Gloucester Gas Project – Extracted Water Management Strategy

Final

Date: 1 February 2016

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Document Revision History

Date	Version	Author	Comment
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Glossary and Abbreviations

GLOSSARY

Alluvium
Unconsolidated sediments (clays, sands, gravels and other materials) deposited by flowing water. Deposits can be made by streams on river beds, floodplains, and alluvial fans.

Alluvial aquifer
Permeable zones that store and produce groundwater from unconsolidated alluvial sediments. Shallow alluvial aquifers are generally unconfined aquifers.

Aquifer[1]
Rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water.

Aquifer (DPI Water)[2]
(i) means a geological structure or formation, or an artificial landfill, that is permeated with water or is capable of being permeated with water
(ii) has the same meaning as (DPI Water's) groundwater system and includes low yielding and saline systems.

Aquitard
A low-permeability unit that can store groundwater and also transmit it slowly from one aquifer to another. Aquitards retard but do not prevent the movement of water to or from an adjacent aquifer.

Bore
A structure drilled below the surface to obtain water from an aquifer or series of aquifers.

Coal
A sedimentary rock derived from the compaction and consolidation of vegetation or swamp deposits to form a fossilised carbonaceous rock.

Coal seam
A layer of coal within a sedimentary rock sequence.

Coal seam gas (CSG)
Coal seam gas is a form of natural gas (predominantly methane) that is extracted from coal seams.

[1] This is a common and widely used definition of an aquifer that is used throughout this EWMS

[2] (i) NSW Water Management Act (2000) definition, and (ii) NSW Aquifer Interference Policy definition

Contamination	Contamination is the presence of a non-natural compound in soil or water, or unwanted compound in chemicals or other mixtures.
Desalinated Water	Desalinated water is the same as treated water. It is extracted water that has been through all the processes and conditioning at the water treatment plant and is suitable for a large range of beneficial uses.
Discharge	The volume of water flowing in a stream or through an aquifer past a specific point in a given period of time.
Electrical Conductivity (EC)	A measure of a fluid's ability to conduct an electrical current and is an estimation of the total ions dissolved. It is often used as a measure of water salinity.
Extracted Water	For the purpose of this EWMS, extracted water is the collective term for both flowback water and produced water.
Fracture stimulation	A stimulation technique that increases a gas well's productivity by creating a pathway into the targeted coal seam by injecting sand and fluids through the perforated interval directly into the coal seam under high pressure.
Flowback	The process of allowing fluids to flow from a gas well following a treatment, either in preparation for exploration testing, a subsequent phase of treatment / workover, or in preparation for returning the well to production.
Flowback water	The return to surface of fracture stimulation fluids before transition to natural formation water (groundwater), after which water flowing from the well is termed produced water.
Fractured rock aquifer	Aquifers that occur in sedimentary, igneous and metamorphosed rocks which have been subjected to disturbance, deformation, or weathering, and which allow water to move through joints, bedding planes, fractures and faults. Although fractured rock aquifers are found over a wide area, they generally contain much less groundwater than alluvial and porous sedimentary aquifers.
General Solid Waste (non-putrescible)	Non-putrescible general solid waste as defined in the NSW EPA Waste Classification Guidelines: Part 1 Classifying Waste – November 2014

Groundwater	The water contained in interconnected pores or fractures located below the water table in an unconfined aquifer or located at depth in a confined aquifer or water bearing zone.
Groundwater system	A system that is hydrogeologically more similar than different in regard to geological province, hydraulic characteristics and water quality, and may consist of one or more geological formations.
Groundwater system (DPI Water)[3]	Groundwater is all water that occurs beneath the ground surface in the saturated zone. A groundwater system is any type of saturated geological formation that can yield anywhere from low to high volumes of groundwater.
Hydraulic fracturing	A technique that increases the productivity of a gas well by creating a pathway into the targeted coal seam by injecting sand and fluids through the perforated interval directly into the coal seam under high pressure.
MicroSiemens per centimetre (µS/cm)	A measure of water salinity commonly referred to as EC (see also Electrical Conductivity). Most commonly measured in the field with calibrated field meters.
Monitoring bore	A non-pumping bore, is generally of small diameter that is used to measure the elevation of the water table and/or water quality. Bores generally have a short well screen against a single aquifer through which water can enter.
P10, P50 and P90 estimates	Probability estimates that the water production profile (or rainfall pattern) will have: (i) a 10% chance of being less than forecast (P10) (ii) a 50:50 chance of being less than or greater than forecast (P50) (iii) a 90% chance of being less than forecast (P90)
pH	The potential of Hydrogen; the logarithm of the reciprocal of hydrogen-ion concentration in gram atoms per litre; provides a measure on a scale from 0 to 14 of the acidity or alkalinity of a

[3] Definitions from NSW Aquifer Interference Policy

solution (where 7 is neutral, greater than 7 is alkaline and less than 7 is acidic).

Produced water	Water that is taken in the course of a prospecting operation that is part of, or incidental to, that prospecting operation, including water that is encountered within and extracted from boreholes, petroleum wells or excavations.
Recharge	The process which replenishes groundwater, usually by rainfall infiltrating from the ground surface to the water table and by river water reaching the water table or exposed aquifers. The addition of water to an aquifer.
Salinity	The concentration of dissolved salts in water, usually expressed in EC units or milligrams of total dissolved solids per litre (mg/L TDS).
Salinity classification	***Freshwater quality –*** water with a salinity <800 µS/cm. ***Marginal water quality –*** water that is more saline than freshwater and generally waters between 800 and 1,600 µS/cm. ***Brackish quality –*** water that is more saline than freshwater and generally waters between 1,600 and 4,800 µS/cm. ***Slightly saline quality –*** water that is more saline than brackish water and generally waters with a salinity between 4,800 and 10,000 µS/cm. ***Moderately saline quality*** – water that is more saline than slightly saline water and generally waters between 10,000 and 20,000 µS/cm. ***Saline quality*** – water that is almost as saline as seawater and generally waters with a salinity greater than 20,000 µS/cm. ***Seawater quality*** – water that is generally around 55,000 µS/cm.
Sandstone	Sandstone is a sedimentary rock composed mainly of sand-sized minerals or rock grains (predominantly quartz).
Sedimentary rock aquifer	These occur in consolidated sediments such as porous sandstones and conglomerates, in which water is stored in the intergranular pores, and limestone, in which water is stored in solution cavities and joints. These aquifers are generally located in sedimentary basins that are continuous over large areas and may be tens or hundreds of metres thick. In terms of quantity, they contain the largest volumes of groundwater.
SAR	Sodium Adsorption Ratio is a measure of the suitability of water for use in agricultural irrigation, as determined by the

concentrations of certain metals dissolved in the water. It is a ratio of sodium to calcium and magnesium ions, and if the ratio is elevated, water can affect the structure of some soil types.

Source Water — In this report, this term is used to define raw water that is used for fracture stimulation programs. The raw water can be either freshwater or brackish produced water.

Standing water level (SWL) — The height to which groundwater rises in a bore after it is drilled and completed, and after a period of pumping when levels return to natural atmospheric or confined pressure levels.

Target criteria — The water quality criteria that is being adopted for treated water for all beneficial uses and stream discharges.

Threshold criteria — The water quality criteria (based on established guidelines or site specific data) that is acceptable for different uses or different receptors.

Total dissolved solids — A measure of the total dissolved ions in water. It is often used (with EC) as a measure of water salinity.

Treated water — Treated water is the same as desalinated water. It is extracted water that has been through all the processes and conditioning at the water treatment plant and is suitable for a large range of beneficial uses.

Water bearing zone — Geological strata that are saturated with groundwater but not of sufficient permeability to be called an aquifer.

Water quality — Term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Water table — The top of an unconfined aquifer. It is at atmospheric pressure and indicates the level below which soil and rock are saturated with water.

Well — Pertaining to a gas exploration well or gas production well.

Working water — Water that has been treated at the WTP and is suitable for return to the field for drilling, fracture stimulation and well workover purposes.

Workover — Downhole refurbishment and/or clean out of a gas well to establish/re-establish gas flows.

ABBREVIATIONS

ADWG	Australian Drinking Water Guidelines
AGL	AGL Upstream Infrastructure Investments Pty Ltd
AI	Aquifer Interference
ANZECC	Australian and New Zealand Environmental Conservation Council
ASR	Aquifer Storage and Recovery
AWG	(Gloucester Councils) Agricultural Working Group
BMP	Brine Management Plan
BST	Brine storage tank
BTEX	Benzene. Toluene, Ethyl benzene and Xylenes
BTP	Brine treatment plant
bbl/d	Barrels per day
CoP	Code of Practice
CSE	Chief Scientist and Engineer
CSG	Coal seam gas
CPF	Central processing facility
DAF	Dissolved air flotation
DEC	Department of Environment and Conservation (now EPA) (NSW)
DECCW	Department of Environment Conservation, Climate Change and Water (now EPA) (NSW)
DEHP	Department of Environment and Protection (DEHP) (Qld)
DF	Disc filtration
DII	Department of Industry and Investments (now DoI) (NSW)

DoE	Department of the Environment (Cth)
DoI	Department of Industry, Skills and Regional Development (NSW)
DoTI	Department of Trade and Investment (now DoI) (NSW)
DPE	Department of Planning and Environment (NSW)
DPI	Department of Primary Industries (NSW)
DRE	Division of Resources and Energy (NSW) within DoI
DWP	Discharge water pond
EA	Environmental Assessment
EPA	Environment Protection Authority
EP&A Act	Environmental Planning and Assessment Act 1979 (NSW)
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999 (Cth)
EPC	Engineering, procurement and construction (contract)
EPL	Environment Protection Licence
EWMS	Extracted Water Management Strategy (required under Condition 3.12 of the Part 3A approval)
FSMP	Fracture stimulation management plan
FEED	Front End Engineering Design
GRL	Gloucester Resources Ltd
GFDA	Gas field development area
GGP	Gloucester Gas Project
GMP	Groundwater Monitoring Program
GMMP	Groundwater Monitoring and Modelling Plan (this is the Groundwater Monitoring Program required under Condition 4.1 of the Part 3A approval)

GSC	Gloucester Shire Council
GSW	General Solid Waste
ha	Hectares
IMP	Irrigation Management Plan
HCRCMA	Hunter Central Rivers Catchment Management Authority (now HLLS)
HLLS	Hunter Local Land Services
IX	Ion exchange
km	Kilometre
km^2	Square kilometres
m	Metre
MEAB	Monoethanolamine Borate
mm	Millimetres
MCW	MidCoast Water
mg/L	Milligrams per litre
ML	Megalitre
ML/d	Megalitres per day
ML/yr	Megalitres per year
Mt	Megatonnes
NGSF	Newcastle Gas Storage Facility
NOW	NSW Office of Water (now DPI Water)
OCSG	Office of Coal Seam Gas (NSW) within DRE
OWS	Oily water separator
P10	Probability estimate that has a 10% chance of being less than forecast

P50	Probability estimate that has a 50:50 chance of being less than or greater than forecast
P90	Probability estimate that has a 90% chance of being less than forecast (P90)
PAC	Planning Assessment Commission
PEL	Petroleum Exploration Licence
POEO Act	Protection of the Environment Operations Act 1997 (NSW)
PPL	Petroleum Production Lease
PWMP	Produced Water Management Plan
RO	Reverse Osmosis
RWP	Receiving water pond
SAR	Sodium Adsorption Ratio
STP	Stratford to Tomago pipeline
STV	Short term trigger values
t	Tonne
t/d	Tonnes per day
t/a	Tonnes per annum
TDS	Total Dissolved Solids
TED	Tiedman East Dam
THPS	Tetrakis (hydroxymethyl) phosphonium sulphate
TND	Tiedman North Dam
TPH	Total Petroleum Hydrocarbons
TSD	Tiedman South Dam
TSS	Total Suspended Solids
TWT	Treated water storage tank

UF	Ultra filtration
µS/cm	MicroSiemens per centimetre
µm	Microns
WAL	Water Access Licence
WM Act	Water Management Act 2000 (NSW)
WTreatP	Water Treatment Plan
WTP	Water treatment plant

Executive Summary

This document is the final Extracted Water Management Strategy (EWMS) for managing extracted water associated with AGL Energy's (AGL) Stage 1 Gloucester Gas Project (GGP).

AGL is committed to maximising the reuse of extracted water from the Stage 1 Gas Field Development Area (GFDA) of the GGP for beneficial purposes.

The final EWMS has been developed after a Consultation Draft of the EWMS was released in August 2014 and the Final Draft of the EWMS was released in September 2015. The EWMS was twice workshopped with key agencies and local government, and twice publicly exhibited. Five agency submissions were received and two public submissions provided comment on the Consultation Draft with five agency submissions and no public submissions received on the Final Draft. There were eight initial 'Expressions of Interest' received for using the desalinated water for beneficial reuse.

Since September 2014, the Front-End Engineering Design (FEED) and specialist studies have been completed and water production data from the Waukivory Pilot have been obtained. The water balance in this EWMS is based on the development of 110 gas wells over a period of three years and extracted water being pumped from depths greater than 250m.

AGL's EWMS maximises the reuse of high quality treated water for local beneficial purposes. The EWMS is a framework and strategy document prepared to address the Part 3A project approval requirements in relation to the treatment of extracted water, and the reuse and discharge of treated water after desalination. The EWMS is not intended to provide the engineering designs for the water management infrastructure, specifications for the treated water plant or identify the final irrigation areas, stream discharges or repositories for solid wastes. Rather this document provides the overall strategy for extracted water management from source to final reuse. Detailed designs for the required infrastructure will be available after an investment decision is made to proceed with the project and the EPC contract for water treatment is awarded and delivered.

The preferred extracted water management strategy provides a flexible and sustainable approach that incorporates available and proven water treatment technologies and water management practices.

AGL received Project Approval 08_0154 for Stage 1 of the GGP from the New South Wales (NSW) Planning Assessment Commission (PAC) under (the now repealed) Part 3A of the *Environmental Planning and Assessment Act 1979* (*EP&A Act*) in February 2011.

The project also received approval (EPBC 2008/4432) under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) in February 2013.

Condition 3.12 of the Project Approval requires AGL to develop an EWMS to the satisfaction of the Secretary of the Department of Planning and Environment (DPE) in consultation with relevant government agencies prior to commencement of the construction of the project. There was a modification to the Part 3A approval in September 2014, however there was no material change to Condition 3.12.

This EWMS is being submitted for the Secretary's satisfaction of the proposed water management approach prior to an investment decision to proceed with the GGP and the preparation of engineering scopes for tender.

Extracted water is the collective term for both flowback water and produced water. Control, management, monitoring, reuse and/or discharge of these waters and disposal of associated waste streams are key considerations for Stage 1 of the GGP and important issues for government agencies and the local community.

The Stage 1 project approval allows for a maximum of 2 megalitres per day (ML/d) of produced water (on average over any 12 month period) to be pumped, treated and then either irrigated or disposed. Flowback water volumes are in addition to this volume. However with the benefit of additional flow testing programs since 2011, the extracted water volumes are now likely to be much less than these initial estimates for produced water. Water production rates (for extracted water) for the P50 water production profile are now expected to be around 0.6 ML/d at their peak diminishing to less than 0.1 ML/d after five years. For the P90 water production profile the peak production is 0.9 ML/d diminishing to around 0.1 ML/d after 5 years.

Infrastructure

The project comprises the following water management infrastructure:

- Stage 1 GFDA, including:
    - 110 coal seam gas wells and associated wellhead infrastructure
    - Existing holding ponds at the Tiedman property
    - Water gathering lines
    - Water distribution lines.
- Central Processing Facility (CPF) with associated infrastructure, including:
    - Receiving water pond
    - Pre-treatment system
    - Water treatment plant
    - Water treatment storage tank
    - Discharge water pond
    - Brine treatment plant
    - Water reuse infrastructure within the CPF.
- Associated ancillary infrastructure and works such as:
    - Existing and new irrigation infrastructure
    - River discharge infrastructure
    - Stock watering infrastructure.

Preferred Strategy

AGL is committed to maximising the reuse of extracted water. Upon careful consideration of all the options, AGL's preferred strategy for extracted water management is:

- Treatment and desalination of extracted water to produce treated water and mixed salt.
- Reuse of treated water for CPF processes, and drilling, fracture stimulation and workovers (i.e. working water).
- Beneficial reuse of high quality treated water for local irrigation, farming and stock purposes.
- Discharge of treated water (to a fresh/drinking water standard) to streams (when irrigation or stock watering is not possible).
- Landfilling of the primary solids from the pre-treatment process to an appropriately licensed facility.
- Landfilling of the mixed salt from the brine stream to an appropriately licensed facility.

The engineering components of the preferred strategy at the CPF are:

- Centralised water treatment facility with a variety of treatment plants and process water storages.
- Pre-treatment to prepare extracted water for desalination.

› Desalination of extracted water using various technologies but primarily reverse osmosis for working water, beneficial reuse and stream discharge.

› Post treatment to condition the treated water for all reuses.

› Brine concentration.

› Crystallisation of brine water to produce salt.

Infrastructure will be sized and operated to meet the expected water production profile and it will include some redundancy to cater for short term peaks, maintenance, breakdowns and alike. The capacity of the WTP will initially be in excess of 1 ML/d so there will be capacity to cater for variable flows. As flowback water volumes diminish and produced water volumes decline, the desalination capacity of the WTP will be scaled back to reflect the production profile. This will also mean decreasing irrigation areas, negligible wet weather releases to the Avon River, and less crystallised salt waste. Treated water will be prioritised for working water, general consumption at the CPF and stock usage.

Irrigation areas of up to 60 ha are planned on local properties, however water volumes and irrigation areas will quickly decline after the first few years of operation. In dry to average seasons most water will be irrigated with no expected discharges to the Avon River. Water balance modelling suggests that no treated water will be discharged after Year 3 of operations.

The treated water quality from the final discharge water pond (DWP) will be low salinity and suitable for a variety of uses. Treated water after desalination is expected to be between 200 and 250 mg/L total dissolved solids (TDS). Heavy metal concentrations will be negligible or 'non detect' with barium, strontium, and zinc likely to be present in very low concentrations. There will be no methane or BTEX in the final treated water for reuse or stream discharge. The target water quality for different reuses and stream discharge (i.e. the discharge water quality) is expected to be between 200 and 400 mg/L TDS depending on the chemical conditioning required. Conditioning will neutralise the pH and lower the sodium adsorption ratio (SAR) so as to be suitable for irrigation and stream discharge (and as a raw drinking water supply source). Only one final water quality standard is proposed irrespective of the final treated water use.

The long term average salt production for the brine treatment plant (BTP) will be less than 200 tonnes per annum. This equates to one truckload of salt per month for off-site disposal at a licensed facility in accordance with regulatory requirements.

New market opportunities for water and mixed salt will be further investigated, depending on 'Expressions of Interest' received for the available water and salt once a decision is made to proceed with the project. AGL has emphasised to potential users that the water production profile is likely to be highly variable and that treated water availability is not guaranteed. The desalinated water should be considered as a supplementary source of supply.

Consultation Process

The consultation process involved:

› Distribution of the Consultation Draft EWMS and inviting all the nominated agencies (Office of Coal Seam Gas (OCSG), NSW Office of Water (NOW), Environment Protection Authority (EPA), Department of Planning and Environment (DPE), Hunter Local Land Service (HLLS), Gloucester Shire Council (GSC) plus MidCoast Water (MCW)) specified in Condition 3.12 to a workshop in August 2014.

› Sending copies of the EWMS to other government agencies not directly involved in the development of the EWMS.

› Advertising the release of the EWMS and community information sessions.

› Holding an initial workshop with GSC, MCW, regulators and other government agencies (13 August 2014).

› Launching the EWMS at the Gloucester Community Consultative Committee (GCCC) on the 21 August 2014.

- Publishing and exhibiting the Consultation Draft of the EWMS on AGL's website (21 August to 19 September 2014).
- Presenting to the Advance Gloucester meeting on the 20 August 2014.
- Organising and attending two community information sessions in August 2014.
- Being available (via mail, phone or drop in to the local office) to answer queries during the exhibition of the EWMS, and ongoing as water treatment queries have arisen.
- Preparing a final draft of the EWMS for agency review incorporating comments and feedback from the initial consultation.
- Holding a second workshop with DPI Water, EPA, GSC and MCW (16 September 2015).
- Publishing and inviting comments on the Final Draft of the EWMS on AGL's website (8 September to 6 October 2015).
- Presenting to GSC Councillors and staff on 17 September 2015.

The general consensus of the agency submissions on the Consultation Draft was support for AGL's extracted water strategy and the availability of additional water that could provide additional drought security with some reservations surrounding low flow discharges and the stream disposal options.

There was further support and mostly minor supplementary comments on the Final Draft of the EWMS with the revised proposal to reduce extracted water volumes, maximise reuse and have zero or negligible stream discharges of treated water.

AGL is submitting this Final EWMS to the DPE to comply with Condition 3.12 of the Part 3A project approval. It is submitted so as to obtain the Secretary's satisfaction regarding the strategy prior to AGL making a final investment decision on the project.

1. Introduction

1.1. Background

AGL Upstream Infrastructure Investments Pty Ltd (AGL) received Project Approval 08_0154 for Stage 1 of the Gloucester Gas Project (GGP) from the New South Wales (NSW) Planning Assessment Commission (PAC) under (the now repealed) Part 3A of the *Environmental Planning and Assessment Act 1979* (*EP&A Act*) in February 2011. The approval was upheld after a challenge in the Land and Environment Court.

The GGP also received approval (EPBC 2008/4432) under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) in February 2013.

The GGP includes the Stage 1 gas field development area (GFDA) comprising 110 gas wells. To allow gas to flow from these wells, deep groundwater will be extracted with the gas (referred to as produced water). To extract gas safely and efficiently, wells may be fracture stimulated and depressurised. Water produced from fracture stimulation (i.e. the returning injection water) is called flowback water. The term 'extracted water' refers predominantly to produced water but also includes flowback water when wells are first fracture stimulated.

Condition 3.12 of the Project Approval requires AGL to develop an Extracted Water Management Strategy (EWMS) to the satisfaction of the Secretary of the Department of Planning and Environment (DPE) in consultation with relevant government agencies prior to commencement of the construction of the project.

This document is the EWMS and complies with condition 3.12. It also summarises the background studies and regulatory framework that apply to extracted water management for the GGP, and describes the preferred technologies and processes for extracted water management for the Stage 1 Gas Field Development Area (GFDA).

This plan is a strategy document and not a detailed Produced Water Management Plan (PWMP), Water Treatment Plan (WTreatP), Brine Management Plan (BMP) or Irrigation Management Plan (IMP) for the design, operation, management and monitoring of the water treatment infrastructure and reuse facilities of the Stage 1 GFDA.

1.2. Overview of the GGP

The GGP will provide AGL with an additional supply of gas for distribution to commercial, industrial and residential customers within NSW, thereby reducing the requirement for gas to be imported from other states.

For Stage 1 of the GGP, activities will be undertaken and infrastructure will be constructed to produce up to 80 TJ/day of gas into the NSW gas supply network via AGL's Newcastle Gas Storage Facility (NGSF). These activities and infrastructure are:

› Stage 1 GFDA:

  » Gas production from 110 wells and associated infrastructure.

  » Pumping and treatment of flowback water and produced water.

  » Beneficial reuse of flowback water and produced water.

  » Maintenance and operation of a water monitoring network.

  » Rehabilitation of each gas well site to a minimised surface area for gas production and ongoing operations.

- Central Processing Facility (CPF): The CPF will include construction and subsequent operation of gas compression, water treatment facilities and water storage. The CPF will be located at the southern end of the Stage 1 GFDA south of Stratford near the junction of Bucketts Way and Parkers Road.
- Stratford to Tomago Pipeline (STP): A 96 km high pressure gas pipeline will be constructed and operated to transfer gas south from the CPF to Tomago (10 km NW of Newcastle). The pipeline will connect to a transfer point at the NGSF and then to the existing NSW gas distribution network at Hexham via an existing 5.5 km pipeline.

In relation to the water infrastructure and management, the approval includes the construction operation, and maintenance of:

- A water gathering system and associated infrastructure within the Stage 1 GFDA.
- A water treatment plant (WTP) within the CPF for desalination of extracted water.
- A brine treatment plant (BTP) within the CPF for the crystallisation of salt.
- An oily water separator within the CPF for removal of oil-in-water emulsions from the process water generated by the gas compression process.
- Three new storage ponds, each of up to 25 ML capacity located within the CPF to store extracted water and treated water.
- Associated infrastructure.

The approvals under the EP&A Act comprise the Concept Plan Approval (PAC, 2011a) and the Project Approval (PAC, 2011b) for Stage 1 of the GFDA. The Concept Plan Approval allows for the extraction of coal seam gas (CSG) as a staged development within the approved concept area in the Gloucester Basin. The Project Approval allows for gas to be extracted from 110 wells and associated infrastructure in the Stage 1 GFDA which is located to the north-east and south-east of Stratford.

The Concept Plan Approval and Project Approval were modified in September 2014 to allow minor realignments to the STP corridor and to allow the connection of the pipeline to the Newcastle Gas Storage Facility (NGSF) at Tomago rather than the Hexham gas delivery station. Some of the conditions relating to the main Stage 1 development were also varied however there was no material change to Condition 3.12.

The Concept Plan Area, including associated GGP infrastructure covers approximately 210 km^2. The Project Approval area for the Stage 1 GFDA is approximately 50 km^2. The extent of the GGP is defined by the boundary identified as PEL 285 shown in **Figure 1.1**.

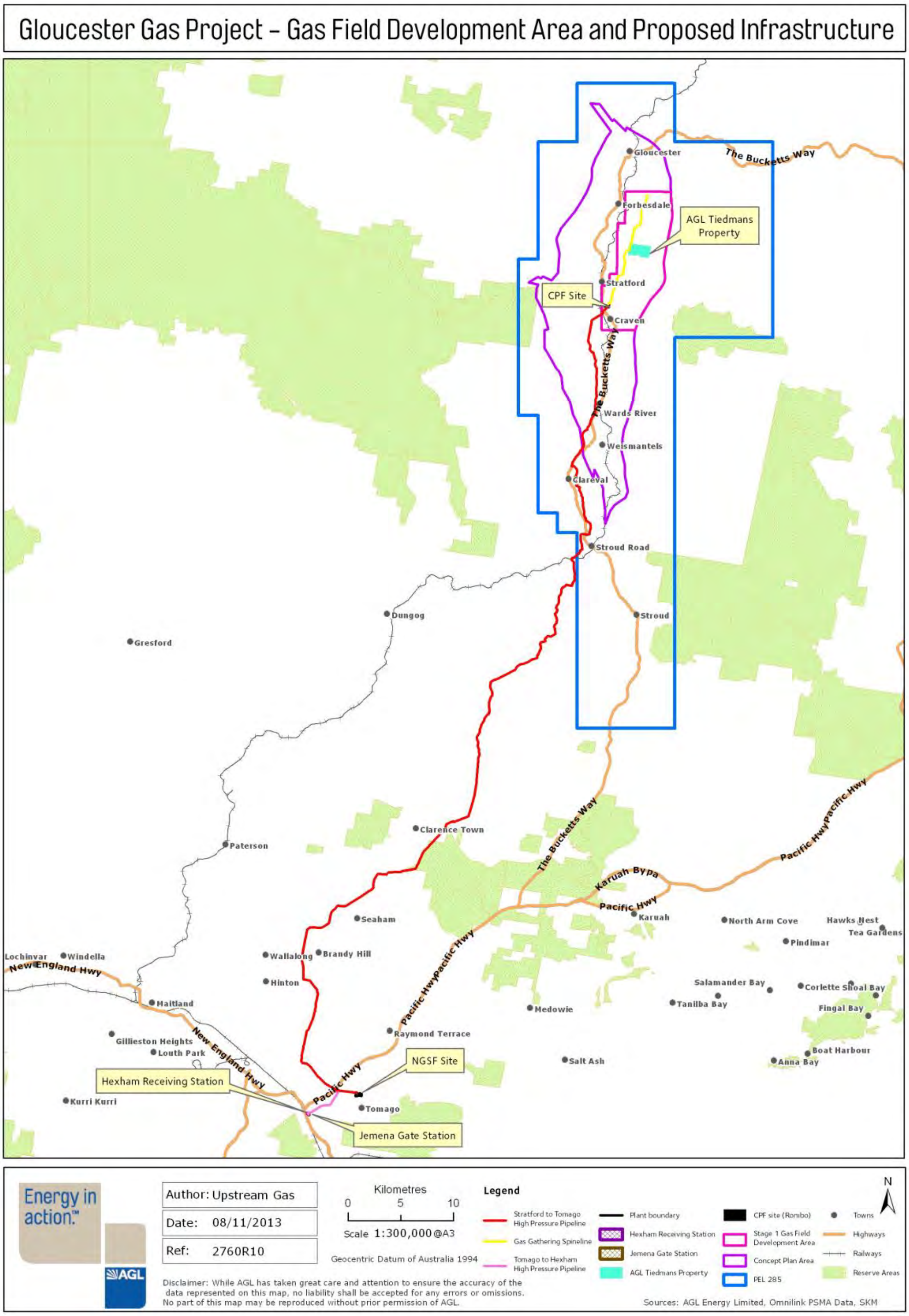


Figure 1.1: Gas Field Development Area and Proposed Infrastructure

1.3. Objectives

The objectives of this EWMS are to:

› Provide a framework for the capture, treatment and reuse of extracted water for the GGP.

› Summarise background studies and the regulatory framework that are applicable to GGP extracted water management.

› Document the stakeholder consultation undertaken for the development of the EWMS.

› Describe and evaluate options that are available for GGP extracted water treatment (reuse and disposal).

› Provide information on the estimated quality and quantity of GGP extracted water.

› Describe AGL's preferred option for extracted water treatment including:

  » existing and proposed water management infrastructure;

  » treated water quality target;

  » the irrigation of treated water;

  » the discharge of treated water by stream discharge (if required); and

  » waste, brine and salt management.

› Describe the proposed water monitoring principles and outline the monitoring program that is required to support the EWMS to protect the environment.

› Meet the requirements of the Part 3A Condition 3.12: Extracted Water Management and to obtain the approval of the Secretary of the DPE.

1.4. Consultation

The management of extracted water is critical to the gas development program, and it presents opportunities and challenges for long term social outcomes and protection of water and the environment. Consequently, the interests of a wide range of stakeholders have been recognised in the development of this EWMS.

The EWMS provides a clear description for the community, regulators and other stakeholders of how AGL proposes to manage extracted water for Stage 1 of the GGP. The EWMS has been developed in consultation with DPE, OCSG, NOW, EPA, Hunter Local Land Services (HLLS), MidCoast Water (MCW), Gloucester Shire Council (GSC), and the wider community. Stakeholder and community feedback was taken into account as part of the EWMS consultation process.

The EWMS is based on a sustainable approach to development and is guided by the following principles:

› Minimising adverse environmental impacts and enhancing environmental benefits associated with the activities, products or services.

› Conserving, protecting, and enhancing, where the opportunity exists, the availability of water resources in the operational areas.

› Engaging regularly, openly and transparently with people and communities affected by the activities, considering their views in the decision-making process.

› Working cooperatively with communities, governments and other stakeholders to achieve positive economic, social and environmental outcomes, and seeking partnership approaches where appropriate.

- Protecting public and animal health, identifying and managing aspects of public concern, and being cognisant of community issues in relation to outputs to the environment.
- Identifying, assessing, managing, monitoring and reviewing risks to property, the environment and the communities within the project area.

The EWMS will evolve over the life of the Stage 1 GFDA of the GGP as:

- Produced water volumes diminish.
- Modifications to planning approvals are sought.
- Technological advances are developed and adopted in water treatment and brine management.
- New reuse opportunities are identified for both water and salt.
- Regulations, licences, codes of practice, and industry standards change.

Any updated versions of the EWMS will be developed in consultation with DPE, DRE, EPA, DPI Water, GSC and MCW.

1.5. Inclusions and exclusions in the EWMS

The EWMS is a framework and strategy document prepared to address the Part 3A project approval requirements. It is consistent with the Environmental Assessment (EA) and Submissions Report exhibited in 2009 and 2010 respectively, and it includes a description of:

- The extracted water management options.
- AGL's preferred water reuse and discharge strategy.
- Extracted water quantity and quality characteristics.
- Stakeholder consultation process.
- Likely components of the water management infrastructure for water gathering, treatment and reticulation.
- Treated water quality targets for reuse and stream discharge.
- Waste and brine management.
- Proposed monitoring requirements.

There is also information included in the EWMS that confirms that reinjection and aquifer storage and recovery is not feasible for managing extracted water, treated water or brine given the geology and hydrogeology of the Gloucester Basin (Condition 21 of the EPBC approval).

The EWMS is not intended to provide the engineering designs for the required water management infrastructure, specifications for the treated water plant or identify the final irrigation areas, stream discharges or repositories for solid wastes. Also the EWMS does not provide specific detail relating to water treatment, brine management, irrigation management or water monitoring. Rather this document provides the overall strategy for extracted water management from source to final reuse or stream discharge.

Detailed designs for the required infrastructure will be available after an investment decision is made to proceed with the project and the Engineering, Procurement and Construction (EPC) contract for water treatment is awarded and delivered.

1.6. Summary of Submissions

1.6.1. Consultation Draft

A summary of the seven submissions received from government agencies, GSC, MCW and the public on the Consultation Draft of the EWMS and AGL responses is provided in **Appendix A**. Issues raised in submissions are summarised below together with an indication of where each particular issue is discussed in the final EWMS.

Water treatment

- Engineering design detail for the WTP – not required to be included in the EWMS. Section 5.1 provides an overview.

Reuse water supply and stream discharges

- Provision of water to third parties (no commitments can be made at this stage - general discussion in Section 5.4.3).
- Stream discharge location (general discussion in Sections 11.6.2, 9.2 and **Appendix C**).
- Inclusion of water balance modelling (Sections 5.1 to 5.5, 11.1 to 11.4 and **Appendix B**).
- Contingencies to minimise stream discharge (Section 5.5 and **Appendix B**).
- Low flow discharges (no longer part of the EWMS) (see Section 5).

Management of wastes

- Brine disposal (general discussion in Section 5.1.3; Section 11.4 and Section 13.4).
- Salt encapsulation (encapsulation off-site at a licensed facility plus general brine management discussion in Section 13.4 and Section 13.5).
- Explore reuse opportunities (Section 13.4).

Water quality criteria

- Target values for reuse and discharge (Section 12).
- Site specific water quality criteria (Section 2.4.2).

Water monitoring locations

- Monitoring in the vicinity of the Tiedman storages (general discussion in Section 14 and then **Appendix E**).
- Monitoring frequencies at the WTP (**Appendix E**).
- Preparation of a Produced Water Management Plan (PWMP) – not required to be included in the EWMS.

1.6.2. Final Draft

A summary of the five submissions received from government agencies, GSC, MCW and the public on the Final Draft of the EWMS and AGL responses is provided in **Appendix A**. Issues raised in submissions are summarised below together with an indication of where each particular issue is discussed in the final EWMS.

Definitions

- Several definitions to be added or improved (Glossary).

Threshold water quality analytes

› List of analytes to include organics (updated Tables 2.5 and 2.6 in Section 2.4).

Target water quality criteria

› Expand the proposed analytical suite and reduce/amend the target criteria for certain analytes (Section 12 and Table 12.1).

River discharge criteria

› Clearly elaborate the flow conditions under which river discharges will occur (Section 9.3).

Management of water for different reuse options

› Further assess criteria for irrigation, stock and working water and manage associated risks (Section 12 – with additional detail to be included in the PWMP)

Management of brine and salt

› Provide more information on brine management and the fate of salts (Section 11.4 – with additional detail to be included in the PWMP)

Monitoring program

› Consider additional monitoring for buried water gathering systems and irrigation areas (Section 11.5 – with additional detail to be included in the PWMP)

Involvement with a PWMP

› Regulatory and consultation process is to be determined (in consultation with Government – not included in the EWMS).

Storage capacity of ponds and tanks at the CPF

› Consider maximising water storage potential at the CPF (Section 11.2).

Many of the issues raised in the consultation process (particularly regarding the Consultation Draft) related to engineering and operational issues surrounding extracted water management. The issue of whether an approved PWMP and any other supporting plans are required and when will need to be determined in consultation with Government. AGL proposes to develop a PWMP prior to commissioning of the CPF and therefore detailed engineering and operational issues regarding all aspects of extracted water management are not included in this EWMS (which is an overall strategy document). As the detailed WTP, BTP and associated design aspects are not available at this time, details regarding these engineering components are not included in this strategy document.

2. Regulatory Framework

2.1. Background

AGL received Concept Plan approval for the GGP from the PAC under the former Part 3A of the EP&A Act in February 2011. The Project Approval for Stage 1 of the GGP was issued at the same time (Application 08_154). The project also received approval under the Commonwealth EPBC Act in February 2013 (EPBC 2008/4432).

The Project Approval and EPBC Approval apply to the following water management infrastructure which were identified in the EA:

- Stage 1 GFDA, including:
  - 110 coal seam gas wells and associated wellhead infrastructure;
  - existing holding ponds at the Tiedman property (except the Tiedman East storage (TED) which was constructed later under separate approvals);
  - water gathering lines; and
  - water distribution lines.
- CPF with associated infrastructure, including:
  - receiving water pond;
  - pre-treatment system;
  - water treatment plant;
  - water treatment tank;
  - discharge water pond;
  - brine treatment plant; and
  - water reuse infrastructure within the CPF.
- Associated ancillary infrastructure and works such as:
  - existing and new irrigation infrastructure;
  - river discharge infrastructure; and
  - stock watering works.

No further planning approvals are required to construct, commission and operate the proposed water infrastructure.

2.2. Legislative Requirements

The EWMS considered the requirements of existing project approvals and legislation, and the potential for additional approvals. A summary of the NSW and Commonwealth legislation relevant to extracted water management for the Stage 1 GFDA is provided in **Table 2.1.**

Table 2.1 **Regulatory Framework for Management of Extracted Water**

ACTIVITY	APPROVAL AND LEGISLATION	RESPONSIBLE AUTHORITY
Design, construction, operation and monitoring of storage ponds for flowback water, produced water, treated water and the brine water (concentrated brine stream)	Project Approval EPBC Approval	DPE DoE
Petroleum licence to produce CSG and therefore generate extracted water as a by-products	Exploration - PEL 285 issued under the *Petroleum Onshore Act 1991* Operation - PPLs issued under the *Petroleum Onshore Act 1991*	DRE within DoI
Dewatering and the pumping of groundwater to surface (where it becomes produced water) and reuse for beneficial uses (such as industrial, irrigation and stock)	Operation – Part V bore licences issued under the *Water Act 1912* (these will transition to a WAL under the *Water Management Act 2000*) Given approval has been granted under Part 3A of the *EP&A Act*, a bore licence cannot be refused and must be generally consistent with the Part 3A approval	DPI Water
Reuse or discharge of (treated) extracted water (for reuse or disposal)	Non-scheduled activity requiring an EPL issued under the *POEO Act*. Given approval has been granted under Part 3A of the *EP&A Act*, an EPL cannot be refused and must be generally consistent with the Part 3A approval	EPA
Transport of salt products (for reuse or disposal)	Tracked in accordance with the *Protection of the Environment Operations (Waste) Regulation 2014*	EPA
Supply of untreated or treated water to a third party	No additional approvals are required	None

Environment Protection Licence

Under the provisions of the POEO Act, EPA issued Environment Protection Licence (EPL) 20358 for certain scheduled activities within the Petroleum Exploration Licence (PEL) 285. AGL must not allow (through act or omission) the pollution of land, water or air in managing the extracted water for the project. In accordance with Clause 9A of Schedule 1 of the POEO Act, the relevant scheduled activity is "*Coal seam gas exploration, assessment and production*".

As the project has been approved under Part 3A of the EP&A Act, an EPL cannot be refused as it is necessary for carrying out the Stage 1 GGP and must be substantially consistent with the Project Approval.

Water Management Act 2000

Under the provisions of the *Water Management Act 2000*, approvals are required to carry out certain activities within and near waterways and for the use of water. However, given the project has been approved under Part 3A of the EP&A Act, a water use approval under Section 89, a water management work approval under Section 90, or an activity approval under Section 91 of the *Water Management Act 2000* are not required for the project, including for extracted water management. However, Water Access Licences (WALs) are required under the respective Water Sharing Plans (WSPs) for the take of water. At the present time only surface water sources are covered by WSPs. AGL currently has valid water licences under the WSP for extracting water for irrigation and industrial activities.

AGL currently holds 13 (production) bore licences under the *Water Act 1912* for the extraction of deep groundwater from the sedimentary rocks of the Gloucester Basin. These existing licences will be replaced by new licences for the gas wells proposed for the Stage 1 GFDA. These applications will be lodged in 2016 for up to 730 ML per year to be extracted for the GGP. As the licences allow for the construction of the gas wells and the take of water for industrial, stock and irrigation purposes, these licences will be sufficient to authorise the take and reuse/discharge of produced water. It is expected that conditions reflecting the requirements of the Aquifer Interference (AI) Policy will be applied to each of these licences.

Protection of the Environment Operations (Waste) Regulation 2014

Waste regulation regulations, classifications, and procedures were updated during the last 12 months. The Protection of the Environment Operations (Waste) Regulation 2014 commenced on 1 November 2014 and has been progressively implemented in 2014 and 2015.

Brine, crystallised salt, or solids resulting from the treatment of flowback water or produced water are classified in accordance with the NSW Waste Classification Guidelines (EPA, 2014) and have to be disposed of at an appropriately licensed facility. Salt is generally considered to be a General Solid Waste (non-putrescible) and is accepted at licensed solid waste landfills in NSW.

Under the provisions of the Protection of the Environment Operations (Waste) Regulation 2014, the transport (for reuse or disposal) of "*non-toxic salts*", such as the salt products resulting from the treatment of produced water, is required to be tracked.

Policies, Guidelines and Codes of Practice

The NSW Government has published the NSW Gas Plan, a number of CSG policies/guidelines and Codes of Practice (CoP). There are also a number of new and revised CoPs in preparation. The Exploration Code of Practice for Produced Water Management, Storage and Transfer (DoI, 2015) has recently been released however it has little relevance to this EWMS as it only applies to exploration programs. It also only applies to produced water storage and transfer, and not water reuse and disposal, nevertheless the relevant principles outlined in this CoP will be addressed in the proposed PWMP. Relevant CoPs or guidelines relating to extracted water management will be included in the conditions of the Petroleum Production Lease/s (PPLs).

The AI policy is relevant given there are minimal impact considerations defined for groundwater systems that could be potentially impacted by the development and the capture, treatment, storage and reuse of extracted water.

These documents require consideration in identifying management options for CSG by-products, including extracted water and treated water. Consideration of the objectives and strategies set out in the Queensland Government Coal Seam Gas Water Management Policy have also provided a framework for the development of water management initiatives for this project.

Several water quality guidelines were also taken into consideration to identify the appropriate level of treatment for the intended water reuse and disposal. The relevant policies, guidelines and codes are listed in **Table 2.2.**

Table 2.2 Policies, guidelines and codes for management of Extracted Water

PLANS, POLICIES AND CODES OF PRACTICE	YEAR	AUTHOR	RELEVANCE
NSW State Groundwater Policy and its various component policies	August 1997	DLWC now DPI Water	Protection of water resources (groundwater quantity and water quality) and groundwater dependent ecosystems
ANZECC Guidelines for Fresh and Marine Water Quality	October 2000	ANZECC	Water quality criteria for different beneficial uses and for the protection of aquatic ecosystems
Code of Practice for Coal Seam Gas - Fracture Stimulation	September 2012	DoTI now DoI	Fracture stimulation activities UNDER REVIEW
Code of Practice for Coal Seam Gas - Well Integrity	September 2012	DoTI now DoI	Well design, drilling, completion, workover and abandonment activities UNDER REVIEW
NSW Aquifer Interference Policy	September 2012	NOW now DPI Water	Management and protection of groundwater systems where that activity is an interference activity rather than a consumptive use activity
Coal Seam Gas Water Management Policy	December 2012	DEHP	CSG water management framework in QLD
Groundwater Modelling and Monitoring Plans – information for prospective mining and petroleum exploration activities	February 2014	NOW now DPI Water	Document to assist with the development of water monitoring networks to ensure the data requirements for: › Hydrogeological conceptualisation › Assessment of baseline and regional conditions › Time series data for any future groundwater model calibration
Waste Classification Guidelines	November 2014	EPA	Disposal and transport of liquid and general solid wastes
NSW Gas Plan	November 2014	NSW Govt	Plan outlining five priorities to developing NSW gas reserves including 'strong and certain regulation'
Exploration Code of Practice – Produced Water Management, Storage and Transfer	July 2015	DoI	Flowback water and produced water storage, handling, transfer and associated management activities FOR EXPLORATION PROGRAMS only

2.3. Environmental Approvals

The Environmental Assessment (EA) (*AECOM, 2009*) for the GGP was submitted to the then NSW Department of Planning and Infrastructure in November 2009 to seek approval for the GGP and Stage 1 GGP under Part 3A of the EP&A Act. In May 2010, following public exhibition of the EA, a Submissions Report was prepared for the project (*AECOM, 2010*).

This EWMS is consistent with the proposed infrastructure and water treatment technologies in the EA (See Chapter 5 and Section 5.5.4).

Concept plan and project approvals were granted in February 2011 (Application 08_0154).

2.3.1. Part 3A Project Approval Conditions

Condition 3.12 of the Part 3A Project Approval requires that, prior to commencement of construction of the project, AGL must develop an EWMS to the satisfaction of the Secretary of the DPE. The EWMS is required to be developed in consultation with the OCSG/DRE within DoTI (formerly DII), NOW, HLLS (formerly HCRCMA), EPA (formerly part of DECCW), and relevant Councils.

Condition 3.13 provides that AGL must ensure that any water storage ponds developed at the CPF or on the Tiedman site that are part of the extracted water proposals are appropriately lined.

This EWMS has been prepared to satisfy the requirements of Conditions 3.12 and 3.13. **Table 2.3** lists the components of Conditions 3.12 and 3.13 and where these components are addressed in the EWMS. In addition to the detail provided in this EWMS to address parts a) to i) of Condition 3.12, AGL will prepare a detailed PWMP prior to commissioning of the CPF.

Table 2.3 Condition 3.12 and 3.13 Requirements and the EWMS

CONDITION	SECTION OF EWMS WHERE THE RELEVANT CONDITION IS ADDRESSED
<u>Condition 3.12 Introductory Paragraph</u> Unless otherwise agreed to by the Secretary, prior to the commencement of construction of the project, the Proponent shall develop an **Extracted Water Management Strategy** in consultation with OCSG, NOW, Hunter LLS, EPA and relevant Councils and to the satisfaction of the Secretary.	The process and outcomes of consultation with the relevant agencies and Councils are **summarised in Sections 1.4 and 1.6, detailed in Section 7, and discussed throughout the EWMS.**

CONDITION	SECTION OF EWMS WHERE THE RELEVANT CONDITION IS ADDRESSED
Condition 3.12 a) Identifies the final suite of water disposal and re-use option(s) that would be implemented to manage groundwater extracted from the gas production wells.	The key components of the water discharge and reuse options that would be implemented for extracted water management are: • treatment of extracted water at the WTP which includes reverse osmosis for desalination of produced water; • water reuse for hydraulic fracture operations; • water reuse for non-potable uses at the CPF; • water reuse for stock purposes; • treated water irrigation at properties in the local area (including AGL properties); • discharge of treated water to the Avon River; and • salt products disposed to licensed facility as a general solid waste. **Details of these components are provided in Sections 5, 8, 9, 10, 11 and 13.**
Condition 3.12 b) Identifies the water quality required to achieve the disposal / re-use option(s) identified in a) above, including the procedure for monitoring of treated water to ensure that required water quality criteria are achieved.	Water quality thresholds are provided in **Section 2.4.** Treated water quality targets for all reuses and stream discharge are provided in **Section 12**. Treated water monitoring requirements are provided in **Section 14 (and Appendix E)**.

CONDITION	SECTION OF EWMS WHERE THE RELEVANT CONDITION IS ADDRESSED
Condition 3.12 c) If discharge to surface waters is proposed identifies details of all practical measures investigated to prevent, control, abate or mitigate that discharge; details of the receiving environment including water quality and flow conditions; proposed discharge rate and frequency; and details of all practical measures investigated to protect the environment from harm as a result of that discharge including demonstration that any discharge would satisfy the requirements of condition 3.1.	The EWMS identifies reuse as the preferred option for treated water; however if required, treated water will be stored during extended wet periods, and only discharged to surface water (i.e. the Avon River) if an extreme wet weather period prevailed. The following information regarding the discharge of treated water to surface water is provided: • prevention, control, abatement and/or mitigation measures for treated water discharged to surface water (**Section 9**); • details of the receiving environment including water quality and flow conditions (**Section 9.2 and Appendix C**); • proposed discharge rate and frequency (**Section 9 and Appendix B**); and • practical measures to protect the environment from harm as a result of discharge to surface water (**Section 9 and Appendix C**).
Condition 3.12 d) If re-use for irrigation is proposed -- demonstrates that there is demand for the volumes of water to be generated, details of all practical measures investigated to protect the environment from harm including details of optimal application rates to prevent over irrigation and associated salinity issues or groundwater contamination, and demonstration that any discharge would satisfy the requirements of condition 3.1.	The EWMS identifies reuse as the preferred option for all treated water. The reuse of treated water for irrigation is proposed as the primary reuse opportunity (after all working water requirements are satisfied). The following information regarding the reuse of treated water for irrigation is provided: • demand for the volumes of water to be generated (**Sections 8.1, 8.4, 8.5**); • practical measures to protect the environment from harm (including details of optimal application rates to prevent over irrigation and associated salinity issues or groundwater contamination) (**Sections 8.3, 8.4, 8.5 and Appendix B**); and • practical measures to protect the environment from harm as a result of irrigation of treated water (**Sections 8.4, 8.5, 14 and Appendix E**).

CONDITION	SECTION OF EWMS WHERE THE RELEVANT CONDITION IS ADDRESSED
Condition 3.12 e) If extracted water is proposed to be made available to the market demonstrates that suitable buyers of the water have been secured and where the water is proposed to supplement drinking water supplies, demonstration that the water quality is suitable for drinking water supplies;	There are no contracts in place to supply water to third parties at this time, although a Memorandum of Understanding (MoU) has been signed with Dairy Connect to explore opportunities in the future and eight others have indicated expressions of interest. It is expected that treated water will be available for community use. Prior to supply of treated water to the market, AGL will undertake a thorough investigation of market opportunities. This investigation is expected to have a long lead time (over 12 months) to enable consultation, negotiation and information gathering and sharing. It is expected that final arrangements will be described in more detail in the PWMP and commercial arrangements will either be included in Access and Compensation Agreements or new Water Supply Agreements.
Condition 3.12 f) Identifies the final option for the management of the salt volumes produced from the extracted water treatment process.	The EWMS proposes that salt (brine) produced following the treatment of extracted water will be further concentrated to create a mixed salt suitable for disposal offsite by road transport to a licensed landfill. The description of brine treatment and salt volumes is provided in **Section 13 (primarily Section 13.5).**
Condition 3.12 g) Includes a contingency strategy for the management of extracted water should the volumetric rate of groundwater extraction be greater than two mega litres per day (consistent with the requirements of condition 3.11), including analysis of associated risks to groundwater users and/ or surface waters and groundwater dependent ecosystems.	This is highly unlikely and has a low consequence, and is therefore a low risk. A description of the contingency plan for the management of greater than 2 ML/d extracted water is provided in **Section 11.8**. Current modelling suggests that extracted water volumes will be less than 1 ML/d, and produced water volumes will be even less.
Condition 3.12 h) Provides an assessment of the need for control measures to be implemented at the extracted water and brine evaporation ponds to minimise wildlife (including bird) access to these ponds, with consideration to the water quality and associated risks to wildlife likely to be posed by these storage ponds.	The EWMS proposes that ponds will be fenced with a 2 m high chain linked fence with 250 mm of the bottom fence buried to prevent animals digging below the fence for access. Control measures for wildlife are provided in **Section 11.9**. No brine evaporation ponds are proposed. Brine will be contained in a dual-lined storage tank with a nominal capacity of 2 ML.

CONDITION	SECTION OF EWMS WHERE THE RELEVANT CONDITION IS ADDRESSED
Condition 3.12 i) Provide for the development of site specific water quality criteria in accordance with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 (ANZECC Guidelines, 2000), as necessary, in consultation with DECCW, for the purposes of conditions b), c), d) and e) above.	**Water quality targets** for proposed reuses of treated water and stream discharges are provided in **Section 12 (Section 2.4.2 provides threshold information)**. Site specific water quality criteria will be developed during the preparation of the PWMP and in consultation with EPA.
Condition 3.13 The Proponent shall ensure that any water storage ponds developed at the CPF or on the Tiedman property as part of the project (including extracted water, treated water and brine evaporation ponds) are appropriately lined to ensure no leaching of stored waters and designed consistent with a 1 in 100 year flood design standard.	No brine evaporation ponds are proposed. New water storage ponds for the GGP at the CPF/WTP will be double lined (i.e. dual layers) using high density polyethylene (HDPE) for leak detection and capture purposes (consistent with the Exploration Code of Practice for Produced Water Management, Storage and Transfer). The ponds will be designed consistent with a 1 in 100 year flood design standard and will be above the predicted PMF flood levels (BMT WBM, 2014). There is also an existing double lined pond for storing extracted water at Tiedmans. Once the stored produced water has been treated, the existing single lined ponds at the Tiedman property will be used to store treated water prior to stock and irrigation use (and stream discharge). The existing ponds are also above the predicted PMF flood levels (BMT WBM, 2014). Details of existing and proposed water storage ponds are provided in **Sections 10.1 and 11.2**.

2.3.2. EPBC Approval Conditions

This EWMS has been prepared to satisfy the requirements of Conditions 21, 22 and 23 of the EPBC approval (EPBC 2008/4432) for Stage 1 GGP. **Table 2.4** lists the wording of Conditions 21, 22, and 23 and where these components are addressed in the EWMS.

Table 2.4 Condition 21, 22 and 23 Requirements and the EWMS

CONDITION	SECTION OF EWMS WHERE THE RELEVANT CONDITION IS ADDRESSED
Condition 21 The person taking the action must provide the department with a copy of the extracted water management strategy (also known as produced water management strategy) required under state approval conditions. If the strategy is not to the satisfaction of the Minister (and in particular if it does not consider the feasibility and likely effectiveness of reinjection of extracted water), he may require a supplement to be developed, which must be approved by the Minister prior to commencement of the action, and must be implemented	In accordance with the requirement of Condition 21 the EWMS has included a review of the feasibility and likely effectiveness of reinjection of extracted water (refer to **Section 11.7** of this report entitled *Aquifer Storage and Recovery*) which concluded that reinjection of produced water is not considered appropriate for the Gloucester Basin and the GGP. This conclusion is also supported by the NSW Office of Water in their submission. Details are provided in **Sections 7.7 and 11.7**.
Condition 22 The person taking the action must ensure that no more than 2 megalitres per day (averaged over a twelve month period) of groundwater is extracted. In addition, the person taking the action may only extract sufficient groundwater as is required to undertake the action in accordance with these conditions.	This condition relates to the produced water volumes which will be less than the extracted water volumes. Discussed in **various sections with additional details provided in Section 11.8.**
Condition 23 The person taking the action must ensure that any water storage ponds associated with the action are appropriately lined to ensure no leaching of stored waters and designed consistent with a 1 in 100 year flood design standard.	**Sections 10.1 and 11.2** confirm this requirement.

2.4. Water Quality Criteria

There are two sets of water quality criteria described in this EWMS:

(i) **thresholds** which are the regulatory water quality criteria for different uses as defined by the appropriate ANZECC 2000 criteria; and

(ii) **targets** which define the treated water quality that can be achieved using the proposed water management and treatment processes.

The proposed water quality targets (subject to discussion with EPA regarding EPL licence conditions) will be adopted as the criteria for all beneficial reuses and potential stream discharges.

In this section there is a discussion on the appropriate water quality thresholds while Section 12 discusses the proposed water quality targets for treated water (after desalination and required chemical conditioning).

2.4.1. Water Quality Thresholds for Irrigation and Stock Use

For the GGP development, AGL is planning to desalinate extracted water (see Section 5) rather than irrigate blended water which was the approved program for exploration phase produced water.

It is recognised that water quality alone does not define irrigation sustainability. Other factors such as soils, crop types, the vulnerability of adjacent and underlying water resources, rainfall, irrigation application rates, and management practices are also important considerations. However from a water quality perspective, the ANZECC guidelines (2000) for irrigation use have been adopted as the threshold values for the GGP.

The values in **Table 2.5** are the **threshold values** for treated water for irrigation and stock reuses (i.e. the adopted ANZECC water quality criteria that should not be exceeded). The **target values** that AGL plans to adopt for treated water are (in most instances) much lower than these threshold values (these are discussed further in Section 12). The irrigation guideline values for metals are the short term trigger values (STV) which are defined as the maximum concentration in the irrigation water which can be tolerated for relatively short periods of time (up to 20 years).

Table 2.5 Water quality parameters and threshold values for irrigation and stock water

Parameter	Unit	Irrigation Guideline Value (1)	Stock Guideline Value (7)
pH (range)	pH units	6.0 – 9.0	-
Salinity (EC)	µS/cm	1,000-3,000 (2)	3000-15000 (8)
Sodium	mg/L	230-460 (3)	-
Calcium	mg/L	-	1000
Chloride	mg/L	350-700 (4)	-
Sulfate	mg/L	-	1000
Boron	mg/L	2.0-6.0 (5)	5
Iron	mg/L	10.0	-
Manganese	mg/L	10.0	-
Nitrate/Nitrite	mg/L	-	400/30
Total Phosphorus	mg/L	0.8-12 (6)	-
Fluoride	mg/L	2.0	2.0
Aluminium	mg/L	20	5
Arsenic	mg/L	2	0.5
Beryllium	mg/L	0.5	-
Cadmium	mg/L	0.05	0.01
Chromium (VI)	mg/L	1.0	1.0
Cobalt	mg/L	0.1	1.0
Copper	mg/L	5.0	0.5
Lead	mg/L	5.0	0.1

Parameter	Unit	Irrigation Guideline Value (1)	Stock Guideline Value (7)
Mercury	mg/L	0.002	0.002
Molybdenum	mg/L	0.05	0.15
Nickel	mg/L	2.0	1.0
Selenium	mg/L	0.05	0.02
Uranium	mg/L	0.1	0.2
Vanadium	mg/L	0.5	-
Zinc	mg/L	5.0	20.0
BTEX compounds		-	-
PAH compounds		-	-
Phenolic compounds		-	-

(1) ANZECC 2000 Water Quality Guidelines: Water quality for irrigation waters and general use, short-term trigger values.
(2) Plant specific but this is the general range for improved pastures and likely crop types.
(3) For moderately tolerant crops – sodium range
(4) For moderately tolerant crops – chloride range
(5) For moderately tolerant to tolerant crops – boron range
(6) Requires site specific assessment
(7) ANZECC 2000 Water Quality Guidelines: Water quality for livestock drinking water requirements (the most conservative values are quoted).
(8) Approximate conversion of the TDS limits for poultry – sheep at a conversion factor of 0.65. The dairy cattle EC limit is 6000 µS/cm
- : no guideline value available

2.4.2. Water Quality Thresholds for Surface Water Discharge

The water quality of surface waters in the Avon River catchment is highly variable and is reflective of the soils and underlying geology. It is a lowland river system as defined under the ANZECC 2000 guidelines for the protection of freshwater ecosystems as stream elevations within the GGP area are less than 150 mAHD. It is also a disturbed catchment and is generally referred to as a saline catchment because of sodic and saline soils that are derived from the underlying sedimentary rocks that were deposited in estuarine and shallow marine environments (DIPNR, 2004).

It is known that the catchment flows become more saline as stream flows diminish and groundwater base-flow becomes a more dominant part of the surface water regime. High salinity outflows are also evident in stream water quality immediately after high rainfall events. The catchment water quality is not typical of the ANZECC 2000 range of 200-300 µS/cm for NSW coastal lowlands although the guidelines recognise that some coastal catchments in south eastern Australia have salinities in the range 125-2200 µS/cm (Table 3.3.3 of Volume 1 of the ANZECC 2000 guidelines).

Currently there is insufficient available data to develop site specific values in accordance with the ANZECC methodology (ANZECC recommends a minimum of two years of contiguous monthly data at the reference site before a valid trigger value can be established). Quarterly data is available since October 2011, however given the variability in water quality with high and low flows, further discussions with EPA are required to confirm whether the methodology can/should be applied at this site, and whether the data requirements (quality data sets and length of data required) are sufficient.

When there is sufficient seasonal and high-low flow water quality data available, AGL proposes to develop site specific guideline values based on actual water quality data collected from the TSW01 stream gauge site, as long term data from this site are considered to more appropriately reflect local conditions than the ANZECC freshwater ecosystem criteria. The site is located downstream of the confluence of the Avon River and Dog Trap Creek, and is adjacent to the Tiedman irrigation areas. The gauge location is shown on **Figure 11.1**.

The ANZECC (2000) guidelines for the protection of freshwater ecosystems have been adopted as the default thresholds for any stream discharges under the EWMS. The 95% trigger values for the protection of ecosystems (slightly to moderately disturbed systems) are considered the most appropriate guideline values. These values are provided in **Table 2.6**.

Table 2.6 ANZECC (2000) Criteria for Discharge to Surface Waters

Analyte	Units	ANZECC 2000 guideline values 95% protection (1)
pH	pH units	6.5 - 8.0(2)
Salinity (EC)	µS/cm	125 - 2200(2)
Dissolved Oxygen	%	85 - 110(2)
Turbidity	NTU	6 - 50(2)
Major ions		
Suspended Solids	mg/L	-
Total Hardness as $CaCO_3$	mg/L	-
Silica	mg/L	-
Fluoride	mg/L	-
Sulphur	mg/L	-
Sulphate as SO_4^-	mg/L	-
Chloride	mg/L	-
Hydroxide Alkalinity as $CaCO_3$	mg/L	-
Carbonate Alkalinity as $CaCO_3$	mg/L	-
Bicarbonate Alkalinity as $CaCO_3$	mg/L	-
Total Alkalinity as $CaCO_3$	mg/L	-
Calcium	mg/L	-
Magnesium	mg/L	-
Sodium	mg/L	-
Potassium	mg/L	-
Aluminium	mg/L	0.055
Arsenic (As V)	mg/L	0.013
Barium	mg/L	-
Beryllium	mg/L	ID
Boron	mg/L	0.37
Bromine	mg/L	-
Cadmium	mg/L	**0.0005**
Cobalt	mg/L	ID

Analyte	Units	ANZECC 2000 guideline values 95% protection (1)
Chromium (Cr VI)	mg/L	**0.0025**
Copper	mg/L	**0.0035**
Iron	mg/L	ID
Manganese	mg/L	1.9
Molybdenum	mg/L	ID
Nickel	mg/L	**0.0275**
Lead	mg/L	**0.0136**
Selenium	mg/L	0.011 (total)
Strontium	mg/L	-
Vanadium	mg/L	ID
Zinc	mg/L	**0.02**
Mercury	mg/L	0.0006
Uranium	mg/L	ID
BTEX compounds	µg/L	B – 950; T – ID; E – ID; X - 550
PAH compounds	µg/L	Naphthalene – 16; Others - ID
Phenolic compounds	µg/L	320

(1) ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystem.
(2) ANZECC 2000 - Water Quality Guidelines: default trigger values for the protection of freshwater aquatic ecosystems, South-East Australia, lowland river ecosystems. Note that the ANZECC guidelines for salinity suggest that *NSW coastal rivers are typically in the range 200–300 µS/cm* but they also state that *lowland rivers may have higher conductivity during low flow periods and if the system receives saline groundwater inputs*. The Avon River catchment is one such NSW coastal catchment where salinities exceed the typical NSW range.
(3) ID – insufficient data to determine guideline.
(4) **Bold** values have been corrected for moderate water hardness (based on ANZECC 2000 Table 3.4.4).
- : no guideline value available.

2.4.3. Comparison with NSW Effluent Irrigation Guidelines

A guideline for the irrigation of effluent was prepared by the NSW Department of Environment and Conservation (now EPA) in 2004 (DEC, 2004). This guideline is educational and advisory in nature and relates to the irrigation of effluent. Extracted water is not captured under the current definition of effluent. It is not a mandatory or regulatory tool. The emphasis is on best management practices related to the management of effluent by irrigation, to be used to design and operate effluent irrigation systems, with the goal of reducing risks to the environment, public health and agricultural productivity.

The objective of the effluent guideline is to manage waste waters with high nutrient loads where that water is irrigated and beneficially reused. AGL's extracted water is mostly natural waters that are low in nutrients but high in salinity.

The effluent water quality and irrigation considerations outlined in the guideline are summarised in **Table 2.7.** The guidelines reference the ANZECC (2000) irrigation guidelines and the long term (100 years) threshold values for metals.

Table 2.7 Effluent Water Quality Guidelines and Suggested Trigger Values

Analyte	Units	Effluent Irrigation Guidelines (1)
pH	pH units	5.0 - 8.5
Aluminium	mg/L	5
Arsenic	mg/L	0.1
Beryllium	mg/L	0.1
Cadmium	mg/L	0.01
Cobalt	mg/L	0.05
Chromium (Cr VI)	mg/L	0.1
Copper	mg/L	0.2
Iron	mg/L	0.2
Manganese	mg/L	0.2
Mercury	mg/L	0.002
Molybdenum	mg/L	0.01
Nickel	mg/L	0.0275
Lead	mg/L	2
Lithium	mg/L	2.5
Nickel	mg/L	0.2
Selenium	mg/L	0.02
Zinc	mg/L	0.2

(1) These trigger values are lower than the short term (20 year) threshold values proposed in Table 2.5 for irrigation reuse.

It is proposed to adopt the values in **Table 2.5** as the threshold values for irrigation and stock reuse under AGL's EWMS given the relatively short periods that treated water will be available for reuse.

3. Background Studies

3.1. AGL Irrigation Program Studies

AGL irrigated produced water from historical exploration (mostly pilot testing) programs ahead of the commencement of the GGP. The Tiedman Irrigation Program (TIP) approval recently expired and was for a maximum of 70 ML of produced water over a maximum area of 40 ha. The water from exploration programs, which was stored in the Tiedman and Stratford ponds, was blended with freshwater sources to provide a water quality suitable for irrigation use.

The surface water and groundwater monitoring program commenced in October 2011 and was established in accordance with the approved Tiedman Water Management Plan (AGL 2012). The program ensured that the quality of the water used for irrigation met the ANZECC irrigation criteria (refer **Table 2.5**) and that the application of irrigated water did not result in impacts on the local surface water or groundwater resources. Water level and water quality data were evaluated for each monitoring period together with periodic soil sampling reports for the irrigation area.

Blended water irrigation occurred across two areas on the Tiedman property; the Stage 1A area – 12 ha and the Stage 1B area – 4 ha. The irrigation areas are shown on **Figure 3.1**.

Monitoring of the TIP has indicated that marginal to brackish irrigation water can be irrigated successfully in this high rainfall landscape. The TIP ended on 30 April 2015 with the reuse of 54 ML of the original 55 ML of produced water that was in storage. During the irrigation program period from April 2013 to April 2015, approximately 130 ML of blended water (with a salinity of around 1,500 µS/cm) was irrigated across 16 ha with the following results:

- There were no salinity impacts to the Avon River and the underlying groundwater system.
- Treated soils were effective in minimising the SAR hazard.
- Salt tolerant crops grew effectively and productivity was high.
- There was some salt exported in crops.
- There was some slight build-up of sodium in the soil profile, but the loading was small.

A series of six-monthly water compliance reports were prepared as part of the approval requirements of the Division of Resources and Energy (DRE) and Office of Coal Seam Gas (OCSG). These are:

- The baseline and the initial irrigation period to 30 June 2013 (PB 2013c).
- The period 1 July 2013 to 31 December 2013 (PB, 2014a).
- The period 1 January 2014 to 4 July 2014 (PB, 2014d).
- The period 5 July 2014 to 31 December 2014 (PB, 2015a).
- The period 1 January 2015 to 30 June 2015 (PB, 2015c).

The findings of the most recent water compliance report were that monitoring during the approval period to 30 April 2015 showed that there was no change in stream levels, alluvial or shallow fractured rock groundwater levels attributable to the irrigation program activities. Similarly there was no change in the water quality characteristics of the adjacent Avon River and underlying groundwater systems. Salt tolerant crops have been successfully grown with no impacts to surface water or shallow groundwater.

These studies have confirmed that deficit irrigation with appropriate monitoring is a suitable reuse approach for produced water. The studies have demonstrated the beneficial reuse of blended produced water through irrigation.

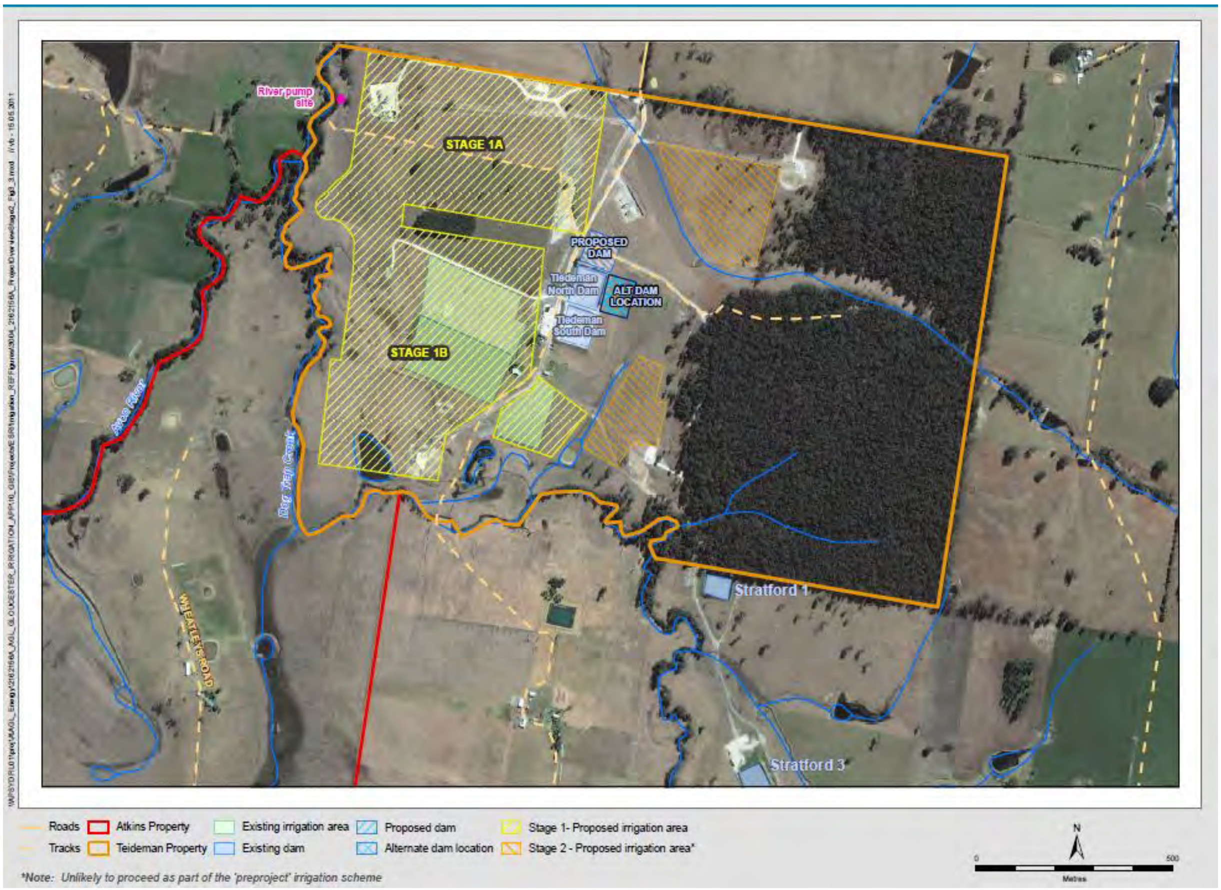


Figure 3.1: Tiedman Irrigation Areas

3.2. AGL Water Monitoring Network and Program

AGL implemented an extensive surface water and groundwater monitoring program in 2011. For this program, a comprehensive groundwater network comprising nested monitoring bores was established. Subsequent and ongoing site investigations have continued to expand this network. The current water monitoring network across the Stage 1 GFDA is 40 groundwater and ten surface water monitoring sites (plus there is more monitoring across the remainder of the basin). Four annual monitoring reports (for years 2012, 2013, 2014 and 2015) have been published for the groundwater monitoring data for the period January 2011 to June 2015. There is currently more than 54 months of baseline project and exploration project water data. PB 2015g focuses on the last monitoring period (July 2014 to June 2015). These reports are available on AGL's project website at http://www.agl.com.au/about-agl/how-we-source-energy/natural-gas/natural-gas-projects/gloucester-gas-project/gloucester-gas-project .

The status reports highlighted that groundwater level trends in the monitoring bores vary depending on the climatic conditions, the lithology and depth of the screened interval. These reports provided the following observations:

- Groundwater levels in monitoring bores screened in the alluvial deposits respond rapidly to significant rainfall events.
- Groundwater levels in shallow rock monitoring bores decrease slightly in response to the below average rainfall and increase slightly in response to the above average rainfall. There are no strong responses to individual rainfall events in the shallow rock monitoring bores.

- Groundwater levels in interburden and deep coal seam monitoring bores show minimal change over the monitoring period, and groundwater levels do not respond to individual rainfall events.
- Alluvial aquifer water quality is fresh to slightly saline, has slightly acidic to neutral pH and reducing conditions exist. The major ion chemistry is sodium-chloride dominant.
- Groundwater in the shallow rock unit is marginal to slightly saline, has neutral to alkaline pH conditions. The major ion chemistry is sodium-chloride-bicarbonate dominant.
- Groundwater quality of the interburden is brackish. The major ion chemistry is sodium-chloride dominant.
- Groundwater salinity in the deep coal seams is typically brackish to slightly saline, with neutral to alkaline pH. The major ion chemistry is generally sodium-chloride-bicarbonate dominant.

This comprehensive monitoring program is continuing at the dedicated groundwater and surface water sites in accordance with the existing program. In addition to the annual status reports there are regular updates prepared on water level trends. All results are published periodically on AGL's Gloucester website.

Some of these monitoring locations will be key site locations for where AGL is undertaking irrigation reuse or controlled stream discharge. Further details will be provided once AGL's Groundwater Monitoring and Modelling Plan (GMMP) for Stage 1 has been prepared.

3.3. AGL Flow Testing Programs

There have been few flow testing programs in recent years to fully characterise the deep groundwater (produced) water quality across the Gloucester Basin. The best available water quality information is from testing programs on Waukivory 03 and Craven 06 in 2013/14 (PB, 2014c, PB, 2015b) and the four gas wells that are the Waukivory pilot in 2014/15 (PB, 2015c, 2015d, 2015e and 2015f). The produced water quality from Craven 06 is slightly saline, is sodium-chloride-bicarbonate dominant, is low in trace metals and has few other analytes. Total BTEX and TPH concentrations were low. This water quality has been used extensively in this EWMS as being typical of expected produced water qualities across the Stage 1 GFDA. However a more conservative water quality range will be used for the purpose of desalination plant design.

The Waukivory fracture stimulation and flow testing program is providing additional information on water production profiles and water quality.

3.4. AGL Hydrology Study

A hydrology study of the Avon River catchment (and downstream areas) was completed in 2014 (PB, 2014b). The purpose of this study was to characterise surface water features across the Gloucester Basin, particularly in the vicinity of the GFDA by reviewing surface hydrology and water quality information previously collated and collecting additional data following a gap analysis.

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. Based on water levels within the Stage 1 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.

Different water quality results were recorded during high and low flow events. Salinity and dissolved metal concentrations are generally lower during high flow sampling events (apart from an initial salinity spike) compared to routine water quality monitoring conducted during lower flows.

This information was useful in determining likely river locations and conditions for the discharge of excess treated water during extreme rainfall and high river flow periods.

Other hydrology and salinity studies conducted by others have similar catchment conclusions. Although high salinity values have been recorded in the Avon River catchment, the higher flow volumes of lower salinity water from the Gloucester River and Barrington River, have the ability to dilute natural salt loads from the Avon River (DIPNR 2004).

3.5. Gloucester Shire Council - Baseline Water Surveys

Gloucester Council (using consultants SMEC), under the Water Study Project initiative (see Section 7.9), completed baseline water surveys of properties in private ownership within and immediately adjacent to the Stage 1 GFDA in March 2014. Properties owned by GRL, Yancoal and AGL were not included in the water surveys. GRL has confirmed that there are no existing groundwater supply works on their properties. There are no existing groundwater supply works at AGL's properties.

The surveys involved sighting all private water supply sites and infrastructure, and taking water samples from:

› All groundwater assets (if present).

› From at least one surface water site.

› One rainwater tank water site.

Property survey reports were sent to all landowners and summary information is available from http://www.gloucester.nsw.gov.au/environment/water-study-project-new/baseline-water-survey

The surveys did not locate any groundwater bores or shallow wells/excavations within the Stage 1 area (only two spring fed dams). Summary details are provided in **Table 3.1**.

Table 3.1 Summary statistics from the property surveys – Stage 1 GFDA

Attributes	Number / Description
Number of properties surveyed	19
Number of bores and wells	Zero
Number of springs/spring fed dams	2
Number of dams #	14
Number of surface water sites #	10
Number of rainwater tanks #	14
Typical usage	Springs – Stock Dams – Stock and irrigation Creeks and rivers – Stock and irrigation Rainwater tanks – Domestic

Note # - these are the sampled sites only and not necessarily the total number of sites

There is negligible groundwater used for water supply in the Stage 1 GFDA. The two identified spring locations intercept either perched groundwater or shallow groundwater (from fractured rock) in the landscape. Water from rivers and creeks or overland flow captured and stored in farm dams is the primary source of supply for agriculture and grazing. Tank water is used for potable and non-potable domestic purposes.

In relation to the EWMS, these surveys have emphasised the importance of surface water sources over groundwater sources.

3.6. Gloucester Shire Council – Flood Study

Gloucester Council (using consultants BMT WBM), under the Water Study Project initiative (see Section 7.9), completed a major flood study of the Avon and Gloucester River catchments in 2014/15. Both the CPF site and the Tiedman property where most of the above ground water infrastructure and irrigation areas are sited, are located off the Avon River floodplain and beyond the 1:100 and PMF flood limits (BMT WBM, 2015).

3.7. Bioregional Assessment Study

The Gloucester Sub-region Bioregional Assessment (GSBA), is funded by the Commonwealth Department of the Environment, and is part of the Bioregional Assessment Program (BAP) being delivered by the Office of Water Science. The context statement for the Gloucester Sub Region was released in May 2014 (DoE, 2014a), the coal and CSG resource assessment statement in October 2014 (DoE, 2014b), and the water dependent asset register in January 2015 (DoE, 2015a).

The GSBA is an independent scientific analysis of the current extent of knowledge on the ecology, hydrology, geology and hydrogeology of the Gloucester sub region with an explicit assessment of the potential direct, indirect and cumulative impacts of CSG and large coal mining developments on water dependent assets.

The GSBA provides information that is relevant to understanding the regional context of water resources within which CSG and coal mining development is occurring. The remaining studies of the GSBA will involve numerical modelling and address many of the water assets and attributes of the catchment.

4. Evaluation of Extracted Water Options

4.1. AGL's EA Produced Water Options

Numerous options were identified for the beneficial use or disposal of the produced water and treated water in the Environmental Assessment (EA) for Stage 1 of the GGP (AECOM, 2009). The suitability of each option was qualitatively evaluated based on the following criteria:

› Technical.

› Environmental.

› Social.

› Economic.

› Regulatory.

Each option was given a score out of 25 (higher score represents a better outcome) based on the criteria. The results from the EA for different reuse and disposal opportunities for produced water and brine are summarised in **Table 4.1.**

The assessment in the EA indicated that the reuse of produced water for irrigation (agriculture and horticulture) and stock watering would be the most beneficial to the community and also result in the fewer (potential) environmental issues once the produced water is treated to meet acceptable standards. The assessment also highlighted that stream discharge was favoured as the preferred disposal strategy if reuse opportunities were limited.

For the final solid salt product, the assessment indicated that the transport of the product to a salt producer for reuse would be the most suitable method of disposal.

Based upon the quality of produced water from the early pilot wells, the EA considered that treatment of the produced water would be required prior to beneficial reuse or disposal.

A number of produced water treatment technologies were discussed in the EA, comprising:

› Sterilisation.

› Evaporation.

› Filtration.

› Desalination:

  » Reverse Osmosis (RO);

  » Capacitive Desalination (CDI);

  » Electrodialysis Reversal (EDR);

  » distillation; and

  » SAR reduction.

The EA considered that the RO desalination process is the most suitable produced water treatment option. The RO desalination process results in two streams: a low salinity water stream (treated water); and a concentrated brine stream.

Table 4.1 Options Considered for Produced Water and Brine Disposal and/or Reuse (*AECOM, 2010*)

Disposal/ Use	Description	Treatment	Result	Comment
Water Disposal / Reuse Options				
Produced Water				
Surface Discharge	Discharge of all produced waters to a receiving surface waterway	Salt removal to meet approval requirements	15	Treatment necessary for discharge approval. High cost for no beneficial use
Underground Re-injection	Re-injection of produced water into coal seam or other aquifer	Likely to be required	7	Significant investigation and field studies would be required to prove feasibility
Evaporation	Evaporation of all produced water	Mechanically assisted process required as climate is not conducive to solar evaporation	10	Capital and energy intensive
Removal	Transport all water in trucks to licensed disposal facility	Not required	14	Costly solution that has positive and negative impacts
Recharge Ponds	Store produced water in shallow ponds to allow recharge to shallow aquifers	Salt removal to meet requirements	7	Significant investigation and field studies would be required to prove feasibility
Artificial Wetlands	Use a constructed wetland to treat water and provide wildlife habitat	Salt removal likely to eliminate issues with long-term loading	12	Long-term loading and water quality maintenance issue.
Recreation	Constructed storage to create facility for local recreation (water sports, wildlife habitat)	Treatment required to improve quality	12	May not be suitable in local landscape. Long-term water supply issue.
Stock watering	Supply of produced water to local farms for stock watering	Some salt removal or dilution required, though less than other options	17	Impractical disposal option for all flows though viable in combination with other agricultural uses.

Disposal/ Use	Description	Treatment	Result	Comment
Water Disposal / Reuse Options				
Irrigation (agriculture)	Supply of produced water to local farms for irrigation	Salt removal required	20	Practical beneficial use for water appropriate for local land use
Irrigation (horticulture)	Supply of produced water to local horticultural or agribusiness operations	Salt removal required	20	New business opportunities. Appropriate beneficial use.
Aquaculture	Supply of produced water to an aquaculture enterprise	May not be required	15	Challenging management of flows. Local operator would be required.
Industrial	Supply of produced water to local industry most likely coal processing	Would be determined by end user	14	No identified demand; sharing disposal with mine influenced by expected mine life
Municipal	Supply of water to supplement local town potable supplies or for irrigation of municipal reserves and properties	High level of treatment required for potable supply	14	Not an economic alternative to existing (adequate) supplies
Brine				
Evaporation	Evaporation of concentrated waste stream in purpose built evaporators	Not applicable	14	Standard approach to waste disposal in inland areas; probably not viable in high rainfall/coastal areas
Aquifer Re-injection	Injection of concentrated waste stream into coal seam or other aquifers	Not applicable	7	Costly investigation, infrastructure and approval process
Transport	Haulage of all concentrated waste to licensed disposal facility	Not applicable	14	May be suitable for low volumes
Salt Production by transporting salt to a salt producer	Use of advanced yet proven technology to create a saleable salt product and zero liquid emissions	Not applicable	17	Ideal solution if feasible. Requires investigation and interest from third party.

The EA proposed that the extracted water would be stored in a receiving water pond (maximum 25 ML). Post treatment the treated water would be stored in a maximum 25 ML treated water pond and 25 ML discharge water pond). Treated water would then be transferred to the Tiedman property prior to reuse or disposal. The capacity of the additional water storage (three holding ponds) at the Tiedman property was to be 60 ML. Management of the treated water was to be through reuse (e.g. such as irrigation) or, if reuse is not possible, discharge to surface water.

The EA identified that concentrated brine was to be stored separately to the treated water in a brine tank at the CPF.

Based on the options analysis in the EA (AECOM, 2009), the top six water reuse/disposal options were:

› Treated water for irrigation.

› Treated water for local horticultural or agribusiness.

› Supply of produced water to local farms for stock use.

› Discharge of treated water to a receiving surface waterway.

› Aquaculture.

› Salt production by exporting the salt to a salt producer or landfill.

These preferred options align with those options in the recent GSC study (RPS, 2014) described in Section 4.2.

4.2. Gloucester Shire Council - Produced Water Evaluation Study

A water evaluation study was prepared for Gloucester Shire Council by consultant RPS Group, as part of an independent assessment of produced water disposal and reuse options for Stage 1 of the GGP (RPS Group, 2014).

The water evaluation study identified a number produced water reuse and disposal options covering a wide spectrum of possibilities.

Produced water reuse options considered were:

› Irrigation of industrial crops (hemp), pasture and feed crops (lucerne).

› Intensive and non-intensive livestock farming, which includes cattle (beef and dairy), sheep and pig farming.

› Poultry farming.

› Intensive (recirculated) aquaculture, which includes inland fresh to saline aquaculture.

› Silviculture for timber production.

› Energy and Mining Sector, which includes, among others, reusing water for drilling and hydraulic fracture stimulation as part of the gas extraction process and coal washing at the nearby coal processing facilities.

› Industrial and commercial sector, and non-potable applications, which included water for concrete production and irrigation of urban parks and green areas.

› Drinking water supply, direct (into the supply network) or indirect (surface water discharge upstream of drinking water off-takes).

› Aquifer Storage and Recovery (ASR) in shallow aquifers (nominally less than 150 m depth) for later irrigation use.

Produced water disposal options considered were:

- Direct surface water discharge to regional water bodies, including the Avon River, Mammy Johnsons River and Gloucester River.
- Direct sea discharge.
- Reinjection to deep aquifers, including re-injecting the coal seam aquifers after gas extraction has been completed.
- Surface water storage and/or evaporation.

The evaluation concluded that none of the produced water reuse and disposal options are feasible as stand-alone options. However, a combination of complementary options were assessed and found to be potentially viable. These included:

- Irrigation of industrial crops (like hemp), pastures or feed crops (like lucerne) is a feasible and preferred option in combination with other options.
- Irrigation in combination with livestock intensive farming is a preferred option, possibly with a degree of storage and/or disposal to meet the water production to demand unbalanced schedule.
- Intensive (recirculated) aquaculture was considered a feasible and preferred option in combination with other options, mainly because it requires a constant water supply that can be tailored to match the production rates.
- Silviculture (forestry) was considered a feasible and preferred option in combination with other options, mainly because of its low initial and ongoing costs and the environmental benefits associated.
- The Energy and Mining application sector was identified as a feasible and preferred option in combination with other options, primarily due to the existing coal mining industry in the region.
- Irrigation of urban parks and green areas is also a feasible and a preferred option in combination with other options.
- Artificial Storage and Recovery (ASR) of shallow aquifers was evaluated as a means of storing water for irrigation uses, which may or may not be feasible subject to finding a suitable location and depending on particular conditions of the shallow aquifers in the region, especially permeability and achievable injection rates.

Direct surface water discharge to surface water such as the Avon River was feasible but not preferred unless it was a lesser option associated with a feasible and preferred reuse option. Combined options are more likely to be successfully implemented, especially if the options chosen are complementary and make the most of the productivity of the land and water used.

In summary, the preferred reuse groupings from this independent assessment were:

- Irrigation.
- Livestock.
- Aquaculture.
- Industrial.

The water evaluation study conclusions are consistent with the preferred water management strategy outlined in AGL's Environmental Assessment (EA) (AECOM, 2009).

4.3. Re-evaluation of Options

A re-evaluation of preferred reuse options from the EA (AECOM, 2009) and options revisited in Councils independent options assessment (RPS Group, 2014) was completed as part of the finalisation of this EWMS. The 2014 EWMS consultation process has also confirmed these preferred reuses.

AGL's justification for adopting irrigation and stock usage is as follows:

› The Stage 1 GFDA is located with a primary production area (agriculture, grazing and mining) and reuse for irrigation and stock are appropriate local land uses.

› The availability of a supply of treated water (albeit small) will improve the drought security of local farms by providing new water and the opportunity to grow additional crops and improved pasture to provide additional stock feed.

› New business opportunities may arise if there is sufficient new water.

These reuses were supported in the agency and community submissions, and AGL has already received a number of 'Expressions of Interest' from local farmers for the use of this treated water.

In addition AGL has included industrial reuse for its own drilling and fracture stimulation programs. By reusing as much extracted water as possible, and recycling it for multiple drilling and fracture stimulation programs, this practice ensures there is a minimal take from town water and other freshwater sources. This reuse will be the predominant reuse of treated water during the initial years of the project.

The following reuses were discounted from the recommended combinations in the RPS study:

› Intensive livestock production – there are no intensive livestock operations located close to the Stage 1 GFDA and no new industries are likely in the short to medium term. Given the relatively small volumes of water likely to be available longer term, occasional stock use for beef and dairy cattle on existing properties is considered a better stock water supply option.

› Aquaculture – there are no existing aquaculture operations located close to the Stage 1 GFDA and no new industries are likely to emerge in the short to medium term. Also further investigations and research would be required to assess whether the variable water quality would be suitable for different fish and crustacean species.

› Silviculture (forestry) – there are no plantation forestry operations located close to the Stage 1 GFDA and no new industries are likely to emerge in the short to medium term.

› Mining – further discussions with the miners suggest they have sufficient freshwater and mine water for their process water applications at this time. Discussions suggest that miners may provide water to AGL for reuse rather than vice versa.

› Irrigation of urban parks and green areas – Council expressed no interest in using treated water within Gloucester for non-potable uses. Also at the present time, CSG infrastructure is prohibited within the 2km residential buffer area so such a scheme would be difficult to build and operate.

› Artificial Storage and Recovery (ASR) – data and desktop technical feasibility assessments suggest that reinjection would not be viable unless the treated water volumes were very small and a suitable high permeability and depleted storage location was identified. Groundwater recharge is prohibited under the current planning approval and NOW is not supportive of any ASR scheme.

5. AGL's Preferred Water Reuse and Discharge Strategy

AGL has re-evaluated the original beneficial reuse proposals presented in the EA in 2009 (AECOM, 2009 and 2010), reviewed the broad opportunities that were described in the Gloucester Shire Council report (RPS Group, 2014), and reviewed the results of the Tiedman (blended water) irrigation program (PB, 2015a).

Upon consideration of the options and following community feedback, AGL's preferred strategy for managing extracted water for the Stage 1 GFDA is:

- Treatment and desalination of extracted water to produce treated water and brine.
- Reuse, when required, of treated water for CPF processes, and drilling, fracture stimulation and workovers (i.e. working water).
- Beneficial reuse of treated water for stock and irrigation purposes.
- Discharge of treated water to streams (when irrigation is not possible and high flows are occurring along the Avon River).
- Landfilling of the primary solids from the pre-treatment process to an appropriately licensed facility.
- Landfilling of the mixed salt from the brine stream to an appropriately licensed facility.

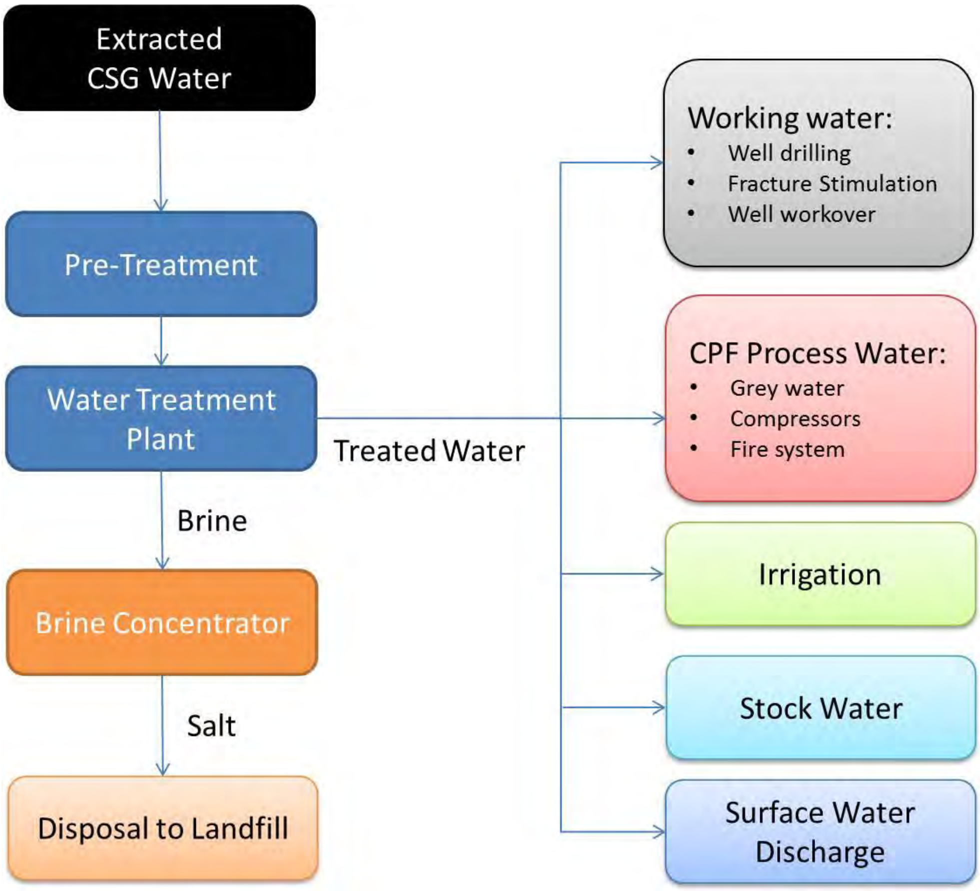
Treated water reuse will be maximised and treated water river discharge will be minimised (and potentially will be zero if average rainfall conditions prevail and water production rates are as predicted in the early years of the project).

A small but useful new source of low salinity water will be available for consumptive uses within the northern Avon River catchment. All new water for consumptive uses will be piped to the reuse areas. The Avon River will not be used as a distribution channel for treated water during low flow periods. The mixed salt removed from the extracted water via desalination and salt concentration and crystallisation processes will be trucked off-site and disposed to licensed facilities outside of the catchment as general solid waste (GSW) (non putrescible).

Water balance modelling together with the current water production profile for 110 wells has been used to generate the volumetric estimates for treated water for reuse and brine water for disposal. A separate report for the water balance modelling is provided in **Appendix B**.

5.1. Extracted Water Management Components

The proposed extracted water management system is shown in **Figure 5.1**. This flowchart generally represents the proposed flow path options for extracted water for Stage 1 of the GGP.



(Note – the treated water is the final desalinated water)

Figure 5.1: Extracted Water Management Flowchart

AGL has undertaken a comprehensive assessment of the options for water reuse and discharge and has identified the following engineering components for the preferred strategy:

- Centralised water treatment plant to be located at the CPF.
- Pre-treatment of extracted water prior to desalination.
- Desalination of extracted water for:
  - working water (drilling, fracture stimulation, and well workover),
  - CPF process water,
  - beneficial reuse, and
  - surface water discharge.
- Brine concentration.
- Crystallisation of brine water.

The engineering components of the strategy are described in the following sections.

5.1.1. Extracted Water Gathering System

The extracted water gathering system consists of a central spine line with a network of smaller pipelines from each of the wells. The flowback and produced water will be gathered and transferred to the receiving water pond (RWP) located at the CPF through the main water gathering lines. It is proposed that an additional (return) line will be installed adjacent to the extracted water gathering line to provide working water to each well for drilling, fracture stimulation and work-over requirements (and potentially stock watering purposes).

A third (bi-directional) water pipeline will be installed between the Tiedman storages and the CPF to allow water (mainly treated water) to be transferred between these two storage facilities. Installation of extracted water and working water lines will reduce the number of vehicle and truck movements within the Stage 1 GFDA over the life of the project.

5.1.2. Water Treatment Plant

The water treatment plant (WTP) will be located at the CPF and will comprise all the plant and equipment from the receiving water pond (RWP) to the discharge water pond (DWP). The primary components are:

Pre-treatment systems

The extracted water will be treated by several pre-treatment systems to remove particulate matter, compounds that could scale the RO membranes, and residual fracture stimulation additives to render this water acceptable as feed water to the reverse osmosis (RO) plant.

The proposed pre-treatment systems prior to the RO plant include:

› Dissolved air flotation (DAF) unit.

› Disc filtration (DF) unit.

› Microfiltration and ultrafiltration (MF/UF) units.

› Ion exchange (IX) unit.

For the GGP start-up, it is expected that water from freshwater sources or any residual water located in AGL's Tiedman storage ponds from exploration programs will be used and processed through the pre-treatment systems and the RO plant. This water will gradually be recycled and replaced by flowback water and produced water from the fracture stimulation, dewatering and commissioning phases of the Stage 1 program.

Desalination plant

Water from the pre-treatment system will be desalinated by the RO unit. RO membrane separation technology is the preferred desalination option to treat the extracted water generated over the life of the project. RO is well proven, robust and is widely applied within the Australian CSG industry as the preferred desalination technology.

RO desalination potentially offers the lowest life cycle cost and the highest water recovery (i.e. potentially treated water recovery greater than 85%) to minimise the size, capital cost, and energy consumption. High water recovery will also reduce the operating cost associated with the further treatment of the RO brine concentrate which is likely to use thermal brine concentration and crystallisation technology to produce salt.

Post Treatment systems

Any residual hydrocarbons in the treated water from the RO plant will be treated and removed by using granulated activated carbon (GAC) located between the RO plant and the treated water tank/s (TWT).

5.1.3. Brine Management Plant

Based on the composition of produced water and the design of the WTP, a small brine stream will be produced over the life of the project. A preliminary review of a wide range of brine management options was undertaken with the preferred option involving a brine concentration and crystallisation process which produces a mixed salt.

AGL's preferred approach is the production of a mixed salt suitable for transport to a licensed facility as GSW in accordance with regulatory requirements. This approach will remove all the salt from site (and the Avon River catchment).

At this stage, the variable composition of the salt, and the low and variable volumes produced means that it is unlikely to be commercially viable to reuse this product. However, the design of the WTP and brine management plant will be such that new treatment technologies and reuse applications can be 'bolted on' in the future if appropriate.

5.1.4. Water Reuse and Discharge

To maximise beneficial reuse of the treated water, AGL prefers irrigation and stock as the prime beneficial reuses with rare discharge to the Avon River at times when irrigation and storage is not possible. The water volumes proposed for process water reuse are small by comparison with irrigation use. Working water volumes are higher for the first three years but are negligible thereafter. The treated water quality will be managed to ensure that:

› Only one treated water quality type will be generated and this quality will be the lowest salinity required for irrigation, stock, working water or stream discharge purposes.

› The water quality for irrigation will not exceed the water quality thresholds for irrigation and stock use (see Section 2.4.1).

› The water quality for discharge to the Avon River will not exceed the ANZECC environmental thresholds and flow conditions (see Section 2.4.2).

In practice the target water quality able to be achieved by the WTP for the treated water will be significantly lower than the proposed irrigation and river discharge water quality thresholds. The target water quality criteria will be the adopted criteria for treated water reuse and stream discharges.

5.1.5. Water Production Profile

The water production profile for Stage 1 has been revised based on the expected design and construction, fracture stimulation and commissioning schedules for the 110 gas wells that will comprise the Stage 1 development. Based on the latest available information on geology, flow rates and likely schedule for field development, extracted water volumes are expected to be much lower than the approved 2 ML/d.

These aggregated water production profiles are shown in **Figure 5.2** for the P10, P50 and P90 water production scenarios. The profiles are shown in cubic metres per day (m^3/day). Curves are also compared against the P50 water production profile for extracted water that was used in earlier water projections.

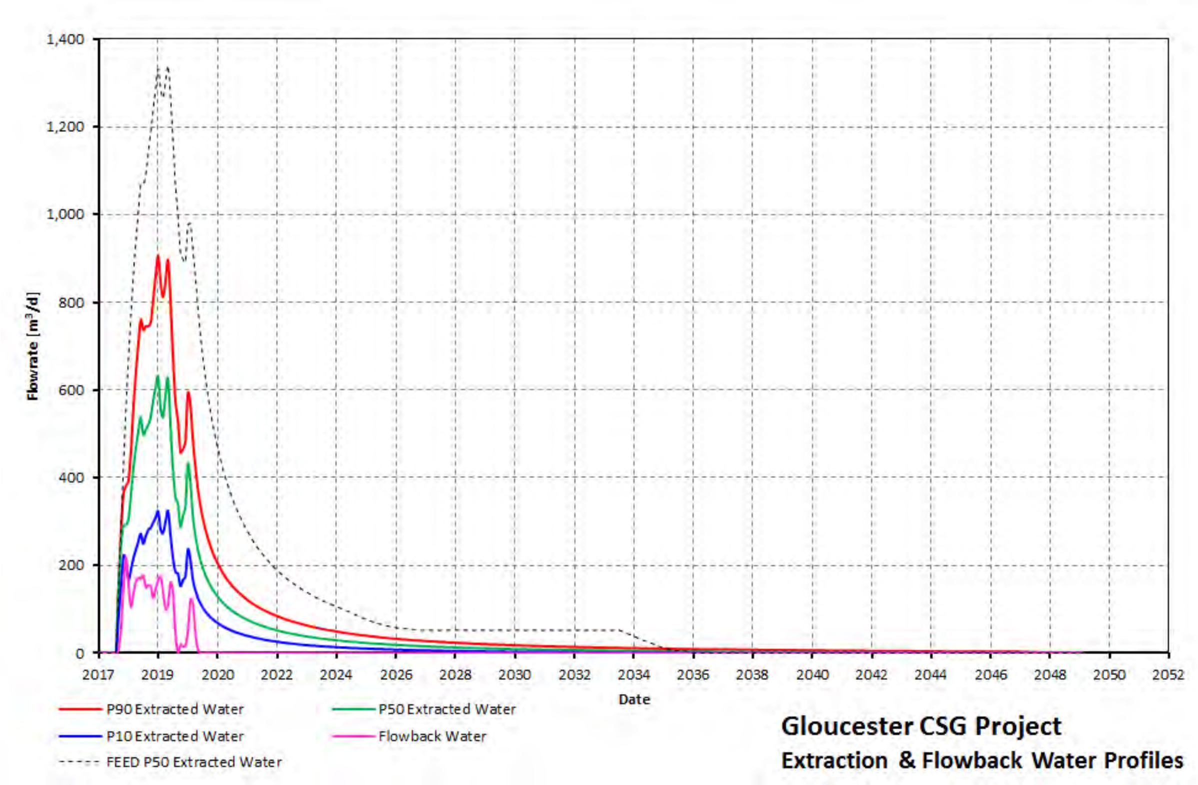


Figure 5.2 - Predicted extracted water flow profiles

The current water balance modelling (Worley Parsons, 2015) is presented in **Appendix B**. Modelling suggests that the maximum (P90) water production rates (for extracted water) will be peak at around 0.9 ML/d within the first 36 months. Flows will then diminish to less than 0.1 ML/d after five years.

5.2. Reuse for Working Water

Working water is water that has been treated at the WTP and is suitable for return to the field for drilling, fracture stimulation and well workover purposes when required. Water will be treated at the WTP to a high standard to meet all reuse and discharge requirements.

Drilling

It is estimated that approximately 0.5 ML of water will be required for drilling at each well. Initially, drilling water will be sourced from existing holding ponds at Tiedmans or freshwater sources. When and if available, treated water will be used in preference to these water sources. However given the early timing for the drilling program, treated water is unlikely to be available for the first 50% of new gas wells.

Fracture Stimulation

The initial fracture stimulation water will be sourced from AGL's existing holding ponds at Tiedmans or freshwater sources at the start of the fracture stimulation campaign. Once treated water from the WTP is available, this water will be used for fracture stimulation. AGL estimates between 0.5 and 1.5 ML of water will be required to fracture stimulate each well (and average around 1 ML per well). Water volumes will be dependent on the final well designs and the number of fracture stimulation intervals. It is estimated that the total demand for fracture stimulation water will be approximately 100 ML over the entire well development phase.

Workovers

Well workover operations will be conducted over the life of the project and are likely to be approximately 0.05 ML per well. Working water will be sourced from treated water from the WTP. It is expected that workover frequency and associated working water demands for each well will be highest in Years 2 to 5 with a large decrease beyond Year 5.

5.3. Reuse for CPF Operations

There will be a small demand for water at the CPF to supply the following:

› General use (e.g. for non-potable domestic needs).

› Process water for compressors and cooling systems.

› Service water for wash down, maintenance, landscaping and dust suppression.

These demands for water at the CPF will be sourced from the treated water tank (TWT) or the discharge water pond (DWP) within the WTP. The quantity of water required to supply CPF operations is very small and is estimated to be approximately 2 ML per year.

