9

HYDROLOGY AND GEOMORPHOLOGY

ENTER HERE

BACK TO CONTENTS

SUPPLEMENTARY REPORT TO THE EIS

arrow energy
go further

9 Hydrology and Geomorphology

9.1 Introduction

This chapter presents the findings of the supplementary hydrology and geomorphology study (see the Hydrology and Geomorphology Technical Report (Appendix G) of the SREIS). The report describes the hydrologic, hydraulic and geomorphologic studies undertaken to address the likely impacts caused by the construction and operation of the two central gas processing facilities (CGPFs) co-located with the two water treatment facilities (WTFs), as well as the potential impacts to the hydrology and geomorphology of the potential receiving environment as a result of possible releases of treated (and in certain instances untreated) CSG water. These impacts have been considered in context of other riverine environmental objectives such as water quality and aquatic ecology. Studies undertaken to assess the impacts on surface water quality are presented in the Surface Water chapter (Section 8) of this SREIS and surface water impacts on aquatic ecosystems are described in the Aquatic Ecology chapter (Section 10) of the SREIS.

9.1.1 SREIS Study Purpose

The supplementary hydrology and geomorphology assessment was undertaken to address updates to the project description, to provide additional information made available since publication of the EIS, and to incorporate legislative updates that may impact on the management of surface waters.

9.1.1.1 Project Description Update

Updates to the project description presented in the EIS, that have the potential to change or refine the EIS surface water impact assessment are described in Table 9-1 below.

Table 9-1 Summary of Key Project Description Water Components and Changes

Component	EIS Project Description	SREIS Project Description Refinements
Production wells	• Up to 6,625 production wells drilled over approximately 40 years; • Single well pads only; and • Estimated total water produced 276 GL.	• Approximately 4,000 production wells drilled over approximately 36 years; • All multi-well pads of up to 6 production wells each; and • Estimated total water produced 153 GL.
Field gathering and compression systems	Ten field compression facilities (FCF) and 17 drainage areas of approximately 12 km radius.	One FCF within each of the 33 drainage areas of approximately 6 km radius.

Component	EIS Project Description	SREIS Project Description Refinements
WTFs	• Four integrated processing facilities (IPFs; including both gas and water processing facilities) with dams up to 1 km^2; and • Peak flows of 15-30 ML/d CSG water from each WTF.	• Two CGPFs, each with an associated WTF; • Peak flow capacity of 12.9 ML/d CSG water produced at WTF1; • Peak flow capacity of 20 ML/d CSG water produced at WTF2;and • Potential future third WTF in Blackwater area being considered
Linear Infrastructure (e.g. roads and pipelines)		Updated linear infrastructure to be constructed as per refined Project layout and reduced number of well pads to connect.

The indicative locality of WTF1 in the vicinity of Skull Creek; one of the tributaries of the upper Isaac River and downstream of the Burton Gorge Dam. This proposed locality is relatively close to the nearest reaches of the Isaac River.

Scrubby Creek has been tentatively identified as the nearest watercourse flowing to the northeast of the WTF2 potential area of interest. The nearest reach of the lower Isaac River to the WTF2 area of interest is located in the order of 10 km to the west.

