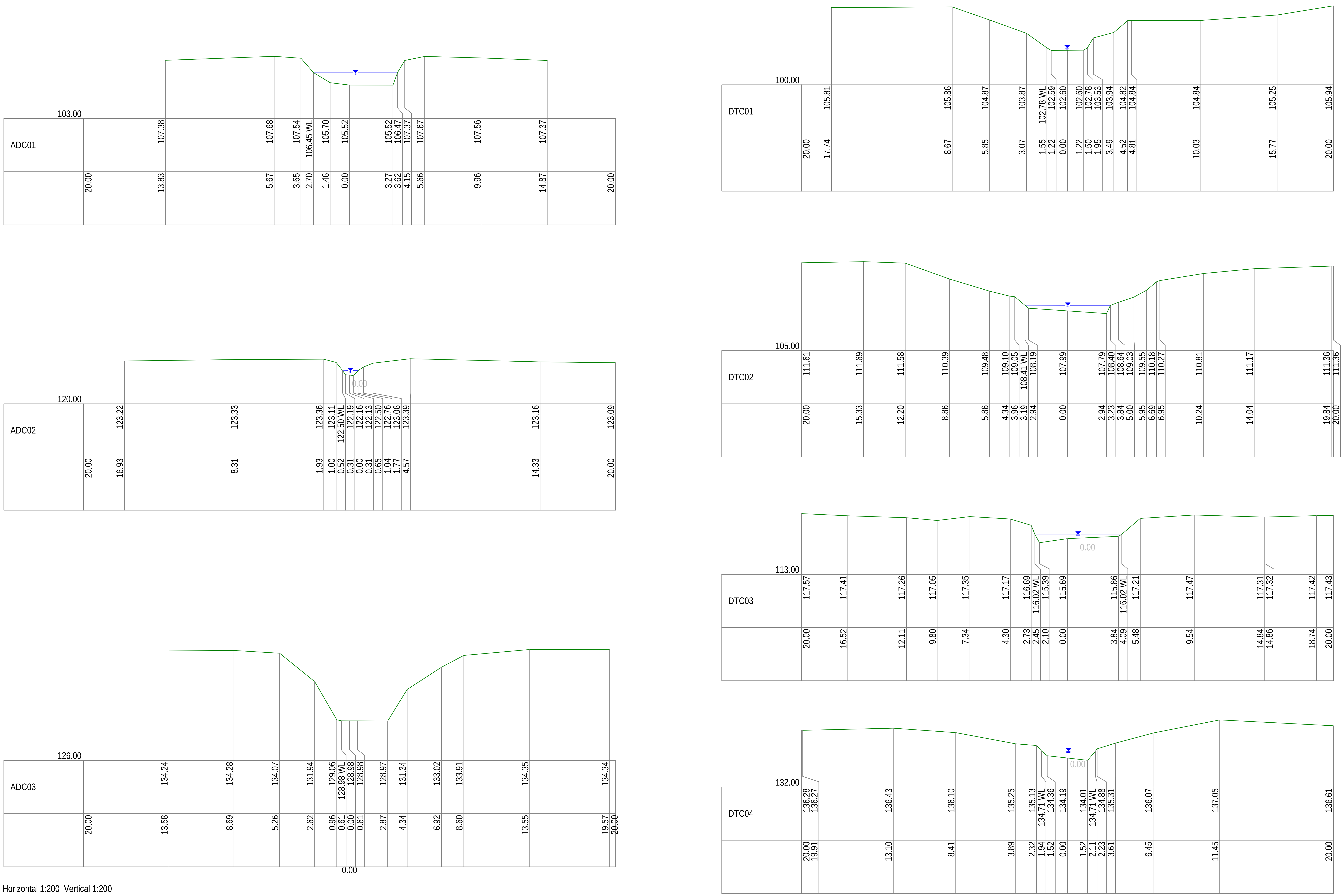
SHEET 2

SCALE - AS SHOWN
DATUM - AHD
DATE - 4/09/2013

JOB No. 2456 _4

DWG No. DWG2456 _4

AMENDMENTS	DATE	BY	AMENDMENTS	DATE	BY



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SITE CROSS SECTIONS

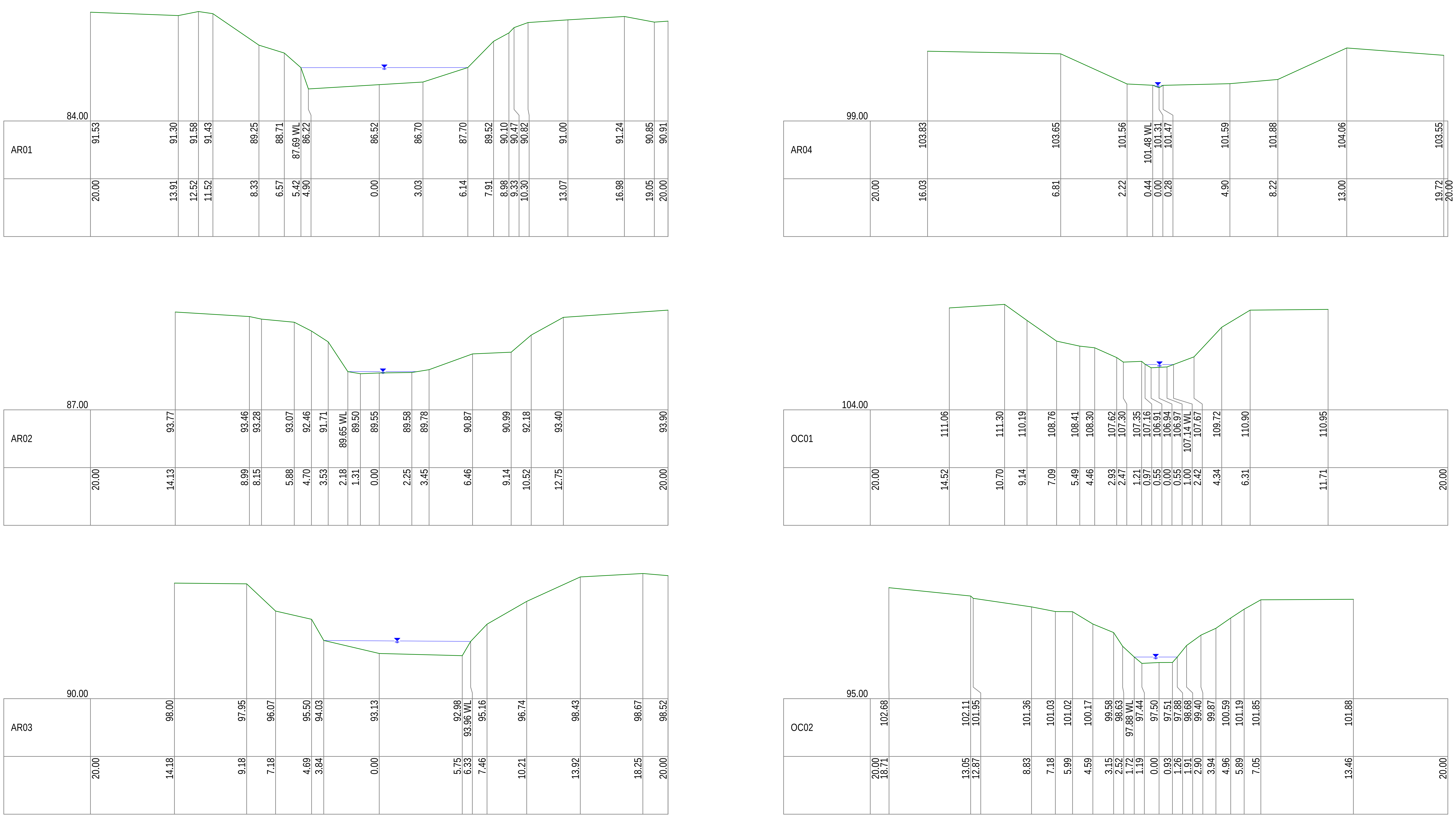
SHEET 3

SCALE - AS SHOWN
DATUM - AHD
DATE - 4/09/2013

JOB No. 2456_4

DWG No. DWG2456_4