Drinking water at the CPF will be trucked to the site from a potable water supply source.

5.4. Reuse for Agricultural Purposes

5.4.1. Reuse for Stock

There will be a small demand for stock water supplies on AGL owned properties and neighbouring properties within and adjacent to the Stage 1 development. Quantities and flow rates are dependent on seasonal conditions and contractual arrangements to supply stock water. These have not been determined at this time. The stock reuse component is part of the treated water volume identified for irrigation reuse. Water is expected to be delivered via the working water delivery lines and will be to a high standard defined by other beneficial reuses. It is expected that this water will be stored on-farm in tanks, troughs, and farm dams.

5.4.2. Reuse for Irrigation

Under this irrigation reuse option, treated water from the WTP would be transferred to storage ponds at the Tiedman property and applied to local crops and pasture.

Crops potentially available for cultivation would include lucerne, hemp, forage sorghum, triticale and oats. The improved pasture is likely to be a mixture of kikuyu, ryegrass, clover and chickory. The rate of water uptake by these crops/pasture is estimated to be approximately 4 ML/ha/year in an average rainfall year. This estimate is based on the irrigation program that was successfully conducted at the Tiedmans property from April 2013 to April 2015. Irrigation rates are expected to be seasonal and vary according to soil moisture and weather conditions. Demand for irrigation water will be higher during dry periods when evapotranspiration rates are high (mostly spring and summer). Seasonally the irrigation application rates could vary between 2 ML/ha/year and 6 ML/ha/year.

5.4.3. Future Water Opportunities

Over the course of the project, new opportunities may arise for the beneficial use of untreated and treated extracted water. As part of the Consultation Draft dialogue, AGL made an initial call for 'Expressions of Interest' from third parties for use of both water (treated and untreated) and salt. Eight expressions of interest were received for the use of desalinated water for irrigation and stock purposes. AGL will continue to identify potential third party users for both water and salt.

There is the opportunity to supply farming properties with treated water close to the proposed reticulated water pipelines. Treated water will be suitable for both stock and irrigation uses so there is the potential for farmers to be supplied with additional water or replacement water during periods of drought. Stock water is a higher priority than irrigation water and hence it is expected that stock supplies would be maintained in preference to irrigation supplies.

The ongoing availability and quantity of this water for external consumptive uses will diminish with time and there are risks regarding new developments based on what could be a limited and declining water supply if subsequent stages are not developed.

Gloucester Shire Council's Agricultural Working Group (AWG) is also assessing potential new industry opportunities for the Gloucester area. If good quality water is available (even for start-up periods of around 5 years) then new opportunities such as industrial hemp, saline aquaculture and silviculture may emerge (although it is again stressed that water availability is limited and start up opportunities would have to align with the early years of the GGP). Further details are provided in RPS Group, 2014.

Expansion of the existing dairy and beef industries depends on the availability of improved pastures and/or fodder crops. Water for irrigation is limited from surface water sources and desalinated water (which is new water from the deep groundwater systems) is only expected to provide a small increase in available water supplies.

Even assuming high water production rates (P90 case), modelling suggests that the water for irrigation and stock use will peak at just over 200 ML/yr in the early years of production and average less than 60 ML/yr for the whole operational period (Worley Parsons, 2015). This new water represents less than a 10% increase on estimated current water use for these purposes across the catchment (RPS Group, 2014).

5.5. Surplus Water Discharge to Surface Water

The last (and least favourable) extracted water management option is to discharge treated water to surface water. There will be no discharge of (untreated) extracted water to any surface water receptors. Discharge to the Avon River will only occur when the preferred irrigation and stock options are not available due to climatic conditions, namely extreme wet weather periods, and there is insufficient detention storage capacity for treated water for an extended period.

Treated water reuse will be maximised and treated water river discharge will be minimised (and potentially will be zero if average rainfall conditions prevail and water production rates are as predicted in the early years of the project).

AGL has completed an ecological and geomorphological assessment study to confirm a suitable discharge location along the Avon River (Cardno, 2015). Further details are provided in Section 9.2 and **Appendix C**.

If extreme rainfall conditions prevail during the early years of the development, small discharges of treated water into the Avon River may be required as a 'pressure relief valve' on the system. Total volumes are expected to be less than 20 ML. These projections only occur for the worst case climate conditions and only for the peak of the extracted water production period in Year 3 of the project

(Worley Parsons, 2015). After the first three years, AGL does not expect to use this option as there will be sufficient storage for produced water and treated water in all but the wettest years.

Discharges (if required) would be managed in accordance with the relevant licences.

Taking into account community and regulatory feedback, it is expected that periods of high flow would represent the most favourable conditions for discharge of treated water. During these periods (immediately after the high flow/flood peak) the lowest salinity would be present in the streams and the treated water quality would be compatible with the receiving waters. Natural flow volumes in the Avon River would also be high ensuring that there would be adequate dilution of any treated water discharges. These favourable conditions are likely to occur during or following periods of sustained rainfall when irrigation water demands are low.

Therefore, surface water discharge represents a complementary option to the preferred long term reuse of treated water for irrigation and stock.

6. Extracted Water Quantity and Quality Characteristics

The target coal seams will be fracture stimulated to increase gas flow. Initially, freshwater (or stored produced water that is treated) will be used for fracture stimulation operations. A large proportion of this fracture stimulation fluid is recovered during initial dewatering as flowback water.

During dewatering, the extracted water composition will change from flowback water to natural groundwater composition (i.e. the natural formation water in the coal seams). The extracted water quality and quantity will be monitored. Flowback will be deemed complete from individual wells when the extracted water volume is equivalent to 100% of the injected water volume and water quality (primarily salinity) matches the natural formation water (groundwater) quality. Subsequent extracted water is termed "produced water".

6.1. Flowback Water Volumes

Between 0.5 and 1.5 ML of water will be required to fracture stimulate each well depending on the final well designs. For the life of the drilling and fracture stimulation program for the Stage 1 GFDA approximately 100 ML of water will be required. The initial water for drilling programs will be from freshwater sources. The water for fracture stimulation programs is expected to be treated water from the WTP delivered by the working water delivery lines.

Flowback water will be recycled through the WTP. For each well it is expected that approximately 30% of flowback water will be recovered within seven days of commencing dewatering and that the remaining flowback would be recovered within approximately eight to 12 weeks of pumping commencing. In rare circumstances, not all flowback water maybe recovered from some wells.

6.2. Flowback Water Quality

The quality of flowback water will depend on the composition of the fracture stimulation fluid and the quality of the coal seam groundwater. A detailed Fracture Stimulation Management Plan (FSMP) will be developed prior to any fracture stimulation taking place in the Stage 1 GFDA.

The typical fracture stimulation fluid gel types include:

› Conventional linear gels: These gels are formulated with a wide array of polymers in an aqueous base. Polymers used to formulate linear gels include cellulose derivatives, guar or its derivatives. These polymers are dry powders that hydrate or swell when mixed with water and form a viscous gel.

› Borate cross-linked fluids: Borate cross-linked fracturing fluids utilise borate ions to crosslink the hydrated polymers and to provide increased viscosity. The polymers most often used in these fluids are guar and hydroxypropyl guar (HPG). These gels have high viscosity at upwards of pH 9 and are used to carry proppants. Following fracture stimulation, the pH is reduced to between 3.0 and 4.0 so that the cross-links are broken and the gel is less viscous and can be readily pumped out.

A linear gel system was mostly adopted for the Waukivory Pilot program (AGL, 2014a).

The flowback water is expected to contain a mixture of the injected water, formation water, and the fracture stimulation additives. Typically the flowback water will contain very low concentrations of fracture stimulation additives such as Monoethanolamine Borate (MEAB), Tetrakis (hydroxymethyl) phosphonium sulphate (THPS), and BTEX compounds from the coal formations. As evidenced during the Waukivory Pilot, these compounds are difficult to detect at low concentrations and some are now known to be naturally occurring (such as the MEA and BTEX compounds)

Also some compounds disassociate in water to their elemental constituents, and others biodegrade or volatilise. Consequently it is not proposed to adopt any treated water quality targets for these chemical additives (except for the naturally occurring BTEX compounds).

There has been substantial focus on flowback water quality associated with the Waukivory Pilot program. Water quality results and trends are described in the quarterly technical reports (PB, 2015c, 2015d, 2015e and 2015f). In addition, several human health and risk assessment studies have been completed for the fracture stimulation activities and flowback water quality (EnRisks, 2013 and EnRisks, 2015). Risks to human health and the environment from fracture stimulation additives, BTEX compounds and other chemical constituents are considered to be negligible or low.

Typical flowback water and produced water quality is provided in the extracted water specification in **Appendix D**. The proposed water quality target criteria for treated water is provided in Table 12.1.

6.3. Produced Water Volumes

Typically, dewatering rates decrease over the life of each well.

Based on the results of flow testing programs across the basin, current well designs, and the development timetable, a likely water production profile has been developed for the 110 wells that comprise the GGP Stage 1. The median or most likely water production profile is referred to as the P50 profile. In addition the water balance modelling has considered P10 (low) and P90 (high) water production profiles (Worley Parsons, 2015). These water production profiles (which are for extracted water which includes flowback water as well as produced water) are provided in **Figure 5.2**.

AGL has project approval to extract up to 730 ML of produced water per year across the Stage 1 GFDA at a rate of 2 ML/d on average across the water year. Latest water balance modelling suggests that the daily and annual (extracted) water production rates will be much less than these approved volumes (and produced water volumes will be less again).

This is because of the geology and likely schedule for field development, and the fact that the wells will be completed in low permeability strata and the shallowest coal seam targets are now likely to be greater than 250 mbgl (rather than the original 150 mbgl).

6.4. Produced Water Quality

The quality of the produced water varies according to the geology of the region. Summary information is provided in RPS Group, 2014.

The most recent water quality data is available from historical flow testing programs across the basin being the testing programs on Waukivory 03 (WK03) located towards Gloucester and Craven 06 (CR06) located in the southern part of the Stage 1 GFDA. Water testing undertaken at the CR06 well site provides an indication of expected produced water quality in the average to maximum water salinity range. The current Waukivory flow testing program in the northern part of the Stage 1 GFDA is also providing additional information on water quality.

The CR06 well is located near the centre the Gloucester Basin. Wells which are located more centrally within the basin (and completed across deeper coal seams) are expected to produce water with a higher salinity than wells which are located further east. This is due to groundwater recharge mostly occurring along the eastern coal seam outcrop area and shorter residence times.

The results from CR06 are therefore considered representative and are being used as the basis of design of the WTP at the CPF. Additional water quality data from the Waukivory wells now on test has provided additional data on the spatial variability of flowback and produced water quality. Typical flowback water and produced water quality is provided in the specification in **Appendix D**.

6.5. Extracted Water Characteristics

Flowback water can vary between freshwater and slightly saline water depending on the raw water source that is used for fracture stimulation programs. Most produced waters from the Stage 1 development area are expected to be either brackish or slightly saline. At worst, the water quality will be moderately saline as deep groundwater quality in the Gloucester Basin is known to be brackish to moderately saline.

For extracted water:

› Heavy metal concentrations are either low or negligible.

› Iron and manganese concentrations can be high.

› Boron concentrations can be high in flowback water.

› Nutrient levels are low in produced water except for occasional high ammonia.

› Hydrocarbon concentrations are low although may be slightly higher in flowback water.

The concentration of fracture stimulation additives in flowback water is low and negligible concentrations are expected in produced water. In practice at the WTP flowback water will be comingled with produced water (because wells will be commissioned at different times). The proposed water treatment plant will remove fracture stimulation additives and reduce salinity, resulting in treated water that is suitable for proposed reuse options (predominantly working water then stock and irrigation uses) and for discharge to surface waters.

The following is a summary of the expected longer term produced water characteristics based on the results of 12 months of water quality results from the Craven (CR) 06 well.

Salinity

The produced water is generally dominated by sodium, chloride and bicarbonate. The salinity at CR06 varied between 5500 and 7500 µS/cm.

pH

The pH of most natural waters ranges between 5.0 and 8.0. The pH of produced water at Gloucester is alkaline (generally pH 7.5 – 9.5) and at CR06 varied between pH 7.2 and 9.6.

Sodium and Chloride

Sodium (Na) and chloride (Cl) are two of the most common elements in produced water (ranging from 1,000 mg/L to 3,500mg/L for sodium with CR06 showing a concentration of around 1,750 mg/L and chloride levels ranging from 400 mg/L to 2,000 mg/L with CR06 showing a maximum concentration of 1,570 mg/L).

Potassium

The potassium (K) levels in the produced water at Gloucester are low with a predicted range of 5 mg/L to 30 mg/L, with CR06 showing a concentration of around 12 mg/L.

Calcium and Magnesium

The calcium (Ca) and magnesium (Mg) content is relatively low. Calcium is expected to range from 1 mg/L to 75 mg/L with CR06 showing a concentration of around 20 mg/L whereas magnesium is predicted to range from 1 mg/L to 10 mg/L with CR06 showing a concentration of around 5 mg/L.

Alkalinity

Alkalinity is the measure of water's ability to neutralise acids. Carbonate ions (CO_3^-) from dissolved salts such as calcium carbonate ($CaCO_3$), bicarbonate ions (HCO_3^-) from dissolved salts such as calcium bicarbonate ($Ca[HCO_3]_2$), sodium bicarbonate ($NaHCO_3$), and magnesium bicarbonate ($Mg[HCO_3]_2$) are the major chemicals contributing to alkalinity in the produced water.

Hydroxide ions (OH^-) are a minor contributor in most cases which is the case for the Gloucester water with a hydroxide alkalinity figure of <1 mg/L expressed as $CaCO_3$.

The bicarbonate levels in the produced water are predicted to range from 1,300 mg/L to 6,000 mg/L (expressed as $CaCO_3$) with CR06 indicating an alkalinity of around 2,000 mg/L.

Suspended Solids

Suspended solids or total suspended solids (TSS), is a measure of the concentration of solid particulate matter present in water (expressed as mg/L).

The TSS level in the produced water (at the wellhead) is predicted to range from 200 mg/L to 500 mg/L with the CR06 sample showing a figure of up to 300 mg/L. Lower concentrations are expected when water is pumped to/from the RWP and enters the WTP. Although these are elevated TSS levels, it is not likely to be of concern since settlement within the RWP and suspended solid removal during pre-treatment will capture all particulate matter.

Silica

The silica (Si) levels in the produced water are expected to range from 10 mg/L to 40 mg/L (with CR06 showing a concentration of around 15 mg/L). If the current silica concentrations are representative of the produced water quality, over the long term, silica should not pose a constraint to high recovery RO or to the performance of the RO system if appropriate anti-scalant is adopted.

Manganese

The manganese (Mn) levels in the produced water are expected to range from 0.1 mg/L to 1.0 mg/L with CR06 showing a concentration of around 0.4 mg/L.

Iron

The iron (Fe) levels in the produced water are expected to range from 1 mg/L to 70 mg/L, with CR06 showing a variable concentration of up to 35 mg/L. This is a high iron concentration but typical of natural groundwater.

Strontium

The strontium (Sr) concentrations in the produced water are expected to range from 1 mg/L to 10 mg/L, with CR06 showing a concentration of between 3 and 4 mg/L.

Fluoride

The fluoride (F) present in the produced water is predicted to range from 0.1 mg/L to 3.0 mg/L, with CR06 showing a concentration of around 1.5 mg/L.

Boron

The boron (B) present in the produced water is predicted to range from 0.1 mg/L to 0.5 mg/L with CR06 showing concentrations up to 0.35 mg/L. Flowback water can however have higher concentrations of dissolved boron due to the breakdown products of MEAB. Levels from the Waukivory pilot site have recorded concentrations up to 12 mg/L.

Other Trace Metals & Inorganics

The arsenic, beryllium, cadmium, chromium, cobalt, lead, mercury, molybdenum, nickel, selenium, uranium and vanadium content of CR06 produced water were mostly below the limit of reporting for the particular metal, and do not present any issues in regard to WTP operation or to the target treated water quality requirement.

The aluminium, barium, copper, and zinc content of CR06 were at low levels and do not present any issues in regard to WTP operation, and do not exceed the threshold values for irrigation and stock water or stream discharge.

Trace metals and inorganics are generally found in negligible to low concentrations in the produced water from the Gloucester Basin groundwater systems.

BTEX and other hydrocarbons

The total benzene, toluene, ethyl benzene and xylenes (BTEX) concentration in produced water is predicted to range between 10 and 100 µg/L with CR06 showing concentrations up to 20 µg/L. Concentrations are expected to be higher in flowback water from individual gas wells immediately after fracture stimulation where concentrations of total BTEX could be up to 1000 µg/L (1 mg/L) at individual well sites.

The concentrations of other hydrocarbon compounds such as phenolic compounds and polycyclic aromatic hydrocarbons (PAH) are expected to be negligible to low. Concentrations at CR06 were negligible and were less than 5 µg/L for a couple of individual phenolic compounds. No PAHs were detected in the produced water from CR06.

These hydrocarbon concentrations are typical of formation waters that occur in deep coal seams across the Gloucester Basin.

7. Stakeholder Consultation

Under Condition 3.12 of the Part 3A Project Approval, AGL must consult with the:

› Office of Coal Seam Gas (OCSG).
› NSW Office of Water (NOW).
› Hunter Local Land Services (HLLS).
› Environment Protection Authority (EPA).
› Relevant Councils.

Relevant councils are deemed to be Gloucester Shire Council (the whole of the Stage 1 development is located within their local government area) and MidCoast Water (who are responsible for water supply and sewerage matters across Gloucester Shire, Taree City, and Great Lakes Shire areas).

The development of the EWMS must be to the satisfaction of the Secretary of the DPE. In recent times agency roles and responsibilities have changed in relation to regulating CSG exploration and production activities so the discussion below reflects on both the consultation process in 2014/2015 and the current regulatory arrangements.

In addition to those nominated in the Project Approval, AGL identified a number of key stakeholders who were consulted during the development of the EWMS. All the relevant stakeholders and their past/current interest in relation to extracted water management are described in Sections 7.2 to 7.10.

A one day workshop was held in Gloucester on 13 August 2014 prior to the formal release of the EWMS to discuss the strategy and content of the Consultation Draft with the relevant agencies. OCSG, NOW, EPA, DPE, Gloucester Council (GSC), and MidCoast Water (MCW) staff attended. A number of changes were made to the Consultation Draft prior to its formal release on the 21 August 2014. A second workshop was held on 16 September 2015 with DPI Water, EPA, GSC and MCW staff to discuss the content and changes associated with the Final Draft of the EWMS.

Although not required under the Part 3A approval, AGL also placed the EWMS on exhibition for two four week periods to obtain community responses to the extracted water management proposals. The exhibition period for the Consultation Draft was 21 August to 19 September 2014 and for the Final Draft was 8 September to 6 October 2015. **Appendix A** summarises both the agency and community submissions.

The final EWMS is submitted to the Department of Planning and Environment (DPE) to address Condition 3.12 and to ensure that the EWMS is to the satisfaction of the Secretary. Under Condition 21 of the EPBC Approval, the Commonwealth Department of Environment (DoE) must also be provided with a copy of the EWMS and the EWMS must be to the satisfaction of Minister for the Environment. The DoE has indicated that once the EWMS is submitted, Department officers will review it, provide comments requesting changes (if required) and then brief the (Ministers) delegate seeking approval.

7.1. Consultation Process

The consultation process for the EWMS included:

› Distribution of the Consultation Draft EWMS and inviting all the nominated agencies (Office of Coal Seam Gas (OCSG), NSW Office of Water (NOW), Environment Protection Authority (EPA), Department of Planning and Environment (DPE), Hunter Local Land Service (HLLS), Gloucester

Shire Council (GSC) plus MidCoast Water (MCW)) specified in Condition 3.12 to a workshop in August 2014.

- Sending copies of the EWMS to other government agencies not directly involved in the development of the EWMS.
- Advertising the release of the EWMS and community information sessions.
- Holding an initial workshop with GSC, MCW, regulators and other government agencies (13 August 2014).
- Launching the EWMS at the Gloucester Community Consultative Committee (GCCC) on the 21 August 2014.
- Publishing and exhibiting the Consultation Draft of the EWMS on AGL's website (21 August to 19 September 2014).
- Presenting to the Advance Gloucester meeting on 20 August 2014.
- Organising and attending two community information sessions in August 2014.
- Being available (via mail, phone or drop in to the local office) to answer any queries during the exhibition of the EWMS, and ongoing as water treatment queries arise.
- Preparing a final draft of the EWMS for agency review incorporating comments and feedback from consultation.
- Holding a second workshop with DPI Water, EPA, GSC and MCW (16 September 2015).
- Publishing and inviting comments on the Final Draft of the EWMS on AGL's website (8 September to 6 October 2015).
- Presenting the EWMS to GSC Councillors and staff on 17 September 2015.

AGL also proactively informed the community through various media about the strategy for produced and flowback water in order to address concerns regarding:

- Salinity/salt loads from produced water.
- Heavy metals and contaminants in extracted water and treated water.
- Potential impacts from our operations e.g. water affecting local river systems.
- Differentiating exploration activities from proposed production activities.
- Ongoing irrigation of untreated produced water or blended water was not proposed.
- Completion of the Tiedman irrigation program, and not continuing with the blended water irrigation program.
- The sustainability of the preferred strategy and associated practices.

7.2. Division of Resources and Energy (DRE)

NSW Department of Industry, Skills and Regional Development (DoI) is the lead economic development agency in New South Wales responsible for driving sustainable economic growth across the state. DoI replaced the Department of Trade and Investment (DoTI) and the Department of Industry and Investments (DII) in recent years.

The Division of Resources and Energy (DRE) delivers policy, programs and compliance services across the mineral resources and energy sectors. The Division consists of the following business units and program areas: Mineral Resources, Energy, National Policy and Sustainability, Mine Safety, Industry

Investment, Office of Coal Seam Gas and Coal Innovation NSW. Its functional responsibilities relate to:

Minerals and mining

- Deliver quality geological and geophysical maps and data about NSW.
- Authorise mining exploration and production.
- Keep the environment safe during exploration and mining activities.
- Regulate health and safety for the mining and petroleum industries.
- Attract local and offshore investment into the NSW resources sector.

Energy

- Distribute safe reliable and cost-competitive energy to consumers.
- Provide financial assistance through customer programs to energy consumers.
- Support growing investment in renewable energy in NSW.
- Monitor electricity and gas networks and licensed pipelines.

In regard to CSG activities, DRE is responsible for geological mapping, exploration activities, titles, health and safety, and is the repository of all the geological data collected across NSW (including well completion reports and data).

DRE were invited to the first workshop but did not attend, although representatives from OCSG were present. A copy of the Consultation Draft EWMS was sent to the DRE for information. No comments were received. The Final Draft of the EWMS was sent to DRE/OCSG.

7.2.1. Office of Coal Seam Gas (OCSG)

In 2014, the OCSG was operating independently to DRE. It has been subsumed back into DRE as part of the changed regulatory environment for managing CSG projects by the NSW Government. From 1 July 2015, OCSG still reviews and approves exploration and some production activities associated with CSG projects. The environmental compliance and enforcement requirements associated with PELs and PPLs are now administered by the Environment Protection Authority (EPA).

Ongoing, the OCSG group within DRE is responsible for:

- Administering CSG titles and activity approvals granted under the Petroleum (Onshore) Act 1991 and associated assessments under the Environmental Planning and Assessment Act 1979.
- Monitoring and auditing title compliance, including rehabilitation and security deposits.
- The application of workplace health and safety requirements under the Petroleum (Onshore) Act 1991 and the Work Health and Safety Act 2011 (NSW) to petroleum operations.

There is a single PEL 285 across the whole of the Gloucester Basin and AGL has made application for two PPLs across the approved Stage 1 GFDA.

Under the renewed PEL 285, there is a requirement to have a Produced Water Management Plan (PWMP) for prospecting operations with the potential to generate more than 3 ML/yr of produced water. This plan has been completed and approved (AGL, 2014b and AGL, 2015a) and is published on AGL's and DRE's websites for our PEL 285 exploration activities. OCSG advised in their 2014 submission that it is unlikely that a PWMP will be formally required under the PPL conditions, however a similar document may now be required under other approvals (such as the EPL) given the changed regulatory responsibilities.

OCSG provided a brief submission on the Consultation Draft on relevant Codes of Practice and advised that the PPLs are more likely to focus on rehabilitation standards and security matters than produced water management matters. For the Final Draft EWMS, the Environmental Sustainability Unit of DRE provided brief comments explaining that:

- The PPL/s for the project will require operations to be carried out in accordance with the relevant Codes of Practice (CoPs).
- A Produced Water Management Plan will not be required as a condition of a PPL.

7.3. Land and Water Commissioner

The New South Wales Land and Water Commissioner was appointed by the NSW Government in 2013 to provide independent advice to the community regarding exploration activities on Strategic Agricultural Land throughout the state.

The role of the Land and Water Commissioner is to build community confidence in the processes governing exploration activities in NSW and to facilitate greater consultation between government, community and industry.

The Land and Water Commissioner has shown a strong interest in the Gloucester Gas Project, currently chairs the Gloucester Dialogue, and advocates stronger discussion with the community on land use practices and water reuse opportunities as outlined in this EWMS.

A copy of the Consultation Draft EWMS was sent to the Land and Water Commissioner for information. No comments were received. The Final Draft of the EWMS was not sent to the Land and Water Commissioner.

7.4. Chief Scientist and Engineer (CSE)

In 2013, at the request of the NSW Government, the NSW Chief Scientist and Engineer (CSE) conducted a review of coal seam gas (CSG) related activities in NSW, with a focus on the impacts of these activities on human health and the environment. One of the key terms of reference was to:

- Identify and assess any gaps in the identification and management of risk arising from coal seam gas exploration, assessment and production, particularly as they relate to human health, the environment and water catchments.

An initial report (July 2013), a final report (September 2014) and a number of background papers have been prepared by the Office of the CSE and its independent experts. Several of these relate to produced water and produced water management.

A copy of the Consultation Draft EWMS was sent to the CSE for information. No comments were received. The Final Draft of the EWMS was not sent to the CSE.

7.5. Environment Protection Authority (EPA)

The EPA is the lead regulator of environmental and health impacts of CSG activities across NSW with responsibility for compliance and enforcement. From 1 July 2015 the EPA is the primary regulator for CSG across NSW and is responsible for the compliance and enforcement of all licence and consent conditions for gas exploration and production activities.

Also since late 2013, the proponents of all CSG projects, from exploration, assessment to production are now required to hold an environment protection licence (EPL) issued by the EPA for their premises.

When the EWMS is approved and a financial investment decision is made on the project, AGL will seek a variation to modify the EPL for the GGP. The variation will cover the reuse of treated water, the discharge of treated water to streams, and the disposal of all waste streams generated at the CPF. The expected focus will be on soil/water monitoring aspects of the EWMS.

EPA provided a detailed submission on the Consultation Draft of the EWMS on the basis that there would only be an EWMS and not a more detailed and focused PWMP prepared prior to construction of the Stage 1 development. EPA were wanting a more detailed assessment of the WTP design but many of the requested details are beyond what has to be submitted to comply with Condition 3.12 of the Part 3a approval and will only be available after the awarding of the WTP contract. The initial EPA submission focused on:

- WTP infrastructure system details (Section 11 – detail not required to be included in the EWMS).
- Waste streams associated with the WTP (Section 13 – detail not required to be included in the EWMS).
- Trigger values for water reuse and discharge (Exec Summary, Section 2.4 and Section 12).
- Assessment of the current irrigation program (Section 3.1).
- River flow objectives (Section 11.6.2 and Section 12) and low flow discharges (now deleted from the EWMS based on earlier consultation and feedback).
- Brine tank system details (detail not required to be included in the EWMS).
- Salt and disposal options (detail not required to be included in the EWMS).
- Nominated receiving facilities (detail not required to be included in the EWMS).
- Other waste streams (Section 13 - detail not required to be included in the EWMS).

EPA provided a second submission on the Final Draft of the EWMS. EPA noted the improvements to the Consultation Draft of the EWMS and supported the strategies described in the Final Draft EWMS. EPA suggested a number of technical matters required additional detail and further explanation, and these have been addressed in this Final version of the EWMS. These primarily related to:

- Treated water quality particularly salinity targets, catchment criteria, mineral balances, suspended solids, dissolved oxygen and river discharge implications (Section 2.4 and Section 12 – particularly Table 12.1).
- Brine water and salt management (Section 11.4 and Section 13.5).
- Monitoring requirements (Section 11.5.1 and Appendix E).

Again there were additional comments and recommendations related to engineering design, water treatment performance, monitoring programs and landfill suitability that are not addressed in the EWMS, and are more appropriate for the proposed PWMP.

Further detail is provided in **Appendix A** while AGL's responses to the issues raised by EPA are also provided in the nominated sections.

7.6. DPI Water

The NSW Office of Water (NOW) was replaced by DPI Water in July 2015. DPI Water remains part of the Department of Primary Industry (DPI) and reports to the Minister for Primary Industries, Lands and Water. DPI Water is responsible for the investigation and management of surface water and groundwater resources across NSW. They administer the Water Sharing Plans across the state and specifically the necessary licensing requirements under the Water Management Act (2000) and Water Act (1912). They are responsible for the allocation and use of all water resources, and the protection of riverine environments and groundwater systems.

Under the Aquifer Interference Policy, DPI Water is tasked with assessing water reuse and disposal methods of produced water associated with CSG developments (specifically in relation to impacts to surface water and groundwater).

NOW provided a detailed submission on the Consultation Draft of the EWMS with queries on:

- Water to third parties (Section 5.4.3).
- Additional studies to support the discharge of treated water to Dog Trap Creek/Avon River (Section 11.6.2 and Appendix C).
- Additional monitoring bores at Tiedmans (Section 14 and Appendix E).
- Monitoring frequencies (Appendix E).
- Definition of flowback water (definitions and Section 1.1).
- Additional water balance modelling (Section 5 and Appendix B).
- Surface water discharges (Section 11.6.2, Appendix B and Appendix C).
- ASR feasibility (Section 11.7).

DPI Water provided a further submission on the Final Draft of the EWMS with comments on:

- Definitions of aquifers and groundwater systems (Glossary).
- Further reviews of the EWMS (Section 1.4).
- Provision of water to third parties (Section 2.2 and Table 2.1).
- WAL requirements (Section 2.2).
- Expanded analytes for the threshold criteria (Section 2.4.1 - Table 2.5; and Section 2.4.2 - Table 2.6).

Further detail is provided in **Appendix A** while AGL's responses to the issues raised by NOW/DPI Water in both their submissions are also provided in the nominated sections.

7.7. Hunter Local Land Services (HLLS)

Hunter Local Land Services (HLLS) have a role to play in natural resource management, water and soil management issues on a catchment scale. Local Land Services consult with local communities, including landholders and Aboriginal groups, to develop strategies for natural resource management for the 11 respective regions across NSW. Until Local Strategic Plans are developed, existing Catchment Action Plans that were developed under the previous Catchment Management Authority model continue to apply. The HLLS covers the Hunter, Karuah and Manning River catchments.

HLLS was invited to the August 2014 workshop but did not attend. The exhibited EWMS was also sent to HLLS with a reminder for comments by mid-September. The HLLS did not provide a submission on the Consultation Draft of the EWMS.

Similarly for the Final Draft, HLLS was invited to the 2015 workshop and was sent a copy of the Final Draft EWMS. HLLS did not provide a submission to the Final Draft of the EWMS.

7.8. Gloucester Shire Council (GSC)

Gloucester Council represents the interests of the rate payers of the shire and has a strong interest in mining and gas projects, and the associated impacts on ratepayers and the local environment.

Gloucester Council employed a Water Scientist to undertake a Water Study Project which includes managing a number of specialist studies under a cooperation agreement with AGL that commenced in October 2013 and concluded in September 2015. The components of the Water Study were:

- Baseline water surveys of the whole Gloucester Basin.
- Flood study (Avon and Gloucester River catchments).
- Produced water study.
- Technical peer reviews.

Council is also looking at encouraging new industries and investment under its Economic Development Committee initiative. The primary objective of this Committee is to promote sustainable economic growth within the Gloucester Shire.

The produced water study (RPS Group, 2014) is the basis of the produced water management options that are described in Section 4.1 and could provide an economic stimulus to local development.

Council was concerned that the Consultation Draft of the EWMS was too general in some places and if a PWMP was not going to be prepared then more detail regarding water treatment, wastes, water quality criteria and monitoring was required. Council provided a detailed submission on:

- Preferences for salt management (Section 13.4).
- Development of a PWMP (Executive Summary, Section 1.1, Section 1.6, Section 14).
- Site specific water quality criteria (Section 2.4.2).
- Water quality targets (Section 12).
- Surface water discharge location and rates (Section 9.3 and Appendix C).
- Approvals (Section 2).

The GSC provided a second submission on the Final Draft of the EWMS with comments on:

- The commitment to a PWMP (no additional text – as above).
- Addition of microbiological parameters for the target water quality criteria (no new text).
- Maximising storage opportunities at the CPF (Sections 11.2.1 and 11.2.3).

Further detail is provided in **Appendix A** while AGL's responses to the issues raised by Council in both their submissions are also provided in the nominated sections.

7.9. MidCoast Water (MCW)

MidCoast Water (MCW) is the water supply authority delivering reticulated supplies to consumers across the Karuah and Manning River catchments. Their Mission Statement is to manage the provision of sustainable water related services to meet community needs. In regard to the environment, MCW's charter is about conserving resources, protecting and enhancing the natural environment and is particularly focused on water cycle management.

MCW provided a detailed submission on the Consultation Draft of the EWMS with comments on:

- Reliance on river discharge (Section 11.6.2, Appendix B and Appendix C).
- Continued consultation with MCW (noted).
- River discharges under low flows (now deleted from the EWMS based on earlier consultation and feedback).
- Operational risks (to be included in the PWMP).

- Surface water discharge location and rates (Section 9.3 and Appendix C).
- Monitoring plan deficiencies (Section 14 and Appendix E).

MCW provided a further submission on the Final Draft of the EWMS with comments on:

- Adding extra parameters to the target water quality criteria (Section 12 and Table 12.1).
- Revising some of the proposed target values for water quality analytes (Section 12).
- Monitoring the RO water quality (before post treatment processes) (Appendix E).
- Clarifying the specific flow conditions under which stream discharges would occur (Section 9.3).
- Managing the distillate from the BTP (Sections 11.2.2 and 11.2.3).

Further detail is provided in **Appendix A** while AGL's responses to the issues raised by MCW in both their submissions are also provided in the nominated sections.

7.10. NSW Health

NSW Health is responsible for the public health system across NSW, and provides advice on the suitability of water sources for drinking water supplies.

A copy of the Consultation Draft of the EWMS was sent to the appropriate Environmental Health Officer in the Hunter New England Health Service and to the Water Quality unit of NSW Health for comment after advice from MCW. NSW Health did not provide any comments on the EWMS. The Final Draft of the EWMS was not sent to NSW Health.

7.11. Broader Community

The broader community was also invited to comment on the Consultation Draft and Final Draft of the EWMS. The initial document was publicly released on the 21 August 2014 at the Gloucester Community Consultative Committee (GCCC), drop in community information sessions were held same day (an afternoon and evening session), the EWMS was exhibited for a period of 28 days, and was placed on AGL's Gloucester Gas Project website with a call for submissions. AGL advertised extensively that the document could be downloaded from AGL's Gloucester website:

www.agl.com.au/gloucester

The following community organisations were advised that the document was available for comment:

- Gloucester Community Consultative Committee (GCCC).
- Gloucester Dialogue.
- Advance Gloucester.

For the Final Draft of the EWMS, advice was provided to the GCCC and members of the Technical Steering Committee of the Water Scientist Project that the document was available from AGL's Gloucester website and any further comments or submissions were welcome. The Final Draft was also discussed at the Gloucester Dialogue meeting of 23 October 2015.

Submissions on the Consultation Draft of the EWMS were received up until the 19 September 2014. Only two public submissions were received. The individual submissions provided comment on:

- Likely discharge of CSG (produced) water into the Manning River catchment.
- Size and cost of a desalination plant.
- Desalination is a public relations exercise, not a serious proposal from AGL.

- CSG water contains contaminated salts while seawater contains non-toxic sea salt.
- Flowback water should be separate to produced water.
- The RO plant and the desalination proposal requires a full EIS.
- Treated water should be sold to new ventures at below market rates.
- Water generated but not used during winter and wet periods should be stored in the Stratford mine 'clean water' dam.

Further details and responses regarding these submissions are provided in **Appendix A**.

There were no public submissions on the Final Draft of the EWMS.

In 2014, AGL also sought early "Expressions of Interests" for the reuse of desalinated water and mixed salt. Eight expressions of interest were received for the use of desalinated water for irrigation and stock purposes. In entering into further discussions, AGL will emphasise that supplies are not guaranteed and that there are risks regarding new developments based on what could be a limited and declining water supply if subsequent stages of the gas project are not developed.

8. Irrigation and Stock Reuse

The application of treated water to irrigate crops and pasture, and to provide supplementary stock water has been identified as the preferred extracted water management option. Irrigation and stock use is a preferred option for the following reasons:

› Provides a new (small) source of water which is valued by the community and which will have tangible benefits to the primary producers of the district.

› Offers sustainable, beneficial reuse of extracted water.

› Stock use would occur during drier seasons when supplementary water is required for livestock.

› Irrigation use can be scaled to respond to changing volumes and seasonal conditions.

› Irrigation is a proven technology.

› Cost effective (for a CSG project of this size).

Irrigation will be undertaken on hillside locations (away from water courses) at AGL's Rombo, Tiedman and Pontilands properties. Opportunities to supply landowners adjacent to the Stage 1 development area with both irrigation and stock water are being investigated.

8.1. Benefits and Constraints of Irrigation

Benefits

The potential benefits associated with irrigation are:

› Beneficial reuse of a new water source for the area (after the essential requirements of working water, process water and stock water).

› Economic benefits to landholders in the vicinity of the GGP.

› Reduced pressure on existing water resources.

› Low cost of transportation of water given that:

 » the pipework is part of the gas gathering and working water pipeline network; and

 » the proposed irrigation areas are located in close proximity to the CPF and the Tiedman storage ponds.

Constraints

The constraints associated with irrigation are:

› Irrigation rates are dependent on weather conditions (especially rainfall and runoff) which may fluctuate significantly.

› Irregular and unpredictable volumes and availability of treated water.

› Irrigation application rates and usage is lower in winter when crop and pasture requirements are less.

8.2. Benefits and Constraints of Stock

Benefits

The potential benefits associated with stock use are:

- Supplementary water to graziers during dry periods.
- Economic benefits to landholders in the vicinity of the GGP.
- Reduced pressure on existing water resources.
- Low cost of transportation of water given that:
  - the pipework is part of the gas gathering and working water pipeline network; and
  - the proposed stock use areas are on AGL and private property at the end of the water gathering lines.

Constraints

The constraints associated with stock use are:

- Little additional water is required during average and wet seasons.

8.3. Site Characteristics

Location

To manage the development of the Stage 1 GFDA, an expanded irrigation area of approximately 60 ha is proposed to be developed on AGL owned properties or nearby agricultural properties. An additional area of 40-50 ha is proposed to the existing 16 ha under irrigation on AGL's Tiedman property. Potential irrigation areas are shown on **Figure 11.4**.

Sizing of the individual irrigation areas will be determined using the following criteria:

- Efficient irrigation design and layout.
- Conflicts with existing and future gas infrastructure.
- Soil suitability, including; depth and soil nutrient deficiencies.
- Slope.
- Presence of rock outcrops.
- Environmental considerations, including potential for soil erosion and drainage.

No additional area is required for stock watering.

Crop selection

Crops such as lucerne, triticale and forage sorghum and pasture that includes kikuyu, ryegrass, clover and chickory have been proven as part of the Tiedman Irrigation Program. These crops together with improved pasture are suitable for the prevailing soil and water conditions. Even though the treated water that is going to be applied is high quality (i.e. low salinity), salt tolerant species are still under consideration because of the sodic and saline nature of the underlying soils.

The balance between cropping and pasture is still to be decided but most of the new irrigation areas are expected to be improved pasture.

8.4. Irrigation Methods

Methods

There are several irrigation methods which have control over the water application rates including drip, centre pivot and linear/lateral move irrigators.

A small travelling irrigator and a large linear move irrigator have been used to date to intensively irrigate (up to 4 to 5 ML/ha/yr) the current Tiedman irrigation area. A mixture of linear move and travelling irrigators is proposed for the expanded irrigation scheme.

No direct application of water to land by flood irrigation is proposed.

Reticulation and Storage

The three existing water storage ponds at Tiedman property (and current irrigation infrastructure) will be retained to provide operational storage and water balance capacity required for the containment of treated water and freshwater (TSD and TND), and produced water (TED) (if in-field capacity is required).

The TSD and TND storages will allow treated water from the WTP to be matched to crop demand. These storages will also allow water to be stored over winter or during wet periods if water is unable to be irrigated. If there is a demand for freshwater for fracture stimulation or other industrial uses then this may also be stored in either of these ponds (although water is most likely to be taken from the WTP and piped direct to the required site through the working water lines).

The TED will (most likely) remain as an in-field storage for flowback water and produced water, although if there is no requirement for in-field storage, this dam will be used to store treated or freshwater from time to time.

8.5. Irrigation Demand

Based on the irrigation program results, approximately 4 ML/ha/year of irrigation water is required in an average season to grow summer and winter crops, and improved pasture. Actual application rates for fodder and improved pasture were between 4 and 5 ML/ha/year in recent years. Higher application rates (up to 7 to 8 ML/ha/year) could have been achieved during 2012/13 and 2013/14 if sufficient water was available. These seasons were drought seasons so 4 ML/ha/year is considered a reasonable expectation during an average season.

Typical monthly irrigation application rates for an average season are presented in **Table 8.1**.

Table 8.1: Estimated Monthly Irrigation Rates (average years)

MONTH	MONTHLY IRRIGATION (ML/ha)	MONTH	MONTHLY IRRIGATION (ML/ha)
January	0.5	July	0.2
February	0.3	August	0.3
March	0.1	September	0.5
April	0.2	October	0.5
May	0.1	November	0.6
June	0.0	December	0.6
		TOTAL	**4.0**

Note: Highest demand is in Spring and Summer.

8.6. Stock Demand

Stock demand for treated water is uncertain. Less than 1 ML per property per year is expected to be required in all but the driest years. Water is most likely going to be required when farm dams are low and poor quality water is available from the river. Treated water piped through the working water delivery lines could substitute for tankered water and allow stocking rates to be maintained. Water for stock watering will take precedence over water for irrigation. The total volume of treated water available will remain the same.

9. Discharge to Surface Waters

AGL proposes to discharge treated water to local waterways when it is not possible to irrigate, and treated water storages are full and there is limited capacity in the system to store any additional water at either the CPF or Tiedmans. Surface water discharges are only expected to occur during Year 3, if higher than expected water production rates occur and these rates coincide with an extreme wet period. Volumes are expected to be less than 20 ML in total.

It is proposed to only discharge treated water from the discharge water pond at the CPF (or from the Tiedman storage ponds) that has been conditioned to meet the water quality target identified in Section 12.

It is proposed to discharge to surface water in combination with a high flow event in the catchment when the Avon River is flowing and further dilution is possible. Discharge during higher flows is the preferred option but given that all treated water storages would be filled first, the main flow peak may have passed in the Avon River. The most likely discharge scenario is that water would be discharged on the recession curve of a major flow event rather than at the peak of such an event.

Discharge rates are likely to be small and unlikely to ever exceed 2 ML per day. Based on the available data on the NOW website for the Waukivory stream gauge, this volume represents around 0.001% of the flow during a typical Avon River flood event. Discharges would be managed such that the creek geomorphology and the local ecology in the Avon River at the discharge location and immediately downstream are preserved.

Water quality will be tested at the DWP prior to discharge (see Section 14 and **Appendix E**).

9.1. Benefits and Constraints of Discharge to Surface Water

Benefits

The benefits associated with the managed discharge of treated water to surface waters during high flow events are:

- Ability to maintain gas production across the Stage 1 area without shutting down wells.
- Additional freshwater for the environment.

Constraints

None identified (after the geomorphological and ecological study discussed in Section 9.2 below).

If discharges occurred during periods of higher flow then the potential of harm to the stream, the bed load and the aquatic ecology are considered to be negligible because the volume of natural flow would be large compared to the discharge volumes (Cardno, 2015).

9.2. Discharge Site Characteristics

Taking into account regulator and community comments, a geomorphological and ecological study has been completed to determine the best location for the few occasions when stream discharges are likely to be required for treated water (Cardno, 2015). A location on the Avon River upstream of the confluence of Dog Trap Creek has been recommended. The proposed discharge location in relation to the proposed water pipeline from the CPF to the Tiedmans storage ponds in shown on **Figure 9.1**. Full details are provided in **Appendix C**.

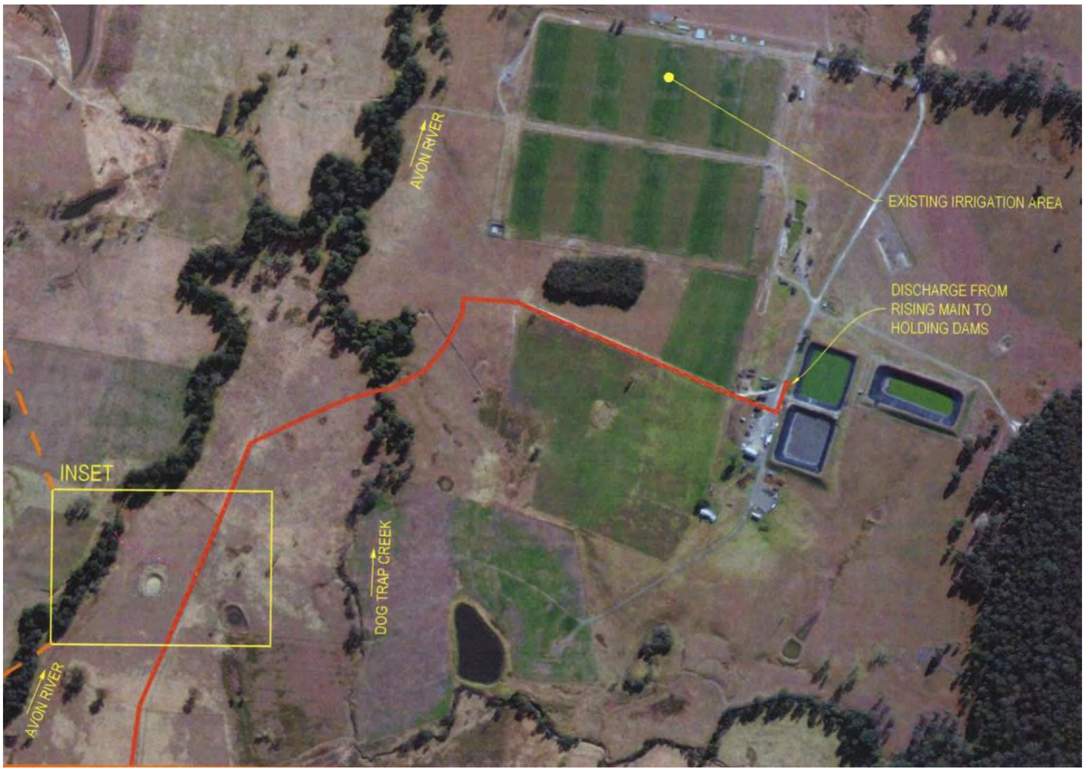


Figure 9.1: Proposed Avon River Discharge Location

The managed discharge outfall would be a very small structure designed to convey the treated water into the receiving surface waters without creating scour or erosion. The structure would address the following key design principles:

› Dispersion of treated water so it mixes with existing flows within a relatively short distance.

› Compatibility with upstream and downstream water quality.

› Dissipation of energy associated with the new inflow.

› Appropriate scour protection on the creek river banks.

9.3. Proposed Flow Regime

Stream discharge would only occur when there was at least a 5-fold mixing factor at the point of discharge. It is expected that the maximum discharge rate would be around 2 ML/d and would average less than 0.5 ML/d.

Substantially more dilution would occur once Avon River flows are joined by inflows from the downstream tributaries Dog Trap Creek and Waukivory Creek. Further downstream the large Gloucester River and the Barrington Rivers provide even more dilution prior to these catchments joining the Manning River.

AGL is proposing stream gauge location TSW01 (on its AGL's Tiedman property) to determine when discharges of treated water can occur. Visible flow in the river would be required and flows in excess of 2.5 ML/d are proposed before any treated water would be discharged (but typically would be higher and in association with a high-flow event). Additional gauging is proposed to generate a calibrated rating curve for this Avon River stream gauge site.

AGL's proposal is that stream discharge of treated water be allowed when:

› Stream flows at the nominated downstream gauging location exceed 2.5 ML/d.

› AGL's treated water storages exceed 80% of their storage capacity.

› Salinity of the treated water to be discharged is within ±20% of the (downstream) water quality.

AGL would discharge treated water at rates not exceeding 2 ML/d, and only when there was (at least) a 5-fold mixing factor. The water balance modelling (Worley Parsons, 2015) suggests that stream discharges would be a rare event and only occur in Year 3 if P90 water production volumes occurred in combination with P90 rainfall events.

If a controlled discharge was planned, AGL would advise downstream users of the start date/time, the likely duration, and the proposed discharge rate. Details would be provided in the local Gloucester press and on AGL's Gloucester website. Discharge water quality would also be available for review on the website.

After each event, AGL would publish the relevant compliance monitoring data required under the EPL on its website.

For comparison purposes at this time, the flow data from the DPI Water Waukivory Gauging Station 208028 located downstream of the confluence with Waukivory Creek (about 3 km downstream of the Tiedman property) is presented in this EMWS to indicate when stream flow discharges may typically occur.

The flow hydrograph for this Gauging Station is provided in **Figure 9.2**.

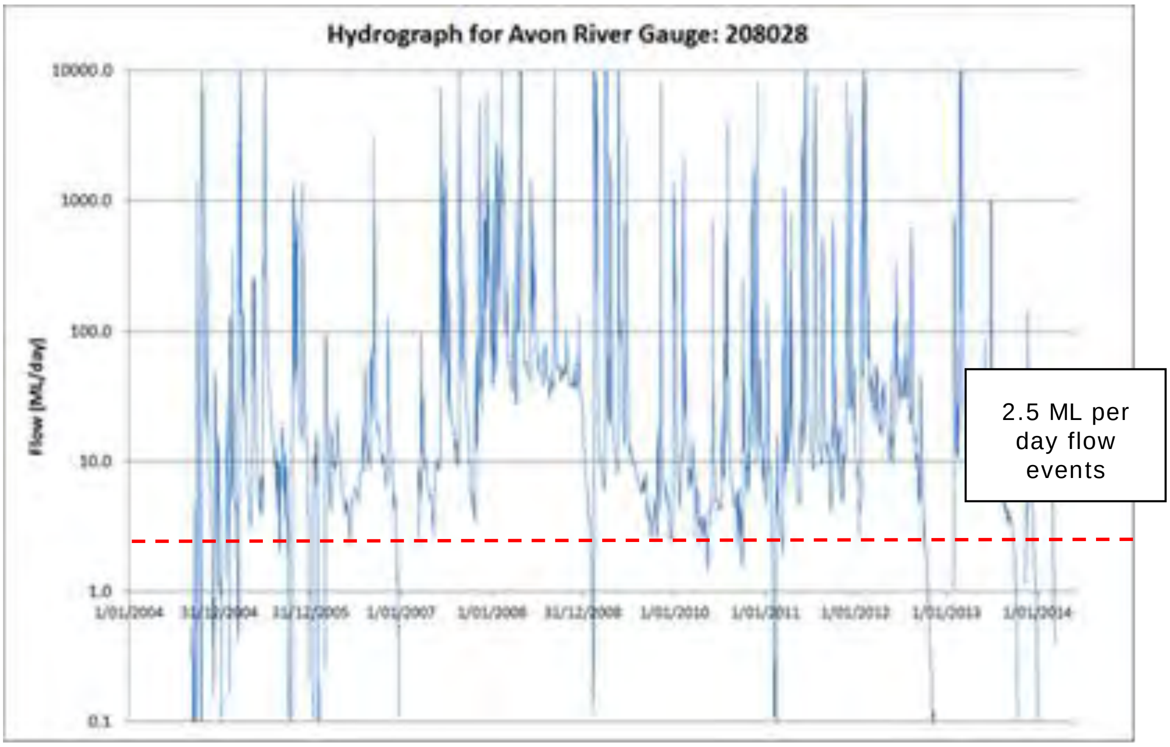


Figure 9.2: Streamflow Data for the Avon River (Gauge 208028)

The treated water will be discharged to the Avon River in a controlled manner, taking into consideration the sensitivity of the receiving watercourse. Details are provided in Cardno, 2015. In-stream water quality monitoring (upstream and downstream) will be undertaken to ensure that the released water does not cause adverse effects on the receiving environment. Further details regarding the proposed monitoring program are provided in Section 14 and **Appendix E**.

10. Existing Water Management Infrastructure

AGL has some existing infrastructure to gather, store and treat freshwater and produced water. Existing water management infrastructure is located on the Tiedman and Pontilands properties and includes the following:

- Three 20 ML lined water storage ponds.
- An underground pipeline network linking the Stratford and Waukivory pilot wells to the ponds.
- A pump station located on the Avon River and pipeline to the Tiedmans ponds.
- Pontilands Dam (50 ML storage) and associated pumps.
- A pipeline from the Pontilands Dam to the Tiedmans ponds.
- A pump station between the two western Tiedman ponds to transfer water between these ponds and the irrigators.
- A pipeline to transfer river water to the ponds.
- Irrigation infrastructure.

10.1. Water Supply Pumps, Dams and Ponds

Avon River Pumping Station

AGL holds a Water Access Licence (WAL), which allows extraction of up to 32 ML per year from the Avon River. A pump station licensed under a combined works approval for irrigation purposes has been constructed to extract water from the Avon River under this licence (refer **Figure 10.1**).

Figure 10.1: Pump Site on the Avon River (Fodder King, 2013)

Pontilands Dam

AGL holds a WAL, which allows extraction of up to 20 ML per year from this large off-river dam on an unnamed gully that drains to the Avon River. AGL holds a combined works approval for the dam and two pump sites and to use this water for industrial, irrigation and stock purposes.

Water Gathering Network

Produced water is separated from the gas flows at each wellhead when under test. Locally, the extracted water from the nearby pilot wells is conveyed to the Tiedman property via a buried pipeline network. For more remote exploration sites, produced water is brought to site by road tankers.

This local water gathering network will be replaced by the gathering network for the Stage 1 development.

Water Storage Ponds

Two 'turkey nest' ponds at the Tiedman property were constructed in 2008 to store freshwater and extracted water (TSD and TND). An additional storage (Tiedman East Dam – TED) was constructed by the NSW Soil Conservation Service in 2013 and is a double lined storage with seepage control for storing extracted water. These storages are approved under various REFs and ongoing approvals issued by DRE for PEL 285. These ponds will continue to store either extracted water, blended water or freshwater until the commissioning of the CPF.

The storages are not licensable under the *Water Management Act*, however all the water that is pumped into the storages is either licensed under existing WALs and works approvals, or existing bore licences under the *Water Act*.

Each pond is an above ground rectangular storage located on high ground beyond the Avon River floodplain. Each has a full supply capacity of 20 ML and each is lined with a high-density polyethylene (HDPE) membrane. A list of the ponds and their function is provided in **Table 10.1**. The two older ponds at the Tiedman property (TSD and TND) will be utilised in the proposed water management strategy for the irrigation and discharge of treated water from the WTP. The newer pond (TED) will be an in-field storage for extracted water (or longer term) a treated water storage pond.

Table 10.1: Summary of Existing Water Storage Ponds at the Tiedman Property

Name	Volume (ML)	Current Function	Proposed Function under EWMS	Lining
Tiedman North Dam (TND) *	20	Storage of catch dam water, residual blended water and produced water from pilot wells	Storage of freshwater from the Avon River or treated water from the CPF	Single lined with a HDPE membrane
Tiedman South Dam (TSD) *	20	Storage of freshwater	Storage of freshwater from the Avon River or treated water from the CPF	Single lined with a HDPE membrane
Tiedman East Dam (TED) **	20	Storage of flowback water and produced water	Storage of extracted water from pilot wells	Double lined with a HDPE membrane, mesh layer and inspection sump

Key: *: these two ponds are maintained with a freeboard of 500mm should there be an extreme rainfall event
**: TED is maintained with a freeboard of 600mm should there be an extreme rainfall event.

The ponds are located off the floodplain beyond the 1:100 and PMF flood levels (BMT WBM, 2015) and are only filled by reticulation and direct rainfall within their embankments. Therefore the ponds have minimal impact on surface runoff and do not reduce or impede catchment flows. There is a water monitoring system dedicated to the integrity of the existing water storage ponds.

10.2. Irrigation areas

AGL recently completed its blended water irrigation program for the historical produced water that was stored since the late 2000s. Blended water (produced water mixed with freshwater) was irrigated across the Tiedman property on two small areas known as Stage 1A (12 ha) and Stage 1B (4 ha). Details are provided in Section 3.1 with the summary status of these two areas described in **Table 10.2**.

Under the broader irrigation scheme for the Stage 1 GFDA both the Stage 1A and 1B areas will be expanded. Treated (freshwater) water would be used for irrigation rather than blended water.

Table 10.2: Likely irrigation expansion areas on AGL's the Tiedman Property

Name	Active Irrigation Area (ha)	Likely to be Expanded as part of Stage 1 GFDA	Viable Irrigation Area (ha)	Current/Future Irrigation Method
Stage 1A	12	Yes	~20	Linear-move irrigator
Stage 1B	4	Yes	~20	Travelling irrigator

An aerial view of the Tiedman property is shown in **Figure 10.2**.

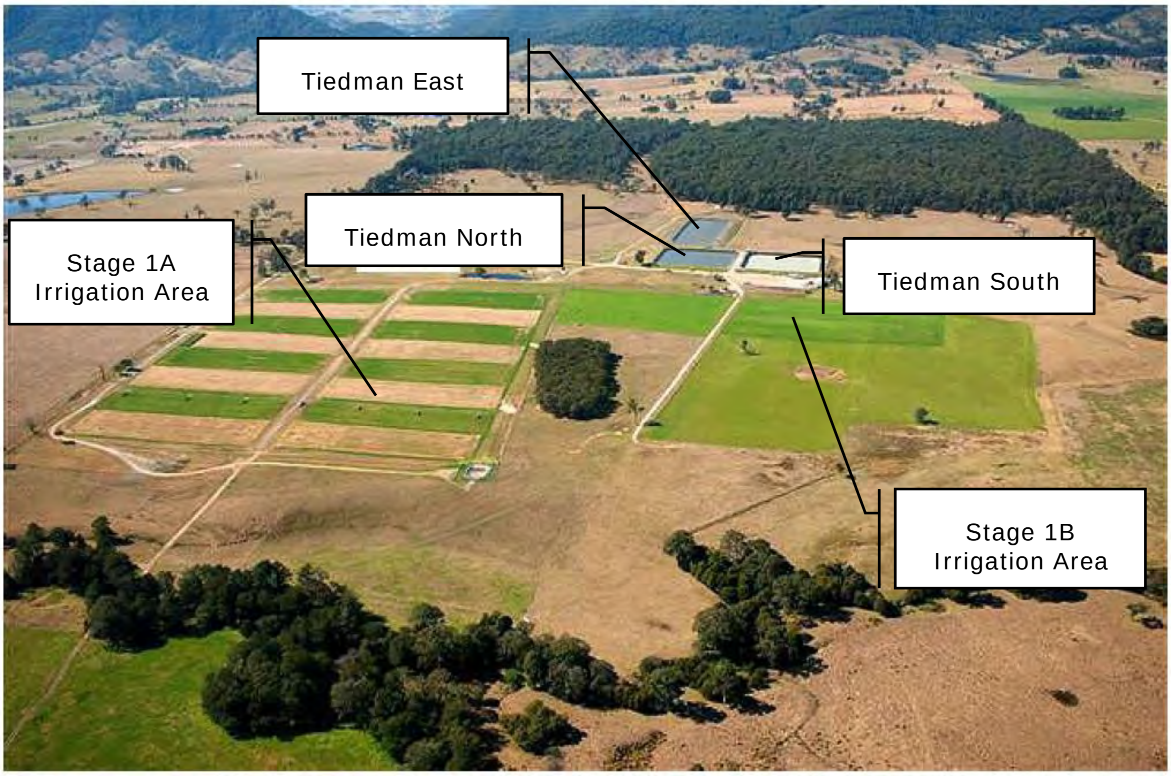


Figure 10.2: Aerial View of the Tiedman Property showing Pond Locations and Irrigation Areas Stage 1A & 1B (Fodder King, 2013)

11. Proposed Water Management Infrastructure

The preferred strategy detailed in Section 5 requires new infrastructure to gather, store and treat extracted water, and to reuse and dispose of treated water. There are also additional infrastructure requirements associated with the many beneficial reuse options and opportunities. Key additional infrastructure requirements (that were all identified in the EA and the Part 3A approval) include:

- Gathering and distribution pipelines.
- Receiving water pond (RWP).
- Pre-treatment facility.
- Water treatment plant (WTP).
- Brine treatment plant (BTP).
- Post treatment facility.
- Treated water tank (TWT).
- Discharge water pond (DWP).
- Irrigation infrastructure.
- Stream discharge infrastructure.

Final engineering design details for the gathering lines, water treatment systems and holding ponds are not yet available. These will be developed under an EPC contract that will be tendered and awarded as one of the first early works packages for the GGP Stage 1 development. Tendering and contract negotiations will be 'Commercial-in-Confidence'.

Under Condition 3.12 and the submittal of the EWMS, engineering designs for the water infrastructure and detailed descriptions of the adopted desalination and treatment technologies are not required. Hence general descriptions of the proposed water management infrastructure are provided in this EWMS.

Several of the initial agency submissions (from EPA, GSC, MCW and broader community) called for additional information on the design elements of the WTP. These issues are not addressed in this EWMS but instead are more appropriate for inclusion in the PWMP and any supplementary plans that may be prepared for the project.

The location of the proposed CPF site relative to the Tiedman property is shown in **Figure 11.1.** Both the CPF site and the Tiedman property where most of the above ground water infrastructure is sited, are located off the Avon River floodplain and beyond the 1:100 and PMF flood limits (BMT WBM, 2015). The location of each of these areas compared to the modelled extent of flooding is shown in **Figure 11.2**.

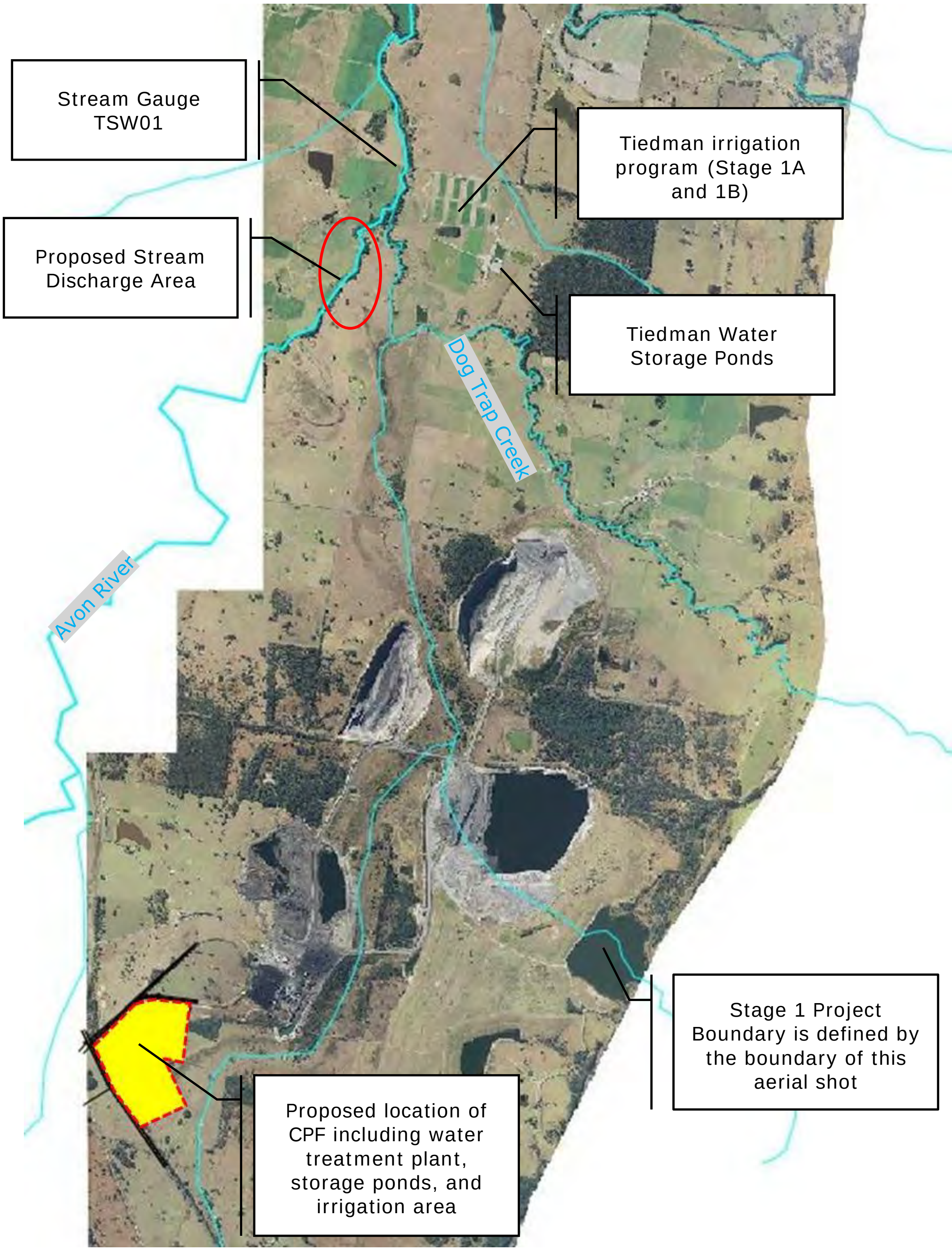


Figure 11.1: Proposed CPF Location Relative to the Tiedman Property within the Stage 1 GFDA

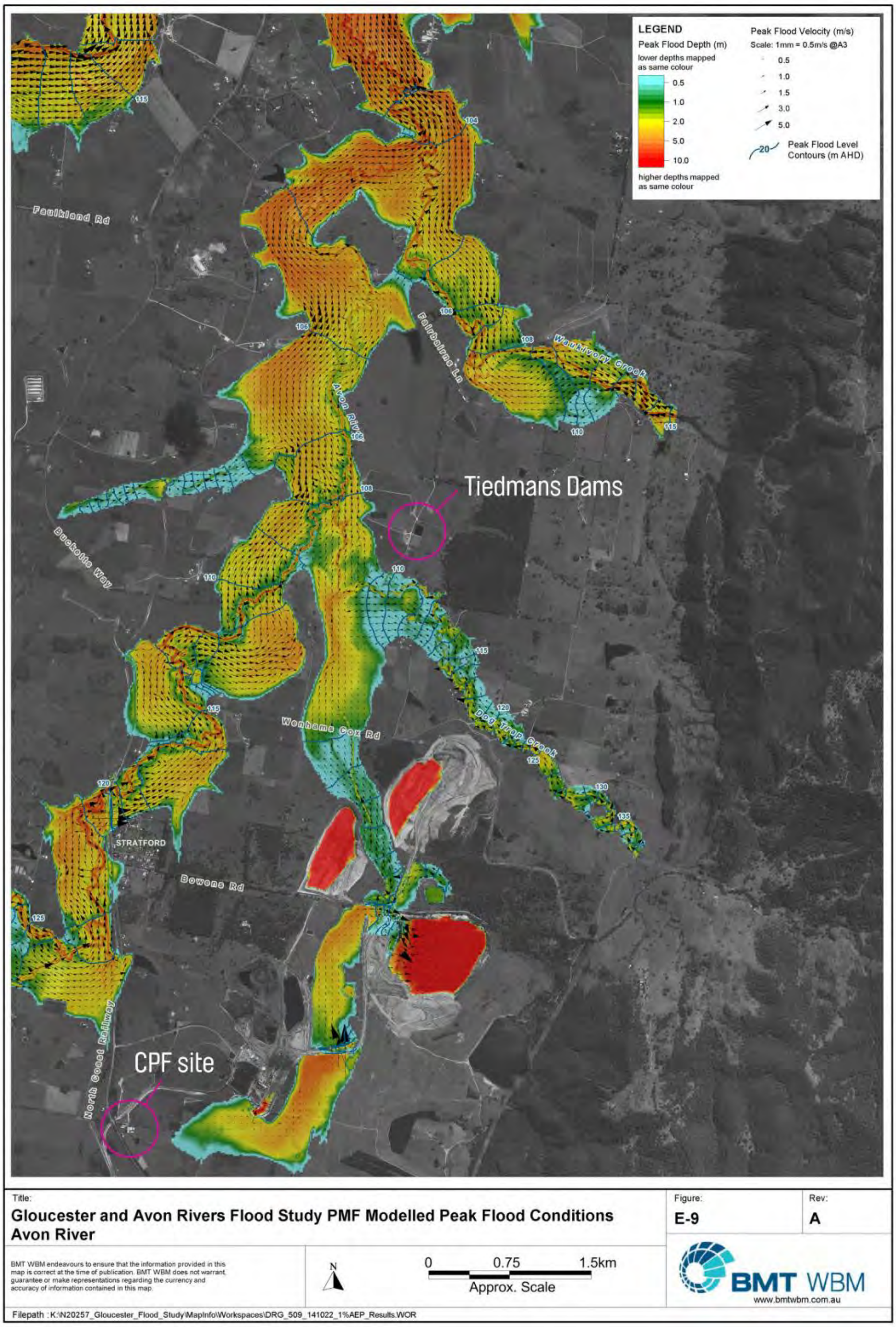


Figure 11.2: Proposed above-ground water infrastructure in relation to predicted flood levels

11.1. Water Infrastructure Flow Schematic

A simplified block flow diagram is provided in **Figure 11.3**, which gives an overview of all the water management infrastructure. Further detail is also presented in **Appendix B**.

For the purposes of this EWMS, the probable size of the water treatment plant and associated assets is described. Final dimensions and the exact location of all the assets won't be known until the awarding of the early works EPC contracts and the engineering design is completed.

The water infrastructure components of the Stage 1 project are unchanged from the assets identified in the Consultation Draft of the EWMS. Ponds and tanks have been reduced in size in accordance with the lower water production profile, expected water throughput, and expected plant redundancy. With the current lower than anticipated water production profile, each of the ponds at the CPF are expected to be less than 25ML in capacity and the treated water pond will be replaced by enclosed above ground (and bunded) tank/s.

All the water infrastructure will be located north of Parkers Rd as originally proposed in the EA (AECOM, 2009) with the exception of the Discharge Water Pond (DWP). This holding pond and the proposed 'Rombo' irrigation area will be located south of Parkers Rd.

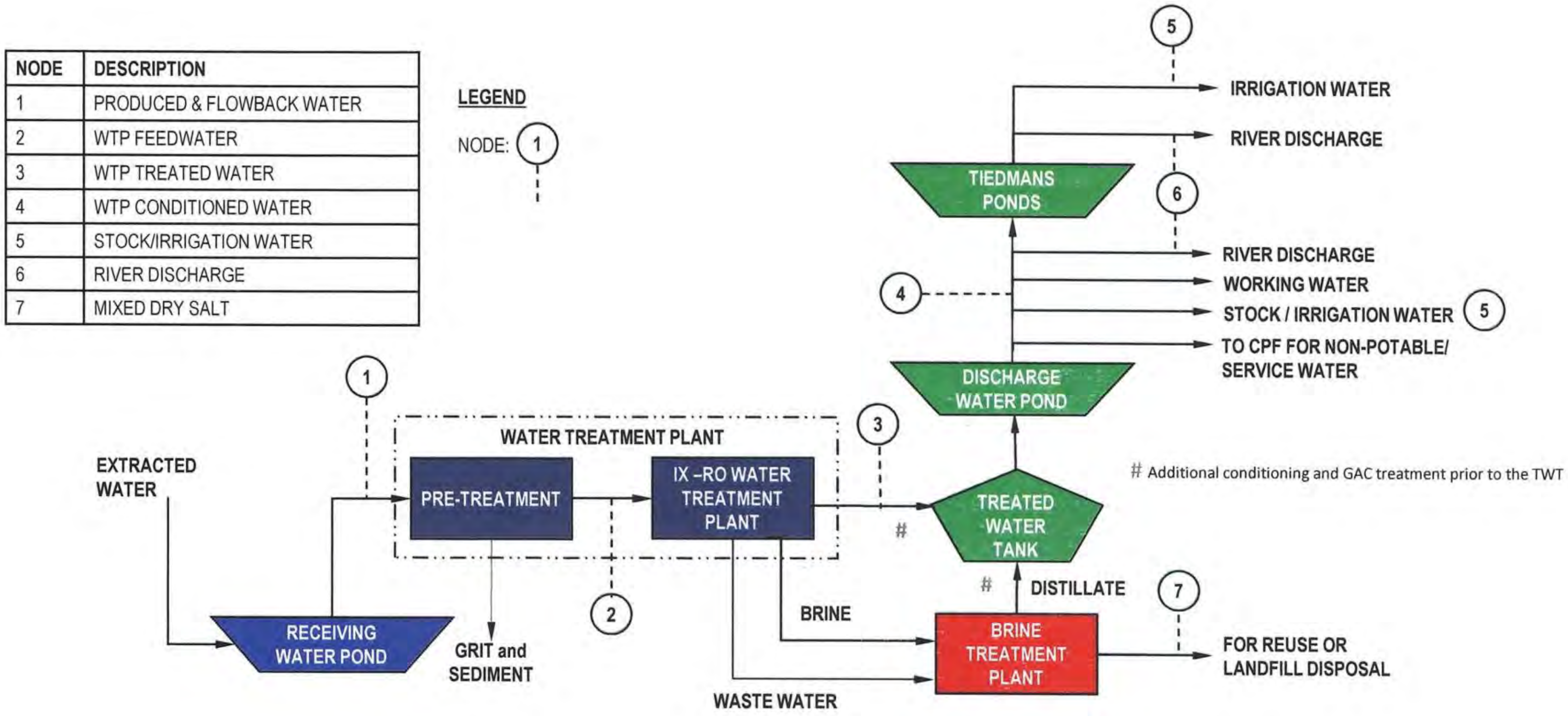


Figure 11.3: Water Infrastructure Flow Schematic

11.2. Storage Ponds and Tanks

Water storage ponds and tanks will be required as part of the extracted water management strategy. The proposed ponds and tanks will be located at the CPF and will store the following:

- Extracted water.
- WTP feedwater (pre-treatment water).
- WTP treated water (RO water, distilled water from the BTP and conditioned water).
- Brine water.

AGL has approval to construct up to three new ponds (each up to 25 ML capacity) at the proposed CPF site, however with the expected lower water production rates only two smaller ponds and two smaller treated water tanks are proposed.

The proposed ponds and tanks (and expected sizes) are:

- Receiving Water Pond (12 - 15 ML capacity).
- Treated Water Tanks (2 x 1 ML).
- Discharge Water Pond (maximum 20 ML capacity).
- Brine Storage Tank (2 ML).

The three existing ponds and irrigation infrastructure at the Tiedman property will be retained.

New ponds will be double lined with an HDPE membrane to reduce the potential for seepage. There will be a filter mesh between the dual layers of each of the ponds, together with seepage control, inspection sump and pump out capability. They will be holding ponds with a relatively small footprint and will not be constructed as evaporation ponds.

Ponds developed as part of the GGP will be lined and have level detection systems and will be designed to retain a 1-in-100 year rainfall event and meet flood design standard.

11.2.1. Receiving Water Pond (12-15 ML capacity)

The Receiving Water Pond (RWP) will receive extracted water delivered from a water gathering network. The RWP will also receive return water from the DAF plant and process water that is treated by an oily water separator located in other parts of the CPF. Process water inflows are expected to be relatively minor (less than 0.01 ML/d).

The proposed RWP design is based on an interconnected two compartment system, consisting of a feed compartment and a buffer compartment. Each compartment will be capable of receiving all of the flowback water flow, produced water, any process or recycle streams. The RWP will be designed to enable maintenance without disrupting WTP operation and receiving various flows. This grit and sediment that accumulates in the RWP would be periodically removed by a floating suction.

The RWP would always be operated at reduced storage levels so as to maximise capacity to store inflows if the water treatment plant capacity was restricted in any way. The maximum daily inflow to the RWP is expected to be approximately 1 ML/d initially reducing to 0.5 ML/d longer term (well below the approved produced water volume of 2 ML/d). The RWP will therefore have a capacity to detain extracted water inflows for up to 15 days during the peak water production period (and for much longer periods during low water production periods) should there be any disruption to WTP operations.

The water balance (**Appendix B**) assumed that the RWP was 10.5 ML capacity (top water level) with an overflow level being at 12.7 ML capacity. To further minimise the potential for stream discharges, AGL is considering a slightly larger RWP than what was proposed in the water balance together with optimising the extracted water stored within TED (the in-field detention storage).

11.2.2. Treated Water Tanks (2 x 1 ML capacity)

The Treated Water Tanks (TWT) will receive treated water from the WTP after the Reverse Osmosis (RO) process and distilled water from the BTP after the brine concentrator and crystalliser processes. The TWT is expected to receive a peak inflow of around 0.97 ML/d (assuming 90% recovery through the RO plant and 80% recovery through the BTP) and provide a couple of day's storage at peak production rates.

The treated water and distilled water will be further treated (if required) to remove any residual hydrocarbons by passing water through GAC filters (see Section 11.3.3) then chemically conditioned (see Section 11.3.4) prior to temporary storage in the two TWTs.

11.2.3. Discharge Water Pond (maximum 20 ML capacity)

The Discharge Water Pond (DWP) will receive treated water from the TWT (after conditioning). The DWP is expected to receive a peak inflow of around 1 ML/d (assuming all treated water after conditioning is stored in this pond).

The water balance (**Appendix B**) assumed that the DWP was 10.5 ML capacity (top water level) with an overflow level being at 12.7 ML capacity. To further minimise the potential for stream discharges, AGL is considering a larger DWP (potentially up to 20 ML) than what was proposed in the water balance.

The target water quality will be in accordance with the most sensitive water quality required (see Section 12) and will be well below the adopted thresholds for each reuse (see Sections 2.4.1 and 2.4.2).

A floating pontoon pump station/s will be installed in the DWP to pump water to the Tiedman storage ponds, Rombo irrigation area and to the surface water discharge location as required.

11.2.4. Brine Storage Tank (2 ML capacity)

The brine storage tank (BST) will receive RO brine concentrate from the WTP. The RO brine will be highly saline with a predicted TDS concentration in the order of 60,000 mg/L which is about 50% more saline than sea water. The maximum RO brine flow received by brine storage tank is expected to be approximately 0.1 ML/d. This maximum flow rate will occur towards the end of the initial development phase, as more wells come online. Longer term the volumes of brine will be very small.

The BST is expected to be enclosed and located indoors in a secure and bunded area to provide secondary containment.

The BST has been sized at 2ML for a 20 day detention time at maximum production rates (and for much longer periods during low water production periods).

11.3. Extracted Water Treatment System

The WTP will operate 24 hours a day seven days a week and will be modular so that it can be upsized/downsized as required.

11.3.1. Pre-treatment Systems

Pre-treatment systems are required in combination with desalination plants to condition the extracted water ahead of the RO plant and to minimise the fouling of membranes. This is especially the case where there is particulate matter in the extracted water and variable water quality from wells in different parts of the basin taking produced water from different coal seams.

A pre-treatment system with a 1 ML/d maximum design flow rate will be provided to treat extracted water. This will remove physical and biological contaminants to provide appropriate quality water suitable as feed water to the RO plant. Subject to the final WTP design, the three major components of the pre-treatment system are:

Dissolved Air Flotation (DAF)

DAF uses micro-bubbles of dissolved air that attach to solids, causing them to float to the surface where they are removed by a mechanical skimmer. It is assumed that algae solids will have a propensity to float and that DAF will be the most suitable technology for the removal of these solids. DAF is preferred as the clarification technology for the purposes of the WTP design.

The DAF will remove suspended solids, algae, and potential iron and manganese oxides. These are the primary solids that will be collected via dewatering. The grit and sediment will be spadeable and suitable for disposal at a licensed facility as GSW in accordance with regulatory requirements. It is expected that at the peak inflow rate of 0.9 ML/d that the peak volume of dry solids would be around 1 m^3/d (maximum two trucks per month).

Disc Filtration (DF)

A DF system (a solids screening process) may be required to protect the UF membrane operation. The DF system nominally removes solids greater than 200 µm that are not captured and removed by the DAF plant.

A small volume of watery fine sediment will be generated that will be returned to the DAF plant for further treatment and removal.

Microfiltration/Ultrafiltration (MF/UF)

The MF/UF system provides sufficient net usable filtrate to maintain design flow to the downstream RO membranes of the desalination plant. The MF/UF filtrate tank receives and balances MF/UF filtrate from the MF/UF train/s prior to delivery to the ion exchange system.

The MF/UF train/s will produce a filtrate with turbidity less than 0.1 NTU and a Silt Density Index (SDI) of less than 3. Backwash waste from the MF/UF is sent to the spent backwash balancing tank and ultimately back to DAF plant for further treatment.

Ion Exchange (IX)

MF/UF filtrate is transferred to the ion exchange (IX) system. The function of the IX system is to soften RO feed water to minimise scaling potential of the membranes (primarily hardness such as calcium, magnesium and other trace metal salts) that could potentially cause membrane scaling and therefore shortening the life of the RO membranes.

IX product water will be delivered to the RO feed tank with IX regeneration waste passing directly to a brine storage tank for brine treatment plant processing.

11.3.2. Desalination

The primary component of the WTP to desalinate extracted water is RO. The WTP would be designed with a modular configuration to accept a maximum flow rate of 1.2 ML/d (i.e. two treatment trains each with a capacity of 0.6 ML/d). For the majority of the production phase period, the WTP would operate at less than 50% of its design capacity. The proposed WTP modular design allows the facility to be flexible, and easily reconfigured, so it can be adapted to meet the changing water production needs over time.

The WTP would treat extracted water that has been through the pre-treatment system to a raw water quality suitable for all beneficial reuses and river discharge options, namely:

› General (non-potable) consumption (for the CPF).

› Working water.

› Stock water.

› Irrigation water.

› Treated water for managed discharge to the Avon River.

11.3.3. Post treatment systems

Treated water from the RO plant will be further treated (if required) to remove any residual dissolved hydrocarbons. If present in waters at the RWP and at the RO plant after desalination, these compounds will be treated and removed by passing the treated water through granulated activated carbon (GAC). Two GAC vessels will need to be regenerated every 3 to 6 months. The vessels will be bypassed if there are no hydrocarbons present in the waters at the RWP or after desalination.

11.3.4. Post RO treatment and conditioning

In addition to GAC treatment, some final water conditioning will be required after RO desalination to ensure that the water quality is suitable for its intended use/stream discharge (Section 12). Calcium and/or magnesium addition (through calcium chloride and magnesium sulphate solutions) will be required post desalination to achieve the required sodium adsorption ratio (SAR) for beneficial use as irrigation water.

Dechlorination with sodium bisulphite is required to achieve the ANZECC guideline value for chlorine for river discharge. It is also likely that pH adjustment will be required to achieve the target water quality for both irrigation/stock reuse and stream discharge. Adjustment of pH can be achieved by caustic addition.

Further details on dosing chemicals, quantities and measures to ensure that correct mix ratios occur (and overdosing does not occur) will be provided in the PWMP after the EPC contract for water treatment is awarded and the WTP is delivered.

11.4. Brine Treatment

A preliminary review of a wide range of brine management and treatment options was undertaken which identified thermal evaporation technology as the preferred brine treatment process option for the GGP to produce a dry mixed salt. The brine treatment plant (with a nominal design capacity of 0.2 ML/d) will comprise a brine concentrator and brine crystalliser, and be capable of treating the entire brine stream. This capacity is double the expected RO brine feed flow rate. A centrifuge will be required to turn the final salt paste into a dry mixed salt.

The salt produced from the thermal brine management system will be handled on site by an appropriate salt handling system. The dry mixed salt will be contained in 1 tonne nominal capacity bulkabags and stored undercover on hardstand to ensure that these wastes do not become wet and then dissolve and leach into the environment. Salt stockpiles will be minimised and salt will be trucked for off-site disposal to a licensed landfill at regular intervals. It is expected that a maximum of two trucks per week would be required at peak production but this would reduce to less than one truck per month for the longer term.

11.5. Gathering and Distribution Systems

The type of pipelines required for managing the production, treatment and distribution of extracted water are described below:

11.5.1. Water Gathering Lines

A low pressure water gathering system will connect each well to the CPF. Small volumes of extracted water may be stored at low water-producing well sites in bunded above-ground (enclosed) tanks so that water can be pumped efficiently in batches to the CPF (or tankered if volumes are very small). Extracted water will discharge directly into the RWP. During the field development period, all collected flowback water/produced water will be discharged to the RWP prior to treatment.

These water gathering lines will be co-located with the gas gathering network. All water gathering lines will be inspected and integrity (pressure) tested prior to being commissioned. Ongoing pressure monitoring and inspection of these lines will occur as part of the field operations. Further details will be provided in the PWMP.

11.5.2. Transfer of Treated Water to Wells and to the Tiedman Property

A separate line will also be installed to deliver working water to wells for fracture stimulation and workovers. This working water line will be co-located with the water and gas gathering lines. The working water lines may also deliver stock water to landowners who have expressed an interest in receiving treated water for on-farm use.

Post construction, treated water will be transferred from the DWP for the following uses:

› Water for the CPF: water for non-potable uses within the CPF via separate delivery lines.

› Stock water: water to individual tanks and troughs on properties via the working water delivery lines.

› Irrigation Water: water either directly to the Rombo irrigation area or to the water storage ponds on Tiedmans via a separate distribution spine line.

› Discharge to Avon River: water for discharge to the preferred discharge location via an offtake from the distribution spine pipeline (delivering treated water to Tiedman property for irrigation). Alternatively the conceptual design also allows for stream discharge from the Tiedman holding ponds.

These lines will be co-located with the gas and water gathering lines where possible. All return water lines will be inspected and integrity (pressure) tested prior to being commissioned.

11.5.3. Miscellaneous Distribution Pipelines

It is envisaged that the following transfer pipelines will be required:

› Upgrade of irrigation network: As a result of new irrigation area development, the irrigation network will need to be upgraded and expanded. This will require the new pumps and pipelines to supply treated water to the irrigation areas at Rombo, Tiedmans, Pontilands and possibly Avondale.

› Future offtakes for private agricultural and industrial/commercial users: There may be a future demand for treated water for private agricultural and industrial customers. As a consequence, provision may be made for the 'tees' to be installed in the treated water pipeline (with blanked flanges) to allow connections for offtake pipelines in the future.

Within the CPF area there will be transfer pipelines, including associated pumps and controls to connect ponds and tanks. All water and transfer systems required within the CPF (or generated by the CPF design such as sewage and stormwater) will be dealt with onsite as part of the detailed design for the WTP and CPF.

11.6. Reuse and Discharge Infrastructure

11.6.1. Irrigation

Some 60 ha of irrigation area has been identified at the start of the project for the irrigation of treated water. This area is based on a maximum requirement to irrigate a maximum of 200 ML of treated water per annum. The recent blended water irrigation program at Tiedmans achieved application rates of between 4 and 5 ML/ha/yr on both fodder crops and irrigated pasture during dry to average seasons. 60 ha of irrigation aligns with this maximum water volume (and doesn't allow for the other proposed reuses) therefore AGL expects that the actual irrigation area required longer term will be much less.

A number of potential irrigation areas on AGL-owned properties have been identified as being suitable. It is expected that there will be several irrigation areas that are between 10 ha and 20 ha in size and spread across the AGL-owned properties of Rombo, Tiedmans, Pontilands and possibly Avondale. There may be some rotation between irrigation areas. The irrigation areas in likely priority area are:

› Rombo (southern CPF area) (10ha).

› Tiedman (several areas totalling 40ha).

› Pontilands (10ha) (if required).

› Avondale (if required).

The final agricultural layout, crop types and irrigation strategy will be described in a farm master plan that focuses on the probable irrigation areas, irrigation infrastructure, irrigation methods and crop types. Other properties in the vicinity of the CPF and Stage 1 area will also be considered for supplementary irrigation. The delivery of water to private properties and the reduction in AGL irrigated areas will be the subject of further negotiation with individual landowners as part of the required access and compensation agreements.

The possible irrigation areas on AGL-owned properties are shown on **Figure 11.4**.

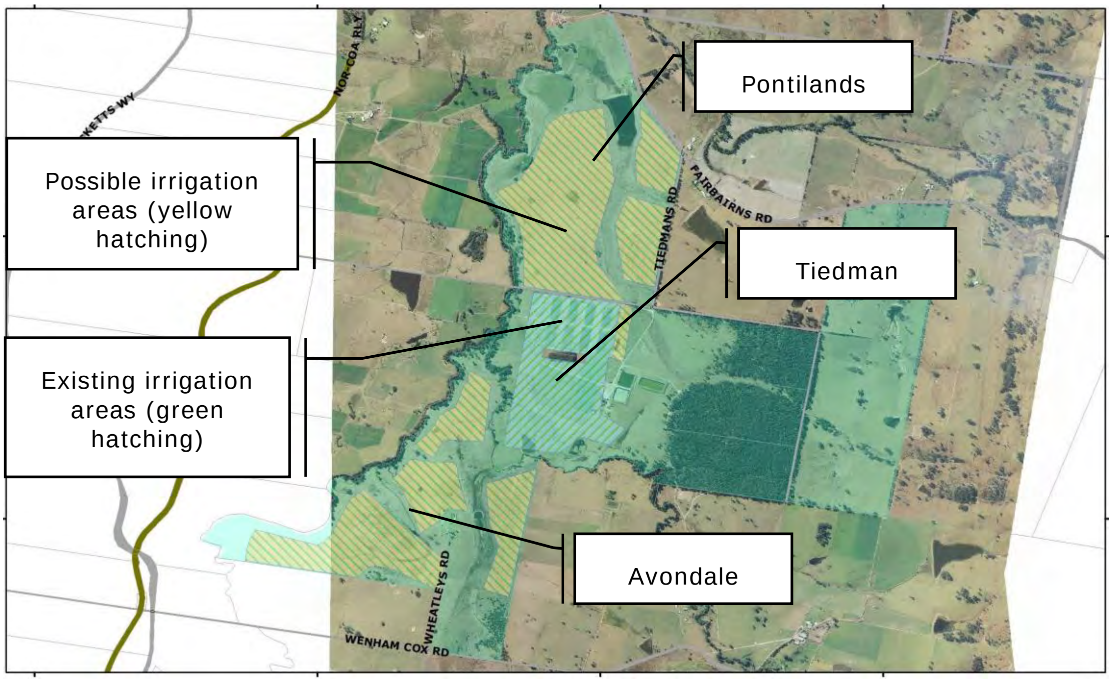


Figure 11.4: Existing and Proposed AGL Irrigation Areas for Treated Water (except Rombo – southern block of the CPF)

11.6.2. Stream Discharge

If required, discharges will be to the Avon River upstream of the confluence of Dog Trap Creek and the Avon River (the indicative area is shown on **Figure 11.1**). The final preferred site is location AV2 outlined in the ecological and geomorphic impact assessment study (Cardno, 2015). This location is shown in **Figure 9.1** and described in **Appendix C**. The preferred area is near the proposed return water pipeline transporting treated water to the Tiedman holding ponds.

Discharge of high quality treated water to streams (when no other options are available) generated the greatest amount of regulator and water supply authority discussion on the Consultation Draft. The volumes and likely frequency of proposed stream discharges are now significantly lower than proposed in the Consultation Draft. Importantly, water quality for any stream discharges will be freshwater quality (the final target water quality criteria are subject to approval under AGL's EPL).

The water balance modelling study (**Appendix B**) suggests that no treated water will require discharging to the Avon River during dry and average seasons. The discharge of treated water to the Avon River is only expected for the P90 water production profile and only if P90 rainfall events occur. Discharge volumes are expected to be less than 20 ML in total (Worley Parsons, 2015). After the first three years of operations, AGL does not expect to use this option as there will be sufficient storage for produced water and treated water in all but the wettest years.

AGL will maximise the storage of treated water prior to any requirement to stream discharge. This stream discharge option is a last resort if irrigation and stock watering are not possible and all water storages at the CPF and at Tiedmans are close to full (there is expected to be at least 90 to 100 ML of storage capacity within the system). Development or the availability of additional irrigation area is not a solution during extended wet seasons when no irrigation is possible for long periods (Worley Parsons, 2015).

11.7. Aquifer Storage and Recovery

The following is a review of reinjection of produced water that is provided in response to Condition 21 of the EPBC Act (EPBC 2008/4432) approval for Stage 1 of the GGP. The EPBC approval requires this assessment even though reinjection to groundwater is specifically banned under the Part 3A approval.

Aquifer Storage and Recovery (ASR) is a prospective reuse/disposal strategy for treated and untreated produced water when the geology and hydrogeological characteristics of a sedimentary basin are suitable. If there are suitable conditions, the potential opportunities are:

› Deep Disposal - Disposal of untreated water/brine to deep groundwater systems when there is sufficient storage/confining layers and there is no connectivity to beneficial aquifers and environmental receptors.

› Shallow Storage and Recovery - Recharge of treated water to shallow beneficial aquifers when there is sufficient storage and permeability characteristics for later recovery and use.

At Gloucester neither the geology nor the hydrogeology are suitable for deep disposal or shallow storage and recovery. From a geological perspective:

› The rock types are mostly coal seams, and consolidated siltstones, mudstones and conglomerates.

› There are no known moderately or highly permeable formations (such are porous sandstones).

› The basin is deformed with many high dip areas and faulted compartments.

› There are no (conventional) deep structural reservoirs with competent cap rocks over large areas where containment could be guaranteed.

› All rock types are consolidated with faults and fractures the main defects in the rock mass.

› The rocks would have to be hydraulically fractured to create any reasonable storage for injected water.

From a hydrogeological perspective:

› The potential for additional groundwater system storage is low.

› All of the rock permeabilities are low.

› The groundwater systems are full (there are no depleted storage areas at this time).

› The water quality is poor in all aquifers and water bearing zones.

› There is minimal groundwater use therefore storing freshwater in shallow aquifers and then trying to recover this water is unlikely to be taken up by local landowners.

› If untreated produced water/brine water was injected under pressure into deeper groundwater systems, the formations would not accept much water because of the required high pressures, limited storage and low permeabilities.

› If treated water was injected into the shallow fractured rock groundwater systems (beneficial aquifers to ~ 75 m depth) then again there is limited storage and any injected volume would displace a similar volume of slightly saline water into the landscape. It is also uncertain as to what degree of mixing would occur and whether freshwater quality could be maintained.

› If treated water was injected or drained into the shallow alluvial aquifers again there is limited storage and any recharged water would drain into the Avon River or displace a similar volume of brackish to slightly salty water into nearby rivers (mainly the Avon River).

There are other impediments to ASR type schemes including:

- The construction of additional bores/wells that would require fracture stimulation.
- Reinjection of produced water to deep water bearing zones and shallow beneficial aquifers would require additional environmental approvals.
- Reinjection into groundwater systems is specifically banned under the Part 3A approval for Stage 1 of the GGP.
- Re-pressurising the intermediate and deep coal seams would diminish gas production.

In conclusion, there are negligible prospects of being able to dispose of small to moderate volumes of untreated produced water, brine or treated water to any of the groundwater systems within the Gloucester Basin. If produced water volumes reduced to very low volumes (say less than 0.01 ML/d) then ASR could be re-evaluated (together with other low volume options) to assess its suitability on a local scale. Disposal schemes rather than reuse schemes would be the focus given there is negligible groundwater use across the basin at this time and the likelihood of groundwater development occurring (given the reliability of rainfall and surface water runoff) is low.

DPI Water endorsed AGL's conclusion that aquifer recharge (storage and recovery) is not a feasible water and brine management strategy for this project.

11.8. Management of Excess Extracted Water

Extracted water may occasionally be generated at rates greater than 1 ML/d for very short periods of time if a large number of wells are fracture stimulated in a single program and brought on line quickly. However based on the most recent water production profiling, it is unlikely that the actual extracted water rates would exceed 1 ML/d. AGL's dewatering is capped at a maximum 2 ML/d of produced water extraction (Condition 3.11 of the Part 3A approval).

Exceedances of this rate (irrespective of whether it is flowback water or produced water) for a few days or weeks as new wells are commissioned is not considered to be an issue from an operational perspective as there is sufficient storage capacity at Tiedmans and at the CPF for higher extracted water flows. In the unlikely event of a higher rate of produced water extraction occurring for an extended time the following issues arise:

- Lack of water treatment capacity at the CPF.
- Lack of storage capacity with the wellfield.
- Insufficient irrigation area.

Each of these issues has been assessed and mitigation/management measures are proposed.

WTP Capacity

The WTP at the CPF will be sized to treat an extracted water flow rate of 1.2 ML/d. Two RO treatment trains (each of 0.6 ML/d capacity) are proposed to cater for breakdowns, maintenance and occasional flow peaks. Some day to day variability is expected and some excess capacity is being built into the design to ensure that the water treatment system is fully functional at all times.

To cater for extracted water flows greater than 1.2 ML/d that might occur for longer periods (highly unlikely scenario), the WTP can be expanded by adding additional RO modules to increase capacity. There is also a large RWP (12-15 ML) with multiple compartments to cater for occasional higher inflows. Around 10 days of storage is considered reasonable to address this unlikely scenario. Buffer storage for extracted water is also available in-field at Tiedmans (TED storage) in the event of higher water production volumes.

In the extremely unlikely scenario where extracted water volumes were exceeding 2ML/d for extended periods (thereby potentially breaching the cap of 730 ML per year), AGL would need to apply for a project modification and for an increase in groundwater allocation. It is more likely that newer wells would be shut in or not brought into production until water production rates diminished at existing sites.

The WTP will be of a packaged modular flexible system that would be designed with adequate redundancy (e.g. using several 0.6 ML/d capacity RO treatment modules) primarily to provide redundancy and operational flexibility to manage variable flow rates.

Storage Capacity

The total storage capacity of holding ponds and tanks at the CPF and at Tiedmans will be at least 90 to 100 ML. This equates to around 100 days of storage if the maximum flow rate of 0.9 ML/d is generated from the wellfield for any length of time.

Irrigation Area

A shortage of available irrigation area is also an unlikely scenario as more than 60 ha of irrigable area will be available on AGL properties alone (although it is unlikely that more than 60 ha will be utilised at any one time).

Stream Discharge

If there was insufficient irrigation area, all treated water storages were full, and the flow conditions in the Avon River were suitable, then treated water would be discharged to the river to relieve the pressure on having to build additional storage for treated water for an extended period. Stream flow discharges for extended periods is an extremely unlikely scenario (Worley Parsons, 2015).

11.9. Control Measures for Wildlife Access

The storage of produced water as part of the GGP infrastructure has the potential to impact on wildlife that could access the storage ponds. Wildlife access to ponds can also have detrimental impacts on the storage itself by damage to the pond lining and degradation of water quality.

The following control measures will be implemented for the proposed and existing ponds:

- Ponds will be fenced with a 2 m chain linked fence with 250 mm of the bottom fence buried to prevent animals digging below for access. Human and vehicle access will be provided with suitable locked gates.
- The new WTP ponds at the CPF will be within the perimeter of the main facility that will also be fenced.
- The WTP ponds will be constructed as deep ponds to reduce the footprint and surface area.

With these control measures in place, wildlife and livestock, will not be able to access the ponds and will ensure that the produced water ponds do not pose a significant risk to wildlife.

Given the availability of alternative water sources in the area, including farm dams, creeks and rivers, and due to the presence of infrastructure and personnel at the CPF, it is considered unlikely that birds would preferentially utilise the new water storage ponds. In any event, birds have not been an issue at the three similarly sized ponds at Tiedmans to date. Netting of the ponds will be considered as a contingency response if birds are wanting to colonise the ponds.

12. Treated Water Quality Target

The treated water salinity from the WTP will most likely be less than 250 mg/L TDS. The proposed water treatment technologies (particularly the RO plant) will remove the larger dissolved cations, anions and any heavy metals to achieve this low salinity water quality. The proposed water quality target is to apply after conditioning and is based on the expected output of the RO plant and other proven water treatment technologies that are proposed to be used.

The desalination process will produce extremely pure water that can be corrosive and be dominated by the smaller ions such as sodium (Na) and chloride (Cl). To soften and rebalance the ionic ratios, some additional conditioning is required for the treated water from the RO plant. These chemical adjustments generally add calcium, magnesium and extra chloride ions back into the treated water to adjust the SAR and to make it more suitable for the proposed uses. Minor pH adjustment to neutralise the acidity is also anticipated.

To monitor the efficiency of the desalination and conditioning process:

› There will be monthly monitoring of the RO water quality.

› There will be continuous EC and pH loggers in TWT and the DWP.

› There will be monthly water quality sampling of the treated water in the TWT and the DWP.

AGL is proposing that the DWP be the compliance monitoring location for the treated water complying with the proposed target water quality criteria.

AGL is proposing water for the following beneficial reuses:

› Working water (for drilling, fracture stimulation and workover of wells).

› CPF process water.

› Stock water.

› Irrigation water.

› Supplementary environmental flows (discharge water).

In the Consultation Draft of the EWMS, AGL proposed different water quality for different reuses. This would be difficult to manage and control at the WTP (and would require batching rather than a generating a constant stream of treated water). Consequently in this Final EWMS, AGL has adopted a simplified approach.

AGL is proposing to produce one water quality stream. Water from the RO plant will be conditioned after the RO plant and before the TWT to be suitable for all proposed uses. Stream discharges have the most stringent water quality criteria and therefore the treated water will be conditioned to meet this target criteria (final criteria are subject to negotiations with EPA and approvals under AGL's EPL). Stream discharge salinity and temperature will closely match the Avon River water quality at the time of discharge. No discharges will occur unless the treated water salinity is within ±20% of the Avon River salinity at the (downstream reference) TSW01 stream gauge location. All other treated water analytes will be less than the target water quality criteria.

Stream discharges may not occur at all if normal to dry rainfall patterns prevail in the initial years of operation. Proposed stream discharge criteria are provided in Section 9.3. Discharge water volumes (if required) will be very small and will only be released during natural high flow periods to ensure there is sufficient dilution.

For the purpose of this EWMS, a salinity level of 200 mg/L TDS (about 300 µS/cm) has been assessed as the most likely treated water salinity after RO desalination. This salinity will increase slightly after chemical conditioning. No upper limit can be confirmed at this time but is unlikely to exceed 400 mg/L (about 600 µS/cm). Consequently the proposed salinity water target range for treated water (for both reuse and stream discharge) is >300 µS/cm and <600 µS/cm.

For comparison, water with a salinity less than 1000 µS/cm (about 600 mg/L) is freshwater and drinking water quality. Similarly the Avon River water quality at the TSW01 stream location (based on five years of continuous EC monitoring data collected since 2011) suggests that natural river salinities are in the range 200 to 600 µS/cm with occasional salinity peaks up to 1300 µS/cm immediately after heavy rain (PB, 2014e).

A summary of the proposed target water quality criteria for water reuse and stream discharge is provided in **Table 12.1**. The analytical suite and primary parameters have been expanded in the Final EWMS based on comments from EPA and MCW.

This criteria has been developed from the basis of design for the WTP infrastructure and the known water quality that can be achieved with the proposed water treatment technologies. The proposed water quality targets include all those analytes listed in Table 2.6 and are equivalent to or better than the ANZECC (2000) 95% trigger values for the protection of freshwater aquatic ecosystems.

The analytical suite includes the elemental constituents of the likely fracture stimulation compounds but not the individual compounds as they disassociate in water and are difficult to detect at low concentrations. This is the approach that has been adopted for the Waukivory Pilot water monitoring program.

In addition, the non-potable and process water for reuse within the CPF will be taken from the TWT or DWP and will be chlorinated so as to provide disinfection and human health protection in the event of cross contamination or human contact with this secondary water source.