9.1.1.2 Study Objectives

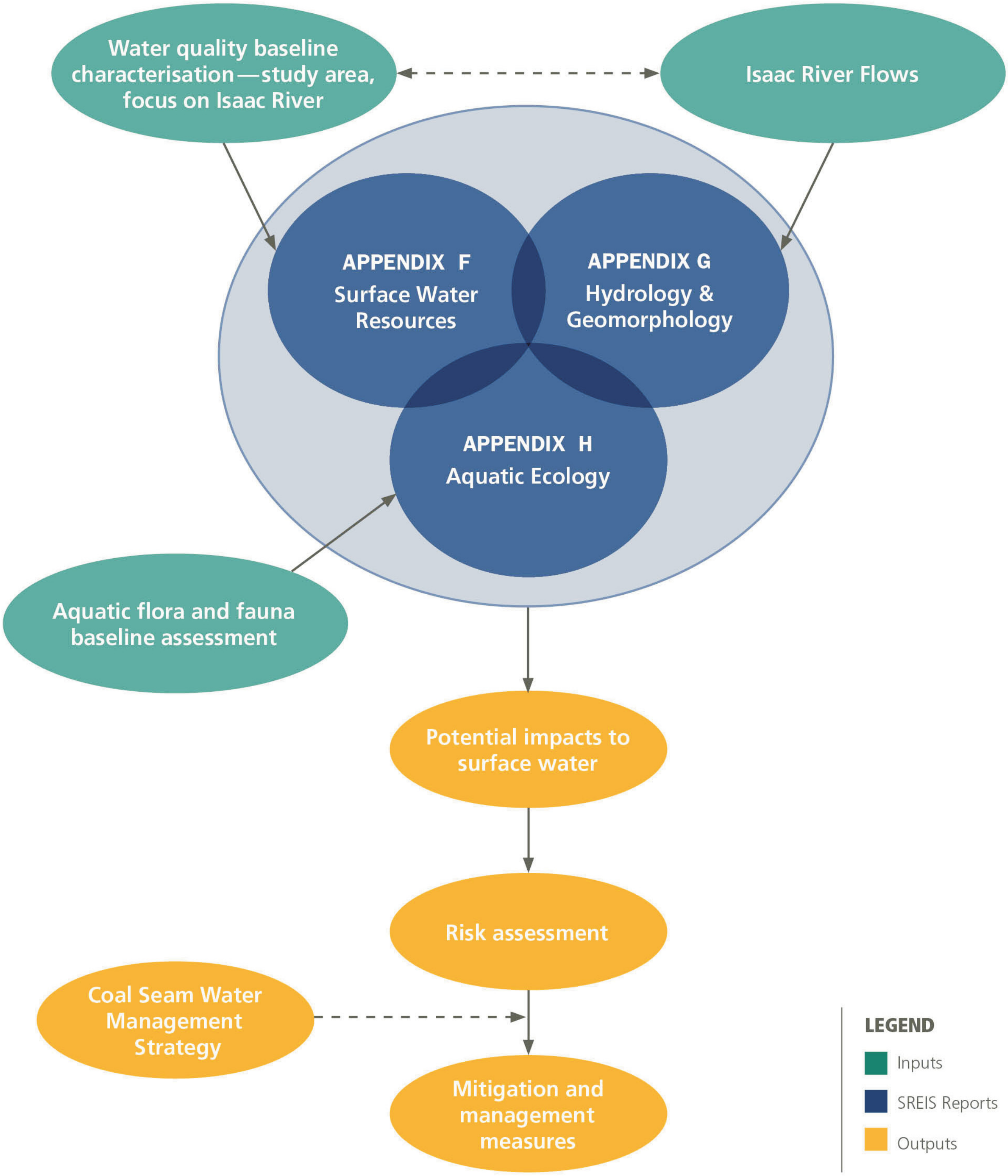
Arrow is required to prepare a SREIS to present information on updates to the project description, address issues identified in the EIS as requiring further consideration and/or information, and to respond to comments raised in submissions on the EIS.

This report describes the hydrologic, hydraulic and geomorphologic studies undertaken to address the potential impacts caused by the construction and operation of two proposed WTFs, as well as the impacts that may be caused to the potential receiving environment during any possible discharges of treated (and in certain circumstances untreated) CSG water. Studies conducted include:

- Describe the current flow regime of the Isaac River main channel in the potential locality of the WTFs (using a ‘Spells’ or Environmental Flow Analysis) to inform the CSG water and salt management strategy for future CSG water discharges;
- Assess flood risks at two suggested localities for CGPFs, which include a WTF and associated infrastructure, including climate change consideration:
  - Hydrologic modelling of 1% Annual Exceedance Probability (AEP) catchment runoff using runoff-routing software RORB; and
  - Two-dimensional hydraulic modelling of the two potential CGPF and WTF localities, using the hydraulic flow model TUFLOW;
- Hydraulic assessment for possible surface water discharges; and

- Geomorphologic desktop assessment of the potential receiving reaches of the Isaac River main channel associated with the indicative WTF localities.