AMENDMENTS	DATE	BY	AMENDMENTS	DATE	BY



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SITE CROSS SECTIONS

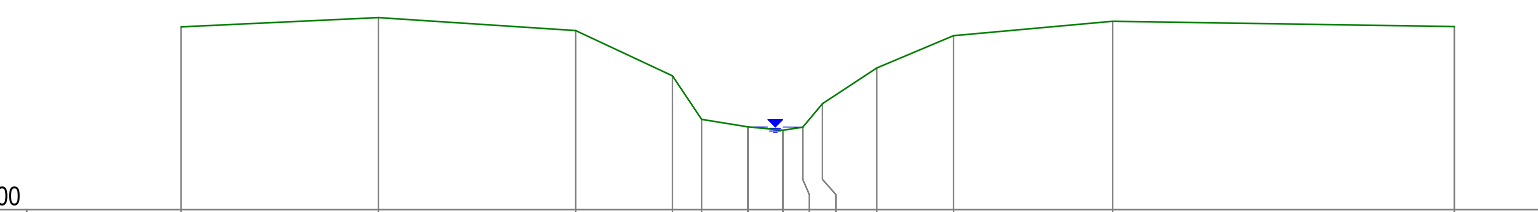
SHEET 4

SCALE - AS SHOWN
DATUM - AHD
DATE - 4/09/2013

JOB No. 2456 _4

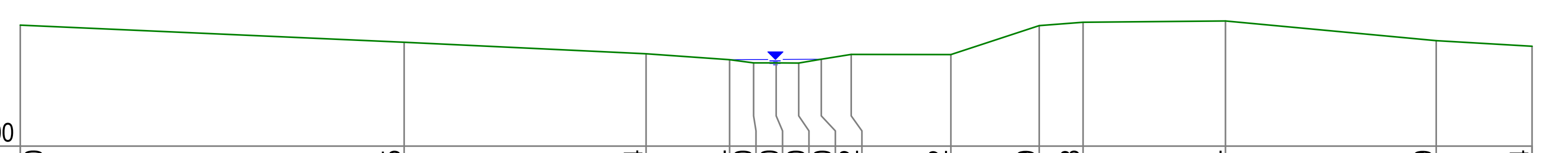
DWG No. DWG2456 _4

AMENDMENTS	DATE	BY	AMENDMENTS	DATE	BY



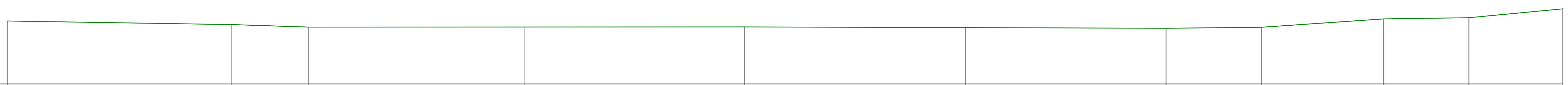
98.00

TT01															
	102.83	103.08	102.74	101.54	100.39	100.19 WL	100.10	100.18	100.81	101.75	102.60	102.99	102.84		
	20.00	15.92	10.70	5.48	2.92	2.15	0.92	0.00	0.52	1.04	2.48	4.51	8.72	17.76	20.00



112.00

TT02															
	115.20	114.75	114.44	114.28 WL	114.20	114.20	114.20	114.30	114.42	114.42	115.19	115.28	115.31	114.79	114.64
	20.00	9.84	3.44	1.23	0.60	0.00	0.60	1.19	1.99	4.62	6.96	8.12	11.89	17.46	20.00