Table 12.1: Target Water Quality Criteria for Treated Water (after conditioning)

Primary Parameter	Unit	Range or Upper Limit	Remarks
pH	pH units	6.5 to 8.0	ANZECC freshwater ecosystem criteria
Suspended solids	mg/L	<10	
Turbidity	NTU	<15 ^	Below the ANZECC criteria for upland and lowland rivers in SE Australia
Dissolved oxygen	% saturation	>85% saturation	ANZECC freshwater ecosystem guideline
Salinity (EC)	µS/cm	>300 and <600	Below ANZECC freshwater ecosystem criteria
TDS	mg/L	>200 and <400	Below the ANZECC freshwater ecosystem criteria and ADWG criteria 200 mg/L is the expected output from the RO plant but the actual target water quality at the DWP will be slightly higher depending on the chemical conditioning required
Sodium	mg/L	<80 *^	
Calcium	mg/L	<10 *^	
Magnesium	mg/L	<2 *^	
Total alkalinity (as $CaCO_3$)	mg/L	<60 *^	

Primary Parameter	Unit	Range or Upper Limit	Remarks
Iron	mg/L	<1	
Manganese	mg/L	< 0.5	Below ANZECC freshwater ecosystem criteria
Aluminium	mg/L	<0.05	Below ANZECC freshwater ecosystem criteria
Antimony	mg/L	<0.003	ADWG criteria
Arsenic	mg/L	<0.01	Below ANZECC freshwater ecosystem criteria
Barium	mg/L	<0.7	Below the ADWG criteria
Cadmium	mg/L	<0.0005	ANZECC freshwater ecosystem criteria
Chromium	mg/L	<0.0025	ANZECC freshwater ecosystem criteria
Copper	mg/L	<0.0035	ANZECC freshwater ecosystem criteria
Lead	mg/L	<0.0136	ANZECC freshwater ecosystem criteria
Mercury	mg/L	<0.0006	ANZECC freshwater ecosystem criteria
Nickel	mg/L	<0.0275	ANZECC freshwater ecosystem criteria
Selenium	mg/L	<0.011	ANZECC freshwater ecosystem criteria
Strontium	mg/L	<0.7	
Zinc	mg/L	<0.01	Below ANZECC freshwater ecosystem criteria
Chloride	mg/L	<100 *^	
Sulphate	mg/L	<40 *^	
Total Nitrogen (as N)	mg/L	<0.25	Below ANZECC freshwater ecosystem criteria
Total Phosphorus	mg/L	<0.05	Below the ANZECC criteria for lowland rivers in SE Australia
Fluoride	mg/L	<1	Below the ADWG criteria
Boron	mg/L	< 0.37	ANZECC freshwater ecosystem criteria
Residual disinfectant (monochloramine)	mg/L	<0.05	
Ammonia	mg/L	<0.25	
SAR		<9 (preferably <6)	Limit is for irrigation water quality
BTEX compounds	µg/L	B <1; T <15 E <15; X <15	All equal to or below ADWG criteria and ANZECC freshwater ecosystem criteria

Key: * - these are likely to be typical values after RO and prior to conditioning. There are no published trigger values for the protection of freshwater ecosystems for these analytes.

^ - to be confirmed by EPC contractor – upper limits are expected to be less than the values quoted in this table.

13. Brine and Waste Management

Several waste streams will result from operations associated with managing extracted water. This waste is expected to be generated and controlled at the following locations:

- Receiving water pond (RWP) receiving extracted water from the field.
- Pre-treatment processes (primarily the DAF plant).
- WTP (IX and RO plants) processes.

The RO plant within the WTP and the Brine Treatment Plant (BTP) will also generate brine (and salt) as the main by-product of the desalination process.

Primary solids from the pre-treatment system and salt will be collected and disposed at an offsite waste facility as general solid waste (GSW) in accordance with regulatory requirements. Liquid wastes will be recycled within the each of the component processes of the WTP and then included in the brine waste stream for ultimate salt disposal.

13.1. Receiving water pond

Extracted water as received from the gathering systems may contain small volumes of grit and sediment. This is expected to collect in the first of the cells in the RWP. Occasional cycling of cells will be required to remove the sediment. Waste volumes will be highly variable with most sediment generated during the gas well commissioning period. Volumes are expected to decrease as wells mature and produced water volumes decrease. Solid waste volumes cannot be quantified at this time but will be small.

Once removed from the RWP these sediments will be dried and stockpiled in an appropriate contained and bunded facility with the small volume of solid wastes from the pre-treatment processes. These will be periodically disposed at an offsite waste facility in accordance with regulatory requirements.

13.2. Pre-treatment waste management

The pre-treatment facility will collect finer grit and sediment that does not settle in the RWP.

Backwash waste streams from the DF and MF/UF systems will be sent to the spent backwash balancing tank and then recycled through the DAF plant. Minor quantities of solid waste (fine grit and sediment) will be generated as an output of the DAF process. Sediment volumes are expected to be less than 1m^3/d (as 25% dry solids at maximum flow rates) and will be dried and stockpiled in an appropriate contained and bunded area of the CPF. These will be combined with the RWP solid wastes and periodically disposed at an offsite waste facility as GSW in accordance with regulatory requirements.

13.3. WTP waste management

Several of the WTP processes generate minor chemical waste streams typical of all desalination plants. Chemical wastes will be directed to the Brine Storage Tank (BST) for BTP processing. The chemical waste streams are:

- IX acid regeneration waste.
- UF membrane CIP waste.

› RO membrane CIP waste.

These waste streams are generated periodically and their volume is negligible compared to the RO brine stream volumes. Any acid or alkaline wastes will be neutralised prior to being diverted to the Brine Storage Tank.

13.4. Brine management

RO membrane desalination will generate a brine concentrate stream that will contain the salts present in the extracted water, but at significantly elevated concentration levels.

Salt recovery and reuse of brine and salt streams is AGL's preferred management strategy, however given the variability in the produced water salinity within the Gloucester Basin and the salt being a mixed sodium-chloride-bicarbonate salt, the reuse opportunities appear limited.

The RO desalination process will produce a highly concentrated brine stream (estimated to have a salinity of around 60,000 µS/cm or 50% higher than seawater) which will be further treated using a thermal technology (i.e. brine concentration and crystallisation or if technically appropriate, brine crystallisation without preceding brine concentration) to produce a salty paste. A centrifuge is then used to create a mixed (dry) salt suitable for disposal off site as a solid waste.

This approach by removing the salt from site and exporting it from the catchment would avoid the legacy of land at the CPF being rendered unusable in the future if there was solid waste encapsulated at the site.

The mixed salt content of the produced water and the small and decreasing volumes will most likely preclude its use as a saleable salt. However, the design of the WTP and brine management system will be such that new treatment technologies could be 'bolted on' over time to provide more sustainable salt management solutions if proven to be economically viable. The possibility of using the mixed salt as the basis of salt lick blocks for cattle will be further investigated.

The maximum volume of salt that would be generated at the maximum P90 water production rate of 0.9 ML/d if the water salinity was 5000 mg/L TDS would be 4.5 tonnes per day (t/d). The peak P50 water production profile rate of 0.6 ML/d would produce 3 t/d of salt. Once the produced water volumes dropped to 0.1 ML/d (after five years) the salt tonnage would reduce to a very small 0.5 t/d.

13.5. Final Salt Disposal

The mixed dry salt will be predominantly sodium-chloride-bicarbonate (Na-Cl-HCO_3) salt. Sodium chloride (NaCl) is table salt while sodium bicarbonate ($NaHCO_3$) is bicarbonate of soda (used for a variety of household uses including cooking (baking), cleaning, and personal health). The crystallised salt by-product would most likely be classified as General Solid Waste (GSW) (non-putrescible) under the NSW *Waste Classification Guidelines* (EPA, 2014).

There are no assays available for the crystallised salt derived from produced water from Gloucester gas wells at this time. An initial composite sample of flowback water from the four Waukivory wells that was evaporated to salt then analysed for specific contaminants has confirmed that the initial salt from these wells conforms to GSW (PB, 2015h). Further produced water and solid waste results will inform the final reuse, waste classification and landfill options. Assessing the landfilling options and the fate of this salt in a GSW landfill is outside of the requirements for this EWMS but will be further addressed in the proposed PWMP.

The total identified capacity to receive GSW in the Newcastle/Sydney Basin is approximately 2.3 Mt per annum. The expected peak salt production in the initial years is expected to be less than 1000 tonnes per annum (t/a) with the long term average salt production expected to be less than 200 t/a. This equates to about two trucks per week initially and then one truckload of salt per month for disposal at a licensed facility outside of the catchment. This average compared to the regional capacity to receive such waste represents around 0.009% of the general solid waste stream. The relative percentages are shown in **Figure 13.1**.

AGL has identified multiple landfills operated by major waste disposal companies in the Newcastle/Sydney Basin region that are licensed to receive crystallised salt as General Solid Waste (non-putrescible). No approaches to landfill operators have been made at this time to accept this solid waste.

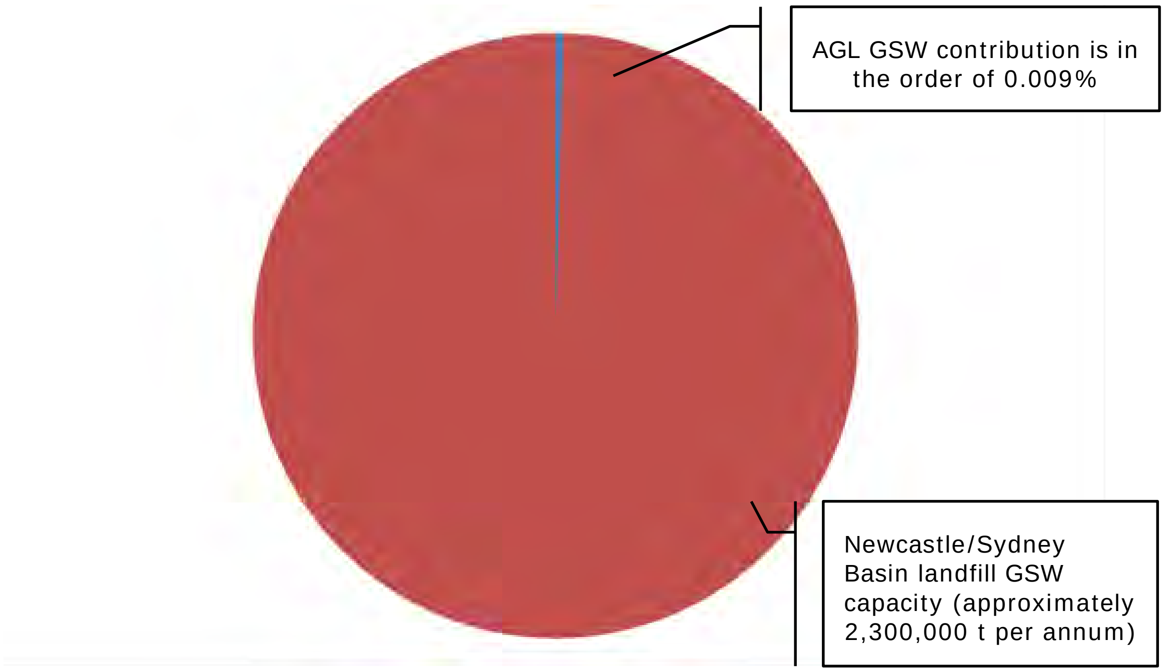


Figure 13.1: AGL's Estimated Contribution to GSW (non-putrescible) received in Newcastle/Sydney Basin Region

14. Monitoring Plan Principles

This section outlines the monitoring principles and the likely monitoring requirements for the management of extracted water and treated water.

Detailed monitoring requirements will be included in a Produced Water Management Plan (PWMP) and any supplementary plans (such as the GMMP) required prior to commissioning of the CPF. An outline of the probable water monitoring program for the proposed water infrastructure and reuses is provided in **Appendix E**.

The water monitoring objectives and principles for managing extracted water and protecting human health and environmental receptors are:

- To effectively monitor the water infrastructure (gathering lines, holding ponds and tanks, reticulation pipelines and storage ponds) to ensure there are no leaks or overflows.
- For extracted water, to protect human health by minimising exposure pathways and to undertake monitoring at locations where there is storage or detention of extracted water prior to treatment.
- For extracted water, to protect the environment by ensuring there is an adequate surface water and groundwater monitoring network in place to capture baseline data and then transient data at appropriate frequencies for the life of the Stage 1 GFDA.
- For treated water, to ensure that the treated water quality meets the proposed water quality targets and never exceeds the thresholds proposed in this EWMS.
- For treated water, to protect the environment by ensuring that the natural water levels and quality in natural systems (both surface water and groundwater) are not impacted by the proposed reuses or rare stream discharges by having an adequate surface water and groundwater monitoring network in place.

The PWMP will:

- Detail inspection and testing procedures for assessing and maintaining the integrity of the gathering systems, reticulation pipelines, storage ponds and tanks, and pond liners.
- Identify the water monitoring network for extracted water, the water treatment plant and reuse water applications.
- Identify the upstream and downstream monitoring requirements for the proposed stream discharge location.
- Detail the locations of monitoring points, parameters to be measured, frequency of monitoring, and monitoring/sampling methodology.
- Identify trigger values for primary parameters and the final adopted analytical suite.
- Describe investigations to assess the level of impact caused in the event of leakage to underlying groundwater or adjacent surface water from water gathering and water storage infrastructure.
- Detail additional hydrology/hydrogeological investigations to assess the extent and significance of any water level or water quality impact that occurs as a result of reuse or discharge.

Some of the likely water monitoring content for the PWMP is outlined in **Appendix E**.

Monitoring requirements for the sediment/grit and salt wastes is not addressed in this EWMS but will be included in the proposed PWMP.

15. Conclusion

AGL is committed to maximising the reuse of extracted water from the Stage 1 GFDA of the GGP for beneficial purposes. Upon careful consideration of all the reuse and disposal options and consultation with the regulators and the community, AGL's preferred strategy for managing extracted water is:

- Pre-treatment and desalination of extracted water to produce treated water and brine.
- Reuse of treated water for CPF processes, and drilling, fracture stimulation and workovers (i.e. working water).
- Beneficial reuse of treated water for stock and irrigation purposes.
- Discharge of treated water to streams (when irrigation is not possible and high flows are occurring along the Avon River).
- Landfilling of the primary solids from the pre-treatment process.
- Landfilling of the mixed salt from the brine stream.

The engineering components of the preferred strategy at the CPF are:

- Centralised water treatment facility with a suite of treatment plants and process water storages.
- Pre-treatment to condition extracted water for desalination.
- Desalination of extracted water using various technologies but primarily RO for working water, beneficial reuse and stream discharge.
- Minor post-treatment to condition the treated water for all reuses and stream discharge.
- Brine concentration.
- Crystallisation of brine water to produce salt.

The EWMS provides a flexible and sustainable water management approach that can readily incorporate available and proven water treatment technologies and appropriate water management practices.

The following extracted water beneficial use options are:

- Reuse for CPF operations.
- Reuse for working water (including drilling, fracture stimulation and well workovers).
- Reuse for stock water.
- Reuse for irrigation.
- As a last resort discharge to the Avon River.

Controlled stream discharges may not occur at all if normal to dry rainfall patterns prevail in the initial years of operation. Discharge water volumes (if required) will be very small and will only be released during high flow periods.

There will be minimal wastes generated by the proposed extracted water strategy. Small volumes of grit/sediment from the WTP and mixed dry salt from the BTP will be suitable for disposal off-site as general solid waste.

Further investigation of new market opportunities for water and mixed salt will continue with a local focus on 'Expressions of Interest' received for the available water and salt.

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Appendices

Appendix A – Summary table of submissions and AGL responses

Appendix B – Water Balance Modelling Report (Worley Parsons)

Appendix C – Environmental Assessment and Design of High Flow Discharge Location for Treated Water (Cardno)

Appendix D – Expected flowback water and produced water quality specification

Appendix E – Probable water monitoring program

Appendix A – Summary table of submissions and AGL responses

Extracted Water Management Strategy - September 2014 Agency Submissions on the Consultation Draft

Issue No.	Submission By	Date Received	Issue/Comment	AGL Response	Amendment to Report (Yes/No) (1)	Relevant Section (1)
A001	NSW Office of Water (now DPI Water)	17/09/2014	***Provision of Reverse Osmosis Water to third parties (section 5.8)*** . NOW notes the lack of security of water supply, and recommends that the finite nature of the water supply be made clear to those parties lodging an expression of interest. NOW considers that new industries should understand the risks and limitation of investing based on limited water supply	AGL agrees - text updated	Yes	Updated in Section 5.4.3
A002	NOW	17/09/2014	***Discharge of Water to Dog Trap Creek/Avon River*** . Although the EWMS indicates that discharge water will be treated to ANZECC standards, it does not address the potential ecological or geomorphic impacts of the proposal. The following studies should be completed: * Identification of proposed discharge point and alternatives; * Geomorphic Assessment, including assessment of impacts of discharge * Detailed design of outlet devices and scour protection; * Ecological assessment to determine the impacts of discharge on ecosystem conditions and assets, and the impacts on biota and the downstream environment; * Consideration of temperature of discharge water and the risk of thermal pollution and associated impacts on the aquatic ecosystem	Geomorphological and ecological study completed for potential discharge locations along the Avon River/Dog Trap Creek	Yes	Section 11.6.2 and Appendix C
A003	NOW	17/09/2014	***Discharge of Water to Dog Trap Creek/Avon River*** . NOW requests: * Confirmation of volumes likely to be discharged to Dog Trap Creek. * Modelling being the estimated water use and discharge rates to also be provided. Present both 'likely' and 'worst case scenario	Dog Trap Creek now discounted as a discharge location. Volume to the Avon River expected to be zero for P50 water production case and less than 20ML for P90 water production case .	Yes	Section 5.1.5, Section 5.5, Section 11.6.2 and Appendix B
A004	NOW	17/09/2014	***Monitoring Bores in the vicinity of the Tiedmans Storages.*** NOW recommends that as a control measure, monitoring bores also be installed up gradient of the Tiedmans storages to facilitate comparative analysis. These should include construction in both the shallow and weathered rock zones, acting as a control of the down gradient bores to ascertain if any water quality fluctuations are naturally occurring, or as a consequence of seepage. Additionally these bores should be installed prior to commencement of Stage 1 to allow for attainment of baseline levels	Additional monitoring has been included north of the Tiedman storages prior to commissioning of Stage 1 (upgradient not possible as storages are at the top of the ridgeline)	Yes	Appendix E
A005	NOW	17/09/2014	***Monitoring Frequency (ref Pg 106)*** . NOW does not support any decrease in monitoring frequency based solely on the period of time elapsed since project commencement. Any proposed reduction in monitoring frequency should be subject to assessment of monitoring data.	Noted - any PWMP and GMMP will be written accordingly. Monitoring program to be reviewed annually.	Minor	Appendix E
A006	NOW	17/09/2014	***Definition of 'Flowback' Water, and Adequacy of Water Balance*** . Confirmation is requested as to whether the definition of 'flowback' water includes water injected for fracture stimulation purposes. If injected water is not included in the water balance, the predicted volume of extracted water may be under-estimated. Subsequently, calculated storage volumes may be inadequate, resulting in a higher reliance on surface water discharge. To further assess this issue, it is requested that the modelling behind the estimated water use and discharge rates be provided	Flowback water is included in the water balance modelling. Full Water Balance Modelling Report included as Appendix. Extracted water volumes are lower than originally predicted. Storage will be more than adequate.	Yes	Appendix B

Issue No.	Submission By	Date Received	Issue/Comment	AGL Response	Amendment to Report (Yes/No) (1)	Relevant Section (1)
A007	NOW	17/09/2014	***Adequacy of Contingency Planning (surface water discharge).*** The EWMS relies on surface water discharge as the contingency for management of excess extracted water. It is requested that additional contingency measures be investigated in the event that surface water discharge is deemed inadequate.	Water production profiles are now 25% lower than originally proposed in 2014. The strategy relies on storage then surface water discharge Storage volumes (both extracted water and treated water) will be maximised before any discharge occurs	Yes	Section 5.5, Section 11.6.2 and Appendix B
A008	NOW	17/09/2014	***Aquifer Storage Feasibility Study*** . Condition 21 of EPBC Act Approval 2008/4432 required AGL to undertake a feasibility study into aquifer storage. NOW endorses AGL's conclusion that aquifer recharge is not a feasible water and brine management strategy for this project.	Noted	No	Text is provided in Section 9.7
A009	Environment Protection Authority (EPA)	19/09/2014	**Water Treatment Plant**. System details will need to be specified for treatment processes, pre-treatment processes, treatment chemicals and water discharge/delivery configuration and methods (including quality and timing) as part of a final EWMS or other appropriate document to confirm the suitability of the RO system for the proposed water management options, i.e. whether the produced water quality is fit-for-purpose	Final engineering design and WTP system details are not available at this time. System details are beyond the requirements of this EWMS	No	NA
A010	EPA	19/09/2014	**Water Treatment Plant**. All system inputs and outputs (waste streams) must be identified, including quantities to be stored on-site and storage specifications	Streams identified in the Water Balance Modelling Report, however actual quantities are dependent on the actual water production profile and the fine sediment loads transported to the WTP which are unknown at this time.	Minor	Appendix B
A011	EPA	19/09/2014	**Water Treatment Plant**. Technological limitations of RO to reduce levels of some indicators need to be considered (e.g.. Boron) and any treatment or cleaning/maintenance chemicals that may be introduced into the RO treatment process will need to be assessed for each end use or discharge option.	WTP will meet the proposed water quality targets	Yes	Section 12
A012	EPA	19/09/2014	**Trigger values for water reuse and discharge (ref: EWMS Exec Summ - Preferred Strategy)**. Trigger values expressed as TDS do not relate to ANZECC guidelines for salinity which are generally expressed in micro Siemens per centimetre (µS/cm EC). If TDS is to be used an appropriate conversion factor should be determined based on adequate data for both TDS and EC that provide a robust correlation	Target water quality has been reassessed as part of the FEED studies and latest Basis of Design. Both TDS and EC limits are proposed for treated water	Yes	Section 12

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A013	EPA	19/09/2014	**Trigger values for water reuse and discharge (ref: EWMS Exec Summ - Preferred Strategy)**. A salinity trigger value for surface water discharge of < 500 mg/L TDS (upper range) is not consistent with ANZECC (2000) guidelines for salinity (see Table 2.6 in EWMS). 500 mg/L TDS is approximately 730 µS/Cm which exceeds the upper end of the ANZECC default trigger level range for upland rivers (350 µS/cm) and exceeds trigger values for NSW coastal lowland rivers of 200-300 µS/cm (see Table 3.3.3 of ANZECC 2000). This is potentially significant during any low flow discharges when there may be inadequate dilution to achieve the ANZECC or site specific triggers at the edge of an initial (near-field) mixing zone. The overall load of salts discharged to the catchment should be a further consideration in appropriate trigger values for the discharge volumes and timing that may be proposed in the final EWMS.	Table 2.6 are the proposed water quality thresholds (water quality criteria that will never be exceeded). The **target water quality values** for treated water resuse and stream discharge (Table 12.1) are much lower and based on the expected design performance of the RO plant and associated conditioning of the treated water. The ANZECC guidelines does specify an EC salinity range of 125 to 2200 uS/cm for some lowland streams in SE Australia (Table 3.3.3). The Avon River fits into this category as it drains the Gloucester Basin which contains estuarine and marine deposited rocks and saline soils dervied from these rock types	Yes	Section 2.4.2 and Section 12
A014	EPA	19/09/2014	**Trigger values for water reuse and discharge**. Following RO, treated water can be extremely pure. Treated water could potentially be used in an environmentally detrimental manner if it is too pure (e.g. inadequate salt levels) for the receiving waters or reuse application. Water in the natural environment contains levels of dissolved solids/salts, nutrients and organise matter. If not undertaken properly, releasing highly pure water into a natural water body could potentially cause harm to the receiving waterbody, therefore additives to the pure water may be needed prior to end use or disposal. The expected lower range target for treated water of 150 mg/L TDS specified in the EWMS is likely to be adequate to prevent environmental impacts due to low salinity. Initially mixing in a near-field zone could also be taken into account in assessing surface water discharge risk of low salinity.	Pure water from the RO plant will not be directly released into the environment. The treated water will be conditioned at the WTP to add back in essential salts and to adjust pH (if necessary) prior to reuse and any stream disposal. High flow discharges are only proposed so the dilution factor is expected to be greater than 5 times.	Yes	Section 11.3.3. and Section 12
A015	EPA	19/09/2014	**Trigger values for water reuse and discharge**. The EPA recommends that Table 10.5: "Stream Discharge Water Quality Targets" should include a lower limit (in addition to an appropriate upper limit) taking into account the relevant ANZECC (2000) range for salinity for upland rivers or lowland rivers (whichever is relevant where upland streams are defined as those above 150m altitude).	A single water quality type will be prepared for all reuse water and any water that has to be discharged to streams. Table 12.1 proposes lower and upper limits for salinity.	Yes	Section 12
A016	EPA	19/09/2014	**Trigger values for water reuse and discharge (ref: EWMS 2.4.2)**. The default ANZECC trigger values should apply to receiving waters associated with GGP (these are mostly the 95% species protection trigger values). The 80% species protection trigger values are not appropriate for the GGP. Existing poor condition is not an appropriate basis for establishing water quality objectives. It is not appropriate to allow poor environmental performance or water pollution simply because a waterway is degraded. The goal is to restore highly modified systems to slightly to moderately disturbed systems. The community have selected a goal for slightly to moderately disturbed conditions which relates to the default trigger values (i.e. 95% species protection but in some cases the 99% species protection values are the default value for chemicals that may bio accumulate).	Agree that the 95% species protection criteria should apply. Reference to 80% criteria deleted	Yes	Section 2.4.2

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A017	EPA	19/09/2014	**Trigger values for water reuse and discharge (ref: EWMS 2.4.2)**. Prior to collecting data, AGL should justify an appropriate reference site based on a good quality site that represents slightly to moderately disturbed conditions in the catchment. Reference sites should be agreed with the EPA prior to data collection. Data requirements specified in ANZECC should be adopted.	Details are to be included in any PWMP prepared for the project and/or the GMMP that needs to be prepared for water management purposes Nominated reference site is TSW01 which is a typical Avon River location located immediately downstream of the proposed discharge location. AGL is open to consideration of other sites. Requires further liaison with EPA at PWMP/GMMP/EPL stage	No	Section 14 and Appendix E is relevant
A018	EPA	19/09/2014	**Trigger values for water reuse and discharge (ref: EWMS 5.1.5)**. The expected target treatment water quality (subject to refinement based on the other comments provided) should be adopted as the irrigation, river discharge and other end use thresholds as they reflect treatment performance of the system when it is working in a proper and efficient manner. Environment protection licence limits will be set to reflect a proper and efficient treatment process taking into account end use discharge requirements.	A single treated water type is proposed as the output from the WTP	Yes	Section 12
A019	EPA	19/09/2014	**Assessment of the current irrigation program in the EWMS (ref: EWMS 2.4.1 & 3.1)**. ANZECC thresholds alone are not adequate to assess irrigation sustainability. ANZECC (2000) volume 3 sets out a risk based approach that takes into account the whole landscape, irrigation water quality, soils, site and application rates. The EWMS should refer to Section 9.2 of ANZECC (2000) Volume 3, including Table 9.2.1 and figure 9.2.1. Data and assessment from the current irrigation scheme has not provided adequate information to assess long term sustainability of the irrigation scheme using blended water. Based on the proposal and initial results the EPA assessed that the irrigation of blended water is likely to be unsustainable. Treatment is therefore required to remove salt loads and therefore the target water quality related to treatment performance should be adopted as initial threshold values for treated water irrigation.	Blended water is not under consideration for the Stage 1 development. The reuse of exploration phase produced water should not be confused with the reuse of (treated) extracted water from the Stage 1 development. Revised target water quality criteria proposed in Section 12	Yes	Section 12
A020	EPA	19/09/2014	**River flow objectives (ref: EWMS 5.6)**. The EPA recommends that opportunities to time flows with natural flow patterns/regimes should be incorporated into the EWMS.	Agreed - stream discharges will be minimised and only occur during periods of higher stream flow.	Yes	Sections 9.2 and 9.3
A021	EPA	19/09/2014	**Brine tank**. The EWMS notes that the WTP will include a brine tank. There are no details in the report regarding the design of the tank (open top / enclosed, indoors / outdoors), and system design contingencies (alarms, bunding). This needs to be addressed in the EWMS.	Brine tank will be enclosed and indoors Design element for inclusion in any PWMP - not an EWMS item	Minor	Section 11.2.4
A022	EPA	19/09/2014	**Salt and disposal options**. Salt produced from the thermal brine treatment system is to be stored in 1 tonne bulkabags. The EWMS does not identify the maximum on-site storage capacity that will be dedicated for the storage of salt, or details of the storage area (location, surface / floor, containment).	Design element for inclusion in any PWMP - not an EWMS item	No	NA

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A023	EPA	19/09/2014	**Salt and disposal options**. The disposal of brine generated by reverse osmosis remains a key area of concern due to its high concentration of salts and other chemicals and the fate of these salts in landfill has not been assessed at this stage. Several licenced waste facilities have been identified but none were specifically nominated as the final destination of the produced mixed salts. AGL must ensure that suitable licensed sites are identified in the EWMS, and that these premises have sufficient capacity to accept the quantity of mixed salts to be generated from the activity. The EWMS should also identify contingency measures should the volume of salts generated from the activity exceed available landfill capacity for either short or extended periods. Details of the landfilling methods and long term fate of the salt in each landfill should be specified and assessed in the EWMS. Containment methods during landfilling should prevent off-site migration to ensure that the salt does not contaminate or harm the environment.	Not a matter for inclusion in the EWMS as defined by the Part 3A condition. With lower extracted water volumes, salt volumes will also be reduced. Containment is the responsibility of the licensed facility that receives the General Solid Waste waste stream.	No	NA
A024	EPA	19/09/2014	**Salt and disposal options**. The EWMS should take into account future opportunities for reuse of the salt after landfilling.	Containment (and any landfill recovery) is the responsibility of the licensed facility that receives the waste stream.	No	NA
A025	EPA	19/09/2014	**Other waste streams**. The EWMS should clearly identify all waste streams (solid and liquid), quantities, on-site storage capacity and handling of each waste stream, waste classification and the fate of all waste products generated from the water treatment process, including the pre-treatment system. The EPA regulates waste through the Protection of the Environment Operations Act 1997 (POEO Act), together with the Waste Avoidance and Resource Recovery Act 2001 and the Protection of the Environmental Operations (Waste) Regulation 2005. All waste should be classified according to the NSW Waste Classification Guidelines (DECCW 2008). These key statutes and guidelines contain the requirements for classifying, managing, storing, transporting, processing, recovering and disposing of waste; and need to be considered in the assessment of waste products generated by the proposed treatment of extracted water.	Noted. Assays for the sediment/grit from the WTP and the mixed salt are not available at this time. For inclusion in any PWMP. Also noted that new (2014) waste regulation and guidelines now apply	Minor	Section 2.2 and Section 13.5
A026	EPA	19/09/2014	**Quality of treated working water**. Working water, used for well workovers, drilling and fracture stimulation, post-treatment is defined as having a salinity <7000 µS/cm (pg 82). Prior to utilising treated extracted water for working water, it is specified as sourced from freshwater sources (i.e. Pontilands dam and Avon River). Working water must continue to be of similar quality and no harm to the receiving environment. There are likely to be instances when electrical conductivities of 6999 µS/cm for drilling water would be harmful to shallow beneficial groundwater.	Working water will now be low salinity treated water from the WTP	Yes	Section 12
A027	EPA	19/09/2014	**Recommended Guidelines**. Volumes 1 -3 of the ANZECC (2000) guidelines should be referred to in the EWMS, e.g. Lower-reliability trigger values specified in Volume 2 under the detailed description for each chemical can be used as a basis for determining discharge risks when "ID - insufficient data to determine guideline" is indicated in Volume 1. Volume 3 provides detailed guidance in relation to reuse option. ***(Refer to Attachment B - Recommended Guidelines, which summarise the relevant guidelines)***	Noted.	No	

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A028	Gloucester Shire Council (GSC)	19/09/2014	***Waste Management Preference*** . Council advocates for reuse or recycling of salt by-products from desalination where appropriate, and encourages AGL to consider investing in treatment technologies that will allow for a potential waste stream to be beneficially reused and avoid landfill.	Salt volumes and tonneages are low. Mixed dry salt characteristics may vary over time. No economic value at present given its variable quantity and quality.	Minor	Sections 13.4 and 13.5
A029	GSC	19/09/2014	***Development of a Produced Water Management Plan*** . At the workshop held on 13 August, it was identified that further detailed information on produced water management such as treatment technologies, expected produced water quality and river disposal location are expected to be provided in a subsequent Produced Water Management Plan, that AGL will have a requirement to prepare under a Petroleum Production Lease (PPL) (***ref: EWMS 7.3***). It is unclear however at this stage as to: a) whether the PPL will require the development of a Produced Water Management Plan b) what the conditions of a Produced Water Management Plan would be were it to be included as a condition of approval for a PPL c) how a Produced Water Management Plan would interact with an Extracted Water Management Strategy for the same project i.e. production during stage 1, in contracts to the existing PEL Produced Water Management Plan requirements that cover exploration activities. d) whether community consultation would be undertaken for a Produced Water Management Plan were it to be developed	DRE have advised that a PWMP is unlikely to be included in the PPL/s. This matter requires further consideration by Government - its not a matter for AGL to resolve in the EWMS	Yes	Mostly Sections 1.1, 1.4, 2.2 and 7.2.1
A030	GSC	19/09/2014	***Development of a Produced Water Management Plan*** . It needs to be made clear that if a Produced Water Management Plan is not a condition of the PPL, whether AGL will still commit to the preparation of a Produced Water Management Plan, or will operate within the provisions of the EPL, the consent conditions and the EWMS, all of which been approved, granted or prepared.	AGL will operate the project under all relevant planning consents, plan approvals and licences, and is committed to a PWMP.	Yes	Section 2.3.1 and Section 14
A031	GSC	19/09/2014	***Development of a Produced Water Management Plan*** . Until the above details are confirmed and provided, it is considered appropriate that the EWMS be considered the primary document for the water management for Stage 1 of the GGP, and the Strategy be updated to provide additional details as requested by relevant Council's and State Government agencies and the Part 3A consent conditions, particularly in relation to: * further characterisation of extracted water, including provision of existing produced water quality data and statistics showing upper and lower limits that will be used as part of the treatment process design * further description of process analysis and selection for proposed treatment processes, as well as the physical unit operations that will be incorporated into the treatment plant design and further detail of waste management from pre and post treatment processes * provision of results from detailed monitoring that describes receiving environment water quality and flow condition for treated water discharges * analysis of risk to groundwater users and or surface waters and groundwater dependent ecosystems as part of a contingency strategy for volumetric extraction greater than 2 ML per day * assessment of the potential impacts to water quality due to wildlife access	The detail provided in the EWMS is considered appropriate for this strategy document	Minor	Some extra detail provided in: Section 6 (water quality characteristics) Section 10 (existing infrastructure) Section 11 (proposed infrastructure)

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A032	GSC	19/09/2014	***Development of a Produced Water Management Plan*** . It is not expected that the PPL for the GGP will specifically require AGL to prepare the Plan in consultation with Council's or undertake community consultation on the Plan. Therefore it is unclear to Council as to whether further consultation opportunities will be provided once the EWMS be approved. As such, while the EWMS provides a framework for produced water management as part of Stage 1 of the GGP, there is additional detail that is yet to be provided in subsequent documentation in which Council would expect to have the opportunity to provide input. Alternatively, the EWMS should be modified to be the primary management plan for produced water management and be modified to feature additional details as requested during the consultation process.	This matter requires further consideration by Government - its not a matter for AGL to resolve in the EWMS No plan to modify the EWMS. The EWMS is a strategy document that needs to be endorsed by all stakeholders to provide certainty for developing the extracted water/treated water management infrastructure for the Stage 1 GFDA	Minor	
A033	GSC	19/09/2014	***Development of site specific water quality criteria*** . The EWMS should provide additional detailed information on the development of site specific water quality criteria in accordance with the ANZECC guidelines, including: * proposed locations for monitoring to develop site specific water quality criteria * parameters to be incorporated into a monitoring program * frequency of monitoring	There is a process outlined for the development of site specific water quality criteria. Not being progressed at this time. Likely location is the reference site TSW01.	No	NA
A034	GSC	19/09/2014	***Development of site specific water quality criteria*** . Evidence of consultation with the NSW Office of Water/NSW Office of Environment should also be included in the Strategy, as per the conditions of approval	Not being progressed at this time. Likely location is the reference site TSW01.	No	NA
A035	GSC	19/09/2014	***Development of site specific water quality criteria*** . Although no required as part of the conditions of approval, it is considered appropriate that for process water reuse as described in the Strategy that a human health assessment framework also be taken into consideration. Numerous examples of dual reticulation of non-potable water and industrial water reuse exist, with a focus on microbiological contaminant and upper limits for these as indicators of water quality. As the process water reuse as described in the Strategy such as toilet flushing, fire water systems and service water have high potential for human contact, it is considered appropriate that a bacteriological water quality target be incorporated into the Strategy, and that the upper limit or range for this parameter (potentially E. coli, as an indicator organism) be suitable for direct contact and ingestion.	There is no source or possibility of bacterial contamination from the treated water processing and distribution. Process water will however be chlorinated prior to reuse at the CPF.	Yes	Section 12
A036	GSC	19/09/2014	***Surface Water discharge*** . As the stream gauge 208028 is located downstream of the Waukivory Creek confluence with contributes approximately 31% of flow to the Avon River, it would be preferable for a stream gauge site to be used that is more representative of flows near the proposed river discharge location. Alternatively, flows of a higher magnitude should be considered to be measured at the 208028 site that would be an estimate of flows of > 5ML/day at the proposed river discharge location. A rainfall trigger instead of a flow trigger could also be considered.	GS 208028 is for comparison purposes only TSW01 is the likely gauging location. Flow is a better criteria than rainfall - can get high rainfall locally and limited runoff and conversely higher catchment runoff can occur with small local rainfall events.	Yes	Section 9.3

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A037	GSC	19/09/2014	***Further Approvals*** . While it is acknowledged by Council that the Part 3A approval incorporates the Central Processing Facility and associated infrastructure, there is likely to be additional approvals required for components of the project associated with the CPF under the Local Government Act 1993 that may require Council approval	Noted no extracted water management infrastructure approvals are likely to involve Council.	No	NA
A038	GSC	19/09/2014	***Comment on EWMS - Glossary; pg1.*** Total dissolved solids is referred to in the report, but is not included in the glossary, EC is.	Included in Glossary	Yes	Glossary
A039	GSC	19/09/2014	***Comment on EWMS - Exec Summary - preferred strategy; pg11.*** Add 'workovers' to glossary	Included in Glossary	Yes	Glossary
A040	GSC	19/09/2014	***Comment on EWMS - Exec Summary - preferred strategy; pg11.*** "more areas may be developed initially to cater for production peaks …" If these are AGL properties in the first instance, this should be mentioned, otherwise I would expect further information about securing buyers of the water in accordance with the conditions.	Irrigation and stock reuse will involve a mixture of AGL and privately owned properties - 60ha is expected maximum. New water balance modelling confirms that 60ha is sufficient for peak water production.	Yes	Section 9.6.1 and Appendix B
A041	GSC	19/09/2014	***Comment on EWMS - Exec Summary - preferred strategy; pg11.*** "… between 500mg/L TDS" convert to EC or add TDS to glossary	Included in Glossary	Yes	Glossary
A042	GSC	19/09/2014	***Comment on EWMS - 1.2; pg14.*** include the right month which the Concept Plan Approval and Project Approval were modified	Done	Yes	Section 1.2
A043	GSC	19/09/2014	***Comment on EWMS - Table 2.1; pg19.*** change responsible authority from 'OCSG within *DoTI* ' to OCSG within *DTIRIS* '	EWMS updated with new agency arrangements	Yes	Section 7
A044	GSC	19/09/2014	***Comment on EWMS - Table 2.3 - condition 3.12 i); pg25.*** There is more detail on this in Section 2.4 than Section 10, so this should also be referenced in the table. Alternatively the report could be restructured so that information pertaining to this condition is not in two disjunct sections of the report.	Agencies need to recognise difference between thresholds and target water quality criteria. Basic structure left as is	Minor	Table 2.3
A045	GSC	19/09/2014	***Comment on EWMS - Table 2.6; pg29.*** If you are not familiar with the ANZECC guidelines, then it appears based on the previous paragraph that the ranges for pH, EC, DO and turbidity are the 80 to 95% trigger values e.g. 125 is the 95% trigger value, and 2200 is the 8-% trigger value for EC. This was interpreted to be the case by a community member who asked me about it, so the table might need to be adjusted to make the source of these values clearer, as the superscript (2) appears to have been overlooked.	Reviewed Table 2.6 and content appears OK	No	Table 2.6
A046	GSC	19/09/2014	***Comment on EWMS - 3.5; pg33.*** Title should read "Gloucester Shire Council Baseline Water Survey"	Done	Yes	Section 3.5
A047	GSC	19/09/2014	***Comment on EWMS - 3.5; pg33.*** They weren't all farming properties, some were lifestyle properties in Forbesdale Estate.	Done	Yes	Section 3.5
A048	GSC	19/09/2014	***Comment on EWMS - 3.5; pg34.*** If these are going to be identified as groundwater sources formally in AGL documentation, then follow up sampling should be undertaken to confirm this, as discussed previously.	??	No	NA
A049	GSC	19/09/2014	***Comment on EWMS - 6.4; pg53.*** A summary of produced water quality was included in the Gloucester Shire Council produced water evaluation study. This could be referenced in the EWMS	Done	Yes	Section 6.4
A050	GSC	19/09/2014	***Comment on EWMS - Table 10.2; pg83.*** Bacteria have been removed from first to second draft?	Now only one water quality table for all reuses - singular water quality table. Bacteria criteria not warranted (see A035 above)	No	Refer new Table 12.1

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A051	Midcoast Water	19/09/2014	***Reliance on river discharge*** . MCW preference is to avoid river discharges and increase irrigation volumes.	Done - revised water balance modelling clearly demonstrates reliance irrigation rather than river discharges	Yes	Appendix B
A052	Midcoast Water	19/09/2014	***Reliance on river discharge*** . MCW strongly recommend that the irrigation area be extended beyond proposed 60 ha or the storage capacity increased to reduce discharges to the Avon River and maximise reuse. Having extensive reticulated water system covering entire Stage 1 of the project provides opportunity to deliver water to additional area of land for irrigation. Small expansion of storage capacity at Tiedmans property beyond what is proposed would also reduce river discharges. There is no modelling data presented in the strategy to justify that proposed irrigation area and storage capacity are at optimum level.	Water balance modelling has confirmed no benefit in expanding irrigation area beyond 60ha. With lower extracted water volumes there are now no Avon River discharges likely with P50 water production profile - only P90 and during wet seasons to Year 3	Yes	Appendix B
A053	Midcoast Water	19/09/2014	***Reliance on river discharge*** . In addition the adopted irrigation water application rate of 4 ML/ha/year may be overestimated as it was obtained from the irrigation project at Tiedman property. MCW recommend that some contingency, apart from increase in river discharges, has to be provided to the management of water design to accommodate for differences between adopted and actual values.	Different irrigation modelling approach adopted in latest Water Balance modelling approach Application rates likely to be between 2 and 6 ML/ha/yr Storages will provide additional buffer given the expected lower produced water volumes	Yes	Various
A054	Midcoast Water	19/09/2014	***Consultation process*** . MCW welcomes the opportunity to provide input into the EWMS. However the presented strategy is a high level document, lacking necessary technical details for proper assessment of expected risks and effectiveness of proposed control measures. More details are expected to be included in the subsequent management plans such as the Produced Water Management Strategy. These documents will be developed based on the presented strategy. As we have a substantial stake in catchment protection we would like to see MCW's involvement in the consultation process to continue beyond the strategy level. Our expertise in water treatment/reuse may also add value to the further planning process.	Noted - will keep MidCoast Water in the loop. Discharges of treated water to the Avon River will be <20ML and are not expected to extend beyond Year 3. Catchment implications are negligible.	No	NA
A055	Midcoast Water	19/09/2014	***Discharges to river under low flow conditions*** . A statement that "AGL is not discounting the opportunity to discharge water during lower flow periods to provide stock water supplies to downstream users" is included in chapter 5.6 addressing the surplus water discharge to surface waters. We do not agree with the statement that such discharge would improve water quality in the river and maintain environmental flows. We strongly oppose the idea of using waterways as transportation routes for recycled water. Such water has to be transported by pipelines.	Low flow discharges have been removed from the reuse and stream discharge strategy	Yes	Taken out of EWMS
A056	Midcoast Water	19/09/2014	***Operational risk*** . MCW would like to underline that the proposed extracted water management scheme will be very complex with a number of risks associated with its operation. A comprehensive risk assessment has to be undertaken and contingency measures developed during the planning process.	Numerous risk assessment studies completed. Detail for the PWMP	No	NA

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A057	Midcoast Water	19/09/2014	***Discharge point location and dilution factor*** . It is proposed that up to 1.5 ML/day of treated water from the WTP will be discharged to Dog Trap Creek and the discharge would only occur when there was at least a 5-fold mixing factor. Flows are to be greater than 5 ML/d for the discharge to occur. Apart from the fact that the above figures are inconsistent, the dilution factor with the stream flow is to be assessed using flows at the gauging station located on the Avon River d/s of confluence with Waukivory Creek. The chapter is poorly worded as it confuses dilution of the discharge in the Avon River with dilutions in the Dog Trap Creek. It is not acceptable to use Avon River flows to claim that dilutions are appropriate for Dog Trap Creek. It is highly unlikely that such small tributary can accept 1.5 ML of discharge without adverse impact on the creek. A discharge point location has to be moved or dilution factor for Dog Trap Creek estimated and found acceptable.	Specialist consultants report prepared. Preferred discharge location is now located on the Avon River south of the confluence with Dog Trap Creek (AV2). A rating curve will be established for TSW01 gauge site and discharges aligned to flows at this location (a dilution factor of 5 is still proposed)	Yes	Various but mainly Section 9
A058	Midcoast Water	19/09/2014	***Deficiencies in monitoring plan*** . The Monitoring Plan contained in chapter 14 contains only general information regarding proposed monitoring. Water quality monitoring is proposed on quarterly basis, which is in our opinion highly inadequate. Especially the discharge water pond has to be sampled more frequently (monthly or fortnightly).	Principles outlined in Chapter 14. Outline of monitoring program provided in Appendix E - pond monitoring has been increased to monthly. More details to be provided in subsequent plans	Yes	Appendix E
A059	Midcoast Water	19/09/2014	***Deficiencies in monitoring plan*** . MCW are particularly concerned with the lack of a sampling point to monitor the performance of the RO treatment. Continuous salinity loggers are proposed in the receiving water pond and the discharge water pond, but not in the treated water pond or water flowing out of the RO treatment. Salinity in the discharge water pond will be higher than in the treated water pond or out of RO as it is proposed to dose chemicals to achieve balanced water for irrigation. Only the measurements of salinity upstream of chemical dosing can give an indication of the RO effectiveness. The most effective monitoring point to assess the performance of the RO system would be a continuous measurement of salinity/conductivity in the pipe flowing out of RO system.	Monthly sampling of the treated water is proposed. AGL considers this to be adequate given the testing at the DWP. Further clarification would be provided in any PWMP/GMMP.	Yes	Appendix E
A060	Office of Coal Seam Gas (OCSG)	25/09/2014	The Petroleum Production Lease(s) (PPL) that will be required for the Stage 1 GGP may contain conditions requiring AGL to undertake operations in accordance with relevant OCSG Codes of Practice (CoPs). These CoPs may include Well Integrity (Drilling) CoP and Fracture Stimulation CoP. Other CoPs or guidelines may be in place that will be included as conditions of PPLs (e.g.. regarding rehabilitation standards and security).	Noted. AGL will operate the project under all relevant planning consents, codes, plan approvals and licences.	Yes	Section 1.4 and 2.2
A061	OCSG	25/09/2014	At present a Produced Water Management Plan may not be required as a condition of a PPL, CoP or guideline for production activities. The regulation of extracted water as part of the Stage 1 GGP should be via the EWMP required as a condition of consent. I note section 7.3 of the draft EWMP states that it is expected that a similar condition to the PEL285 condition requiring a Produced Water Management Plan will be included in PPLs for the Stage 1 GGP. I would be happy to discuss this section with you.	DRE/OCSG have indicated that a PWMP will not be part of any PPL that is issued. The detail required for a PWMP is not appropriate for this EWMS --- its up to Government to decide whether and when an approved PWMP is required and any associated approval process	Yes	Various but mainly Sections 1.6, 7.2.1 and 14

Issue No.	Submission By	Date Received	Issue/Comment	AGL Response	Amendment to Report (Yes/No) (1)	Relevant Section (1)
A062	OCSG	25/09/2014	I note that the Environment Protection Authority and Office of Water have made specific comments relating to monitoring requirements and operational matters that will require licensing under the Protection of the Environment Operations Act 1997 and Water Management Act 2000 respectively.	Noted and recognised in the EWMS report	Yes	Section 2

Notes

(1) Amendments and changes as made to the Final Draft version of the EWMS

Extracted Water Management Strategy - October 2015 Agency Submissions on the Final Draft

Issue No.	Submission By	Date Received	Issue/Comment	AGL Response	Amendment to Report (Yes/No)	Relevant Section
A001	DPI Water	2/10/2015	***Definition of aquifer (Glossary)***. DPI Water's definitions in the Water Management Act and the Aquifer Interference Policy should be reflected in the glossary.	AGL definitions retained and DPI Water's definitions added - Glossary updated	Yes	Glossary
A002	DPI Water	2/10/2015	***If the EWMS is updated it should be in consultation with DPI Water***.	Agreed	Yes	Section 1.4
A003	DPI Water	2/10/2015	***DPI Water does not authorise supply of untreated and treated water to a third party.*** DPI Water regulates the original extraction of water only.	Noted and text changed	Yes	Section 2.2 and Table 2.1
A004	DPI Water	2/10/2015	***WAL is required for all production activities.*** Text to be amended to differentiate exploration from production activities	Noted and text changed	Yes	Section 2.2
A005	DPI Water	2/10/2015	***Extra criteria be added to the Water Quality threshold tables.*** Updates required for organic compounds	Extra criteria added for BTEX, PAH and Phenolic compounds (where available in ANZECC guidelines)	Yes	Tables 2.5 and 2.6
A006	DPI Water	2/10/2015	***Include water chemistry tabulation of typical extracted water***	This table is already included in the EWMS (Appendix D of the Final Draft and Appendix D of the Final)	No	No change required - Appendix D
A007	DPI Water	2/10/2015	***Use DPI Water controlled activity guidelines where appropriate***	Noted -- a level of detail required for the engineering design and construction programs. Reference will be included in the PWMP	No	NA
A008	MidCoast Water	1/10/2015	***Treated Water Quality Criteria.*** Table 12.1 is incomplete and some of the targets appear inadequate. Table should reflect the main components of the extracted water and include hydrocarbons, extra heavy metals, and nitrogen. Check target levels for phosphorus, suspended solids, turbidity and salinity	Table 12.1 updated with expanded analytical suite that is more aligned with the composition of extracted water and those analytes listed in the the threshold Tables 2.5 and 2.6. AGL's Gloucester Engineering Mgr has provided advice on the RO technology limitations.	Yes	Section 12 and Table 12.1
A009	MidCoast Water	1/10/2015	***Consider setting targets for the RO treated water*** (prior to conditioning) in addition to post conditioning	AGL will monitor RO treated water quality but there is little value in providing another set of WQ targets for the pure RO water when this water is immediately conditioned (and monitored) to meet the final discharge water quality. In addition the operator will be monitoring the efficiency and output of the RO plant.	No	No change required
A010	MidCoast Water	1/10/2015	***Fix inconsistencies regarding the flow conditions under which river discharges will occur.*** It would be best to suggest specific flow conditions under which (i) river discharge is allowed (ii) the maximum volume of river discharge that is allowed per day	Relevant sections amended to improve clarity	Yes	Text amended to improve clarity in Section 9.3
A011	MidCoast Water	1/10/2015	***Consider transferring the distillate from the BTP to the pre-treatment facility*** rather than to the Discharge Water Pond. So as to avoid possible contamination of the treated water pond.	The distillate is distilled water derived from evaporation so there cannot be any salt transferred to the TWT or DWP. This distillate will be tested during the commissioning period of the BTP and then periodically during operations to ensure it is very low salinity. Water will be sent to the TWT and not direct to the DWP .	Yes	Extra words of explanation added and the text in Sections 11.2.2 and 11.2.3 updated.
A012	MidCoast Water	1/10/2015	***Improve the definitions of P10, P50 and P90***	Agreed - Glossary and abbreviations updated	Yes	Glossary
A013	Gloucester Shire Council	7/10/2015	***Commitment to a Produced Water Management Plan.*** Commitment to a PWMP is commended by Council. However Council want the examine detail at a future date and have the capacity to comment prior to release/implementation.	Whether a regulatory PWMP is required (and any consultation process) is a matter for DPE/EPA to determine.	No	No additional text added

Issue No.	Submission By	Date Received	Issue/Comment	AGL Response	Amendment to Report (Yes/No)	Relevant Section
A014	Gloucester Shire Council	7/10/2015	***Addition of microbiological parameter/s to WQ targets.*** Given there is dual reticulation within the CPF, and the treated water is likely to be used for non-potable uses, there is a potential for cross contamination and secondary contact with these waters	Treated water cannot be contaminated within the WTP and the water will be chlorinated prior to being sent for CPF uses -- AGL does not see the need for microbiological WQ targets for the (conditioned) treated water	No	No additional text added
A015	Gloucester Shire Council	7/10/2015	***Maximising water storage facilities at the CPF.*** Water storage opportunities (pond and tank sizes) should be maximised at the CPF so as to further minimise the potential for stream discharges	AGL will consider larger storages as part of the final design - AGL under its Part 3A approval has approval to construct three storages up to 25 ML capacity. The Final of the EWMS has allowed for storages that are potentially 20%+ larger than what was assumed in the revised water balance - this alone reduces the potential for stream discharges by 40%	Yes	Extra text added to Sections 11.2.1 and 11.2.3
A016	Gloucester Shire Council	7/10/2015	***Additional storage to cater for bypass or backwash.*** Consider in the design phase	To be further evaluated as part of the final WTP design	No	No additional text added
A017	DoI - DRE	16/10/2015	PPLS will have conditions requiring the project to be operated in accordance with CoP	Noted	No	NA
A018	DoI - DRE	16/10/2015	PWMP will not be required as a condition of the PPL/s.	Noted	No	NA
A019	EPA	16/12/2015	**Effluent Quality.** EPA disagrees with some of the target water quality criteria proposed. Need to propose appropriate criteria based on a range of approaches including: * risk assessment of treatment processes * literature on chemicals used in the CSG industry * ANZECC (2000) and where no trigger values available * dilution achieved in a mixing zone	Noted. The target water quality suite and criteria have been expanded and the nominated levels revised based on the expected limits of the RO treatment train for these high sodium-chloride-bicarbonate waters and current ANZECC/ADWG guidelines. The RO treatment is to address the slightly saline natural formation waters and not to specifically treat for any CSG chemical additives (these are at low concentrations in extracted water which then naturally biodegrade and volatilise during the water collection and treatment process). It is proposed to reuse all treated water locally for beneficial purposes except if extreme weather conditions prevail in the initial years of production. Rare stream discharges will not require dilution as treated water quality will be within the expected range of natural water quality.	Yes	Extra text added to Section 12 - water quality parameters and analytes in Table 12.1 have been revised

Issue No.	Submission By	Date Received	Issue/Comment	AGL Response	Amendment to Report (Yes/No)	Relevant Section
A020	EPA	16/12/2015	**Effluent Water Quality**. Salinity criteria are not consistent with ANZECC (2000) guidelines and the ANZECC trigger value of 300 uS/cm should be used as the primary water quality criteria in the absence of site specific data; EWMS needs to justify maximum salinity concentration, and it should be in the context of a maximum discharge rate and receiving water characteristics.	EPA is confusing the threshold guidelines with the target water quality criteria to be adopted for reuse and stream discharge. The proposed WQ criteria are mostly lower than the ANZECC thresholds. The ANZECC guidelines do not explicitly state that the salinity range for NSW coastal stream is 200 - 300 uS/cm -- they say they are **typically** in this range -- the Avon River is a known saline catchment and AGL, MCW and DPI Water all have data confirming natural salinities outside of this range. AGL's site specific Avon River data has been used in proposing the revised water quality targets (>300 to < 600 uS/cm is now the proposal for the salinity criteria for treated water).	Yes	Extra text added to Section 2.4.2 and Section 12 - water quality parameters and analytes in Table 12.1 have been revised
A021	EPA	16/12/2015	**Effluent Water Quality**. AGL should select a suitable reference site and determine appropriate WQ criteria - EPA suggest that TSW01 is unlikely to meet the requirements of a good/slightly disturbed reference site.	Requires further discussion with EPA when preparing the PWMP, however AGL advises that for TSW01: * this site is not in a moderately to highly disturbed part of the catchment * the site has not been affected by the previous irrigation program or storage dams It appears to be a good reference site for assessing and monitoring river water quality	No	NA but refer to Appendix E
A022	EPA	16/12/2015	**Effluent Water Quality**. Further consideration of SAR and maximum limits for conditioning additives such as calcium, magnesium and chloride are required to avoid overdosing	SAR is not an issue for stream discharges - it's a measure to assess the suitability of water for irrigation on different soil types. SAR criteria reducd from <15 to <9 and preferably <6. Maximum limits for water conditioning additives will be included in the PWMP after the WTP is delivered and commissioned.	Yes	Table 12.1 updated with revised limits
A023	EPA	16/12/2015	**Effluent Water Quality**. Discharge criteria of 50 NTU is not appropriate and levels lower than 15 NTU should be able to be achieved by proper and efficient operation of the WTP	It appears as if EPA is confusing the threshold guidelines with the target water quality criteria for treated water to be adopted for reuse and stream discharge. The proposed WQ criteria in the Final Draft EWMS and this Final EWMS is <15 NTU. This level will be further reviewed and revised downwards in the PWMP after the WTP is delivered and commissioned.	Yes	Footnotes added to Table 12.1
A024	EPA	16/12/2015	**Effluent Water Quality.** Inconsistencies between the threshold (Table 2.6) and target water quality (Table 12.1) criteria.	Revised - tables now revised to indicate >85% saturation	Yes	Tables 2.1 and 12.1
A025	EPA	16/12/2015	**Effluent Water Quality.** Other analytes - there are some gaps in the range of proposed indicators; criteria should be developed (or justification provided as to why limits are not needed) for treatment and cleaning/maintenance chemicals, and likely additives/pollutants in flowback water and extracted water	Revised - the proposed target water quality table has been changed to include a larger range of analytes Extra justification provided as to why elemental constituents are being monitored and why specific compounds are not appropriate water quality criteria	Yes	Section 6.2, Section 12 and Table 12.1

Issue No.	Submission By	Date Received	Issue/Comment	AGL Response	Amendment to Report (Yes/No)	Relevant Section
A026	EPA	16/12/2015	**Flow regime** - discharges could occur during both wet and dry periods and maximum discharge flow need to be proposed and agreed.	No stream discharges are proposed during low flow periods. Stream discharge is only proposed after an extreme rainfall period when storages are full and beneficial reuse of treated water is not possible. Water balance modelling suggests this would only be in Year 3 and only if P90 extracted water flows and a P90 rainfall period coincided.	Yes	The proposed discharge volumes and flow regime criteria have been restated in Section 9.3
A027	EPA	16/12/2015	**Communication** - there needs to be communication with downstream users during stream discharges	Agree - a brief outline of the expected communication protocol is included in the EWMS - Further details would be included in the PWMP.	Yes	Extra words added to Section 9.3
A028	EPA	16/12/2015	**Irrigation Reuse.** STV should be reviewed after 5 years of operation; previous irrigation practice are a potential residual risk and should be taken into account when assessing irrigation criteria and for soil contaminant levels	AGL see no need to review the thresholds for stock and irrigation as it is the target water criteria that will apply to all treated water. SAR criteria revised to <9 (and preferably <6) No irrigation criteria proposed for soils given the variability of natural soil profiles and there being no evidence of degradation (apart for a slight sodium increase) associated with the irrigation trial This irrigation reuse strategy involves low salinity treated water not raw produced water or blended water reuse	Minor	Table 12.1 updated
A029	EPA	16/12/2015	**Irrigation Reuse.** Limitations of RO technology to reduce some analytes (eg boron) needs to be considered	Noted. Given the basis of design and the current RO technology, there are no analytes that would appear to constrain the irrigation reuse of the treated water	No	NA
A030	EPA	16/12/2015	**Stock Reuse.** Should liaise with DPI regarding stock drinking water uses and criteria	ANZECC 2000 threshold WQ criteria for stock are quite comprehensive. The proposed target water quality criteria for the treated water are well below these threshold values so further liaison with DPI is not considered warranted at this time.	No	NA
A031	EPA	16/12/2015	**Working Water Reuse.** Working water must be of similar quality and not harmful to the receiving environment.	Noted. Drilling water will most likely be sourced from freshwater sources given there is no raw produced water stored in the Tiedman holding dams. Raw water for fracture stimulation will most likely be treated at the WTP prior to being delivered and used for fracture stimulation purposes. There are also very few low salinity beneficial aquifers in the area (most are brackish-slightly saline) and these are all cased off and protected during CSG drilling and fracture stimulation programs.	No	NA
A032	EPA	16/12/2015	**Brine.** Fate of salt in landfill. Long term fate of salt in landfills need to be assessed	This is beyond the requirements of the EWMS but will be further assessed in the PWMP.	No	Clarification words added to Section 13.5
A033	EPA	16/12/2015	**Brine.** Brine tank and mixed dry salt storage. Further information is required on the storage of mixed dry salt to ensure there is no escape or loss during rainfall events prior to off-site disposal	Salt storage will be indoors on hardstand and volumes will be minimised	Yes	Clarification words added to Section 11.4

Issue No.	Submission By	Date Received	Issue/Comment	AGL Response	Amendment to Report (Yes/No)	Relevant Section
A034	EPA	16/12/2015	**Proposed Monitoring Program.** Additional consideration and information is required in respect of: * more rigorous monitoring of buried water gathering systems * soil and/or shallow groundwater monitoring in the proposed irrigation areas away from the proposed storages where monitoring will be in place	As suggested by EPA these are issues to be addressed in the PWMP. There will also be details in the required GMMP. No monitoring within the proposed irrigation areas is proposed given the high quality (low salinity) of the treated water to be used for irrigation.	Yes No	Some additional text regarding buried water gathering systems is provided in Section 11.5.1 NA

Extracted Water Management Strategy - September 2014 Public Submissions on the Consultation Draft

Issue No.	Submission By	Date Received	Issue/Comment	AGL Response	Amendment to Report (Yes/No)	Relevant Section
P001	Local Community Member	19/09/2014	AGL is to be commended for adopting a RO approach rather than the environmentally flawed concept of diluting the produced water and using it for irrigation as practiced at Tiedmans	Noted - RO was always the preferred water treatment approach for the Stage 1 development	No	Sections 5 and 11
P002	Local Community Member	19/09/2014	It is a serious mistake to use the term "extracted water" in the EWMS as the combination of flowback water and produced water as this will aggravate community opposition. The two types of water need to be kept separate.	This is the terminology used by the Department of Planning and Environment in the Part 3A conditions. For integrated project water management, there is no technical or environmental justification for keeping these water types separate. AGL plans and responses must be consistent with the consent conditions.	No	NA
P003	Local Community Member	19/09/2014	I imagine that the RO facility will require an EIS because of its potentially significant impacts in relation to: a. Disposal of salt. b. Disposal of heavy metal brine – resin extracted metals. c. Use and allocation of the 'pure water' product. d. Concept of disposing of excess water into the Avon River and ecosystem changes. e. Impact of the use of additional irrigation water in the valley.	The RO facility for treating wastewater and irrigation/stock reuse was outlined in the original (exhibited) EA and is covered under the Part 3A approval. No further planning approvals are required. AGL has twice provided the community with the further opportunity to comment on the extracted water proposals with the exhibition of this EWMS.	No	NA
P004	Local Community Member	19/09/2014	It is only by preparing an EIS and related DA that the community will have any confidence in this development of a RO plant. Without such a level of scrutiny there will be considerable community opposition and a further issue against AGL's "social licence" to operate in the area.	Noted. The EWMS has been exhibited twice (AGL only received two community submissions on the Consultation Draft)	No	NA
P005	Local Community Member	19/09/2014	The irrigation water should be made available to irrigators that decide to initiate a new industry such as growing (and Processing) industrial hemp. This water should be at below market rates to enable an industry to start and then purchase commercial water as the RO volume decreases. By doing this AGL would indicate a real commitment to supporting the Gloucester area. The processing plant would also be a potential market for energy and an employment source in the area. Further information on this will be available in the Agricultural Strategy that Gloucester Shire will release in October 2014.	The expected treated water volumes are very small (now most probably < 0.6 ML/d) and will diminish as the field matures. There is insufficient water for any substantial new industry - start up water maybe available together with supplementary water to existing irrigators. AGL is committed to an Expression of Interest process to gauge interest in beneficially reusing all available water.	Yes	Section 5
P006	Local Community Member	19/09/2014	The concept of using the "clean water" environmental dam storage at Stratford mine should be considered as a way of storing water when not being used by irrigators in the winter. This would also expand the volume of irrigation water available for a new irrigation crop industry	Not commercially viable for very small volumes of treated water. Would require a modification to the EA and the current project approval for the Stage 1 development	No	NA
P007	Manning Valley Community Member	17/09/2014	Likely discharge of CSG (produced) water into the Manning River catchment	There will be no discharge of untreated extracted water to the Avon River (or anywhere within the Manning catchment). All extracted water will be treated to meet a target water quality that is suitable for local irrigation, stock and stream discharge.	Yes	Sections 5.5, 9.2 and 11.6.2

Issue No.	Submission By	Date Received	Issue/Comment	AGL Response	Amendment to Report (Yes/No)	Relevant Section
P008	Manning Valley Community Member	17/09/2014	Size and cost of a desalination plant	The FEED for the Stage 1 gas development and the basis of design for the WTP have been prepared, however tenders will not be called for until an investment decision is made on the project. The RO desalination plant is likely to comprise 2 x 0.6 ML/d modular units given the lower produced water volumes that are likely. No costs are currently available.	No	NA
P009	Manning Valley Community Member	17/09/2014	Desalination is a public relations exercise, not a serious proposal from AGL	The desalination plant is a confirmed component of the WTP infrastructure and the industrial development at the CPF. The project cannot proceed without a desalination plant and an approved extracted water management strategy.	Yes	Section 5 and Section 11
P010	Manning Valley Community Member	17/09/2014	No development consent for a desalination plant	The RO facility for treating wastewater and irrigation/stock reuse was outlined in the original (exhibited) EA and is covered under the Part 3A approval. No further planning approvals are required AGL has twice provided the community with the further opportunity to comment on the extracted water proposals with the exhibition of this EWMS	No	NA
P011	Manning Valley Community Member	17/09/2014	CSG water contains contaminated salts while seawater contains non-toxic sea salt	This is not the case. The CSG produced water is formation water from sedimentary rocks that were mostly deposited in estuarine and shallow marine environments. The salts in the deep groundwater are exactly the same salts that you find in seawater today.	No	Section 6. Community is also referred to the September 2014 Fact Sheet on Heavy Metals and the environment where different water sources and water quality across the catchment were tested (including produced water and seawater)
P012	Manning Valley Community Member	17/09/2014	There is no landfill or licensed facility for the disposal of salt	There is only one salt assay currently available for the salt likely to be derived from the extracted water. It is for flowback water from the Waukivory Pilot. Hence it is premature to talk to licensed facilities about the potential for landfilling this general solid waste until there is an approved EWMS, there is an investment decision to proceed, and more salt assays are available.	No	NA
P013	Manning Valley Community Member	17/09/2014	Removal of boron from extracted water	The desalination plant will be designed with membranes to deal with boron concentrations in the range 0.08 to 22.4 mg/L	Yes	Section 6.5 and Appendix D
P014	Manning Valley Community Member	17/09/2014	Will Stages 2 and 3 overlap with Stage 1	There is no approval to construct any subsequent stages beyond the Stage 1 GFDA at this time. The CPF compressor plant and pipeline capacity will be limited so an expansion beyond the expected production rates of the Stage 1 development are unlikely. New wells will come on line after the first wells decline in production within the Stage 1 area however the total number of operational wells is unlikely to ever exceed 110 wells.	No	NA

Appendix B – Water Balance Modelling Report (Worley Parsons)

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EcoNomics™

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AGL Gloucester Gas Project

Water Balance Modelling Report

401015-00130 – GL4-RPT-H-0003

21-Jul-2015

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SYNOPSIS

A water balance model has been developed to simulate the transfer, storage and management of water extracted from the planned 110 CSG wells in AGL's Gloucester Gas Project. The model was used to assist in the development of the Extracted Water Management Strategy and the sizing of the associated water handling and treatment infrastructure. The model reports results for key system outcomes, such as pond levels, transfers between unit processes and irrigation loads etc. It also calculates volumes and timings of discharges to local waterways, if any.

The model was used to simulate a range of loading, equipment and infrastructure sizing and control philosophy cases to explore the likely response of the system to stochastic influences, such as rainfall and equipment failure. The study found that:

- RWP and DWP volumes of 13 ML (to the overflow level) are expected to be adequate;
- An irrigation area of 60 Ha is expected to be adequate;
- Frost and irrigation area soil type are not expected to be key system determinants;
- Approximately 11 ML of initial storage is required to meet the working water demands;
- The nominated 1.2 ML/d capacity of the WTP, with a 95% availability appears adequate;
- For the system as modelled, for the 90th percentile extracted water production profile and the worst case climatic conditions, it is expected that about 1% of the (treated) total extracted water flow will need to be released to the environment via the Avon River Release Point. The remaining water may be reused for irrigation and stock watering etc.
- No environmental release is expected for the 50th or 10th percentile extracted water production profiles under any climatic conditions; and
- Untreated water was fully contained in the Receiving Water Pond and the Tiedman's East Dam for all scenarios modelled under all climatic conditions.

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PROJECT 401015-00130 - AGL GLOUCESTER GAS PROJECT

REV	DESCRIPTION	ORIG	REVIEW	WORLEY-PARSONS APPROVAL	DATE	CLIENT APPROVAL	DATE
B	Issued for Review	G Gloag	R de Vos		17-Jun-15	N/A	
C	Issued for Review	G Gloag	R de Vos		2-Jul-15		N/A
D	Issued for Review	G Gloag	J Ross		17-Jul-15		N/A
0	Issued for Use	G Gloag	R de Vos	J Ross	21-Jul-15		

CONTENTS

Appendices

ABBREVIATIONS

Term	Definition
BoM	Bureau of Meteorology
CPF	Central Processing Facility
CSG	Coal Seam Gas
DWP	Discharge Water Pond
EC	Electrical conductivity
ET/ET_o	Evapotranspiration
EWMS	Extracted Water Management Strategy
FAP	United Nations Food and agricultural Organisation
FEED	Front End Engineering Design
GFDA	Gas Field Development Area
GGP	Gloucester Gas Project
IX-regen	Ion exchange regeneration waste water
PontD	Pontiland's Dam
RO	Reverse osmosis
RWP	Receiving Water Pond
TDS	Total Dissolved Solids
TED	Tiedeman's East Dam
TN&SD	Tiedeman's North & South Dams (combined)
TND	Tiedeman's North Dam
TSD	Tiedeman's South Dam
TWL	Top water level
TWS	Treated Water Storage/Tank
WTP	Water Treatment Plant

1 INTRODUCTION AND OVERVIEW

1.1 Overview

AGL's *Extracted Water Management Strategy* (EWMS) (AGL, 2014) details how AGL will manage water extracted from coal seam gas (CSG) wells associated with the Gloucester Gas Project (GGP). A water balance model was developed to inform the development of the EWMS. The water balance model was prepared to simulate the transfer, storage, management and beneficial reuse of water extracted from the CSG wells and treated in the Water Treatment Plant (WTP). The water balance model identifies inflows and outflows to the water handling and management infrastructure and assists in the development and timing of the required treatment and management infrastructure.

In this report (and in the EWMS), extracted water is the term used to describe both flowback and produced water from the CSG wells.

1.2 Scope

This Water Balance Modelling Report has been prepared as an appendix to the EWMS. This document presents the methodology adopted to develop the water balance model, the model outputs for various scenarios as well as the key inputs and assumptions on which the modelling is based. Summary details regarding the results of the water balance modelling and discussion regarding project water handling infrastructure are provided in the EWMS.

The scope of the water balance modelling covers the following:

- Receival and storage of the extracted water from the 110 CSG wells forming Stage 1 of the GGP; and
- Transfer of water between the various elements that make up the system, including the storage ponds/dams, the water treatment plant, the irrigation area and environmental releases.

1.3 Changes to the water balance model

A spreadsheet based water balance model was developed during the FEED stage of the project to provide a preliminary, basic understanding of the system. However it had several limitations which reduced its usefulness, including:

- It was based on a weekly balance and consequently was relatively coarse;
- The balance did not allow the impacts of infrequent, large rainfall events to be assessed; and
- A very simple irrigation model was used.

Consequently, when a new water production profile was developed, a new water balance model was developed to address these issues and to provide sound basis for the water balance, using a more refined daily time step. The basis and assumptions of the new model are set out in this report.

1.4 Objectives

The objectives of the water balance modelling are to:

- Assess the proposed water handling and treatment infrastructure against expected extracted water inflows;
- Provide a basis to optimise the sizing of the new water handling and treatment infrastructure;
- Assist the development of appropriate water management options, which maximise beneficial reuse;
- Report flows of the key streams in the water handling and treatment process;
- Develop projections for key project performance indicators, including:
    - Irrigation application rates; and
    - Timing and rates of disposal to local waterways.
- Report performance under a range of scenarios representing various operating conditions, such as:
    - High rates of CSG water extraction;
    - High rainfall; and
    - Changes in the WTP performance.
- Investigate potential risks.

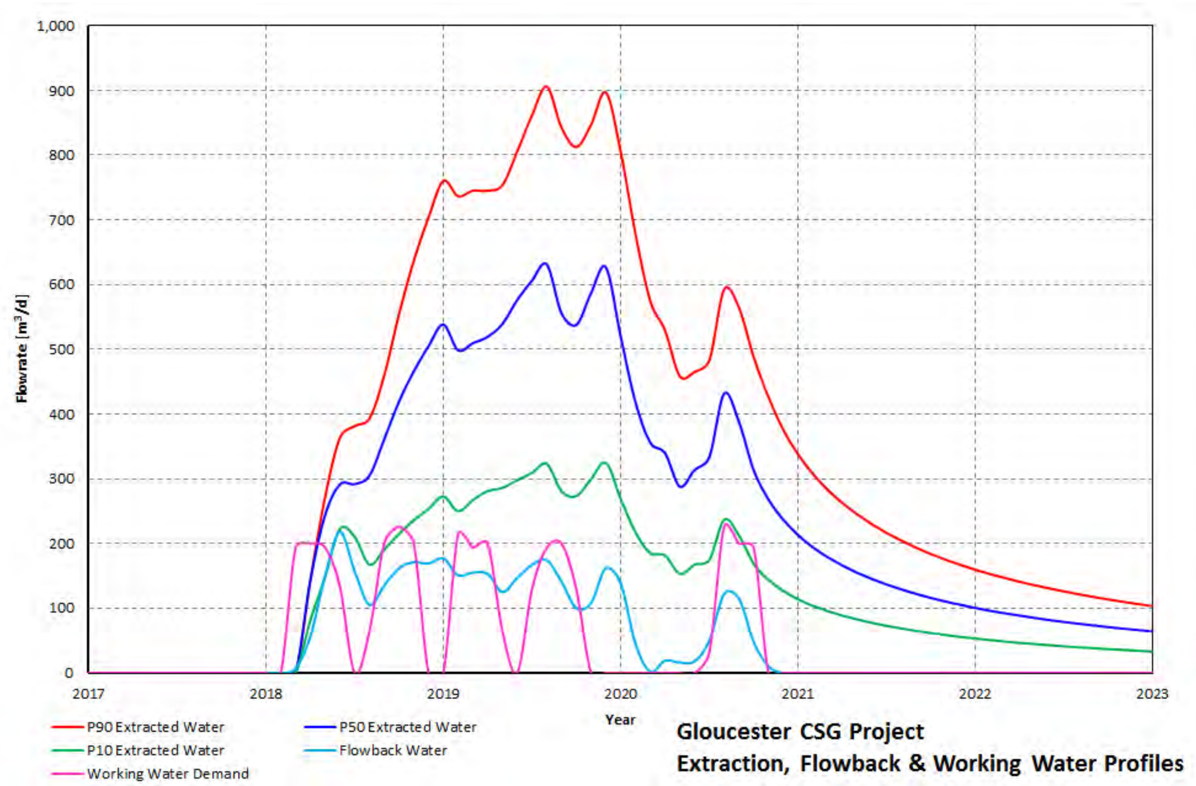
1.5 Key modelling assumptions

The key assumptions and other basis information for the modelling are summarised below:

- The extracted and flowback water production rates as well as the working water demand are summarised in Figure 1-1 for the P90, P50 and P10 cases. The working water demand leads the production and flowback water profiles slightly, while the flowback water peaks match those of the extracted water profiles. The flowback water profile is shown for completeness only as these flows are included in the extracted water profiles. The time period shown in this figure has been limited to 2017 - 2023 to highlight the peak flow and well development programme. The actual profile extents out until 2050;
- 110 wells in total. 13 wells are understood to already exist as part of the pilot programme and consequently 97 wells will be drilled and fracture stimulated as part of the Stage 1 development;
- The well drilling programme will occur over a 24 month period, commencing in April 2017 (water for drilling is not included in the water balance model). Fracture stimulation is scheduled to commence in March 2018 and will be complete by October 2020 (31 months) and water for (and from) the stimulation programme is included in the model. Since the drilling and fracking programmes overlap, the combined construction period is 42 months;
- The WTP's supply specification calls for a plant with a capacity of 1,200 m^3/d, and an availability of 95%. As this is unlikely to be achievable in a single train, for model simulation purposes, it is assumed that the WTP will consist of 2 independent trains configured in a lead-follow arrangement, with each train having a 600 m^3/d capacity. Each train will have an availability of 90%, to match the specification requirements;
- Nominal pond sizes (to the design top water level) are:

  - Receiving water pond: 10,500 m^3 (subject to change);
  - Treated water storage: 1,000 m^3 (subject to change);
  - Discharge water pond: 10,500 m^3 (subject to change);
  - Tiedeman's North Dam: 18,200 m^3
  - Tiedeman's South Dam: 18,200 m^3
  - Tiedeman's East Dam: 20,200 m^3
  - Pontiland's Dam: 50,000 m^3 (approximate)
- A nominal irrigation area of 60 Ha.

Figure 1-1: Water production and demand profiles



1.6 Hold points

Some information is outstanding or has not yet been fully investigated. This includes:

- The final locations and consequently the sizes of the WTP ponds and tanks have yet to be decided;
- The influence of salinity has not been directly investigated, either as a result of changes in the salinity of the extracted water or the impact of rainfall. An order of magnitude impact of water chemistry is investigated however as a reduction in the WTP's capacity.

2 WATER HANDLING INFRASTRUCTURE

The key water handling and treatment process are:

- Water gathering and storage;
- Water treatment (including brine management); and
- Water management.

2.1 Water gathering

The water received at the Water Treatment Plant (WTP) comprises two components, each with a distinct flow profile over time:

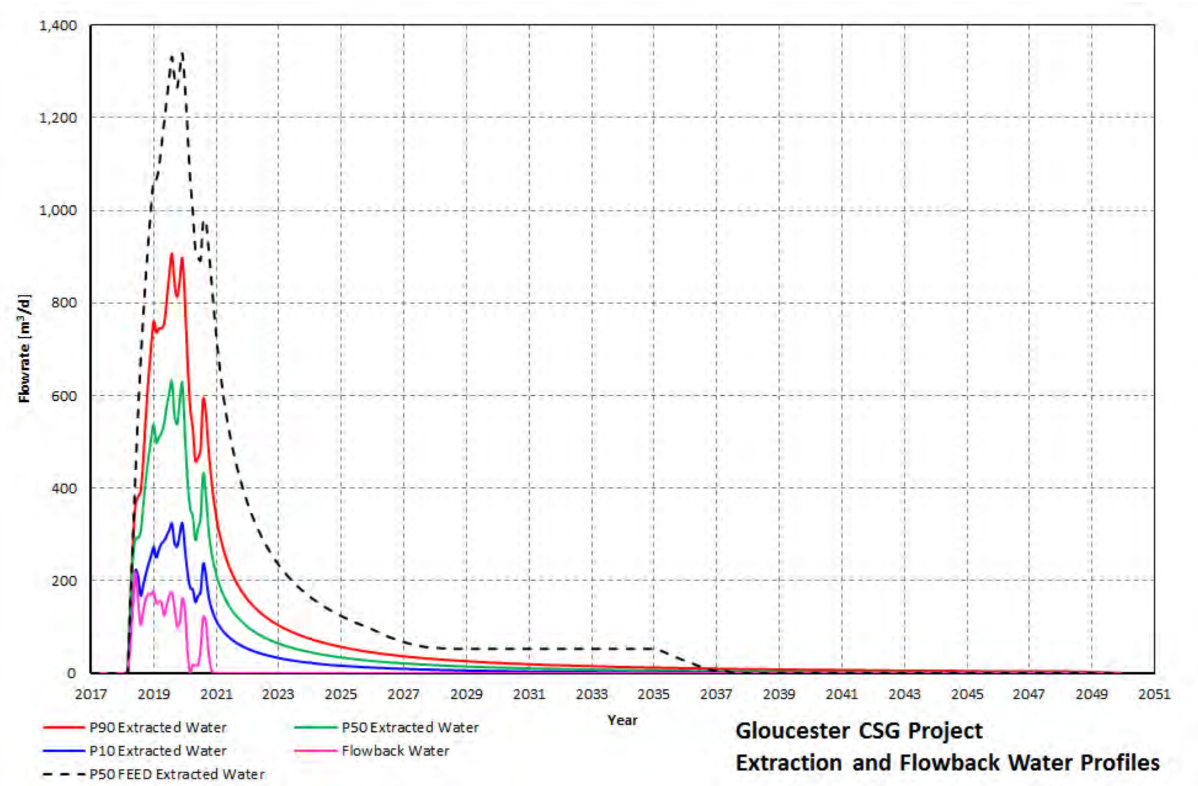
- *Extracted water:* The rate of extracted water production from each CSG well varies with time and the location and nature of the target coal seam. Typical CSG extracted water profiles peak soon after dewatering begins and then exponentially decline over time. AGL have provided expected P10, P50 and P90 water extracted profiles for the 110 wells in the Gloucester Gas Project (GGP) area. These profiles represent the probability that the actual extracted water profile does not exceed the forecast profile. That is, the P90 extracted water profile denotes the profile which is expected to exceed 90% of the forecast extracted water profiles. The P50 profile gives the median or best estimate of the expected profile, with the actual profile having a 50% chance of being greater or less than the forecast. The P90 case is often used for infrastructure sizing purposes.
- *Flowback water (a component of extracted water):* Flowback water is generated primarily as a consequence of the hydraulic fracking procedures used to fracture the coal seam and prepare it for gas production. The water and fracking fluid pumped into the well is recovered over time, with the following typical profile assumed:
    - 20% of the fracking water is recovered in the first 3 days; and
    - The remaining water is recovered over the next 3 months.

Extracted water profiles for the GGP were developed by applying the P10, P50 and P90 type curves to each well in the gas field. Flows from each well are accumulated based on the drilling schedule to produce the daily flowrates. Similarly, the expected flowback water profile was developed from the fracking programme for each well in the project. This data is shown graphically in Figure 2-1. Also shown in the figure is the P50 profile developed for the FEED study, which is given for completeness only.

The extracted water profiles (as given in Figure 2-1) include the impacts of flowback water.

The profiles show production beginning in April 2018 (after the commencement of the fracture stimulation programme), with water production rising rapidly and peaking in mid to late 2019, at about 900 m^3/d (for the P90 case) before tapering down. The flowrate is expected to reduce to approximately 10% of the peak flow by 2023 – just over 5 years after production commences.

Figure 2-1: Expected extracted and flowback water profiles



2.2 Oily water and condensate from the CPF

Water and condensate water arriving at the Central Processing Facility (CPF) with the gas stream is separated and after preliminary treatment is directed to the Receiving Water Pond pending further treatment and disposal. The quantity of water received in this way is assumed to be 5% (adjustable) of the extracted water flowrate.

2.3 Water storages

Several storages will be either constructed or re-purposed to receive and contain water prior to treatment and reuse. The storage volumes and dimensions are given in Table 3-6. The principal storages are:

- Receiving Water Pond (RWP): A new, double lined pond, receiving extracted water from the gathering system and storing it pending treatment in the WTP. The inflow to this pond is diverted to the Tiedeman's East Dam when it is full;
- Treated Water Storage Tank (TWS): New covered and lined storage tank(s) receiving treated water from the WTP and providing a storage for water conditioning to occur. The outflow from the TWS is directed to the Discharge Water Pond;

- Discharge Water Pond (DWP): A new double lined pond receiving flow from the TWS, and holding conditioned water, pending it being transferred to the Tiedeman's North and South dams for reuse;
- Tiedeman's North and South Dams (TN&SD): Existing lined dams used to store the conditioned water pending irrigation and reuse. For modelling purposes, these dams are assumed to be a single unit;
- Tiedeman's East Dam (TED): An existing double lined dam. Extracted water will be diverted to the TED if insufficient capacity is available in the RWP. In the modelling scenarios it is assumed that the TED is full of extracted water from the pilot testing programmes. This water will be pumped through the WTP and stored in the DWP prior to the gas wells being fracture stimulated. This stored water will then be used to meet the initial working water demand;
- Pontiland's Dam (PontD): An existing unlined farm dam, used for the storage of rainwater runoff. Water from this dam may be used to assist in meeting the working water requirements, primarily for drilling.

2.4 Water treatment

The water treatment plant (WTP) itself is only modelled to the extent that it impacts on the overall water balance, which includes:

- The WTP's overall recovery (i.e. the fraction of the water directed to the plant and passes through it as treated water). The recovery is a function several factors, including the feed water salinity, the pre-treatment requirements, temperature, membrane selection and the ions present etc.;
- The WTP's availability. Given the plant is likely to be relatively complex, with multiple, dependent process units, 100% availability of each train is unlikely to occur.

Water received at the WTP will pass through various treatment processes to produce a high quality water, suitable for reuse or release to the environment. Treatment processes, may include coagulation and settlement (or flotation) for the removal of sediment, ultrafiltration for the removal of particulate material, ion exchange for the removal of di-valent compounds and silica, reverse osmosis for the removal of salts and conditioning to produce a stable, balanced water. With the exception of conditioning, each step of the process will produce a product and one or more waste streams, which require further treatment or disposal. Currently it is assumed that all waste streams will be recycled internally to the WTP, with the exception of the dewatered solids (i.e. sediment etc. removed in the clarification stage). These waste streams, along with the dewatered mixed salt product will be directed to offsite disposal. Consequently, the model assumes no recycling from the WTP RWP.

2.4.1 Treated water management

It is intended that treated water will primarily be reused for irrigation of crops and pastures on local properties adjacent to the existing Tiedeman's irrigation area. Secondary uses include water for industrial and stock water uses. Surplus treated water generated during high rainfall periods will be discharged to the Avon River.

2.4.2 Brine management

The water treatment process will generate a brine stream containing salts from the extracted water, with a salt concentration of approximately 10 times the extracted water concentration. This brine stream will be further concentrated using brine concentration and crystallisation to produce a mixed salt product which can be disposed of to an appropriate solid waste landfill.

3 MODEL CONFIGURATION

3.1 Structure

A bespoke water balance model was developed using Intel Fortran-95, using a daily time step. At each time interval, the model accounts for all inflows and outflows from each storage node. The storages modelled are:

- Receiving Water Pond (RWP);
- Treated Water Storage Tank (TWS);
- Discharge Water Pond (DWP);
- Tiedeman's North and South Dams (TN&SD) (modelled as a single unit);
- Tiedeman's East Dam (TED); and
- Pontiland'sDam (PontD). Since this dam receives only rainfall runoff, and is used only intermittently to meet working water demand (in particular on startup), Pontiland's is not an integral part of the water balance model.

The physical and modelling arrangements are given in model's structure is given in Figure 3-1 and Figure 3-2. Figure 3-1 shows how the water infrastructure is physically connected, which differs slightly from the model configuration, with the principal differences being:

- Water is stored is Pontiland's Dam, which may be used to meet the working water demands, in particular at startup (i.e. when the working water demand exceeds the extracted water supply, See Figure 1-1). Pontiland's dam is an existing unlined farm dam with a runoff catchment of approximately 250 Ha and consequently naturally overflows during large wet weather events. The captured water is used for stock watering as well as irrigation. Since:
    - The dam receives no flow from AGL's CSG water gathering or treatment systems;
    - The inflows and outflows cannot be determined accurately;
    - The dam is unlined and overflows naturally in normal operation.

  the Pontiland's dam is not modelled and is not part of the water balance. However, the volume is tracked, assuming it is lined and that the only inflows and outflows are rain falling directly on the dam and evaporation from the water surface. The model assumes that all working water demands can be met from the DWP and the TN&SD.

- The actual arrangement of the Tiedeman's North and South Dams is more complex than is modelled. In reality, although inflow can be directed to both dams, irrigation water is drawn from TSD only. Bi-directional flow is allowed into and out of TND. For modelling purposes, TND and TSD are assumed to be a single dam. This is not expected to significantly impact the results;
- The model includes overflows from each dam or pond to allow a mass balance to be developed. This does not necessary imply that an overflow from a given pond/dam actually exists, or that an overflow will be allowed to occur in practice.

Figure 3-2 shows the interconnectivity between the process units as modelled and the capacities of major infrastructure units (note that the storage volumes given in the figure refer to the overflow volumes rather than the design top water levels). All connections with a stream number are calculated on a daily basis. The model only considers those storages shown in Figure 3-2. Any local storages (if any) located in the gathering system or elsewhere are excluded.

The passage of water through the system is described as follows. All extracted and flowback water is directed to either:

- The RWP, in normal circumstances;
- The Tiedeman's East Dam, when the RWP is full. The TED provides additional containment, in the event of a potential overflow of the RWP. TED is not expected to be used in normal circumstances, as it provides a storage of last resort, and is only expected to be used in the event of prolonged wet weather or a prolonged shutdown of the WTP. Flow directed to the TED is returned to the RWP at a low rate (when volume is available).

Return streams from the WTP are either recycled internally or directed to the RWP. From the RWP, the water is pumped to the WTP, where it receives treatment for salt removal.

The water recovery in the WTP is modelled as simple factors of the feed stream, with a portion of the rejected water returned to the RWP for re-processing. The low TDS, treated water from the WTP is directed to the Treated Water Storage Tank (TWS) from where it is pumped or overflows to the Discharge Water Pond (DWP). Conditioning chemicals are added to the TWS to ensure the water has the right salt balance and pH value for reuse.

Water in the DWP is pumped to individual gas wells (or groups) to satisfy the working water requirements. This water that is delivered via these working water lines is primarily used for fracking and for stock watering, with the majority of the fracking water returned to the water treatment system 'flow-back' water). Water surplus to the working water requirements is pumped to the Tiedeman's North and South Dams for storage pending irrigation or being directed to the environment (i.e. pumped to the Avon River Release Point) when the system's storage capacity is exceeded and irrigation is not possible.

For modelling purposes, the RWP, DWP, TN&SD, TED and the PontD are allowed to overflow to the environment (i.e. to the nominated stream discharge locations) when the storages are full. However, it is understood that in practice the RWP and the TED will not be allowed to overflow and that the gas production wells will be shutdown to prevent an overflow.

Figure 3-1: Water treatment infrastructure physical arrangement

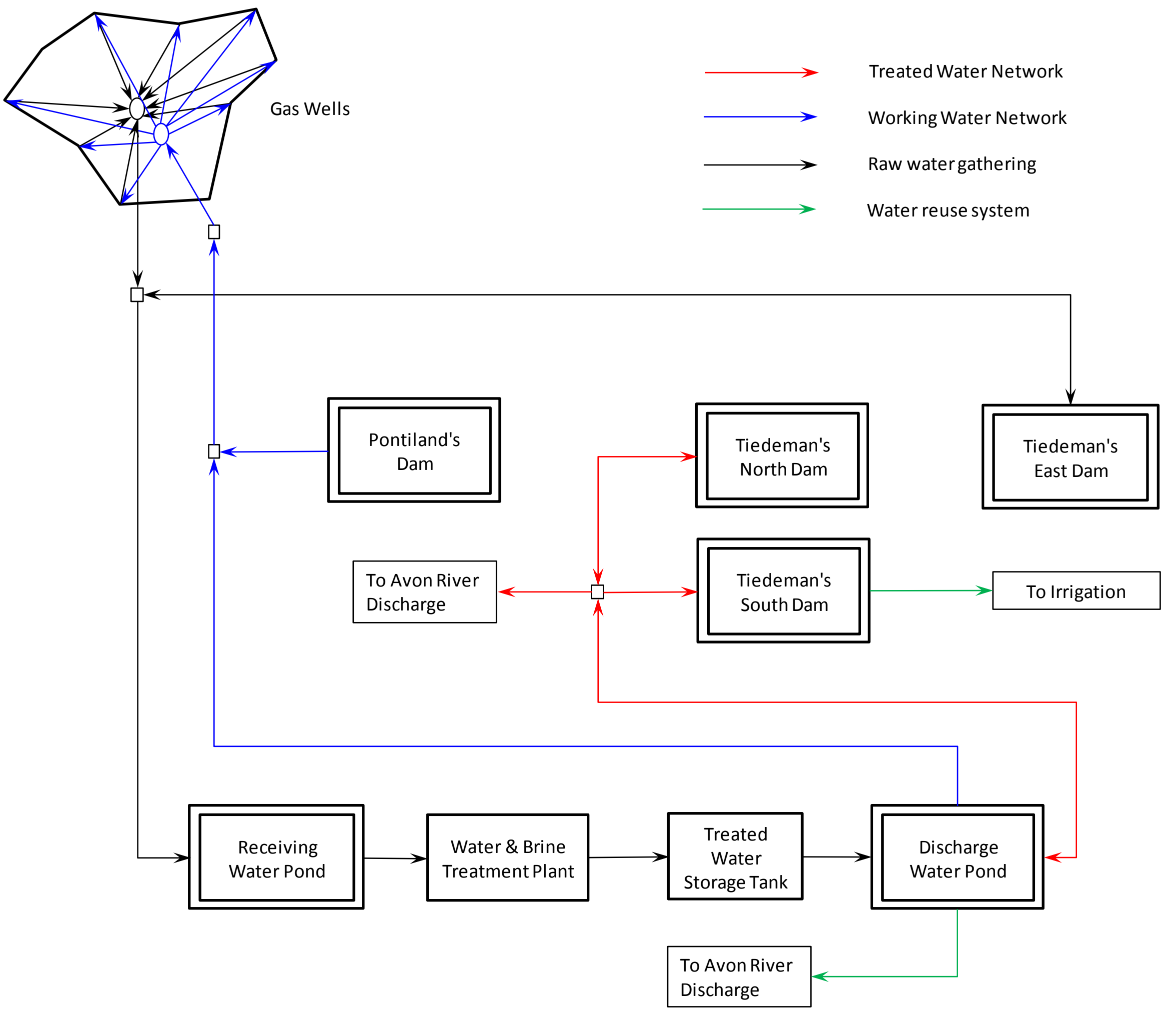
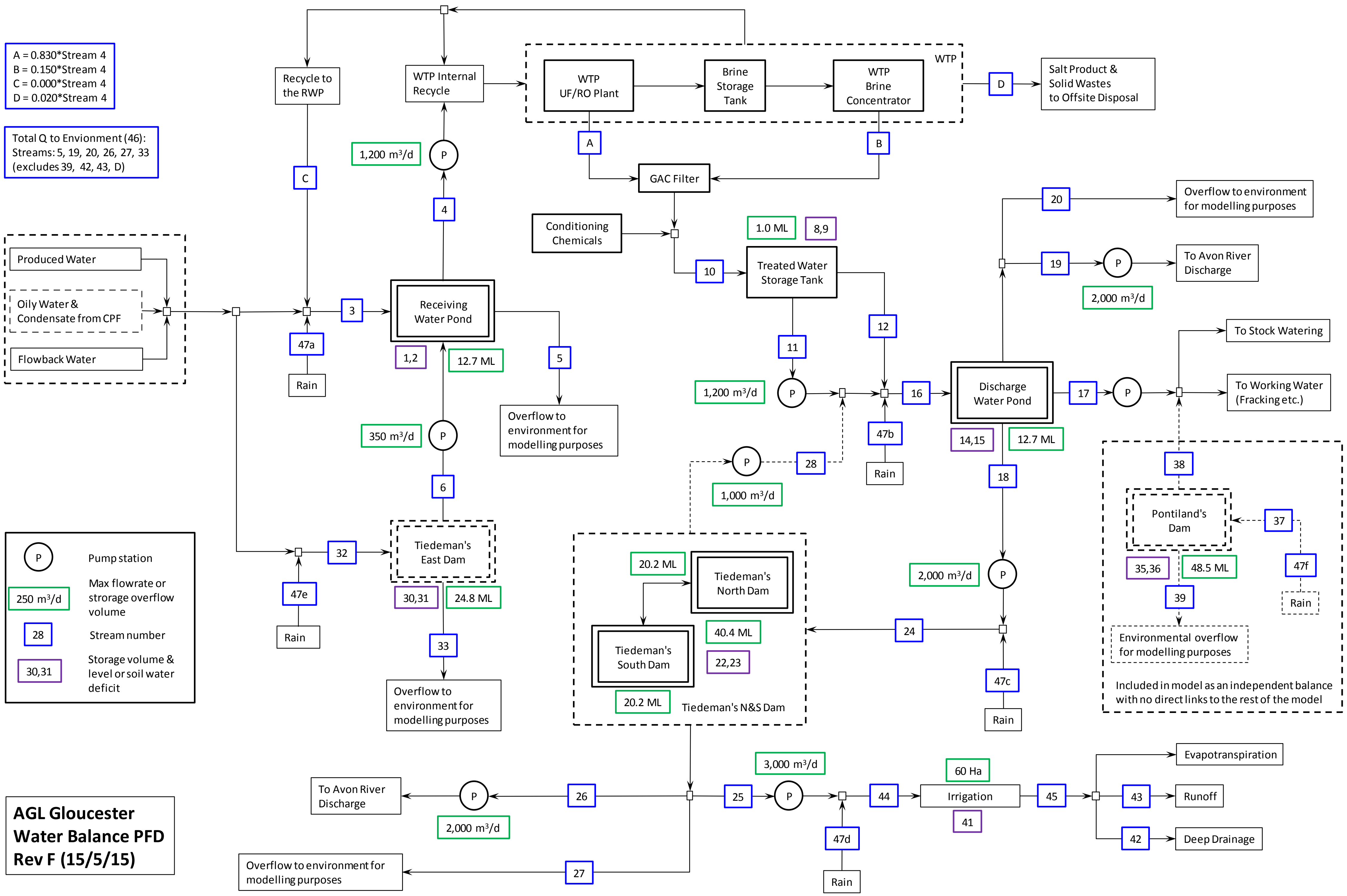


Figure 3-2: Water balance model configuration



All storages are assumed to be fully lined and leak proof. All ponds and dams are assumed to be open to the atmosphere and subject to the impacts of rainfall and evaporation, however the TWS and the Brine Storage Tank (BST) are assumed to be covered tanks (and therefore immune to weather impacts).

The model only considers flow into the system from the gathering system, rainfall and returns from the WTP. It is assumed that the ponds and dams are constructed such that they receive no overland inflows, or inflows from other (external) sources. Similarly, the only outflows from the system are evaporation, irrigation, working and stock water and flows to the environment via overflows or pumped discharges. No other water demands are allowed.

3.2 Modelling approach

The modelling approach adopted produces a 'hydrograph' of the system's performance for a given climate data set. Approximately 130 years of daily climate data is available (see below), giving a similar number of hydrograph profiles. This data set is then assessed to select the profiles of interest, which are then reported.

Thus assuming the first climate data set available begins in 1889, a daily water balance is undertaken using the expected water production schedule (starting on the 1st January 2017), with the climate data shifted to match the production schedule. This gives a single hydrograph, defining all the parameters given in Figure 3-2. The water balance is then repeated using the climate data set starting in 1890, to give a second hydrograph. A third hydrograph is obtained using climate data beginning in 1891 and so forth for all the available climate data set start years (until 2015).

Since the production schedule is several years long, insufficient data is available for the later climate years (e.g. for 2015, climate data is only available for the period January to March). Consequently, the additional data is filled in using data from the start of the period (in this case climate data from 1889 and so forth).

Once all the profiles are available, they are searched to select profiles of interest. In this case, the objective is to minimise the volume of water directed to the environment from pond overflows etc. Consequently, the model searches the profiles for those giving the nominated percentile flows to the environment (for example the profiles giving the minimum, 10th, 50th, 90th and maximum (or other percentiles as appropriate) flows to the environment). This data is then presented in an excel readable format for additional processing such as graphing and tabulation etc.

Inspection of Figure 2-1 indicates that the extracted water profile has a very long, slowly diminishing tail. Consequently, for modelling purposes, production or extracted water is assumed to cease on the 1st January 2038 – a total production run of 21 years. This reduces the amount of data to be managed, and has little impact on the validity of the results.

The model gives a realistic interpretation of how the system would behave, in any of the preceding 130 years. Since the model is based on historical data, which in general will not encompass the complete climate variability, it cannot be said with absolute certainty that a future year will not generate a greater environmental discharge than any of the past years. However as the climate set is reasonably large, and the critical water production period (i.e. the 5 year period incorporating the peak flows) is relatively short, the risk of significantly under predicting the system's performance is small.

Plant availability is incorporated using a pseudo-random number generator. On each day of the simulation, a uniformly distributed random number is generated which represents the probability that the equipment will be available on that day. This allows the model outputs to be adjusted to reflect the expected planned and unplanned equipment maintenance schedules, in a relatively simply way.

3.3 Water balance

The water balance assumes that the ponds/dams are commissioned and filled to their initial starting volumes on a nominated day. From this point forward, until the WTP is commissioned they will be subject to inflows from the gathering system (if any) and rainfall, while outflows are limited to transfers between the ponds/dams (either controlled with pumps or via overflows etc.), evaporation and working water demands. Irrigation from Tiedeman's North and South dams is suppressed until the irrigation system commissioning date is reached. Once the WTP and the irrigation systems are commissioned, the system will function as described in Section 3.1.

Each pond/dam acts as a node, with the volume at the end of the day determined from the initial volume and the difference between the daily inflows and outflows. Evaporation from the ponds/dams is determined using the surface area at the start of the day, using the pan evaporation rate for the day in question. The pan rates were adjusted to estimate evaporation from dams using a factor of 0.75, as determined from data presented by Luke *et al*. 2003. Rainfall entering each pond is calculated from the climate data, using the top of bank pond dimensions.

3.3.1 Pond/Dam control strategy

On each day the flows into and out each pond/dam are calculated, using the following control structure (the actual control values used are given in Table 3-1):

Receiving Water Pond (RWP)

- The flow into the RWP is largely unrestricted, but with the following limits:
    - Extracted water from the gathering system is diverted to the TED when the level in the RWP is high; and
    - Return flows from the TED are suppressed when the level in the RWP is high;
- The flow out of the RWP is determined based on the volume in the pond:
    - When the pond is above a high volume cut off, both the lead and follow WTP trains will operate at their maximum capacities;
    - When the pond is above a mid-volume cut off, the lead WTP train will operate at its maximum capacity;
    - When the pond is above a low-volume cut off, the lead WTP train will operate at its minimum capacity;
    - When the pond is below the low volume cut off all WTP trains will be stopped;

- When the level in the TWS is above a high volume cut off, the WTP will stop if the level in the TED is below a cutoff value. If the level in the TED is above the cutoff value, the WTP will operate at the rate determined above (i.e. based on the level in the RWP), subject to availability limitations. This allows the storage potential of the TED to be utilised, while managing the risk of an overflow occurring.

The control strategy is intended to pump the maximum volume of water to the WTP, without allowing the pond to drain completely or generating long periods between operations. When the TWS is full, water will accumulate in the RWP, and potentially the TED. When the RWP & TED levels are high, the system attempts to pump raw water to the WTP irrespective of the levels in the TWS, DWP or TN&SD, thus preferentially directing treated water to the environment.

Treated Water Storage (TWS)

- Flows into the TWS are determined by the operation of the WTP;
- Flows out of the TWS are determined by the level in the storage:
  - Transfer to the DWP: The transfer pump will only operate if the level is above a high level cutoff and will stop if the level falls below a minimum value. The volume of water that can be pumped per day is limited to a maximum value;
  - The transfer to the DWP will be suppressed when the DWP is above the high volume cut off.

Essentially the control system emulates a simple level control system. When the DWP is full, water will accumulate in the TWS.

Discharge Water Pond (DWP)

- Flow into the DWP is as described above (and in the TN&SD section below for the augmentation of the working water supply), however water can overflow from the TWS in an uncontrolled manner as necessary;
- Flow out of the DWP is controlled as follows:
  - The working water pump's operation has preference and it will operate on demand according to the programme schedule, with the pump starting if the volume is above a mid-volume cut off. The working water pump will lower the pond to an adjustable minimum level in an attempt to meet the working water demands;
  - Flow is pumped at a fixed rate to the TN&SD when the DWP volume is above a high-volume cut off value;
  - Flow is pumped at a fixed rate to the Avon River Release Point when the DWP volume is above a high-high volume cut off value and the TN&SD is full;
  - Flow to the TN&SD is suppressed when the volume in the dam is above a high level cut off.