Whilst this chapter specifically addresses the hydrological and geomorphological aspects of any likely impacts related to activities described in the updated project description, these studies are considered together and in a holistic manner with Project impacts related to water quality and aquatic ecology, which are presented in the Surface Water chapter (Section 8) and Aquatic Ecology chapter (Section 10) of the SREIS. The different and inter-relating aspects that determine river health such as water quality, river hydrology, geomorphology and aquatic ecology, were considered simultaneously to evaluate a full suite of environmental values associated with the Isaac River. This approach was utilised in the assessment of impacts associated with potential discharges of CSG water. This interrelationship is depicted in Figure 9-1.



BOWEN GAS PROJECT SREIS

OVERVIEW OF IMPACT ASSESSMENT PROCESS FOR THE SURFACE WATER ENVIRONMENT

HYDROLOGY AND GEOMORPHOLOGY

Figure: **9-1**

File No: **42627140-g-1024.cdr** Drawn: **RG** Approved: **BC** Date: **05-03-2014** Rev.**A** A4

9.2 Legislative Context

Updates to legislation relating to surface water (including hydrology and geomorphology) since the development of the EIS are detailed in the Surface Water chapter (Section 8.3) of this SREIS.

9.3 Description of Existing Environment

9.3.1 Environmental Flow (Spells) Analysis

The variability of streamflow both seasonally and annually are important determinants of both the structure and function of constituent freshwater and riparian species. Significant alterations to the existing flow regime can result in changes to both ecological and geomorphological processes.

Environmental Flow (Spells) Analysis of the existing flow regime in the Isaac River in the vicinity of both of the indicative WTF localities was undertaken based on methodology utilised by Alluvium (2013) for the Surat Gas Project SREIS assessment, to preserve a consistent approach across Arrow development projects.

The 1% AEP was adopted to predict flows in the receiving environment during such flood events in accordance with current guidelines (NRM, 2012). This information also contributes to the flood assessment contained in Section 9.3.2. The assessment of peak discharges and flow velocities allows for an assessment of the assimilative capacity of the receiving environment to potential CSG water discharges.

The results of the Environmental Flow Analysis have been used as input to the Surface Water Technical Report (Appendix F) of the SREIS, to inform how any potential CSG water discharges can be managed without impacting the identified potential receiving environment.

The analysis considered the hydrological regime within the Isaac River (prior to any discharge of CSG water from the Project) under a range of climatic conditions, in order to gain an understanding of the seasonality and spatial and temporal extent of various flow conditions. Hydrological data was collected from NRM gauges on the Isaac River at Goonyella (130414A; closest gauge to indicative WTF1 locality) and Deverill (1301410A; closest to indicative WTF2 locality). Seasonality of low and high flow conditions at each locality was characterised by analysing the frequency at which certain flow conditions occurred, including the following:

- Low band – cease to flow conditions;
- Mid band – baseflow conditions (the flow volume that is exceeded on 80% of days); and
- High band – high flow conditions (the flow volume that is exceeded on 20% of days).

This frequency analysis was also completed for drought; dry; average, and wet years (definitions of which are provided in the Hydrology and Geomorphology Technical Report (Appendix G, Section 1.7) of the SREIS).

It was found that in the reaches of the Isaac River proximate to the indicative locality of each WTF, the highly ephemeral flow regime was limited to short duration flows occurring between December and April. For the remainder of the year the river is dry or is limited to a series of isolated pools. The results indicate that for both reaches of the Isaac River, high flow conditions (which are considered most favourable for releases) only occur three to four times per season and only last for a relatively short duration (average of 11 to 16 days). Bankfull flows occur on average once every two years and also persist for up to four days depending on location.

In order to preserve identified aquatic, water quality, stream flow and geomorphic objectives, the high seasonal variability of flows means that opportunities for the release of CSG water will be linked to flow conditions and need to take the findings of the environmental flow analysis into consideration.

9.3.1.1 Summary of Environmental Flow Analysis in the Vicinity of WTF1

The nearest NRM stream gauge to the area of interest for WTF1 was on the Isaac River at Goonyella (130414A), located approximately 25 km downstream. The results of the Spells Analysis for the Goonyella gauge show that for all years analysed (1992 – 2012):

- Cease to flow conditions are present for approximately 90% (193 days) of the low flow season (May through November) and approximately 70% (103 days) of the high flow season (December through April);
- High flows (flow exceeded 20% of the time) of 43 ML/d occur three to four times per high flow season and last on average for 11 days;
- High flows (flow exceeded 5% of the time) of 1,262 ML/d occur three to four times per high flow season and last, on average for eight days; and
- Bankfull flow (1 in 2 year ARI) of 1,928 ML/d occurring, on average every two years and lasting, on average for three to four days during the high flow season.