119.00

TT03												
	122.18	122.00	121.87	121.88	121.88	121.85	121.82	121.87	122.29	122.35	122.80	
	50.00	48.12	36.84	32.98	22.16	11.08	0.00	10.08	14.87	21.01	25.29	30.00

Scale Horizontal 1:200 Vertical 1:200

Scale Horizontal 1:200 Vertical 1:200

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CLIENT - AGL UPSTREAM INVESTMENTS P/L

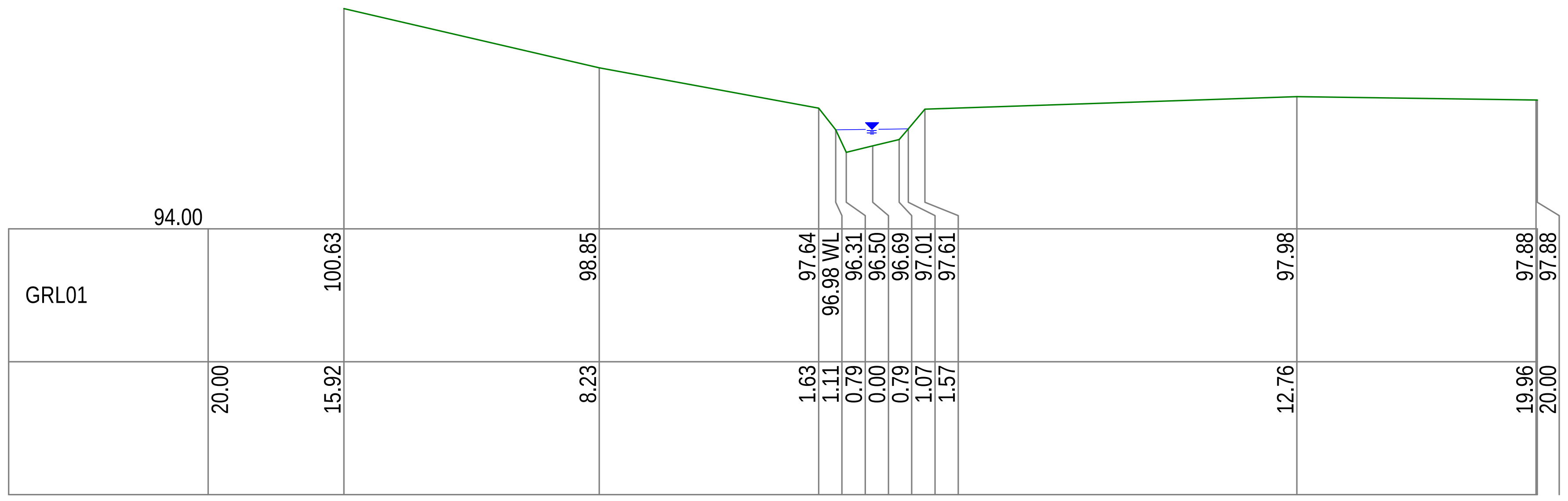
SITE CROSS SECTIONS

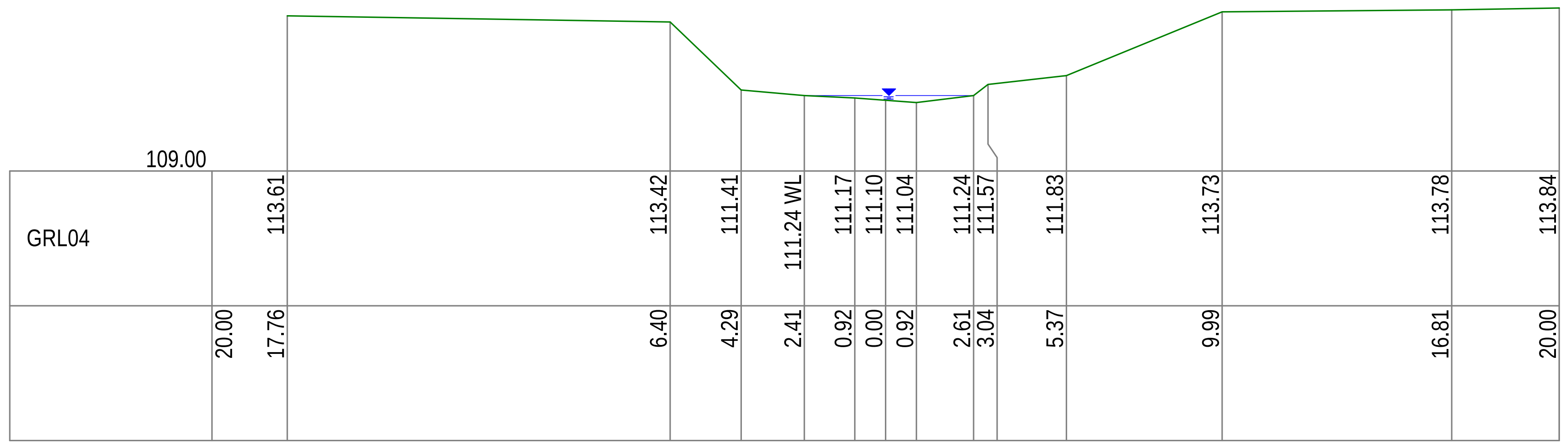
SHEET 5

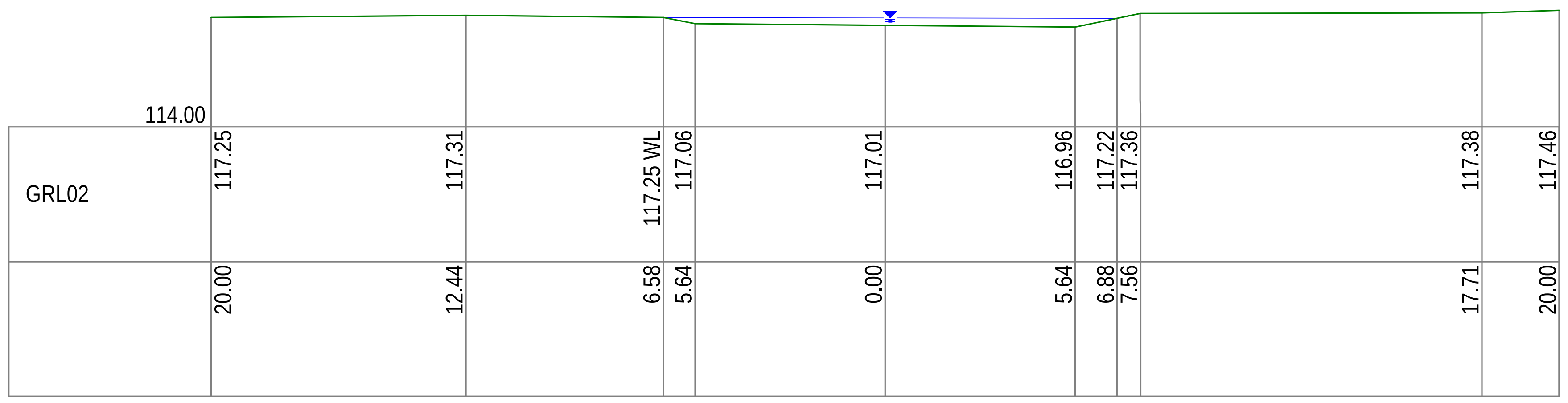
SCALE - AS SHOWN
DATUM - AHD
DATE - 4/09/2013