The control system maintains a reserve volume of water in the pond to meet the working water requirements but otherwise attempts to minimise the volume in the DWP, transferring water to the TN&SD when volume is available. Water will accumulate in the DWP when the TN&SD is full, and will eventually be pumped to the Avon River. In principle, the excess water could be pumped to the TN&SD and discharged to the Avon River from there if desired.

Tiedeman's North & South Dams ((TN&SD) These dams are modelled as a single entity)

- Flow into the dam is as described above;
- Flow out of the dam is controlled as follows:
  - Working water demands (i.e. those demands that cannot be drawn from the DWP) are met first, by pumping water from the dam to the DWP (there is no direct connection between the TN&SD and the working water network). Pumping allowed if the dam volume is above a low level cut off;
  - Flow is pumped to irrigation, as described in Section 3.4, when the volume is above a mid-volume cut off value;
  - Flow is pumped at a fixed rate to the Avon River Release Point when the dam volume is above a high volume cut off value.

The control system attempts to direct water to reuse (either for working water, stock watering or irrigation), until the level in the dam reaches a high level value, after which a fixed amount per day is pumped to the Avon River Release Point.

Tiedeman's East Dam (TED)

- Flow into the dam from the gathering system only occurs when the RWP is full and the flow is diverted to the TED. For modelling purposes is unrestricted, however in reality it is understood that the gas wells will be shutdown to prevent further water inflow into the TED when this dam is nearly full;
- Flow is pumped to the RWP when the level in the dam is above a cut off value and the volume in the RWP is below a cut off value;
- Evaporation from the dam is stopped when the level falls below a minimum value.

The control system attempts to minimise the volume in Tiedeman's East dam, by pumping the water back to the RWP as soon as possible – but without unduly overloading the RWP.

Pontiland's Dam (PontD)

Currently, no control system is imposed on the Pontiland's Dam, with the exception that evaporation from the dam is stopped when the level falls below a minimum value.

3.3.2 Pond/Dam level control values

As described above, the model attempts to maintain the pond and dam volumes within certain limits. These limits are summarised in Table 3-1. For each pond/dam, the volume fraction is compared to the overflow level. The associated water depths at each control volume are also given.

Table 3-1: Pond/Dam level control limits

No.	Limit Description	Stream No. (Fig 3.2)	Volume[1] [%]	[m³]	Level [m]
Receiving Water Pond (RWP)				12,718	4.50
1	Level above which the lead and follow WTP trains operate at their maximum capacities	4	55	6,995	3.05
2	Level above which the lead WTP train operates at its maximum capacity	4	40	5,087	2.44
3	Level above which the lead WTP train operates at its minimum capacity	4	20	2,544	1.45
4	Level above which extracted water is diverted to TED		83	10,556	4.00
5	Level below which the WTP feed pump is suppressed when the TWS tank is full	4	70	8,903	3.58
6	Level above which the TED to RWP (return) pump is suppressed	6	75	9,539	3.75
Treated Water Storage Tank (TWS)				1,000	3.50
1	Level above which the WTP feed pump is suppressed	4	90	900	3.15
2	Level above which the TWS to DWP pump will start	11	25	250	0.88
3	Level below which the TWS to DWP pump will stop	11	5	50	0.18
Discharge Water Pond (DWP)				12,718	4.50
1	Level above which the TWS to DWP pump is suppressed	11	85	10,810	4.06
2	Level below which the working water pump is suppressed	17	4	509	0.36
3	Level below which the DWP to TN&SD pump is suppressed	18	25	3,180	1.72
4	Level above which the Avon River discharge pump will start	19	95	12,082	4.36
Tiedeman's North and South Dam (TN&SD)				40,418	4.00
1	Level above which the DWP to TN&SD pump is suppressed	18	90	36,376	3.69
2	Level above which the TN&SD to DWP (working water flow return) pump is suppressed	28	4	1,617	0.23
3	Level above which the irrigation feed pump can start	25	12	4,850	0.66
3a	Level below which the irrigation feed pump will stop	25	8	3,233	0.45
4	Level above which the Avon River discharge pump will start	26	95	38,397	3.85
Tiedeman's East Dam (TED)				24,800	4.88
1	Level below which the TED to RWP (return) pump is suppressed	6	8	1,984	0.64
2	Level below which evaporation is suppressed in the TED		2	496	0.17
Pontiland's Dam (PontD)				50,360	4.50
1	Level below which evaporation is suppressed in the PontD		2	1,007	0.12

1. Volume fraction is to the overflow level

3.4 Irrigation model

The irrigation system is modelled using the method presented in Allen *et al.* (1998). This model was developed by the United Nations Food and Agriculture Organisation (FAO), and presents a step by step procedure for estimating crop evapotranspiration rates. The procedure involves calculating the base evapotranspiration rate (ET_0), which would be expected for a reference crop growing under ideal conditions. This rate varies based on the climatic conditions, site location and solar radiation etc. The FAO report presents several correlations for the calculation of ET_0, with the model using the Penman-Monteith method, which is reported to be the most accurate. A 10% safety factor (adjustable) is applied to the calculated ET_0, value to ensure some degree of conservatism.

Once the ET_0 value is known, it is corrected for the type of crop expected to be grown in the AGL irrigation area. In this case, a permanent pasture grass is assumed, over sown with a suitable winter crop to ensure that evapotranspiration does not fall to very low values over winter.

The method selects several factors which define how the soil will behave with respect to its moisture holding capacity. These factors are used to correct (reduce) the ET_0 value to reflect the non-ideal conditions in the actual soil:

- *Field capacity* of the soil, which represents the amount of water the soil can hold under freely draining conditions – i.e. this gives the maximum soil moisture content that can be maintained against gravity. It differs from soil saturation, in that the spaces between the soil particles are filled with both water and air, whereas under saturated conditions, the spaces contain only water. Saturated soils will typically drain to the field capacity within 1 to 2 days. This is a soil based parameter that is independent of the crop. The field capacity varies between about 7% for sand and 44% for heavy clay
- *Wilting point,* which is the value at which the soil moisture content is too low for the plant to draw water from the soil. Typically about half of the water in the soil at field capacity is held too tightly to be accessible to plants. This value is primarily dependent on the soil structure, but also to some degree on the type of crop. Typical wilting points vary from about 2% for sand to 26% for heavy clays;
- *Total available moisture content,* is the difference between the field capacity and the wilting point;
- *Readily available soil moisture content*, which is the point at which the crop growth is reduced as a result of the water in the soil becoming harder to access. Currently, a value of 55% of the difference between the field capacity and the wilting point is assumed; and
- *Root zone depth,* which is the depth to which the roots penetrate. Currently the root zone is set at 300 mm, which is suitable for a pasture type crop.

Soil texture data was obtained from the NSW Soil and Land Information Database for several locations adjacent the Tiedeman's Dams. Four of the sites were collected for the AGL-Tiedeman's survey undertaken in July 2011 and are for locations near the dam and trial irrigation area. The remaining 2 sites were from pits approximately 1.5 km to the north (Waukivory Cr.) and south (Wenham's Cox Rd.) of the dams, and were collected in 1996. Some laboratory measured field capacity and wilting point data was also available for the remote sites (however this data should be interpreted with caution as the soil structure and compaction etc. is altered during sample collection).

The data is summarised in Table 3-2, and indicates that the top soil horizon, which appears to extend from the surface to about 0.2 m, has a silty loam or silty clay loam texture. The next horizon, which extends to between 0.3 and 0.5 m deep has a predominantly silty loam texture, with some silty-clay-loam and some light clay. The deeper layers are predominantly light to light-medium clays.

Typical field capacity and permanent wilting point values were obtained from the UNSW TerraGIS website and are given in Table 3-3 for a range of soil textures. These values are not too dissimilar to the measured values, at least for the field capacity, given in Table 3-2. Based on these values, the model uses a field capacity of 30%, and a permanent wilting point of 18%, which are consistent with the soil textures in the top 2 horizons (down to about 0.4-0.5 m). This gives a total available moisture content of 12%, which is well within the normal range for most soils given in Table 3-3. Based on this data, the soil type would not be expected to be a critical determinant of the system's performance.

Table 3-2: Soil texture data

Parameter	Site					
	2	4	5	10	Wenham's Cox Rd	Waukivory Cr
Location	Near dams	Near dams	Near dams	Near dams	2.0 km south	1.3 km north
Map Reference	Dungog 9233	Dungog 9233	Dungog 9233	Dungog 9233	Dungog 9233	Dungog 9233
Easting	402697	402150	402178	402750	402205	402905
Northing	6448725	6449230	6449128	6448821	6447089	6450389
Layer 1						
- Depth [m]	0.00 - 0.15	0.00 - 0.20	0.00 - 0.15	0.00 - 0.20	0.00 - 0.10	0.00 - 0.10
- Texture	Silty clay loam	Silty loam	Silty loam	Silty clay loam	Silty clay loam	Clay loam sandy
- Field Capacity [%]					35	51.9
- Wilting Point [%]					13.8	13
Layer 2						
- Depth [m]	0.15 - 0.30	0.20 - 0.30	0.15 - 0.60	0.20 - 0.40	0.10 - 0.30	0.10 - 0.50
- Texture	Silty clay loam	Silty loam	Light clay	Silty loam	Silty clay loam	Silty clay loam
- Field Capacity [%]					30	43.1
- Wilting Point [%]					11.3	11
Layer 3						
- Depth [m]	0.25 - 0.95	0.30 - 0.50	0.60 - 1.50	0.40 - 1.00	0.30 - 0.60	
- Texture	Light clay	Light clay	Light medium clay	Light clay	Light medium clay	
- Field Capacity [%]					42.8	
- Wilting Point [%]					20.9	
Layer 4						
- Depth [m]	0.95 - 1.50	0.50 - 1.00		1.00 - 1.30		
- Texture	Light clay	Sandy clay		Light clay		
- Field Capacity [%]						
- Wilting Point [%]						

Although the irrigation model limits water application such that the field capacity is not exceeded, rainfall may cause the moisture content to rise above the field capacity. This 'excess' water (i.e. water applied above the field capacity) is assumed to flow to deep drainage (i.e. to drain below the crop root zone) or to run off the site. The model does not deterministically distinguish between runoff and deep drainage but instead uses an adjustable constant to separate the values. Currently the model assumes that 80% of the water applied above the field capacity will runoff the site.

Starting from an initial soil moisture content the model tracks daily variations in the moisture content owing to evapotranspiration and rainfall, and applies irrigation water (if available) when the soil moisture content falls below a nominated value. The model tries to ensure that the soil moisture content remains in the 'readily available moisture' range, such that the crop is never water starved.

Currently, irrigation is applied (when water is available) whenever the soil moisture content falls below 20% of the readily available moisture content.

Table 3-3: Field capacity and wilting point

Soil Texture	Field Capacity[1] [% by Vol]	Wilting Point [% by Vol]	Available Water [% by Vol]
Sand	7 - 17, 10	2 - 7, 5	5 - 10, 7
Loamy sand	11 - 19, 14	3 - 10, 5	8 - 9, 8.5
Sandy loam	18 - 28, 22	6 - 16, 11	12 - 14, 13
Sandy clay loam	24 - 32, 26	16 - 20, 18	8 - 12, 10
Loam	20 - 30, 25	7 - 17, 14	12 - 15, 13
Sandy clay	24 - 32, 26	16 - 26, 22	8 - 12, 10
Silty loam	22 - 36, 28	9 - 21, 15	11 - 15, 13
Silt	28 - 36, 32	12 - 22, 15	12-16, 14
Clay loam	22 - 32, 27	16 - 24, 20	6 - 12, 9
Silty clay loam	30 - 37, 33	17 - 24, 20	12 - 14, 13
Silty clay	30 - 42, 36	17 - 29, 25	12 - 14, 13
Light clay	25 - 32, 28	20 - 24, 22	5 - 8, 6
Medium clay	30 - 40, 35	22 - 26, 24	8 - 14, 12
Heavy clay	36 - 44, 40	24 - 28, 26	12 - 16, 14

Source: www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_water-soil_moisture_classification.html

1. Range and typical (adopted) value

The model also considers rain and irrigation water lost to evaporation before impacting the soil moisture content. Currently rainfall events of less than 2 mm are assumed to have no soil impact, while the equivalent of 1 mm of irrigation water is lost to evaporation in each irrigation event.

Since a daily water balance is being used, the timing of the irrigation is important – i.e. irrigation can occur either early or late in the day. Early irrigation is assumed to occur before any rainfall, which may otherwise mean that irrigation is not required. This means that water reuse is maximised, however a greater portion is wasted to runoff and deep drainage. If irrigation occurs late in the day (i.e. after rainfall) or co-currently with rainfall, the runoff and deep drainage are reduced, but the volume of water that can be disposed of is also reduced. Currently, the model assumes that irrigation occurs early in the day.

Several factors limit the amount of irrigation water that is applied on a given day:

- Water availability: A minimum volume of water is retained in the irrigation dam (irrigation is suppressed when the level falls below 8% of the dam's volume), irrespective of the irrigation demand. Thus the irrigation amount is limited to the difference between the dam's current and minimum volumes;

- Irrigation demand: Irrigation will only occur if the soil moisture content falls below the nominated value. The amount is limited to the quantity required to raise the moisture content from its current value to the field capacity. This ensures that no irrigation water flows directly to deep drainage or to runoff – however runoff and deep drainage will occur if rain falls after irrigation and the field capacity is exceeded; and
- Irrigation system capacity: The flow of water to the irrigation system is limited to the pump and system capacity.

The actual amount irrigated is the minimum of the limits listed above.

3.5 Meteorological data

3.5.1 Data source

Daily climate data was obtained from the Queensland Government's 'SILO' database for the town of Gloucester, located at a latitude of 32 00'S and a longitude of 151 57'E and an elevation of 155 m (The proposed irrigation areas are located at elevations of between 100 and 130 m AHD). SILO (Scientific Information for Land Owners) is an enhanced climate database hosted by the Science Delivery Division of the Department of Science, Information Technology and Innovation (DSITI) containing daily historical climate records for Australia from 1889 onwards. The database is founded on BoM data, with missing data filled in by interpolation from nearby stations or by correlating the data from available measurements or long term averages, to give a complete data set for the period. The following daily average data was obtained from the SILO database for the period 1889 onwards:

- Maximum and minimum temperatures [^{o}C]. Where required, the daily temperature was assumed to be the average of these values;
- Daily rainfall [mm];
- Class A pan evaporation rate [mm];
- Solar radiation [MJ/m^2];
- Vapour pressure [hPa]; and
- Relative humidity [%] at the maximum and minimum temperatures.

The climate data is summarised in Table 3-4 and indicates median maximum and minimum temperatures of 24 and 11.5 ^{o}C, with a range of -4 to 44 ^{o}C. The median annual rainfall is about 960 mm/yr, which is somewhat below the median pan evaporation rate of 1,410 mm/yr.

Table 3-4: Climate Data Summary (Years 1889 - 2015)

Parameter	Units	Min	Percentile			Maximum
			10th	50th	90th	
Maximum temperature	°C	10.5	17.5	24.0	31.0	44.0
Minimum temperature	°C	-4.0	4.5	11.5	18.0	24.5
Annual rainfall	mm/yr	425	651	959	1,268	1,864
Annual evaporation	mm/yr	1,147	1,308	1,408	1,431	1,664
Solar radiation	MJ/m2	2.0	9.0	17	26	34
Vapour pressure	hPa	4.0	9.0	15	22	35
Relative humidity ast Tmax	%	11.0	35.6	48.5	64.5	100
Relative humidity ast Tmin	%	36.9	87.1	100	100	100

3.5.2 Frost frequency expectations

Frost is a potential concern for the irrigation area, owing to its impact on evapotranspiration rates, which can fall to effectively zero for frost sensitive plant species. Frost occurs when the ground temperature falls below zero °C for sufficiently long to either freeze dew or to precipitate ice on the plant surfaces, however other weather conditions are also typically required, such as sufficient humidity and low wind speeds.

Since all the required data to predict frost events was not available, for this assessment, the propensity for frost to occur was investigated simply by determining the frequency of sub zero temperatures thereby giving the maximum likelihood of frost occurring. This data is summarised in Table 3-5, which gives the minimum temperatures during the winter months (May to October). Generally the minimum temperatures remain above 0 °C, with June, July and August being the critical months. For the 127 year record period, sub zero temperatures were obtained in about 25% of years in July, with lower values obtained in June and August. Consequently, on average, frost may be expected in 1 year in every 4, however micro-climate effects may cause more frequent events in some areas.

Table 3-5: Frost propensity (1889 – 2014)

Parameter	Units	May	June	July	August	September	October
Minimum Temperatures							
- Lowest	[°C]	-2.0	-1.5	-4.0	-1.5	0.0	1.0
- 5th Percentile	[°C]	1.5	-0.5	-1.4	-0.5	1.1	3.0
- 10th Percentile	[°C]	2.0	0.0	-1.0	-0.5	2.0	4.0
- 25th Percentile	[°C]	2.5	1.0	0.0	0.5	2.5	5.0
- Highest	[°C]	8.0	5.5	4.5	4.0	7.5	10.5
Years with Sub-zero Temperatures							
- Number	[#]	1	9	30	14	0	0
- Percentage	[#]	0.8	7.1	23.8	11.1	0.0	0.0

3.6 Frost impacts

As discussed in Section 3.5.2, frost has the potential to impact the irrigation system by reducing the evapotranspiration rate for some period after the event. However frost events and their impacts on plant growth are difficult to estimate (Snyder *et al.* 2005), with the impacts dependent on a variety of factors, including:

- Plant species and variety;
- The growth phase (e.g. seedlings, flowering, mature etc.);
- Recent historical temperatures, which can 'harden' the plant against the impact of frost;
- Micro-climate, which can vary quite considerably over relatively short distances (< 200 m); and
- Severity of the frost event (e.g. temperature, duration, humidity soil moisture and wind etc.).

Given the complexity of the frost response, it was assumed that:

- Frost impacts will be managed through the selection of a range of pasture grasses, at least some of which will be frost tolerant, or that the irrigation area will be annually over sown with an appropriate frost resistance species (it is likely that this would only be required for the first 4 – 5 years of the project i.e. until the peak production period has passed); and.
- Frost impacts can be indicatively assessed by reducing the evapotranspiration rate by an adjustable amount for an adjustable period following a sub-zero minimum temperature.

3.7 Pond volumes and areas

The pond/dam volumes and dimensions have been approximated as regular truncated rectangular prisms, with flat floors. The dimensions and volumes of the storages are given in Table 3-6. There is a slight difference between the pond volumes as designed and modelled, as described below:

- The original (FEED) 'as-designed' ponds incorporated a dead volume, with a depth of approximately 0.5 m above the floor of the pond. This volume is generally unusable owing to the difficulty of extracting water from a pond at a depth of less than about 0.5 m. This is not formally modelled however. Although minimum cut offs are used in all ponds, these relate only roughly to the dead volume. The modelled low volume cut offs are generally set to ensure that the discharge pumps will not start if insufficient volume is available for a typical day's pumping;
- The 'as-designed' ponds have target and reportable top water levels, whereas the modelled ponds only consider the overflow volumes. This is because the water model is focused on how much water will overtop the ponds, and not so much on a nominal top water level (TWL).

There remains some uncertainty with respect to the pond volumes. The final locations and capacities of the WTP ponds (RWP and the DWP) are yet to be decided. For the base modelling case, it is assumed that the ponds will be located to the north of Parkers Road and will have the top of wall dimensions given in Table 3-6. The ponds are assumed to have a bottom to top of wall depth of 5.0 m. This gives a capacity to the TWL of about 10.5 ML, which is somewhat smaller than the nominal 20 ML values used during the FEED design. If the ponds are located to the south of Parkers Road, where the area is less restricted, larger ponds more akin to the FEED design can be used.

The dimensions of the Tiedeman's East Dam were obtained from the Manufacturer's Data Report (2012/13), which also provided information on the dam's depth and wall slopes. This information has been transcribed into Table 3-6. The dimensions, depths and walls slopes of the Tiedeman North and South Dams were obtained from the Surveyor's Drawings (Calco, 2007).

For modelling purposes, the Tiedeman's North and South dams are assumed to be a single unit. Consequently a Pseudo North & South dam is shown in the table, which has the same surface area and volume (at the overflow level) as the combined north and south dams, with the dimensions adjusted to compensate.

Based on the Surveyor's Drawings (Calco, 2014) for 'Farley Property', Pontiland's is an irregularly shaped dam, with a nominal capacity of 50 ML at the weir level, and a surface area of 4.0 Ha. The dam is about 330 m long, with a maximum width of about 130 m. The dam's maximum depth of 4.5 m is located near the spillway, however owing to the dam's shape, the average depth is considerably less. For consistency with the other dams, the Pontiland's Dam 'equivalent' dimensions are given in Table 3-6, assuming it has a regular shape and a flat floor.

The assumed initial volumes (i.e. the volume held in each pond on the pond commissioning day (See Section 3.8.1)) held in each pond are also given in Table 3-6. For the most part, these values are relatively arbitrary, being set to ensure that the pond/dam does not completely empty prior to water being received from the gathering/treatment systems. TED however is likely to contain about 15 ML of extracted water from the pilot programmes, while the TN&SD is likely to hold greater than 7.5 ML of fresh water. A nominal initial volume of 15 ML was assumed for the PontD.

Table 3-6: Pond/dam dimensions

Parameter	Units	WTP Storages/Ponds			Tiedeman's Ponds				Pontiland's
		RWP	TWS	DWP	North	South	Pseudo N&S	East	Dam
Base of Pond									
- Length	m	82.0	16.9	82.0	65.0	65.0	233.7	110.7	315.4
- Width	m	16.0	16.9	16.0	53.0	53.0	29.3	25.7	112.4
- Area	m^2	1,312	286	1,312	3,445	3,445	6,858	2,847	35,434
Wall slope: Length	V:H (1:X)	3.0	0.0	3.0	3.0	3.0	3.0	3.0	4.0
Wall slope: Width	V:H (1:X)	3.0	0.0	3.0	3.0	3.0	3.0	3.0	4.0
Dead Storage Above Floor									
- Depth	m	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.1
- Area	m^2	1,615	286	1,615	3,808	3,808	7,656	3,265	35,777
- Volume	m^3	730	143	730	1,812	1,812	3,626	1,527	3,561
- Fraction of overflow volume	%	5.7	14.3	5.7	9.0	9.0	9.0	6.2	7.1
Top Water Level (Design)									
- Depth	m	4.0	3.0	4.0	3.7	3.7	3.7	4.2	1.3
- Area	m^2	4,240	286	4,240	6,557	6,557	13,190	6,971	40,098
- Volume	m^3	10,547	857	10,547	18,198	18,198	36,455	20,200	50,197
- Usable storage volume	m^3	9,817	714	9,817	16,386	16,386	32,829	18,673	46,636
Overflow Water Level (Model TWL)									
- Depth	m	4.5	3.5	4.5	4.0	4.0	4.0	4.9	1.3
- Area	m^2	4,687	286	4,687	6,853	6,853	13,747	7,703	40,098
- Volume	m^3	12,718	1,000	12,718	20,209	20,209	40,418	24,800	50,197
- Usable storage volume	m^3	11,988	857	11,988	18,397	18,397	36,792	23,273	46,636
Top of Wall									
- Depth	m	5.0		5.0	4.3	4.3	4.3	5.4	1.8
- Area	m^2	5,152		5,152	7,155	7,155	14,310	8,294	41,910
- Length	m	112.0		112.0	90.8	90.8	259.5	143.0	330.0
- Width	m	46.0		46.0	78.8	78.8	55.1	58.0	127.0
- Volume (apparent)	m^3	15,106		15,106	22,310	22,310	44,539	28,700	70,687
Initial volumes in the ponds	m^3	1,000	500	1,500			7,500	15,000	15,000

3.8 Other input parameters

The model requires certain data to control how the simulation proceeds. The key input parameters and assumptions are detailed in the following subsections.

3.8.1 Starting dates

The model simulation always begins on the 1st January in the selected starting year (currently 2017). Three dates are then selected, with the following current values:

- The pond commissioning and water volume initialisation: 1st September 2017
- WTP commissioning date: 1st March 2018
- Irrigation start date: 15th May 2018

Currently the pond commissioning date (i.e. the date from which volume changes in the ponds are tracked) is relatively arbitrary. The WTP commissioning date has been selected such that the plant begins operation 1 month prior to the start of the extracted water flows (as given in the production water schedule (Figure 1-1)). This offset gives the system and WTP time to transfer and process extracted water held in the TED and make it available for use to meet the initial working water demands. The irrigation start date is delayed slightly to ensure that the initial working water demands are met prior to the water held in the DWP and TN&SD Dam being irrigated. The actual irrigation start date will need to be reviewed when the flows begin to ensure that water is:

- Available to meet the working water demands; and
- Irrigated prior to the dams becoming too full.

3.8.2 Working water requirements

The model is set up to draw working water from the DWP only. However, in the event of the DWP level being low, water can be transferred to the DWP from the TN&SD (which is allowed in the model). It is understood that working water can also be drawn from the Pontiland's Dam, however this is not included in the model.

A monthly working water demand schedule was provided, giving the number of wells to be drilled, fracked and worked, in the month in question. For modelling purposes, the monthly programme was converted to a daily programme with each demand type distributed over the month as evenly as possible, with no regard given to normal working days.

Working water is required for 3 uses:

- *Drilling water*, which is understood to require about 500 m^3 per well drilled. It is understood that this water will not be sourced from the WTP/Tiedeman's Dam system, with the most likely source being the Pontiland's dam. Similarly, spent drilling water will not be returned to WTP system and will be dealt with independently. Consequently, for modelling purposes the drilling water demand was set to zero;
- *Fracture stimulation water.* It is understood that each fracking event requires between 500 and 1,500 m^3 with a nominal value of 1,000 m^3 adopted. Further, it is understood that fracking occurs over a 2 day period and consequently the model assumes a daily demand of half the nominated fracking water flow per event, on each of two consecutive days.
- *Work-over water* relates to the water used to periodically re-habilitate and enhance the gas well's productivity after it has been in operation for some time, with a water demand of about 50 m^3/well worked. The schedule provided currently does not nominate any work-over events and consequently, for modelling purposes the work-over water demand was set to zero.

It is understood that some irrigation water will be used for stock watering. Currently no estimate of the stock watering demand is available and it has not been included in the model, on the assumption that it will be small (insignificant).

The cumulative working water demands are shown in Figure 3-3 for the drilling, fracture stimulation and work-over programme as supplied. The demand is expected to cease in about 2021, with a total draw of just over 100,000 m^3 which is equivalent to about 17.5% of the total P50 extracted water flow.

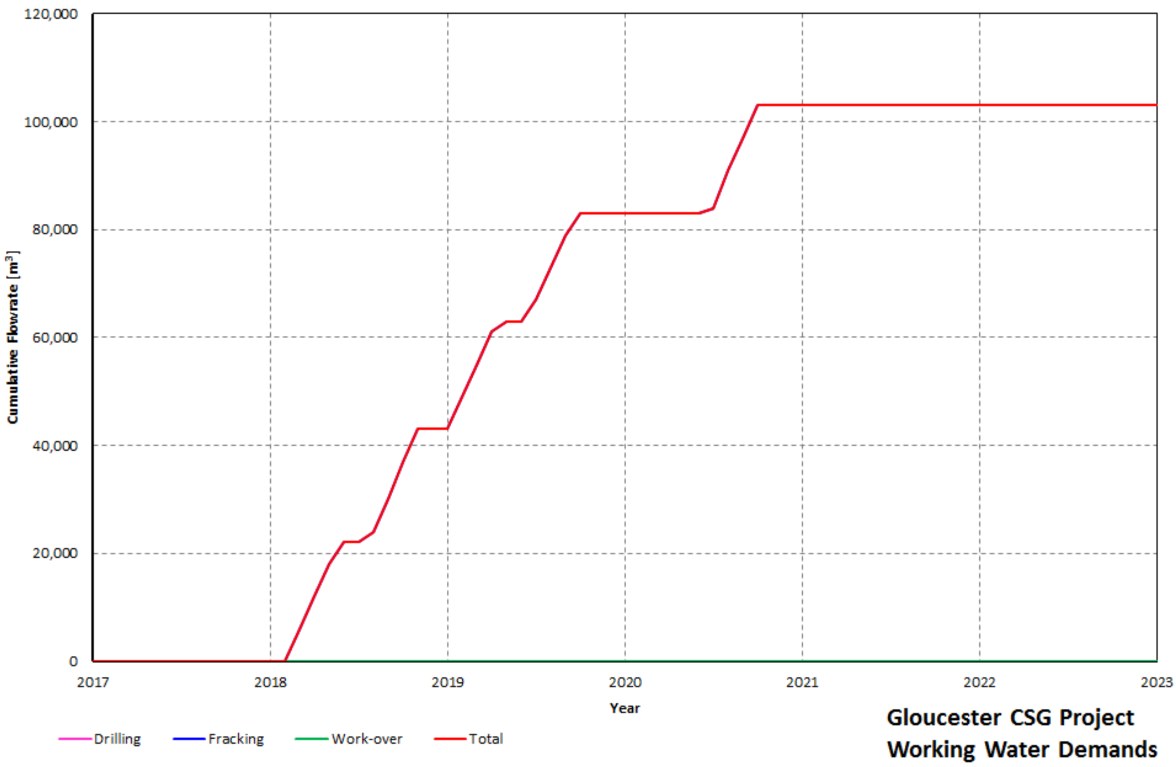
3.8.3 Extracted and flowback water

The model currently allows any of 4 extracted water production profiles to be simulated, including the:

- 50^{th} percentile FEED profile (used for comparative purposes only);
- Expected 10^{th} percentile profile;
- Expected 50^{th} percentile profile; and
- Expected 90^{th} percentile profile.

The model is set up to allow flowback water to be either included in the profiles given above or added in separately. The extracted water profiles given in Figure 2-1 include the flowback water.

Figure 3-3: Working water demands



3.8.4 WTP recovery

The WTP recovery is dependent on several factors, including the total dissolved salts (TDS) concentration in the extracted water, the water temperature, pre-treatment method(s), membrane type, operating pressure and the salts present etc. The recoveries listed below are based on a nominal TDS value of 4,300 mg/L (the expected TDS range is 3,000 – 9,000 mg/L), however the TDS is not a model input. An adjustable water recovery is set at run time, with the following values extracted from the WTP water balance given in Appendix 1 (all the values are fractions of the flow directed to the WTP (i.e. factions of Stream 4 in Figure 3-2):

- Fraction of water returned to the RWP from pre-treatment: 0.000
- Fraction of water recovered in the treatment system: 0.830
- Fraction of water recovered in the brine concentration system: 0.150
- Total: 0.980

The remaining water (about 2%) passes out of the system with the salt product, and other solid wastes generated in the WTP.

3.8.5 Pump and transfer rates

The capacity of pumps directing flow around the system is limited. The current capacities are given in Table 3-7. The model uses daily flowrates, however the instantaneous rate is also given in the table, assuming the pump runs 24 hours per day.

Table 3-7: Pump capacities

Pump	Stream No. (Figure 3.2) [#]	Capacity	
		Daily [m³/d]	Instantaneous[1] [L/s]
Water Treatment Plant Feed Pump			
- 2 Pumps running, full speed	4	1,200	13.9
- 1 pump running at full speed	4	600	6.9
- 1 pump running at minimum speed	4	300	3.5
Treated Water Storage to the Discharge Water Pond	11	1,200	13.9
Discharge Water Pond to working water	17	Unlimited[2]	-
Discharge Water Pond to the Avon River	19	2,000	23.1
Discharge Water Pond to Tiedeman's North & South Dam	18	2,000	23.1
Tiedeman's North & South Dam to Discharge Water Pond	28	1,000	11.6
Tiedeman's North & South Dam to the Avon River	26	2,000	23.1
Tiedeman's North & South Dam to irrigation	25	3,000	34.7
Tiedeman's East to the Receiving Water Pond	6	350	4.1

1. Assumes 24 hour/d operation, 2. Set by demand

3.9 Other assumptions

It is further assumed that:

- The salinity of the extracted water (and hence the treatment/brine concentrator recovery efficiencies) will be constant over the project life;
- An irrigation area of 60 Ha is available;
- Stock water requirements are included in the water volume available for irrigation;
- Drilling water, both the source of and the treatment/disposal of spent drilling water is not included in the model; and
- Inflows from any development beyond Stage 1 are not included in the model.

3.10 Verification

It is not possible to 'prove' the model is correct. It can only be shown to be incorrect. However the model has been developed with all due care and attention, and is believed to correctly simulate the process described.

3.10.1 Mass balance check

The model automatically calculates and reports a mass balance check, incorporating all streams over each of the following components:

- Each pond (i.e. RWP, TWS, DWP, Tiedeman's North & South and Tiedeman's East);
- The combined TWS & DWP system;
- The irrigation area; and
- The entire system.

The balances are summed over the entire production period and report deviations of less than 0.1 m^3. It is acknowledged that this does not mean the simulation is correct – just that it is 'not wrong'.

3.10.2 Stress testing

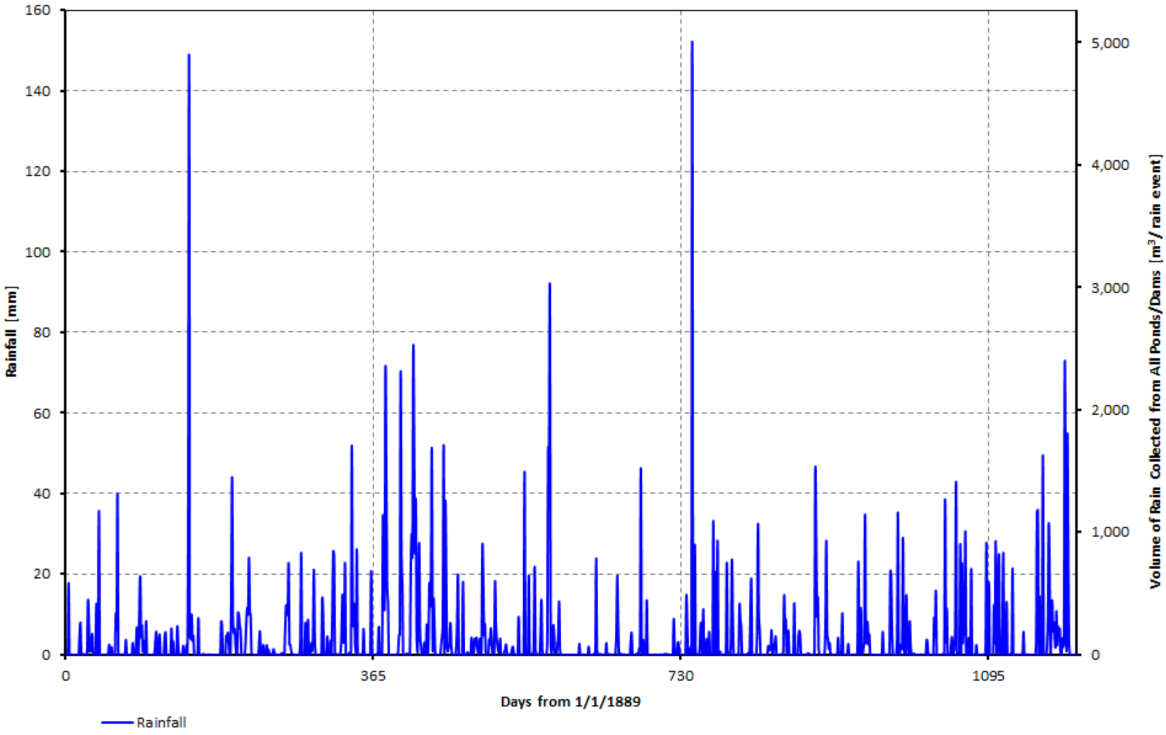
The model has been stress tested by varying the key parameters and observing that the model behaves as expected. Key streams have been analysed in detail, to assess potential errors.

3.10.3 Rainfall

Gloucester is located in a high rainfall area (~ 980 mm/yr on average) and consequently the ponds are impacted by large rainfall events. Figure 3-4 shows the rainfall pattern for the 1st 3 years of the climate data set, starting in the Year 1889. The figure shows several large rainfall events in the order of, or greater than 100 mm. Also shown in the figure is the impact of rainfall on all ponds and dams (excluding Pontilands). Rain events increasing the total stored volume by 1 ML or more are common, with events generating increases of greater than 5 ML occurring every few years.

The RWP has a nominal top of wall surface area of about 5,200 m^2 and consequently 100 and 150 mm rain events will generate flows of about 520 and 780 m^3 respectively on the day. These values are of a similar order of magnitude as the peak daily extracted water production rates.

Figure 3-4: Gloucester rainfall pattern for the period beginning 1st Jan 1889



4 SIMULATION CASES

Several scenarios have been modelled, to investigate the system sensitivities. The key areas that have been examined are:

- Changing the WTP pond sizes;
- Changing the irrigation parameters;
- Changing the WTP recovery and availability;
- Investigating the impact of frost; and
- Investigating the working water availability and initial pond storage requirements.

The scenarios assessed are summarised in Table 4-1. More information on the scenarios modelled is given in the text in the following sections. Graphical outputs for some of the results are presented in Appendices 2 to 13.

Table 4-1: Scenario summary

No.	Scenario	Extracted Water Profile	Climate Profile[1]	Specification
	WTP Pond Sizes			
1	P50 Base case	P50	Min, 10th, 50th, 90th and maximum	Model parameters as detailed in the report
2	P90 Base case	P90	Min, 10th, 50th, 90th and maximum	Model parameters as detailed in the report
3	Large WTP ponds	P90	Min, 10th, 50th, 90th and maximum	Base case plus: RWP = 14.4 & DWP = 23.5 ML[2]
4	Small WTP ponds	P90	Min, 10th, 50th, 90th and maximum	Base case plus: RWP & DWP = 9.5 ML
	Irrigation Parameters			
5	Higher clay content soil	P90	Min, 10th, 50th, 90th and maximum	Base case plus: light clay soil structure
6	Large irrigation area	P90	Min, 10th, 50th, 90th and maximum	Base case plus: 75 Ha irrigation area
7	Small irrigation area	P90	Min, 10th, 50th, 90th and maximum	Base case plus: 45 Ha irrigation area
	WTP Recovery/Performance			
8	WTP capacity reduced by 5%	P90	Min, 10th, 50th, 90th and maximum	Base case plus: 1,140 m^3/d WTP feed flowrate
9	WTP capacity reduced by 10%	P90	Min, 10th, 50th, 90th and maximum	Base case plus: 1,080 m^3/d WTP feed flowrate
10	WTP availability reduced	P90	Min, 10th, 50th, 90th and maximum	Base case plus: 90% availability
11	WTP capacity & avail. reduced	P90	Min, 10th, 50th, 90th and maximum	Base case plus: 90% avail & 1,080 m^3/d cap
	Frost Impact			
12	Light frost impact	P90	Min, 10th, 50th, 90th and maximum	Base case plus: 40% initial ET reduction
13	Heavy frost impact	P90	Min, 10th, 50th, 90th and maximum	Base case plus: 80% initial ET reduction
	Working Water Availability/Storage Requirements			
14	Base case	P10	Min, 10th, 50th, 90th and maximum	Model parameters as detailed in the report
15	Lower initial pond storage	P10	Min, 10th, 50th, 90th and maximum	As described in the text
16	Lower initial pond storage	P50	Min, 10th, 50th, 90th and maximum	As described in the text

1. The climate profile, is that profile which gives the nominated percentile flow to the environment (e.g. 10th or 90th %ile etc.)
2. Volumes at the overflow level

In all cases the pond and dams were operated such that no overflow of the RWP or the TED occurs – to avoid the discharge of untreated water.

4.1 WTP pond sizes

The intent of this modelling was to determine the impact of changing the RWP and DWP sizes. The cases modelled are summarised in Table 4-2. Scenarios 1 and 2 present the 'Base case' 50^{th} and 90^{th} percentile extracted water flows, and how these are impacted by a range of climatic conditions. Graphical representations of selected model outputs are given in Appendices 2 to 5, including:

- The extracted water flow and rainfall (to the RWP);
- The daily volumes of the ponds and dams;
- The working water demands drawn from the DWP and TN&SD;
- The instantaneous and cumulative flow to river discharges (combined total from the DWP, TN&SD and TED);
- Irrigation rates; and
- Cumulative rainfall to the ponds and dams.

As described in Section 3, the balance was undertaken for 127 climate data sets, with each data set starting in a year between 1889 and 2015. The 127 resulting water balances were then searched to extract those profiles giving the nominated percentile flow to the environment (i.e. the summation of all overflows and discharges to the Avon River, taken over the approximately 20 year production period modelled). The model findings are summarised in Table 4-2, which gives the expected flow to the environment for the nominated climate percentiles, as well as the climate data set starting year (which allows the appropriate profile to be selected for reporting purposes). The size of the environmental release is also compared to the total extracted water flow as a percentage for comparison purposes. In cases where the environmental discharge is zero, the profiles are selected based on a secondary measure – i.e. sum of the peak volumes in the DWP, TED and TN&SD (i.e. those storages which can discharge to the environment), which provides an indicative measure of the potential to overflow.

The 'Base Cases', use the input data as described in the preceding sections of this report and provide a point of comparison for input data modifications. For the P50 extracted water profile, no environmental release would be expected – essentially implying that 100% reuse of the treated water may be expected. For the P90 extracted water profile, about 10 ML of water is expected to be released to the Avon River Release Point over the 20 year modelling period for the worst case climatic conditions – equivalent to just over 1% of the total extracted water volume. The rest of the water will be irrigated. As indicated in the graphs in Appendix 3, several release events would be expected at times roughly corresponding to the peak of the extracted water profile. For the 95 percentile climatic conditions, the flow to the Avon River Release Pt falls to about 2 ML (or about 0.15% of the extracted water flow over the 20 year modelling period). As before this release is expected to occur during the peak extracted water production period. No releases would be expected for the lower climate data percentiles for which data is presented. This implies that there is risk of somewhat less than 1 in 100 of an environmental release being required for the system, as modelled.

The graphical output for the TED given in Appendix 2 indicates that a significant degree of storage occurs in the peak period when the extracted water flow is diverted from the RWP. To a large extent, the degree of reliance on the TED is dependent on the control system (in particular the maximum level allowed in the TED before water is pumped to the WTP (from the RWP) irrespective of level in the downstream storages – See Section 3.3.1). This control level was set to ensure no overflow from the TED in the worst climate conditions recorded to date, including a reasonable safety margin. Currently, as indicated in Table 3-1, the control value is set at 70% of the TED capacity. If a greater degree of security against an overflow of the TED/RWP is required, this value can be lowered – at the expense of a greater release of treated water to the Avon River (i.e. from the DWP and the TN&SD).

Table 4-2: Impact of WTP pond sizes

Percentile (of flow directed to the environment)	Scenario 1 P50, Base Case			Scenario 2 P90, Base Case			Scenario 3 P90, Base + Large WTP Ponds			Scenario 4 P90, Base + Small WTP Ponds		
	Start Yr[1]	Discharge to Env		Start Yr	Discharge to Env		Start Yr	Discharge to Env		Start Yr	Discharge to Env	
	[#]	[m^3]	[%]	[#]	[m^3]	[%]	[#]	[m^3]	[%]	[#]	[m^3]	[%]
Minimum	1980	0	0.00	1980	0	0.00	2002	0	0.00	1980	0	0
25th Percentile	1931	0	0.00	1916	0	0.00	1936	0	0.00	1940	0	0
50th Percentile	1933	0	0.00	1963	0	0.00	1989	0	0.00	1925	0	0
75th Percentile	1921	0	0.00	1954	0	0.00	1960	0	0.00	1926	0	0
90th Percentile	1955	0	0.00	1972	0	0.00	1928	0	0.00	1928	0	0
95th Percentile	1890	0	0.00	1891	2,000	0.21	1987	0	0.00	1929	3,300	0.21
Maximum	1948	0	0.00	1948	10,000	1.05	1948	6,000	0.63	1948	14,000	1.47

1. The start year refers to the starting year of the climate data set used for the simulation

Scenarios 3 and 4 explore the impact of changing the RWP and DWP volumes for the P90 water extracted water profile. Scenario 3 shows the impact of increasing the RWP and DWP sizes to 14.4 and 23.5 ML (to the overflow level) respectively, however this has relatively small impact on the environmental release. Similarly, reducing the pond volumes by ~ 25% (to 9.5 ML each) has a relatively minor impact, increasing the magnitude but not the frequency, relative to the base case.

The reason for this appears to be the very sharp peak in 2019/2020. Any restriction to the transfer of water from Tiedeman's to irrigation, causes a backup in the DWP, which in turn restricts the flow through the WTP and causes an overflow of the RWP to TED. Consequently to avoid an overflow of the TED, treated water must be directed to the Avon River Release Pt from the TN&SD. The limiting feature appears to be the ability to move the water though the system rather than the size of the WTP storages *per se*. Clearly however, a larger storage provides more scope, but a relatively small increase does not fundamentally alter the outcome.

4.2 Irrigation parameters

Three scenarios were modelled, with the outcomes presented in Table 4-3, for a soil structure with a higher clay content and poorer total available moisture content than was used for the base case. This entailed changing the soil texture from a silty loam - silty clay loam texture to light clay. The soil's lower total available moisture content (falling from 12 to 6%) resulted in a small improvement to both the magnitude and frequency of the environmental release, as compared to the P90 Base Case. This somewhat unexpected result is attributed to the soil drying out faster, requiring more frequent, smaller water applications to the irrigation area. This has a minor impact on the pond/dam levels and consequently could impact the magnitude of an overflow in either direction (in this casing making it slightly smaller). Consequently, it is believed that the soil texture is unlikely to be a key system determinant. Graphical output data is given in Appendix 6 for the clay rich soil scenario (Scenario 5).

Table 4-3 : Impact of changing the irrigation parameters

Percentile (of flow directed to the environment)	Scenario 2 P90, Base Case			Scenario 5 P90, Base + Light Clay Soil			Scenario 6 P90, Base + 75 Ha Irrigation			Scenario 7 P90, Base + 45 Ha Irrigation		
	Start Yr	Discharge to Env		Start Yr	Discharge to Env		Start Yr	Discharge to Env		Start Yr	Discharge to Env	
	[#]	[m^3]	[%]	[#]	[m^3]	[%]	[#]	[m^3]	[%]	[#]	[m^3]	[%]
Minimum	1980	0	0.00	1980	0	0.00	1900	0	0.00	2002	0	0.00
25th Percentile	1916	0	0.00	1964	0	0.00	1937	0	0.00	1939	0	0.00
50th Percentile	1963	0	0.00	1935	0	0.00	1999	0	0.00	1922	0	0.00
75th Percentile	1954	0	0.00	1974	0	0.00	2011	0	0.00	2007	0	0.01
90th Percentile	1972	0	0.00	1929	0	0.00	1929	0	0.00	1889	4,600	0.42
95th Percentile	1891	2,000	0.21	1954	0	0.00	1892	0	0.00	1901	10,000	1.05
Maximum	1948	10,000	1.05	1948	4,000	0.42	1948	4,000	0.42	1948	26,000	2.73

Increasing the size of the irrigation area from 60 to 75 Ha had only a minor impact, suggesting that a large increase in area would be required to make a substantial difference. In contrast, reducing the irrigation area to 45 Ha, has a more significant impact, increasing both the magnitude and expected frequency of an environmental release (in this case increasing the risk of an environmental release to between 1:40 and 1:100). Under these conditions around 3% of the extracted water flow must be directed to an environmental release rather than irrigated. Selected graphical output for Scenarios 6 and 7 is given in Appendices 7 and 8.

In part, the results obtained reflect an overloaded irrigation condition during the peak production period (where the system relies on storage) and an under-loaded condition at all other times – i.e. there is insufficient water to effective irrigate the entire area. Consequently a small increase in irrigation area does little to relieve the peak period overloading, while a reduction in area increases the storage stress.

The average (i.e. the irrigation rate calculated over the entire 20 year simulation period) and the peak period (i.e. the period from 1st July 2018 to 1st December 2020, when the P90 extracted water flowrate is greater than 400 m^3/d) irrigation rates are given in Table 4-4. The long term average values are quite low – in the order of 77 – 120 mm/yr, however this is somewhat misleading as insufficient water is available to meet the irrigation demand for extended periods. The peak period irrigation rate (where water limitations are less prevalent) varies between ~300 and 500 mm/yr, with the base case giving a value of about 370 mm/yr (~ 1.0 mm/d). These values are similar to typical guidelines values of ~ 0.8 to 1.5 mm/d. Data extracted from the original FEED water balance suggests an irrigation rate of ~ 280 mm/yr, which is somewhat less than that found in this study, but in a similar order of magnitude.

Overall, this assessment suggests that the proposed 60 Ha irrigation area is probably about right and that there is little to be gained from increasing its size. A reduction in size however would not be recommended.

Table 4-4: Nominal irrigation rates

Parameter	Units	Scenario 2 P90 Base Case	Scenario 5 Light Clay Soil	Scenario 6 Large Irrig Area	Scenario 7 Small Irrig Area
Average irrigation rate	mm/yr	88	90	77	117
Peak period irrigation rate	mm/yr	370	367	299	496

4.3 WTP recovery and performance

Although the extracted water salinity is not part of this model, it is recognised that salinity changes, amongst other things such as equipment faults, maintenance work, water chemistry and temperature etc. will impact the WTP's performance. Two issues are of primary concern:

Plant performance: Salinity, water chemistry changes and membrane aging, amongst other reasons, may cause the WTP to operate at less than its design flowrate. The RO system's recovery is believed unlikely to change significantly in response to these changes – rather the throughput will be reduced to protect the brine concentrator system. Consequently Scenarios 8 and 9 consider throughput reductions of 5 and 10% to 1,140 and 1,080 m^3/d respectively.

Equipment availability: The WTP supply specification calls for a total plant with a capacity of 1.2 ML/d and a 95% availability. Given the likely complexity of the plant it is unlikely that this will be achievable in a single train. Consequently, for modelling purposes it was assumed that the plant would consist of two trains, connected in a lead-follow arrangement, each with an availability of 90%. To investigate the impact of a poorer than specified availability being achieved, Scenario 10 considers an overall availability of 90% (i.e. each train has an 80% availability).

Given that availability and plant performance are often related, Scenario 11 considers the impact of a 10% reduction in plant capacity (i.e. to 1,080 m^3/d) and a 90% overall plant availability. The data for these scenarios is summarised in Table 4-5 and Table 4-6. Graphical representation of selected output data is given in Appendix 9 for Scenario 11.

Reducing the WTP capacity by 5% has a small impact on the total volume directed to the environment, however incongruously, a 10% reduction in capacity results is a smaller environmental release. The reason for this result is that the limiting factors for the base case are the DWP, TN&SD and irrigation system, rather than the treatment plant itself, which means that not all the available volume in the RWP and TED is used. If the WTP capacity is restricted however, then some of this excess storage capacity is used up – effectively increasing the risk of an overflow of untreated water but reducing the environmental release of treated water.

Similar outcomes were obtained with the reduced WTP availability (Scenario 10) and combined reduced availability and capacity (Scenario 11). Overflows of the RWP or the TED were not predicted in either case. Nevertheless, graphical data presented in Appendices 3 and 9 for these scenarios show that even a relatively small reduction in capacity and/or availability results in appreciable storage in the TED – highlighting the need to carefully schedule planned maintenance to avoid shutting down the entire plant during critical times. Further, it emphasises that a rapid response will be required for unplanned shutdowns, and the need to ensure that critical spares are readily available. Adequate staff training will be essential to minimise the need for extended shut downs.

Table 4-5 : Impact of a reduction in the WTP's capacity

Percentile (of flow directed to the environment)	Scenario 2 P90, Base Case			Scenario 8 P90, Base + 5% Cap Reduct.			Scenario 9 P90, Base + 10% Cap Reduct.		
	Start Yr	Discharge to Env		Start Yr	Discharge to Env		Start Yr	Discharge to Env	
	[#]	[m^3]	[%]	[#]	[m^3]	[%]	[#]	[m^3]	[%]
Minimum	1980	0	0.00	2002	0	0.00	2002	0	0.00
25th Percentile	1916	0	0.00	1916	0	0.00	1916	0	0.00
50th Percentile	1963	0	0.00	1982	0	0.00	1970	0	0.00
75th Percentile	1954	0	0.00	1953	0	0.00	2011	0	0.00
90th Percentile	1972	0	0.00	1902	0	0.00	2013	0	0.00
95th Percentile	1891	2,000	0.21	1901	2,000	0.21	1929	1,300	0.14
Maximum	1948	10,000	1.05	1948	12,000	1.26	1948	8,000	0.84

Table 4-6: Impact of a reduction in the WTP's availability

Percentile (of flow directed to the environment)	Scenario 2 P90, Base Case			Scenario 10 P90, Base + 90% Availability			Scenario 11 P90, Base + 90% Avail & Cap		
	Start Yr	Discharge to Env		Start Yr	Discharge to Env		Start Yr	Discharge to Env	
	[#]	[m^3]	[%]	[#]	[m^3]	[%]	[#]	[m^3]	[%]
Minimum	1980	0	0.00	1980	0	0.00	2002	0	0.00
25th Percentile	1916	0	0.00	1981	0	0.00	1909	0	0.00
50th Percentile	1963	0	0.00	1925	0	0.00	1982	0	0.00
75th Percentile	1954	0	0.00	1923	0	0.00	1893	0	0.00
90th Percentile	1972	0	0.00	1961	0	0.00	1996	0	0.00
95th Percentile	1891	2,000	0.21	2015	2,000	0.21	1987	2,000	0.21
Maximum	1948	10,000	1.05	1948	8,000	0.84	1948	8,000	0.84

4.4 Frost impacts

As discussed in Section 3.6, frost has the potential to negatively impact the irrigation area. To simulate the impact, the model uses an adjustable factor to reduce the evapotranspiration rate for an adjustable period after the frost event. For simplicity, frost events were assumed to occur following a sub-zero minimum temperature. Two scenarios were considered, with the impact on the evapotranspiration rate detailed in Table 4-7, with selected graphical output given in Appendices 10 and 11. The results of these scenarios are summarized in Table 4-8. Scenario 12 suggests that a light frost is unlikely to significantly impact the systems performance, although the environmental release is expected to increase slightly. In contrast a heavy frost is likely to be more significant, - in the modelled case increasing the environmental discharge under the worst case climatic conditions to about 3% of the total extracted water flowrate.

Although the values presented under these scenarios are illustrative only, they do emphasise the importance of selecting an appropriate frost tolerate crop.

Table 4-7: Frost impact on evapotranspiration rate

Scenario 12 - Light Frost		Scenario 13 - Heavy Frost	
Reduction Period [d]	ET_0 Multiplier [#]	Reduction Period [d]	ET_0 Multiplier [#]
10	0.6	15	0.2
10	0.7	15	0.4
10	0.8	15	0.6
10	0.9	15	0.8

1. ET_0 - Evapotranspiration rate under ideal conditions

Table 4-8: Impact of frost

Percentile (of flow directed to the environment)	Scenario 2 P90 Base Case			Scenario 12 P90, Base +Light Frost			Scenario 13 P90, Base + Heavy Frost		
	Start Yr	Discharge to Env		Start Yr	Discharge to Env		Start Yr	Discharge to Env	
	[#]	[m^3]	[%]	[#]	[m^3]	[%]	[#]	[m^3]	[%]
Minimum	1980	0	0.00	2002	0	0.00	2002	0	0.00
25th Percentile	1916	0	0.00	1940	0	0.00	1977	0	0.00
50th Percentile	1963	0	0.00	1942	0	0.00	1975	0	0.00
75th Percentile	1954	0	0.00	1920	0	0.00	1906	0	0.00
90th Percentile	1972	0	0.00	1988	600	0.06	1891	2,000	0.21
95th Percentile	1891	2,000	0.21	1891	2,000	0.21	1941	4,000	0.42
Maximum	1948	10,000	1.05	1948	10,000	1.05	1898	26,000	2.74

4.5 Working water availability and initial storage requirements

The P10 extracted water Base Case (Scenario 14) is given in Table 4-9, along with P10 and P50 simulations with lower initial storage volumes in the DWP and TN&SD (Scenarios 15 and 16). Graphical output is given in Appendix 12 for the P10 Base Case.

Inspection of Figure 1-1, indicates that the working water requirement exceeds the P10 extracted water flow rate at the start of the production period (in the year 2018) and briefly in late 2020. Storage will be required to meet the working water requirements at these times. In principal it is possible to determine the storage requirements by determining the area enclosed between the working water demand and the P10 extracted water profile, which suggests a net volume of about 8,500 m^3. This is the minimum volume required, and does not consider changes in the pond levels or climate influences. Consequently, the model was run with different initial storage values until no working water deficits were recorded.

Scenario 14 shows the P10 Base Case, which indicates that no environmental discharge occurs (as would be expected) and that the initial storage requirements are adequate to meet the working water demands. Initially some problems were experienced later in the production schedule, with working water deficits occurring in late 2020, however this was easily remedied by increasing the minimum storage volumes in either the DWP (to ~ 30%) or TN&SD (to about 15%). Although this requires 'foresight', it is unlikely to be problematic in practice, since by this stage the extracted water production profile should be better understood, allowing the system management strategy to be amended appropriately.

Table 4-9: Working water requirements

Percentile (of flow directed to the environment)	Scenario 14 P10, Base Case			Scenario 15 P10, Base + WW Storage			Scenario 16 P50, Base + WW Storage		
	Start Yr	Discharge to Env		Start Yr	Discharge to Env		Start Yr	Discharge to Env	
	[#]	[m^3]	[%]	[#]	[m^3]	[%]	[#]	[m^3]	[%]
Minimum	1901	0	0.00	1901	0	0.00	1980	0	0.00
25th Percentile	1897	0	0.00	2012	0	0.00	1986	0	0.00
50th Percentile	1951	0	0.00	1975	0	0.00	2008	0	0.00
75th Percentile	1947	0	0.00	1910	0	0.00	1917	0	0.00
90th Percentile	1963	0	0.00	1925	0	0.00	1889	0	0.00
95th Percentile	1948	0	0.00	1948	0	0.00	1893	0	0.00
Maximum	1892	0	0.00	1950	0	0.00	1948	0	0.00
Min TiedN&S storage[1]		4,500			2,500			2,500	
Min TiedE storage[1]		13,000			11,000			8,400	

1. Minimum initial storage volumes to ensure all working water requirements are met

Several adjustments were made to Scenario 14 to estimate the initial storage requirements. These included:

- Changing the pond commissioning date to 30th April 2018 – i.e. just prior to the commencement of the working water demand, to reduce the impact of rainfall and evaporation;
- Setting the initial stored water volumes in the RWP and DWP to the minimum values that did not completely empty the ponds owing to evaporation losses. This entailed reducing the initial storage volumes in these ponds to about 300 m^3 (in each pond).

Since the treatment of water likely to be held in the TED provides the bulk of the initial working water demand, attention was focused on determining the minimum pre-start storage requirements in this dam. The model output, given in Table 4-9, suggests that for the P10 extracted water profile, about 11 ML of water should be available. Slightly less initial storage water will be required for the P50 and P90 extracted water profiles. This value is somewhat greater than the 8,500 m^3 estimated above with the difference attributed to the minimum storage volume requirements in the various ponds.

Consequently, a minimum volume of at least 11,000 m^3 should be available at the start of the project to ensure the working water requirements can always be met. In practice this water may be located in any one (or more) of the DWP, TN&SD, TED and/or the Pontiland's Dam.

4.6 Water releases to the Avon river

For the 'Base Case' scenarios (i.e. the scenarios depicting the system as designed), flow to the environment (i.e. generated either from a pond/dam overflowing or from water being pumped to the

Avon River Release Pt.) only occurs for the 90th percentile extracted water flows and for wet years in excess of the 90th percentile. Even for these 'extreme' conditions, with estimated likelihood of less than 1 in 100, the quantity of water released to the environment is small – in the order of 1% of the total extracted water flowrate. This is shown in Figure 4-1, which shows the cumulative environmental flows for the 90th percentile extracted water profile (P90) over the 20 year modelling period. Three separate curves are shown – i.e. the maximum, 95th and 90th percentile environmental flows. For the worst case climate conditions (i.e. the climate conditions generating the maximum environmental discharge), pumping to the Avon River occurs on 5 occasions, all near to the peak of the extracted water production period. For the 95th percentile climate case, a single discharge is expected, as before near the peak production period. No overflow is expected for the 90th percentile climate case.

Note that the (for example) 90th percentile climate data does not necessarily refer to the 90th percentile rainfall year, but rather the climate year causing the 90th percentile environmental release. While it is likely that this will be a wetter than average year, serval other factors also influence the outcome, including the timing of major rainfall events, pan evaporation rates, the rainfall quantity and frequency as well as the historical climate data.

The curves given in Figure 4-1 all refer to the base case – i.e. allowing the TED to fill to 70% before the overriding the restrictions on pumping to the WTP when the DWP is full (See Section 3.3.1). If the WTP feed restrictions are lifted at a lower level in the TED, say at 40%, (which provides a safer outcome, since the risk of an overflow of untreated water is reduced) then a greater fraction of treated water must be pumped to the Avon River to maintain the balance. This is shown in Figure 4-2, and indicates that the environmental discharge is increased to about 18,000 m^3 over the production period for the worst case climate conditions. No changes are expected for the 95th and 90th percentile climate conditions. Although the environmental discharge increases under these conditions, it remains less than 2% of the total extracted water flowrate.

Figure 4-1: Cumulative environmental flows (70% accumulation in the TED)

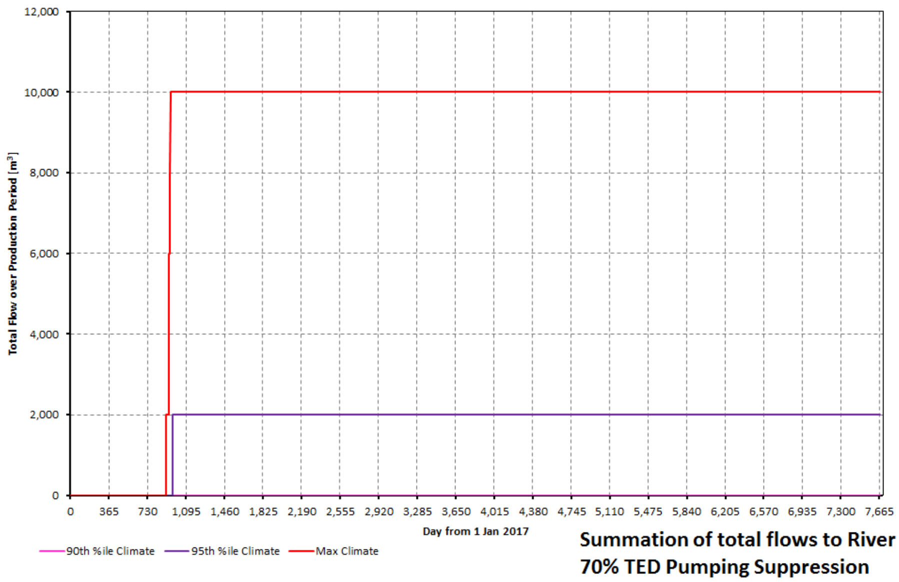
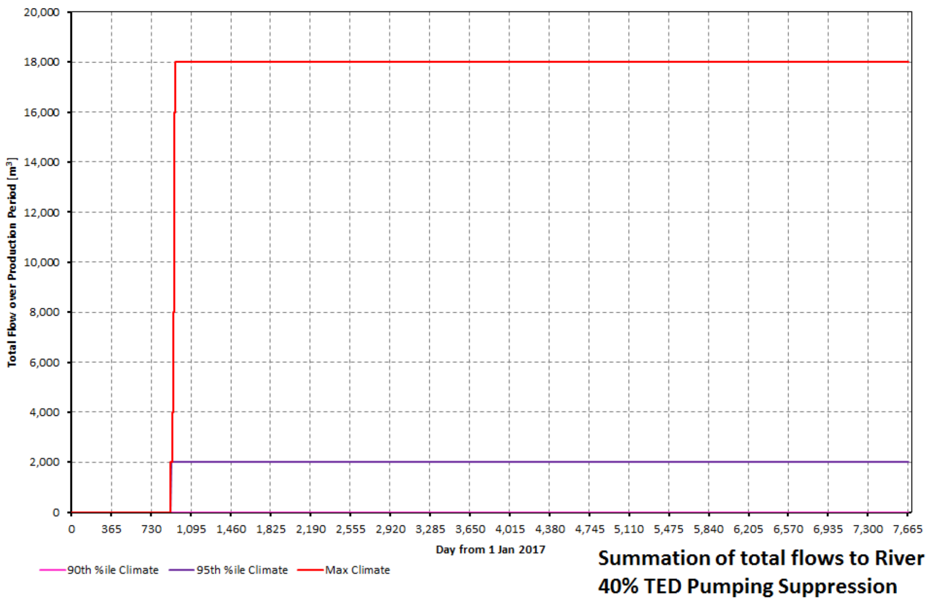


Figure 4-2: Cumulative environmental flows (45% accumulation in the TED)



5 CONCLUSIONS

A daily water balance model has been developed to simulate the transfer, storage and management of water extracted from CSG wells in AGL's GGP. The model was used to help develop the Extracted Water Management Strategy and to provide data for the sizing of the associated water handling and treatment infrastructure. In particular, the model may be used to:

- Estimate flows through key streams in the water handling and treatment process;
- Estimate the supply of treated water for beneficial reuse via irrigation; and
- Investigate potential risks, such as the accumulation of water and potential for uncontrolled discharges.

Key model parameters may be varied to simulate a variety of scenarios and generate the associated outputs. For modelling purposes, the WTP was assumed to consist of 2 trains in a lead-follow configuration, each with a capacity of 600 m^3/d and an availability of 90% to meet the WTP's design specification of 1,200 m^3/d at an availability of 95%.

In general, the results of the water balance modelling show that large rates of CSG water are produced during the early years of production and that these rates decline rapidly after about 3 to 4 years. Treated water can mostly be managed via irrigation and stock watering, with relatively small amounts (~ 1% of the extracted water flow for the 90th percentile extracted water production case) needing to be directed to the Avon River during the peak of the production period. The model indicates the water production is too high in the peak period to be completely irrigated and that the irrigation area is too large in the tailing period to be effectively irrigated. Surface water discharge is not expected to be required after the 4th year of production.

More specifically, the simulation cases undertaken found that for the expected extracted water production profiles:

- The proposed RWP and DWP capacities (i.e. with overflow volumes in the order of 13 ML each) are adequate for most scenarios. It is noted that operation between the design TWL and overflow levels may be expected, in particular during the peak extracted water production periods. Reducing the sizes of these ponds is not recommended
- For the base case or 'as designed' conditions, environmental releases only expected for the 90th percentile extracted water profile (P90) and for climate conditions exceeding the 90th percentile. The risk of a release of treated water to the environment (i.e. to the Avon River) is estimated to be less than 1:100;
- For the 90th percentile extracted water production profile (P90), the environmental release of treated water to the Avon River is expected to be less than 1% of the total extracted water flow;
- The soil type in the irrigation area is believed unlikely to significantly impact the environmental release risk;
- Frost may be expected once in every 4 years on average. Frost is not expected to have a significant impact on the system's performance, provided appropriate frost tolerant plant species are used – at least until the peak production period has passed;

- Several scenarios considered the impact of treatment plant capacity and availability. Although no scenarios modelled resulted in an overflow of the RWP or the TED, reduced WTP availability or capacity significantly increased the reliance on the TED (owing to limitations in the rate at which water can be passed through the treatment plant). This will has some implications regarding built in system redundancies, availability of spares, maintenance planning and staff training etc.;
- A minimum initial water storage requirement of about 11 ML is required at the start of the working water demand period to avoid working water deficits. This water can be distributed between the DWP, TN&SD, TED and the Pontiland's Dam. Deficits later in the production schedule can be managed through judicious operation of the ponds and dams.

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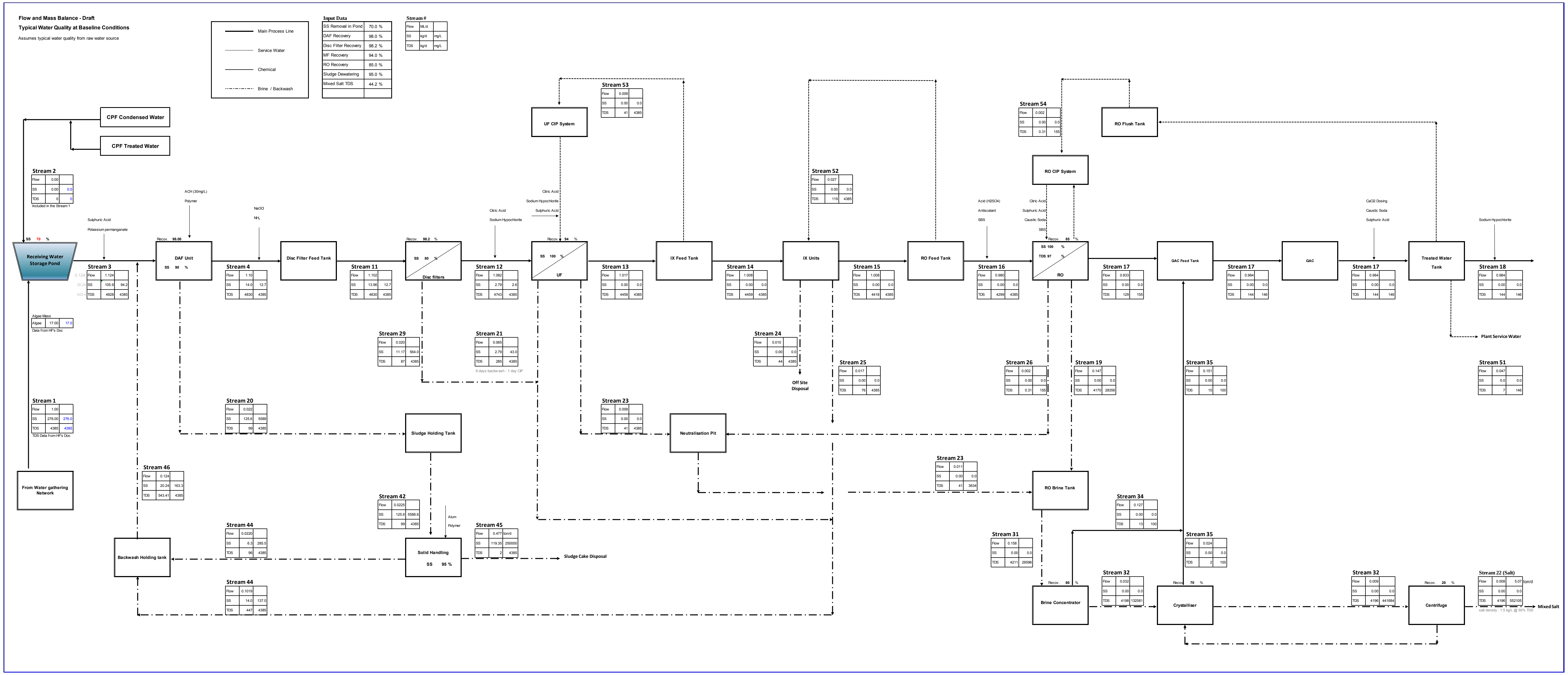
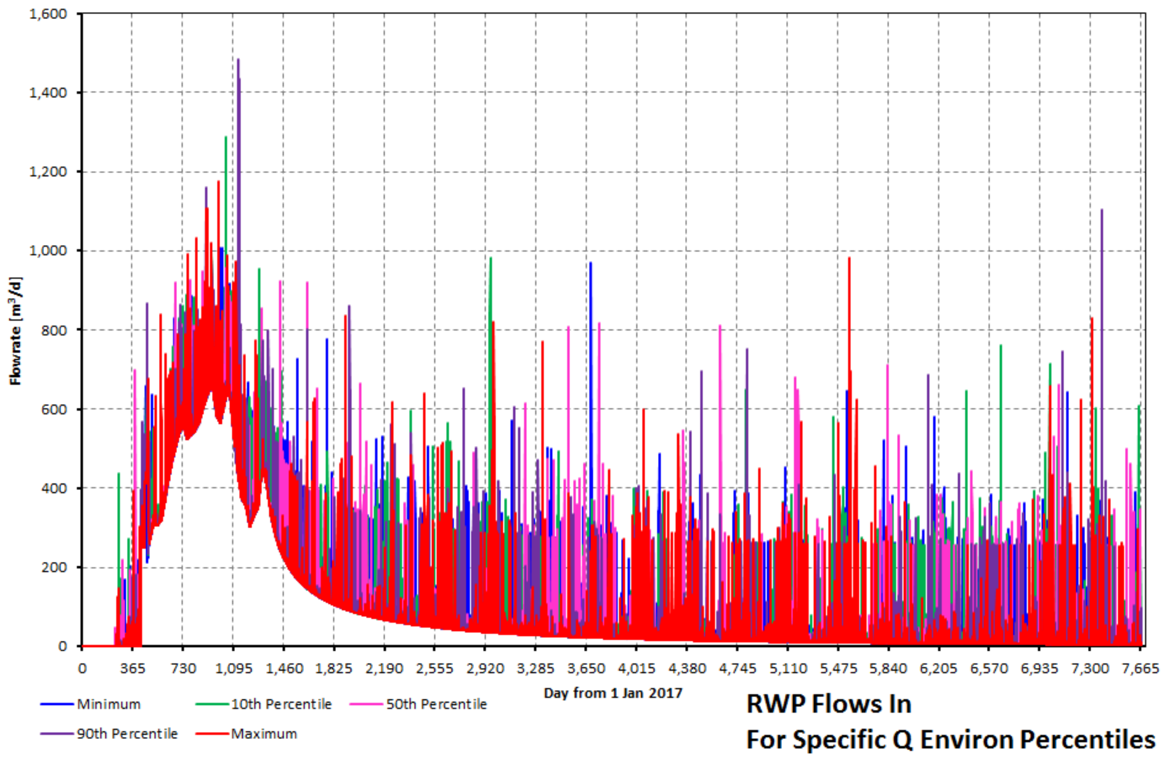
Snyder, RL., de Melo-Abreu, JP. and Matulich, S., 2005, *Frost Protection: Fundamentals, Practice and Economics Vol 2*, FAO Environmental and Natural Resources Series, Food and Agriculture Organization of the United Nations, Rome, 2005.

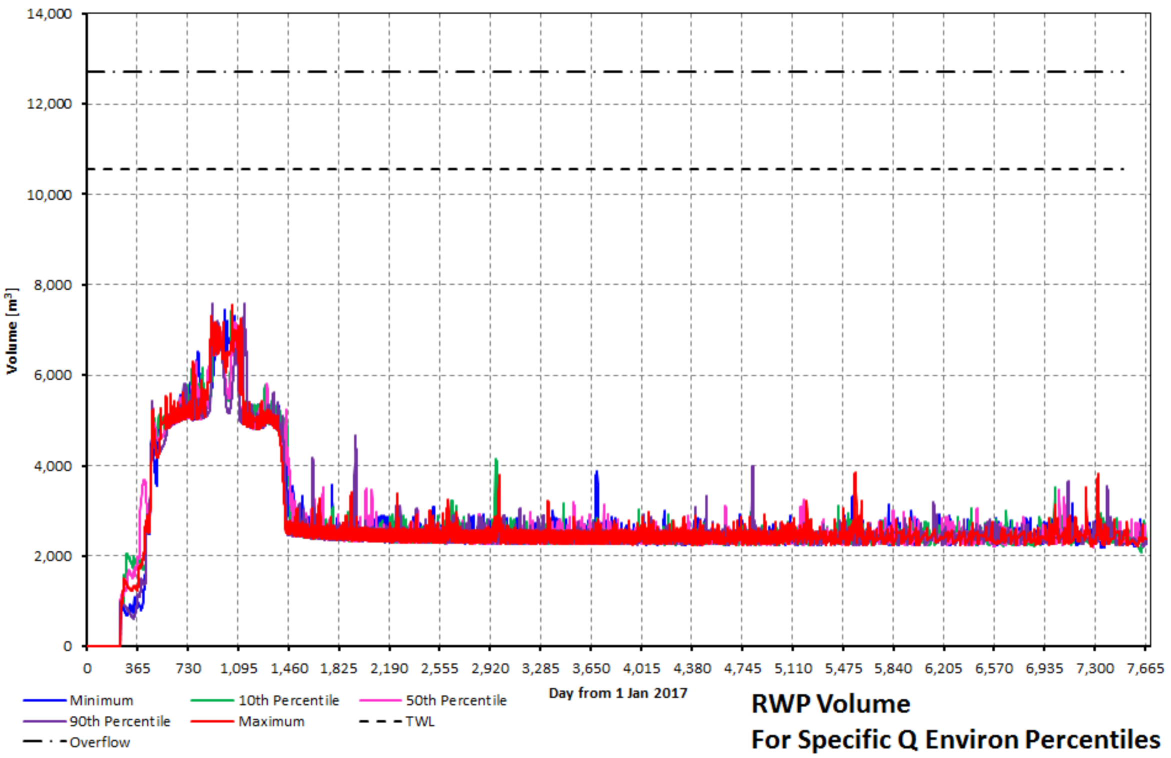
UNSW, TerraGIS website: www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_water-soil_moisture_classification.html

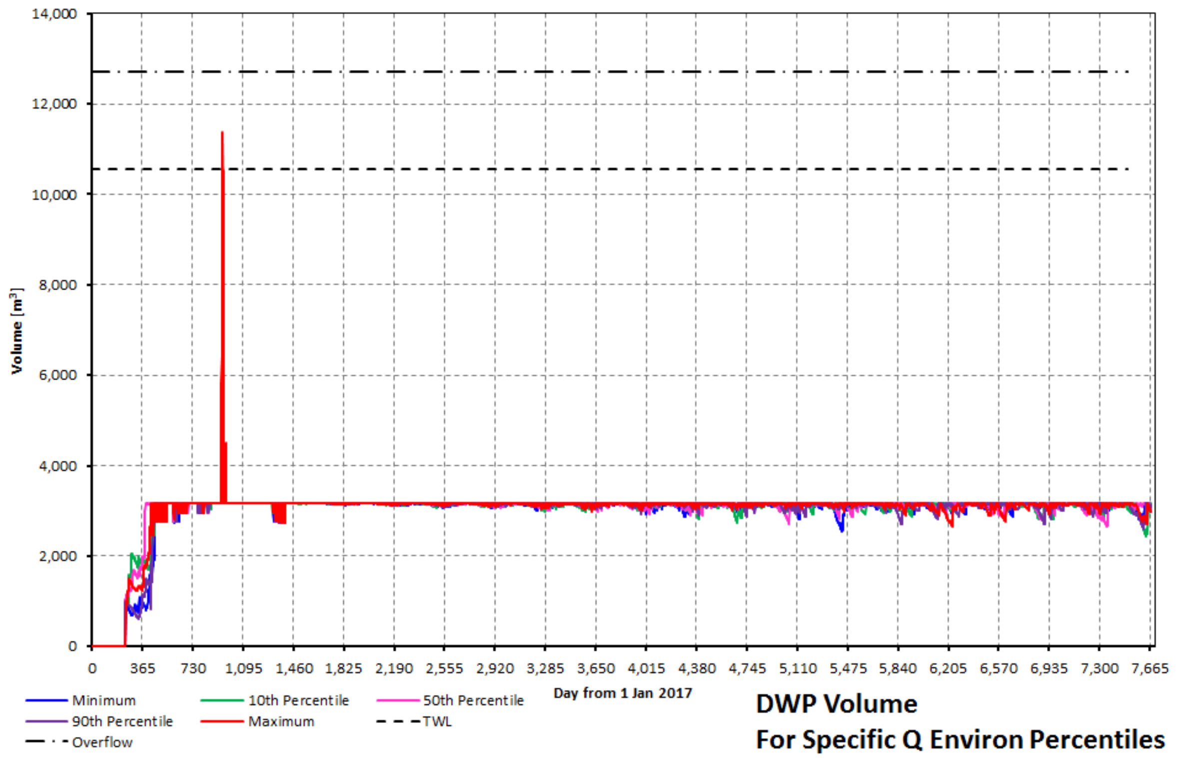
Appendix 1 WTP Water Balance

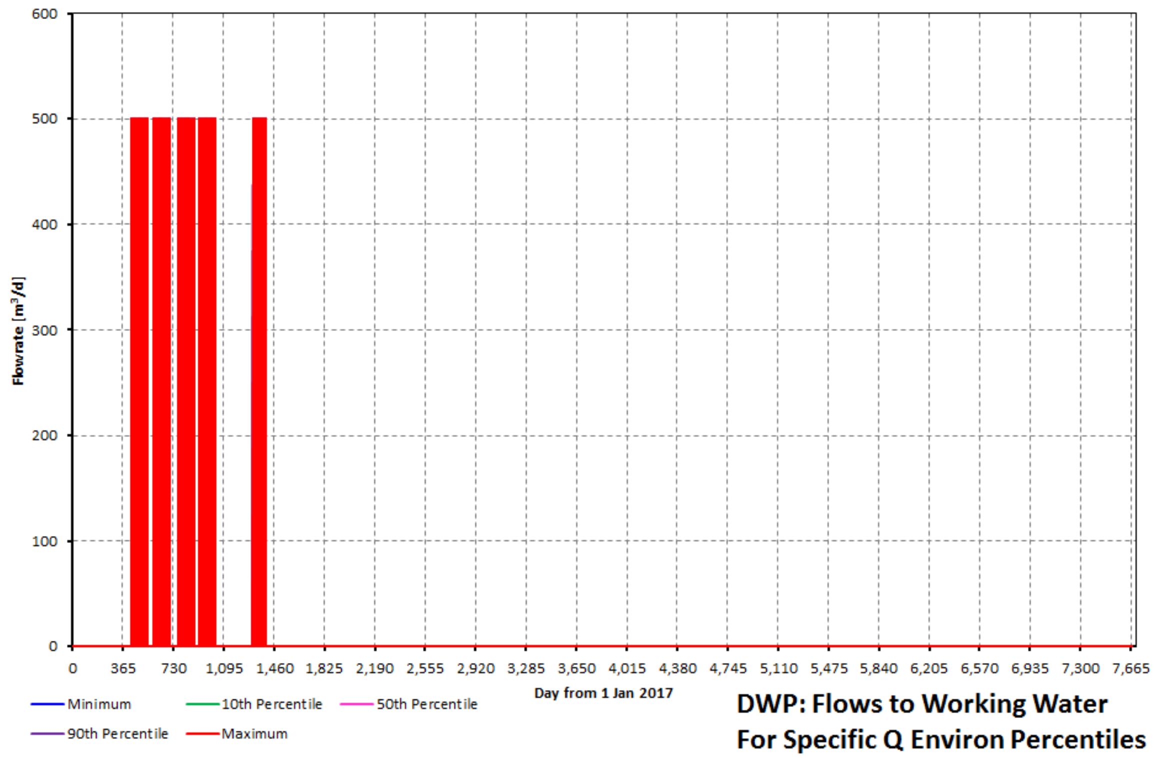

Flow and Mass Balance - Draft
Typical Water Quality at Baseline Conditions
Assumes typical water quality from raw water source
Main Process Line
Service Water
Chemical
Brine / Backwash
Input Data
CPF Condensed Water
CPF Treated Water
Receiving Water Storage Pond
DAF Unit
Disc Filter Feed Tank
Disc filters
UF
UF CIP System
IX Feed Tank
IX Units
RO Feed Tank
RO
RO CIP System
RO Flush Tank
GAC Feed Tank
GAC
Treated Water Tank
Plant Service Water
Sludge Holding Tank
Neutralisation Pit
RO Brine Tank
Solid Handling
Sludge Cake Disposal
Backwash Holding tank
From Water gathering Network
Brine Concentrator
Crystalliser
Centrifuge
Mixed Salt
Off Site Disposal

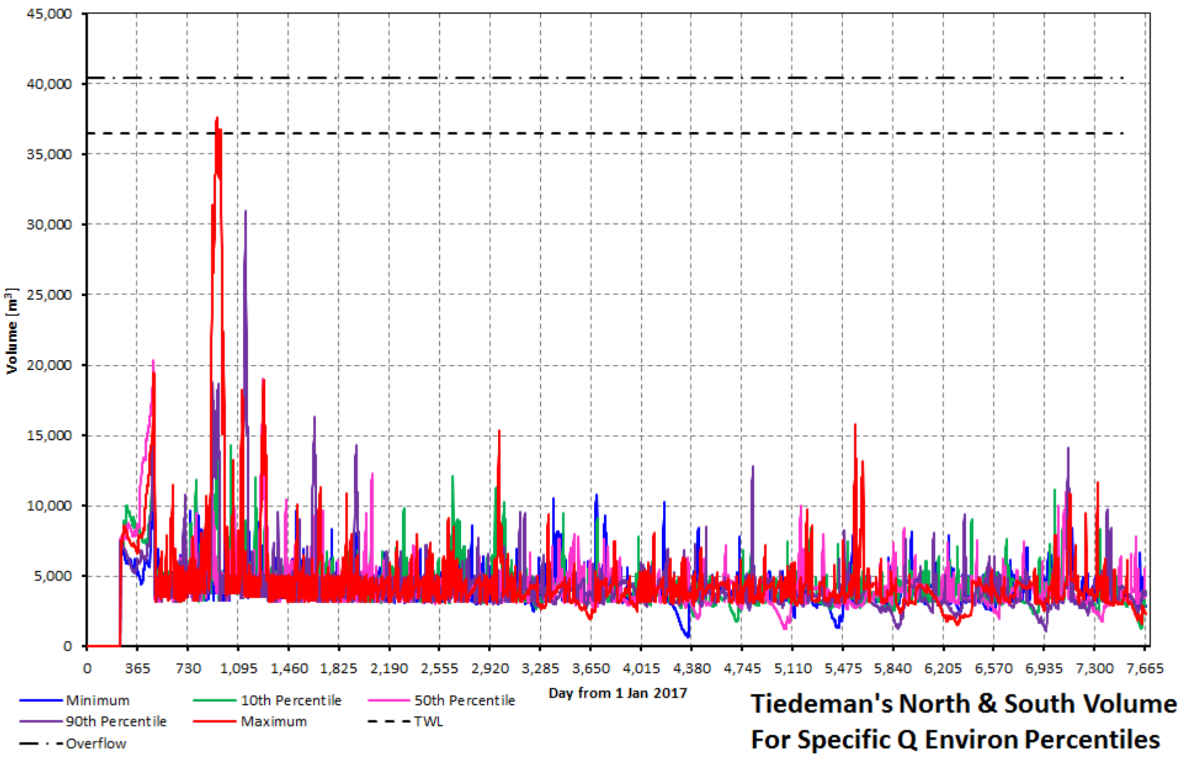
Appendix 2 Simulation Scenario 01: P50 Extracted Water Production: Base Case

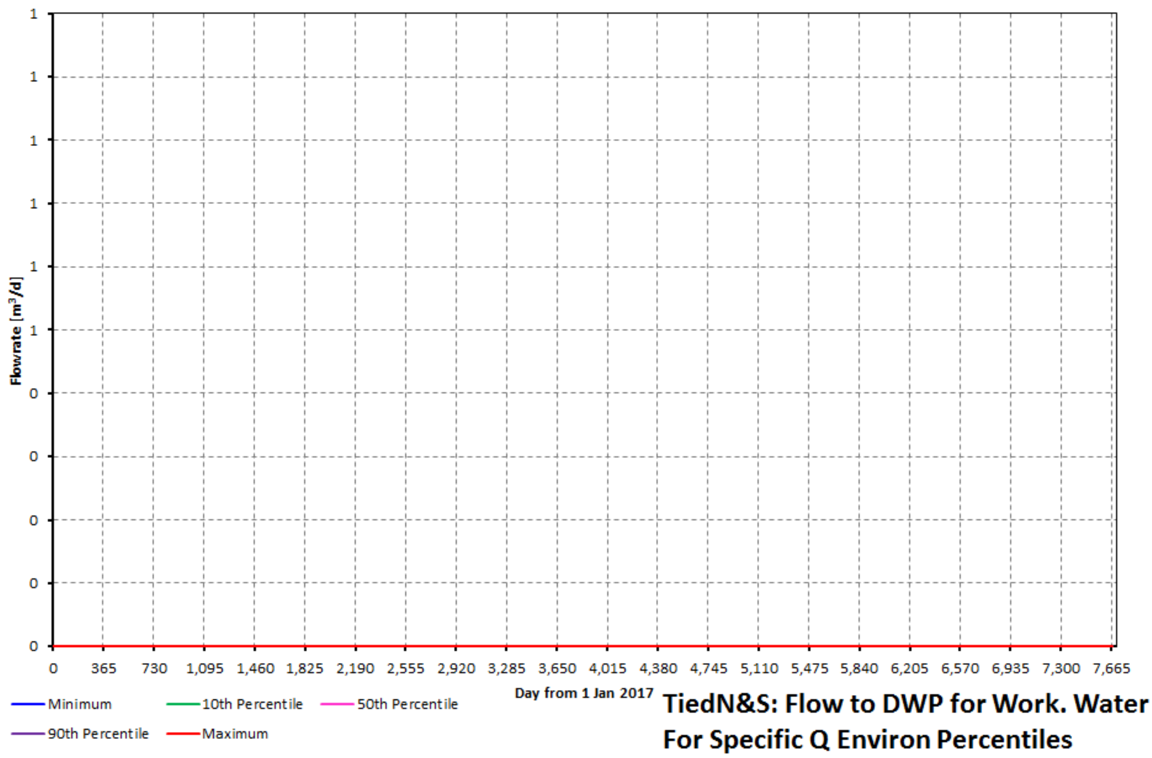

Flowrate [m³/d]
1,600
1,400
1,200
1,000
800
600
400
200
0
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
RWP Flows In
For Specific Q Environ Percentiles

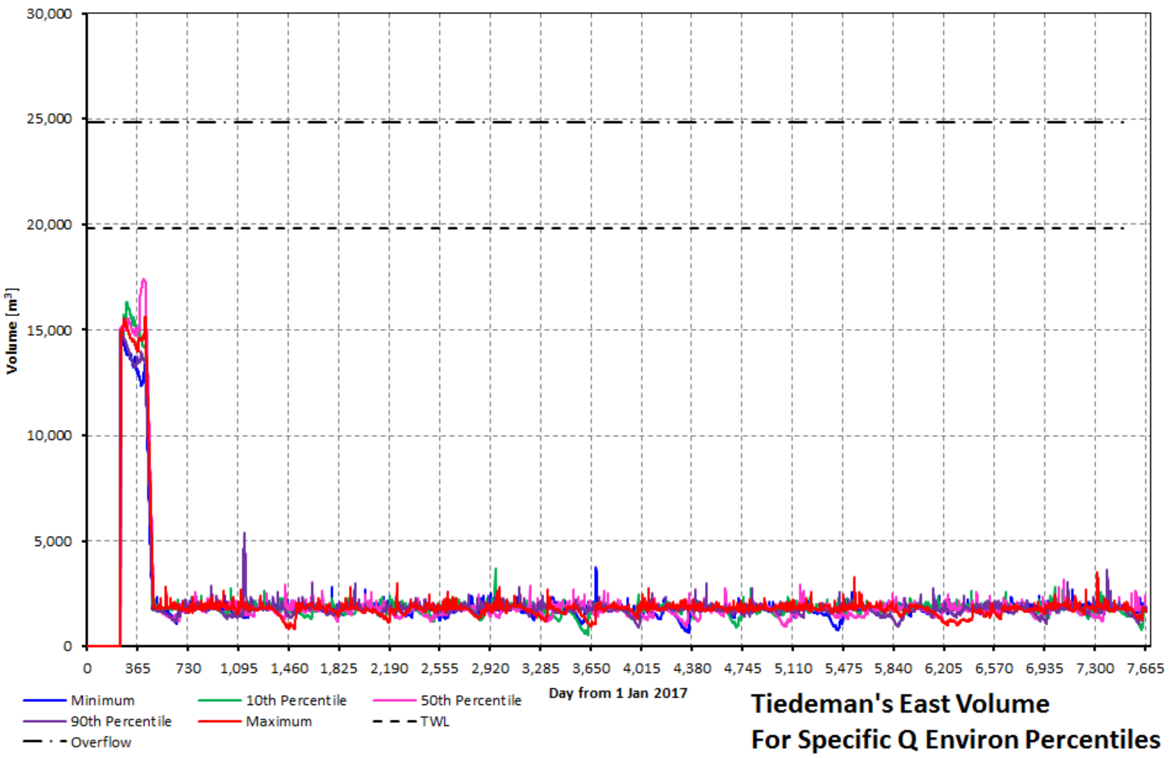

Volume [m³]
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
RWP Volume
For Specific Q Environ Percentiles

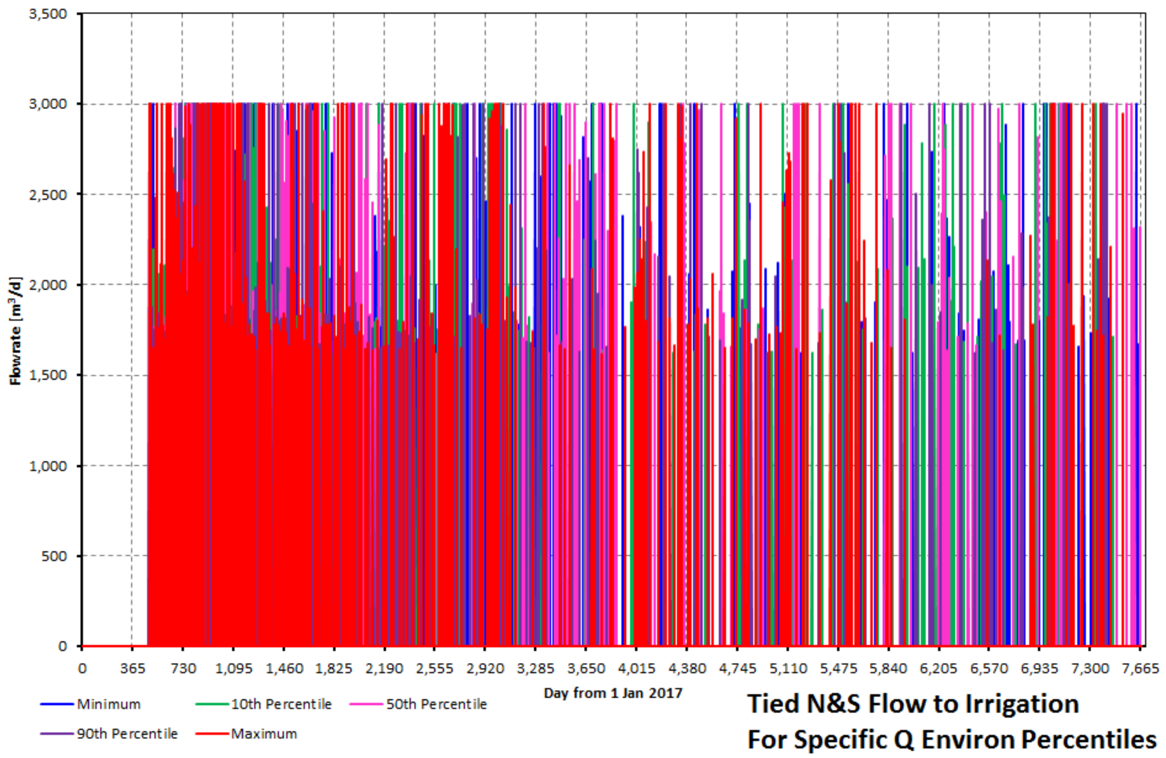

14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Volume [m³]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
DWP Volume
For Specific Q Environ Percentiles

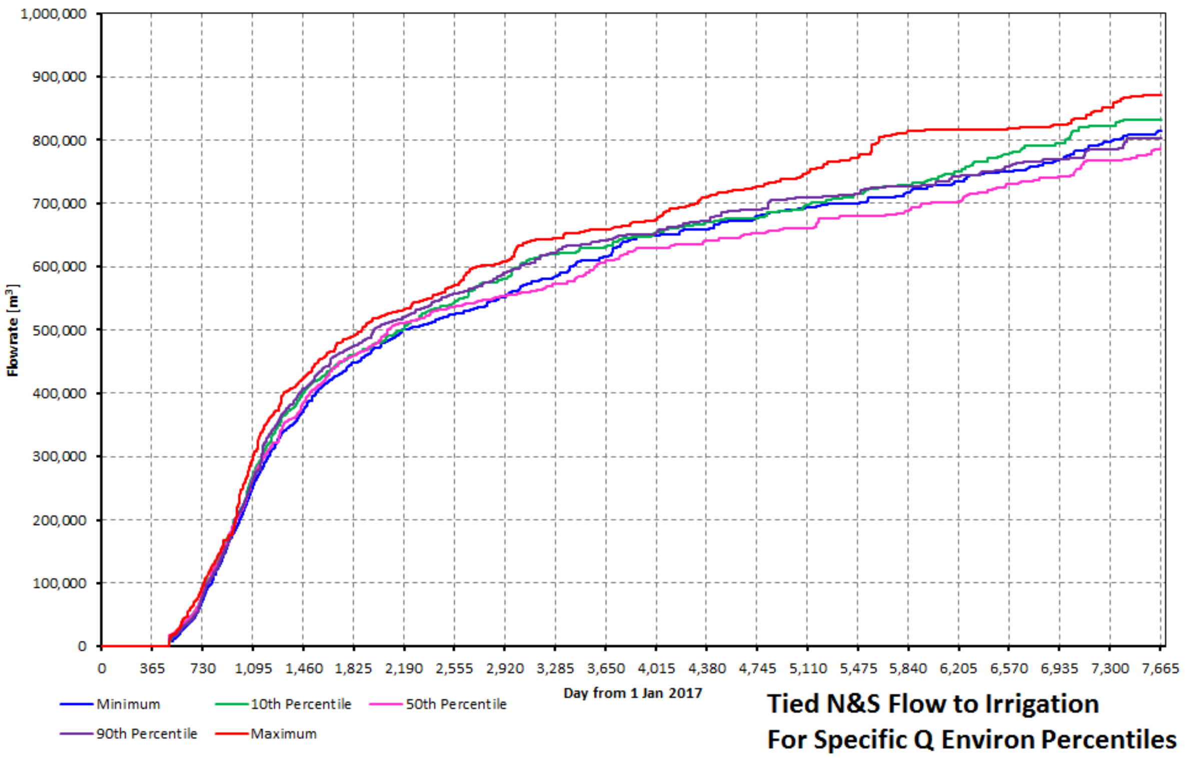

600
500
400
300
200
100
0
Flowrate [m³/d]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
DWP: Flows to Working Water
For Specific Q Environ Percentiles

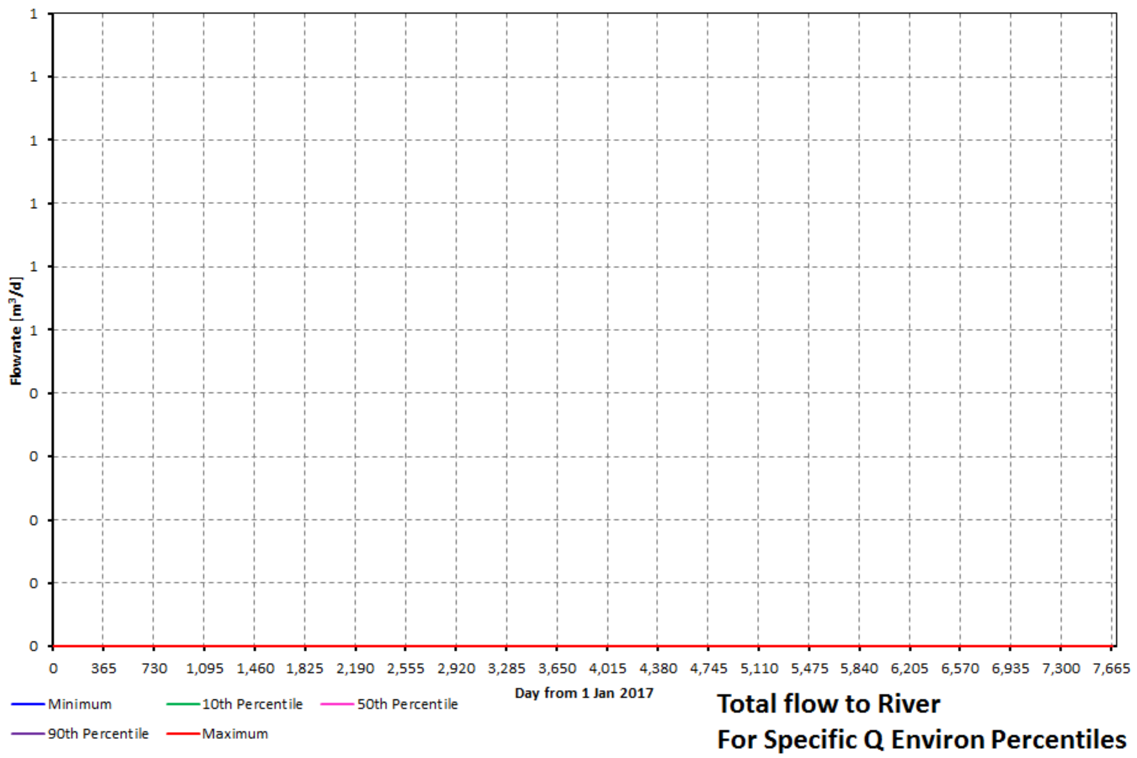

45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's North & South Volume
For Specific Q Environ Percentiles

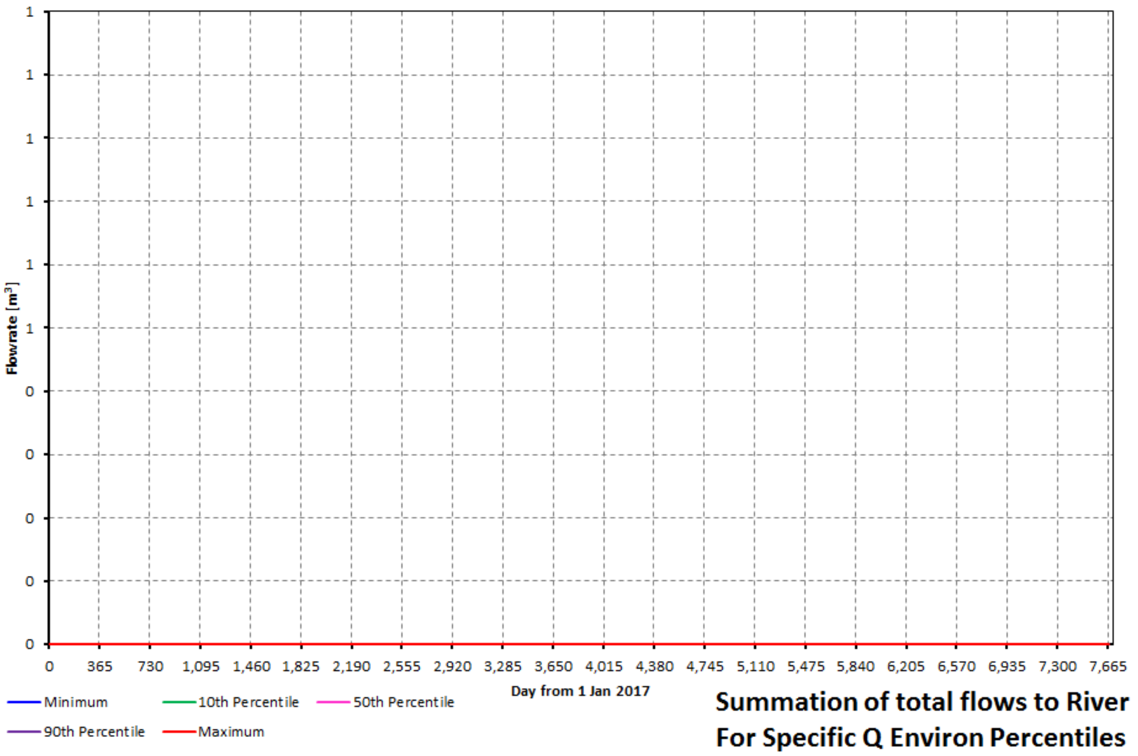

Flowrate [m³/d]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TiedN&S: Flow to DWP for Work. Water
For Specific Q Environ Percentiles


Tiedeman's East Volume
For Specific Q Environ Percentiles
Volume [m³]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow