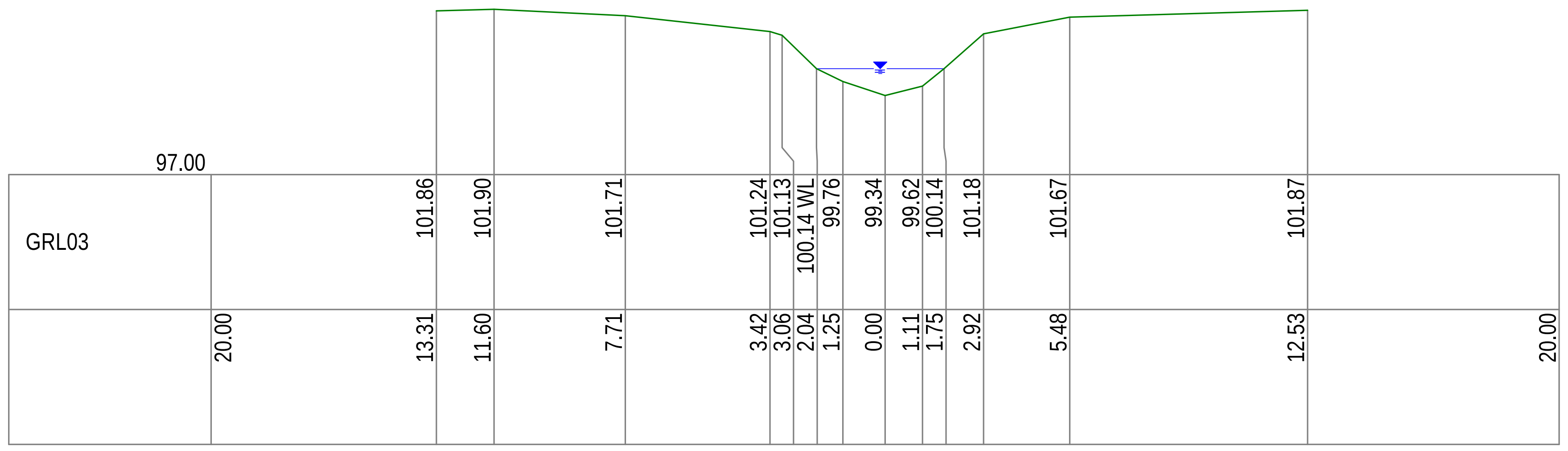
JOB No. 2456 _4
DWG No. DWG2456 _4

AMENDMENTS	DATE	BY	AMENDMENTS	DATE	BY









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SITE CROSS SECTIONS

SHEET 6

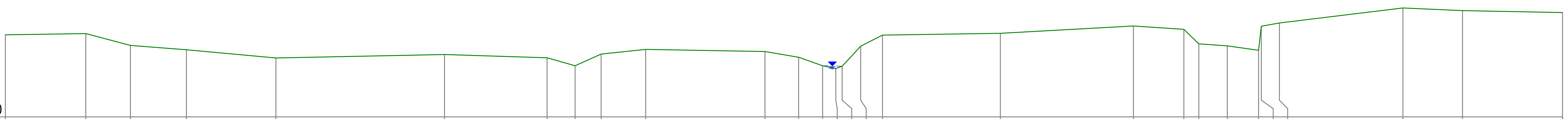
SCALE - AS SHOWN
DATUM - AHD
DATE - 4/09/2013

JOB No. 2456 _4

DWG No. DWG2456 _4

AMENDMENTS	DATE	BY	AMENDMENTS	DATE	BY

85.00



WR01																												
	88.93	88.99	88.42	88.22	87.82	87.99	87.83	87.45	88.01	88.23	88.13	87.86	87.45 WL	87.32	87.43	88.39	88.92	89.00	89.36	89.20	88.50	88.41	88.19	89.34	89.50	90.22	90.09	90.00
	40.00	36.13	33.98	31.28	26.97	18.85	13.91	12.56	11.30	9.16	3.42	1.79	0.64	0.00	0.30	1.20	2.24	7.92	14.33	16.76	17.48	18.85	20.36	20.49	21.36	27.31	30.18	35.00

Scale Horizontal 1:200 Vertical 1:200

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SITE CROSS SECTIONS

SHEET 7

SCALE - AS SHOWN
DATUM - AHD
DATE - 4/09/2013

JOB No. 2456 _4

DWG No. DWG2456 _4

AMENDMENTS	DATE	BY	AMENDMENTS	DATE	BY