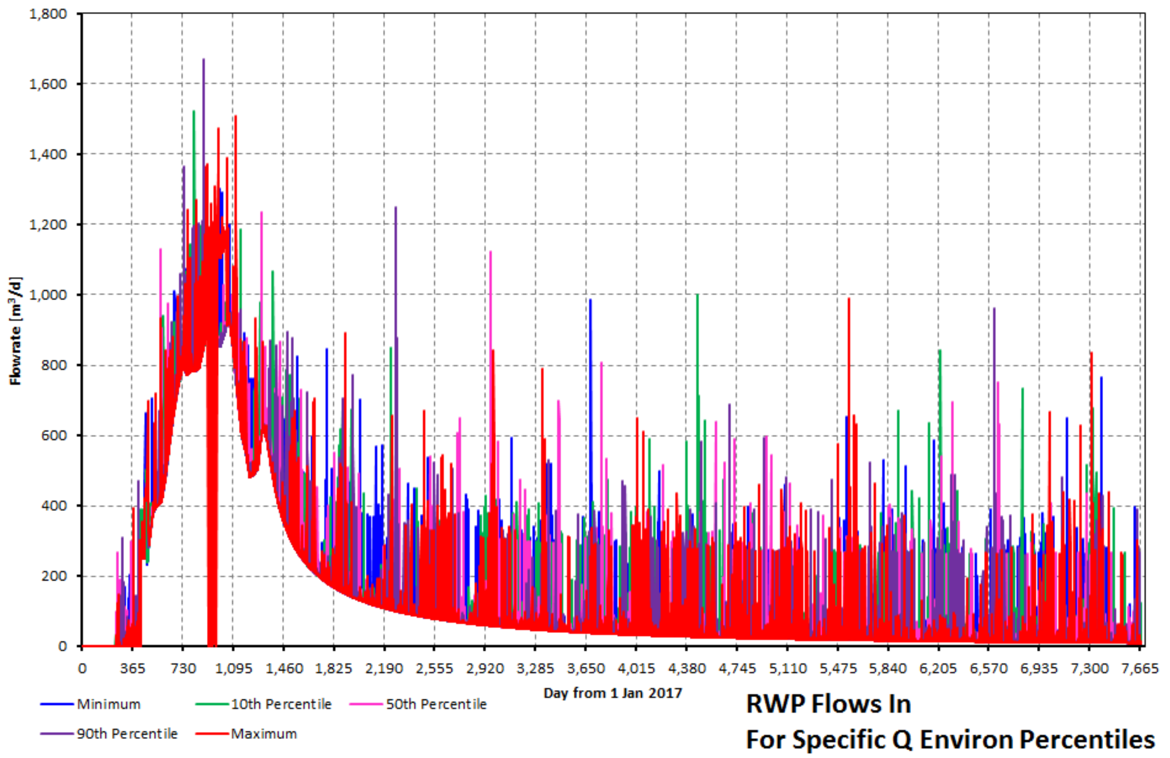

Tied N&S Flow to Irrigation
For Specific Q Environ Percentiles
Flowrate [m³/d]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum

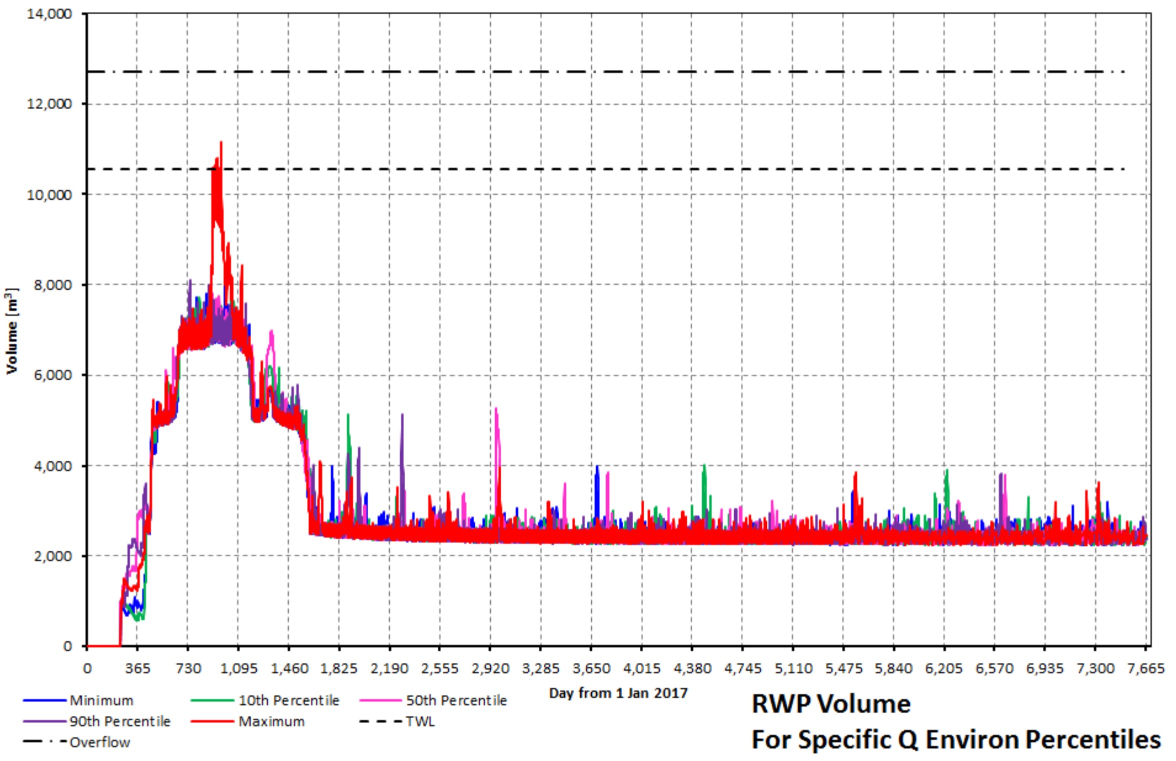

1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Flowrate [m³]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Tied N&S Flow to Irrigation
For Specific Q Environ Percentiles

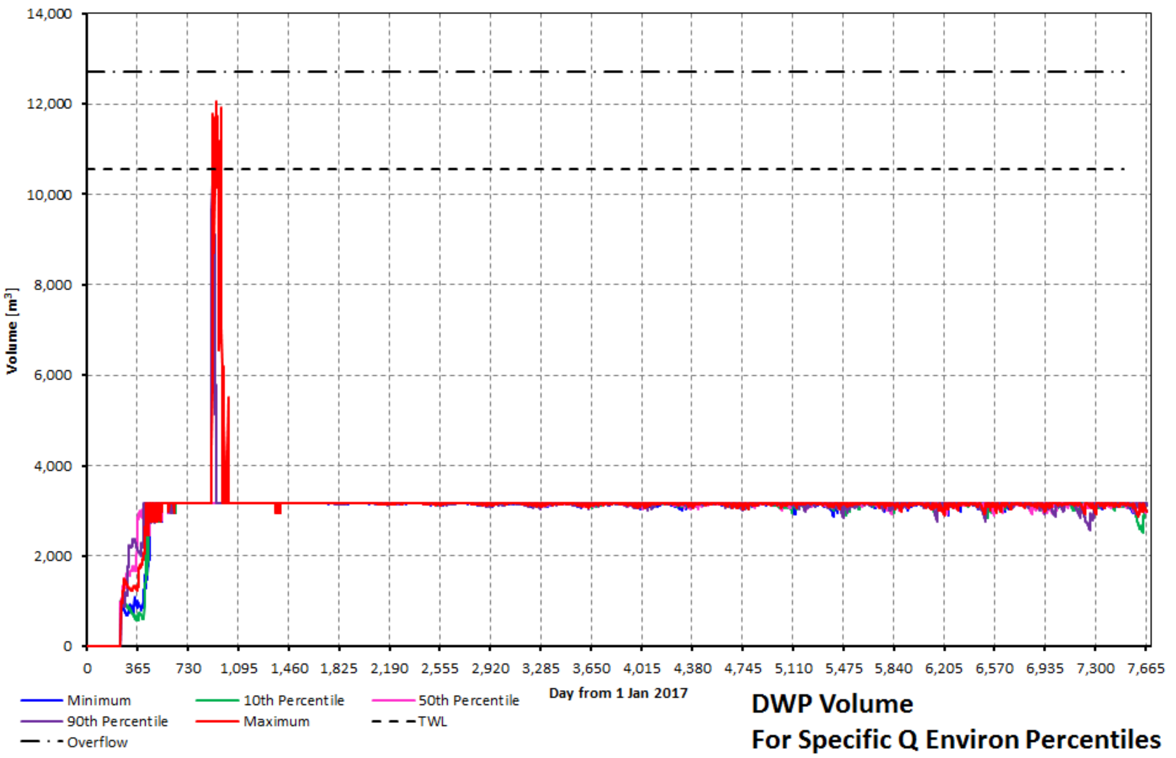

1
1
1
1
1
1
0
0
0
0
0
Flowrate [m³/d]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Total flow to River
For Specific Q Environ Percentiles

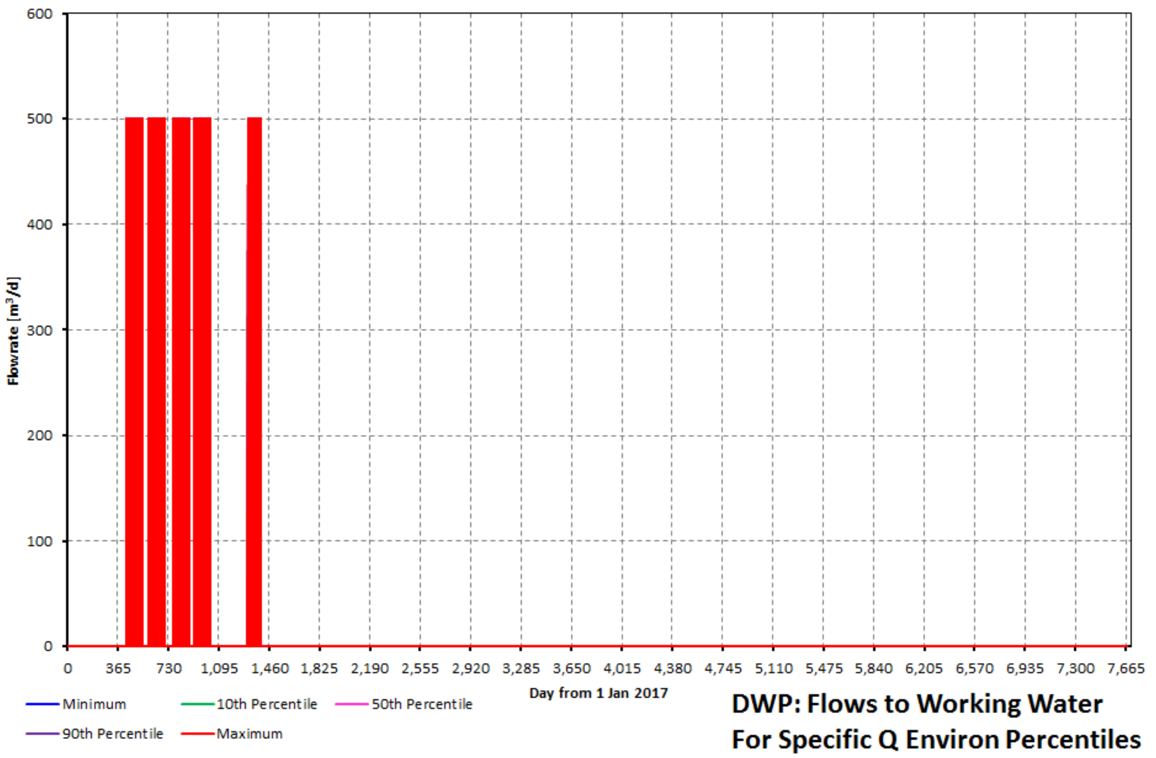

1
1
1
1
1
1
0
0
0
0
0
Flowrate [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Summation of total flows to River
For Specific Q Environ Percentiles

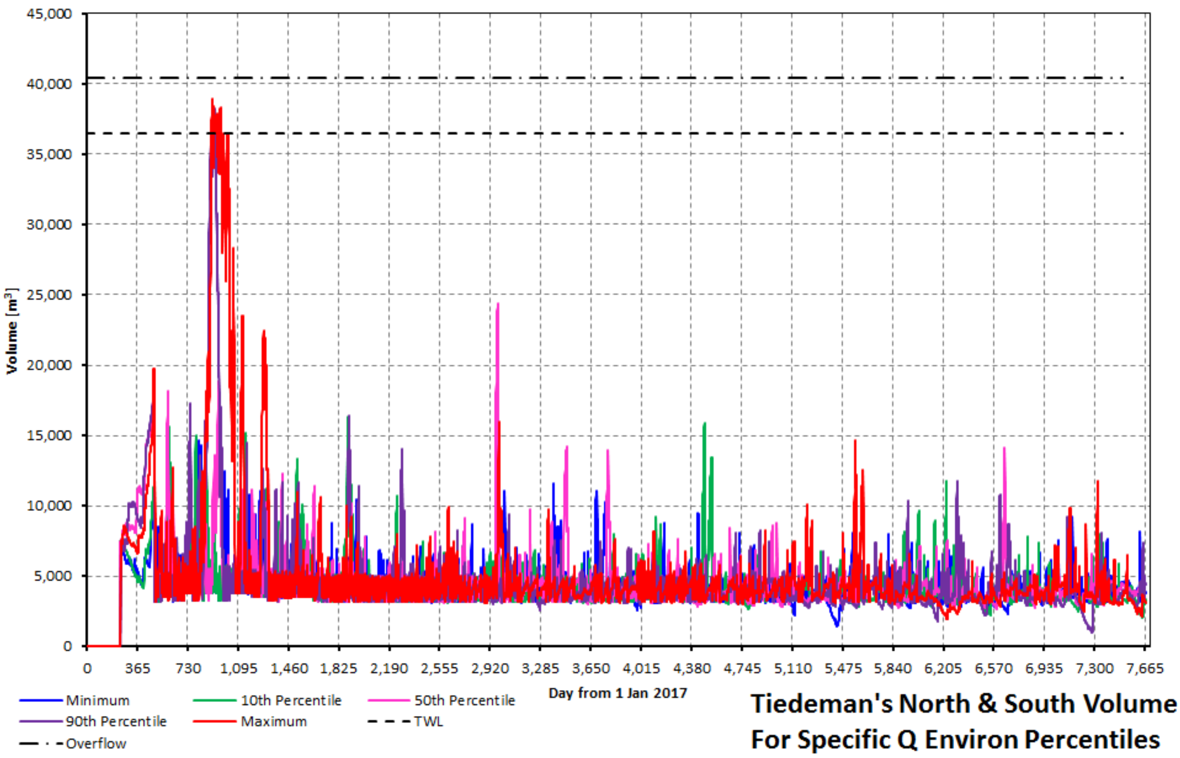
Appendix 3 Simulation Scenario 02: P90 Extracted Water Production, Base Case

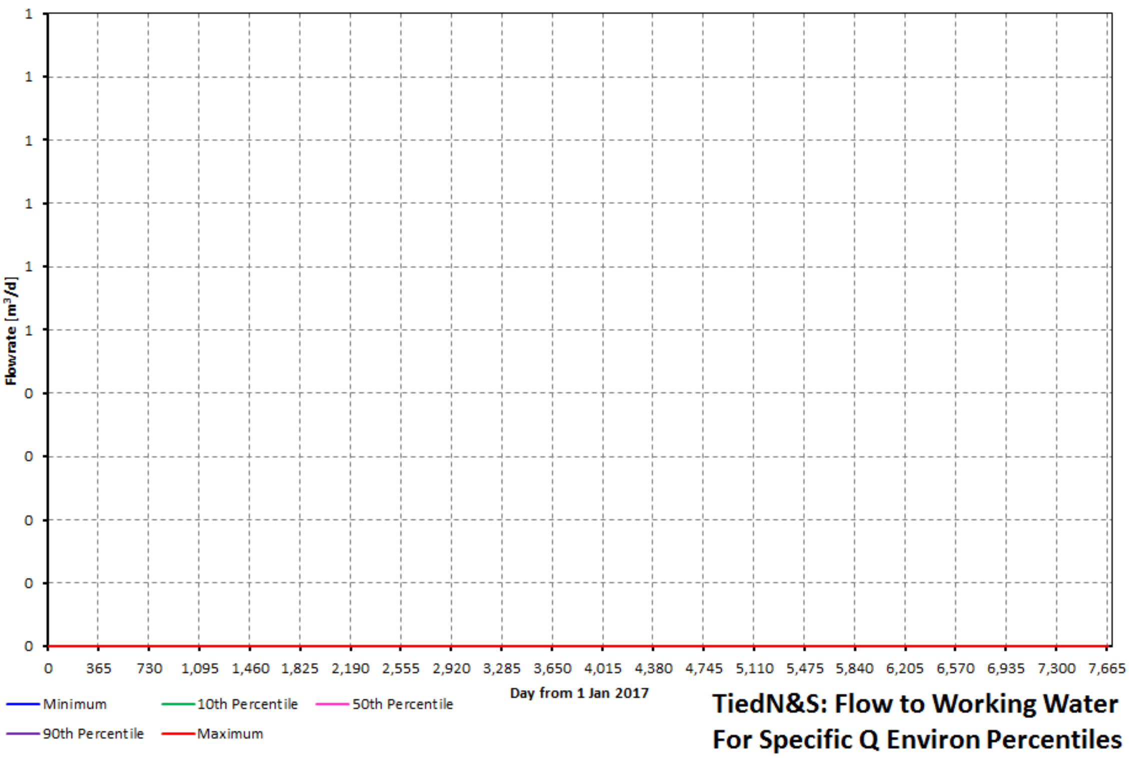

Flowrate [m³/d]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
RWP Flows In
For Specific Q Environ Percentiles

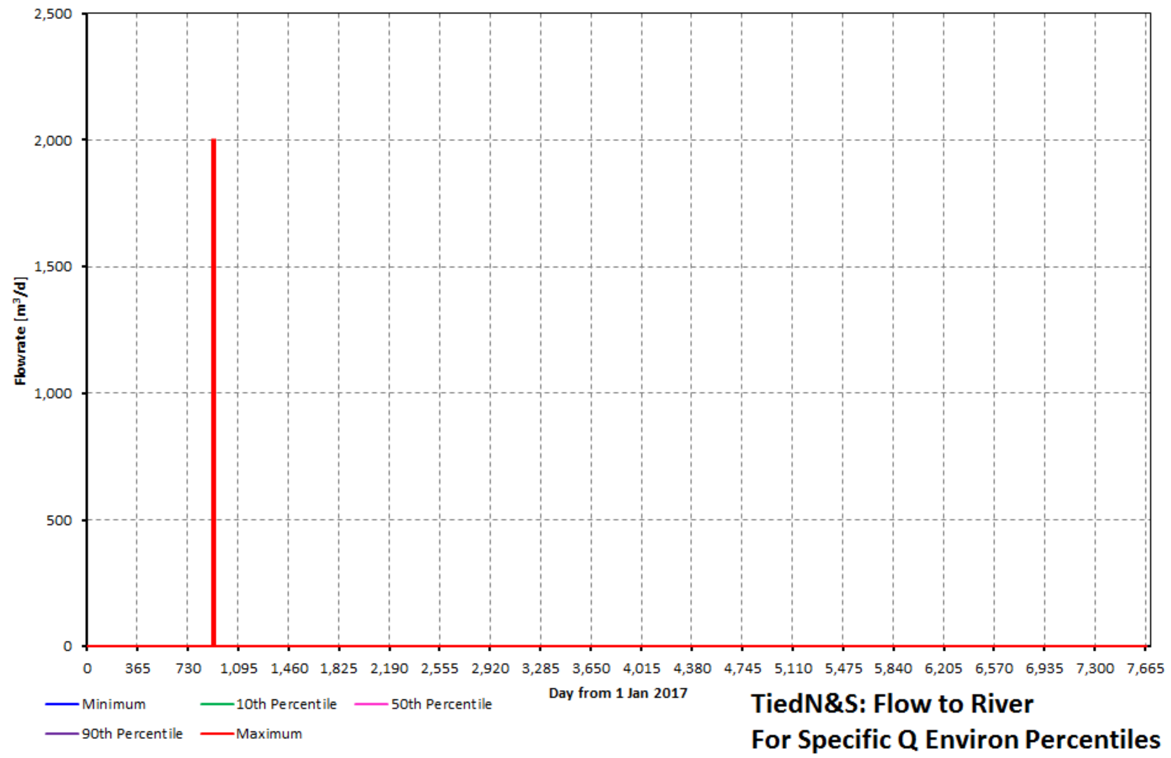

Volume [m³]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
RWP Volume
For Specific Q Environ Percentiles

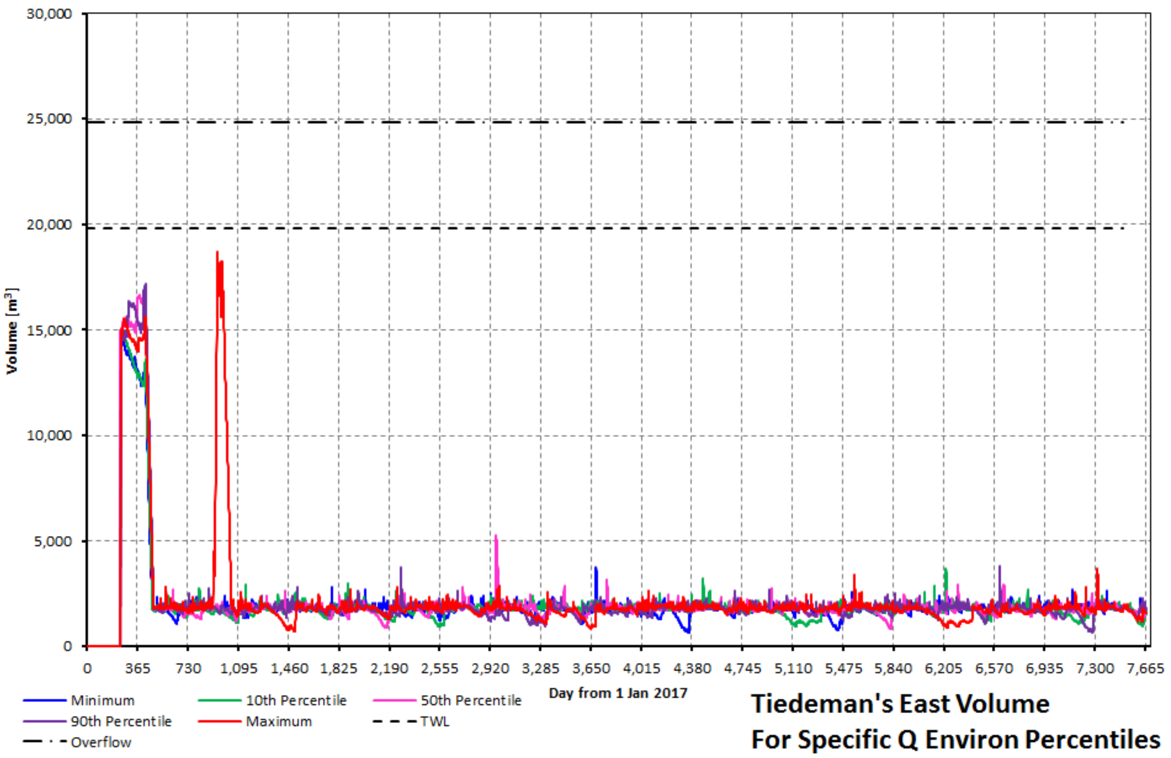

Volume [m3]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
DWP Volume
For Specific Q Environ Percentiles

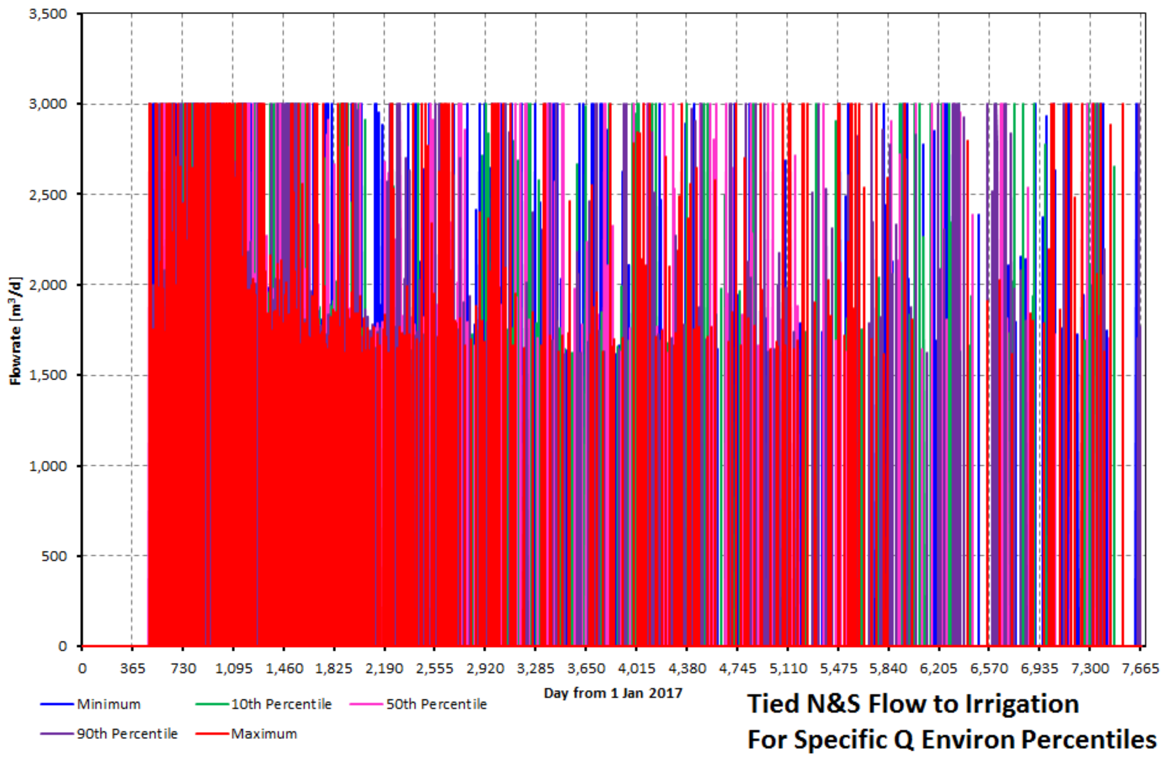

Flowrate [m3/d]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
DWP: Flows to Working Water
For Specific Q Environ Percentiles

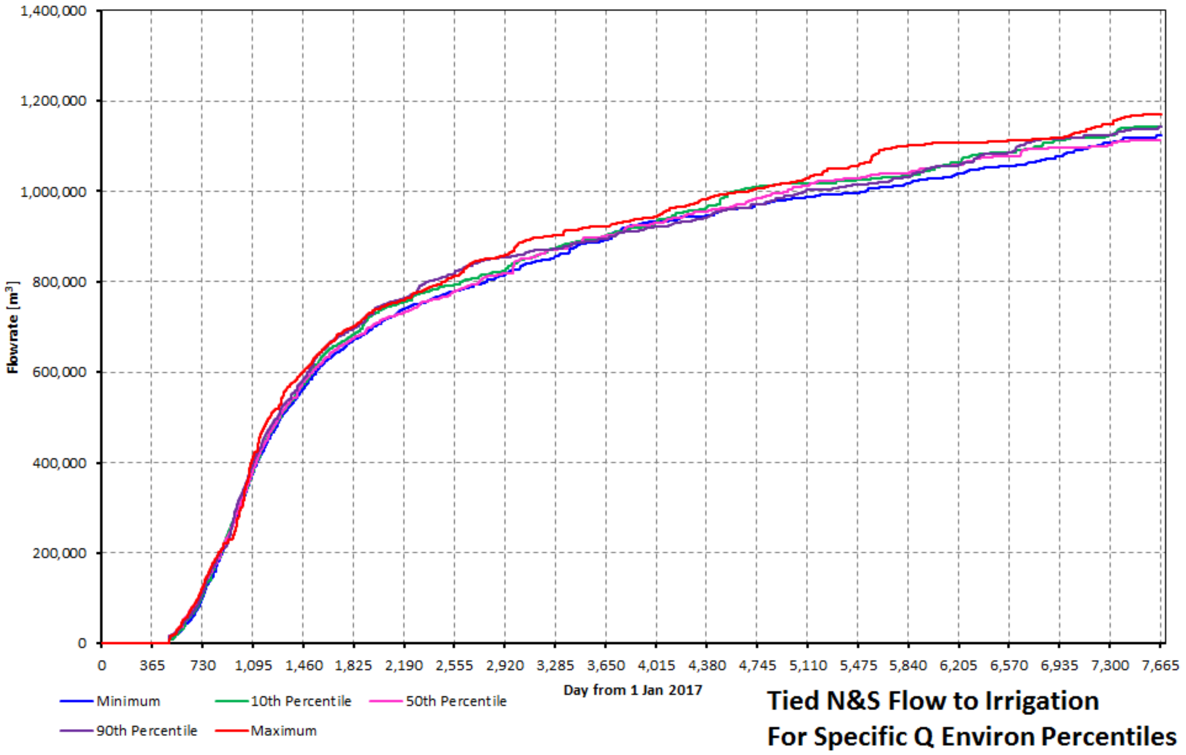

45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's North & South Volume
For Specific Q Environ Percentiles

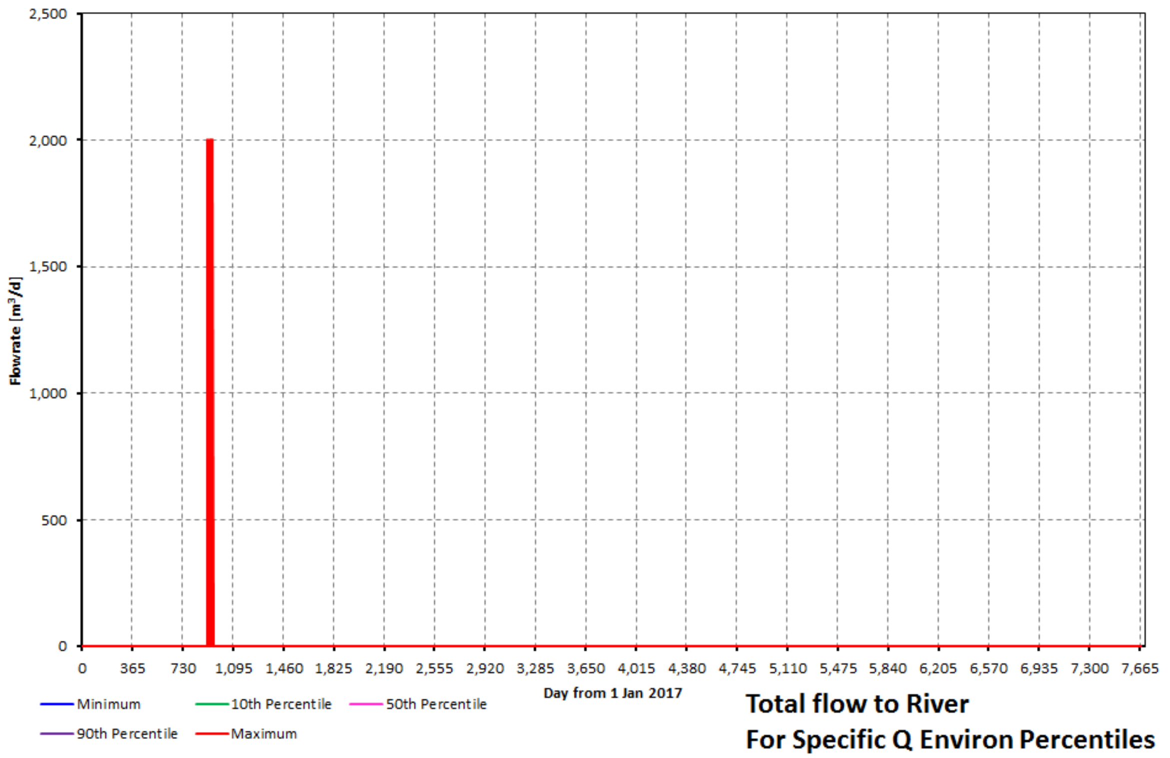

1
1
1
1
1
1
0
0
0
0
0
Flowrate [m³/d]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TiedN&S: Flow to Working Water
For Specific Q Environ Percentiles

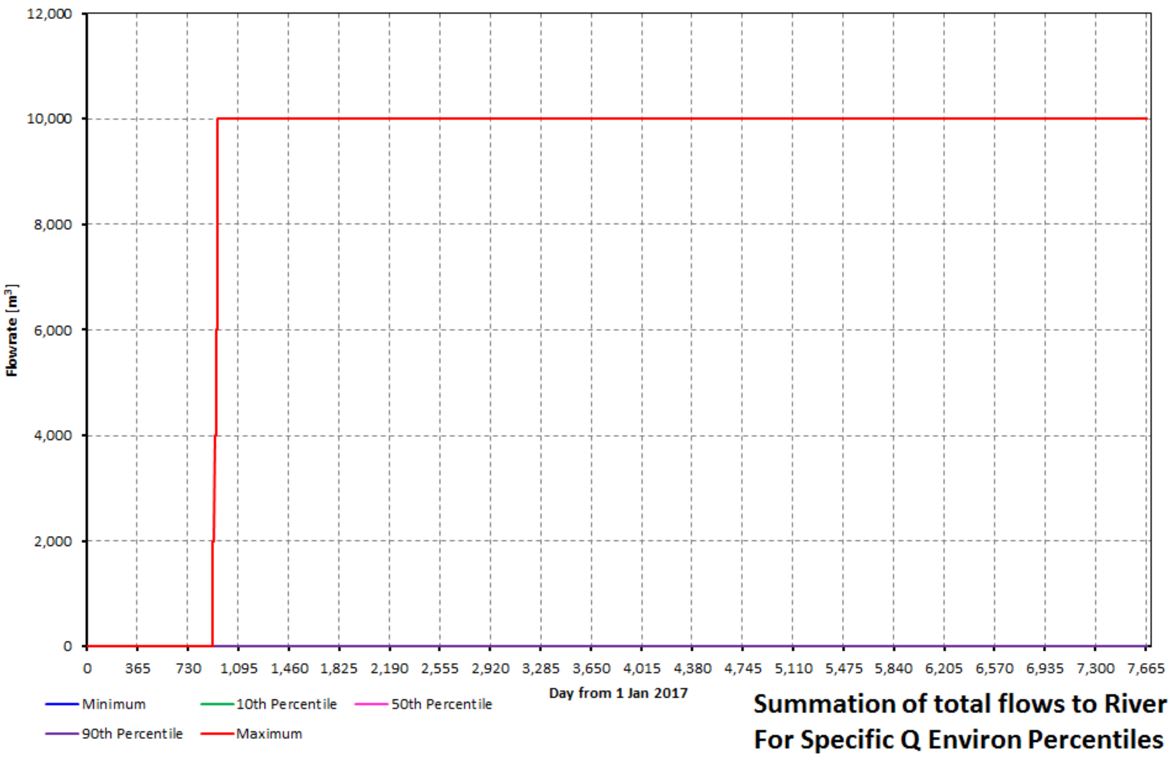

Flowrate [m³/d]
2,500
2,000
1,500
1,000
500
0
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TiedN&S: Flow to River
For Specific Q Environ Percentiles

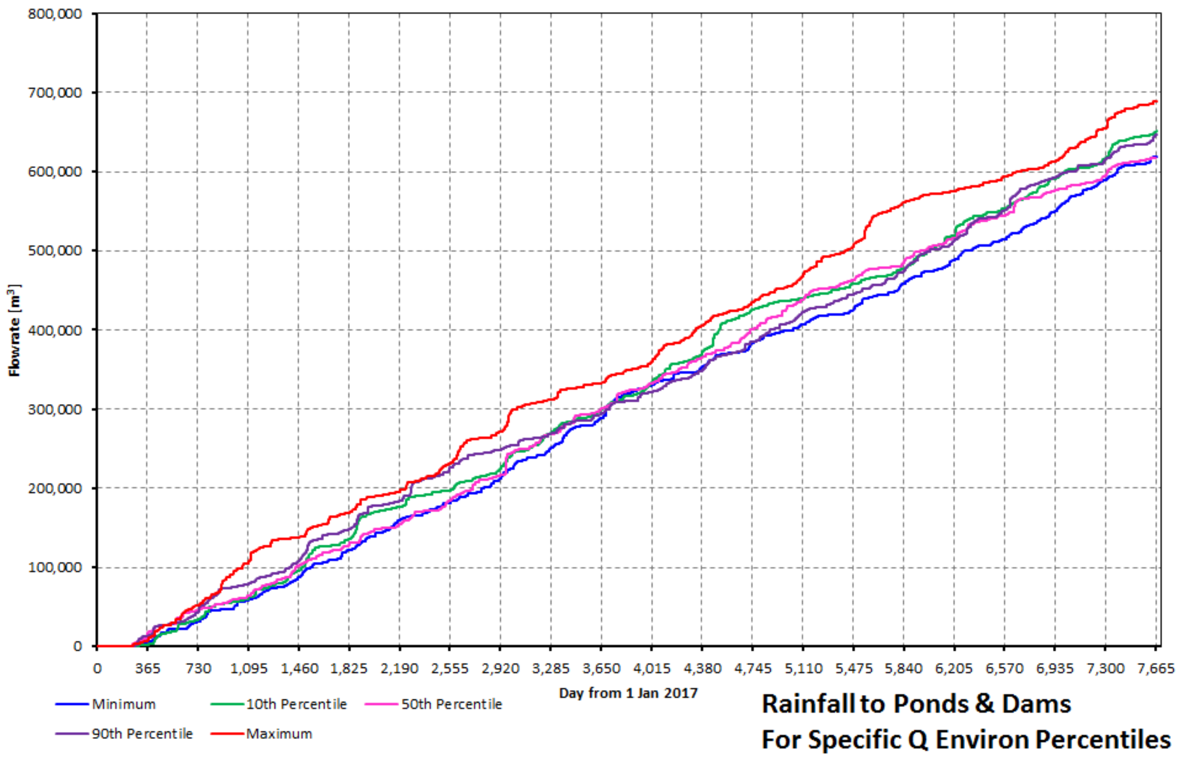

Volume [m³]
30,000
25,000
20,000
15,000
10,000
5,000
0
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's East Volume
For Specific Q Environ Percentiles


3,500
3,000
2,500
2,000
1,500
1,000
500
0
Flowrate [m3/d]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Tied N&S Flow to Irrigation
For Specific Q Environ Percentiles

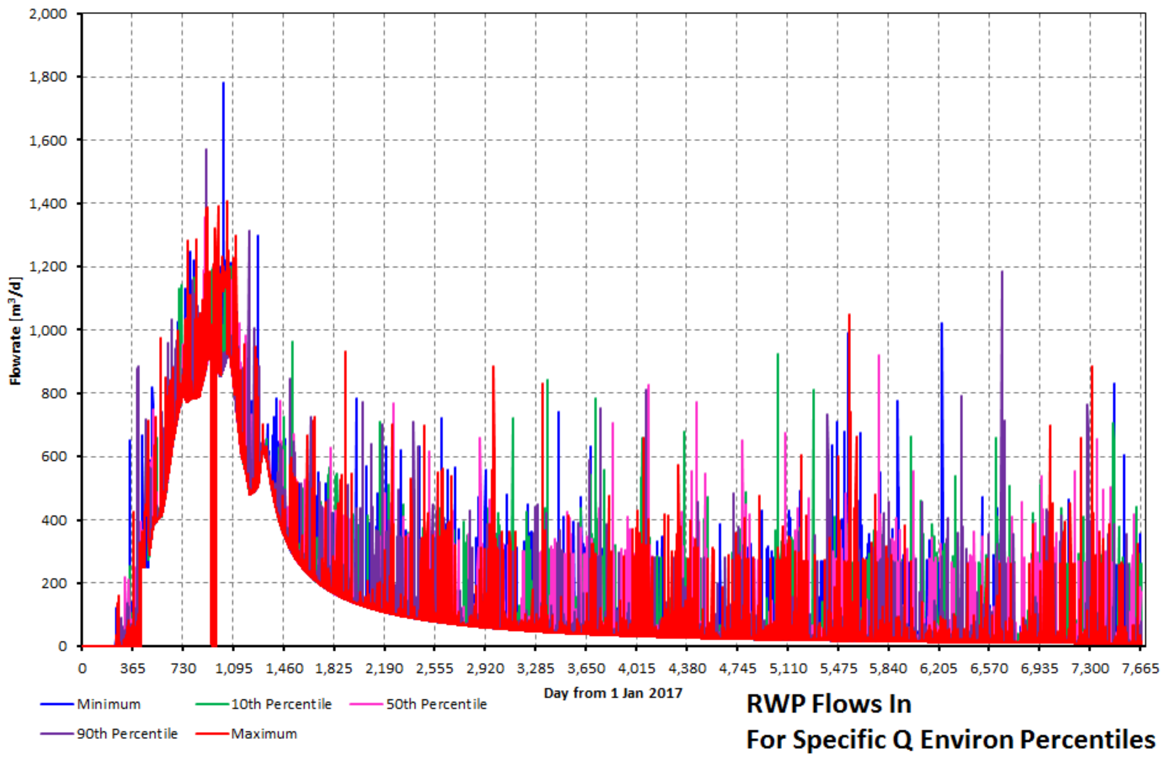

1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Flowrate [m3]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Tied N&S Flow to Irrigation
For Specific Q Environ Percentiles

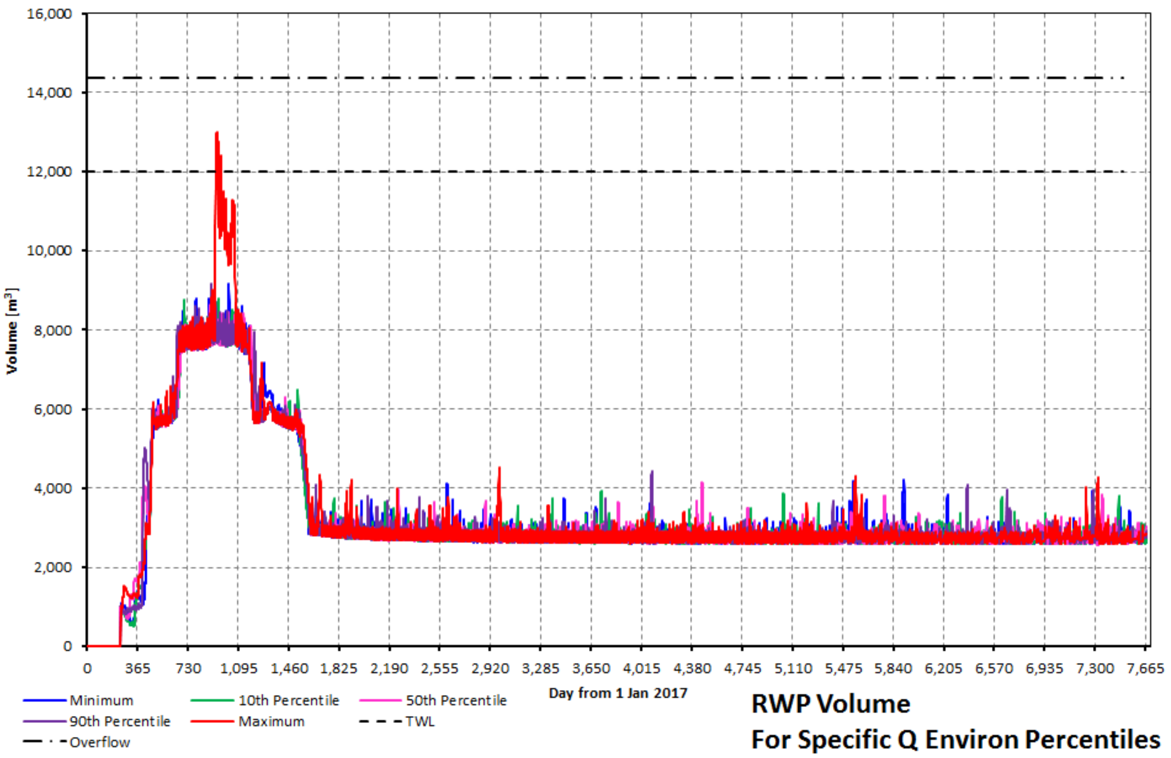

2,500
2,000
1,500
1,000
500
0
Flowrate [m³/d]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Total flow to River
For Specific Q Environ Percentiles

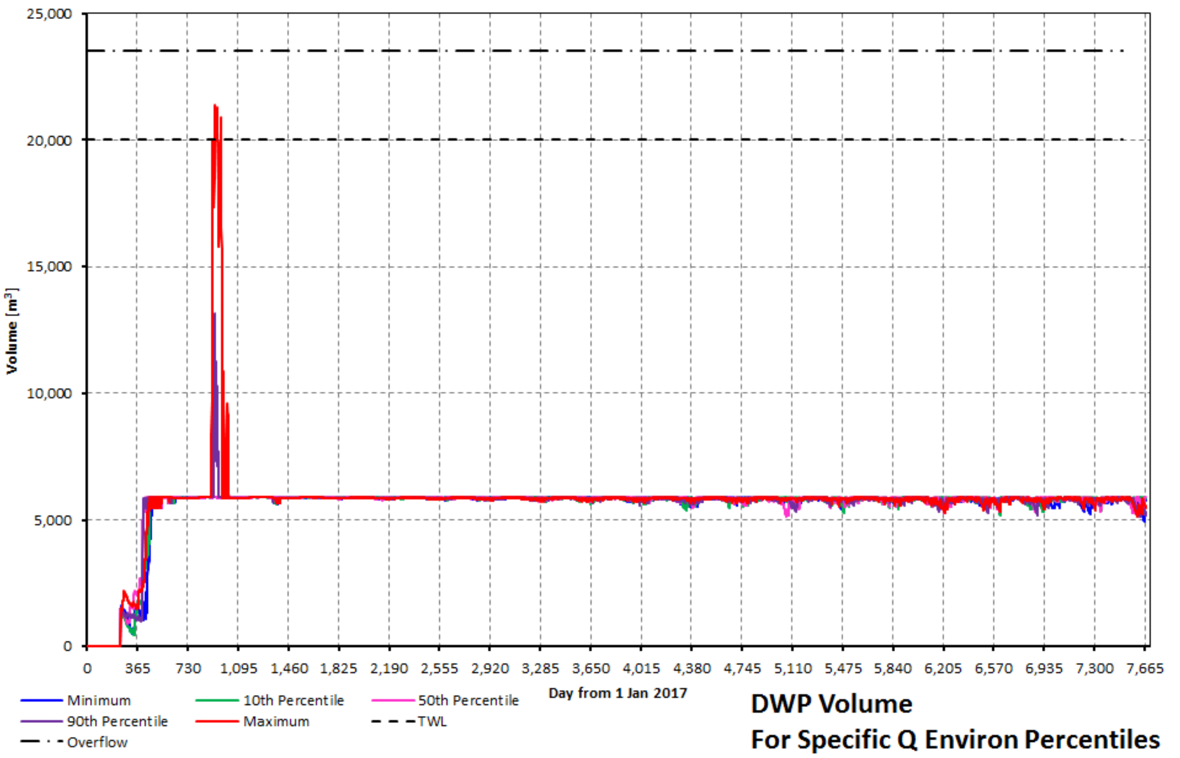

12,000
10,000
8,000
6,000
4,000
2,000
0
Flowrate [m³]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Summation of total flows to River
For Specific Q Environ Percentiles

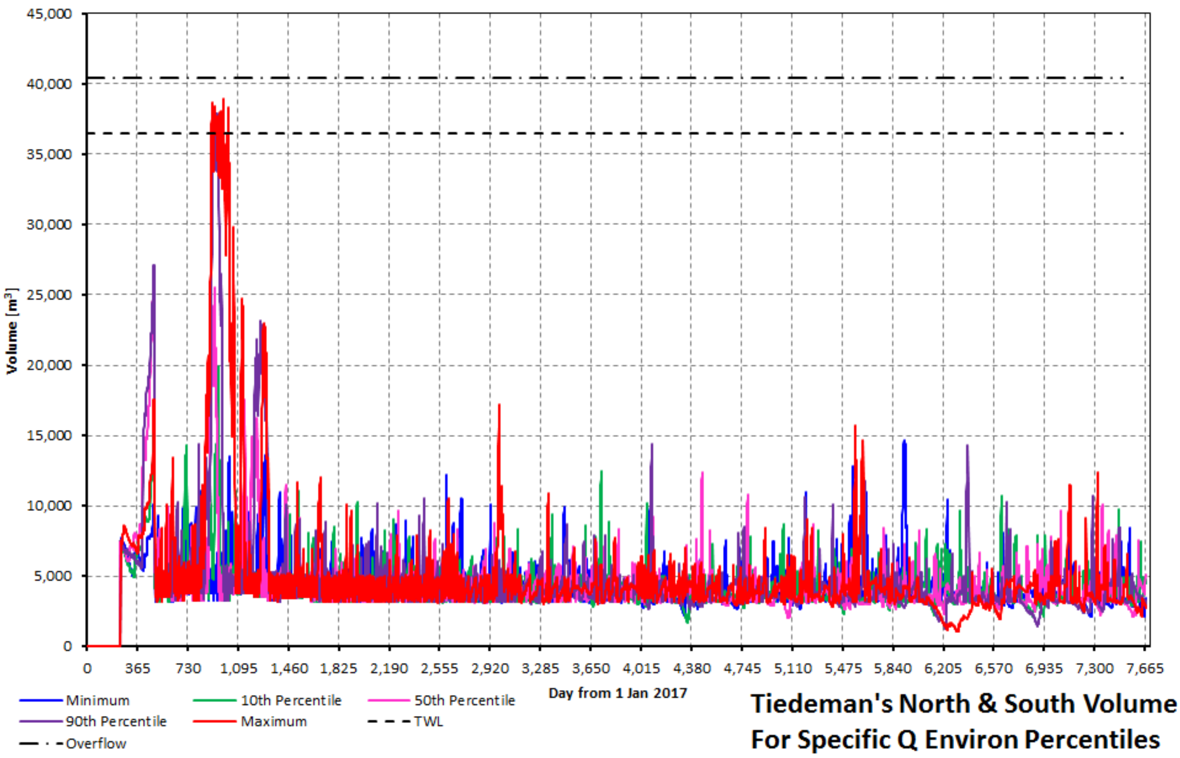

Flowrate [m³]
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Rainfall to Ponds & Dams
For Specific Q Environ Percentiles

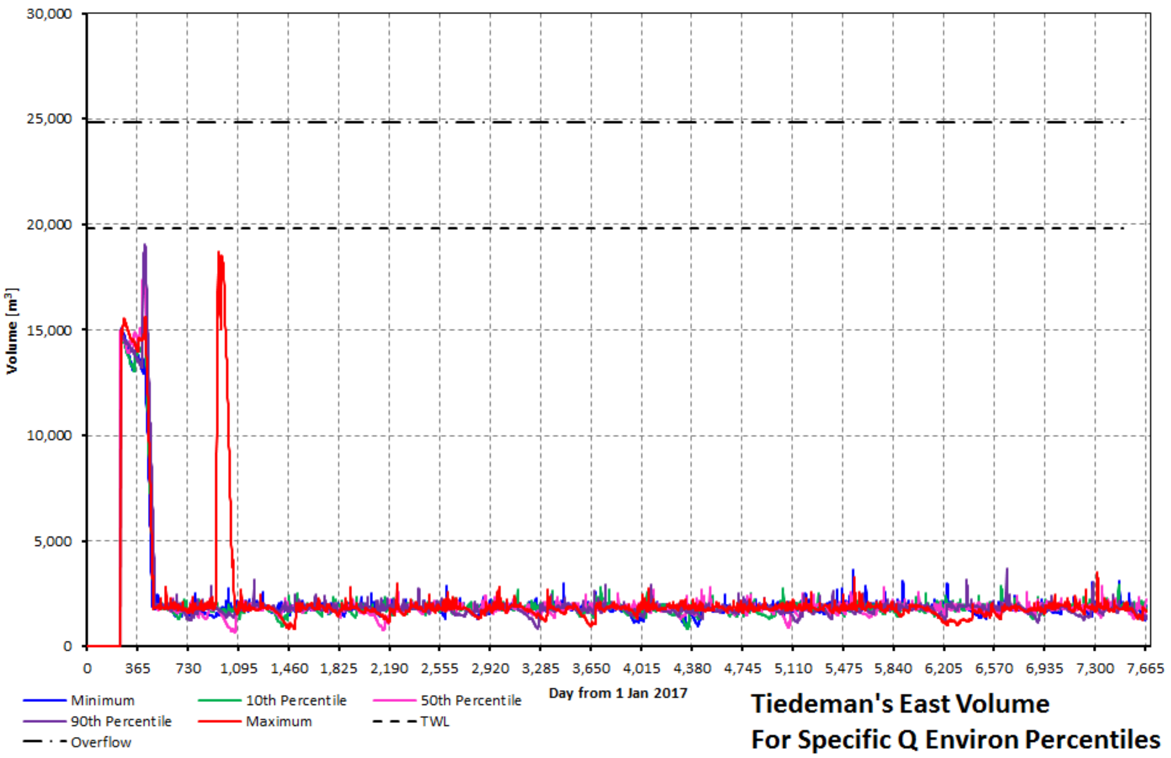
Appendix 4 Simulation Scenario 03: P90 Extracted Water Production, Large WTP Ponds

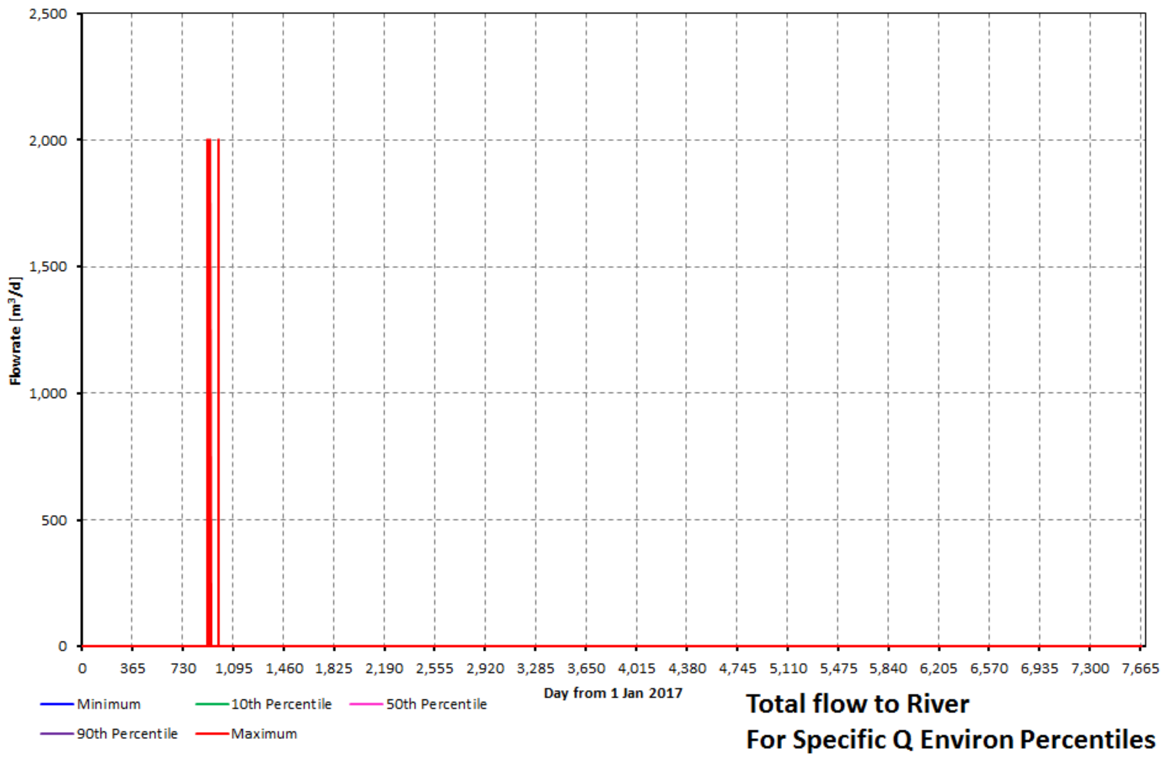

Flowrate [m³/d]
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
RWP Flows In
For Specific Q Environ Percentiles

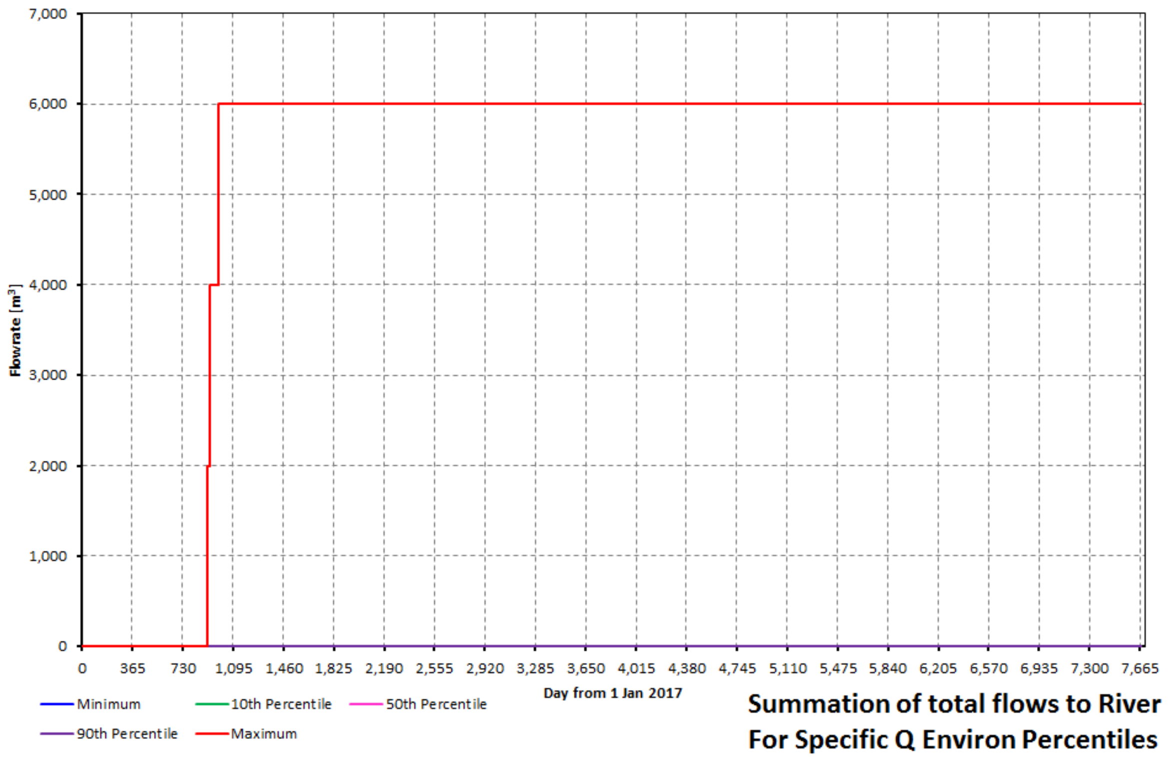

Volume [m³]
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
RWP Volume
For Specific Q Environ Percentiles


Volume [m³]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
DWP Volume
For Specific Q Environ Percentiles

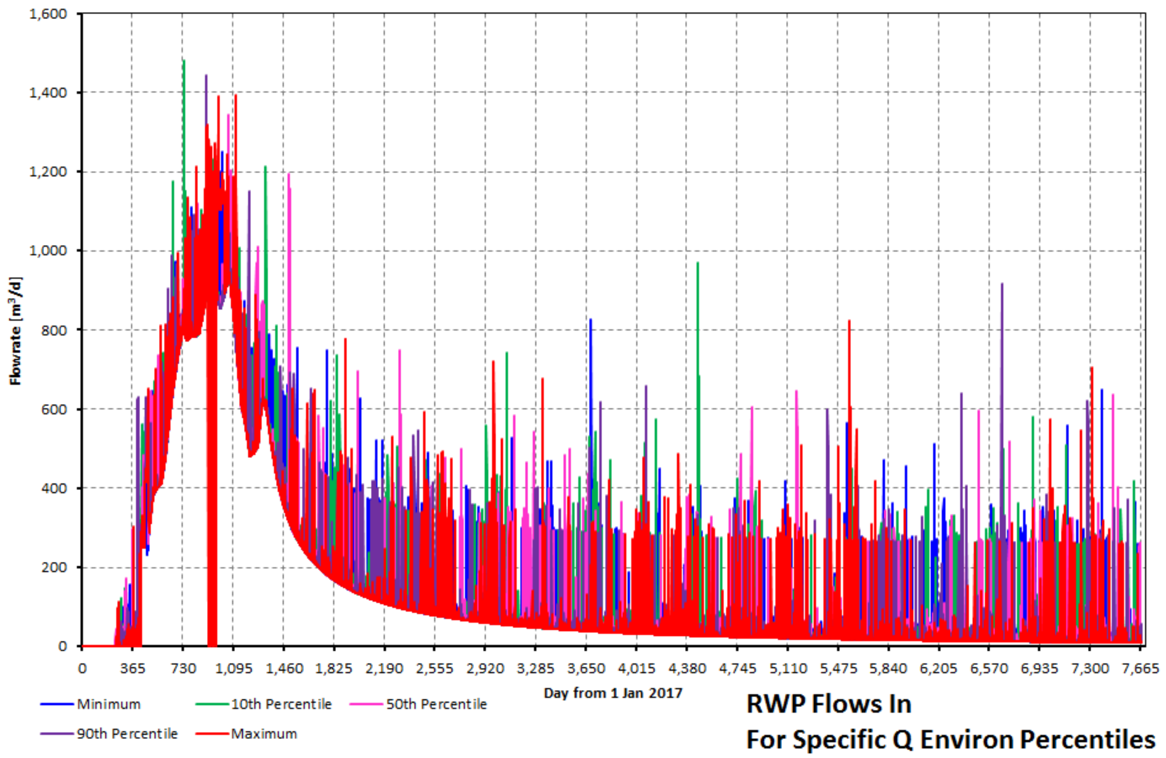

Volume [m³]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's North & South Volume
For Specific Q Environ Percentiles

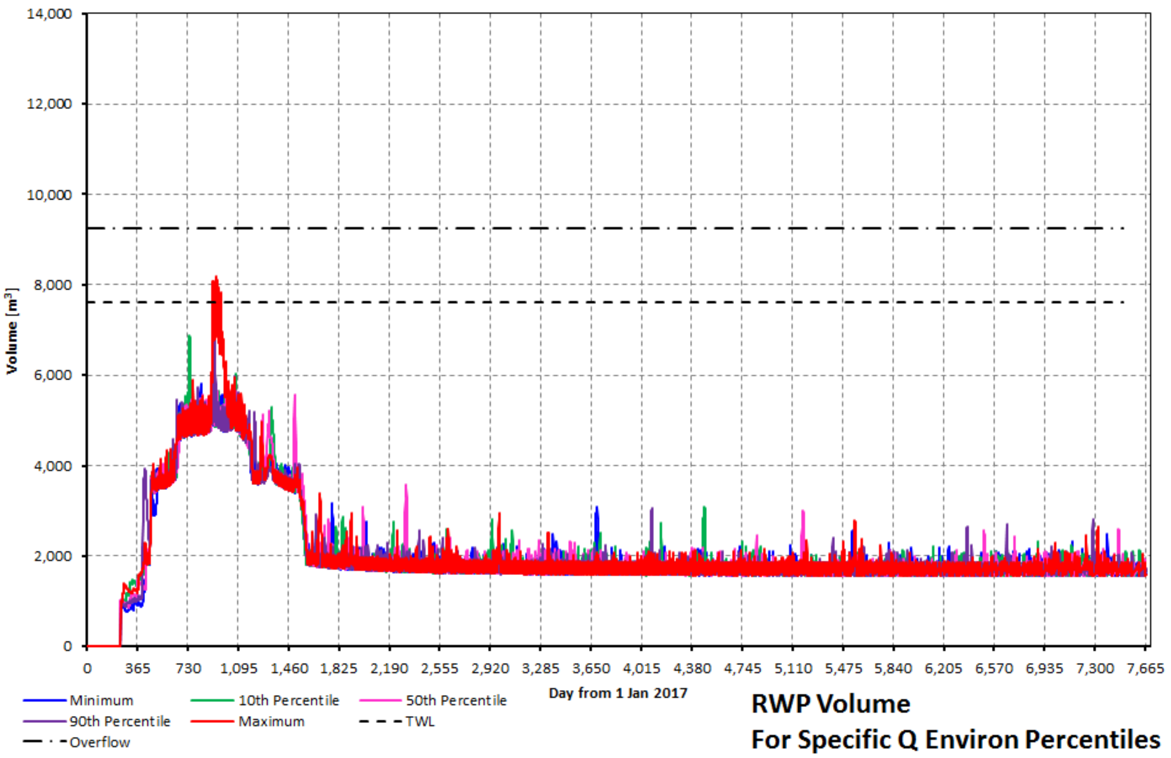

30,000
25,000
20,000
15,000
10,000
5,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's East Volume
For Specific Q Environ Percentiles

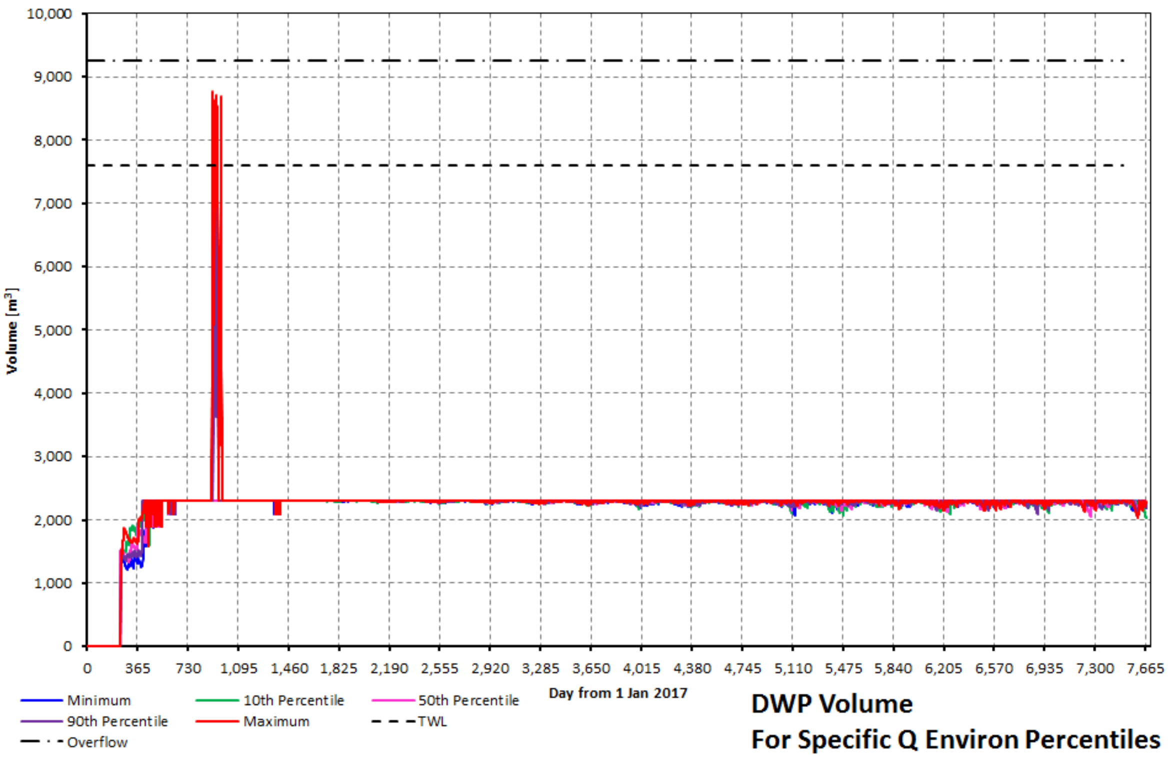

2,500
2,000
1,500
1,000
500
0
Flowrate [m³/d]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Total flow to River
For Specific Q Environ Percentiles


7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Flowrate [m³]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Summation of total flows to River
For Specific Q Environ Percentiles

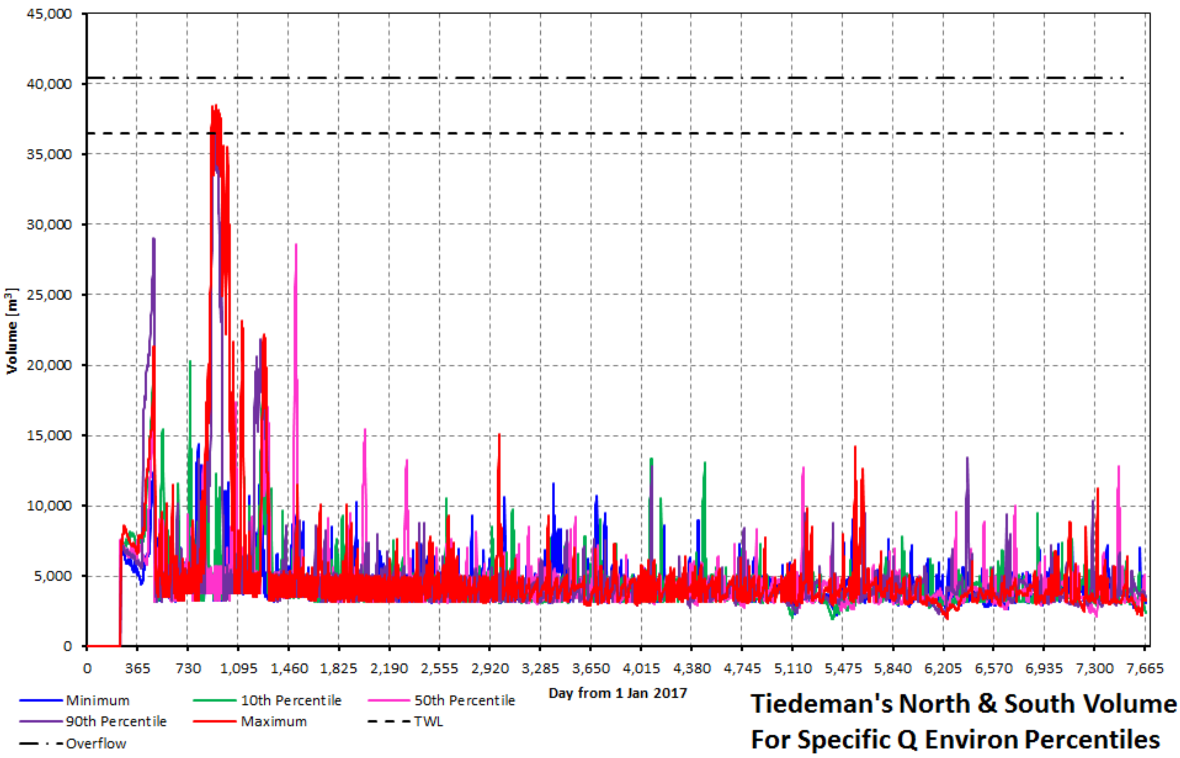
Appendix 5 Simulation Scenario 04: P90 Extracted Water Production, Small WTP Ponds


Flowrate [m³/d]
1,600
1,400
1,200
1,000
800
600
400
200
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
RWP Flows In
For Specific Q Environ Percentiles

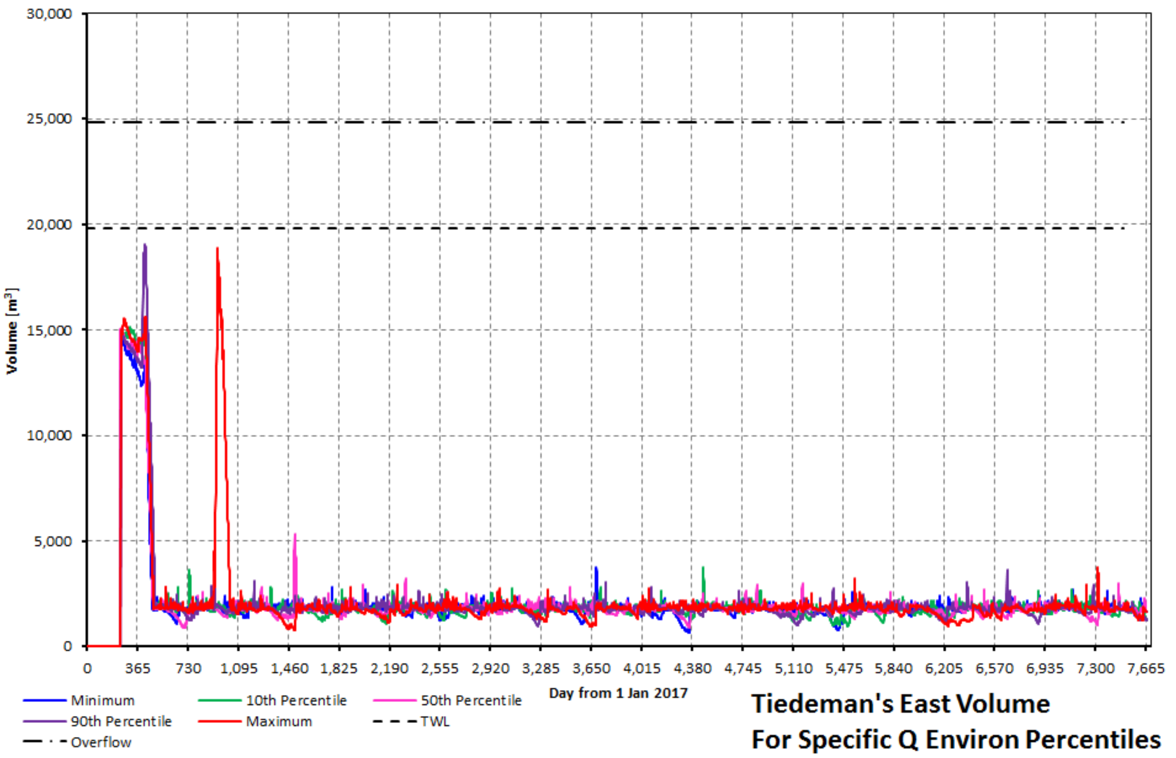

Volume [m³]
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
RWP Volume
For Specific Q Environ Percentiles



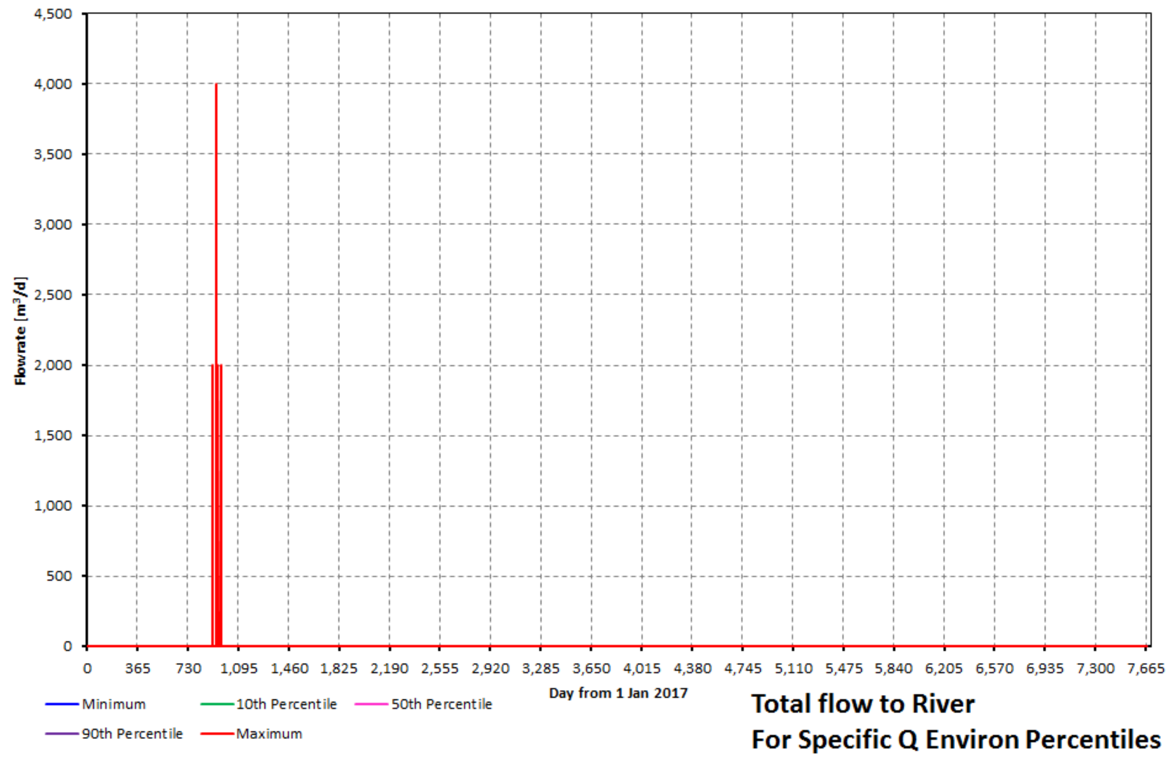
DWP Volume
For Specific Q Environ Percentiles



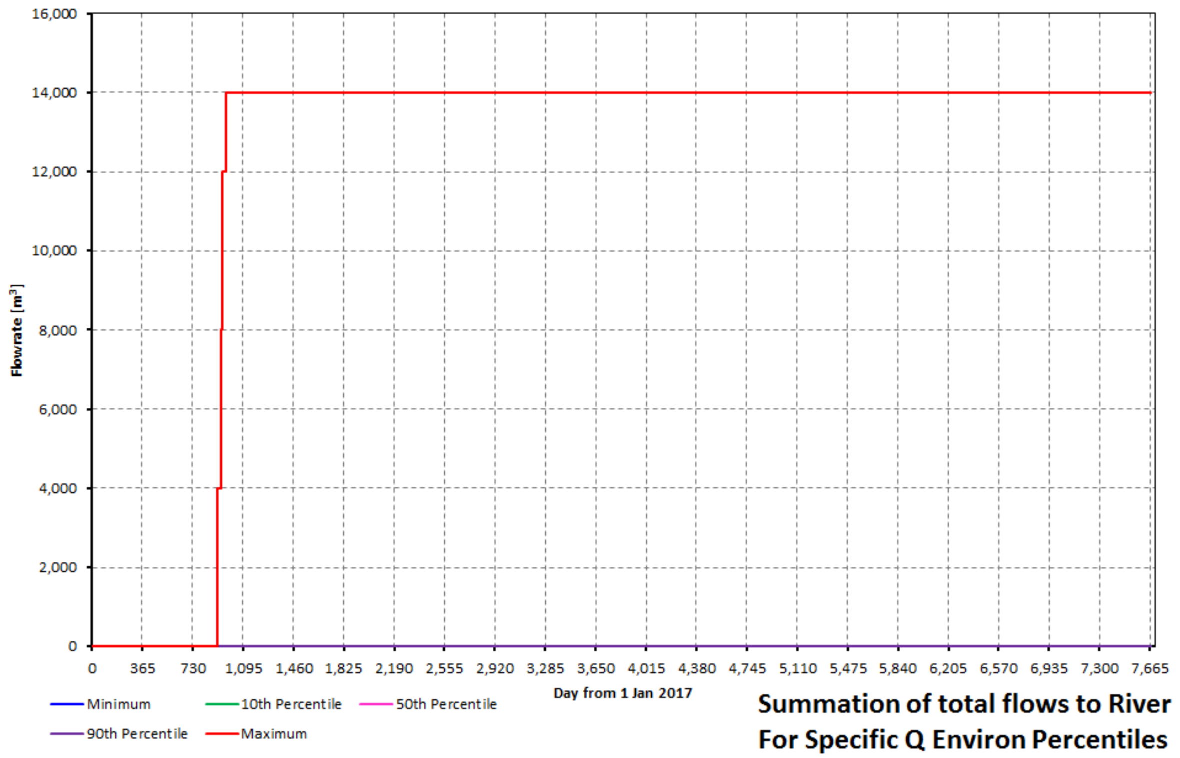
Tiedeman's North & South Volume
For Specific Q Environ Percentiles



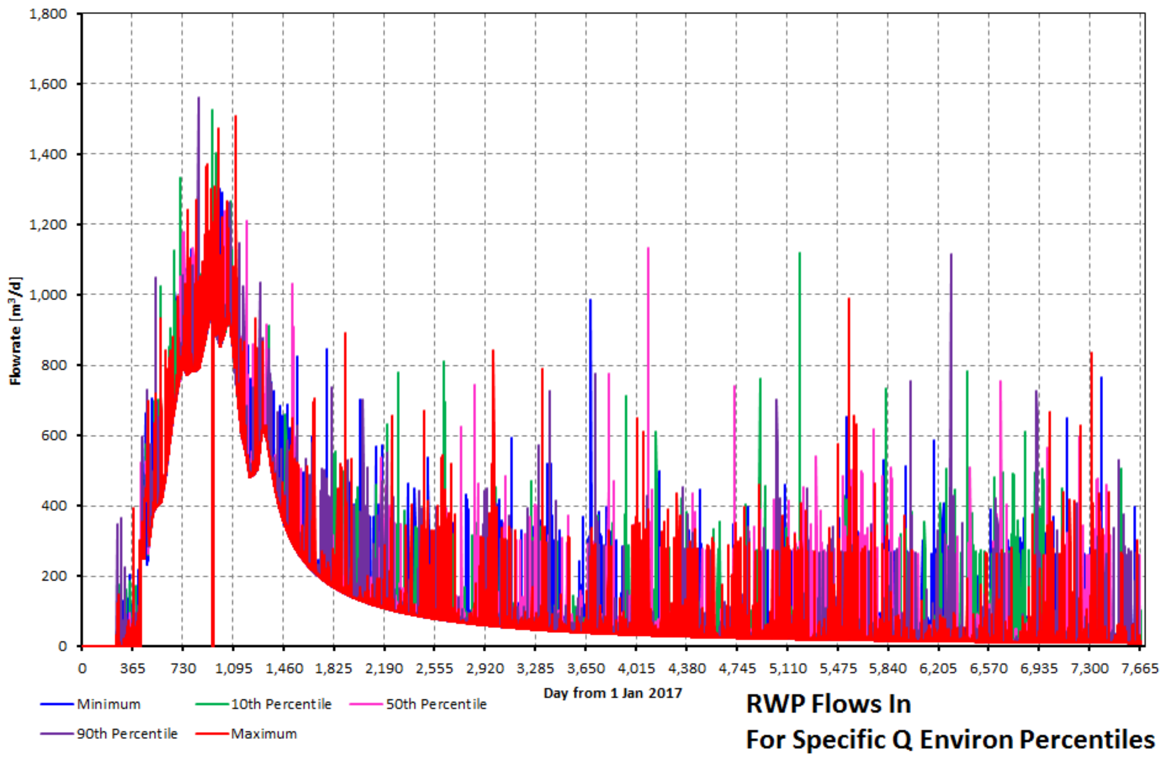
Tiedeman's East Volume
For Specific Q Environ Percentiles

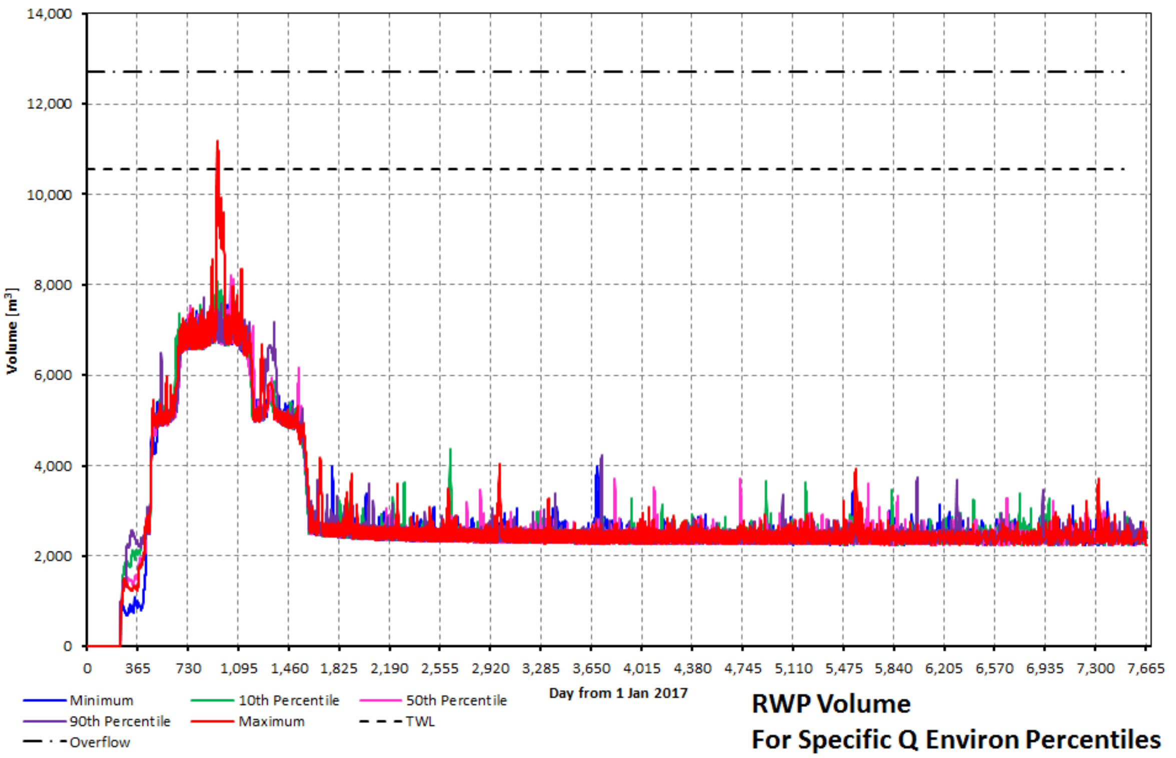


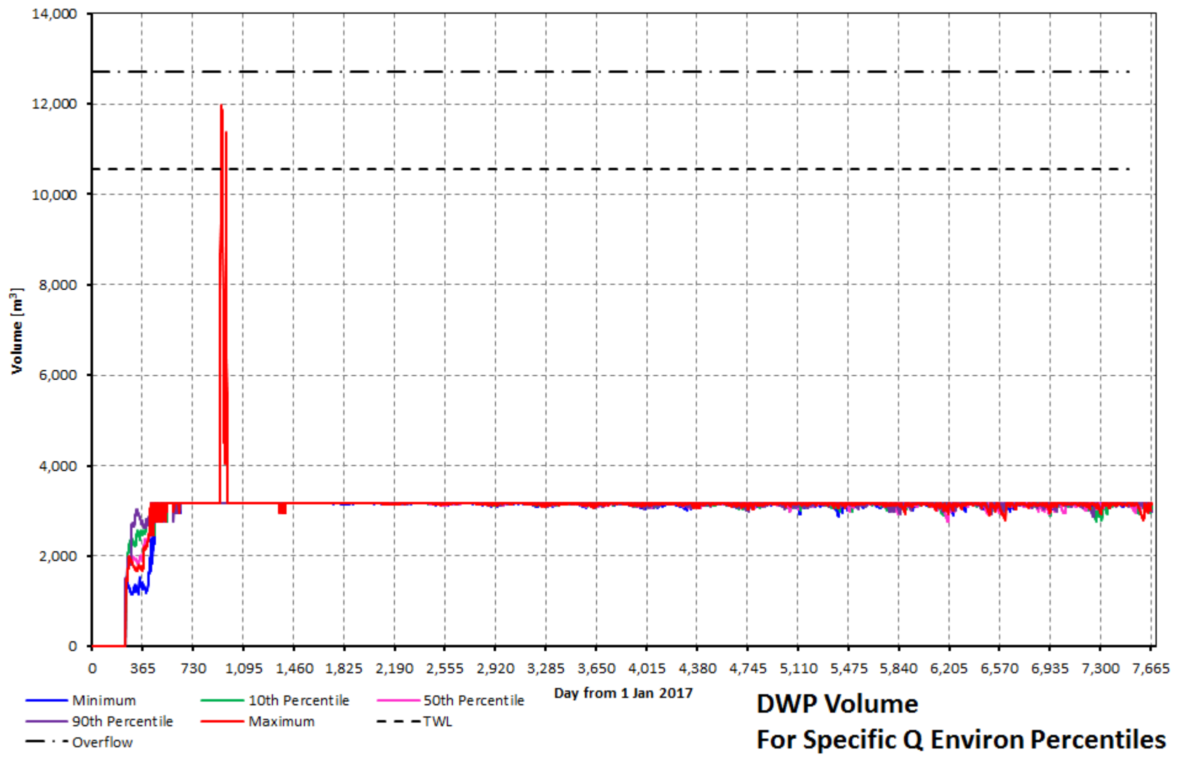
Total flow to River
For Specific Q Environ Percentiles

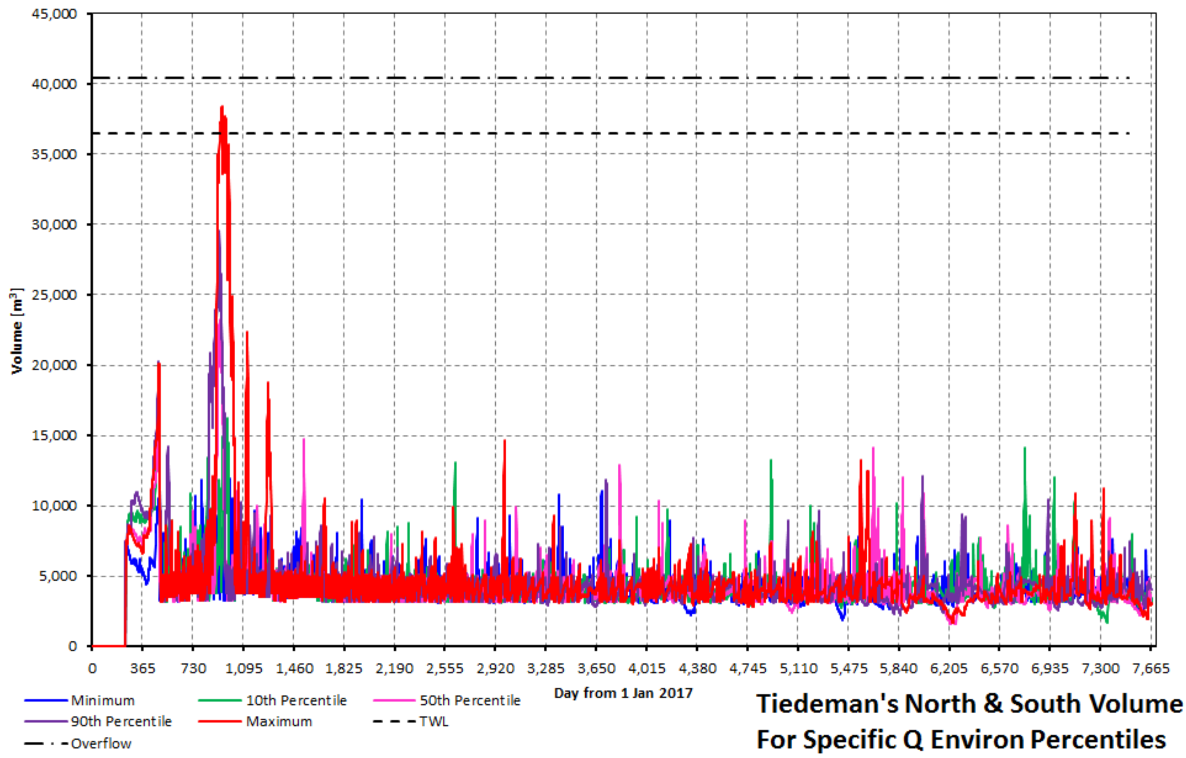

Flowrate [m³]
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Summation of total flows to River
For Specific Q Environ Percentiles

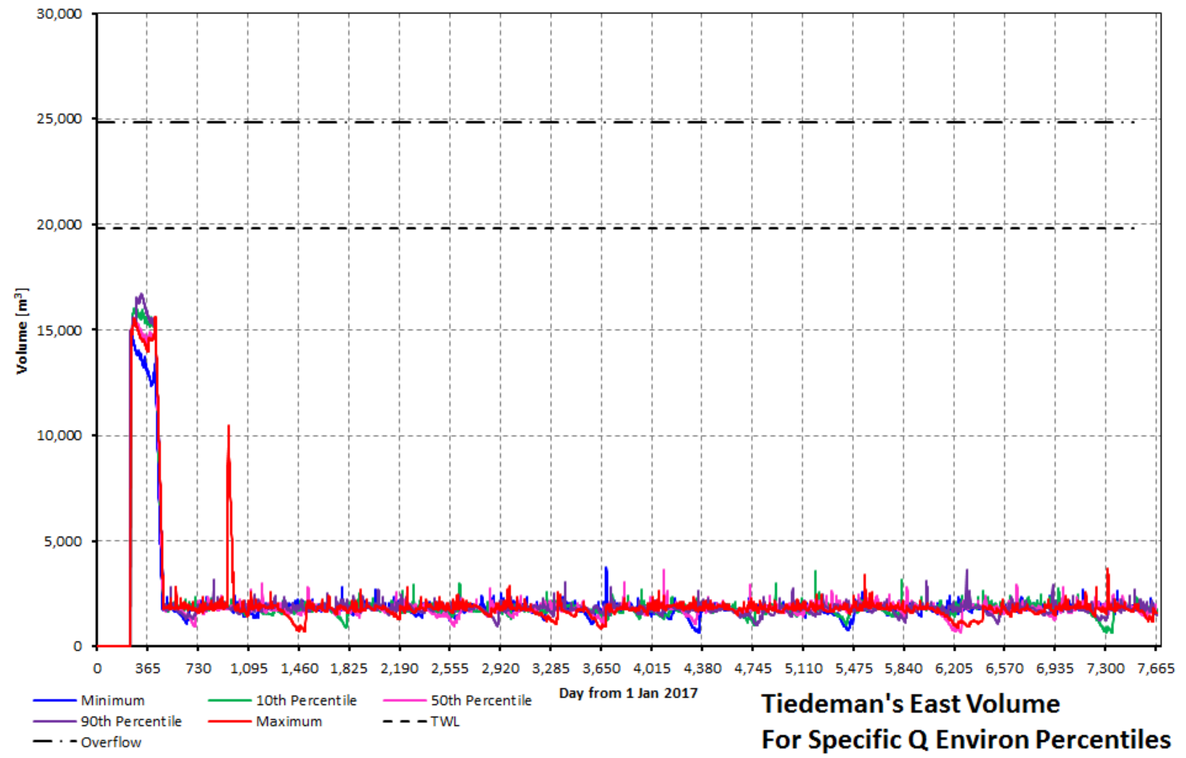
Appendix 6 Simulation Scenario 05: P90 Extracted Water Production, Light Clay Soil

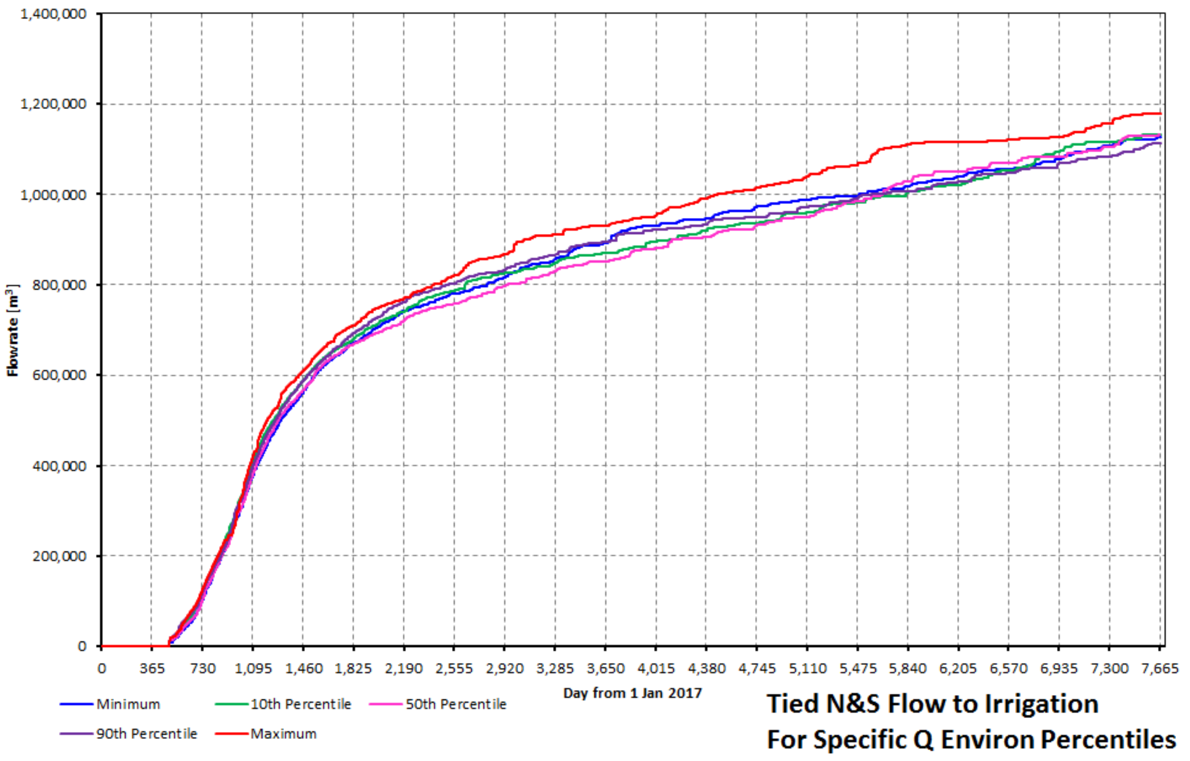

Flowrate [m³/d]
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
RWP Flows In
For Specific Q Environ Percentiles

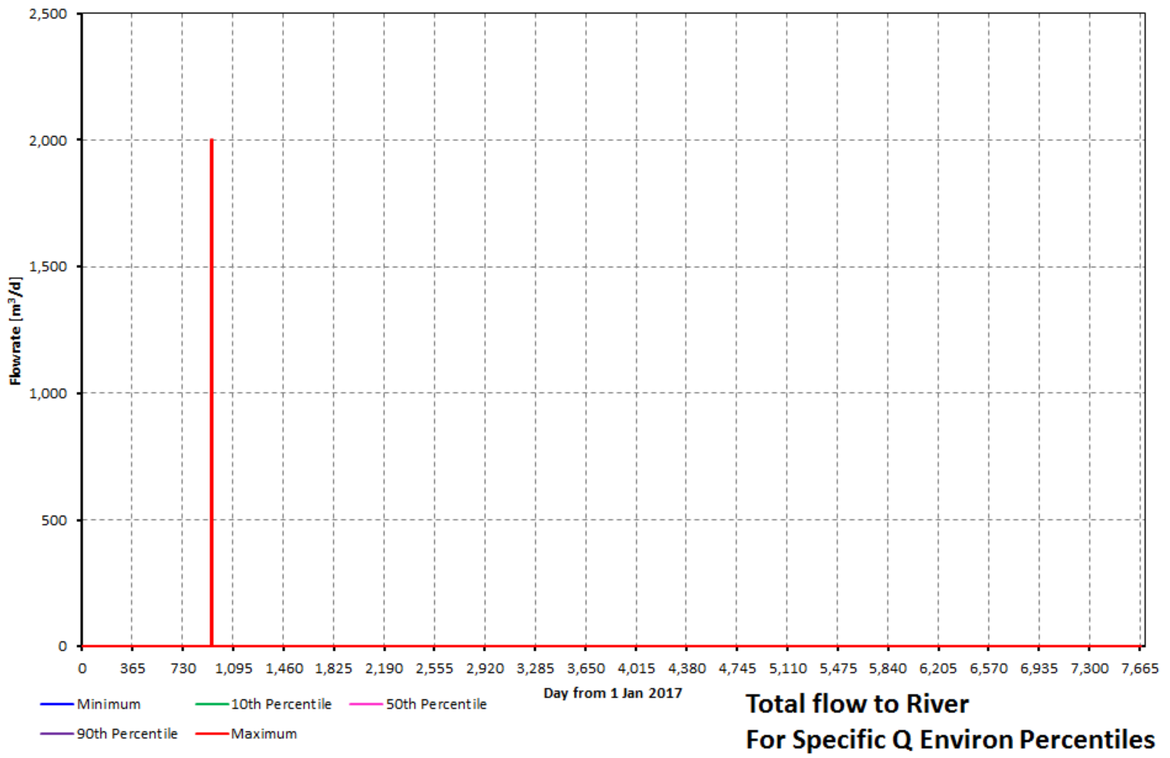

Volume [m³]
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
RWP Volume
For Specific Q Environ Percentiles

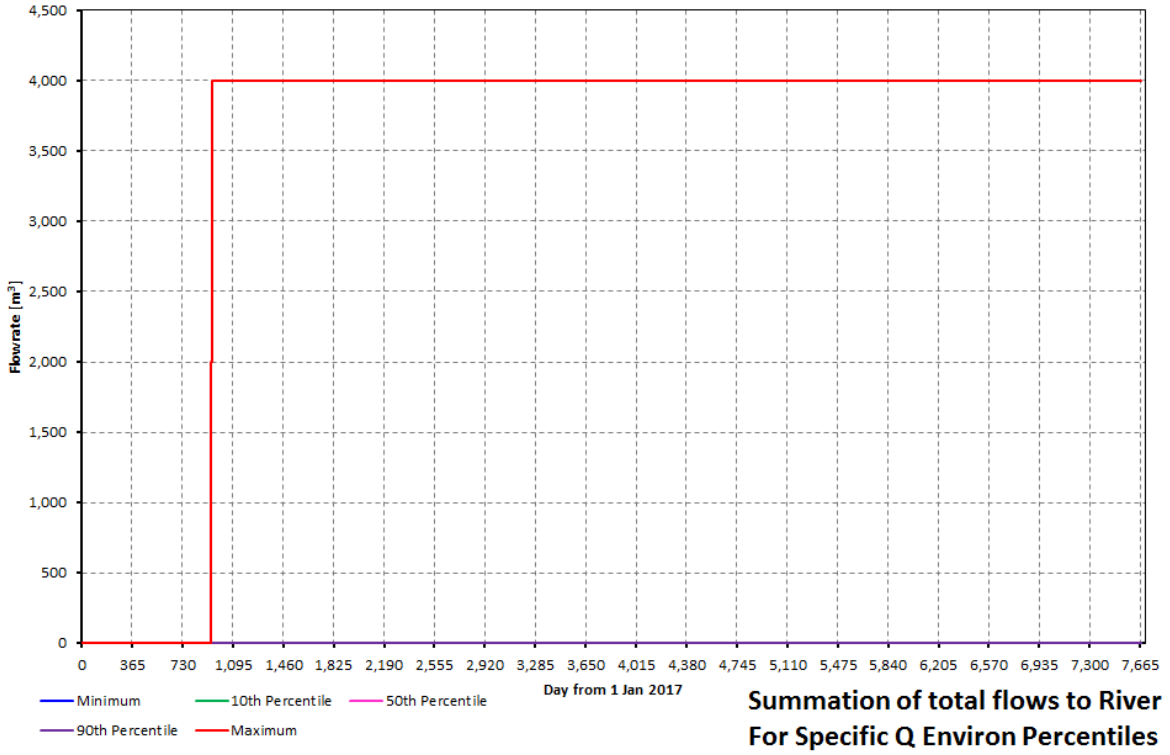

14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
DWP Volume
For Specific Q Environ Percentiles

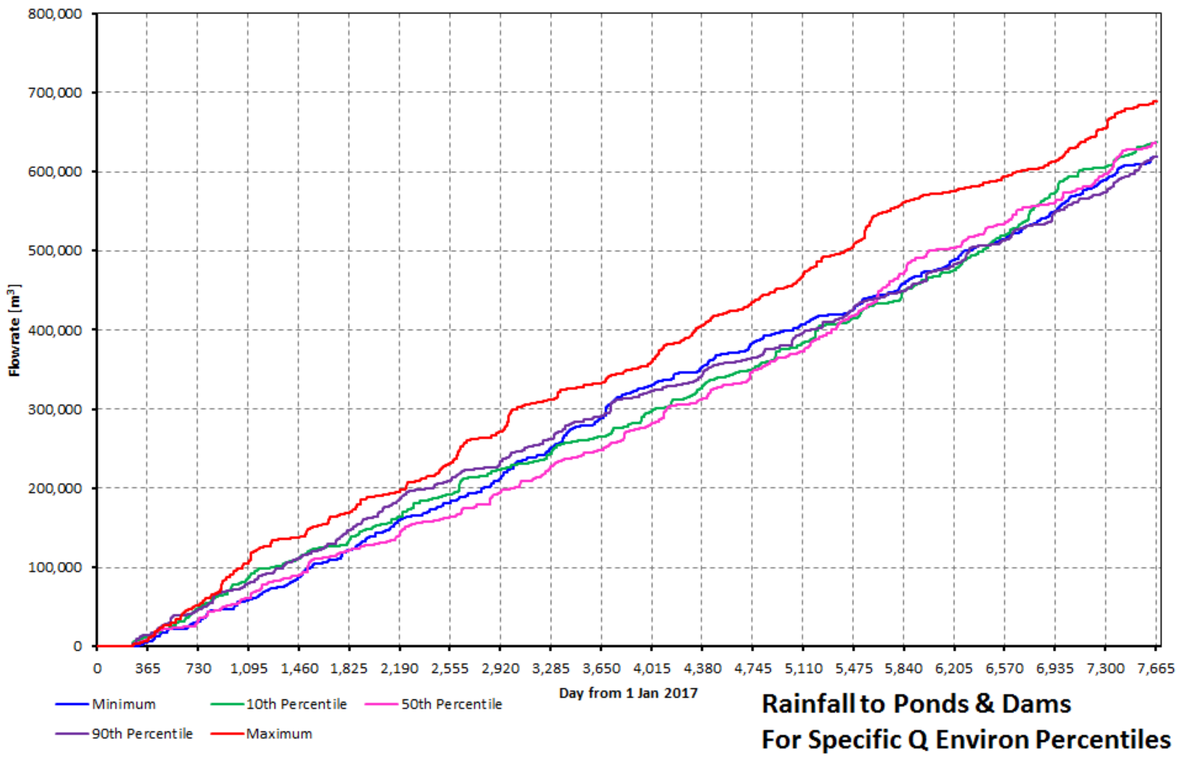

45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's North & South Volume
For Specific Q Environ Percentiles


30,000
25,000
20,000
15,000
10,000
5,000
0
Volume [m³]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's East Volume
For Specific Q Environ Percentiles

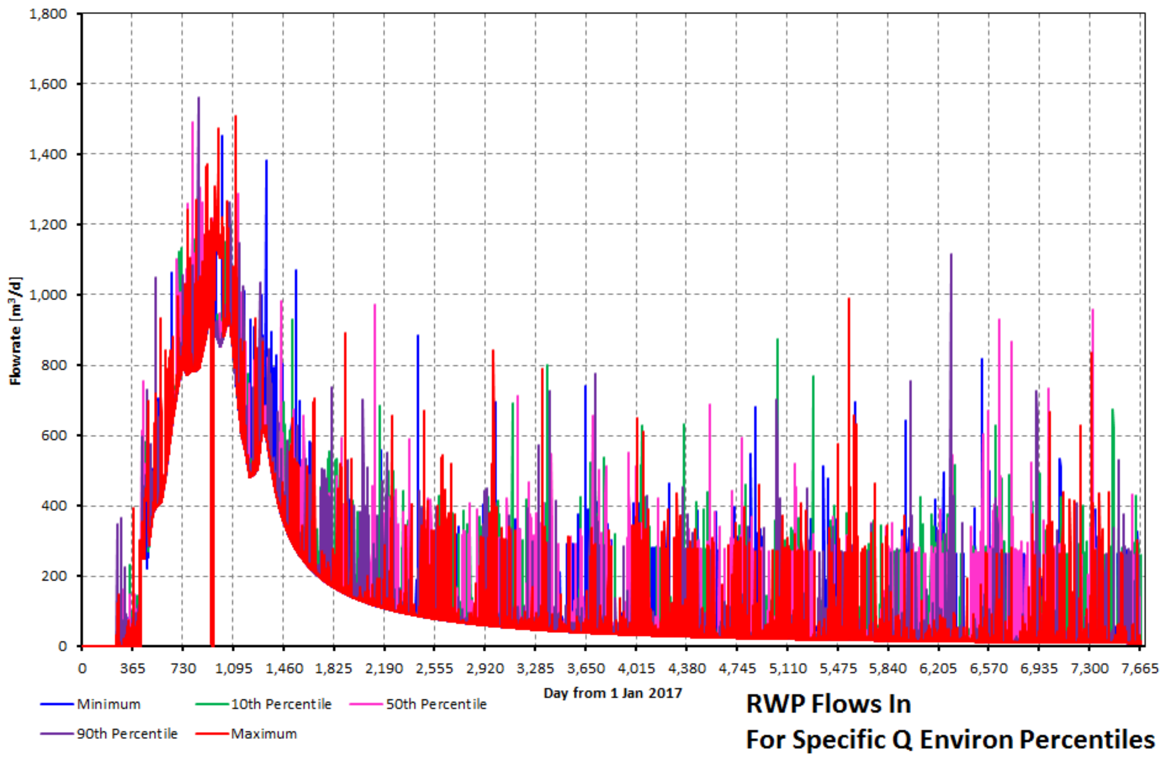

1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Flowrate [m³]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Tied N&S Flow to Irrigation
For Specific Q Environ Percentiles

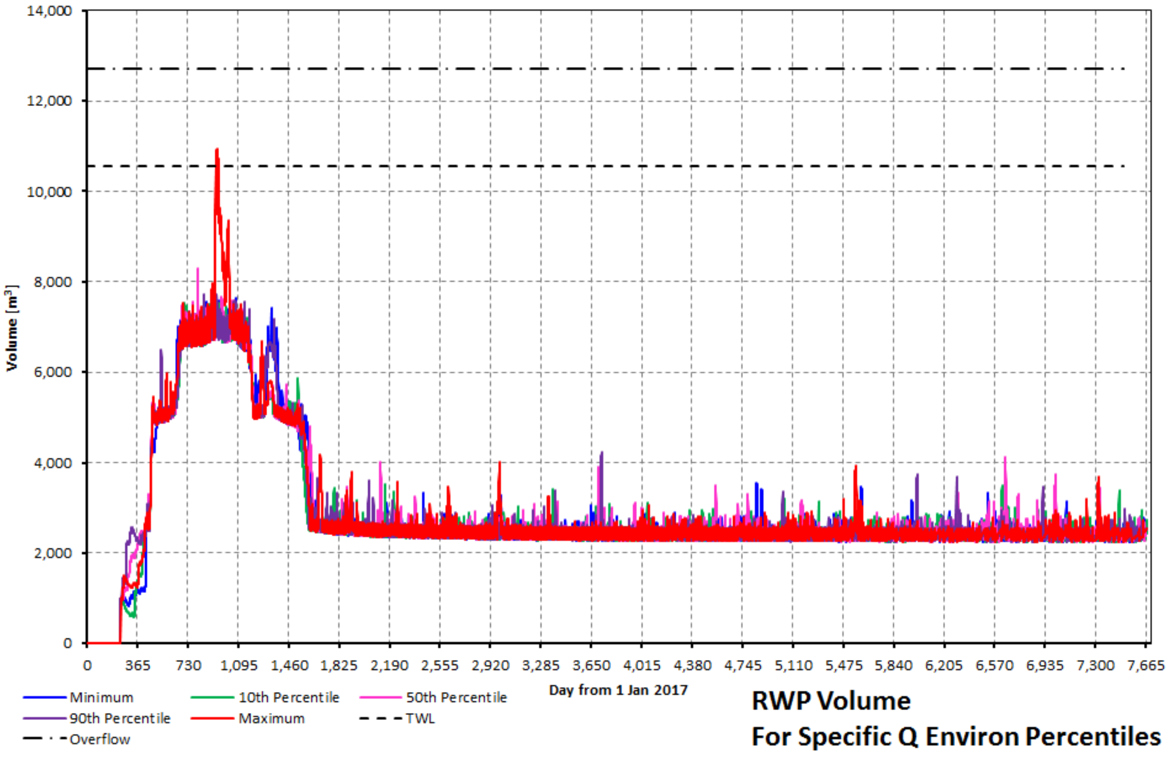

2,500
2,000
1,500
1,000
500
0
Flowrate [m³/d]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Total flow to River
For Specific Q Environ Percentiles

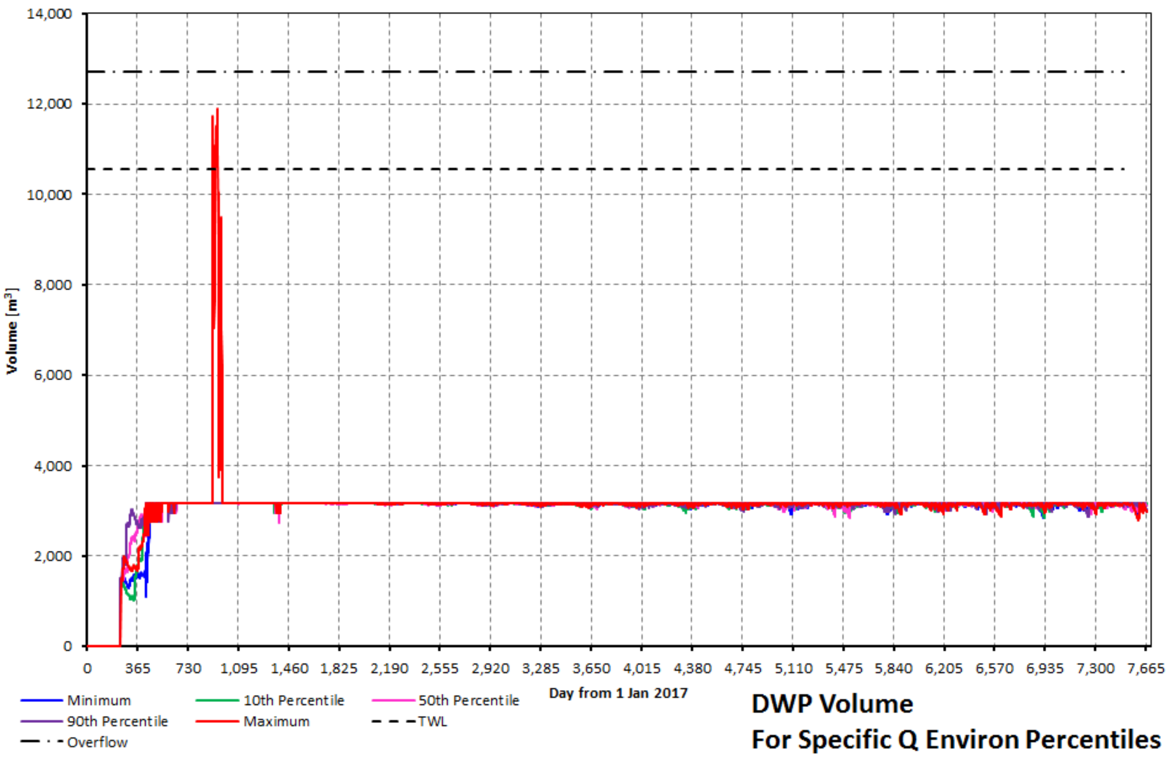

4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Flowrate [m³]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Summation of total flows to River
For Specific Q Environ Percentiles

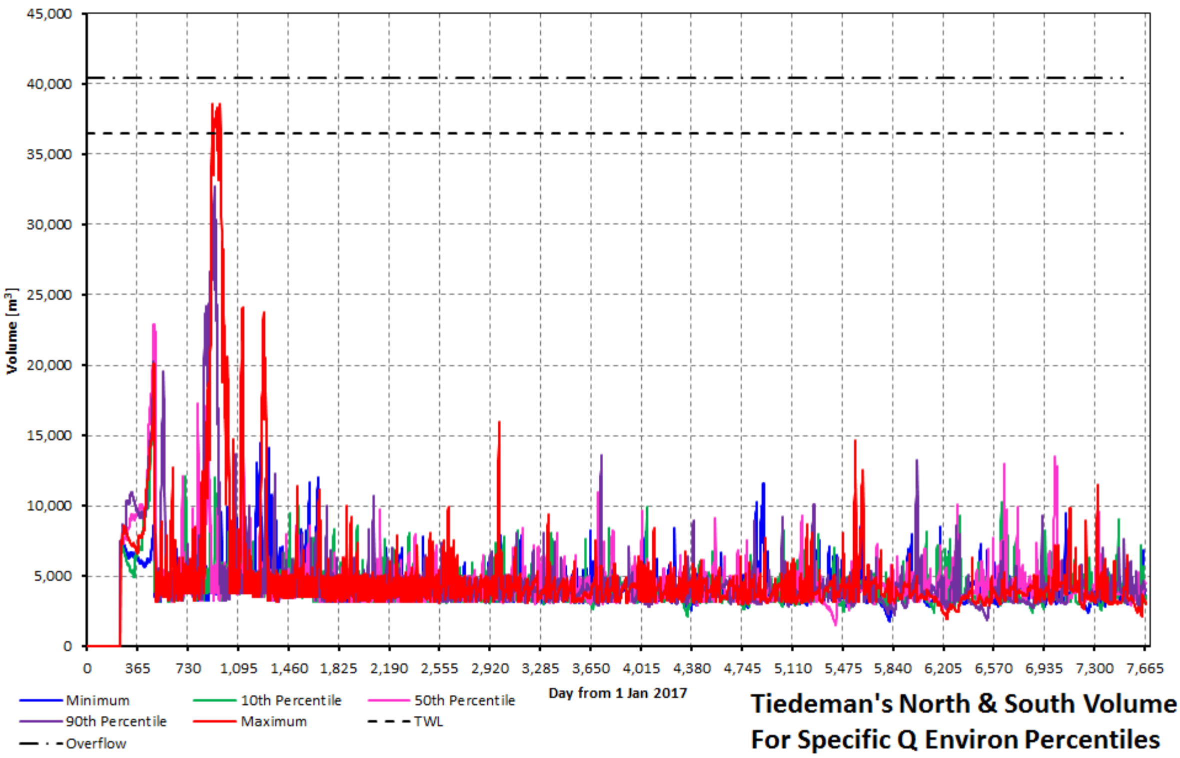

800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Flowrate [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Rainfall to Ponds & Dams
For Specific Q Environ Percentiles

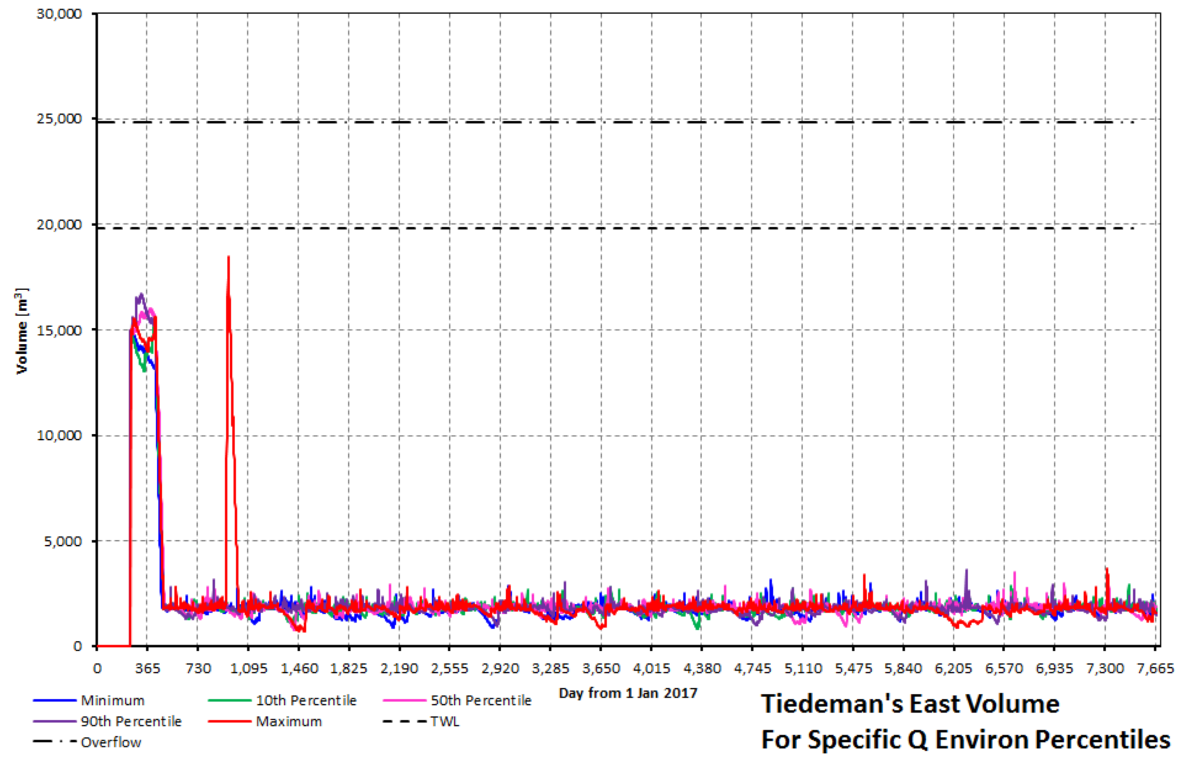
Appendix 7 Simulation Scenario 086 P90 Extracted Water Production: Large Irrigation Area

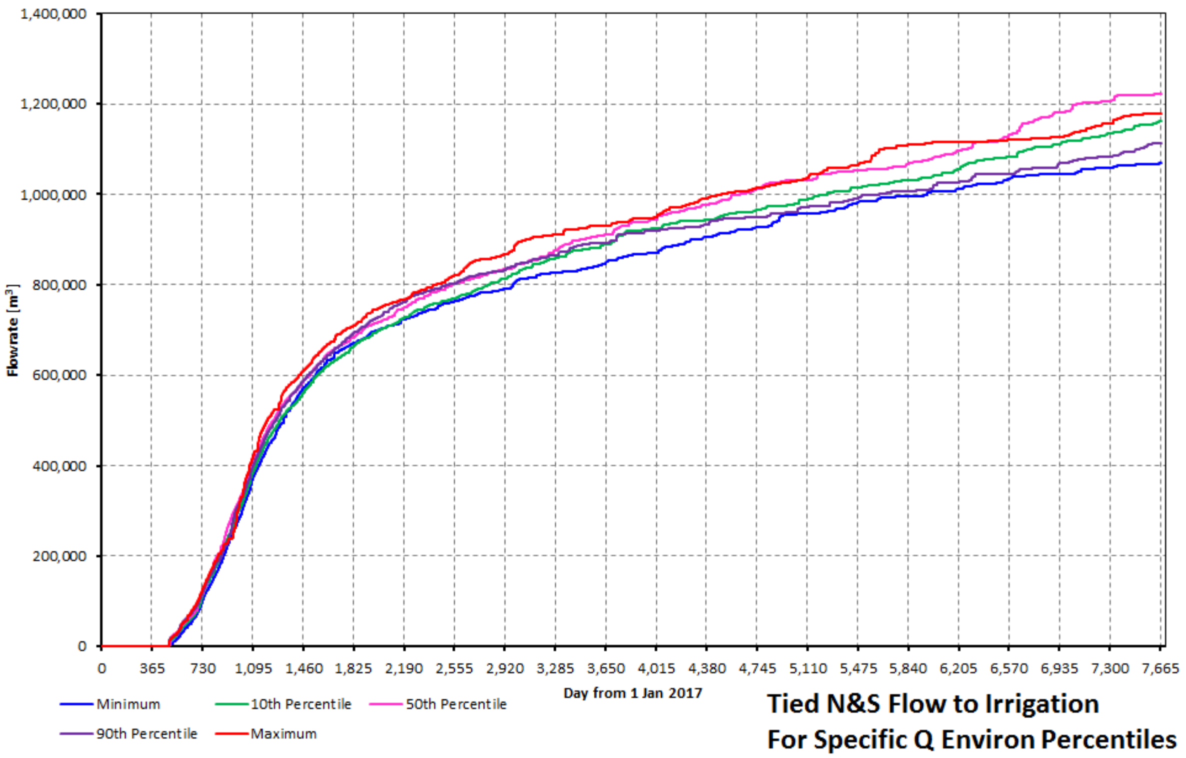

Flowrate [m³/d]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
RWP Flows In
For Specific Q Environ Percentiles

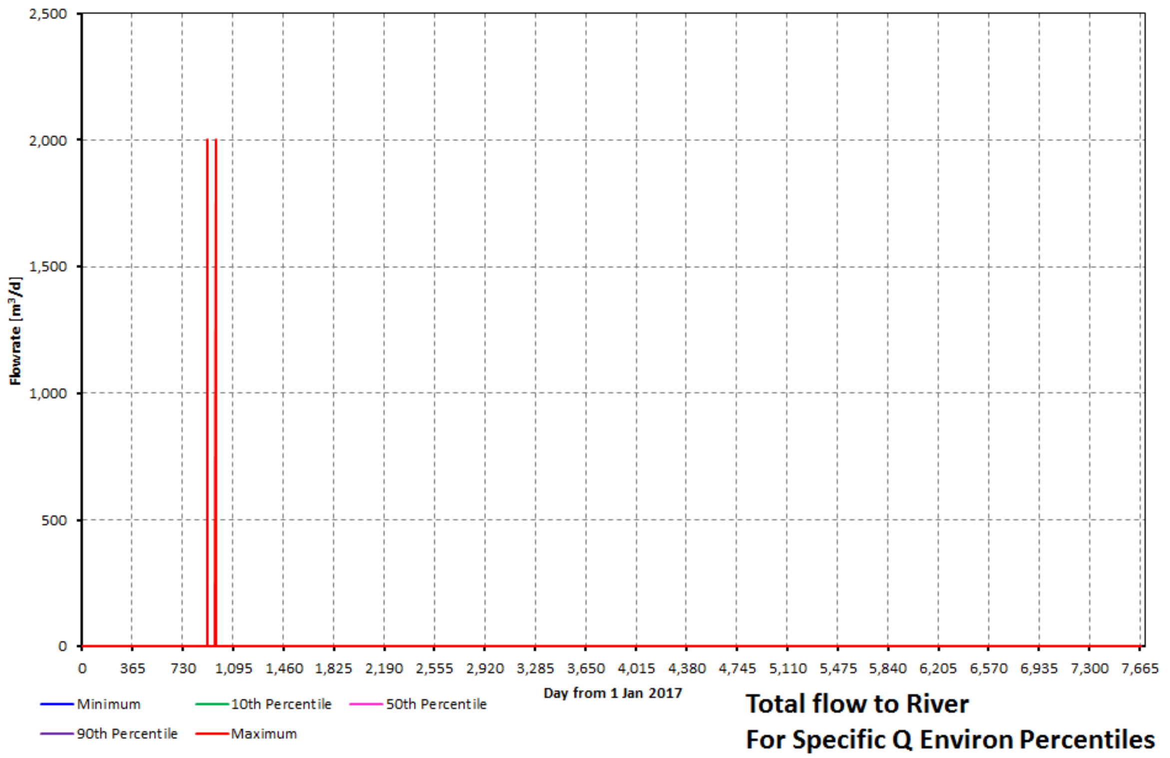

Volume [m³]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
RWP Volume
For Specific Q Environ Percentiles

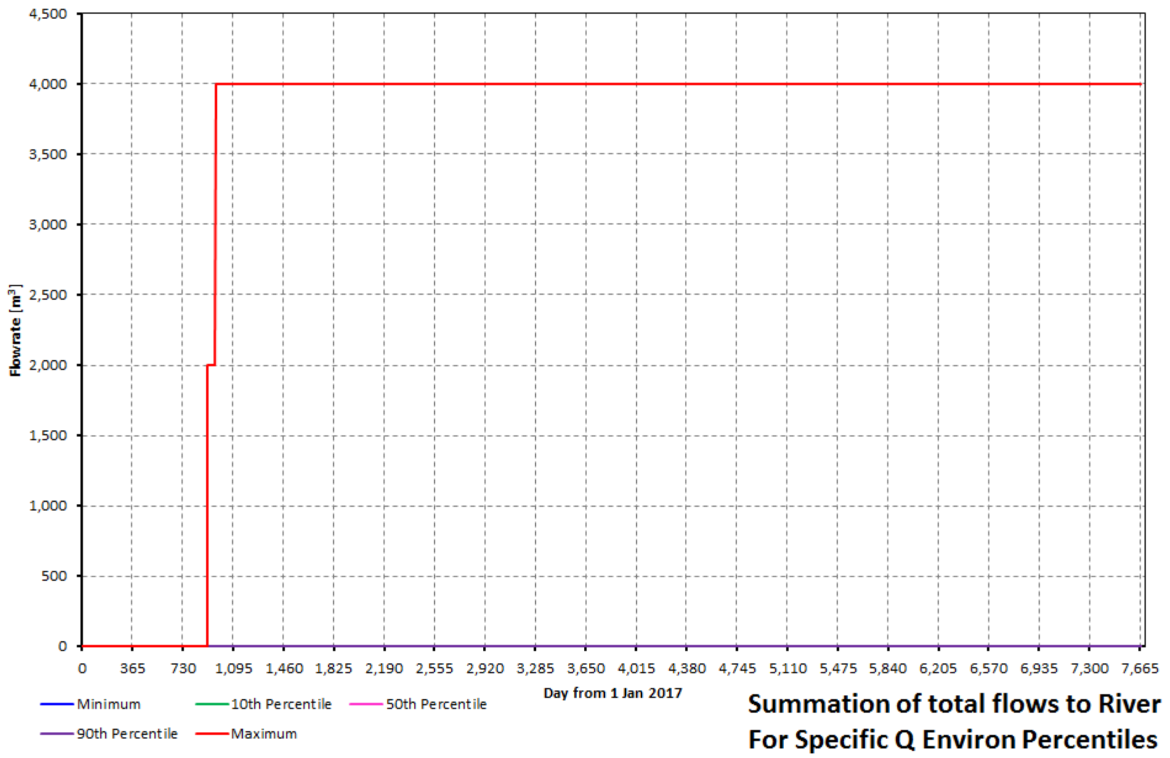

Volume [m³]
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
DWP Volume
For Specific Q Environ Percentiles

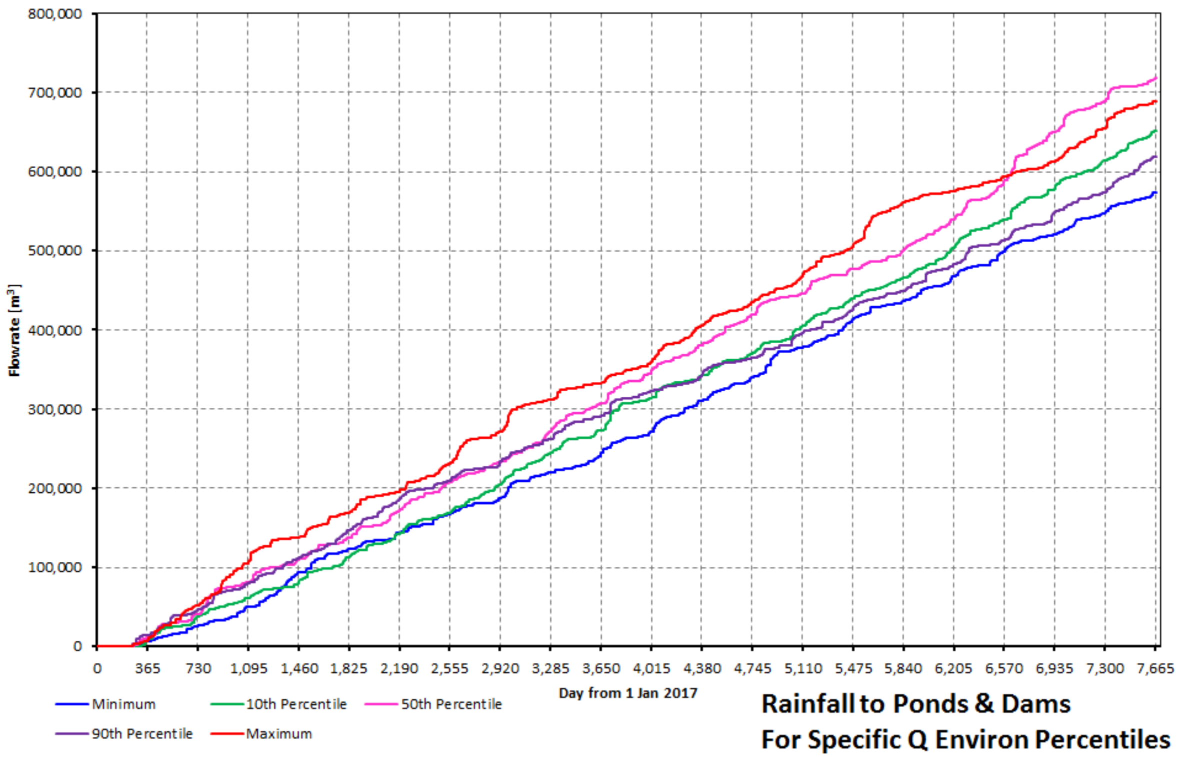

Volume [m³]
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's North & South Volume
For Specific Q Environ Percentiles


Volume [m³]
30,000
25,000
20,000
15,000
10,000
5,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's East Volume
For Specific Q Environ Percentiles

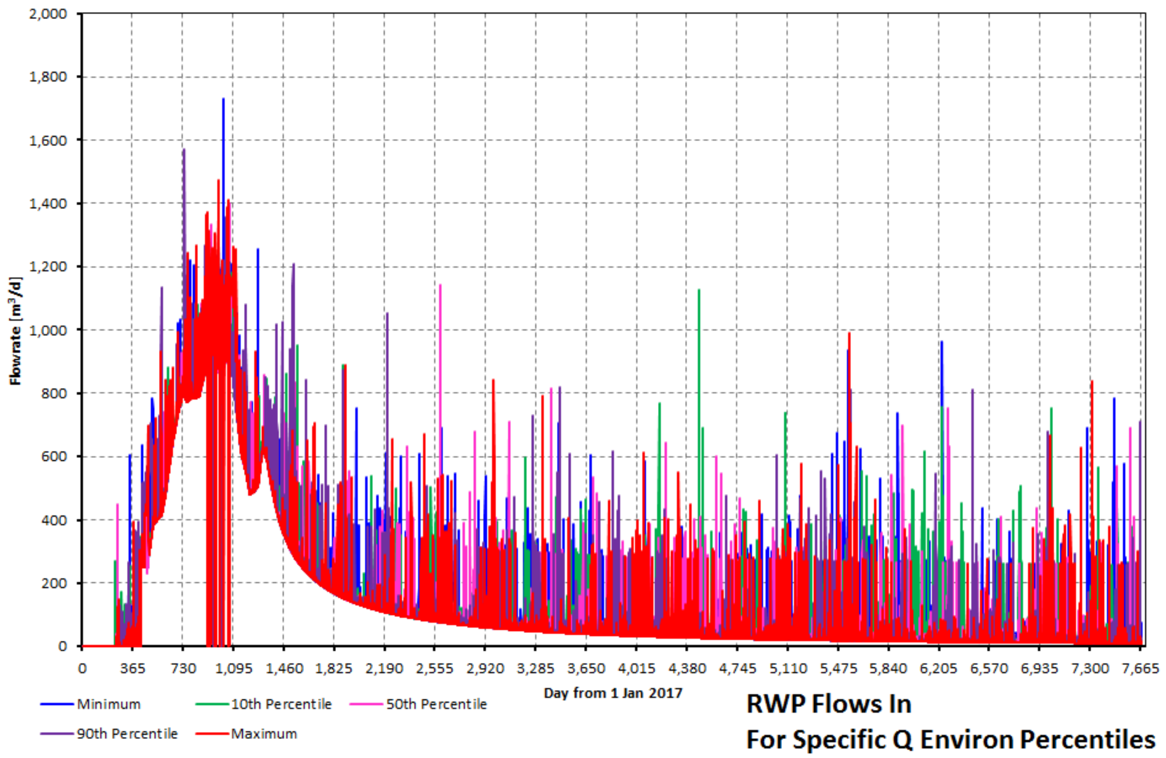

Flowrate [m³]
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Tied N&S Flow to Irrigation
For Specific Q Environ Percentiles

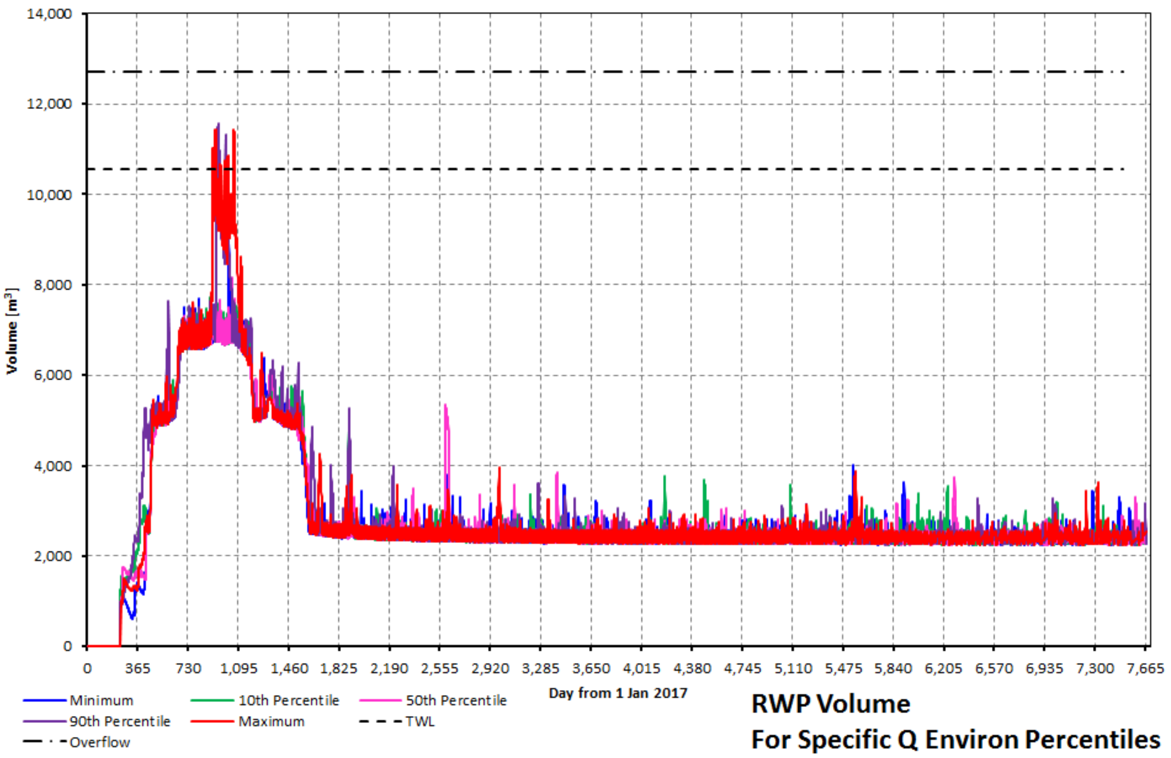

2,500
2,000
1,500
1,000
500
0
Flowrate [m³/d]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Total flow to River
For Specific Q Environ Percentiles

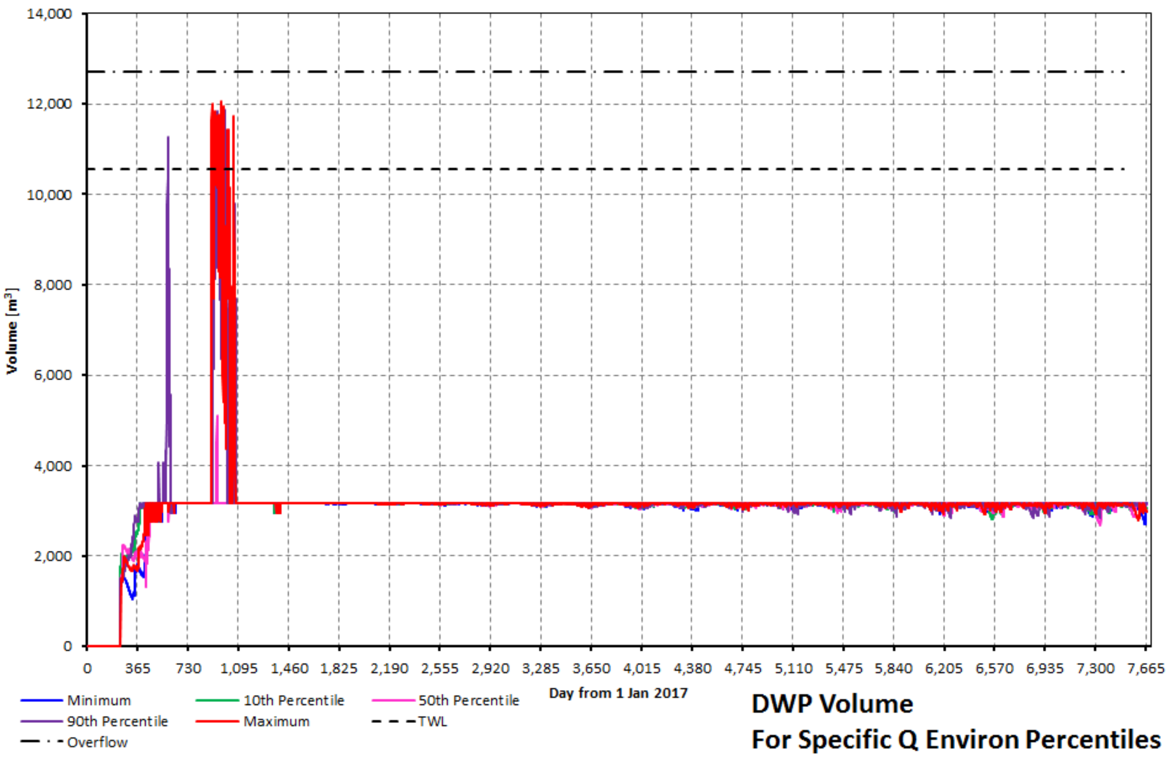

4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Flowrate [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Summation of total flows to River
For Specific Q Environ Percentiles

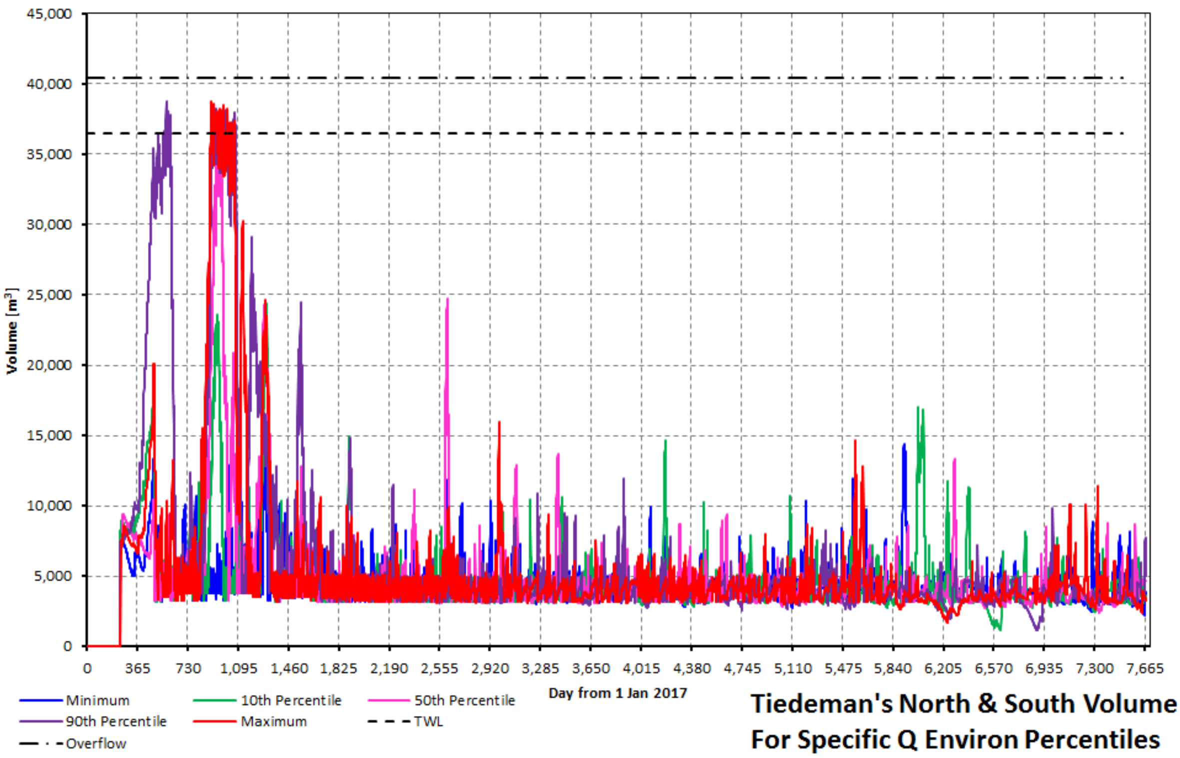

800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Flowrate [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Rainfall to Ponds & Dams
For Specific Q Environ Percentiles

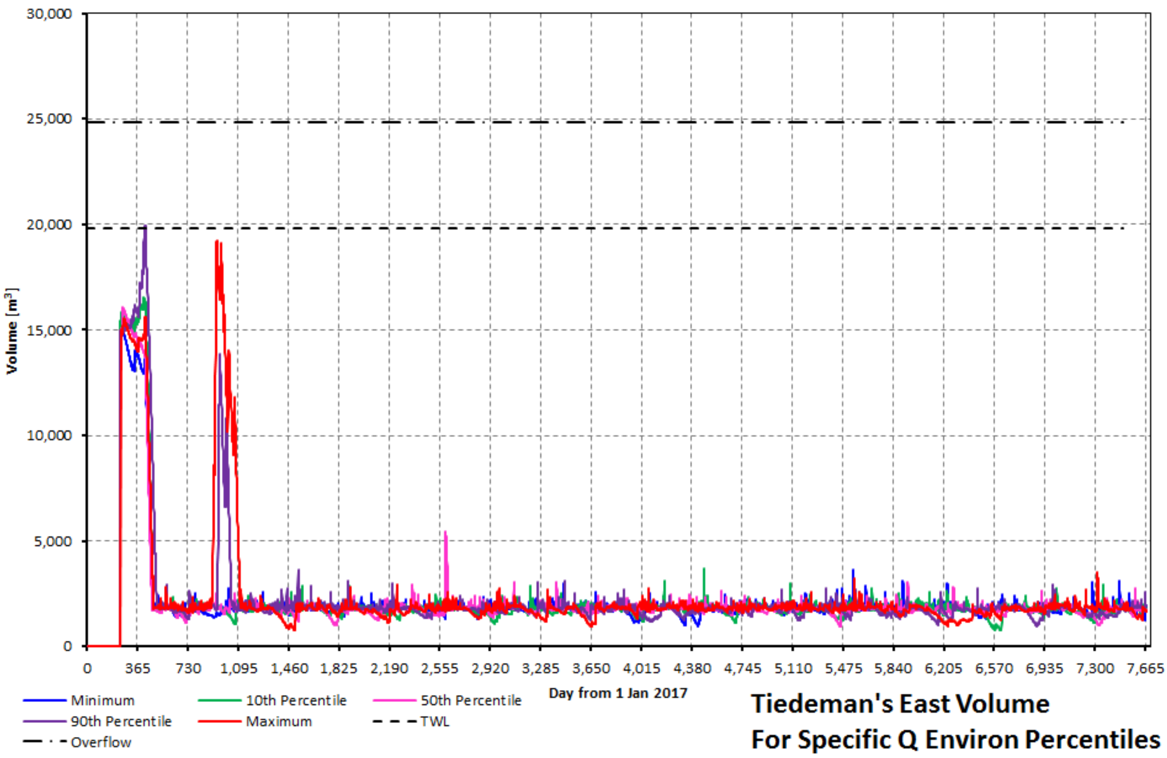
Appendix 8 Simulation Scenario 07: P90 Extracted Water Production: Small Irrigation Area

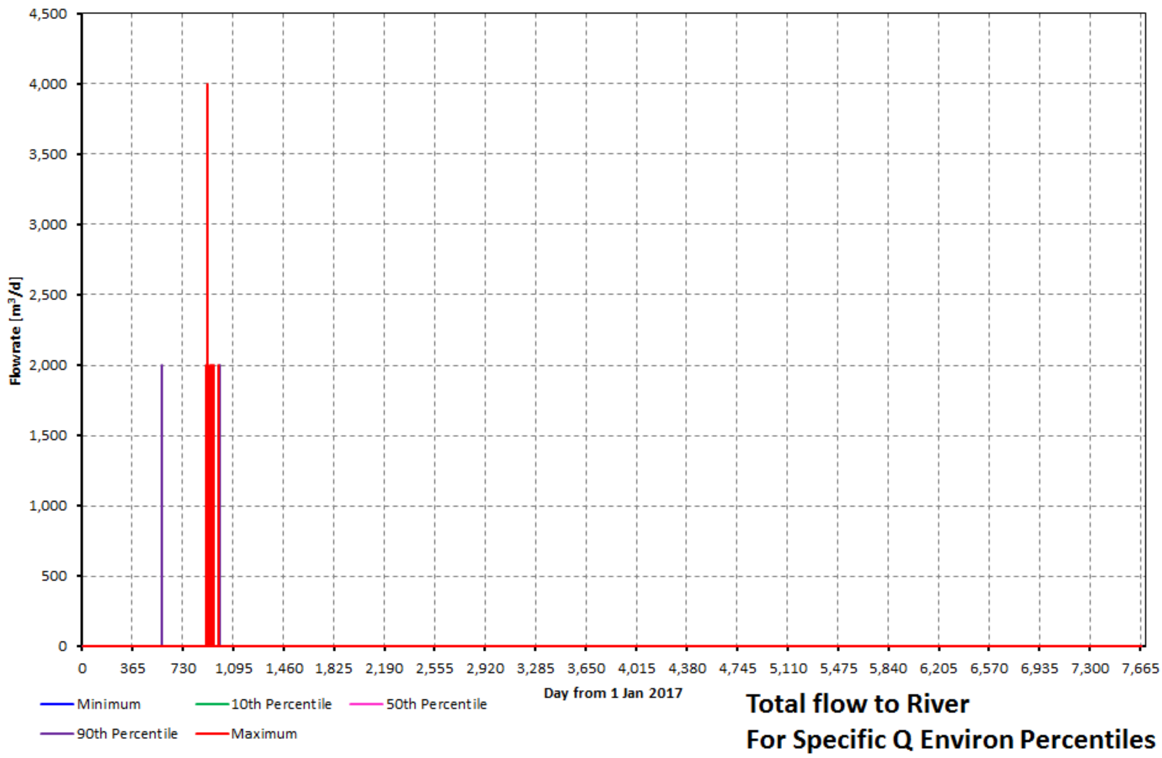

Flowrate [m³/d]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
RWP Flows In
For Specific Q Environ Percentiles

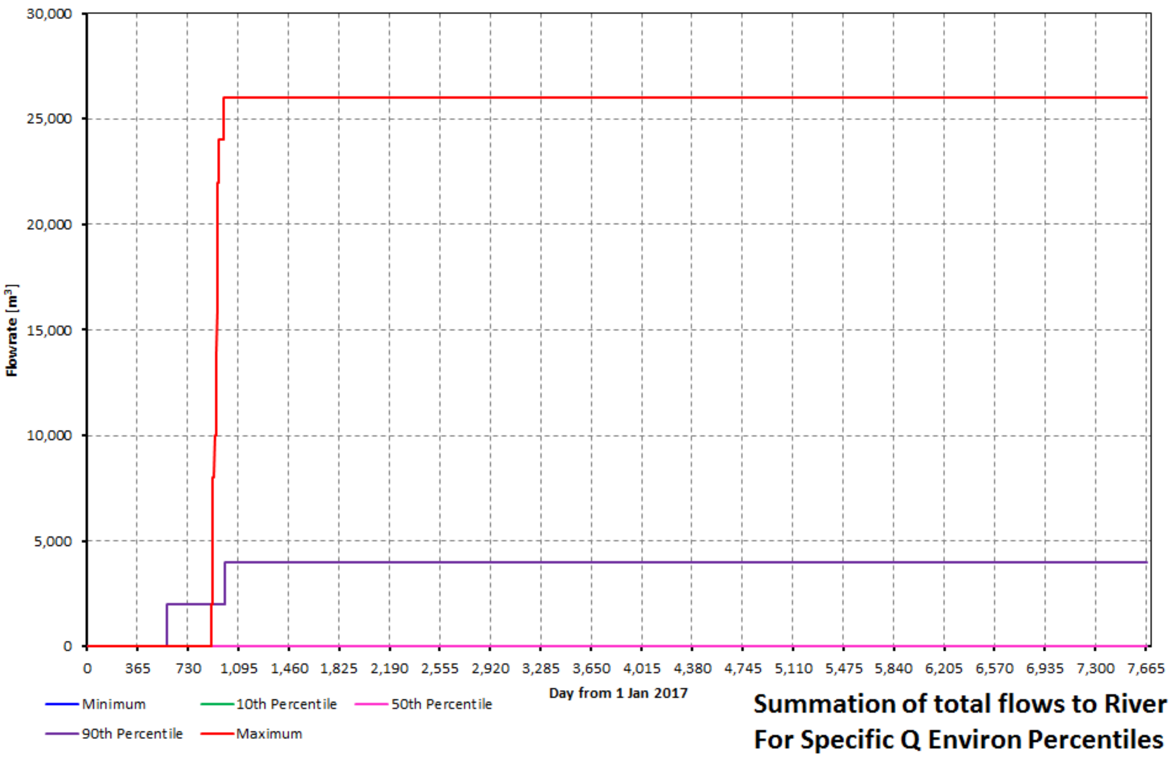

Volume [m³]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
RWP Volume
For Specific Q Environ Percentiles


14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
DWP Volume
For Specific Q Environ Percentiles


45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's North & South Volume
For Specific Q Environ Percentiles

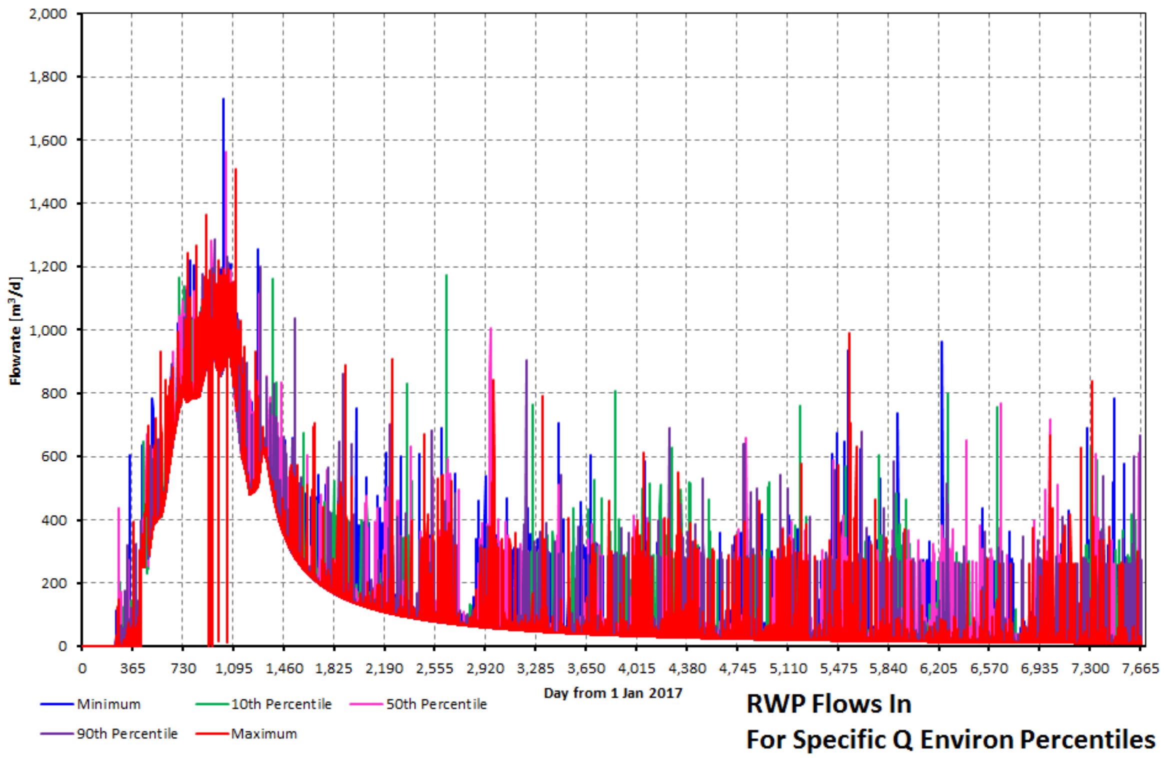

30,000
25,000
20,000
15,000
10,000
5,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's East Volume
For Specific Q Environ Percentiles


4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Flowrate [m³/d]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Total flow to River
For Specific Q Environ Percentiles

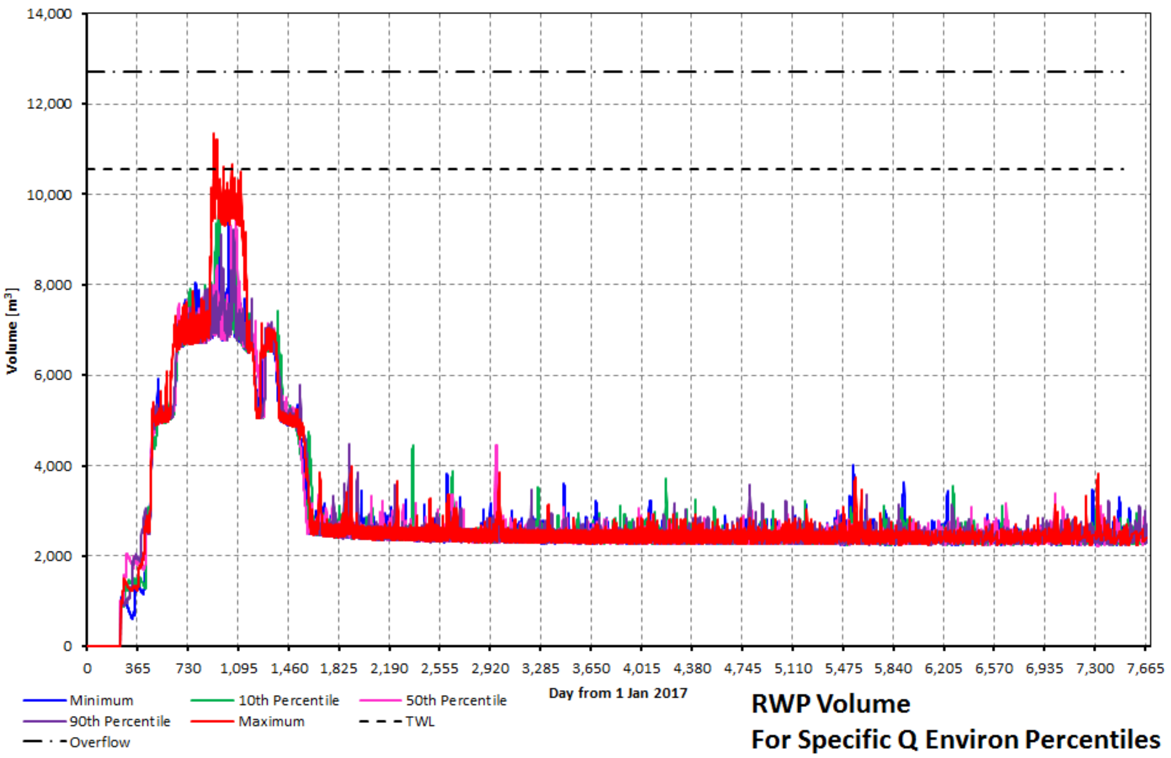


Summation of total flows to River
For Specific Q Environ Percentiles

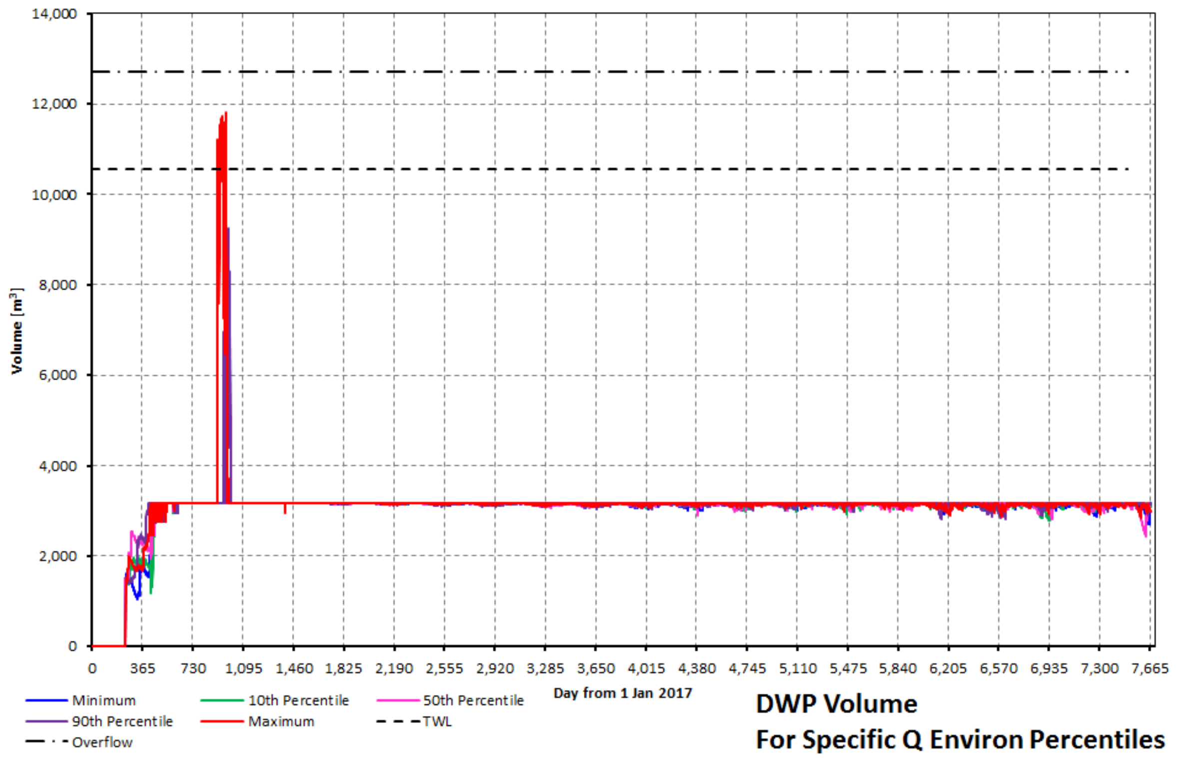
Appendix 9 Simulation Scenario 11: P90 Extracted Water Production: 10% Capacity Reduction & 90% Availability

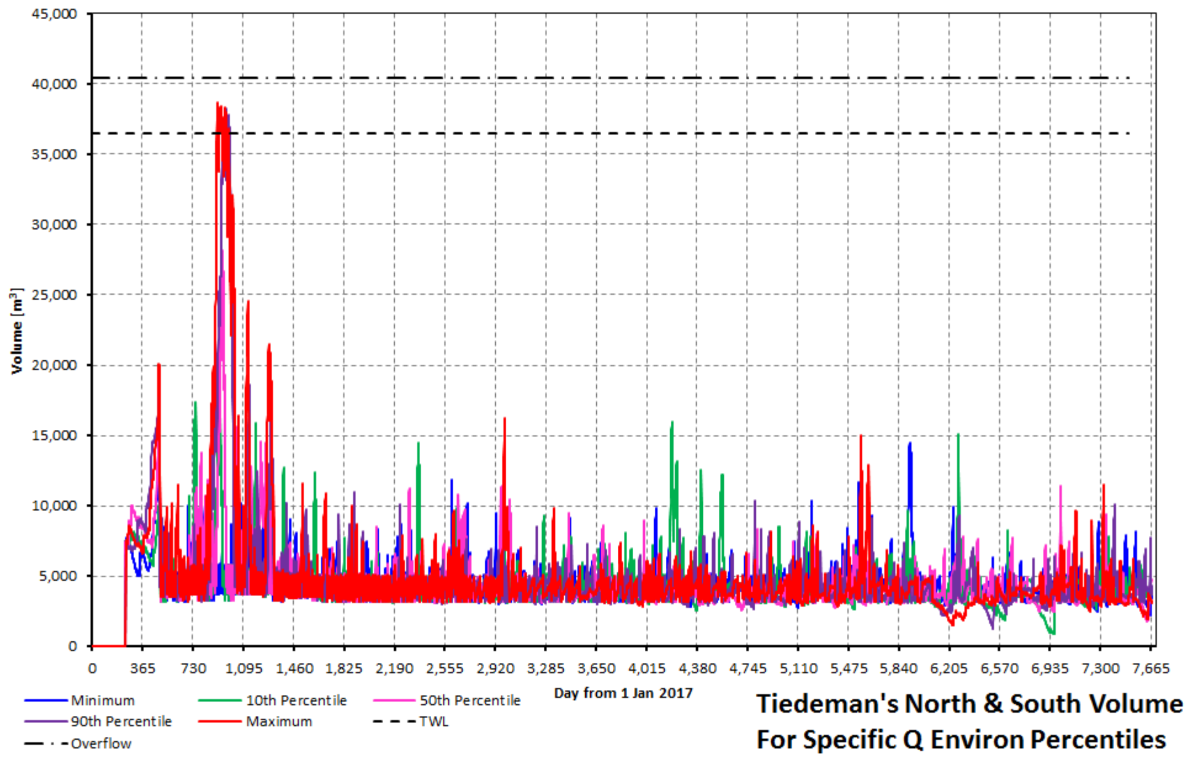


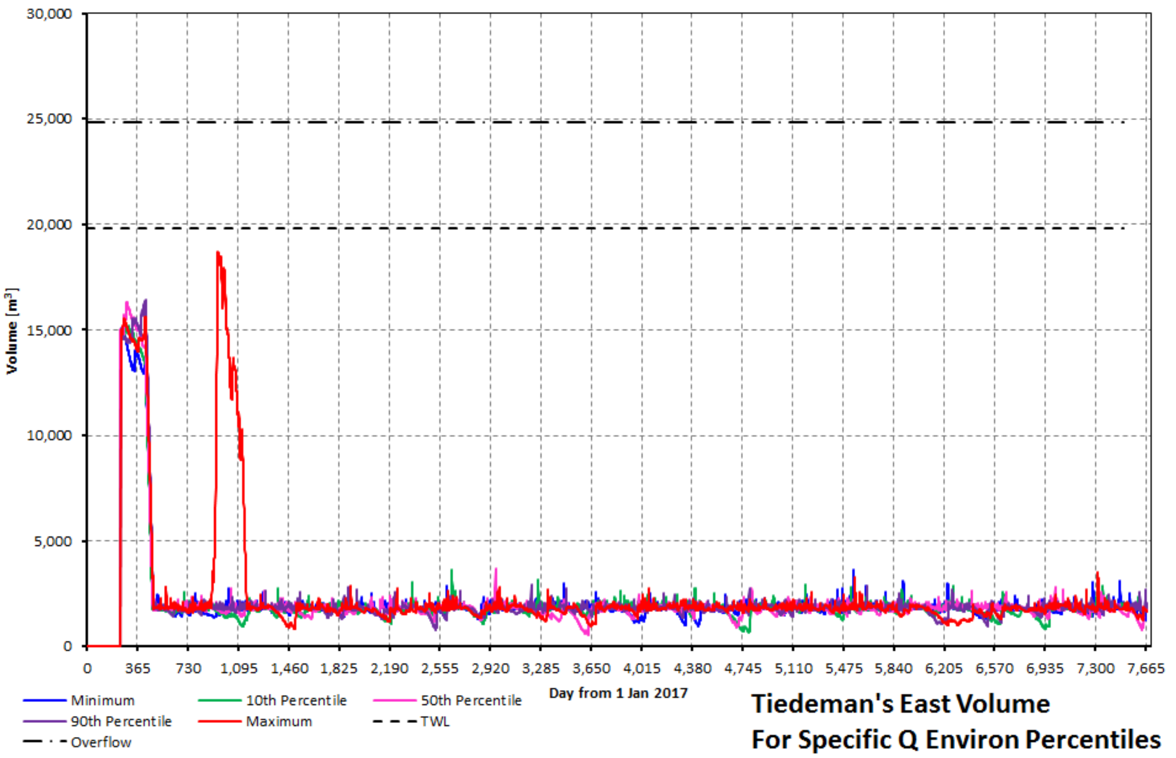
RWP Flows In
For Specific Q Environ Percentiles

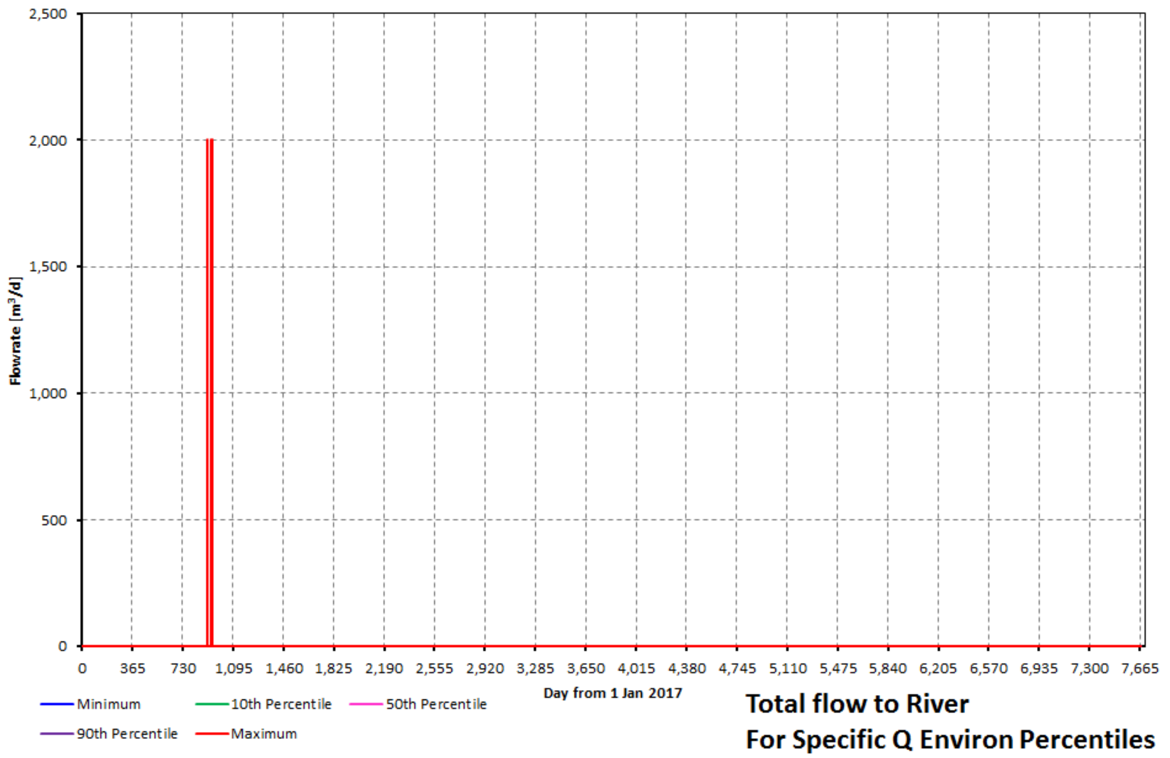


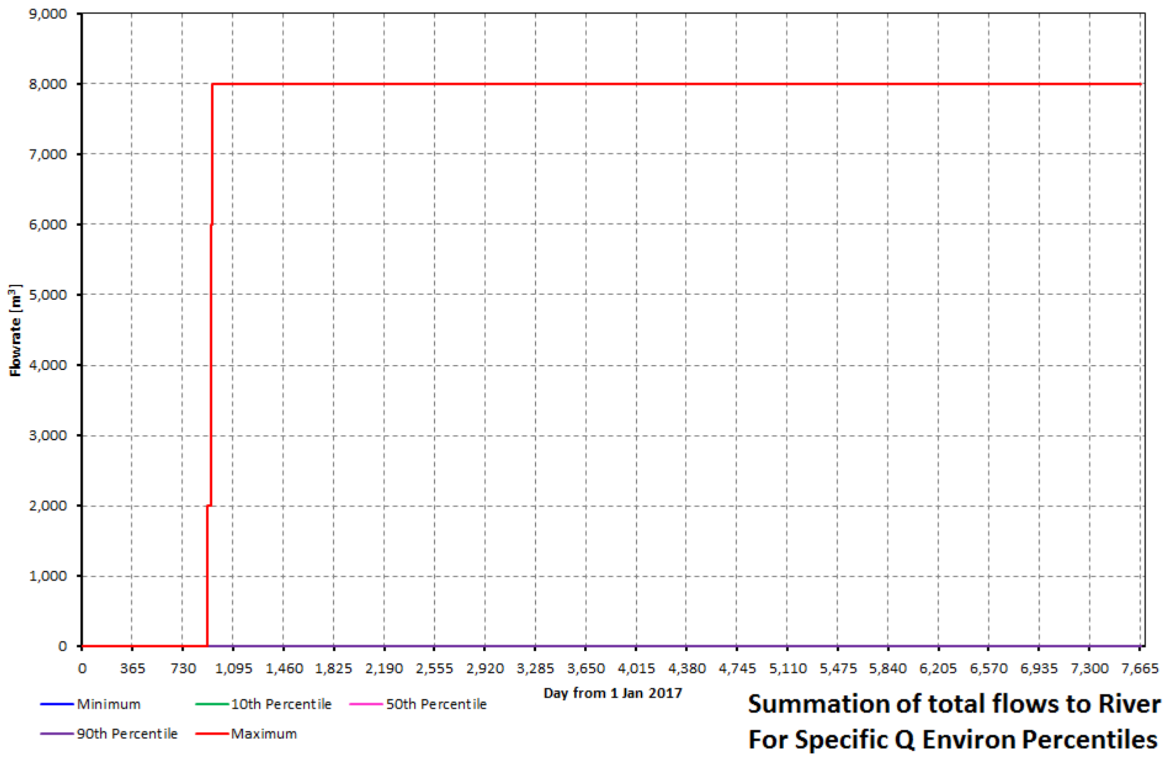
RWP Volume
For Specific Q Environ Percentiles


Volume [m³]
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
DWP Volume
For Specific Q Environ Percentiles

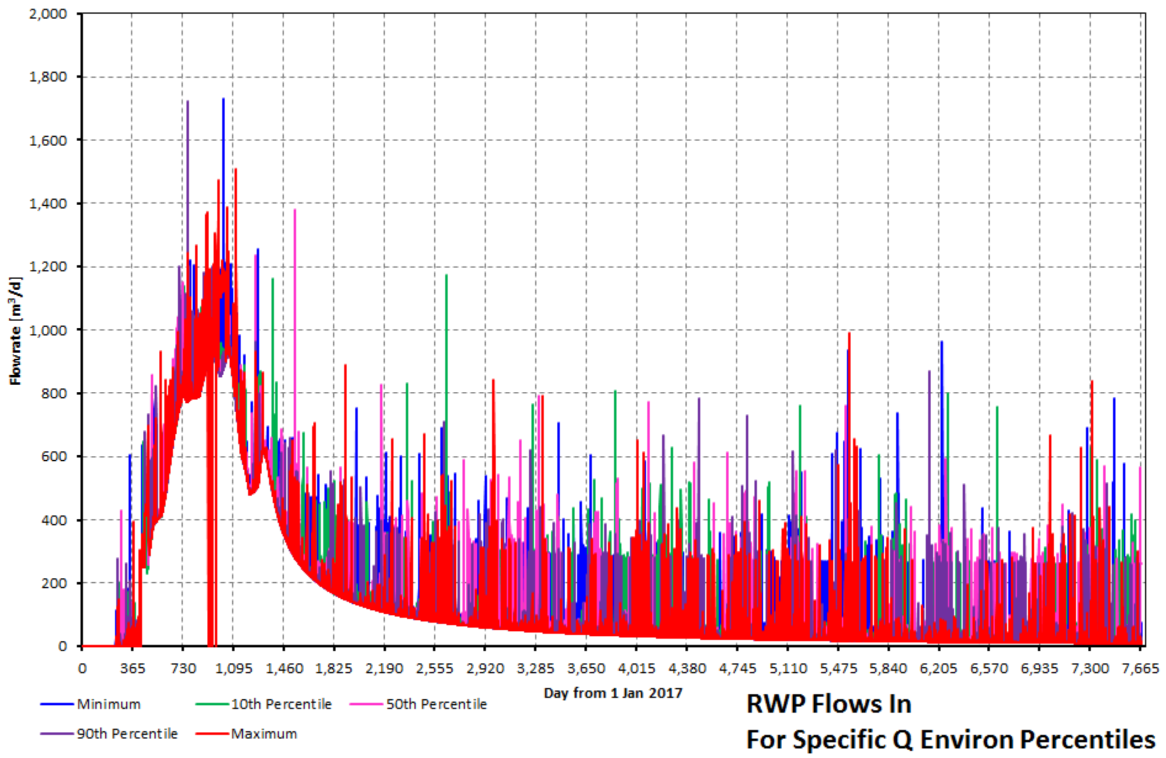

Volume [m³]
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's North & South Volume
For Specific Q Environ Percentiles

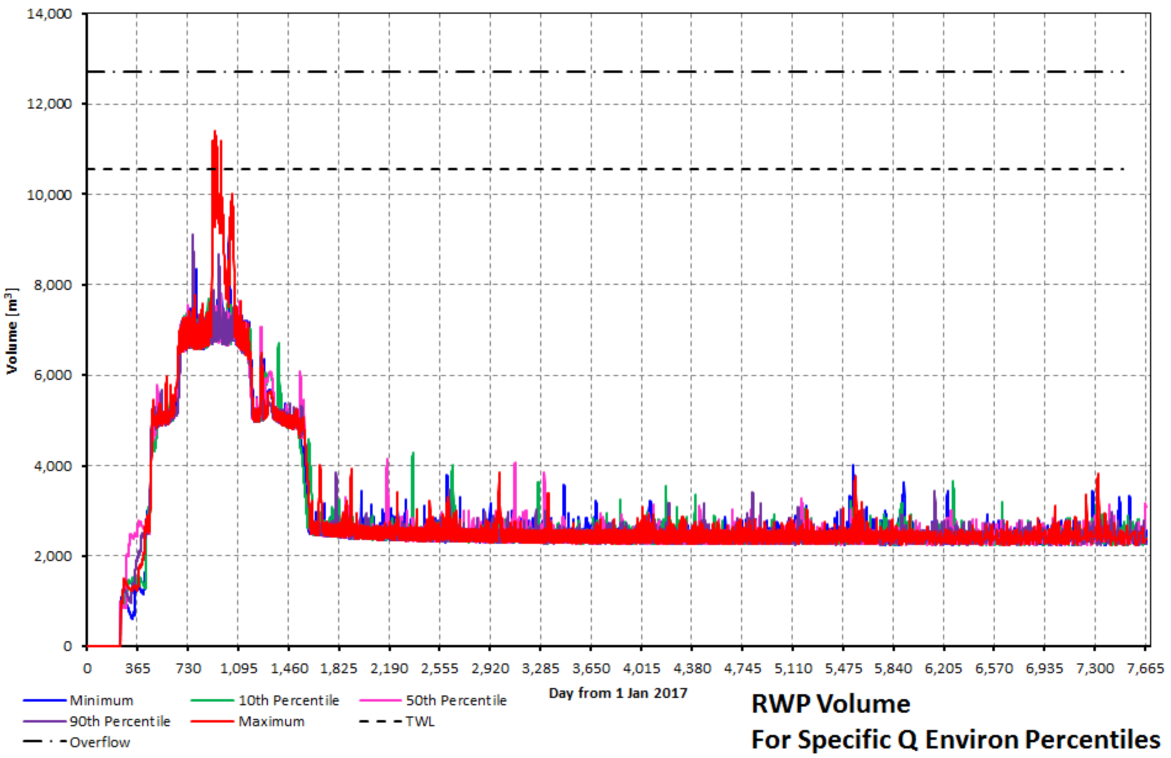

Volume [m³]
30,000
25,000
20,000
15,000
10,000
5,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's East Volume
For Specific Q Environ Percentiles

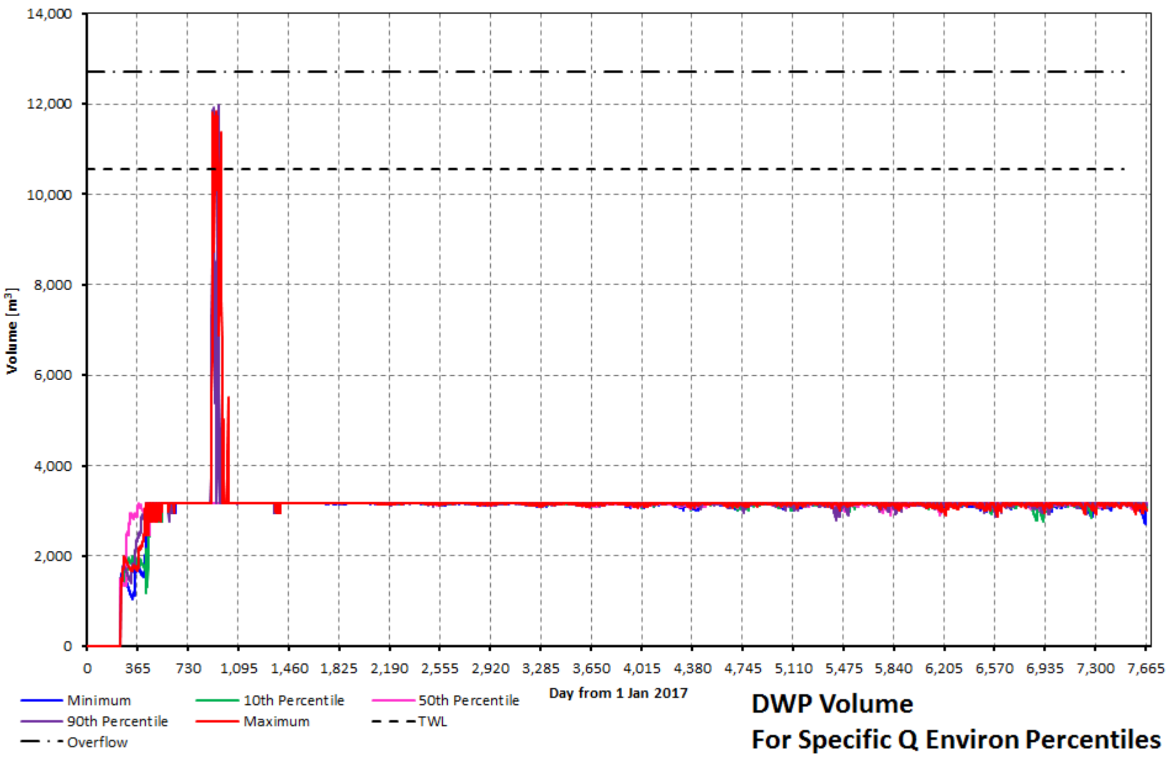

Flowrate [m³/d]
2,500
2,000
1,500
1,000
500
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Total flow to River
For Specific Q Environ Percentiles

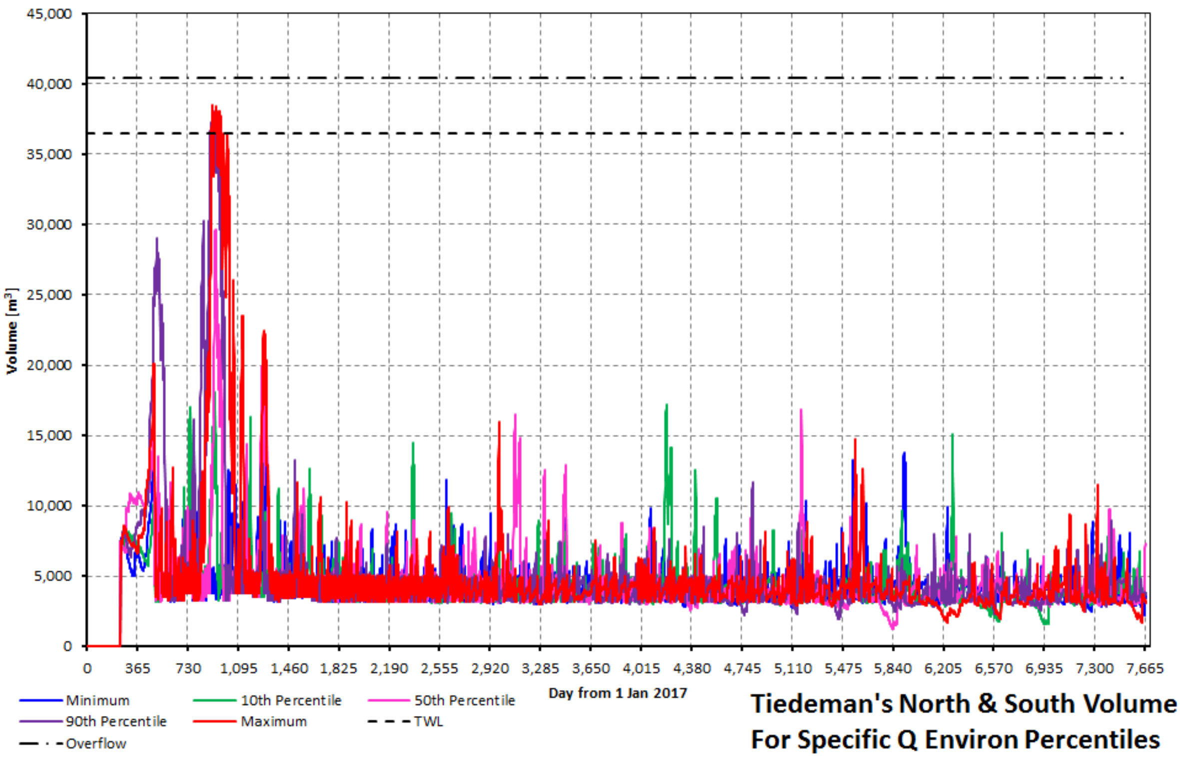

9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Flowrate [m³]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Summation of total flows to River
For Specific Q Environ Percentiles

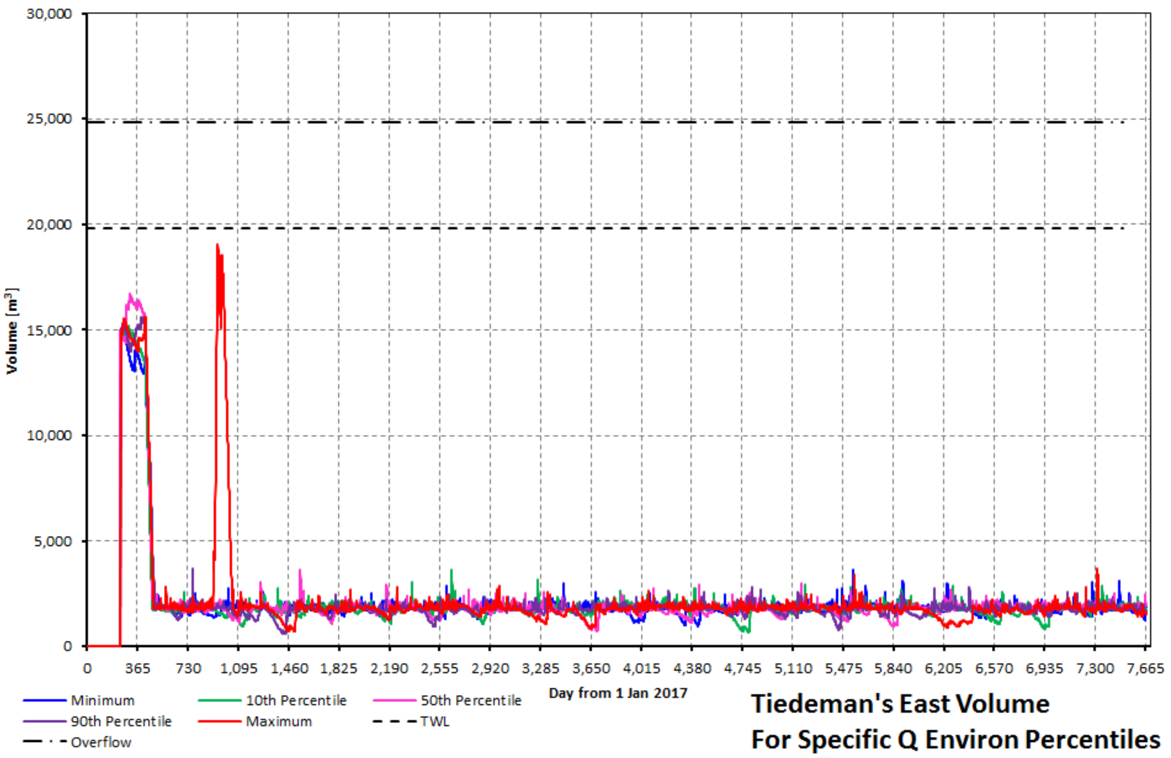
Appendix 10 Simulation Scenario 12: P90 Extracted Water Production: Light Frost

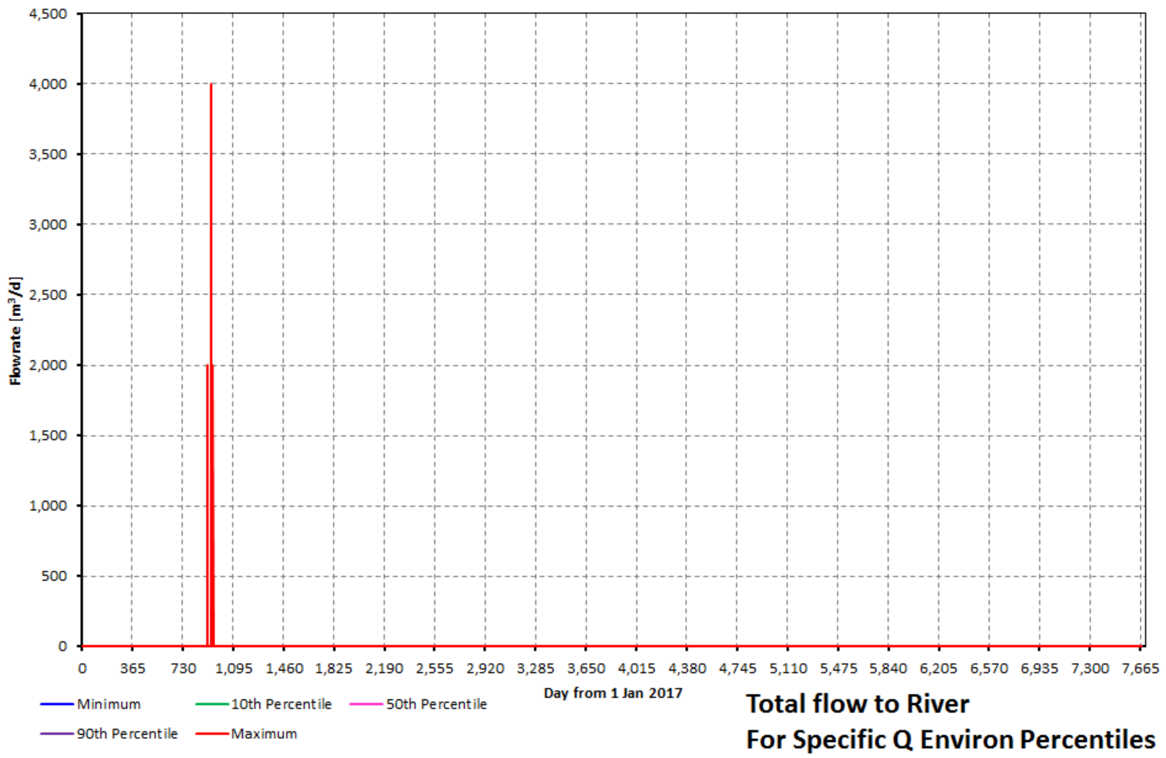

2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Flowrate [m³/d]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
RWP Flows In
For Specific Q Environ Percentiles

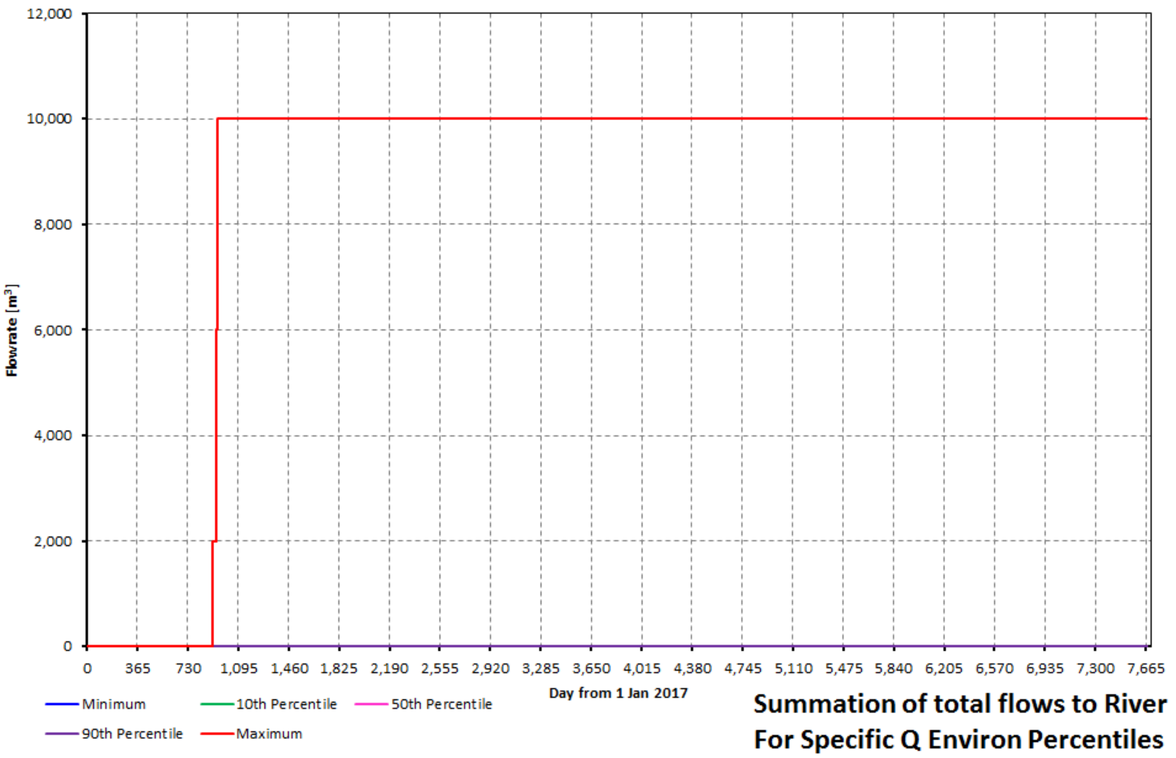

14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Volume [m³]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
RWP Volume
For Specific Q Environ Percentiles


Volume [m³]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
DWP Volume
For Specific Q Environ Percentiles

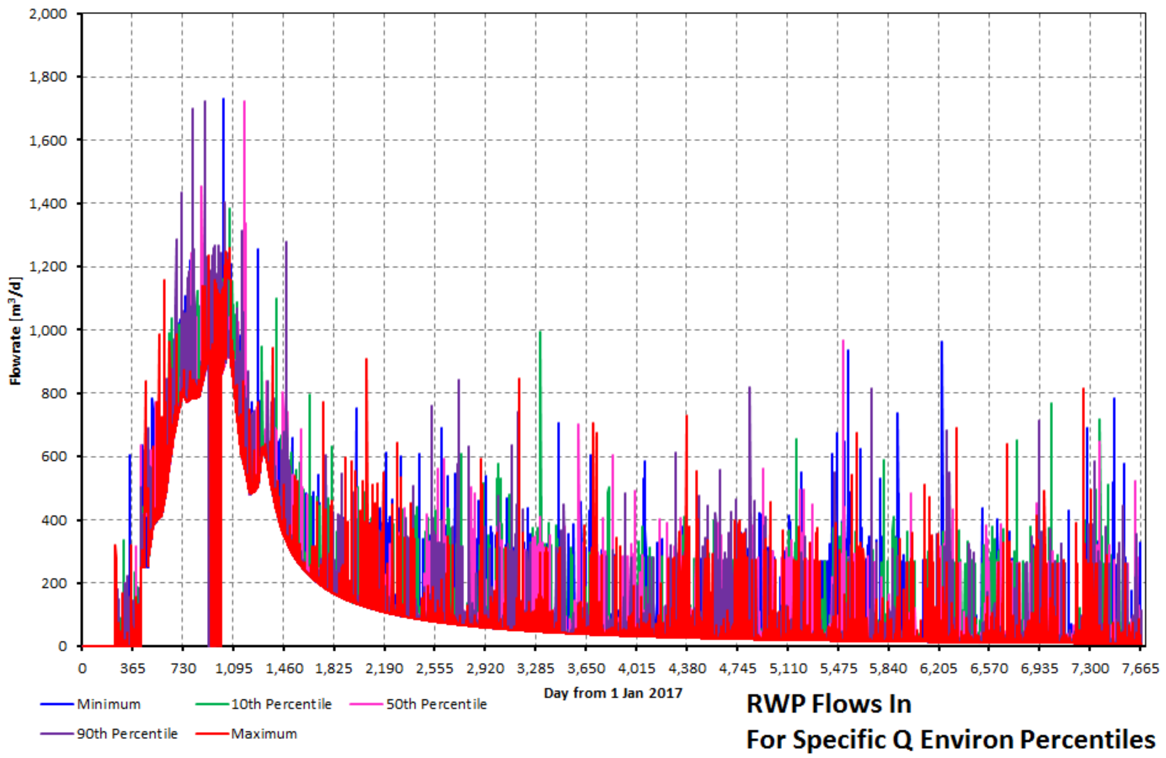

Volume [m³]
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's North & South Volume
For Specific Q Environ Percentiles

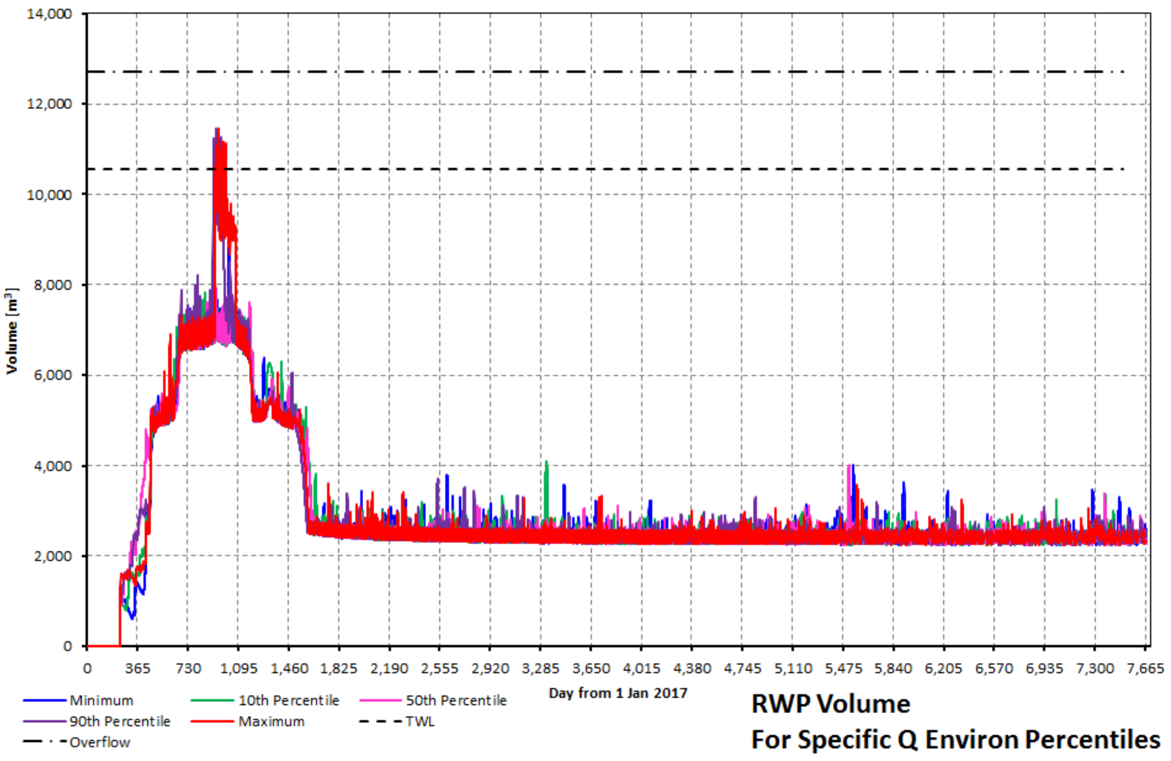

Volume [m³]
30,000
25,000
20,000
15,000
10,000
5,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's East Volume
For Specific Q Environ Percentiles

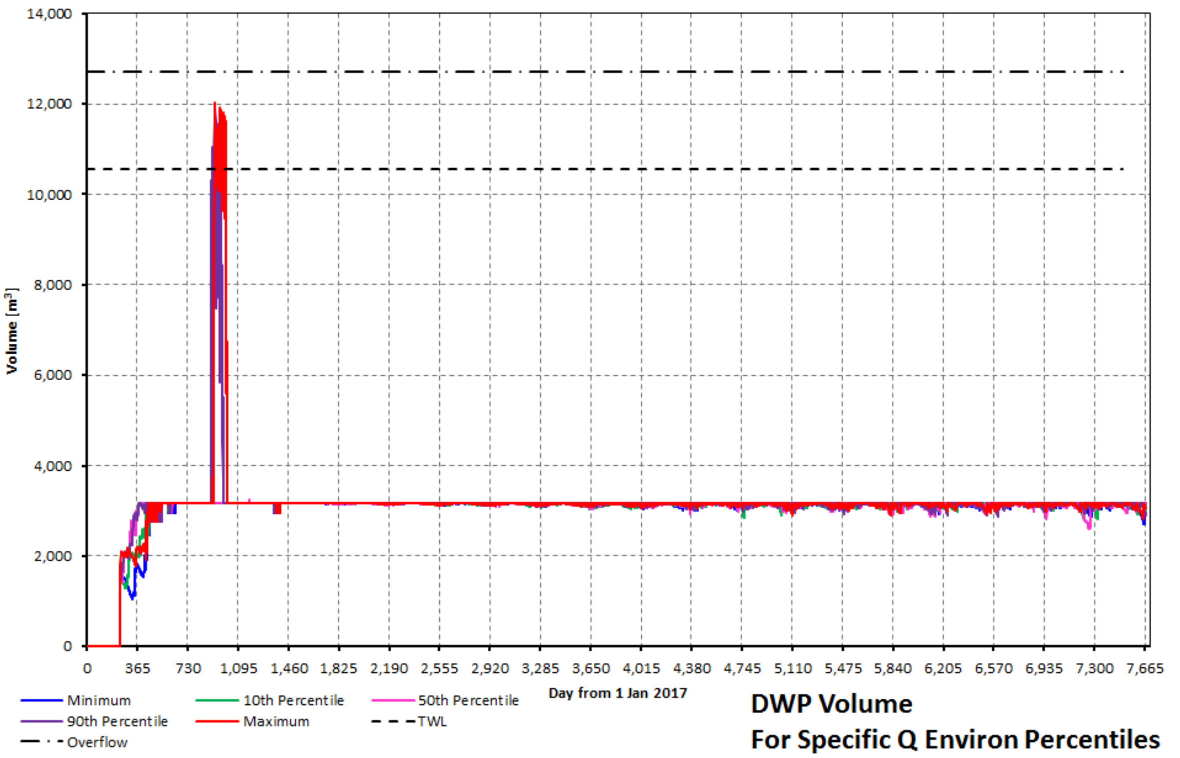

Flowrate [m³/d]
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Total flow to River
For Specific Q Environ Percentiles

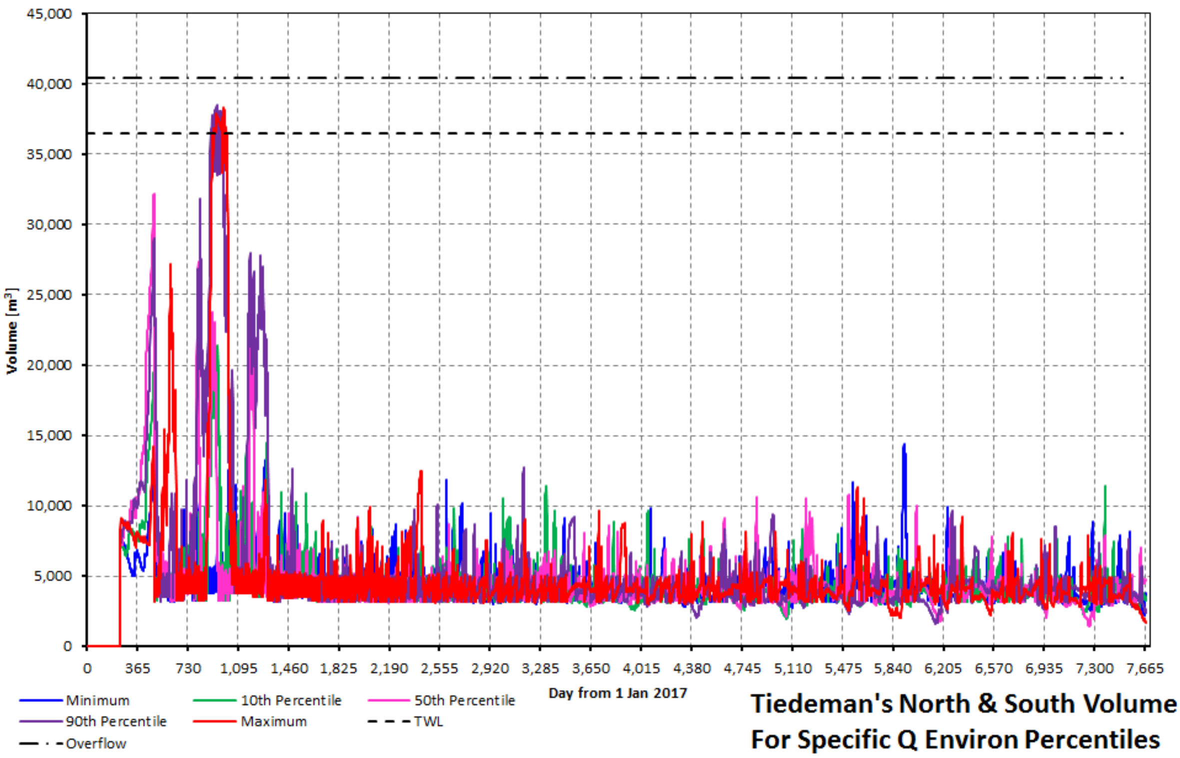

12,000
10,000
8,000
6,000
4,000
2,000
0
Flowrate [m3]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Summation of total flows to River
For Specific Q Environ Percentiles

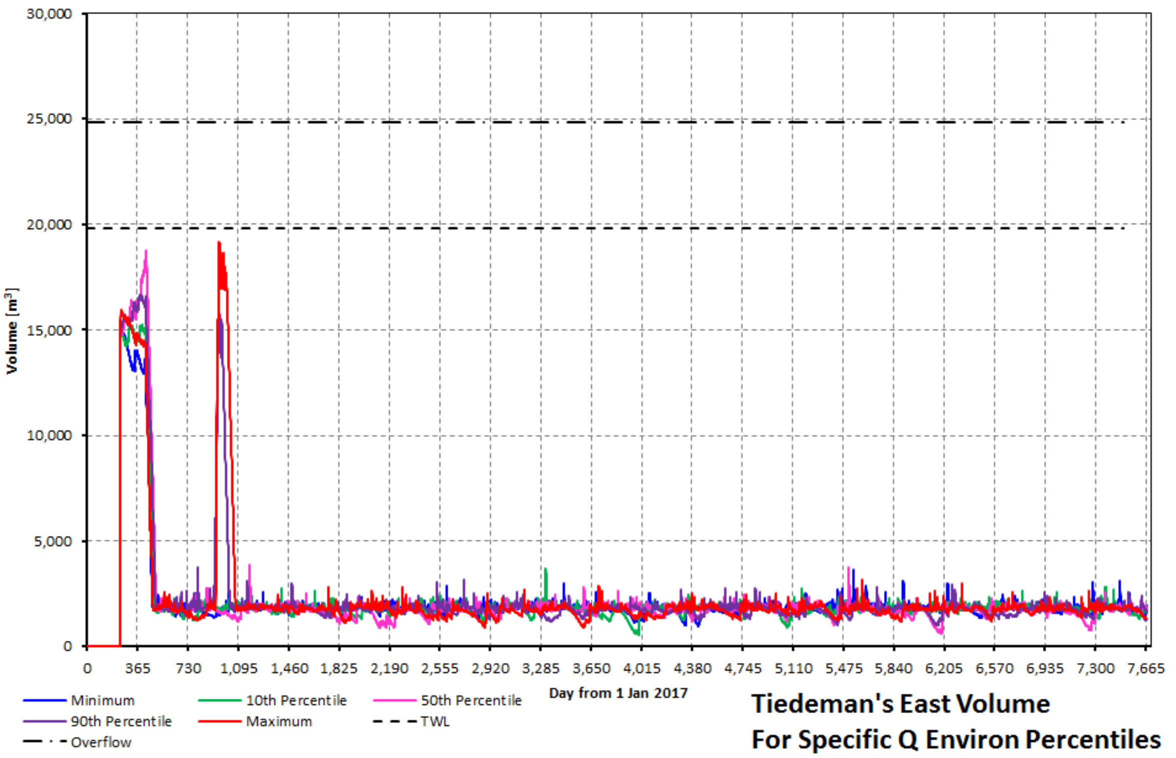
Appendix 11 Simulation Scenario 12: P90 Extracted Water Production: Heavy Frost

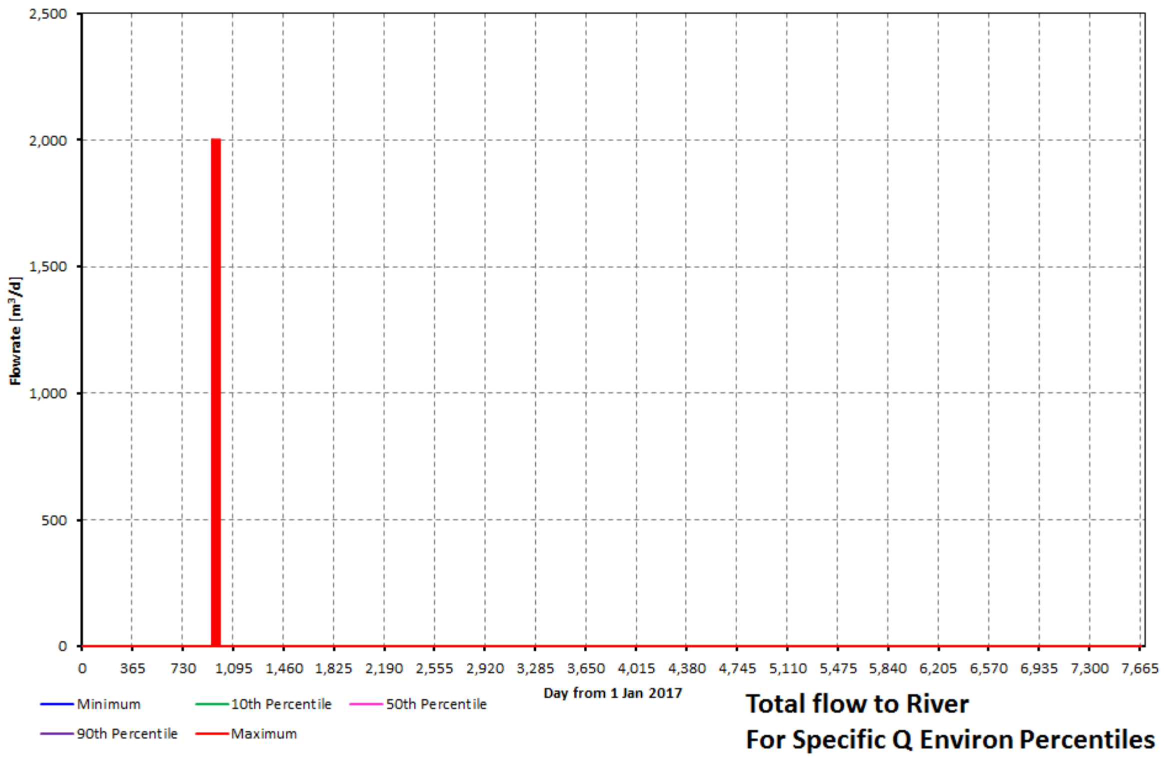

Flowrate [m³/d]
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
RWP Flows In
For Specific Q Environ Percentiles

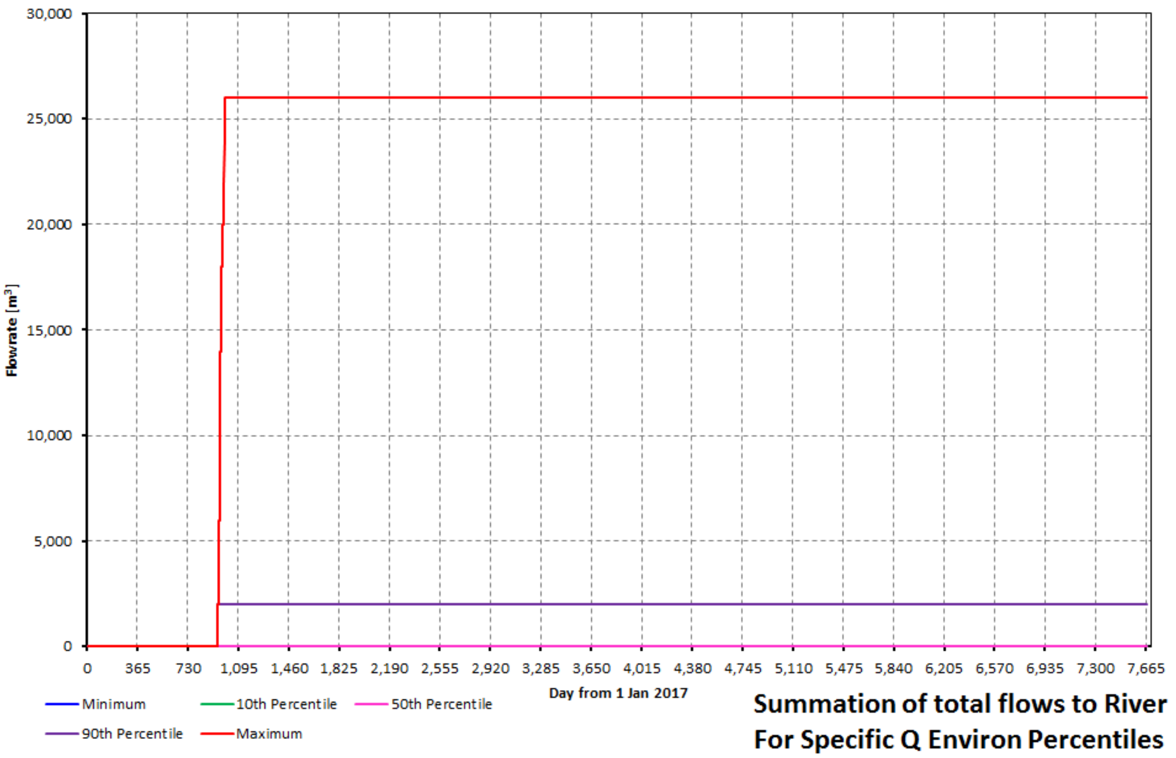

Volume [m³]
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
RWP Volume
For Specific Q Environ Percentiles


14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
DWP Volume
For Specific Q Environ Percentiles

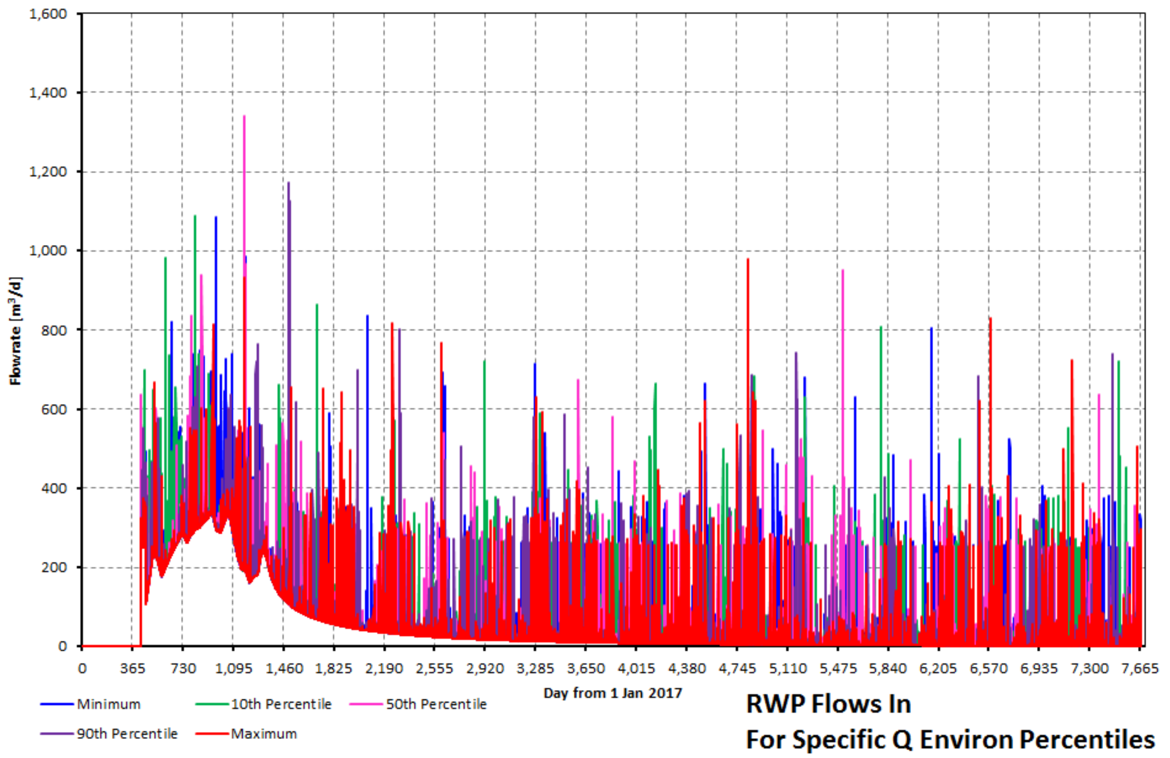

45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's North & South Volume
For Specific Q Environ Percentiles

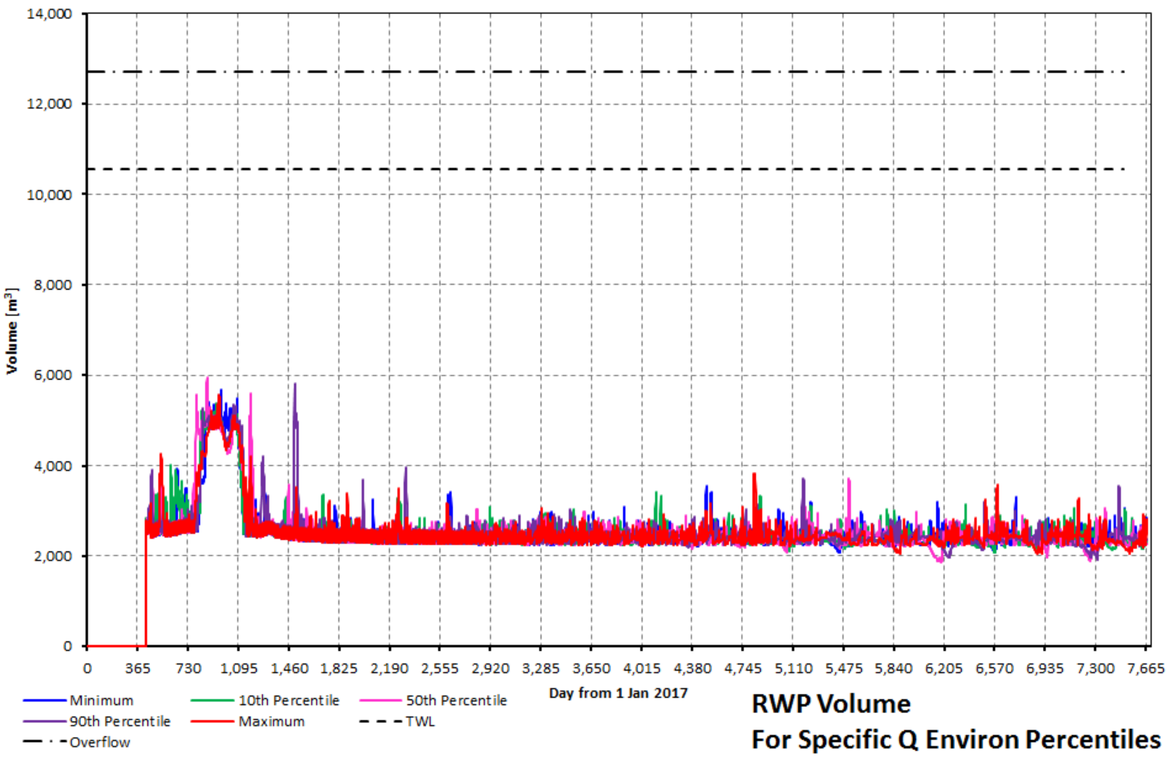

30,000
25,000
20,000
15,000
10,000
5,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's East Volume
For Specific Q Environ Percentiles

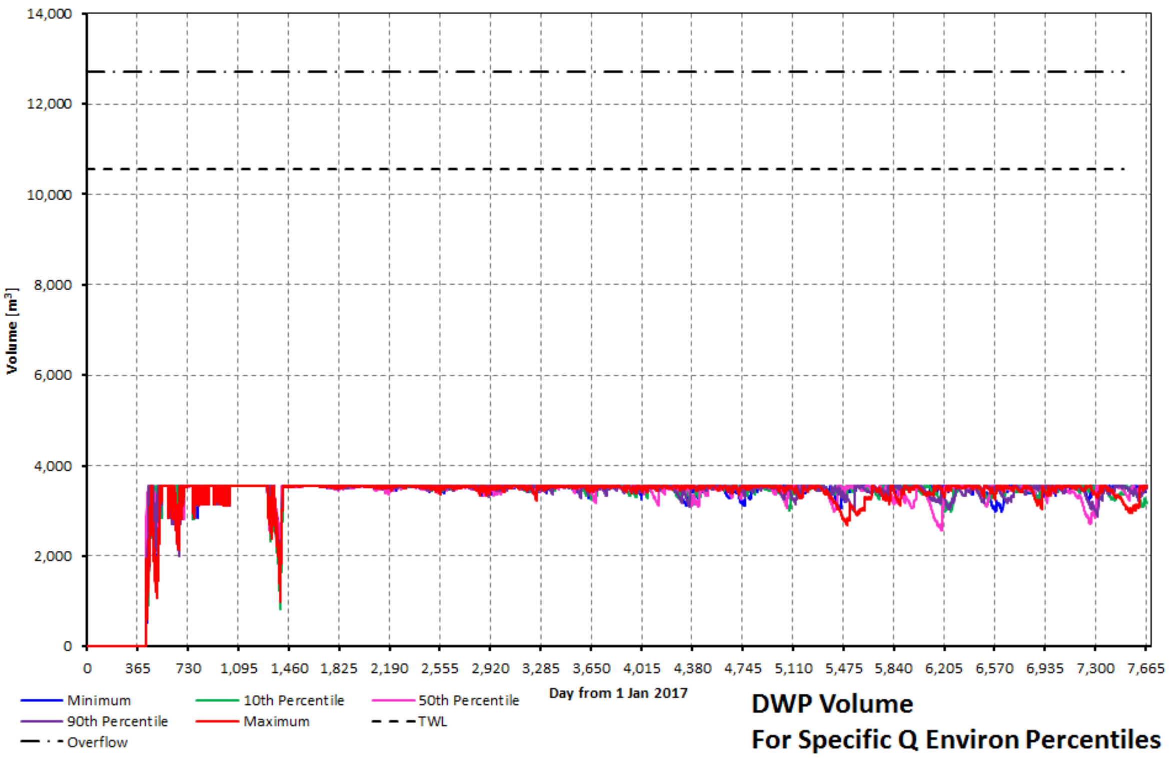

2,500
2,000
1,500
1,000
500
0
Flowrate [m³/d]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Total flow to River
For Specific Q Environ Percentiles

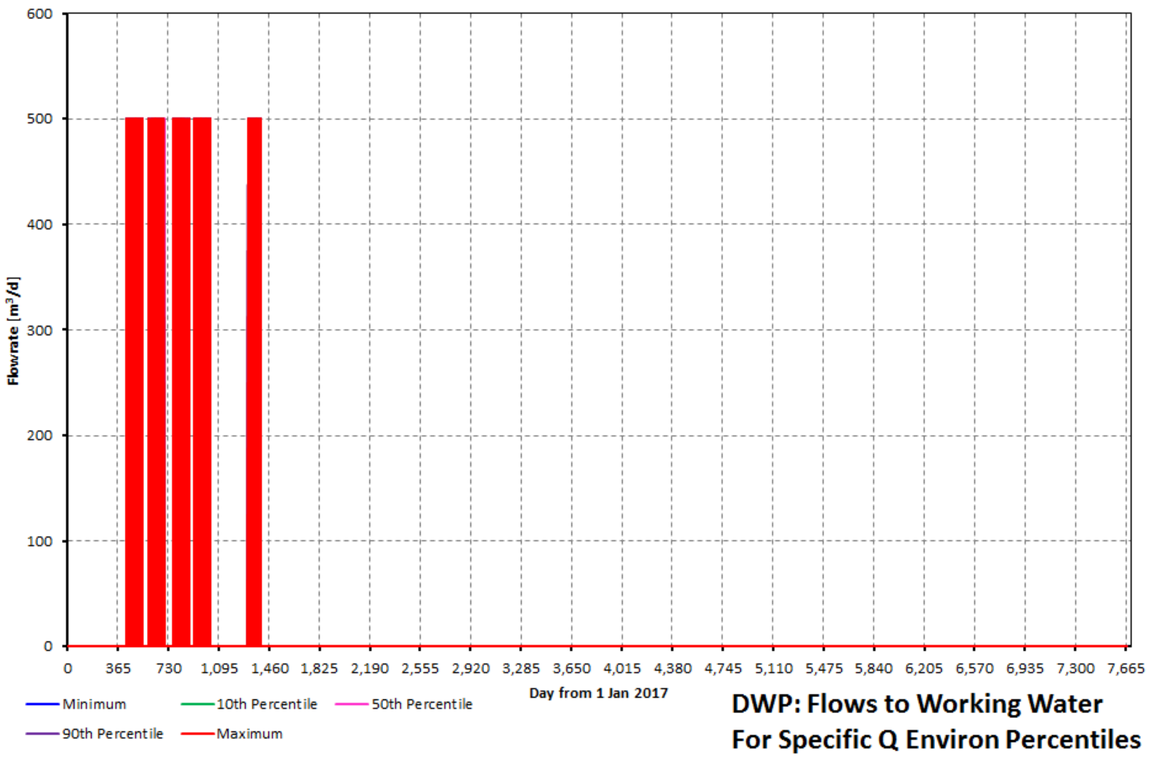

30,000
25,000
20,000
15,000
10,000
5,000
0
Flowrate [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Summation of total flows to River
For Specific Q Environ Percentiles

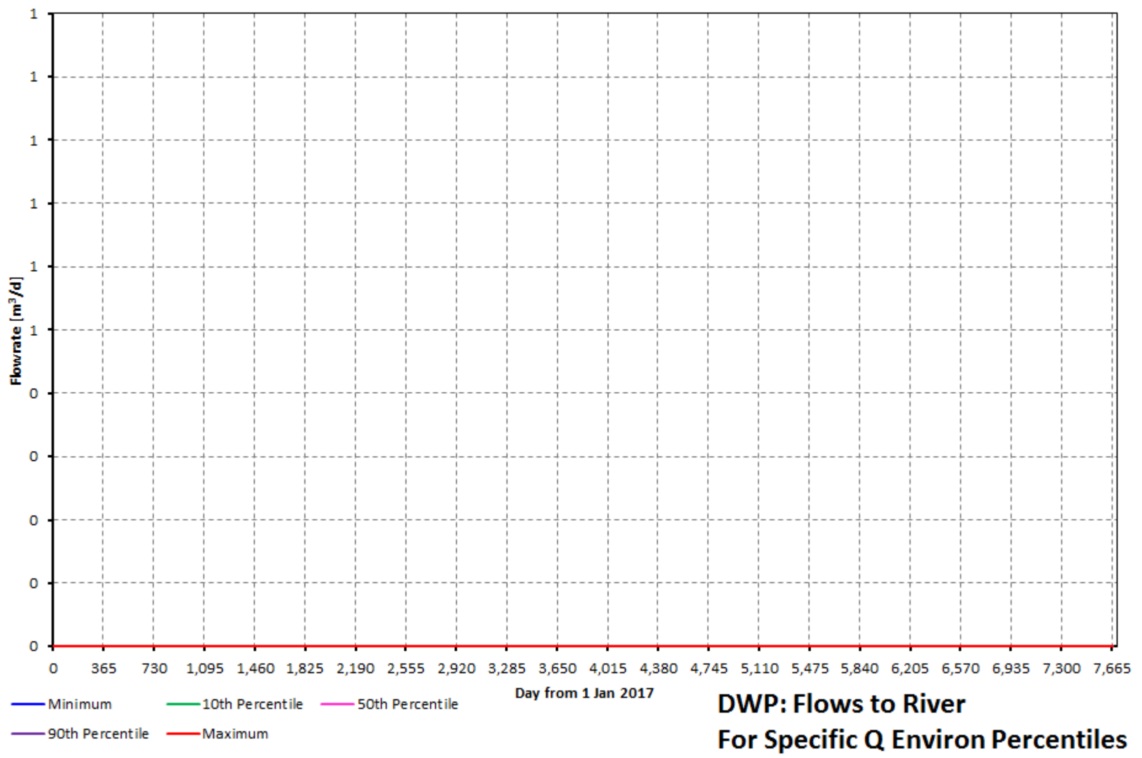
Appendix 12 Simulation Scenario 15: P10 Extracted Water Production: Base Case

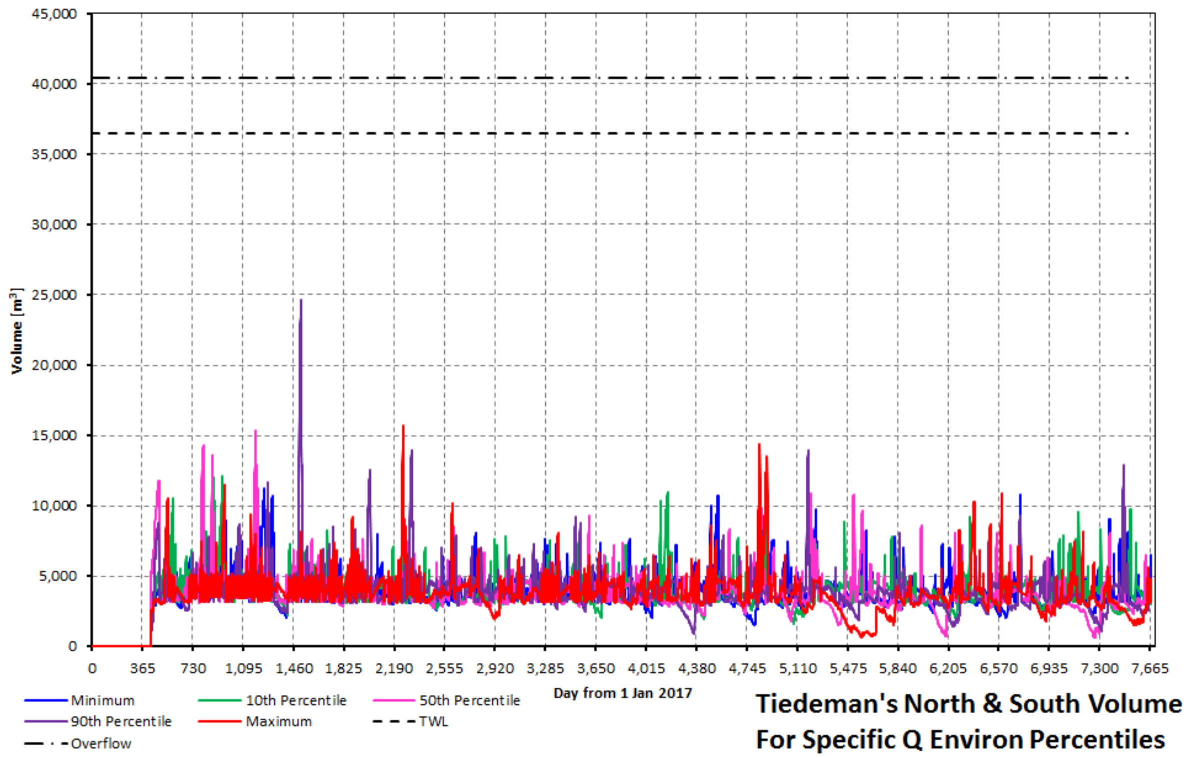

1,600
1,400
1,200
1,000
800
600
400
200
0
Flowrate [m³/d]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
RWP Flows In
For Specific Q Environ Percentiles

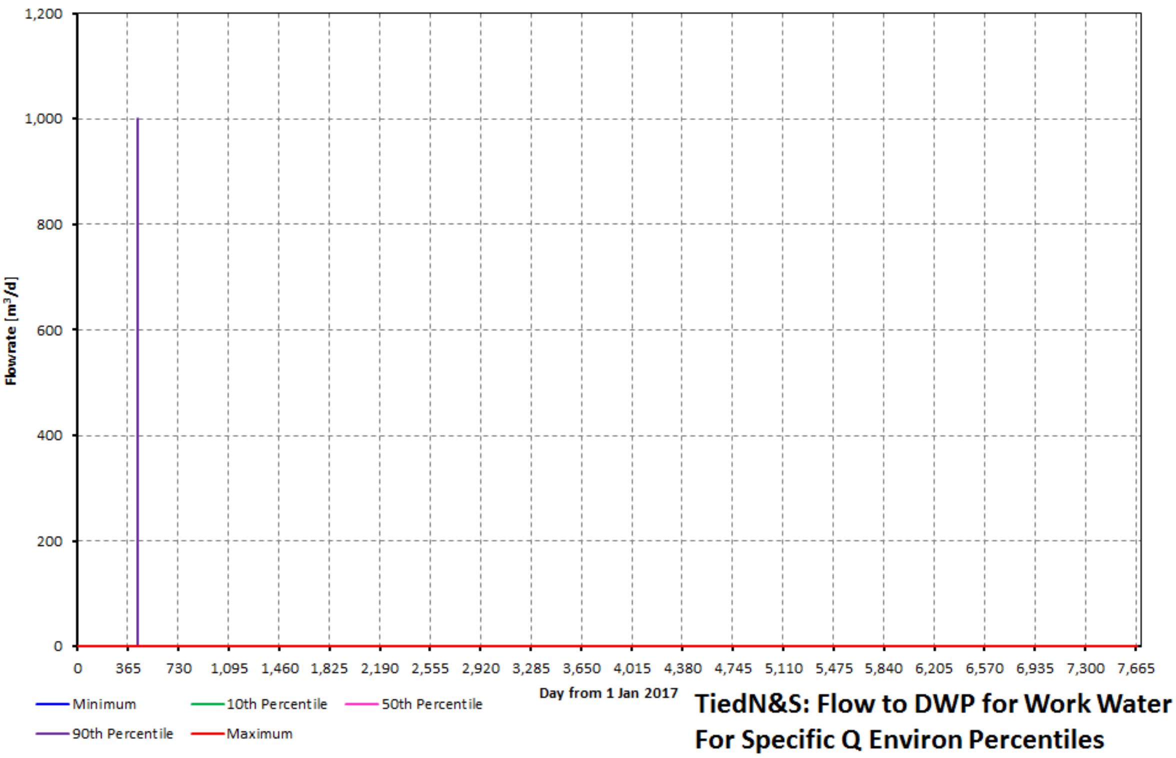

14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
RWP Volume
For Specific Q Environ Percentiles

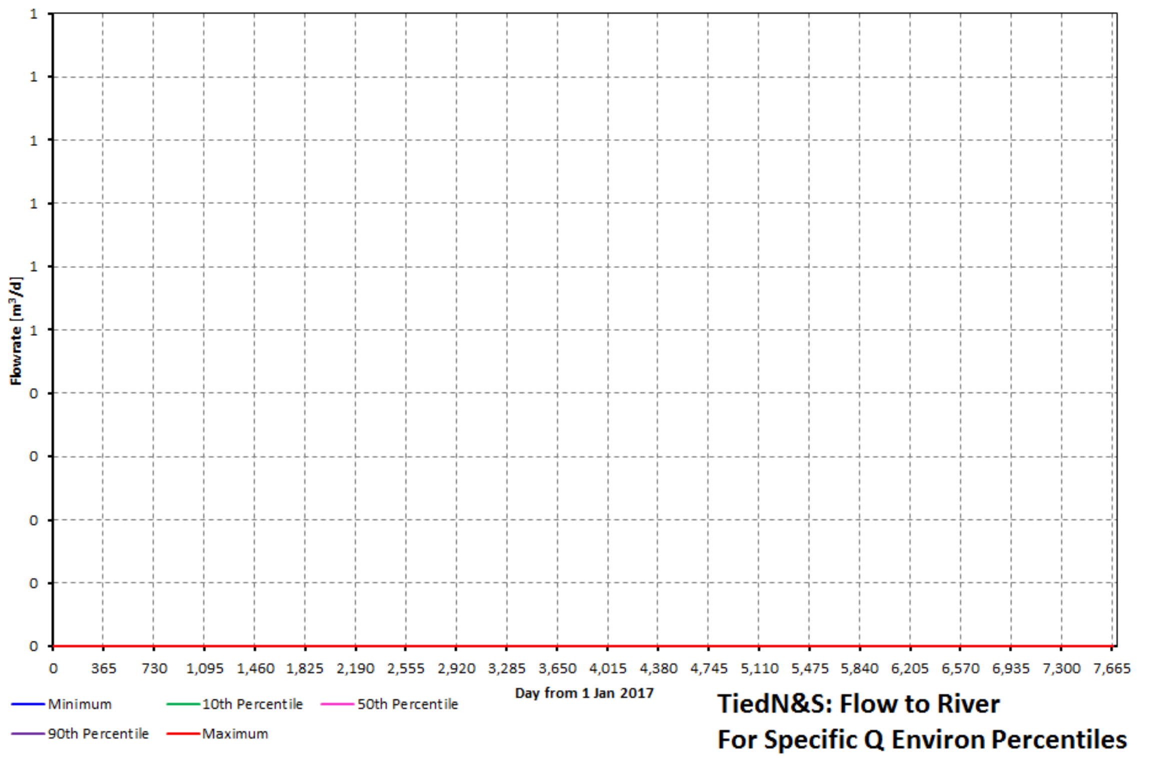

Volume [m³]
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
DWP Volume
For Specific Q Environ Percentiles

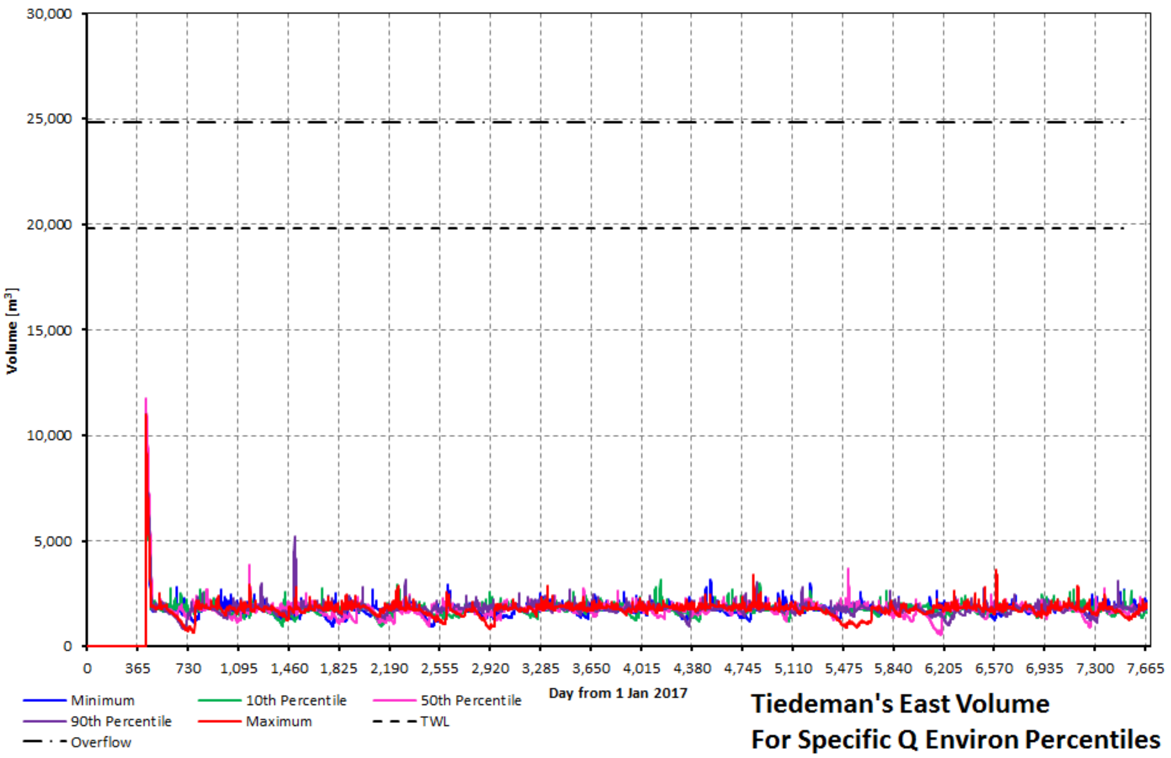

Flowrate [m³/d]
600
500
400
300
200
100
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
DWP: Flows to Working Water
For Specific Q Environ Percentiles

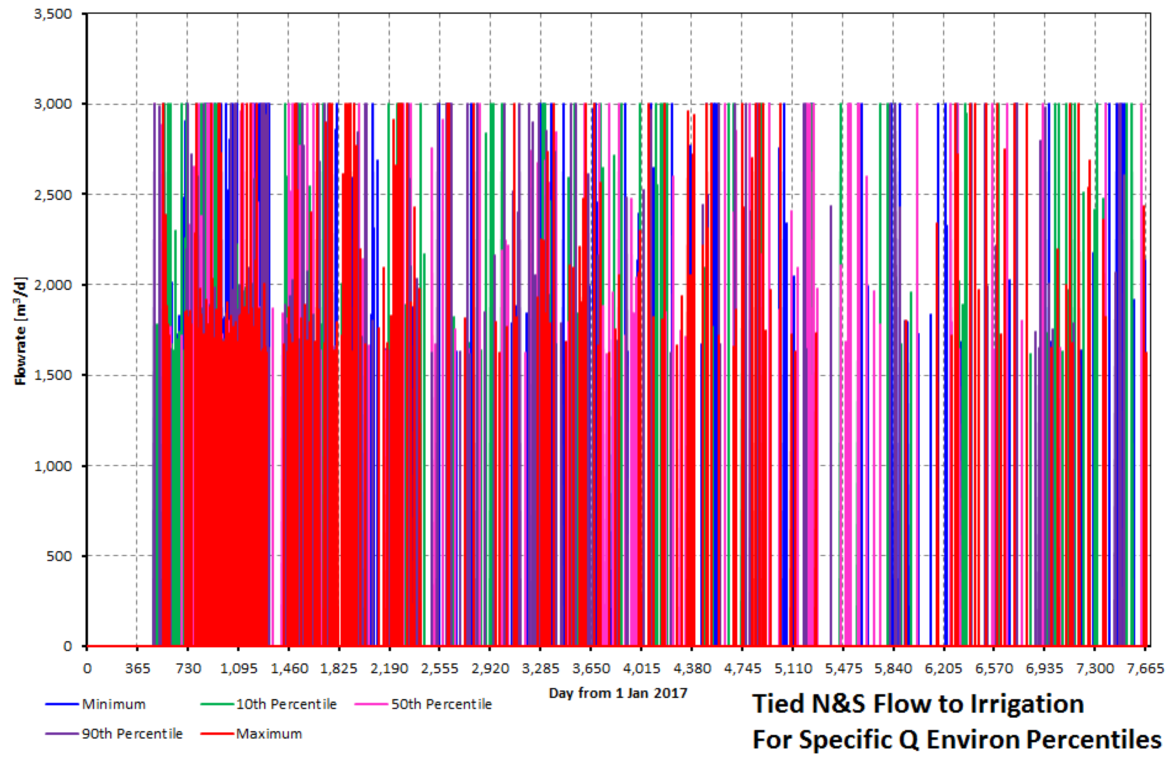

Flowrate [m³/d]
1
1
1
1
1
1
0
0
0
0
0
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
DWP: Flows to River
For Specific Q Environ Percentiles


Volume [m³]
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's North & South Volume
For Specific Q Environ Percentiles


Flowrate [m³/d]
1,200
1,000
800
600
400
200
0
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TiedN&S: Flow to DWP for Work Water
For Specific Q Environ Percentiles


Flowrate [m³/d]
1
1
1
1
1
1
0
0
0
0
0
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TiedN&S: Flow to River
For Specific Q Environ Percentiles


Volume [m³]
30,000
25,000
20,000
15,000
10,000
5,000
0
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Tiedeman's East Volume
For Specific Q Environ Percentiles


Flowrate [m³/d]
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3,000
2,500
2,000
1,500
1,000
500
0
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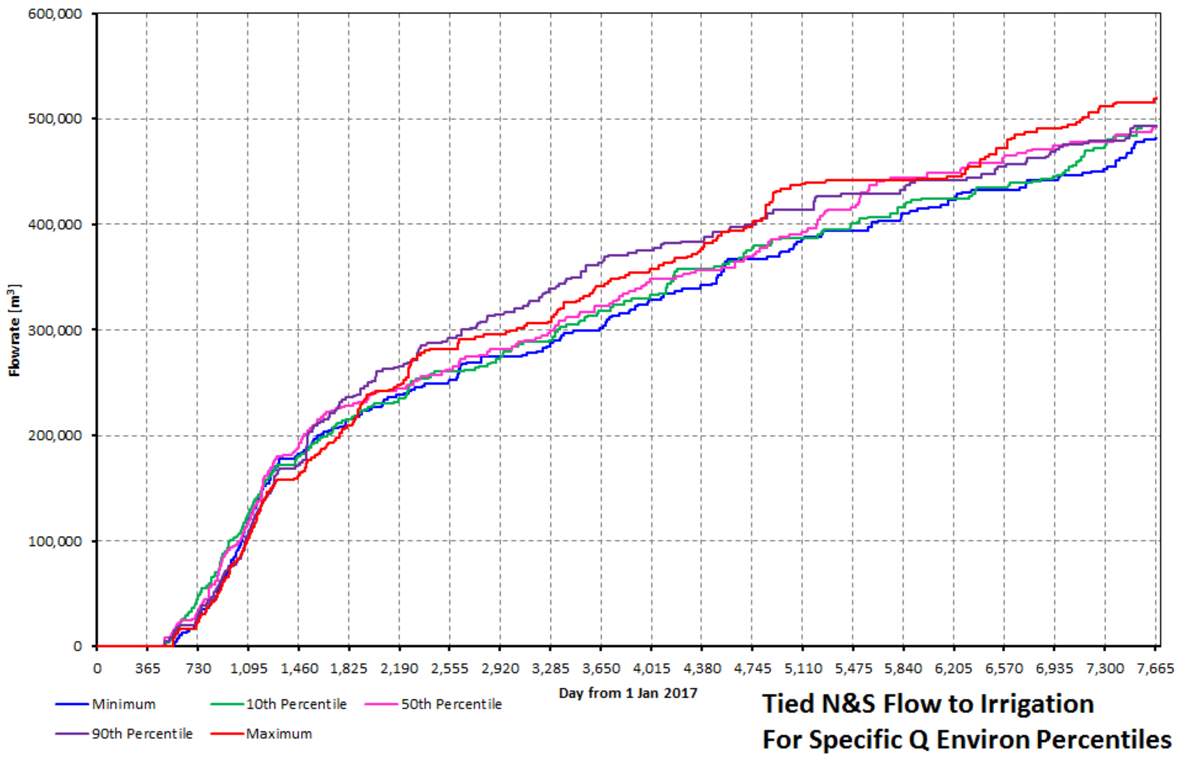
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Tied N&S Flow to Irrigation
For Specific Q Environ Percentiles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500,000
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300,000
200,000
100,000
0
Flowrate [m³]
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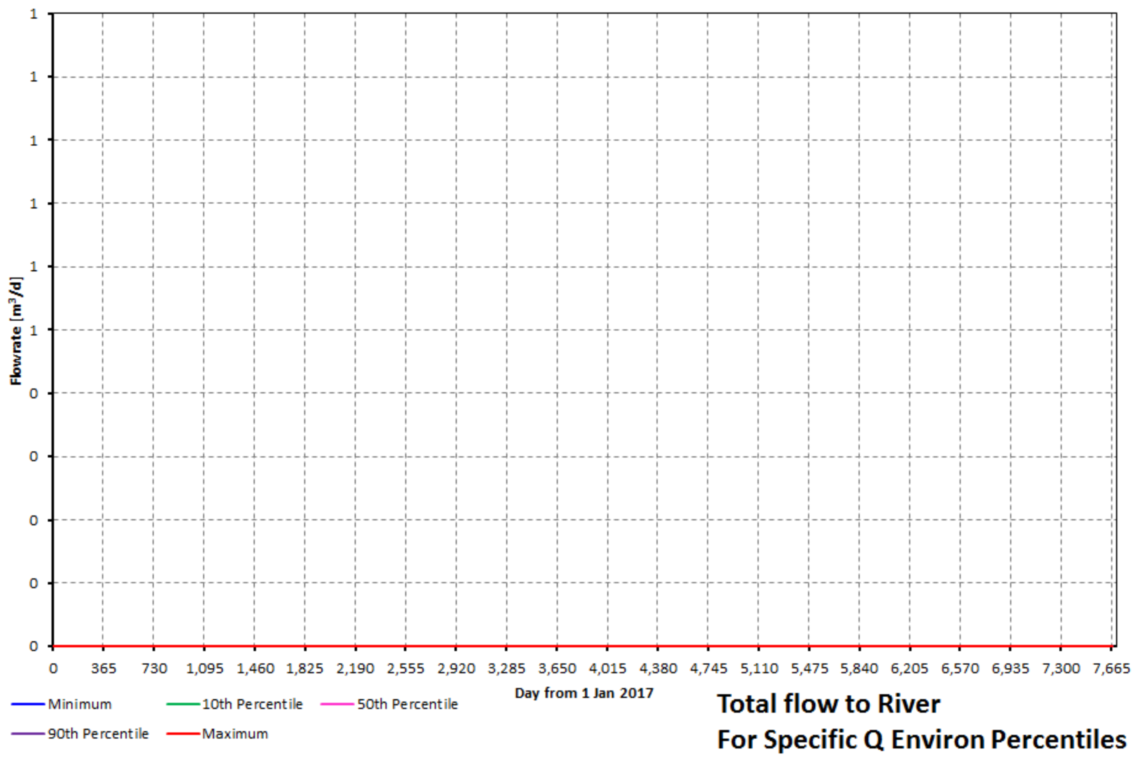
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Tied N&S Flow to Irrigation
For Specific Q Environ Percentiles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1
1
1
1
1
0
0
0
0
0
Flowrate [m³/d]
0
365
730
1,095
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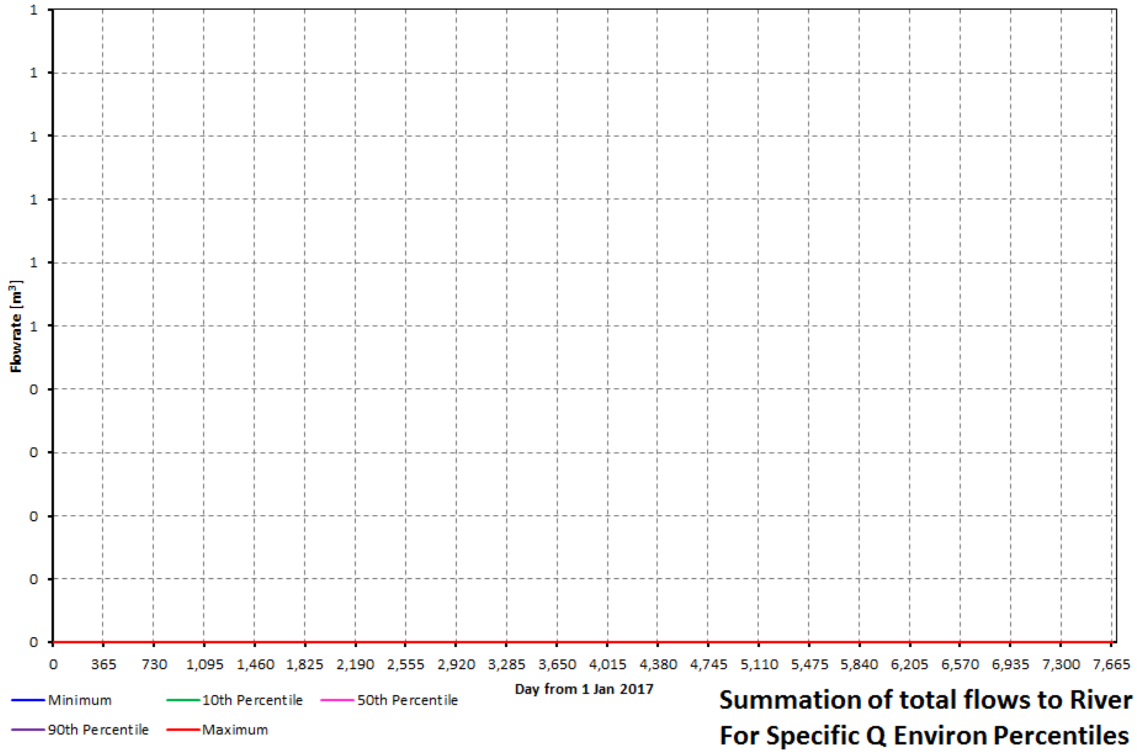
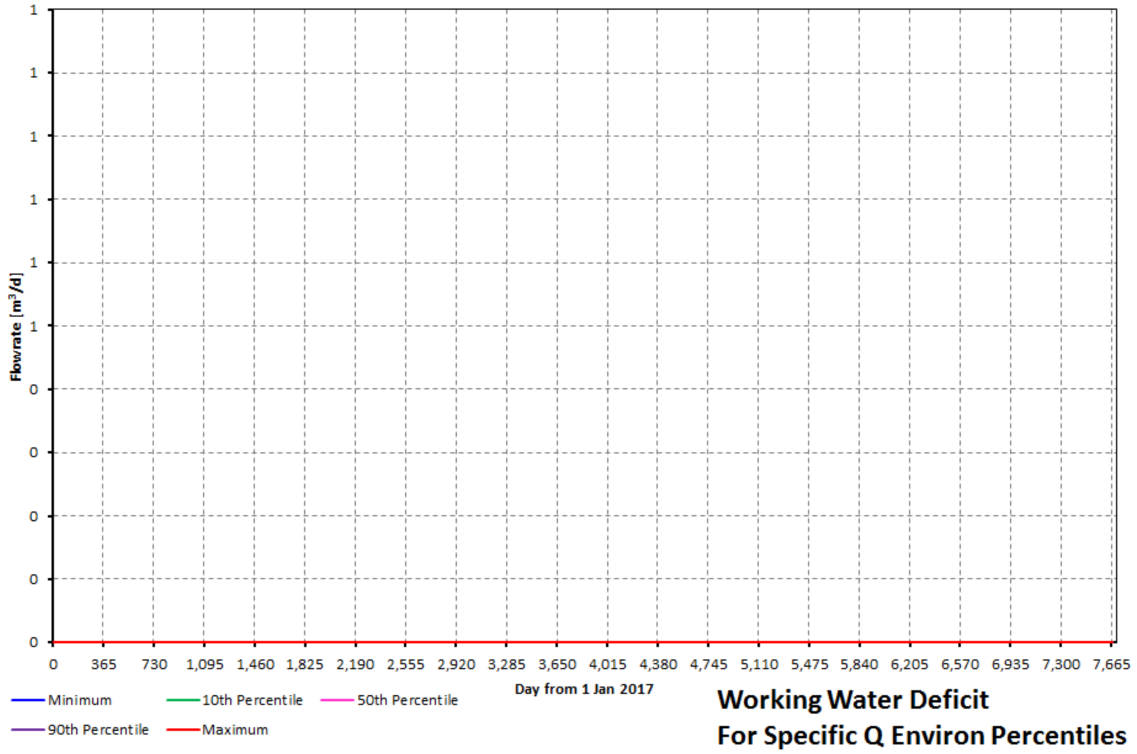
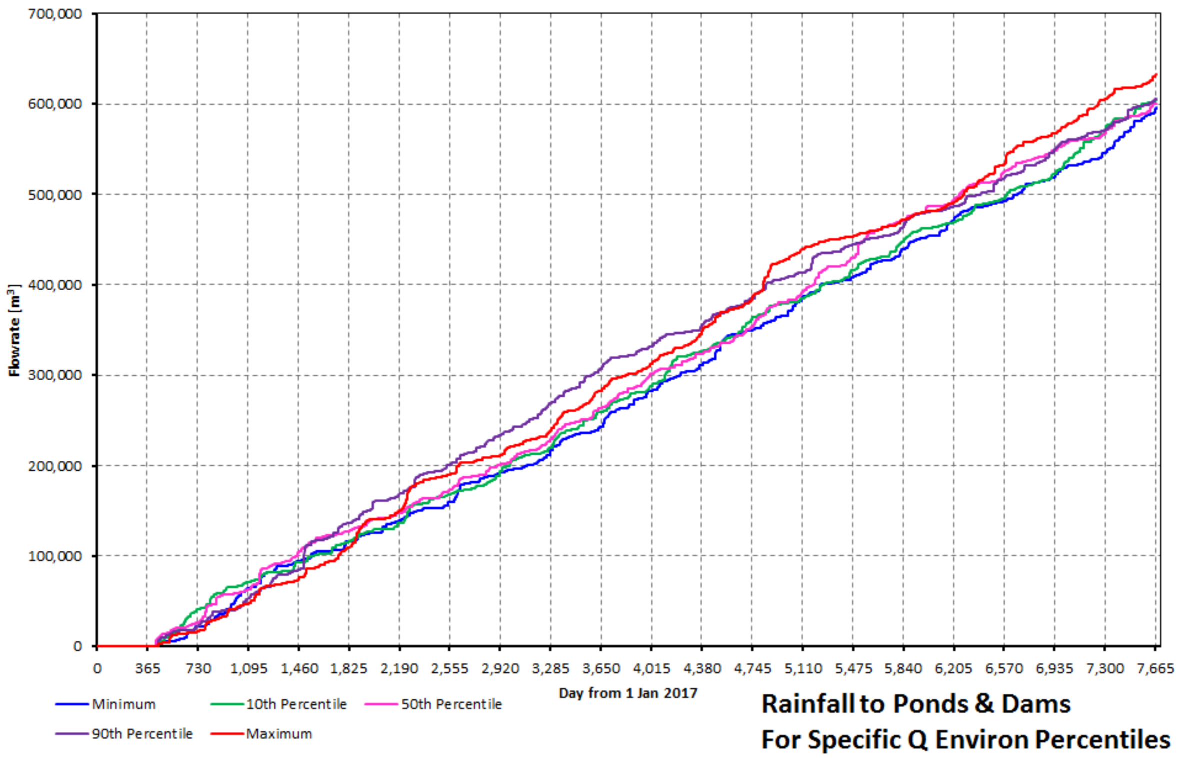
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Total flow to River
For Specific Q Environ Percentiles



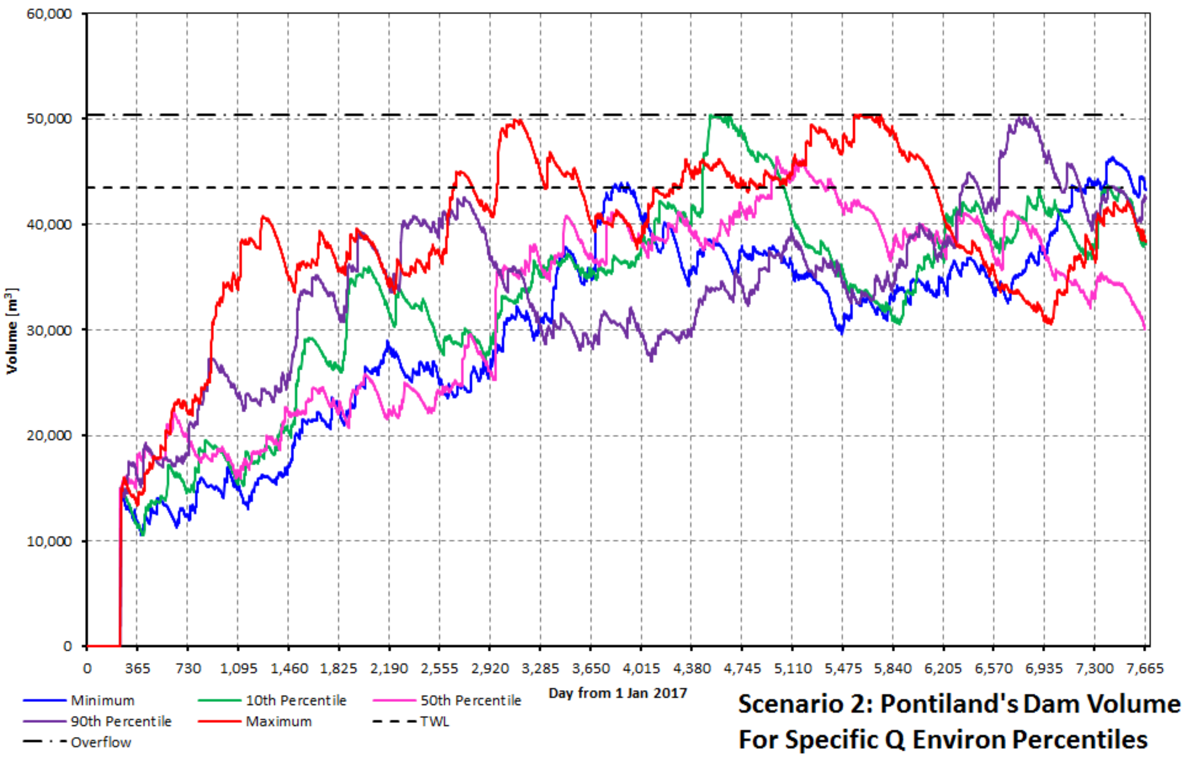
Summation of total flows to River For Specific Q Environ Percentiles



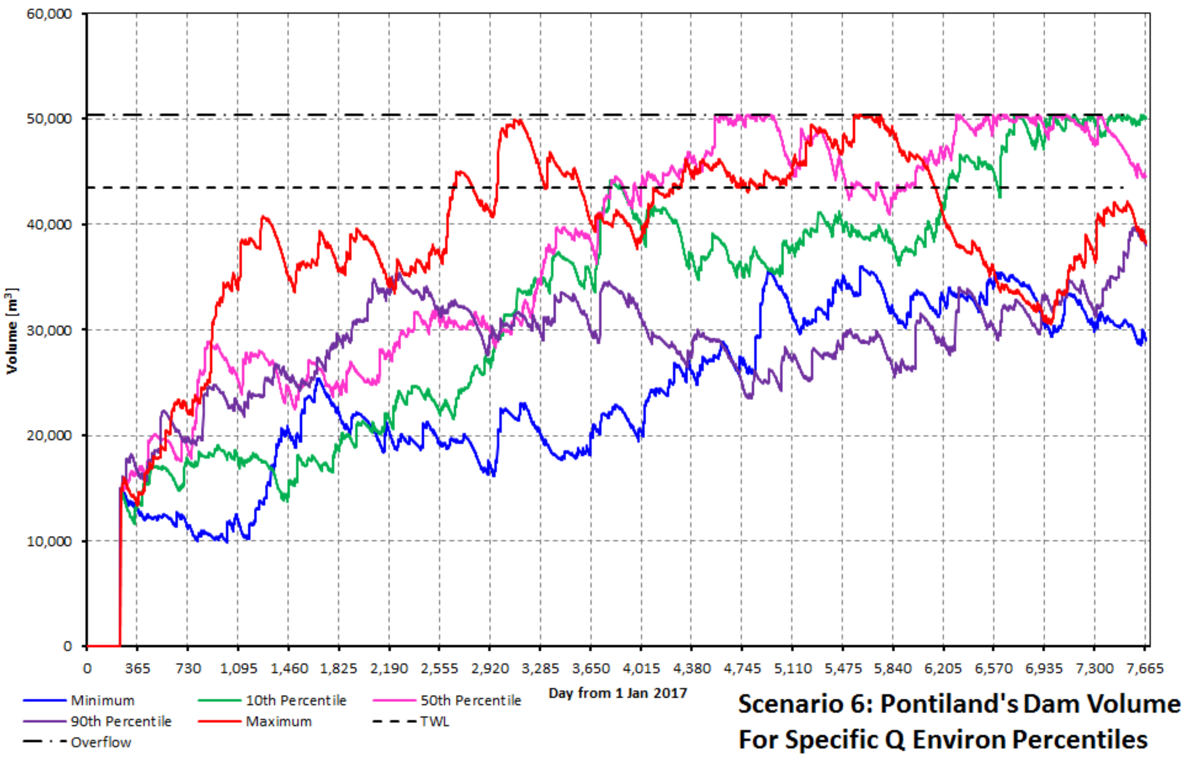
Working Water Deficit For Specific Q Environ Percentiles


700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Flowrate [m³]
0 365 730 1,095 1,460 1,825 2,190 2,555 2,920 3,285 3,650 4,015 4,380 4,745 5,110 5,475 5,840 6,205 6,570 6,935 7,300 7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
Rainfall to Ponds & Dams
For Specific Q Environ Percentiles

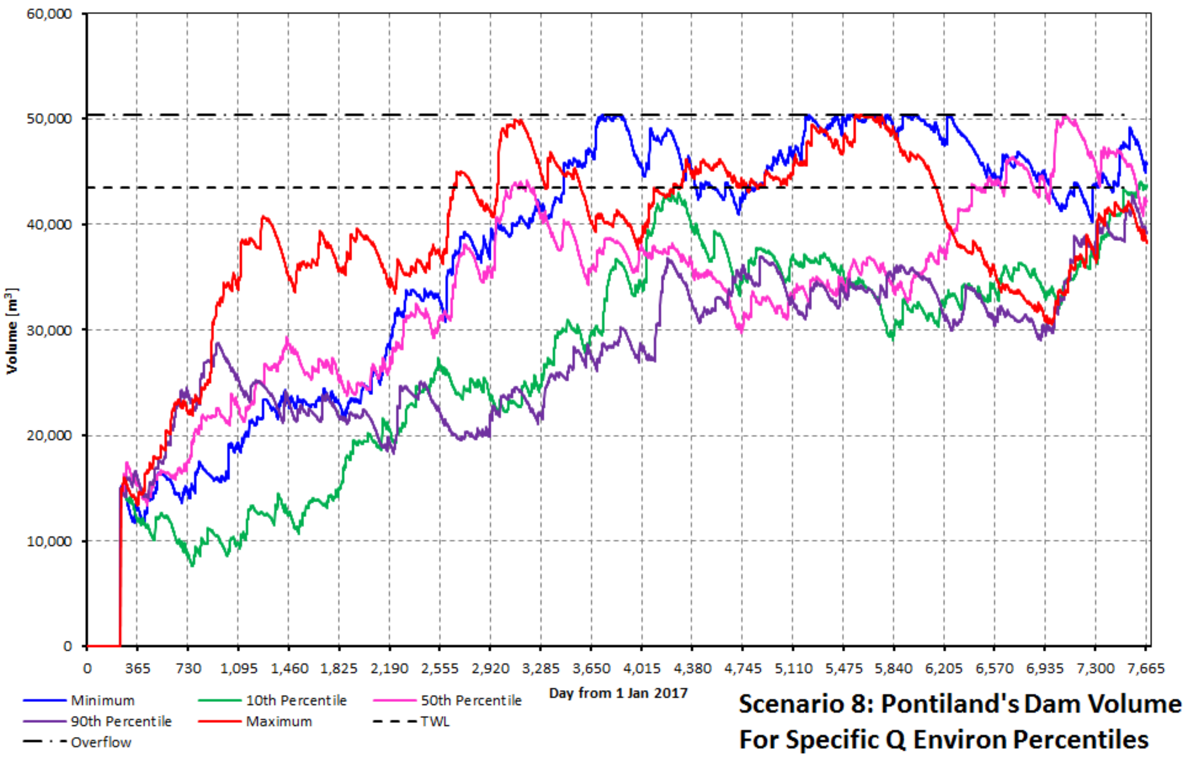
Appendix 13 Pontiland's Dam Profiles

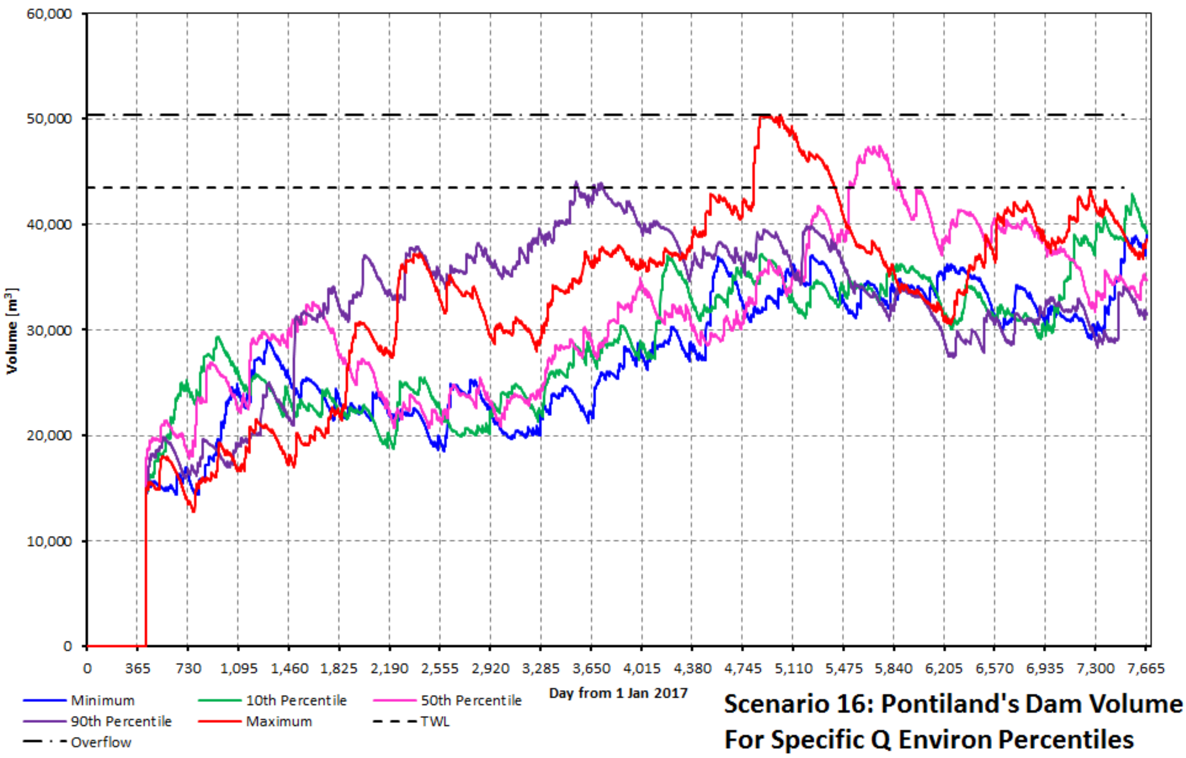


Scenario 2: Pontiland's Dam Volume For Specific Q Environ Percentiles



Scenario 6: Pontiland's Dam Volume For Specific Q Environ Percentiles


60,000
50,000
40,000
30,000
20,000
10,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Scenario 8: Pontiland's Dam Volume
For Specific Q Environ Percentiles


60,000
50,000
40,000
30,000
20,000
10,000
0
Volume [m³]
0
365
730
1,095
1,460
1,825
2,190
2,555
2,920
3,285
3,650
4,015
4,380
4,745
5,110
5,475
5,840
6,205
6,570
6,935
7,300
7,665
Day from 1 Jan 2017
Minimum
10th Percentile
50th Percentile
90th Percentile
Maximum
TWL
Overflow
Scenario 16: Pontiland's Dam Volume
For Specific Q Environ Percentiles

Appendix C – Environmental Assessment and Design of High Flow Discharge Location for Treated Water (Cardno)

Gloucester Gas Project

Environmental Assessment and Design of High Flow Discharge Location for Treated Water

59915194

Prepared for
AGL Energy Limited

14 August 2015

Cardno®
Shaping the Future

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Version	Effective Date	Description of Revision	Prepared by:	Reviewed by:
A	24.07.15	Draft for review	Kate Reeds Emma Maratea Scott Brisbin	Andrew Simon Chris Holloway
B	11.08.15	Final for review	Kate Reeds Scott Brisbin	Chris Holloway
0	14.08.15	Final for use	Kate Reeds	Chris Holloway

Executive Summary

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. As part of the GGP and associated Extracted Water Management Strategy (EWMS), AGL commissioned Cardno NSW/ACT Pty Ltd (Cardno) to undertake an investigation into the potential environmental impacts and engineering requirements associated with a high flow discharge outlet downstream of the GGP Central Processing Facility (CPF) and close to AGL's proposed irrigation reuse areas.

The proposed high flow discharge outlet for treated water will facilitate the release of water associated with the Stage 1 Gas Field Development Area (GFDA) gas extraction activities in the initial years of operation, when volumes of extracted water from the well field are high and when extended wet weather conditions preclude irrigation and/or stock re-use. In developing the EWMS, further investigations were considered necessary to determine the optimum location of the high flow discharge outlet and where any potential downstream impacts (if any) can be minimised.

Cardno undertook a desk and field based study of the geomorphological and ecological characteristics of the Study Area to assist in the identification of one or more suitable high flow discharge locations. Preliminary designs of the discharge structure/outlet were also required, including consideration of any flood or scour protection works.

Location selection and development of a preliminary design was carried out in a staged approach. Information relevant to the study area was initially compiled as part of a desktop review. This information was then used to identify potential reaches within the Study Area (including Avon River and Dog Trap Creek) for more detailed field inspection. The field inspection was carried out on 30 June 2015 along a one kilometre reach of each watercourse. Four sites were identified as potentially suitable for placement of the high flow discharge outlet and were subject to detailed geomorphological and ecological assessments. All relevant information from the literature review and field investigation was then compiled to inform a semi-quantitative Multi-Criteria Analysis (MCA). The aim of the MCA was to determine the preferred discharge location on the basis of key assessment criteria including: the predicted increase in flow (ml/day), observed bank stability, habitat condition, loss of native riparian habitat, fish habitat class, suitability of bank formation to accept headwall and discharge flows, pipe route length and resulting construction and restoration costs. Each criterion was weighted and sensitivity tested to ensure a robust outcome was achieved.

Results of the field investigation and MCA suggested that any of the four locations considered (AV1, AV2, AV3 and DT1) would be potentially suitable for placement of the outlet. While no measurable impacts to the geomorphological or ecological integrity of the receiving waterways were expected at any of the four locations, location AV2 was considered to represent the lowest level of risk.

The preliminary design for the high flow discharge outlet was therefore drafted on the basis of the preferred AV2 location. The proposed design would consist of a gravity pipe line running from the rising main to the west toward the Avon River, a pit near the top of creek bank, headwall and discharge outlet. Rock scour protection consisting of sandstone boulders and geotextile is also proposed downstream of the headwall.

Several measures are recommended to minimise habitat disturbance during the construction process, in particular, erosion and sediment controls and rehabilitation of existing habitat (consisting predominantly of introduced species) with native bank-stabilising vegetation. Native vegetation may also be incorporated into the rock scour protection.

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Glossary

Term or Acronym	Definition
AGL	AGL Energy Limited
CPF	Central Processing Facility
CSG	Coal Seam Gas
DoPE	NSW Department of Planning and Environment
DSEWPaC	Department of Sustainability, Environment, Water, Population and Communities
DWP	Discharge Water Pond
EP&A	NSW Environmental Planning and Assessment Act
EPBC	Commonwealth Environmental Protection and Biodiversity Conservation Act
EWMS	Extracted Water Management Strategy
GFDA	Gas Field Development Area
GGP	Gloucester Gas Project

1 Introduction

1.1 Background

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 the 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.

The current GGP includes the construction, operation and decommissioning of not more than 110 CSG wells and associated infrastructure, including gas and water gathering lines within the Stage 1 GFDA. The GGP will involve depressurising of deep groundwater and the extraction of gas from multiple coal seams within the Gloucester coal measures. The dewatering of deep coal seams will result in produced water and managing the extracted water (i.e. flowback water and produced water) from the Stage 1 gas well field is a critical aspect of the development.

As part of the approvals process for the GGP, AGL has developed a draft Extracted Water Management Strategy (EWMS) for the Stage 1 GFDA. The draft EWMS outlines the preferred processes for the treatment, re-use and discharge of water associated with Stage 1 GFDA gas extraction activities, including summaries of background technical studies. The primary beneficial uses of treated extracted water would be storage for irrigation and stock re-use, although in the initial years of the Stage 1 development, treated water will also need to be discharged into suitable adjacent waterways (either the Avon River or Dog Trap Creek) when volumes of extracted water from the wellfield are high and when extended wet weather conditions preclude irrigation and/or stock re-use. In developing the EWMS, further investigations were considered necessary to determine the optimum location of the high flow discharge outlet where any potential downstream impacts (if any) will be minimised.

AGL commissioned Cardno NSW/ACT Pty Ltd (Cardno) to undertake an investigation of the potential environmental impacts and engineering requirements associated with a high flow discharge location downstream of the Central Processing Facility (CPF) for the GGP.

The scope of work specifically includes a geomorphological and ecological assessment of the downstream study area to assist in the identification of one or more suitable discharge locations. Preliminary designs of the discharge structure/outlet are also required, including consideration of any flood or scour protection works.

1.2 Aims and Objectives

The specific aims of the study were to:

> Provide an overview of the hydrology of the streams and the water quality of the receiving waters at the investigation site;

> Undertake a geomorphological assessment of the Avon River and Dog Trap Creek areas along the southern and western boundaries of AGL's Tiedmans property and the western boundary of AGL's Atkins (Avondale) property south of Gloucester ;

> Undertake an ecological assessment of the same riverine areas to determine the impacts of discharge on ecosystem conditions and assets, and the impacts on biota and the immediate downstream environment;

> Consider the temperature of discharge water and the risk of thermal pollution and associated impacts on the local aquatic ecosystem;

> Identify a preferred discharge location (and any alternatives) that would be suitable to discharge 0.5 to 2 ML per day of treated water directly into a high flow event occurring along the Avon River;

> Provide a preliminary design of the proposed discharge/outlet structure together with flood protection and any scour protection measures required to protect the structure, stream banks and riparian vegetation.

1.3 Proposal to Discharge to Surface Waters

It is understood that the quality, frequency and volume of produced water for discharge into surface waters will be managed to ensure similar conditions and flow regimes are maintained within the receiving waterway, thereby minimising the potential for downstream environmental impacts.

In order to achieve this, AGL propose the following:

> Water discharged from the CPF and/or storage dams will have been conditioned and treated to meet the surface water quality targets as provided by AGL, July 2015 (refer Section 3.3). Any discharges will also be managed in accordance with the necessary EPA and NSW Office of Water (NOW) approvals.

> No discharges of treated water are expected if average to dry seasons prevail as all water would be beneficially reused though stock and irrigation use. After the first three years, AGL does not expect to use this option as there will be sufficient storage for produced water and treated water in all but the wettest years.

> It is expected that most water would be discharged during periods of higher flow when irrigation is not possible because of preceding wet weather conditions.

> The annual discharge of treated water into the receiving waterways is expected to be of the order of 1% of the total extracted water flowrate (less than 20 ML/yr). These projections only occur for the worst case climate conditions and occur near to the peak of the extracted water production period in Year 3 of the project (Worley Parsons 2015).

> It is expected that the maximum discharge rate would be up to 2 ML/d but average less than 1 ML/d.

1.4 High Flow Outlet Design Considerations

Selection of a proposed high flow discharge location should aim to minimise construction related and operational downstream impacts on scouring and erosion, bank stability, aquatic habitat quality and associated aquatic biota. The high flow discharge structures would therefore be designed to ensure:

> Adequate dispersion and mixing within a relatively short distance;

> Dissipation of energy associated with the new inflow;

> Compatibility with upstream and downstream water quality; and

> Appropriate scour protection on the creek banks and bed local to and immediately downstream of the outlet.

2 Study Methodology

2.1 Overview

Location selection and development of a preliminary design was carried out in a staged approach. Information relevant to the study area was initially compiled as part of a desktop study. More detailed location specific information was then collected at four potential discharge locations during a one day field investigation. All relevant information was then compiled and disseminated to inform a semi-quantitative Multi-Criteria Analysis (MCA) with the aim of determining the preferred discharge on the basis of key assessment criteria. A preliminary engineering design was then developed for the preferred location. This process is summarised in **Figure 2-1**.

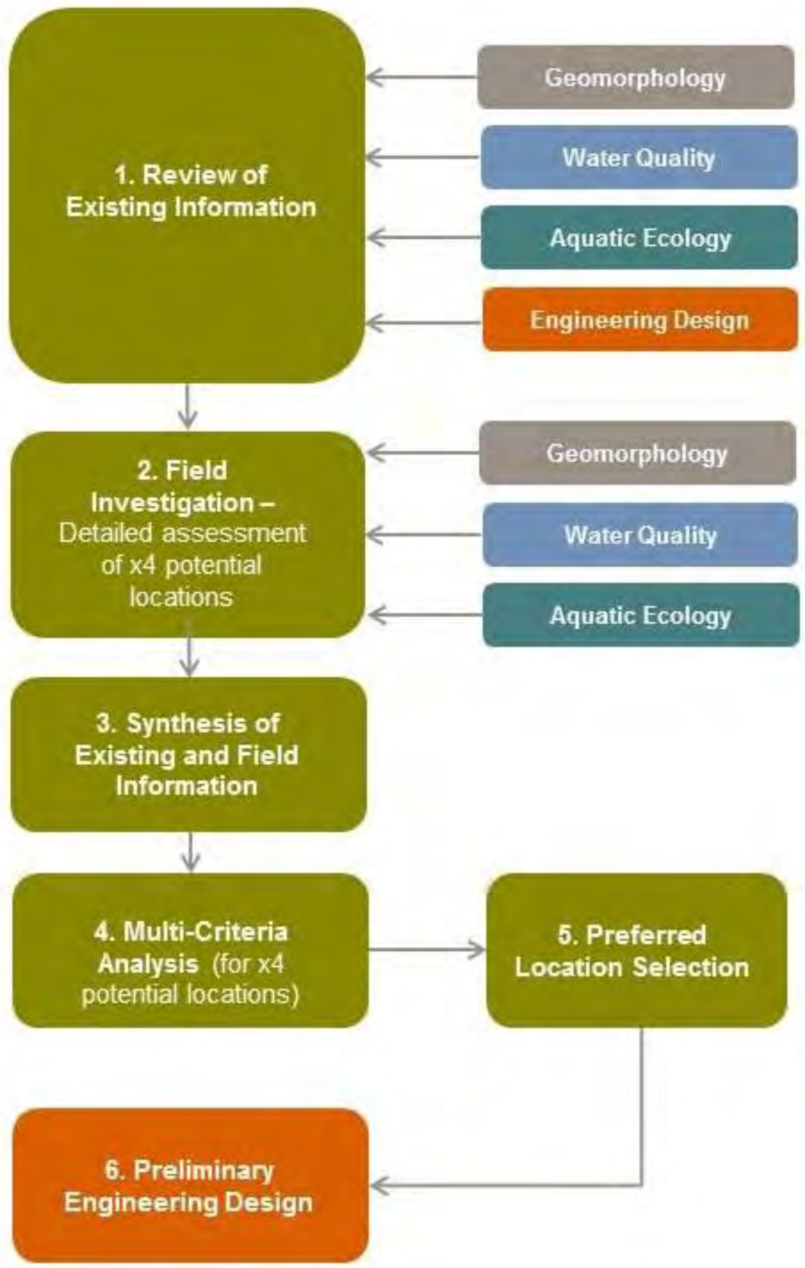


Figure 2-1 Approach to study methodology

2.2 Study Area

The Study Area for the high flow discharge location assessment is indicated in **Figure 2-2** below.

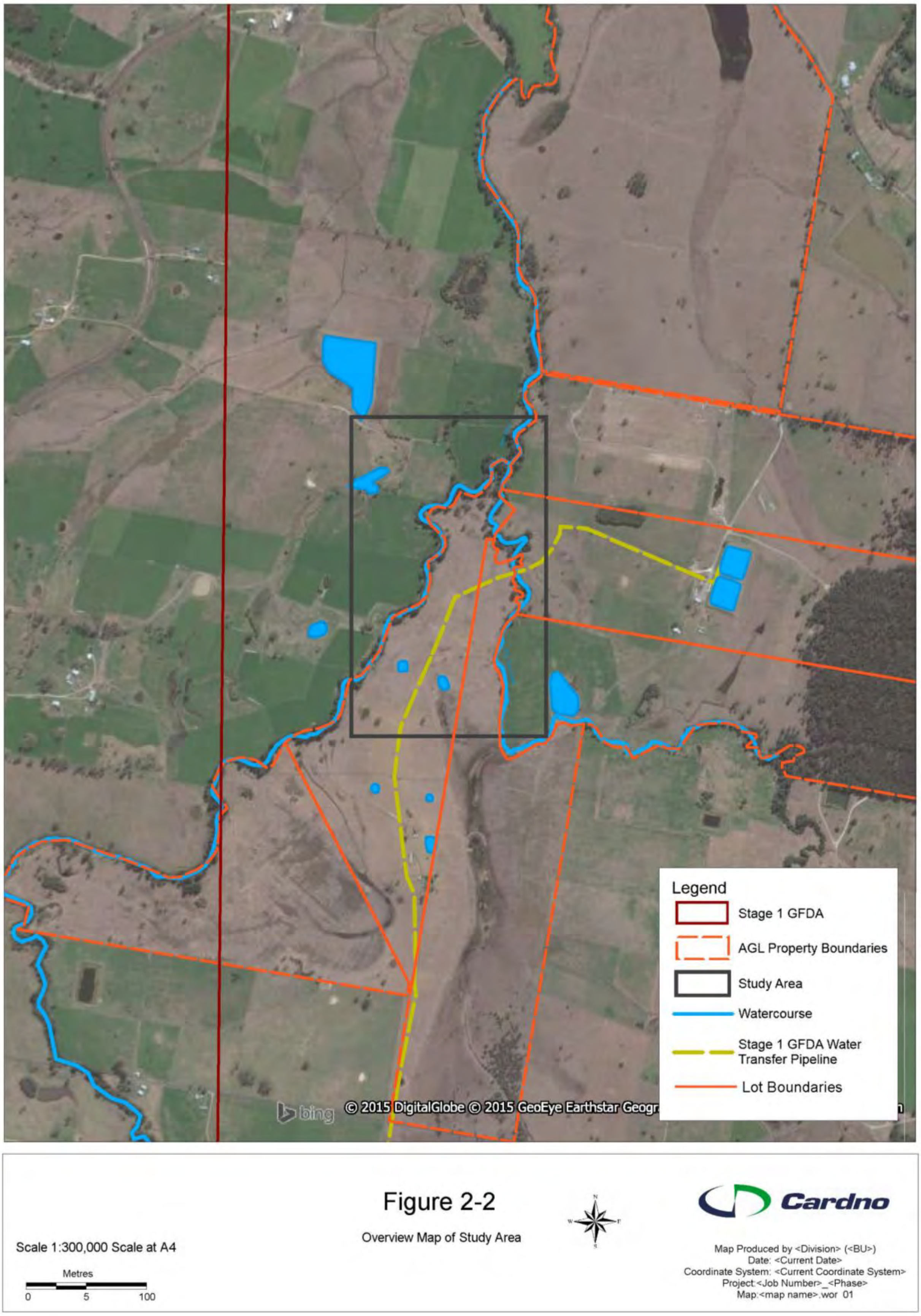


Figure 2-2 Overview map of Study Area

2.3 Review of Existing Information

2.3.1 Geomorphology

Existing information on geomorphology of the streams within the Study Area was obtained by review of aerial photography (Google Earth images), technical reports and relevant literature using the internet and the Cardno library/database. The review of this data was important to identify the key geomorphological characteristics of the Study Area and enable an initial evaluation of several potential discharge locations to be assessed in detail on-site.

The key technical reports that were used in this review comprised of:

- AGL (2014) - Consultation Draft: Extracted Water Management Strategy;
- BMT WBM (2015) –Gloucester and Avon Rivers Flood Study (report to Gloucester Shire Council); and
- Parsons Brinckerhoff (2014) – Gloucester Gas Project - Hydrological Study (report to AGL).

Water level data for the period 2011 to 2015 was supplied by AGL and utilised in the assessments.

2.3.2 Water Quality

Existing information on water quality of the streams within the Study Area was reviewed to determine the compatibility of the discharge water quality with the natural surface waters. Long –term monitoring data and relevant technical reports were reviewed, particular the long-term water quality data from AGLs surface water monitoring locations, TSW01, TSW02, ASW01, ASW02, and FSW01 (**Figure 3-1)**.

2.3.3 Aquatic Ecology

Existing information on aquatic habitats and associated aquatic biota within the Study Area was obtained by review of aerial photography (Google Earth images), technical reports and relevant literature using the internet and the Cardno library/database.

Aquatic flora and fauna listed under the EPBC Act, the *Threatened Species Conservation Act 1995* (TSC Act) *Fisheries Management Act 1994* (FM Act) and *National Parks and Wildlife Act 1974* (NPW Act) (including threatened and protected species, populations and ecological communities) that are known or likely to occur within the investigation area were identified from the existing literature and publicly available databases including:

- The EPBC Protected Matters Search Tool (search area = Gloucester LGA);
- The Atlas of NSW Wildlife Bionet Database (search area =Gloucester LGA);
- The Atlas of Living Australia (search area = Gloucester LGA);
- NSW DPI Fisheries Records Viewer (search area = Gloucester LGA); and
- Threatened species listed by the Gloucester Shire Council Comprehensive State of Environment Report (2009).

Key threatening processes (KTPs) as listed under relevant schedules of the EPBC, TSC and FM Acts were also reviewed for those with relevance to the proposed discharge to surface waters.

2.4 Field Investigations

2.4.1 General

The stretch of the Avon River and Dog Trap Creek within the proposed Study Area was initially assessed on foot with the exception of densely vegetated and or very winding reaches of waterways which were considered unsuitable (due to greater potential for instability and loss of riparian habitat). Four potentially suitable locations were selected from the remaining reaches of the Avon River and Dog Trap Creek for a comprehensive site assessment. As a minimum, these locations were considered to provide reasonably good bank stability, have minimal native riparian vegetation (but enough to provide stability) and be easily accessed.

At each of the four locations, the time, date, GPS position (datum WGS84; accuracy <5 m) were recorded. An inventory of dominant riparian taxa was listed and site photographs taken.

2.4.2 Geomorphology

Field investigation were undertaken to confirm desktop geomorphological assessments and to note any other factors not previously evident. Detailed location assessments were undertaken at four locations and included the collection of the following data:

> Indices of channel dimensions and form;

> Indices of bank condition;

> Existing flow level (at the time of inspection);

> Evidence of scour and erosion from previous flow events; and

> Floodplain characteristics.

2.4.3 Water Quality

Water quality was measured in-situ with a YSI 6920 water quality probe and meter that were calibrated prior to sampling. The following variables were recorded just below the surface:

> Temperature (°C);

> Electrical Conductivity (μs/cm);

> pH;

> Dissolved oxygen (% saturation);

> Oxidation reduction potential (ORP) (mV); and,

> Turbidity (ntu).

Duplicate readings of each variable were taken in accordance with Australian Guidelines for protection of aquatic ecosystems (ANZECC/ARMCANZ 2000).

2.4.4 Aquatic Ecology

A standardised description of adjacent land and condition of riverbanks, channel and bed was recorded using the 'Riparian, Channel and Environmental Inventory' (RCE), developed by DECCW (Chessman *et al*. 1997) and adapted from Petersen (1992) for NSW conditions. RCE is used to scale and quantify the environmental state of particular locations based on surrounding land use, geomorphology, channel bed forms, and riparian and instream vegetation. The RCE score for each location is calculated by summing the scores for 13 descriptors (**Appendix A**).

The highest possible score (52) is assigned to streams with no obvious physical disruption; the lowest score (13) is assigned to heavily disturbed streams. Overall these scores are categorised as follows:

40-52 (Very good);
27-39 (Good);
14-26 (Moderately impaired); and
0-13 (Highly disturbed).

The potential for locations to provide fish habitat was assessed according to criteria developed by NSW DPI Policy and Guidelines for Fish Habitat Conservation and Management (Fairfull 2013 Update)(**Appendix A**).

2.5 Data Analysis

2.5.1 Geomorphology

The data and literature reviewed for the Study Area was qualitatively assessed to provide a regional and historical setting for the existing geomorphological condition of the Avon River and Dog Trap Creek. The likely capacity of the receiving waters to accommodate the volume of flow and water quality of the proposed discharge to downstream uses was also considered.

Data gathered in the field was assessed using the “River Styles” methodology to identify the key factors influencing the river condition. This task included a review of the reaches within the project boundary to help assess whether any existing erosion is due to local factors only or is more representative of a wider catchment response and whether this would have implications for the proposed discharge structure.

The likely impacts of the proposed discharge on the base flow conditions of the receiving streams would be assessed through analysis of existing water flow gauging and channel size of the receiving streams and contribution of flows within the Avon River and Dog Trap Creek to the Manning River downstream. The existing hydrological investigations and monitoring results were used to estimate instream flood levels at the proposed discharge location for use in the development of a suitable engineering design.

2.5.2 Water Quality

Mean water quality measurements recorded in the field and baseline data derived from the literature review were compared with the (ANZECC/ARMCANZ 2000) default trigger values (DTVs) for protection of aquatic ecosystems for physical and chemical stressors for lowland rivers in southeast Australia as well as AGL water quality targets for treated water. It is noted that the *in-situ* water quality readings were used to provide a snap-shot of water quality at the time of sampling only and should not be extrapolated beyond this.

2.5.3 Aquatic Ecology

Results of the literature review and site investigation were used to compile an inventory of flora and fauna (including fish, macroinvertebrates and aquatic vegetation) occurring at the shortlisted locations. Habitat information relating to location condition and quality was summarised to feed into the overall assessment of location suitability.

2.6 Multi-Criteria Analysis

Information collected as part of the literature review and field investigation was collated for use in a Multi-Criteria Analysis (MCA). The purpose of the MCA was to objectively evaluate each of the four locations identified as part of the field investigation to determine the most optimal outlet location. This was based on a set of criteria considered important in minimising the potential construction and operational impacts of water releases. The following criteria were considered:

> **Predicted % increase in flow (ML/day)**. Assumption is that a location allowing surface discharge scenarios closest to the natural flow regime are preferable for impacts on scour, water quality and existing habitat.

> **Observed bank stability**. Assumption is that stable banks will be less susceptible to potential scouring or erosion and therefore preferable.

> **Habitat condition (as per RCE scores)**. Assumption is that a location with sensitive or ecologically important habitat is less preferable than that not containing such habitat.

> **Loss of native riparian habitat (m^2)**. Assumption is that a location requiring minimal removal of native riparian habitat is considered preferable.

> **Fish habitat class (as per Fairful 2013)**. Assumed that locations with potential key fish habitat are less preferable than those unlikely to support native fish populations.

> **Suitability of bank formation to accept headwall and discharge flows:** Assumed that steeply sloping, high banks will be more difficult to access than easily accessible low banks. This may also have cost implications in regards to engineering and labour requirements.

> **Pipe route length and resulting construction and restoration costs:** Assumed that the longest pipe route would be the most expensive construction option.

Water quality was not considered as a parameter within the MCA as it is assumed that approved water quality targets will be met and that the quality of discharged water will be similar to that of the receiving waters. The hydrological flow data calculated as part of the geomorphological assessment has also been utilised to assess the capacity of the receiving streams to accept the proposed discharge flows and associated water quality.

For each criteria a metric was developed to score each factor from 1 – 4. In order to represent the relative importance of each factor, a weighting between 1 and 3 was then applied. Sensitivity testing was undertaken of the weightings to ensure a robust outcome was achieved. Note that the MCA is a semi-quantitative and partly subjective tool to assist in the decision making process and should be considered a guide rather than providing an absolute result.

3 Results

3.1 Study Area and Environmental Setting

The Study Area is located within the Lower North Coast Subregion of the Hunter – Central Rivers Catchment, in the southern section of the Manning River system (Cardno 2010). The Study Area is within the Avon River catchment approximately 6 km south-southwest of Gloucester. Normal flows within both Dog Trap Creek and the Avon River are at an elevation of approximately 100 to 110 m AHD and flow northwards through the centre of the valley (**Figure 2-2**). The Avon is a perennial stream originating in the Avon River State Forest and Running Creek Nature Reserve, to the east of the Chichester State Forest. It flows east to Stratford and then turns north past the town until its confluence with Dog Trap Creek (approximately 6 km south of Gloucester), Oaky Creek, Waukivory Creek and Mograni Creek. The Avon River joins the larger Gloucester River approximately one kilometre downstream (north) of the confluence with Mograni Creek north of Gloucester town. The Gloucester River is joined almost immediately by the Barrington River and eventually discharges into the Manning River 20 km to the north-east, which flows to the ocean, passing the towns of Wingham and Taree. Dog Trap Creek is an intermittent stream originating in the south east of the Study Area near the Glen Nature Reserve where it flows north-west to the confluence with the Avon River and fed by a number of minor tributaries.

Land use in the region is predominantly agricultural (with much of the land cleared for cattle grazing) or used for forestry, tourism and mining. Two open cut coal mines (Stratford and Bowens Road Mines) are located immediately to the south of the Study Area (Cardno 2011).

3.2 Geomorphology Assessment

3.2.1 <u>Review of Existing Information</u>

3.2.1.1 Valley Setting

The GGP Stage 1 GFDA lies within a regional setting that represents a transition from rounded foothills at the base of the Mograni Range to lowland plains along the valley floor of the Avon River. The reaches of the Avon River and Dog Trap Creek lie within a laterally un-confined valley setting, characterised by less than 10 percent of the channel abutting the valley margin (Brierley and Fryirs 2006).

Sinuosity and gradient were calculated by Parsons Brinckerhoff and can assist in the characterisation of the Avon River and Dog Trap Creek. The sinuosity calculations have been provided below in **Table 3-1**.

Table 3-1 Sinuosity calculations (Parsons Brinckerhoff 2014)

	Stream 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

*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 (Brierley and Fryirs 2006).

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.

3.2.1.2 Sediment Characteristics

Parsons Brinkerhoff (2014) reported approximate median sediment particle size at sites TSW01, TSW02, DTC01 and ASW01 (**Figure 3-1**). Particle sizes at the monitoring sites were composed predominantly of a combination of fine grained material such as clay/silt and sand sediment particles and are shown in more detail in **Table 3-2**. The dominance of sand in the channel material could indicate a lack of cohesive material making the banks susceptible to erosion. However, the size and weight of sand can make it less mobile to lower velocities than finer grained material such as silt and clay.

Table 3-2 Sediment composition (approximated from Parsons Brinckerhoff 2014)

Gauge ID	Sand	Fine Sand	Silt and Clay
TSW01	70%	0%	30%
TSW02	70%	0%	30%
DTC01	22.5%	55%	22.5%
ASW01	100%	0%	0%

3.2.1.3 Geomorphic Condition

The geomorphic condition has been assessed in detail as an outcome of this study, primarily as a product of the field investigations. However, to gain an understanding of the study area prior to scoping the field work, it is useful to review any existing assessments of the geomorphic condition. The hydrology study undertaken by Parsons Brinkerhoff (2014) provided the following assessment of geomorphic 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).

> Generally, geomorphic condition was identified as being in moderate condition in the mid and lower reaches of the Avon River catchment and poor towards the south of the catchment. The geomorphic condition of the Avon River within the GFDA was found to be in moderate condition. Dog Trap Creek was found to be in poor condition. 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.

3.2.1.4 Preliminary Location Identification

Utilising aerial photographs and the review of existing reports (outlined in **Section 3.2.1.1** to **3.2.1.3**), a preliminary understanding was gained of stream behaviour and existence of riparian vegetation. The following criteria were developed from this understanding to identify reaches within the study area as being the most likely to contain an appropriate discharge location:

> Low sinuosity. Locations near or on ‘outside-bends’ are more likely to be impacted by hydraulic forces potentially causing erosion and changing stream form. Reaches were therefore selected that had low sinuosity (i.e. were straighter).

> Lack of hydraulic controls. The presence of features such as tributary entrances, vehicle crossings and the like can cause increased turbulence and more complex hydraulic characteristics. These can be more difficult to assess with regards to likely impacts on or from the proposed discharge outlet.

> Minimal riparian vegetation. Locations with dense riparian vegetation were not considered preferable for the location of the discharge structure due to the likely disturbance to the vegetation (and related instability for the bank sediments) associated with the construction of the outlet. However, it is noted that careful construction techniques can be employed to maintain as much of the existing vegetation as possible, thereby providing enhanced stability.

As well as the reaches identified through the criteria above, an additional location was identified downstream of the confluence of Avon River and Dog Trap Creek for consideration during the field investigations. This location was considered to be useful in provided a contrasting reference to the upstream locations and validating the assessment outcomes.

3.2.2 <u>Results of Field Investigation</u>

Based on the outcomes of the existing data review and site investigation, two preferable locations on the Avon River and one on Dog Trap Creek were selected for detailed assessment with one additional location downstream of the confluence of Dog Trap Creek and Avon River was selected for assessment and comparison with the other three locations (**Figure 3-1**).

3.2.2.1 Location AV1

Location AV1 was located downstream of the confluence of the Avon River and Dog Trap Creek (see photo at **Figure 3-2 a**)).

The channel was deeply incised within the floodplain with a top of bank width to channel depth ratio of 0.1 and steep banks approximately 4 m high and a distance of approximately 30 m between the top of banks. The banks were well vegetated with a combination of ground, shrub and tree cover. Very little riparian vegetation existed beyond the confines of the channel. The banks appeared to be comprised of fine sediment, primarily silt and fine sand. The channel bed width was approximately 10 m wide with ponded water (i.e. zero velocity) to a likely depth of less than 1 m. Visual confirmation of depth and bed material was not possible due to lack of visibility through the water.

Erosion was evident on the banks in the form of benches formed from slumped material from the upper banks on both sides of the channel. The benches, however, were well vegetated and appeared stable. More recent erosion was evident in the form of scour of the lower bank at the observed water level and some dislodged trees and exposed bank material on the upper banks. The tree damage was likely the result of a recent high flow event. Some leaning trees were noted, indicating ongoing erosion, possibly undercutting of the banks. The trees were likely more than 5 years old, indicating that the erosion had occurred within this timeframe. A high flow event could further mobilise the bank through undercutting, scour and possible dislodgement of trees. Cattle access was also noted on the right bank with some damage to vegetation resulting in exposed bank sediment.

3.2.2.2 Location AV2

This location was originally intended to be to the north of AV2 where the banks have been cleared of vegetation. The intention was that this would reduce the impact of the construction of the outlet on riparian vegetation. However, when this section of the stream was inspected on site, it was identified to be unstable due to the lack of vegetation. As such, a more suitable location was identified at AV2 (see photos at **Figure 3-2 b)** and **c)**).

The channel was deeply incised within the floodplain with steep banks approximately 5 m high and a distance of approximately 35 m between the top of banks with a top of bank width to channel depth ratio of 0.2. The banks were well vegetated with a combination of ground, shrub and tree cover. Very little riparian vegetation existed beyond the confines of the channel. The banks were comprised of fine sediment, primarily silt and fine sand. The channel bed was approximately 5 m wide with slow moving flow to a likely depth of less than 1 m. Visual confirmation of depth and bed material was not possible due to lack of visibility through the water.

Evidence of erosion was noted on the banks in the form of benches formed from slumped material from the upper banks on both banks. However, the benches were well vegetated and appeared stable. More recent erosion was evident in the form of scour of the lower bank at the observed water level. Cattle access was also noted on both banks with some damage to vegetation resulting in exposed bank sediment.

Overall, AV2 was very similar to AV1 but with slightly less tree cover, a narrower channel bed and less evidence of recent significant erosion.

3.2.2.3 Location AV3

At this location the channel was deeply incised within the floodplain with steep banks approximately 5 m high and a distance of approximately 35 m between the top of banks with a top of bank width to channel depth ratio of 0.2. The banks were well vegetated with a combination of ground, shrub and tree cover. Very little riparian vegetation existed beyond the confines of the channel. The banks were comprised of fine sediment, primarily silt and fine sand. The channel bed was approximately 4 m wide with slow moving flow to a likely depth of less than 1 m. Visual confirmation of depth and bed material was not possible due to lack of visibility through the water.

Evidence of erosion was noted on the banks in the form of benches formed from slumped material from the upper banks on both banks. However, the benches were well vegetated and appeared stable. More recent erosion was evident in the form of scour of the lower bank at the observed water level and scour caused by a flow obstruction (fallen tree). Cattle access was also noted on the both banks with some damage to vegetation resulting in exposed bank sediment.

Location AV3 was very similar to AV2 (see photos at Figure 3-2 d) and e).

3.2.2.4 Location DT1

Location DT1 is located approximately 700m upstream of the confluence with the Avon River (see photo at **Figure 3-2 f)**). The channel at this location was less incised than those locations assessed on the Avon River. Although it was noted that Dog Trap Creek becomes much more incised downstream towards its confluence with the Avon River, possibly in response to the incised nature of the Avon River. The banks were approximately 2.5 m high with a good cover of pasture grass. There was a distance of approximately 12 m between the top of banks. The top of bank width to channel depth ratio was 0.1. There were some isolated shrubs and no trees present. The banks were comprised of fine sediment, primarily silt and fine sand. The channel bed width was approximately 1m wide with base flow of less than 0.2 m depth and approximately 0.5 m/s velocity. The bed material appeared to be of a similar nature to the bank material.

Evidence of erosion was noted in the form of slumped material, which had good grass cover and appeared relatively stable. Undercutting of the bank was noted, although not severe. Some dislodged bank material was noted, which may have been the result of undercutting just upstream of the proposed discharge location. The flow was clear and did not appear to be carrying mobilised sediments at the time of inspections.

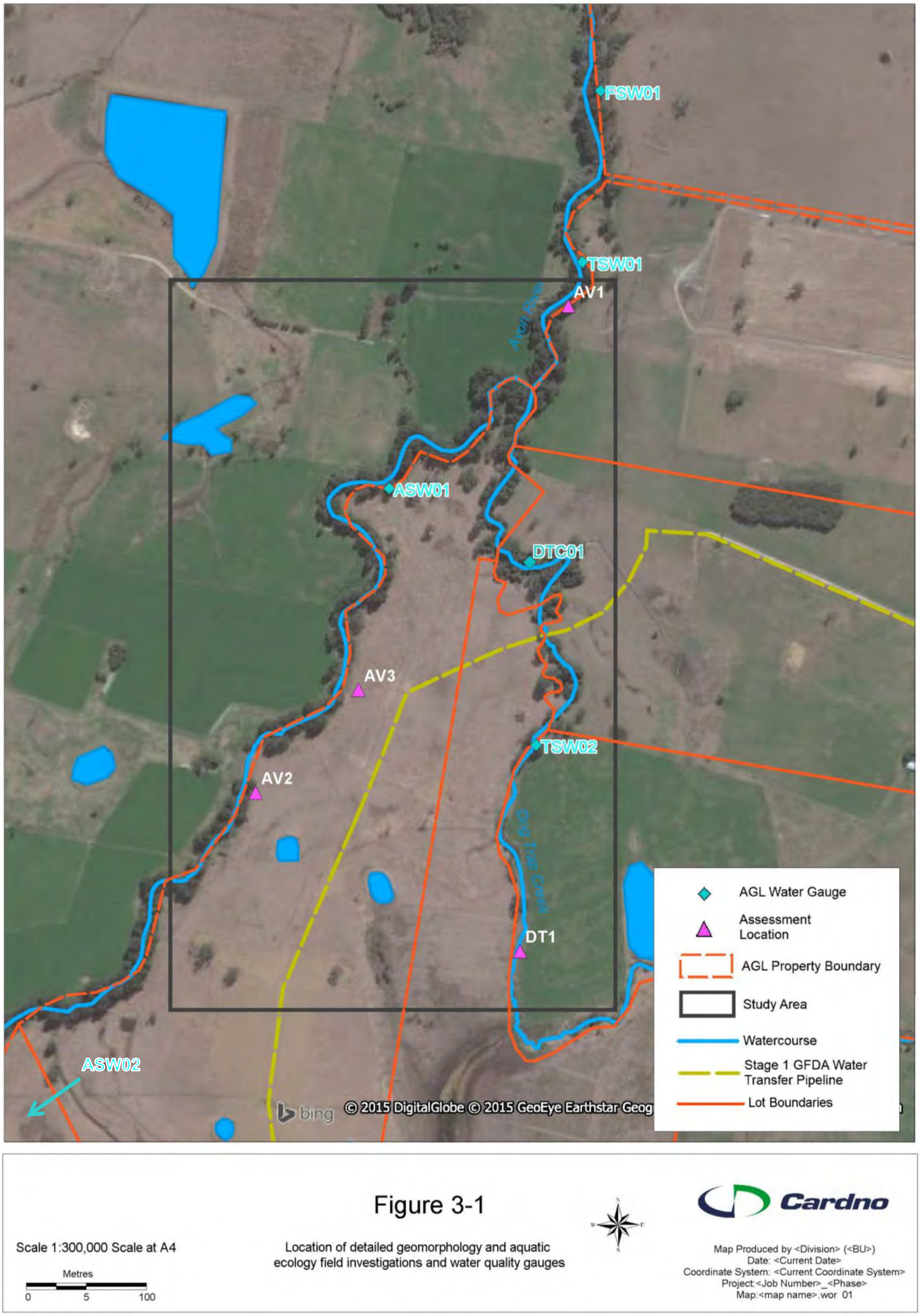


Figure 3-1 Location of detailed geomorphology and aquatic ecology field investigations

a)

b)

c)

d)

e)

f)

Figure 3-2 Location photos (geomorphology) a) AV1 – Left bank looking downstream b) AV2 – looking downstream c) AV2 – upper right bank d) AV3 – looking downstream e) AV3 – upper right bank f) DT1 – looking downstream

3.2.3 Flow Analysis

Estimates of the flow characteristics were undertaken for each location based on water level and channel cross sectional data available for locations nearby to the assessment locations. The water level data was supplied by AGL and the cross section data was obtained for the same monitoring locations from Parsons Brinckerhoff (2014). The discharge was estimated for a range of water levels in the channel including an estimate of ‘low flow’ conditions based on the observation of the low flow channel dimensions measured on location. ‘High flow records’ are determined by the NOW gauges to be the flow rate that occurred for only 20% of the time. It was assumed that the top 20th percentile water levels recorded from the AGL loggers would represent the 20th percentiles flows. This is consistent with the approach adopted by Parsons Brinckerhoff (2014). It should be noted that no detailed hydraulic modelling was undertaken to determine flows. The estimated flow are representative only and have been used to assess the likely capacity of the streams to accept the proposed discharge with regards to changes to shear stress and water quality mixing potential.

The flow and associated shear stress values are shown in **Table 3-3**. It can be seen that the high flow conditions (i.e. based on 20^{th} percentile water levels) in Dog Trap Creek are less than 1 m^3/s. This reflects its small catchment. In contrast, the 20^{th} percentile flow conditions at the locations on the Avon River range from 8 to 10 m^3/s.

The percentage increase in the flows by the maximum proposed flow (2 ML/day) is also shown. It can be seen that for a high flow condition (20^{th} percentile) the increase in flow as a result of the proposed discharge is less than 1 percent at all three locations on the Avon River and less than 5 percent at the location on Dog Trap Creek.

In order to ensure that the discharge flow is less than 5 percent of the total flow in the receiving streams, the stream flow should be no less than 0.5 m^3/s. A flow gauge or water level gauge (correlated to the appropriate flow) may be required at the discharge location if an adequate corresponding gauge is not available.

Table 3-3 Flow estimates

TSW01 (downstream of AV1 and AV2)			Bank full	0.75 Bank full	0.5 Bank full	0.25 Bank full	Low Flow	20th percentile
Manning's n=	0.06	Top width (m)=	13.5	11.9	10.9	9.6	9.3	9.9
channel slope (%) =	0.18	Flow area (m2)=	45.6	29.6	20.1	9.4	7.1	11.3
base width (m) =	8.32	Perimeter (m) =	18.1	15.2	13.2	10.8	10.2	11.3
depth (m)=	4.18	Hyd radius (m) =	2.5	1.9	1.5	0.9	0.7	1.0
depth (m)= 0.75bankfull	2.93	Velocity (m/s) =	1.3	1.1	0.9	0.6	0.6	0.7
depth (m)= 0.5bankfull	2.09	Flow (m3/s)=	59.5	32.7	18.8	6.0	3.9	8.1
depth (m)= 0.25bankfull	1.05	Froude No	0.23	0.22	0.22	0.21	0.20	0.21
depth (base flow)	0.80	VxD ratio =	5.46	3.23	1.95	0.67	0.44	0.89
20th percentile depth (m)	1.25	Impact of Additional Flow (2ML/Day)	0.04%	0.07%	0.12%	0.38%	0.59%	0.29%
side slope (1 in x)=	0.62	Shear stress	44.34	34.43	26.80	15.35	12.21	17.80
ASW01 (downstream of AV3)								
Manning's n=	0.06	Top width (m)=	12.1	10.3	9.1	7.6	6.8	8.1
channel slope (%) =	0.18	Flow area (m2)=	49.8	31.3	20.7	9.3	4.5	12.9
base width (m) =	6.04	Perimeter (m) =	18.6	14.8	12.3	9.2	7.6	10.2
depth (m)= (bankfull)	5.49	Hyd radius (m) =	2.7	2.1	1.7	1.0	0.6	1.3
depth (m)= 0.75bankfull	3.84	Velocity (m/s) =	1.4	1.2	1.0	0.7	0.5	0.8
depth (m)= 0.5bankfull	2.75	Flow (m3/s)=	67.9	36.5	20.7	6.7	2.2	10.7
depth (m)= 0.25bankfull	1.37	Froude No	0.21	0.21	0.21	0.21	0.20	0.21
depth (base flow)	0.70	VxD ratio =	7.49	4.48	2.75	0.98	0.35	1.51
20th percentile depth (m)	1.83	Impact of Additional Flow (2ML/Day)	0.03%	0.06%	0.11%	0.34%	1.03%	0.22%
side slope (1 in x)=	0.55	Shear stress	47.30	37.36	29.74	17.95	10.40	22.29

TSW02 (upstream of DT1)			Bank full	0.75 Bank full	0.5 Bank full	0.25 Bank full	Low Flow	20th percentile
Manning's n=	0.03	Top width (m)=	4.6	3.9	3.4	2.8	2.3	2.6
channel slope (%) =	0.30	Flow area (m2)=	8.1	5.1	3.3	1.5	0.2	0.8
base width (m) =	2.21	Perimeter (m) =	7.5	5.9	4.9	3.5	2.4	3.0
depth (m)= (bankfull)	2.39	Hyd radius (m) =	1.1	0.9	0.7	0.4	0.1	0.3
depth (m)= 0.75bankfull	1.67	Velocity (m/s) =	1.9	1.6	1.4	1.0	0.4	0.8
depth (m)= 0.5bankfull	1.20	Flow (m3/s)=	15.5	8.4	4.8	1.5	0.1	0.7
depth (m)= 0.25bankfull	0.60	Froude No	0.46	0.46	0.46	0.45	0.38	0.44
depth (base flow)	0.10	VxD ratio =	4.58	2.75	1.70	0.61	0.04	0.28
20th percentile depth (m)	0.35	Impact of Additional Flow (2ML/Day)	0.15%	0.28%	0.48%	1.49%	27.19%	3.47%
side slope (1 in x)=	0.49	Shear stress	31.63	25.16	20.20	12.43	2.73	8.28

3.2.4 Synthesis

- Collating the field data and observations with the review of valley setting and sinuosity it is determined that the RiverStyle (Brierley and Fryirs 2006) of the reaches of the Avon River and Dog Trap Creek containing the subject locations are all 'Meandering Fine Grained'. This RiverStyle is characterised by a laterally un-confined valley setting, continuous single channel, high sinuosity, laterally stable channel containing pools and point benches with a fine grained bed and bank material.
- The three locations on the Avon River (AV1, AV2 and AV3) did not vary significantly in their geomorphological characteristics or conditions. Slightly more instability was noted at AV1, this location appeared to be impacted by its location within a meandering section of the stream. However, all locations exhibited moderate evidence of recent and past erosion. The vegetation present at the locations reduced the impacts of ongoing fluvial erosion.
- Despite the lack of complex riparian vegetation at DT1, the presence of pasture grass appeared to also provide stability to the banks.
- When the stream side slope factors are removed, the channel stability ranking scheme scored all locations as having moderate instability. This, combined with the high, steep banks at the Avon River locations, would indicate that bank undercutting or further incision could lead to instability. This should be considered in the design of the outlet.
- The stream flow within the Avon River is considerably greater than within Dog Trap Creek resulting in the proposed discharge flow representing a smaller increase in flow.

3.3 Water Quality

3.3.1 Review of Existing Information

In general, the Avon River catchment has naturally high soil and groundwater salinity which is attributed to the geology of the area i.e. coal and shale deposits (Cardno 2010) and saline groundwater contributions to baseflow, particularly during low rainfall periods, which elevate Electrical Conductivity (EC). Anthropogenic causes of surface water salinity are also present within the Study Area, such as the diffuse but potentially significant contribution from agricultural practices. Downstream of the Avon River, the receiving waters of the Gloucester River have a much lower salinity (Turak *et al*. 2000).

Water quality within the Avon River and Dog Trap Creek has been continuously monitored at several sites as part of AGL's water quality network program from 2011 to 2015. A summary of the data collected at monitoring gauges relevant to the study area are provided below and in **Table 3-4**. Maximum and minimum ranges and percentile data (20th and 80th percentile) have been reported and these data have been used with engineering judgement to determine surface water quality at relevant sites to help identify a suitable discharge location. It is noted that Cardno have not undertaken any quality assurance of this data as part of this assessment.

TSW01

This monitoring site is located on the Avon River within the Tiedman property, approximately 0.3 km downstream of the confluence with Dog Trap Creek. Monitoring at this location has been occurring continuously at 15 minute intervals since 2011. Based on monitoring data collected from March 2011 to March 2015, water temperature ranged between 6.9 and 28.4°C. Salinity levels varied from 1.0 to 1337 µS/cm. Limited data is available for Dissolved Oxygen (DO) and pH levels at this location. The DO levels vary from 13 to 150% sat and pH is near neutral (6-8).

TSW02

This monitoring site is located on the Dog Trap Creek within the Tiedman property, approximately 0.4 km upstream of the confluence with Avon River. Monitoring at this location has been occurring continuously at 15 minute intervals since 2012. Based on monitoring data collected from April 2012 to March 2015, water temperature ranged between 0.1 and 41.7°C. Salinity levels based on monitoring data varied from 5 to 6570 µS/cm. Limited data is available for DO and pH levels at this location. The DO levels vary from 22 to 135%sat and pH is near neutral (7-8).

ASW01

This monitoring site is located on the Avon River within the Atkins property, approximately 0.1 km upstream of the confluence with Dog Trap Creek. Monitoring at this location has been occurring continuously at 15 minute intervals since 2011. Based on monitoring data collected from March 2011 to March 2015 water temperature varied between 5.8 and 26.0°C. Salinity levels based on monitoring data varied from 0 to 1288 µS/cm. Limited data is available for DO and pH levels at this location. The DO levels vary from 14 to 115% sat and pH varies from 6 to 9.

ASW02

This monitoring site is located on the Avon River within the Atkins property, approximately 1.7 km upstream of the confluence with Dog Trap Creek. Monitoring at this location has been occurring continuously at 15 minute intervals since 2011. Based on monitoring data collected from March 2011 to March 2015, water temperature varied between 5.2 and 26.0°C. The salinity levels based on monitoring data vary from 4.2 to 1,307 µS/cm. No other monitored water quality data is available for this location.

FSW01

This monitoring site is located on Avon River, approximately 1.2 km downstream from TSW01. Monitoring at this location commenced in 2012 as part of the Tiedman Irrigation Trial monitoring network. Water quality data for this site were available for Feb 2012, June 2012, Sept 2012, Nov 2013, Mar 2014, Aug 2014, Nov 2014, Dec 2014, Feb 2015, April 2015 and May 2015. Based on these data, salinity levels and temperature at this location vary from 80 to 728 µS/cm and t from 11°C to 28°C respectively. The Dissolved Oxygen (DO) levels at this location vary from 12 to 176 % sat and pH varies from 6 to 9.

Table 3-4 Summary of water quality data recorded from gauges in Avon River and Dog Trap Creek between March 2011 and May 2015. Data sourced from AGL (July 2015). Refer to Figure 3-1 for location of water quality monitoring locations. Highlighted values are outside the ANZECC/ARMCANZ (2000) guideline range.

Variable		Temperature (^{0}C)	Conductivity (µS/cm)	pH	DO (%sat)
ANZECC (2000) guidelines for lowland (<100 m AHD) rivers			125 - 2200 (lowland river)	6.5-8.0	85-110
AGL Target Water Criteria		Ambient **	<800	6.5 - 8.0	>25
TSW01	Max	28.4	1337	8.1	150*
	Min	6.9	1*	6.1	13*
	80th percentile	20.7	539	7.6	98.2
	20th percentile	11.18	241	7.0	31.6*
TSW02	Max	41.7	6570*	7.8	135*
	Min	0.1	5*	6.6	21.6*
	80th percentile	20.6	585	7.5	103.2
	20th percentile	10.6	215	7.0	57*
ASW01	Max	26.0	1288	8.7	115.4
	Min	5.8	0*	5.9	14*
	80th percentile	20.7	414	7.8	83.3*
	20th percentile	11.1	206	7.0	41.5*
ASW02	Max	26.0	1307	Data not available	
	Min	5.2	4*		
	80th percentile	20.5	438		
	20th percentile	10.8	229		
FSW02	Max	27.9	728	8.8	176.1*
	Min	11.0	80*	5.5	11.9*
	80th percentile	23.3	481.6	8.4	112.2
	20th percentile	14.1	215.2	6.9	15.2*

* - These values are outside the ANZECC guidelines;
** - temperatures will be the same as for water stored in the Tiedman irrigation dams or discharge water pond at the CPF
Note: Max and Min have not been reported for *Temperature* due to some erroneous data in the time series

3.3.2 Results of Field Investigations

Field measurements recorded on 30 June 2015 are presented in **Table 3-5** below. Mean values highlighted in bold indicate that the variable measured is outside of ANZECC guidelines and/or the AGL target values for treated water. However it is also worthwhile noting that the natural baseline water quality for the Avon River does not align with the ANZECC water quality criteria so these criteria should not be taken as the ultimate criteria for stream discharges. Further details are provided in the EWMS.

Table 3-5 Water quality measures collected within the Avon River and Dog Trap Creek on 30 June 2015

			Variable	Temperature (^0C)	Conductivity (µS/cm)	Salinity (ppt)	pH	ORP (mV)	DO (%sat'n)	DO (mg/L)	Ave Turbidity (ntu)
ANZECC (2000) guidelines for lowland (<100 m AHD) rivers					125 - 2200 (lowland river)		6.5-8.0		85-110		6-50
AGL Target Water Criteria				Ambient	<800		6.5 - 8.0		>25		<15
Avon River (Approx. 150 m downstream of the confluence with Dog Trap Creek)	AV1	Bottom	Rep 1	9.60	401.00	0.19	7.00	179.80	70.00	7.80	7.60
			Rep 2	9.70	428.00	0.21	6.99	177.00	69.60	7.83	7.40
			Mean	**9.65**	**414.50**	**0.20**	**7.00**	**178.40**	**69.80**	**7.82**	**7.50**
			SE	0.05	13.50	0.01	0.00	1.40	0.20	0.02	0.10
Avon River (Approx. 600 m upstream of the confluence with Dog Trap Creek)	AV2	Bottom	Rep 1	11.37	359.00	0.17	7.46	147.00	82.10	8.99	6.90
			Rep 2	10.60	361.00	0.17	7.41	147.70	77.40	8.59	7.20
			Mean	**10.99**	**360.00**	**0.17**	**7.44**	**147.35**	**79.75**	**8.79**	**7.05**
			SE	0.39	1.00	0.00	0.02	0.35	2.35	0.20	0.15
Avon River (Approx. 400 m upstream of the confluence with Dog Trap Creek)	AV3	Bottom	Rep 1	10.13	357.00	0.17	7.53	175.50	80.00	8.99	6.50
			Rep 2	10.08	355.00	0.17	7.40	169.80	76.90	8.62	6.50
			Mean	**10.11**	**356.00**	**0.17**	**7.47**	**172.65**	**78.45**	**8.81**	**6.50**
			SE	0.03	1.00	0.00	0.06	2.85	1.55	0.19	0.00
Dog Trap Creek (Approx. 700 m upstream of confluence with Dog Trap Creek)	DT1	Bottom	Rep 1	12.00	608.00	0.30	7.36	139.00	88.30	9.52	6.60
			Rep 2	11.83	608.00	0.30	7.28	135.70	87.10	9.40	6.50
			Mean	**11.92**	**608.00**	**0.30**	**7.32**	**137.35**	**87.70**	**9.46**	**6.55**
			SE	0.09	0.00	0.00	0.04	1.65	0.60	0.06	0.05

3.3.3 Synthesis

> The proposed high flow water discharge into the receiving environment will be treated to meet the water quality targets as shown in **Table 3-6** below. The majority of these targets are within the ANZECC guidelines.

> Due to large variations identified for salinity across all the locations from the long term monitoring data, the target guideline of <800 µS/cm) may limit the opportunity for discharging if salinities are at the top of this range.

> Based on the monitoring data assessed, the target value for surface water DO is lower than the recommended ANZECC guidelines and generally lower than the 80th percentile for long-term monitoring data at all long term monitoring locations. This may mean that DO in discharge water may be significantly lower than ambient conditions. That considered, given the limited frequency, relatively low volumes and naturally high flow conditions of planned releases, it is unlikely that there would be any measureable downstream effect.

> The 80th percentile for DO at AV2 across all years of data appears to be lower overall than other locations and may therefore be closest to ambient conditions if a release takes place when DO of discharge water is closer to the lowest target value (i.e. 25% saturation).

> Considering that monitoring station TSW01 is most representative of conditions at AV1, ASW01 is representative of AV2 and AV3 there are little differences in temperature, pH or salinity between the Avon River locations with all being subject to similar seasonal variation. Dog Trap Creek, however, is subject to more pronounced extremes, likely due to its lower flows and ephemeral nature.

Table 3-6 AGL discharge water quality targets

Water Quality Parameter	Unit	AGL Target range *	ANZECC (2000) guidelines for lowland (<100 m AHD) rivers
Salinity (EC)	µS/cm	<800	125-2200
Temperature	°C	Ambient temperatures as per storage dam/ponds	-
pH	pH units	6.5 - 8	6.5 - 8
Dissolved Oxygen	% saturation	>25% saturation	85-110
Turbidity	NTU	<15	6-50
TDS	mg/L	<500	-
Sodium	mg/L	<80	-
Calcium	mg/L	<10	-
Magnesium	mg/L	<2	-
Suspended Solids	mg/L	<10	-
Iron	mg/L	<1	Insufficient data
Manganese	mg/L	<0.5	1.9
Aluminium	mg/L	<0.2	0.055
Chloride	mg/L	<100	-
Sulphate	mg/L	<40	-
Phosphorus	mg/L	<5	0.05
Fluoride	mg/L	<1	-
Boron	mg/L	<0.5	0.37
Residual disinfectant (monochloramine)	mg/L	<0.05	-
Ammonia	mg/L	<0.05	20
Total alkalinity (as CaCO3)	mg/L	<60	-

Note: * - Taken from Final Draft of Extracted Water Management Strategy (AGL, 2015)

3.4 Aquatic Ecology

3.4.1 Review of Existing Information

3.4.1.1 Aquatic Habitat Condition

Many of the watercourses within the Study Area have been cleared to the bank, with the few remaining strips of native riparian vegetation restricted to sections of larger rivers, such as the Gloucester River (AECOM 2009). Riparian habitat has also often been heavily disturbed by weeds including camphor laurel (*Cinnamomum camphora*), lantana (*Lantana camara*), privet (*Ligustrum* sp.) and willow (*Salix* sp.) for example.

Macroinvertebrates have been previously sampled in riffle and pool edge habitat in Avon River as part of a wider assessment of river health in NSW (Turak *et al*. 2000). Ausrivas methods were used to assess the health of the Avon River reach downstream of Stratford during surveys in autumn (pool edge habitat only) and spring (pool edge and riffle habitat) of 1997. The Ausrivas protocol uses a predictive model to determine the environmental condition of a waterway by comparing the observed freshwater macroinvertebrate assemblages (i.e. those collected in the field) with macroinvertebrate assemblages expected from reference (undisturbed) waterways of the same type. The Ausrivas assessments indicated some impairment to the aquatic macroinvertebrate community of the Avon River, consistent with habitat degradation and poor water quality. In contrast, the same study of river health in NSW surveyed three sites in the Gloucester River, two upstream of the Avon River confluence and one downstream

Cardno has carried out surveys of river health within the Gloucester basin as part of impact assessments for coal mining activities. Results indicated that sites were 'generally impaired' (at Oakey Creek) to 'near reference condition' (within Gloucester River), although sites within the Avon River (closest to the Study Area) were recorded as 'good' (RCE scores between 27 and 32) for the disturbed agricultural landscape. Exotic trees, pasture grasses and annual weeds were however, a dominant feature of the riparian habitat with some areas affected by vegetation clearing and bank erosion. Diversity of macrophytes was also relatively low and included a high proportion of introduced and exotic species. Frc environmental (2012) also reported a lack of submerged and floating macrophytes at most sites within the Avon River suggesting that water levels fluctuate considerably and/or that the water column is likely to be highly turbid which reduces light levels. Several introduced and exotic species were also recorded.

Long-term monitoring of the Stratford Mining Complex (IIA 2001 – 2010) found that macroinvertebrate communities from six sites, including two on the Avon River downstream of Stratford were dominated by pollution-tolerant taxa indicating that water quality was 'very poor' to 'poor' and that for the majority of sites and years sampled the assemblages were moderately to grossly impaired (IIA 2009). Water chemistry (particularly salinity) and flow levels were considered to have the greatest influence on macroinvertebrate biological diversity, with the lowest diversity recorded during periods of prolonged periods of low flows and high EC (IIA 2010). Results of the 2013 survey indicated that habitat condition at Site 2 (located within the Study Area) was below reference, but had fair water quality and a healthy assemblage of pollution sensitive taxa present i.e. (mayflies, stoneflies and caddisflies) (IIA 2014).

Little information is available in regard to the condition of Dog Trap Creek, although IIA (2014) reported the downstream area to be heavily impacted by cattle grazing with some bank erosion and minimal riparian vegetation apart from eucalypt and Casuarina trees. Habitat condition was recorded as below reference, water quality as 'poor' and the assemblage of pollution sensitive taxa to be 'slightly impaired'.

3.4.1.2 Fish and Mobile Macroinvertebrates

The Manning river system does not contain large dams, or barriers to fish movement and hence maintains connectivity between the watercourses of the Study Area and the Pacific Ocean. As such, fish are able to migrate between the upper reaches of rivers and estuaries or the sea, which potentially leads to a relatively diverse assemblage within the upper catchment. Minor causeway crossings can be located upstream of the confluence of the Avon and Gloucester Rivers however, which may impede fish passage under low flow conditions.

Cardno (2011) recorded nine species of fish in the Avon River including longfinned eel (*Anguilla reinhardtii*), small native gudgeons and the introduced mosquitofish (*Gambusia holbrooki*). Mosquitofish are a Class 1 noxious species outside the greater Sydney area and have been associated with the decline in abundance of native species as they are tolerant of impaired environmental conditions and able to outcompete native species for food and resources (NSW DPI 2015). Frc environmental (2012) also found mosquitofish to be the most abundant and widespread species (as well as the firetail gudgeon (*Hypseleotris galii*) caught in both the Avon River and Dog Trap Creek.

Other species recorded in the lower Avon River and Manning River catchment include eels (Anguillidae), freshwater herring (*Potamalosa richmondia*), various types of native gudgeons (Eleotridae), mullet (Mugilidae), Australian Bass (*Macquaria novemaculeata*)*,* freshwater catfish (*Tandanus tandanus*)*,* Australian smelt (*Retropinna semoni*)*,* Pacific blue-eye (*Pseudomugil signifier*), rainbow trout (*Oncorhynchus mykiss*) and bullrout (*Notesthes robusta*) (frc environmental (2012), Howell and Creese (2010) and Harris and Gerke (1997). In addition to those species already listed above, a search of the Atlas of Living Australia also returned records of the common galaxias (*Galaxias maculatus*), freshwater herring (*Potamalosa richmondia*) and the introduced goldfish (*Carrasius auratus*).

Mobile macroinvertebrates including high abundances of freshwater shrimp and prawns (Family: Atyidae and *Machrobrachium* sp.) and yabbies (*Cherax destructor*) have also been recorded within the Avon River (Cardno 2011, frc environmental 2012).

Overall, previous studies have categorised the Avon River was as a moderate (Class 2) key fish habitat as per the criteria outlined in Fairful (2013). Policy and Guidelines for Fish Habitat Conservation and Management.

3.4.1.3 Other Vertebrates

Several other aquatic animals are known or considered likely to occur within the Manning River catchment, including eastern snake-necked turtles (*Chelodina longicollis*), Manning River snapping turtle (*Myuchelys purvisi*), platypus (*Ornithorhynchus anatinus*), eastern water dragon (*Physignathus lesueurii*) and frogs.

These species are not listed as threatened but are protected under the NPW Act (as is the case with all native species).

The Eastern snake-necked turtle is common in most of NSW where it inhabits freshwater ponds, lakes and streams. It may also make burrows in riverbanks during dry conditions. The Manning River snapping turtle has only been found in the Manning River Catchment and it is unknown whether it would occur in the Study Area. Platypus and water dragons have been observed to occur within the Study Area (Cardno 2010, frc environmental 2012) and are commonly found throughout the freshwater reaches of the Manning River.

River or streams with earth banks and native vegetation that provides shading and cover is ideal habitat for platypus which make burrows in stream banks, although coarse cobble and /or gravel substratum is preferred. Eastern water dragons also dig burrows to lay eggs, but generally prefer sandy dry soils.

A number of native frog species have also been detected in high numbers throughout gullies and water bodies immediately south of the Study Area including Dog Trap Creek (Ecobiological 2010). Species recorded included striped marsh frog (*Limnodynastes peronii)*, spotted grass frog (*Limnodynastes tasmaniensis)*, eastern dwarf tree frog (*Litoria fallax)*, Peron's Tree Frog (*Litoria peronii)* and dusky toadlet (*Uperoleia fusca*) in particular.

3.4.1.4 Threatened and Protected Species, Populations and Ecological Communities

A total of 35 species of amphibian, three species of aquatic reptile and one species of aquatic mammal were recorded as known or likely to occur within the Gloucester LGA. No species of threatened or protected fishes or macroinvertebrates were listed. Two of the frog species (green and golden bell frog (*Litoria aurea*) and the giant barred frog (*Mixophyes iterates*)), were highlighted as species of concern within the GFDA by the Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC). As such, detailed assessments of significance were completed for these species (AH Ecology 2012) and concluded that it would be unlikely for these species to occur within the GDFA as neither species has been recorded within the Gloucester LGA and limited extent of potentially suitable intact riparian vegetation.

The population of tusked frog (*Adelotus brevis*) in the Nandewar and New England Tableland Bioregions was also listed as potentially occurring in the Gloucester LGA. None of the species listed, however, have been recorded to have occurred within watercourses of the Avon River or Dog Trap Creek within the boundary of the Study Area.

Two Endangered Ecological Communities: 'Freshwater Wetlands on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions' and Swamp Oak Floodplain Forest of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions are mapped as being 'known' to occur within the Gloucester LGA and has potential to occur within the Study Area.

Table 3-7 Species listed under the EPBC, TSC and FM Acts with relevance to the study area

Scientific Name	Common Name	TSC/ NP&W Act	EPBC Act
Amphibians			
Adelotus brevis	Tusked Frog	P	
Crinia signifera	Common Eastern Froglet	P	
Crinia tinnula	Wallum Froglet	V,P	
Lechriodus fletcheri	Fletcher's Frog	P	
Limnodynastes dumerilii	Eastern Banjo Frog	P	
Limnodynastes peronii	Brown-striped Frog	P	
Limnodynastes tasmaniensis	Spotted Grass Frog	P	
Mixophyes balbus	Stuttering Frog	E1,P	V
Mixophyes fasciolatus	Great Barred Frog	P	
Mixophyes iteratus	Giant Barred Frog	E1,P	E
Philoria sphagnicolus	Sphagnum Frog	V,P	
Pseudophryne australis	Red-crowned Toadlet	V,P	
Pseudophryne bibronii	Bibron's Toadlet	P	
Pseudophryne coriacea	Red-backed Toadlet	P	
Uperoleia fusca	Dusky Toadlet	P	
Uperoleia laevigata	Smooth Toadlet	P	
Litoria aurea	Green and Golden Bell Frog	E1,P	V
Litoria booroolongensis	Booroolong Frog	E1,P	E
Litoria brevipalmata	Green-thighed Frog	V,P	
Litoria caerulea	Green Tree Frog	P	
Litoria chloris	Red-eyed Tree Frog	P	
Litoria daviesae	Davies' Tree Frog	V,P	
Litoria dentata	Bleating Tree Frog	P	
Litoria ewingii	Brown Tree Frog	P	
Litoria fallax	Eastern Dwarf Tree Frog	P	
Litoria latopalmata	Broad-palmed Frog	P	
Litoria lesueuri	Lesueur's Frog	P	
Litoria nasuta	Rocket Frog	P	
Litoria pearsoniana	Pearson's Green Tree Frog	P	
Litoria pearsoniana/phyllochroa	Leaf Green Tree Frog species complex	P	
Litoria peronii	Peron's Tree Frog	P	
Litoria phyllochroa	Leaf-green Tree Frog	P	
Litoria revelata	Revealed Frog	P	
Litoria tyleri	Tyler's Tree Frog	P	
Litoria verreauxii	Verreaux's Frog	P	
Aquatic Reptiles			
Chelodina longicollis	Eastern Snake-necked Turtle	P	
Emydura macquarii	Macquarie Turtle	P	
Intellagama lesueurii	Eastern Water Dragon	P	
Aquatic Mammals			
Ornithorhynchus anatinus	Platypus	P	
Endangered Population			
Adelotus brevis	Tusked Frog population in the Nandewar and New England Tableland Bioregions	E2,P	

Endangered Ecological Communities		
Freshwater Wetlands on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions	Freshwater Wetlands on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions	E3
Swamp Oak Floodplain Forest of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions	Swamp Oak Floodplain Forest of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions	E3

**Results of database searches are only indicative and cannot be considered a comprehensive inventory.*

3.4.1.5 Key Threatening Processes

A key threatening process (KTP) is something that threatens, or could potentially threaten, the survival or evolutionary development of a species, population or ecological community as listed under the TSC Act, FM Act or EPBC Act. KTPs potentially applicable to the proposed construction and operation of the high flow discharge outlet are listed in **Table 3-8**. A brief description of these KTPs is also provided below and their relevance to the high flow discharge is discussed in **Section 3.4.3**.

Table 3-8 Key threatening processes relevant to the proposed high flow discharge outlet

Key Threatening Processes	TSC Act	FM Act	EPBC Act
Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands	✓		
Clearing of native vegetation	✓		
Land Clearing			✓
Removal of dead wood and dead trees	✓		
Predation by *Gambusia holbrooki* Girard, 1859 (Plague Minnow or Mosquito Fish)	✓		
Installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams.		✓	
Removal of large woody debris from New South Wales rivers and streams.		✓	
Degradation of native riparian vegetation along New South Wales water courses.		✓	

'Alteration to natural flow regimes' refers to reducing or increasing flows, altering seasonality of flows, changing the frequency, duration, magnitude, timing, predictability and variability of flow events, altering surface and subsurface water levels, changing the rate of rise or fall of water levels and by altering water temperatures. Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands is recognised as a major factor contributing to loss of biological diversity and ecological function in aquatic ecosystems, including floodplains. Impacts potentially associated with altering natural flow regimes can include:

> riparian zone degradation where changes to flows increases erosion, leading to sedimentation impacts upon aquatic communities;

> deeper and more permanent standing water conducive to the establishment and spread of exotic species; and

> changes to the physical, chemical and biological conditions of rivers and streams which alters biota.

Temperature in particular, is considered an important factor in the development and growth of fish (Astles *et al.* 2003). Metabolism, respiration, feeding, reproduction, larval development and migratory behaviour of native fish are all strongly influenced by temperature. Fish eggs, larvae and juveniles are critical growth stages that can also be strongly temperature dependent. In spring and summer the rising temperature of the water becomes an important environmental cue, triggering spawning or migratory behaviour in native fish with a significant release of cold water suppressing spawning in some species for up to 300 km downstream (NSW DPI – Water 2015). As a result, the ability of native fish to reproduce, grow and maintain sustainable numbers may potentially be affected. Introduced species, competing with native fish for food and habitat may flourish under altered conditions.

A related process, 'the installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams' is listed as a key threatening process under the FM Act. Instream structures that modify natural flow may include dams, weirs, canals, navigation locks, floodgates, culverts, flow regulators, levee banks, erosion control structures and causeways.

Clearing of native vegetation, refers to the destruction of a sufficient proportion of one or more strata (layers) within a stand or stands of native vegetation. Potential impacts may include loss of habitat and biological diversity, fragmentation of populations and riparian zone degradation, such as bank erosion leading to sedimentation that affects aquatic communities, the establishment and spread of exotic species and loss of leaf litter which is an important resource for a variety of aquatic species. 'Land Clearing' is also listed as a key threatening process under the Environmental Protection and Biodiversity Conservation Act 1999.

Dead wood and trees including large woody debris present in streams and rivers (snags) provide essential habitat for a wide variety of native animals (including native fish, invertebrates, reptiles and amphibians) and are important to the functioning of many ecosystems.

3.4.2 Results of Field Investigation

Results of the ecological field assessment for locations AV1, AV2, AV3 and DT1 are summarised in the following sections. Sampling locations are indicated in **Figure 3-1**. Some representative photos of the investigation sites are provided **in Figure 3-3**. Representative species recorded at each location are listed in **Table 3-9**.

3.4.2.1 Location AV1

AV1 was characterised by a relatively deep channel shaded by mature Casuarina trees forming a moderately dense riparian corridor along both banks (**Figure 3-3 (a)**). *Lomandra longifolia (*mat rush) was also a predominant macrophyte along the bank edges with occasional *Juncus* sp. (**Figure 3-3 (b)**) providing additional shading and habitat. Several exotic trees and shrubs such as tobacco (*Solanum mauritianum)* and privet (*ligustrum* sp.) were also present. The understorey was comprised of a mix of native and exotic grasses. No in-stream aquatic macrophytes were visible. Occasional snags and rocks also provided some instream habitat for fish and macroinvertebrates.

Surrounding land use was primarily for cattle grazing and access of livestock to bank edges was evident by trampling. The gravel causeway across the Avon River immediately upstream of the site may cause a minor barrier to upstream fish passage, however, only in very low flow conditions. Overall, this location would be considered to have the best potential for fish habitat of the four locations assessed.

RCE Score: 31 (Good)

Fish Habitat Class: 2 (Moderate key fish habitat)

Fish Habitat Sensitivity: II (Moderately sensitive fish habitat)

3.4.2.2 Location AV2

AV2 was characterised by moderately sloping banks consisting predominantly of exotic weeds, grasses and the occasional mature Casuarina which provided some shading (**Figure 3-3 (c)**). The exotic weed *Sida rhombifolia* was prolific, forming a dense understorey (**Figure 3-2 (c)**). In-stream aquatic macrophytes were sparse, apart from slender knotweed (*Persicaria* sp.), water ribbons (*Triglochin* sp.) observed at the water's edge (**Figure 3-3 (d)** and **(e)**), although the presence of other in-stream vegetation was difficult to confirm due to poor visibility. Occasional large snags were observed up and downstream of the assessment location potentially providing habitat for small fish and invertebrates. Surrounding land use was again primarily for cattle grazing and access of livestock to bank edges was evident by trampling.

RCE Score: 29 (Good)

Fish Habitat Class: 2 (Moderate key fish habitat)

Fish Habitat Sensitivity: II to III (Moderately sensitive fish habitat)

3.4.2.3 Location AV3

AV3 was similar to AV2 in terms of habitat composition, but was located approximately 200 m downstream. As for AV2, AV3 was characterised by moderately sloping banks consisting of exotic shrubs (mainly privet), grasses and the occasional mature and young Casuarina trees which provided some in-stream shading (**Figure 3-2 (d)**). Dense clumps of mat rush were predominant along the stream edges. In-stream macrophytes or snags did not appear to be present although, again this was difficult to confirm due to poor visibility. Livestock have also accessed the stream edge at this location likely increasing the turbidity.

RCE Score: 30 (Good)

Fish Habitat Class: 2 (Moderate key fish habitat)

Fish Habitat Sensitivity: II (Moderately sensitive fish habitat)

3.4.2.4 Location DT1

Dog Trap Creek was distinctly different from the three Avon River locations in that any significant riparian corridor was absent and the waterway itself was much narrower and shallower than the Avon River locations (**Figure 3-2 (f)**). Bank vegetation consisted primarily of grasses, occasional exotic shrubs and emergent macrophytes only, including native species such as mat rush, common rush (*Juncus* sp.) and canegrasses. Beds of typha (*Phragmites australis*) and spikerushes (*Eleocharis* sp.) were also abundant downstream of the assessment location. The stream itself was comparatively shallow (varying between 0.05 and 0.3 m) and relatively clear allowing identification of in-stream macrophytes including the introduced starwort (*Calitriche stagnalis*), water ribbons, pondweed (*Pomatogeton* sp.) and *Persicaria* sp. Several exotic weeds and grasses were also noted. This location clearly provided habitat for frogs (as evident by the chorus of calls), although the calls of either the green and golden bell frog or the giant barred frog were not recognised.

RCE Score: 27 (Good)

Fish Habitat Class: 3 (Minimal key fish habitat)

Fish Habitat Sensitivity: II to III (Moderate to minimally sensitive fish habitat)

Table 3-9 Species recorded within the study area on 30.06.15

Common Name	Scientific Name	AV1	AV2	AV3	DT1
Wild tobacco*	*Solanum mauritianum**	✓	✓	✓	
Small leaf privet	*Ligustrum sinense*	✓	✓	✓	
She-oak	*Casuarina* sp.	✓	✓	✓	
Paper bark	*Melaluca* spp.	✓			
Common rush	*Juncus usitatus*	✓			✓
Mat rush	*Lomandra longifolia*	✓	✓	✓	
Wattle	*Acacia sp.*	✓	✓	✓	✓
Creek lilli pilly	*Acmea smithi*	✓			
Paddy's lucerne*	*Sida rhombifolia**		✓		
Starwort*	*Callitriche stagnalis**				✓
Fireweed*	*Senecio madagasgarensis**		✓	✓	
Pondweed	*Pomatogeton* sp.				✓
Water ribbons	*Triglochin procerum*		✓		✓
Slender knotweed	*Persicaria* sp.				✓
Filamentous green algae	*Cladophora* sp.				✓
Common reed	*Phragmites australis*				✓
Mixed exotic weeds and grasses*	*n/a*	✓	✓	✓	✓
Dock Leaf	*Rumex* sp.			✓	✓

a)

b)

c)

d)

e)

f)

Figure 3-3 Location photos (aquatic ecology) a) AV1 looking downstream b) Juncus usitatus c) DT1 looking downstream d) DT1 *Persicaria* sp. e) DT1 *Triglochin* sp. f) DT1 *Calitriche stagnalis* (starwort)

3.4.3 Synthesis

> Despite the surrounding land use and significant amount of exotic and introduced weeds and shrubs within the riparian corridor, the overall habitat condition of the investigation locations was relatively good. On the basis of the literature review and field assessment, it is likely that the reaches of Avon River and Dog Trap Creek within the Study Area would provide habitat for small native fish (such as gudgeons) and mobile invertebrates including freshwater prawns, shrimps and yabbies. Larger diadromous fish including eels and potentially other species may also occur at the Avon River locations, although the lack of clean gravel and/or riffle habitat would limit the diversity of fish and some macroinvertebrates.

> The earthy but relatively stable banks of the Avon River may provide habitat for eastern snake-necked turtle, yabbies and potentially platypus, whereas Dog Trap Creek appeared to provide significant habitat for frogs.

> A large number of threatened and protected species (mostly frogs) were listed as having potential to occur within the Study Area, however there were no records of these particular species occurring within watercourses of the Avon River or Dog Trap Creek within the boundary of the Study Area.

> Given the limited frequency, relatively low volumes and naturally high flow conditions of planned releases, it is unlikely that there would be any measureable downstream effect on aquatic flora or fauna to the extent that any sensitive aquatic species would be affected. It is also unlikely that the proposed high flow discharge would result in the exacerbation of any Key Threatening Processes, however, measures to minimise any construction or operational impacts are recommended (**Section 4**).

> Water to be released during high flow discharge events would be from Discharge Water Ponds (DWPs) where it would be collected over time (and not directly from the reverse osmosis or Water Treatment Plant). Providing that the discharge water is ambient to the receiving waters as per the AGL discharge water quality targets, no measurable effect on aquatic fauna or flora downstream of the discharge location would be expected.

> The area cleared for the pipeline and discharge outlet installation would benefit from removal of introduced weeds and replanting of native riparian vegetation. Scour protection works may also provide habitat diversity for aquatic biota.

3.5 Preliminary Location Selection

As discussed in **Section 2.6**, four preferred locations (AV1, AV2, AV3 and DT1), were initially selected on the basis of existing information and the field investigation. A Multi-Criteria Analysis (MCA) was then undertaken to help determine which of the four locations would be optimal (**Table 3-10**). This was done according to a set of eight criteria relating to geomorphological and ecological conditions and potential design constraints of the preferred locations. Assumptions and rationale for selecting these criteria are outlined in **Section 2.6**.

All of the locations assessed were considered to be relatively similar in terms of the key criteria considered and all would be potentially suitable for a high flow discharge outlet. In determining a preferred location, however, location AV2 was considered optimal in representing minimal environmental risk balanced with the design constraints (**Table 3-10**). While the advantages of discharging into Dog Trap Creek would be that the banks are more accessible and lower than the Avon River locations (potentially requiring less engineering work and habitat disturbance), locations within the Avon River were likely to provide a greater buffer to the additional flow of the discharge water, particularly in the instance of an unforseen low-flow release event. Ecologically, all locations were similar in terms of habitat condition and providing that minimal native habitat is disturbed and re-vegetated, the differences between locations would be minor. The bank slope at AV2 was also considered to be slightly lower and shallower than AV1 or AV3 making the engineering works more accessible. Removal of excessive weed growth, replanting of native vegetation and scour protection (e.g. sandstone rocks) at AV2 would also improve the local habitat condition and provide habitat complexity for small fish and invertebrates.

Table 3-10 Multi-Criteria Analysis (MCA) of locations proposed for high flow discharge outlet

		Overall	Non-Weighted Scores				Weighted Scores			
Criteria - Geomorphology	**Weighting**	**Weighting**	**AV1**	**AV2**	**AV3**	**DT1**	**AV1**	**AV2**	**AV3**	**DT1**
Impact of additional flow from proposed discharge on existing 'high flow' conditions 1 = Greater than 20% increase in flows 2 = 5% to 20% increase in flows 3 = 1% to 5% increase in flows 4 = less than 1% increase in flows	**2**	**4**	4	4	4	3	8	8	8	6
Impact of additional flow from proposed discharge on existing 'low flow' conditions 1 = Greater than 20% increase in flows 2 = 5% to 20% increase in flows 3 = 1% to 5% increase in flows 4 = less than 1% increase in flows	**1**		4	4	4	2	4	4	4	2
Existing channel stability 1 = Significant active erosion likely to lead to mass failure of banks. Lack of vegetation providing stabilisation. 2 = Historic evidence of erosion and some evidence of recent scour or undercutting of banks. Good vegetation cover. 3 = Historic evidence of erosion, no active erosion present. Existing vegetation contributing significantly to stabilisation of banks. 4 = Stable channel. No indication of erosion and adequate vegetation cover to provide stability.	**1**		2	2	2	3	2	2	2	3
Criteria - Ecological			**AV1**	**AV2**	**AV3**	**DT1**	**AV1**	**AV2**	**AV3**	**DT1**
Approximate area of native habitat requiring removal (m^2) 1 = >6 m^2 2 = 4-6 m^2 3 = 2-4 m^2 4 = 0-2 m^2	**2**	**4**	2	4	2	4	4	8	4	8

Potential Fish Habitat Class 1 = Major key fish habitat 2 = Moderate key fish habitat 3 = Minimal key fish habitat 4 = Unlikely key fish habitat	**1**		2	2	2	3	2	2	2	3
Riparian Channel and Environmental (RCE) Inventory Scores 1 = RCE Score 40-52 (Very Good) 2 = RCE Score 27-39 (Good) 3 = RCE Score 14-26 (Moderately impaired) 4 = RCE Score 0-13 (Highly disturbed)	**1**		2	2	2	2	2	2	2	2
Criteria – Design			**AV1**	**AV2**	**AV3**	**DT1**	**AV1**	**AV2**	**AV3**	**DT1**
Suitability of bank formation to accept headwall and discharge flows 1 = Difficult and steep bank slope, high bank levels 2 = Moderately accessible bank, moderate bank height 3 = Accessible bank, low to moderate bank height 4 = Easily accessible bank, low bank height	**1**		1	2	1	4	1	2	1	4
Pipe route length and resulting construction and restoration costs 1 = Longest pipe route and thus likely most expensive construction option 2 = Long pipe route and thus relatively expensive construction and restoration 3 = Moderate length pipe route and thus mid-range construction costs 4 = Shortest pipe route and thus likely lowest construction cost option	**2**	**3**	1	3	3	1	2	6	6	2
Total Scores			**18**	**23**	**20**	**22**	**25**	**34**	**29**	**30**
Overall Rank							**4**	**1**	**3**	**2**

3.6 Preliminary Design

The preliminary design for the high flow discharge outlet has been drafted on the basis of the preferred AV2 location. The preliminary design is based upon the following data:

> Peak flow of 2ML/day (equivalent to approximately 23L/s).

> Outlet at location AV2 as per the Multi-Criteria Assessment as discussed in **Section 3.5**.

It is understood that a transfer water pipe line will deliver water from the discharge water pond (DWP) at the water treatment facility at the CPF in the south to the Tiedman holding ponds in the north. Treated water will then be irrigated over dedicated irrigation areas. During periods of high flow and when the holding ponds are at capacity, water will be diverted direct to the high flow outlet at location AV2 from either the DWP via the transfer pipeline or from the Tiedman holding ponds again via the transfer pipeline.

Due to the location topography and ground level variation it is expected that the transfer pipe line will be a pressurised rising main. Preliminary advice from AGL Engineering is that a DN160 transfer pipe is expected.

The rising main will pass through the proposed diversion/offtake pit (Pit A1). The mechanism for diversion will be designed as part of future works by others. It is expected that a valve or hydraulic gate will be utilised. Refer to the concept engineering plans included in **Appendix C** and **Figure 3-4** for concept arrangement including indicative pit locations. It is noted that AGL advise that the rising main will be 'bi-directional'.

A gravity pipe line will run from the rising main to the west toward the Avon River. The trench for the pipe will be clear of the existing dam located to the south of the proposed gravity pipe line. Typical trench depth is expected to be in the order of 1.0 to 1.5 m in depth (subject to future site detailed survey). The trench surface will be restored and revegetated to match existing conditions.

An inspection pit near the existing top of creek bank (Pit A3) will allow a change in pipe direction and discharge to the outlet headwall (Headwall A4). Discharge from the outlet headwall will be at approximately 60 degrees to the main river channel)(**Figure 3-4 (a)**, **Appendix C**). An intermediate pit, Pit A2, is included between Pit A1 and Pit A3 for maintenance purposes).

A typical creek cross section as discussed in **Section 3.2** was reviewed to inform expected gravity pipe line levels. It is expected that between Pit A1 and Pit A3 the gravity pipe will be laid at approximately 0.5% grade (1 in 200). From Pit A3 to Headwall A4 the pipe grade increases significantly to approximately 30% (1 in 3.3) to match the slope of the existing river bank (**Figure 3-4 (a)**). This will necessitate the installation of concrete bulkheads, or similar, around the gravity pipe to prevent piping failure and migration of the trench backfill material.

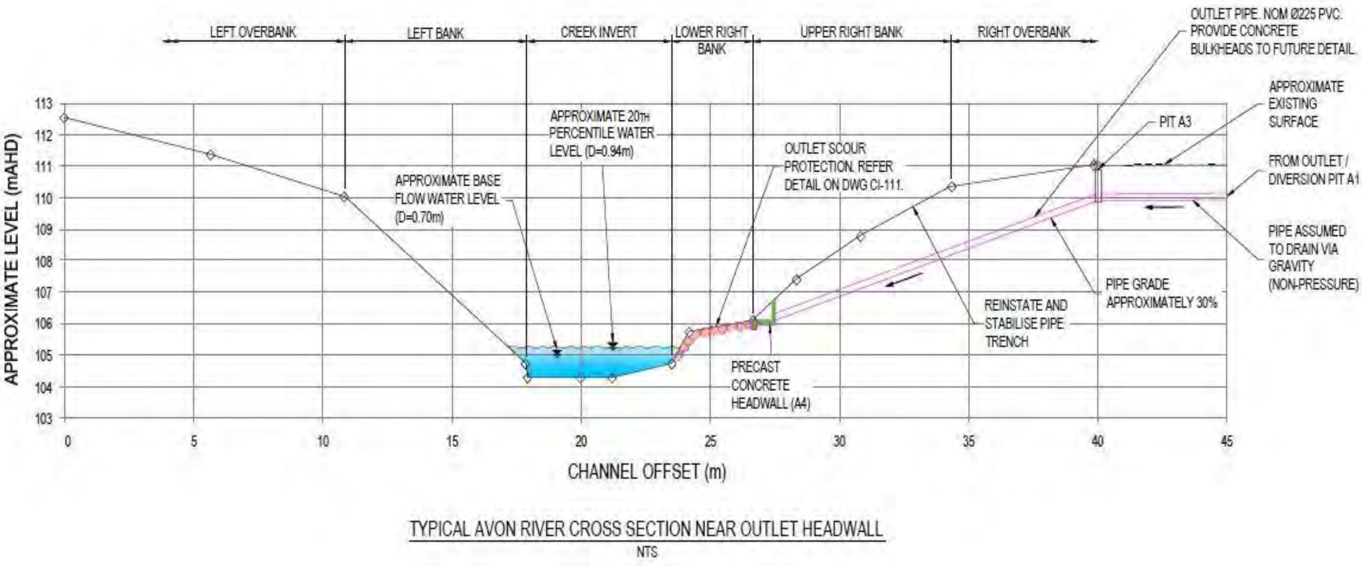
To reduce the grade of the gravity pipe between Pit A3 and Headwall A4 a deeper trench was considered. Where the pipe grade was significantly reduced, trench depths of up to 5 m resulted. This trench depth was considered to be excessive and was not, therefore pursued further.

A concept DRAINS computer model was prepared in order to assess the hydraulic capacity and outlet velocity of the gravity pipe network. The DRAINS model showed that a 225 mm diameter gravity pipe had suitable hydraulic capacity to convey the high flow discharge. The outlet velocity was estimated to be 3.5 m/s.

It is proposed to construct scour protection downstream of Headwall A4 to protect the creek bank from scour and erosion. Scour protection has been designed to consist of hard, durable sandstone with a specific gravity of 2.65. The average rock diameter (d50) is 300 mm. Scour protection will be 600 mm thick and underlain by geotextile to prevent movement of the underlying soil strata. A total of approximately 10 sq. m of rock protection is expected to be required (**Figure 3-4 (b)**, **Appendix C**).

Concept engineering plans for the high flow outlet are presented on Cardno's drawing set 59915194-CI series are included in **Appendix C**.

a)



b)

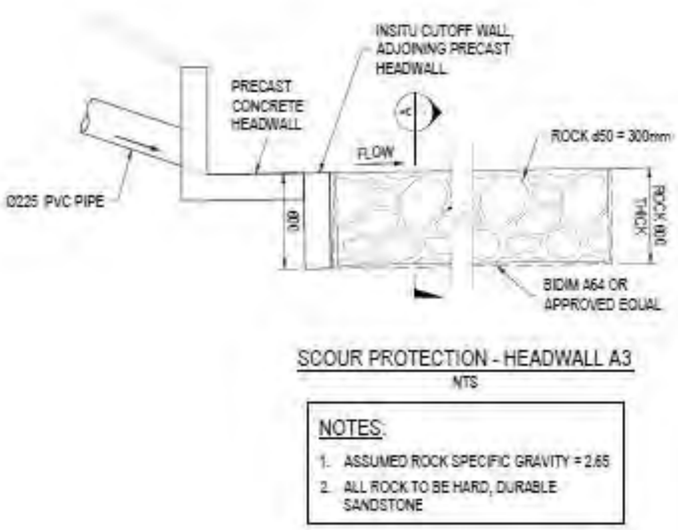


Figure 3-4 a) Typical Avon River cross section near outlet headwall. b) Scour protection – headwall (A3) cross section

4 Conclusion and Recommendations

In terms of geomorphological characteristics of the receiving environment, all sites assessed within the Avon River were relatively similar, consisting of sinuous, laterally stable channels, with pools and fine grained bed/bank material. Moderate bank erosion from past and recent events was evident, although the effects of this appeared to be minimised by stabilising riparian vegetation. Dog Trap Creek was notably different from the Avon River in that it was less incised and had considerably less flow. Water quality at all sites was variable and did not indicate any one site as potentially more suitable than another for the placement of a discharge outlet, although greater extremes in temperature and salinity were apparent at Dog Trap Creek which is naturally ephemeral.

Results of the ecological assessment indicated that the overall habitat condition of the investigation locations was relatively good for small streams situated in an agricultural landscape and likely to provide habitat for a range of native and non-native fish and invertebrates. Other aquatic and semi-aquatic animals including frogs, reptiles and mammals also have potential to occur within the Study Area. Given the limited frequency, relatively low volumes and naturally high flow conditions of the planned releases, any measureable downstream effect on aquatic flora or fauna was considered unlikely. Furthermore, providing that the discharge water is ambient to the receiving waters (as per the AGL discharge water quality targets), no measurable effect on aquatic fauna or flora downstream of the discharge location would be expected e.g. as a result of thermal pollution.

Overall, results of both the field investigation and MCA suggest that any of the four locations considered (AV1, AV2, AV3 and DT1) would be potentially suitable for placement of a high flow outlet for the discharge of treated (freshwater) from the water treatment plant (via DWPs). Although no measurable impacts to the geomorphological or ecological integrity of the receiving waterway would be expected at any of the four locations (based on the maximum daily, and annual discharge rates), location AV2 was considered to represent the least risk in terms of construction and operation. It is assumed that water quality data collected from relevant monitoring sites (within the receiving waterway) will be analysed immediately prior to a high flow release to ensure water quality targets are met. On that basis, impacts to downstream water quality and associated biota are not expected.

Recommendations

The proposed concept design at location AV2 will incorporate concrete bulkheads (or similar) around the gravity pipe, a shallow trench and up to 10 sq. m of scour protection. The following measures are therefore recommended to ensure minimal environmental disturbance:

> The final position of the high flow outlet should avoid the need to remove existing mature trees and other native vegetation;

> Snags or in stream structures (rocks and boulders) should not be removed or displaced from the stream bed;

> Appropriate sediment and erosion controls should be put in place during construction to minimise turbidity within the waterway;

> Introduced weeds should be cleared from the outlet installation site and be re-vegetated with bank stabilising native plants and shrubs; and

> Livestock access should be generally limited where possible to help improve overall habitat condition and water quality as well as limiting further bank erosion.

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Environmental Assessment and Design of High Flow Discharge Location for Treated Water

APPENDIX

A

RCE AND FISH HABITAT CRITERIA

Site Descriptors Used to Calculate RCE Scores (after Chessman *et al*. 1997)

Descriptor and category	Value	Descriptor and category	Value
1 Land use pattern beyond the immediate riparian zone		8 Riffle / pool sequence	
Undisturbed native vegetation	4	Frequent alternation of riffles and pools	4
Mixed native vegetation and pasture/exotics	3	Long pools with infrequent short riffles	3
Mainly pasture, crops or pine plantation	2	Natural channel without riffle / pool sequen	2
Urban	1	Artificial channel; no riffle / pool sequence	1
2 Width of riparian strip of woody vegetation		9 Retention devices in stream	
More than 30 m	4	Many large boulders and/or debris dams	4
Between 5 and 30 m	3	Rocks / logs present; limited damming effe	3
Less than 5 m	2	Rocks / logs present, but unstable, no dam	2
No woody vegetation	1	Stream with few or no rocks / logs	1
3 Completeness of riparian strip of woody vegetation		10 Channel sediment accumulations	
Riparian strip without breaks in vegetation	4	Little or no accumulation of loose sedimen	4
Breaks at intervals of more than 50 m	3	Some gravel bars but little sand or silt	3
Breaks at intervals of 10 - 50 m	2	Bars of sand and silt common	2
Breaks at intervals of less than 10 m	1	Braiding by loose sediment	1
4 Vegetation of riparian zone within 10 m of channel		11 Stream bottom	
Native tree and shrub species	4	Mainly clean stones with obvious interstice	4
Mixed native and exotic trees and shrubs	3	Mainly stones with some cover of algae / si	3
Exotic trees and shrubs	2	Bottom heavily silted but stable	2
Exotic grasses / weeds only	1	Bottom mainly loose and mobile sediment	1
5 Stream bank structure		12 Stream detritus	
Banks fully stabilised by trees, shrubs etc	4	Mainly unsilted wood, bark, leaves	4
Banks firm but held mainly by grass and herk	3	Some wood, leaves etc. with much fine det	3
Banks loose, partly held by sparse grass etc	2	Mainly fine detritus mixed with sediment	2
Banks unstable, mainly loose sand or soil	1	Little or no organic detritus	1
6 Bank undercutting		13 Aquatic vegetation	
None, or restricted by tree roots	4	Little or no macrophyte or algal growth	4
Only on curves and at constrictions	3	Substantial algal growth; few macrophytes	3
Frequent along all parts of stream	2	Substantial macrophyte growth; little algae	2
Severe, bank collapses common	1	Substantial macrophyte and algal growth	1
7 Channel form		**TOTAL**	
Deep: width / depth ratio less than 7:1	4		
Medium: width / depth ratio 8:1 to 15:1	3		
Shallow: width / depth ratio greater than 15:1	2		
Artificial: concrete or excavated channel	1		

NSW DPI Descriptors of Fish Habitat Class (as per Fairful 2013)

Classification	Characteristics of Waterway Type
Class 1 Major key fish habitat	Marine or estuarine waterway or permanently flowing or flooded freshwater waterway (e.g. River or major creek), habitat of a threatened or protected fish species or 'critical habitat'
Class 2 Moderate key fish habitat	Non-permanently flowing (intermittent) stream, creek or waterway (generally named) with clearly defined bed and banks with semi - permanent to permanent waters in pools or in connected wetland areas. Freshwater aquatic vegetation is present. TYPE 1 and 2 Habitats present
Class 3 Minimal key fish habitat	Named or unnamed waterway, intermittent flow and sporadic refuge, breeding or feeding areas for some aquatic fauna (e.g. fish, yabbies). Semi - permanent pools from within the waterway or adjacent wetlands after a rain event. Otherwise any minor waterway that interconnects with wetlands or other Class 1 -3 fish habitats
Class 4 Unlikely key fish habitat	Waterway (generally unnamed), with intermittent flow following rain events only, little or no defined channel, little or no flow or free standing water or pools post rain events (e.g. dry gullies or shallow floodplain depressions with no aquatic flora present).

NSW DPI Fish Habitat Sensitivity (as per Fairful 2013)

Classification	
Type 1 - Highly Sensitive Fish Habitat	Freshwater habitats that contain in-stream gravel beds, rocks greater than 50 cm in two dimensions, snags greater than 30 cm in diameter or 3 m in length, or native aquatic plants.
Type 2 - Moderately Sensitive Fish Habitat	Freshwater habitats and brackish wetlands, lakes and lagoons other than defined in Type 1. Weir pools and dams up to full supply level where the weir or dam is across a natural waterway.
Type 3 - Minimally Sensitive Fish Habitat	Ephemeral aquatic habitat not supporting native aquatic or wetland habitat

Environmental Assessment and Design of High Flow Discharge Location for Treated Water

APPENDIX B

GEOMORPHOLOGY FIELD DATA

Cardno
Shaping the Future

Index of Stream Condition – AV1

Assessment Category	Criterion	Result
Valley Setting	Percentage of channel abutting bed rock or hard material	<10%
Left Bank	Height (m)	4
	Slope	90deg-45deg
	Bank Condition - veg	Trees, Shrubs and Grasses
	Bank Condition - erosion	Eroding
	Bank Material	Silt
	Bank Failure Mode(s)	Slump (old), Scour (recent), Stock access (recent)
Right Bank	Height (m)	4
	Slope	90deg-45deg
	Bank Condition - veg	Trees, Shrubs and Grasses
	Bank Condition - erosion	Eroding
	Bank Material	Silt
	Bank Failure Mode(s)	Slump (old), Scour (recent), Stock access (recent)
Left Bench		Single Continuous
Right Bench		Single Continuous
Channel Width	Top of bank to top of bank (m)	30
Width to Depth Ratio	Bank height / top of bank width	0.1
Channel Bed	Total bed width (m)	10
	Discontinuous / single thread / multi-thread/braided	Single Thread
	Instream Bars	n/a
	Sediment	Unknown - murky water
	Flow - average surface velocity	0m/s
	Estimated Depth	0.8m
Vegetative Cover LEFT BANK	Trees	11%-40%
	Shrubs	1%-10%
	Ground	>60%
	Streamside Zone Width	5m
Vegetative Cover RIGHT BANK	Trees	11%-40%
	Shrubs	1%-10%
	Ground	>60%
	Streamside Zone Width	5m
Stock Access LEFT BANK		Cattle
Stock Access RIGHT BANK		Cattle
Field data Sheet - LEFT BANK		
I - Bank Stability		Limited Erosion

Assessment Category	Criterion	Result
II - Width of Streamside Zone		5-10m
III - Structural Intactness	Tree Layer	20-80%
	Shrub Layer	<20%
	Ground Layer	>80%
IV - Cover of exotic vegetation		40-60%
V - Revegetation of ind woody veg		Very Limited (<1% Cover)
V1 - Livestock access		Yes (Cattle)
Field data Sheet - RIGHT BANK		
I - Bank Stability		Limited Erosion
II - Width of Streamside Zone		5-10m
III - Structural Intactness	Tree Layer	20-80%
	Shrub Layer	<20%
	Ground Layer	>80%
IV - Cover of exotic vegetation		40-60%
V - Revegetation of ind woody veg		Very Limited (<1% Cover)
V1 - Livestock access		Yes (Cattle)
CHANNEL STABILITY RANKING SCHEME		
Slope	0.002 m/m	
Pattern	Meandering	
1. Primary bed material	Silt Clay	4
2. Bed / bank protection	No	1
3. Degree of incision	13%	3
4. Degree of constriction	0-10%	0
5. Streambank erosion LEFT BANK	Fluvial	1
5. Streambank erosion RIGHT BANK	Fluvial	1
6 Streambank instability LEFT BANK	11-25%	0.5
6 Streambank instability RIGHT BANK	11-25%	0.5
7. Established riparian woody-vegetative cover LEFT BANK	11-25%	1.5
7. Established riparian woody-vegetative cover RIGHT BANK	11-25%	1.5
8. Bank Accretion LEFT BANK	0-10%	2
8. Bank Accretion RIGHT BANK	0-10%	2
9. Stage of channel evolution	NA	NA
10. Composition of adjacent side slope LEFT BANK	Fines	2
10. Composition of adjacent side slope RIGHT BANK	Fines	2
11. Percent of slope (length) contributing to sed LEFT BANK	0-10%	0
11. Percent of slope (length) contributing to sed RIGHT BANK	0-10%	0
12. Severity of side-slope erosion LEFT BANK	Low	0.5

Assessment Category	Criterion	Result
12. Severity of side-slope erosion RIGHT BANK	Low	0.5
TOTAL		23

Index of Stream Condition – AV2

Assessment Category	Criterion	Result
Valley Setting	Percentage of channel abutting bed rock or hard material	<10%
Left Bank	Height (m)	5
	Slope	90deg-45deg
	Bank Condition - veg	Trees, Shrubs and Grasses
	Bank Condition - erosion	Eroding
	Bank Material	Silt
	Bank Failure Mode(s)	Slump (old), Lower bank slightly undercut (recent), Stock access (recent)
Right Bank	Height (m)	5
	Slope	90deg-45deg
	Bank Condition - veg	Trees, Shrubs and Grasses
	Bank Condition - erosion	Eroding
	Bank Material	Silt
	Bank Failure Mode(s)	Slump (old), Lower bank slightly undercut (recent), Stock access (recent)
Left Bench		Single Discontinuous
Right Bench		Single Discontinuous
Channel Width	Top of bank to top of bank (m)	35
Width to Depth Ratio	Bank height / top of bank width	0.1
Channel Bed	Total bed width (m)	5m
	Discontinuous / single thread / multi-thread/braided	Single Thread
	Instream Bars	n/a
	Sediment	Unknown - murky water
	Flow - average surface velocity	<0.5m/s
	Estimated Depth	0.6
Vegetative Cover LEFT BANK	Trees	11%-40%
	Shrubs	1%-10%
	Ground	>60%
	Streamside Zone Width	5m
Vegetative Cover RIGHT BANK	Trees	11%-40%
	Shrubs	1%-10%
	Ground	>60%
	Streamside Zone Width	5m

Assessment Category	Criterion	Result
Stock Access LEFT BANK		Cattle
Stock Access RIGHT BANK		Cattle
Field data Sheet - LEFT BANK		
I - Bank Stability		Limited Erosion
II - Width of Streamside Zone		5-10m
III - Structural Intactness	Tree Layer	20-80%
	Shrub Layer	<20%
	Ground Layer	>80%
IV - Cover of exotic vegetation		40-60%
V - Revegetation of ind woody veg		Very Limited (<1% Cover)
V1 - Livestock access		Yes (Cattle)
Field data Sheet - RIGHT BANK		
I - Bank Stability		Limited Erosion
II - Width of Streamside Zone		5-10m
III - Structural Intactness	Tree Layer	20-80%
	Shrub Layer	<20%
	Ground Layer	>80%
IV - Cover of exotic vegetation		40-60%
V - Revegetation of ind woody veg		Very Limited (<1% Cover)
V1 - Livestock access		Yes (Cattle)
CHANNEL STABILITY RANKING SCHEME		
Slope	0.002 m/m	From Lidar
Pattern	Meandering	
1. Primary bed material	Silt Clay	4
2. Bed / bank protection	No	1
3. Degree of incision	9%	4
4. Degree of constriction	0-10%	0
5. Streambank erosion LEFT BANK	Fluvial	1
5. Streambank erosion RIGHT BANK	Fluvial	1
6 Streambank instability LEFT BANK	11-25%	0.5
6 Streambank instability RIGHT BANK	11-25%	0.5
7. Established riparian woody-vegetative cover LEFT BANK	0-10%	2
7. Established riparian woody-vegetative cover RIGHT BANK	0-10%	2
8. Bank Accretion LEFT BANK	0-10%	2
8. Bank Accretion RIGHT BANK	0-10%	2
9. Stage of channel evolution	NA	NA
10. Composition of adjacent side slope LEFT BANK	Fines	2
10. Composition of adjacent side slope RIGHT BANK	Fines	2

Assessment Category	Criterion	Result
11. Percent of slope (length) contributing to sed LEFT BANK	0-10%	0
11. Percent of slope (length) contributing to sed RIGHT BANK	0-10%	0
12. Severity of side-slope erosion LEFT BANK	Low	0.5
12. Severity of side-slope erosion RIGHT BANK	Low	0.5
TOTAL		25

Index of Stream Condition – AV3

Assessment Category	Criterion	Result
Valley Setting	Percentage of channel abutting bed rock or hard material	<10%
Left Bank	Height (m)	5
	Slope	90deg-45deg
	Bank Condition - veg	Trees, Shrubs and Grasses
	Bank Condition - erosion	Eroding
	Bank Material	Silt
	Bank Failure Mode(s)	Slump (old), Lower bank slightly undercut (recent), Stock access (recent), obstruction from fallen tree causing scour just upstream of site.
Right Bank	Height (m)	5
	Slope	90deg-45deg
	Bank Condition - veg	Trees, Shrubs and Grasses
	Bank Condition - erosion	Eroding
	Bank Material	Silt
	Bank Failure Mode(s)	Slump (old), Lower bank slightly undercut (recent), Stock access (recent)
Left Bench		Single Continuous
Right Bench		Single Continuous
Channel Width	Top of bank to top of bank (m)	35
Width to Depth Ratio	Bank height / top of bank width	0.1
Channel Bed	Total bed width (m)	4m
	Discontinuous / single thread / multi-thread/braided	Single Thread
	Instream Bars	n/a
	Sediment	Unknown - murky water
	Flow - average surface velocity	<0.5m/s
	Estimated Depth	0.6
Vegetative Cover LEFT BANK	Trees	11%-40%
	Shrubs	1%-10%

Assessment Category	Criterion	Result
	Ground	>60%
	Streamside Zone Width	5m
Vegetative Cover RIGHT BANK	Trees	11%-40%
	Shrubs	1%-10%
	Ground	>60%
	Streamside Zone Width	5m
Stock Access LEFT BANK		Cattle
Stock Access RIGHT BANK		Cattle
Field data Sheet - LEFT BANK		
I - Bank Stability		Limited Erosion
II - Width of Streamside Zone		5-10m
III - Structural Intactness	Tree Layer	20-80%
	Shrub Layer	<20%
	Ground Layer	>80%
IV - Cover of exotic vegetation		40-60%
V - Revegetation of ind woody veg		Very Limited (<1% Cover)
V1 - Livestock access		Yes (Cattle)
Field data Sheet - RIGHT BANK		
I - Bank Stability		Limited Erosion
II - Width of Streamside Zone		5-10m
III - Structural Intactness	Tree Layer	20-80%
	Shrub Layer	<20%
	Ground Layer	>80%
IV - Cover of exotic vegetation		40-60%
V - Revegetation of ind woody veg		Very Limited (<1% Cover)
V1 - Livestock access		Yes (Cattle)
CHANNEL STABILITY RANKING SCHEME		
Slope	0.002 m/m	From Lidar
Pattern	Meandering	
1. Primary bed material	Silt Clay	4
2. Bed / bank protection	No	1
3. Degree of incision	9%	4
4. Degree of constriction	0-10%	0
5. Streambank erosion LEFT BANK	Fluvial	1
5. Streambank erosion RIGHT BANK	Fluvial	1
6 Streambank instability LEFT BANK	11-25%	0.5
6 Streambank instability RIGHT BANK	11-25%	0.5
7. Established riparian woody-vegetative cover LEFT BANK	0-10%	2
7. Established riparian woody-vegetative cover	0-10%	2

Assessment Category	Criterion	Result
RIGHT BANK		
8. Bank Accretion LEFT BANK	0-10%	2
8. Bank Accretion RIGHT BANK	0-10%	2
9. Stage of channel evolution	NA	NA
10. Composition of adjacent side slope LEFT BANK	Fines	2
10. Composition of adjacent side slope RIGHT BANK	Fines	2
11. Percent of slope (length) contributing to sed LEFT BANK	0-10%	0
11. Percent of slope (length) contributing to sed RIGHT BANK	0-10%	0
12. Severity of side-slope erosion LEFT BANK	Low	0.5
12. Severity of side-slope erosion RIGHT BANK	Low	0.5
TOTAL		25

Index of Stream Condition – DT1

Assessment Category	Criterion	Result
Valley Setting	Percentage of channel abutting bed rock or hard material	<10%
Left Bank	Height (m)	2.5
	Slope	90deg-45deg
	Bank Condition - veg	Grasses
	Bank Condition - erosion	Eroding
	Bank Material	Silt
	Bank Failure Mode(s)	Slump (old), Scour (recent), Stock access (recent)
Right Bank	Height (m)	2.5
	Slope	90deg-45deg
	Bank Condition - veg	Trees, Shrubs and Grasses
	Bank Condition - erosion	Eroding
	Bank Material	Silt
	Bank Failure Mode(s)	Slump (old), Scour (recent), Stock access (recent)
Left Bench		Single discontinuous
Right Bench		Single discontinuous
Channel Width	Top of bank to top of bank (m)	12
Width to Depth Ratio	Bank height / top of bank width	0.2
Channel Bed	Total bed width (m)	1m
	Discontinuous / single thread / multi-thread/braided	Single Thread
	Instream Bars	n/a
	Sediment	silt
	Flow - average surface velocity	0.5m/s

Assessment Category	Criterion	Result
	Estimated Depth	0.2m
Vegetative Cover LEFT BANK	Trees	0%
	Shrubs	0%
	Ground	>60%
	Streamside Zone Width	0m
Vegetative Cover RIGHT BANK	Trees	0%
	Shrubs	0%
	Ground	>60%
	Streamside Zone Width	0m
Stock Access LEFT BANK		Cattle
Stock Access RIGHT BANK		Cattle
Field data Sheet - LEFT BANK		
I - Bank Stability		Limited Erosion
II - Width of Streamside Zone		<5m
III - Structural Intactness	Tree Layer	<20%
	Shrub Layer	<20%
	Ground Layer	>80%
IV - Cover of exotic vegetation		40-60%
V - Revegetation of ind woody veg		Very Limited (<1% Cover)
V1 - Livestock access		Yes (Cattle)
Field data Sheet - RIGHT BANK		
I - Bank Stability		Limited Erosion
II - Width of Streamside Zone		<5m
III - Structural Intactness	Tree Layer	<20%
	Shrub Layer	<20%
	Ground Layer	>80%
IV - Cover of exotic vegetation		40-60%
V - Revegetation of ind woody veg		Very Limited (<1% Cover)
V1 - Livestock access		Yes (Cattle)
CHANNEL STABILITY RANKING SCHEME		
Slope	0.003 m/m	
Pattern	Meandering	
1. Primary bed material	Silt Clay	4
2. Bed / bank protection	No	1
3. Degree of incision	13%	3
4. Degree of constriction	0-10%	0
5. Streambank erosion LEFT BANK	Fluvial	1
5. Streambank erosion RIGHT BANK	Fluvial	1
6 Streambank instability LEFT BANK	11-25%	0.5
6 Streambank instability RIGHT BANK	11-25%	0.5

Assessment Category	Criterion	Result
7. Established riparian woody-vegetative cover LEFT BANK	0-10%	2
7. Established riparian woody-vegetative cover RIGHT BANK	0-10%	2
8. Bank Accretion LEFT BANK	0-10%	2
8. Bank Accretion RIGHT BANK	0-10%	2
9. Stage of channel evolution	NA	NA
10. Composition of adjacent side slope LEFT BANK	Fines	2
10. Composition of adjacent side slope RIGHT BANK	Fines	2
11. Percent of slope (length) contributing to sed LEFT BANK	0-10%	0
11. Percent of slope (length) contributing to sed RIGHT BANK	0-10%	0
12. Severity of side-slope erosion LEFT BANK	Low	0.5
12. Severity of side-slope erosion RIGHT BANK	Low	0.5
TOTAL		24

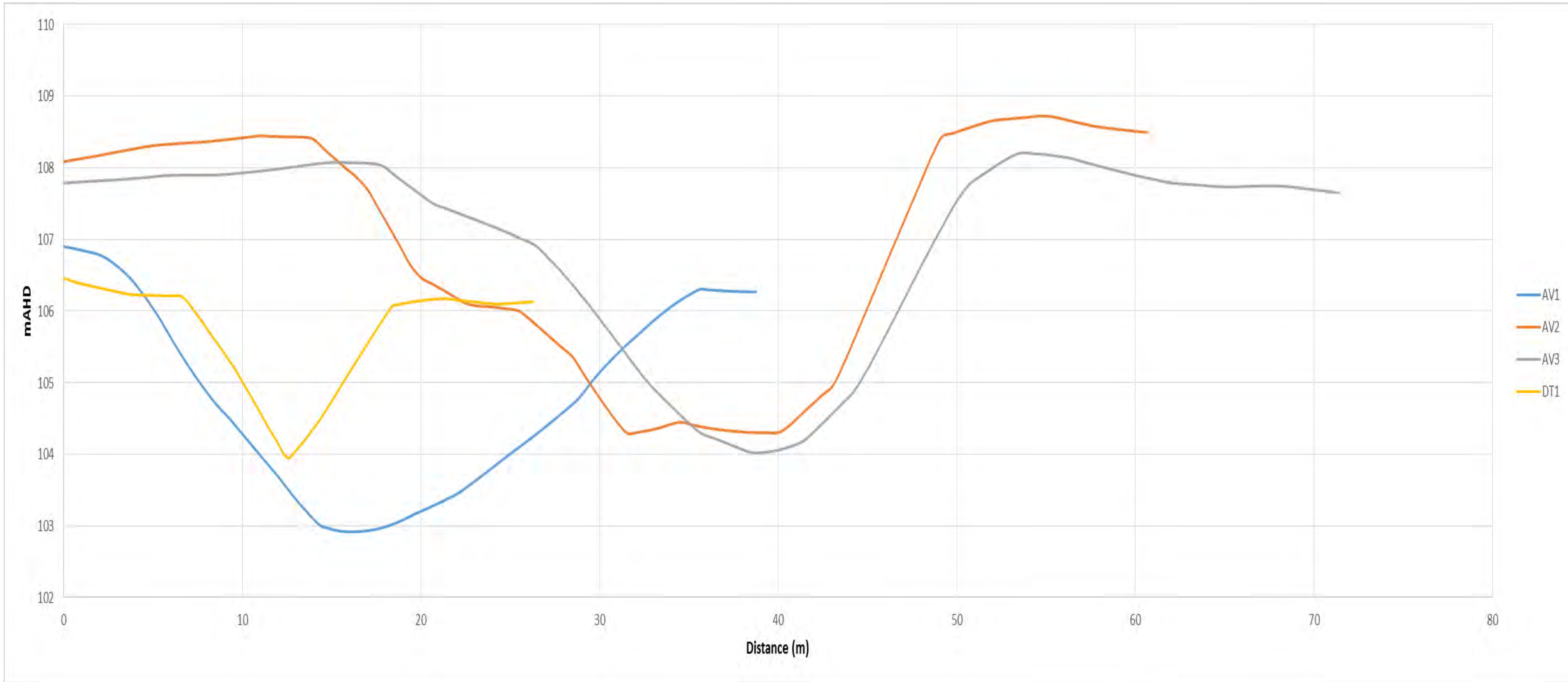

Figure B-1 Estimates of cross sections from Lidar data.

Environmental Assessment and Design of High Flow Discharge Location for Treated Water

APPENDIX C

CONCEPT DESIGN

Cardno
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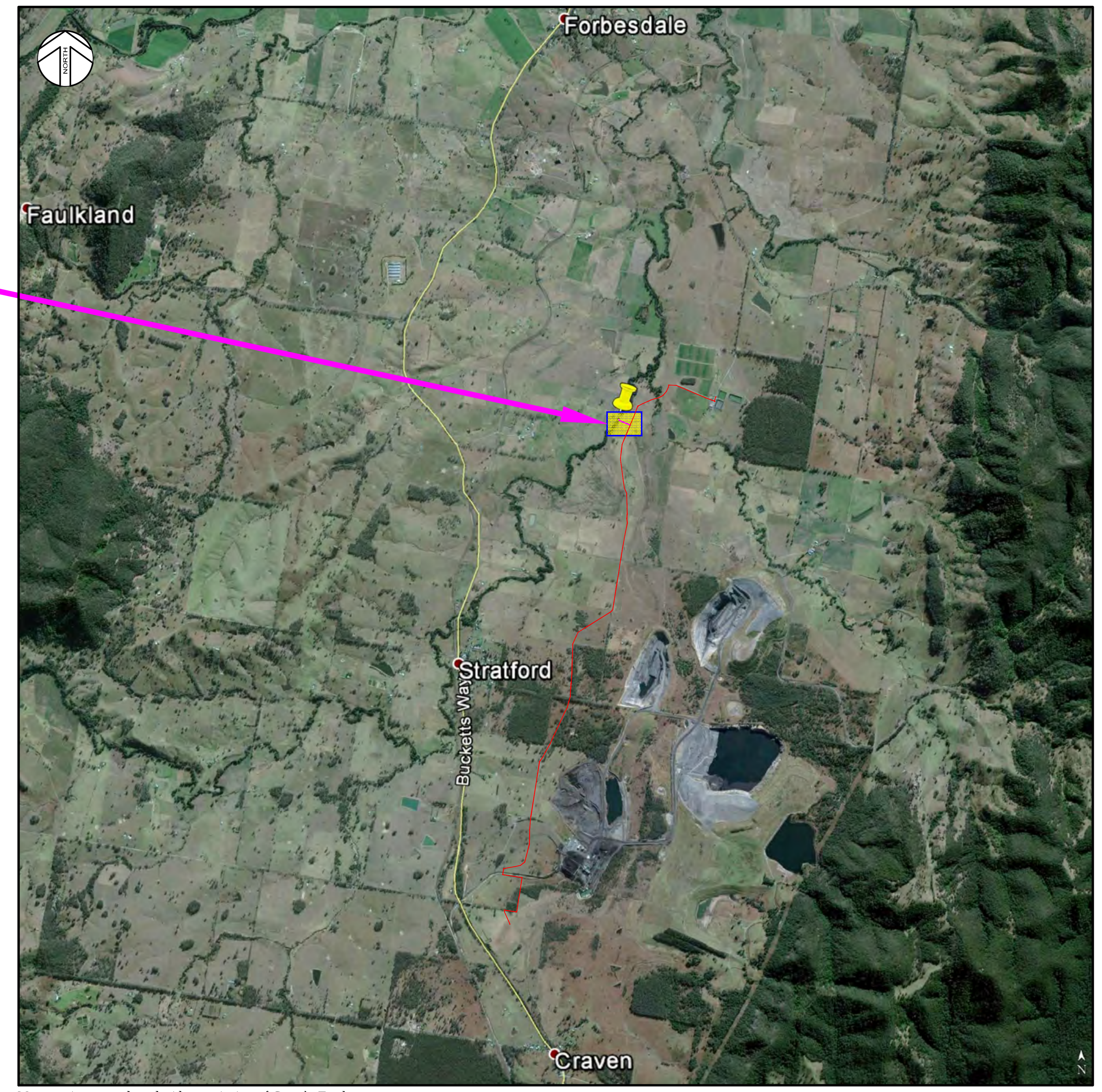
AGL ENERGY LIMITED

GLOUCESTER GAS PROJECT
CONCEPT DESIGN FOR
HIGH FLOW DISCHARGE

COVER SHEET

LOCATION OF WORKS



Map section reproduced with permission of Google Earth

LOCALITY PLAN
NTS

CIVIL DRAWINGS	
NUMBER	TITLE
59915194-CI-100	COVER SHEET
59915194-CI-110	CONCEPT DETAILS - SHEET 1
59915194-CI-111	CONCEPT DETAILS - SHEET 2

Rev.	Date	Description	Des.	Verif.	Appd.
1	23/07/15	INITIAL ISSUE	SGB	SJB	-

Drawn LDB	Date 20/07/15
Checked SGB	Date 21/07/15
Designed SGB	Date 20/07/15
Verified SJB	Date 21/07/15
Approved -	- -

Status: PRELIMINARY
NOT TO BE USED FOR CONSTRUCTION PURPOSES

Scale: N/A | Size: A1

Drawing Number: 59915194-CI-100 | Revision: 1

DEVICE NAME: DWG To PDF.pc3
DATE PLOTTED: 23 July 2015 11:07 AM BY : LAIS DE BRITO
XREF's: x59915194 Maps; x59915194 Civil
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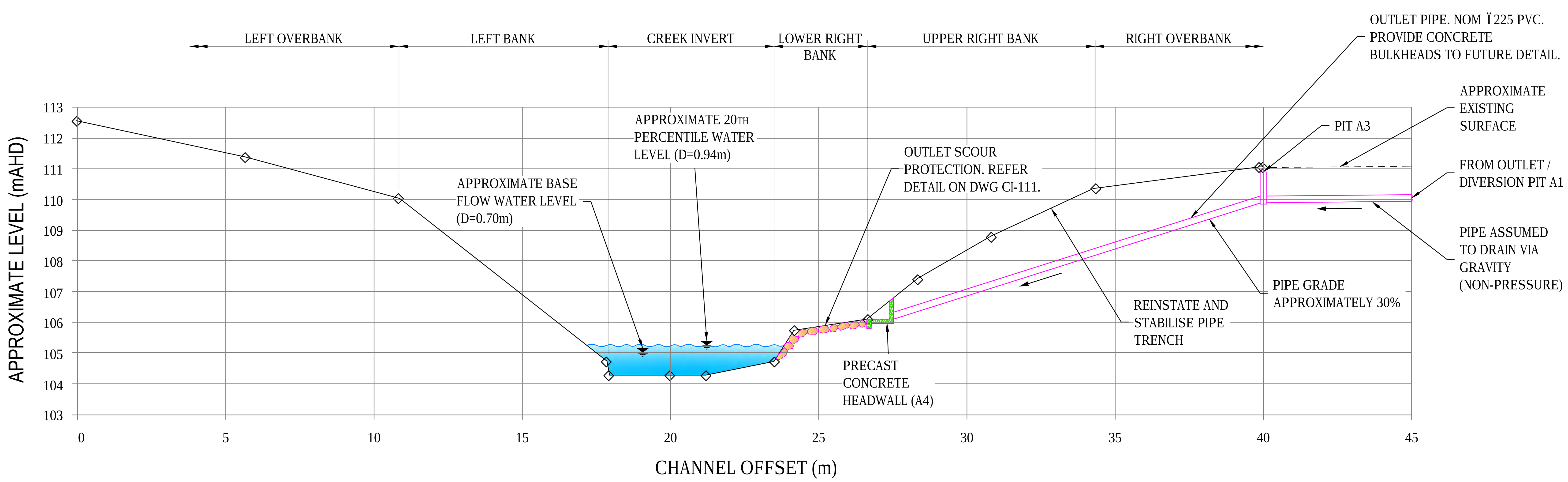
INSET PLAN

SCALE 1:1000

PLAN

SCALE 1:5000



TYPICAL AVON RIVER CROSS SECTION NEAR OUTLET HEADWALL

NTS

CO-ORDINATE TABLE (APPROXIMATE LOCATION ONLY)		
LOCATION	E	N
A1	401 655	6 448 600
A2	401 589	6 448 626
A3	401 523	6 448 652
A4	401 513	6 448 663

Rev.	Date	Description	Des.	Verif.	Appd.
1	23/07/15	INITIAL ISSUE	SGB	SJB	-

THIS DRAWING MUST BE VIEWED IN COLOUR

SCALE 1:1000 @A1

SCALE 1:5000 @A1

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Drawn LDB Date 20/07/15
Checked SGB Date 21/07/15
Designed SGB Date 20/07/15
Verified SJB Date 21/07/15
Approved - Date -

Client: AGL ENERGY LIMITED

Project: GLOUCESTER GAS PROJECT
CONCEPT DESIGN FOR HIGH FLOW DISCHARGE

Title: CONCEPT DETAILS
SHEET 1

Status: PRELIMINARY
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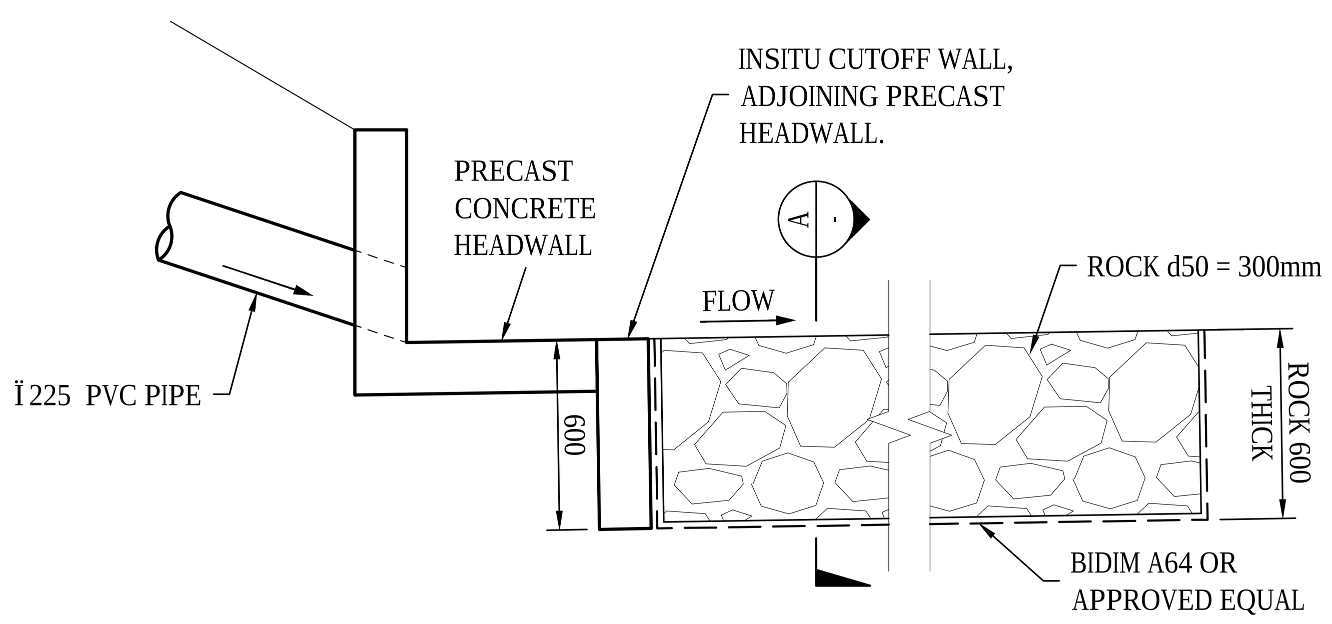
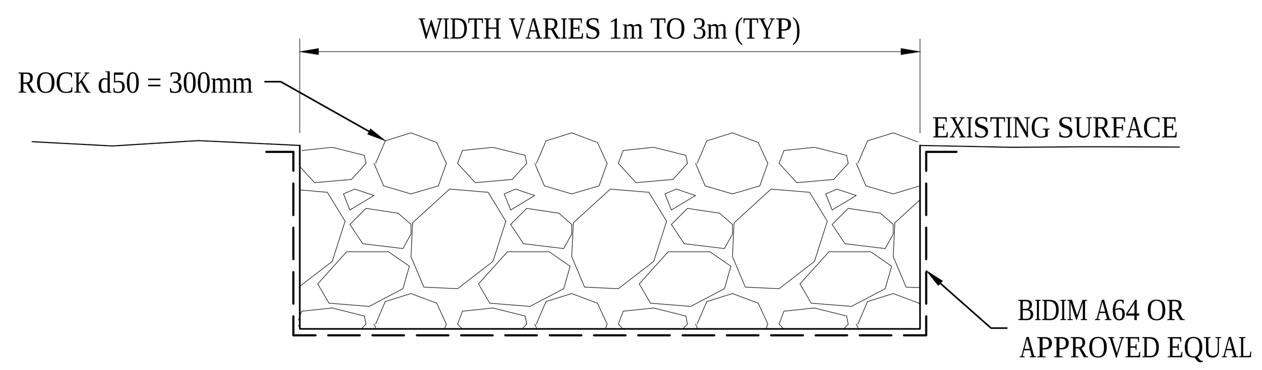
Drawing Number: 59915194-CI-110 | Revision: 1



SCOUR PROTECTION - HEADWALL A3

NTS



SECTION A -

NTS

NOTES:

1. ASSUMED ROCK SPECIFIC GRAVITY = 2.65
2. ALL ROCK TO BE HARD, DURABLE SANDSTONE

Rev.	Date	Description	Des.	Verif.	Appd.
2	23/07/15	INITIAL ISSUE	SGB	SJB	-

0 1 2 4 6 8 10m

SCALE 1:100 @A1

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		Date
Drawn	LDB	22/07/15
Checked	SGB	22/07/15
Designed	SGB	22/07/15
Verified	SJB	22/07/15
Approved	-	-

Client: AGL ENERGY LIMITED

Project: GLOUCESTER GAS PROJECT
CONCEPT DESIGN FOR HIGH FLOW DISCHARGE

Title: CONCEPT DETAILS
SHEET 2

Status: PRELIMINARY
NOT TO BE USED FOR CONSTRUCTION PURPOSES

Datum	Register	Scale	Size
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Drawing Number: 59915194-CI-111
Revision: 1

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Appendix D – Expected extracted water quality specification

	Analyte	Units	LOR	Flowback Water & Produced Water	
				Min	Max
Laboratory analytes	Total Suspended Solids	mg/L	5	<5	276
	DO mg/L (Field)	mg/L	-	n.d	18.3
	Redox (Field)	mV	-	-218	289.1
	pH (Field)	pH_Units	-	5.73	9.63
	Temperature (Field)	°C	-	11.6	29.32
	Electrical conductivity	µS/cm	1	4450	11349
	Total Dissolved Solids	mg/L	10	2912	8160
	Turbidity	NTU	0.1	46.7	507
	Carbonate Alkalinity as $CaCO_3$/L	mg/L	1	<1	44
	Bicarbonate Alkalinity as $CaCO_3$/L	mg/L	1	1360	5100
	Alkalinity (total) as $CaCO_3$	mg/L	1	1360	5100
	Sulphate as SO_4	mg/L	1	<1	19
	Chloride	mg/L	1	394	1570
	Calcium	mg/L	1	6	71
	Magnesium	mg/L	1	1	6
	Potassium	mg/L	1	5	27
	Sodium	mg/L	1	1090	3480
	Fluoride	mg/L	0.1	0.2	1.8
	Reactive Silica	mg/L	0.05	11.2	37.2
	Bromine	mg/L	0.1	0.3	4.2
Key parameters	Diethanolamine	µg/L	1	3	103
	Ethanolamine	µg/L	1	9	305
	Methyldiethanolamine	µg/L	1	2	40
	THPS	µg/L	50	50	440
	Boron	mg/L	0.05	0.08	22.4
	Chlorine Free (Field)	mg/L	-	nd	0.28
	Chlorine Total (Field)	mg/L	-	nd	0.34
	Nitrogen (Total)	mg/L	0.1	3.6	10
	Total Phosphorus	mg/L	0.01	0.38	5.1
Nutrients	Ammonia as N	mg/L	0.01	1.46	8.12
	Ammonium as N	mg/L	0.01	2.06	7.98
	Nitrite + Nitrate as N	mg/L	0.01	<0.01	0.2
	Kjeldahl Nitrogen Total	mg/L	0.1	3.6	10

	Analyte	Units	LOR	Flowback Water & Produced Water	
				Min	Max
	Reactive Phosphorus as P	mg/L	0.01	<0.01	0.58
	Total Organic Carbon	mg/L	1	2	1200
Dissolved metals	Aluminium	mg/L	0.01	<0.01	0.08
	Antimony	mg/L	0.001	<0.001	0.012
	Arsenic	mg/L	0.001	<0.001	0.007
	Barium	mg/L	0.001	0.227	17.6
	Beryllium	mg/L	0.001	<0.001	4.3
	Cadmium	mg/L	0.0001	<0.001	0.0004
	Chromium	mg/L	0.001	<0.001	0.038
	Cobalt	mg/L	0.001	<0.001	0.002
	Copper	mg/L	0.001	<0.001	0.017
	Iron	mg/L	0.05	0.06	42
	Lead	mg/L	0.001	<0.001	0.001
	Manganese	mg/L	0.001	0.01	0.586
	Mercury	mg/L	0.0001	<0.001	<0.0001
	Molybdenum	mg/L	0.001	0.001	0.045
	Nickel	mg/L	0.001	0.002	0.02
	Selenium	mg/L	0.01	<0.01	<0.01
	Strontium	mg/L	0.001	0.96	10.5
	Tin	mg/L	0.001	<0.001	0.002
	Uranium	mg/L	0.001	<0.001	<0.001
	Vanadium	mg/L	0.01	<0.001	<0.01
	Zinc	mg/L	0.005	0.006	0.169
Oil and Grease	Oil and Grease	mg/L	5	<5	<5
Phenols	2-methylphenol	µg/L	1	<1	13.4
	3-&4-methylphenol	µg/L	2	5.8	200
	Phenol	µg/L	1	4.2	14.9
Polycyclic aromatic hydrocarbons	PAHs (sum)	µg/L	0.5	<0.5	57.4
Total recoverable hydrocarbons	C_6 - C_{10} Fraction	µg/L	20	20	1290
	C_{10} - C_{40} Fraction (Sum)	µg/L	100	890	30300
	TRH >C_{10}-C_{16} less Naphthalene (F2)	µg/L	100	nd	310
Total petroleum hydrocarbons	C_6 - C_9 Fraction	µg/L	20	30	1240
	+C_{10} - C_{36} (Sum of total)	µg/L	50	900	25900

	Analyte	Units	LOR	Flowback Water & Produced Water	
				Min	**Max**
Aromatic hydrocarbons	Benzene	µg/L	1	3	319
	Toluene	µg/L	2	4	356
	Ethyl benzene	µg/L	2	<2	9
	Naphthalene	µg/L	5	<5	<5
	Xylene Total	µg/L	2	4	138
	Sum of BTEX	µg/L	1	15	795

Notes:

1. Modified data is from samples taken between 16/12/2014 and 6/02/2015 from AGL's Waukivory Pilot wells WK11, 12, 13 and 14 (flowback water) and samples taken between 28/06/2013 and 25/06/2014 from AGL's Waukivory 03 and Craven 06 gas wells (produced water), respectively.
2. LOR – limit of reporting.
3. nd - no data available.

Appendix E – Water monitoring program

The proposed water monitoring program is outlined in this EWMS to provide regulators and the community with confidence that extracted water (flowback water and produced water) and treated water will be adequately monitored and managed throughout the life of the Stage 1 GFDA. It is proposed that the monitoring program (locations, data sets and frequency) be set for two years then reviewed annually.

CPF WTP Infrastructure

The ponds, tanks and liners and associated above ground pipework will be physically inspected on a monthly basis to assess the integrity of these structures.

Water quality monitoring is proposed at each of the following locations on a monthly/quarterly basis for a comprehensive suite of analytes:

› Receiving water pond (monthly).

› Treated water tank (monthly).

› Brine water tank (quarterly).

› Discharge water pond (monthly).

In addition, it is proposed to place continuous salinity (EC) loggers in the:

› Receiving water pond (final cell before water is sent for pre-treatment).

› Treated water tank.

› Discharge water pond.

Salinity measurements will be taken every hour and the loggers will have a live feed back to the CPF control room. Loggers would be checked and calibrated quarterly.

A groundwater monitoring network (both water levels and water quality) will be installed around the new water storage infrastructure and brine storage areas that have the potential to impact on underlying groundwater resources. Even though the ponds will be double lined with seepage detection, inspection and control, additional monitoring is proposed downgradient of each of the three new water storages and downgradient of the brine storage tank. In addition, the two existing Rombo monitoring bores (RMB01 and RMB02) which are located downgradient of the proposed WTP infrastructure at the CPF will be included in the PWMP.

This monitoring network will:

› Identify background perched water levels and water quality in the weathered rock zone.

› Identify background shallow groundwater levels and water quality.

It is proposed that a very shallow monitoring bore (to around 6 m depth) and deeper monitoring bore (to the water table at around 30 m depth) will be constructed at each of the three main storage locations (two water ponds and the brine storage tank (subject to access)). There are no nearby surface water receptors so no surface water monitoring is proposed at the CPF site.

These three locations will monitor changes in water levels or water quality to ensure the integrity of site WTP infrastructure and to provide early warning of potential impacts to shallow groundwater from ponded water.

Water quality monitoring and testing for the groundwater sites will be undertaken quarterly for the first two years then reviewed annually on the basis of water level and water quality trends to assess whether water quality sampling frequencies need to change.

Groundwater monitoring will commence after construction of the WTP infrastructure but prior to the commissioning of the WTP and CPF. Some existing monitoring locations will continue as per the

Groundwater Monitoring and Modelling Plan (GMMP) (AGL, in Prep). Further details will be outlined in the PWMP.

Water gathering systems

All water gathering lines will be inspected and integrity (pressure) tested prior to being commissioned. Ongoing pressure monitoring and inspection of these lines will occur as part of the field operations. Further details will be provided in the PWMP.

No sub-surface monitoring is proposed for the buried water gathering pipeline network from the individual gas wells to the WTP and for the reticulation pipeline from the WTP to the Tiedman storages (apart from monthly physical inspections of the above-ground pipework at each wellhead and similar pipework at the RWP at the WTP).

Tiedman Water Storage Infrastructure

These three ponds are located at the highest point on the Tiedman property beyond the Avon River floodplain and any possibility of flooding. The ponds and liners will be physically inspected on a monthly basis to assess the integrity of these structures and associated liners.

Water quality monitoring is proposed at each of the following locations on a quarterly basis for a basic suite of analytes:

› Irrigation water pond (TSD).

› Irrigation water pond (TND).

› Produced water storage pond (TED) – only if the storage of produced water occurred during the preceding quarter.

In addition it is proposed to place continuous salinity (EC) loggers in the two irrigation ponds. Salinity measurements will be taken every 6 hours and the loggers will have a live feed back to the CPF control room. Loggers would be checked and calibrated quarterly.

There is already some water monitoring in place at the Tiedman water storage ponds:

› Shallow perched water monitoring bores around each of the single lined ponds (TND-TMB04 and TSD-TMB05).

› Seepage inspection and control at the TED.

It is proposed to increase the amount of monitoring around each of these ponds to be consistent with the monitoring proposals at the CPF. A deeper monitoring bore (to the water table at around 30 m depth) will be constructed at each of the two existing locations. In addition a very shallow monitoring bore (to around 6 m depth) and deeper monitoring bore (to the water table at around 30 m depth) will be constructed adjacent to the seepage inspection area of the double lined dam (TED).

NOW recommended additional upgradient monitoring bores around the Tiedman holding ponds. It is not possible to construct any upgradient monitoring bores around these storages as the storages are located at the top of a ridgeline. AGL offers another location on the northern side of TND to monitor for any seepage losses in a northerly direction.

These four locations with eight individual monitoring bores will monitor any unusual changes in water levels or water quality to ensure the integrity of the water storage ponds and to provide early warning of any impact to shallow groundwater. There are no nearby surface water receptors so no surface water monitoring is proposed at the Tiedman water storage site.

Water quality monitoring and testing will be undertaken quarterly for the first two years then reviewed on the basis of water level and water quality trends to assess whether water quality sampling frequencies need to change for the groundwater sites.

It is expected that the proposed new sites will be constructed prior to the commissioning of the WTP and delivery of any treated water.

Monitoring Network for Irrigation Areas

AGL will carry out monitoring during irrigation to ensure that water quality thresholds for the irrigation, stock and surface water receptor are not exceeded and the reuse water quality target is being achieved. Water quality targets for treated water and individual analytes are set out in **Table 12.1**.

Water quality will be tested prior to release from the Discharge Water Pond (DWP) to ensure it meets the target water quality. As the water quality will be monitored closely at the WTP, it is only proposed to monitor the water quality within each of the two reuse ponds on Tiedmans. No additional monitoring of adjacent surface water or underlying groundwater receptors is proposed for the new irrigation areas. The monitoring of the existing surface water monitoring sites on the Tiedmans and Avondale properties will continue as outlined in the GMMP (AGL, in prep).

No additional water quality monitoring is proposed because the treated water is expected to be equivalent to or better than Avon River quality that others use for stock use and occasional irrigation of similar crops and pasture.

It is proposed that no catch dams or recycling of waters will be required within any of the proposed irrigation areas. The two existing catch dams around the existing Stage 1A irrigation area will be removed. Also no soil sampling is proposed across any of the proposed irrigation areas because:

› There is natural variability in soils across the landscape.

› Minimal salt loads will be applied in the irrigation of treated water.

Also no nutritional or trace metal crop monitoring is proposed given the low salinity water to be applied as irrigation water.

Monitoring Discharges to Surface Waters

AGL will carry out monitoring prior to stream discharge to ensure that water quality thresholds for the surface water receptor are not exceeded and the stream discharge water quality target is being achieved. Water quality targets for treated water and individual analytes to be discharged to the environment (via the Avon River) are set out in **Table 12.1.**

As the water quality will be monitored closely at the DWP, it is only proposed to monitor the water quality upstream and downstream of the Avon River discharge location weekly during periods of discharge. In addition there will be continuous monitoring of salinity (EC) at both these sites. The monitoring of the existing monitoring sites on the Tiedmans and Avondale properties will continue as outlined in the broader Stage 1 Groundwater Monitoring and Modelling Plan (AGL, in prep). The Stream gauge location TSW01 will be the downstream reference site for both river flows and salinity. Data will also be collected at this site to develop (longer term) site specific water quality criteria.

The proposed monitoring network for irrigation and discharge of treated water (comprising existing and proposed monitoring sites) is set out in **Table E.1**. Information is also provided in **Table E.1** on the water quality parameters that will be included for:

› Continuous monitoring.

› Quarterly monitoring.

› Extra monthly monitoring (when required).

Table E.1 Monitoring network for irrigation, stock and discharge of treated water

Monitoring Site ID	Type - Location	Continuous Monitoring	Monthly Monitoring	Expected Quarterly Monitoring
Irrigation Storage Ponds (Tiedmans)				
Tiedman North (treated water)	Sampling of Water Storage Pond Water	Salinity	Physical inspection of surrounding area	Basic suite
Tiedman South (treated water)	Sampling of Water Storage Pond Water	Salinity	Physical inspection of surrounding area	Basic suite
Tiedman East (extracted water)	Sampling of Water Storage Pond Water	None	Physical inspection of surrounding area	Basic suite (only if water transferred in)
TMB04a and b	Seepage – immediately west of Tiedman North Dam	WLs - Yes WQ - No	Physical inspection of surrounding area	Physical parameters then purge dry and assess inflows on quarterly basis. If inflow within 12 hours then basic suite
TMB05a and b	Seepage – immediately south of Tiedman South Dam	WLs - Yes WQ - No	Physical inspection of surrounding area	Physical parameters then purge dry and assess inflows on a quarterly basis. If inflow within 12 hours then basic suite
TMB06a and b (new site at TND)	Seepage – immediately north of Tiedman North Dam	WLs - Yes WQ - No	Physical inspection of surrounding area	Physical parameters then purge dry and assess inflows on a quarterly basis. If inflow within 12 hours then basic suite
TMB07a and b (new site at TED)	Seepage – immediately south of Tiedman East Dam	WLs - Yes WQ - No	Physical inspection of surrounding area	Physical parameters then purge dry and assess inflows on a quarterly basis. If inflow within 12 hours then basic suite

Monitoring Site ID	Type - Location	Continuous Monitoring	Monthly Monitoring	Expected Monitoring (only when stream discharges are occurring)
Stream Discharge location (Avon River)				
Reference Gauge	Existing stream gauge TSW01 on the Avon River downstream of the confluence with Dog Trap Creek	WLs - Yes Salinity - Yes	Yes	Monthly – comprehensive suite (to align with water quality sampling at the DWP and to obtain long term data set to be able to develop site specific water quality criteria) (note that this site will also be the reference site to assess natural flows and to determine whether a minimum 5-fold dilution flow exists)
Downstream Gauge	Avon River downstream of discharge site AV2 but upstream of confluence with Dog Trap Creek	WLs - Yes Salinity - Yes	None	Weekly samples taken for basic suite during discharge period
Upstream Gauge	Avon River upstream of discharge site AV2	WLs - Yes Salinity - Yes	None	Weekly samples taken for basic suite during discharge period

Monitoring Site ID	Type - Location	Continuous Monitoring	Monthly Monitoring	Monthly/Quarterly Monitoring
WTP Site and storage ponds (Rombo)				
Receiving water pond (RWP)	Sampling of Water Storage Pond Water	Salinity	Physical inspection of surrounding area	Monthly – Comprehensive suite
RO plant	Sampling of RO water	None	Physical inspection of surrounding area	Monthly - Comprehensive suite
Treated water tank (TWT)	Sampling of Water Storage Tank Water	Salinity and pH	Physical inspection of surrounding area	Monthly - Comprehensive suite
Discharge water pond (DWP)	Sampling of Water Storage Pond Water	Salinity and pH	Physical inspection of surrounding area	Monthly - Comprehensive suite Weekly – Basic suite when stream discharges are proposed
Brine Storage tank (BST)	Sampling of Water Storage Pond Water	None	Physical inspection of surrounding area	Quarterly - Comprehensive suite
RMB01 and RMB02 (existing)	Shallow and intermediate groundwater	WLs – Yes WQ - No	None	Quarterly - Basic Suite
RWPa and b	Seepage – immediately downgradient of RWP	WLs – Yes WQ - No	Physical inspection of surrounding area	Quarterly - Physical parameters then purge dry and assess inflows on quarterly basis. If inflow within 12 hours then basic suite
TWTa and b	Seepage – immediately downgradient of TWT	WLs – Yes WQ - No	Physical inspection of surrounding area	Quarterly - Physical parameters then purge dry and assess inflows on quarterly basis. If inflow within 12 hours then basic suite
DWPa and b	Seepage – immediately downgradient of DWP	WLs – Yes WQ - No	Physical inspection of surrounding area	Quarterly - Physical parameters then purge dry and assess inflows on quarterly basis. If inflow within 12 hours then basic suite
BSTa and b	Seepage – immediately downgradient of BST	WLs – Yes WQ - No	Physical inspection of surrounding area	Quarterly - Physical parameters then purge dry and assess inflows on quarterly basis. If inflow within 12 hours then basic suite

Water Quality Parameters for Monitoring Program

Water samples collected at the proposed monitoring sites will be analysed for either a basic or comprehensive suite of analytes as described in **Table E.2**. The proposed parameters and analytes include the following physical parameters and laboratory analytes:

- Physical parameters:
  - pH;
  - Electrical conductivity (EC);
  - Redox (Eh);
  - Dissolved oxygen (DO); and
  - Temperature.
- Laboratory analytes:
  - Major ions;
  - Dissolved metals and trace metals;
  - Miscellaneous other analytes;
  - Nutrients;
  - Dissolved gases; and
  - Hydrocarbons.

Table E.2 Laboratory analytical suites

<table>
<tr><th>Category</th><th colspan="3">Suites</th><th colspan="2">Parameters</th></tr>
<tr><td>Check on Field Parameters</td><td rowspan="4">Basic</td><td rowspan="4">Intermediate</td><td rowspan="4">Comprehensive</td><td colspan="2">EC, pH and TDS</td></tr>
<tr><td>Major ions</td><td>Cations
calcium
magnesium
sodium
potassium</td><td>Anions
chloride
carbonate
bicarbonate
sulphate</td></tr>
<tr><td>Dissolved metals and minor / trace elements</td><td>aluminium
arsenic
barium
beryllium
boron
bromide
cadmium
chromium
cobalt
copper
iron</td><td>lead
manganese
mercury
molybdenum
nickel
selenium
strontium
uranium
vanadium
zinc</td></tr>
<tr><td>Other analytes</td><td>Fluoride
Total organic carbon</td><td>Silica</td></tr>
</table>

Category	Suites		Parameters	
Total Suspended Solids			TSS	
Nutrients			Nitrate Nitrite Ammonia	Reactive phosphorus Total phosphorus
Dissolved gases			Methane	
Hydrocarbons			Phenol compounds Polycyclic aromatic hydrocarbons (PAH)	Total petroleum hydrocarbons (TPH)/ benzene, toluene, ethyl benzene and xylenes (BTEX)