It is important to note that the bankfull flows depicted here represent flows for the Isaac River at the Goonyella gauge, and not those calculated for Isaac River reaches tentatively identified as possible discharge locations for WTF1 (see Section 9.3.3). The bankfull flow is a standard flow component (Alluvium, 2013) that depicts a flow that fills the channel, but does not spill onto the floodplain.

9.3.1.2 Summary of Environmental Flow Analysis in the Vicinity of WTF2

The nearest NRM stream gauge to the area being considered for WTF2 was on the Isaac River at Deverill (130410A), which is located approximately 4 km from the boundary of the potential WTF land parcel. The results of the spells analysis for the Deverill gauge show that for all years analysed (1992 - 2012):

- Cease to flow conditions are present for approximately 89% (190 days) of the low flow season (May through November) and approximately 53% (80 days) of the high flow season (December through April);
- High flows (flow exceeded 20% of the time) of 151 ML/d occur three to four times per high flow season and last, on average for 16 days;
- High flows (flow exceeded 5% of the time) of 2,866 ML/d occur three to four times per high flow season and last, on average for 7 days; and
- Bankfull flow (1 in 2 year ARI) of 17,984 ML/d occurring, on average every two years and lasting, on average for two days during the high flow season.

It is important to note that the bankfull flows depicted here represent flows for the Isaac River at the Deverill gauge, and not those calculated for Isaac River reaches tentatively identified as possible discharge locations for WTF2 (see Section 9.3.3). The bankfull flow is a standard flow component (Alluvium, 2013) that depicts a flow that fills the channel, but does not spill onto the floodplain.

9.3.2 Flood Assessment

The purpose of the hydraulic modelling was to identify flood prone areas within the proposed WTF properties that might be inundated during a 1% AEP (equivalent to a 1 in 100 year event) flood event. This information can be used during the design phase to assist in determining appropriate locations for Project infrastructure.

Two separate two-dimensional, steady-state, flood models of the areas tentatively identified for WTF1 and WTF2 were created using hydraulic flow software TUFLOW. TUFLOW is a computer program used to simulate depth-averaged, two and one-dimensional free-surface flows, which commonly occur during flood events with significant floodplain interaction.

During this investigation, sensitivity analyses were undertaken using a 1% AEP flood event model to estimate the potential impact of climate change on flooding in this area. The Queensland Government document '*Increasing Queensland's resilience to inland flooding in a changing climate: Final Report on the Inland Flood Study'* (2010) provides practical guidance for modelling the impact of climate change. The shortest time frame addressed in the document is the year 2050, which is 36 years from 2014. This is slightly shorter than the Project's life span. While conservative, the longer horizon was adopted for climate change modelling in the absence of guidance for short timeframes. The document recommends adopting a two degree Celsius temperature increase for 2050 and applying a 5% storm intensity increase for each degree Celsius of temperature increase. In effect, this required that the existing storm intensities be increased by 10% to account for climate change in the year 2050.

Although the increased rainfall intensity expands flood extents through the site, the areas of interest for the potential localities for the two WTFs showed minor sensitivity to the increases and in all cases the flood extents increased by an amount too small to affect the siting of infrastructure.

The results of the flooding assessment are presented in Figure 9-2 and Figure 9-3.

Area of Innundation	Major Drainage
Area of Innundation (Climate Change Impact)	Minor Drainage
Potential receiving environment for CSG discharge area for CSG water	

N W E S

0 0.5 1 2 km

1:75,000

Projection: Geographic (GDA94)

Source: This product may contain information that is © Mapinfo Australia Pty Ltd and PSMA Australia Ltd., © Copyright Commonwealth of Australia (Geoscience Australia) 2006 , © Copyright The State of Queensland (Department of Natural Resources and Water) 2008, © The State of Queensland (Department of Mines and Energy) 2006-2008,© The State of Queensland (Department of Environment and Resource Management) 2010, Bing Maps © Microsoft Corporation and its data suppliers, Images from Client Feb 2012.

arrow energy go further

BOWEN GAS PROJECT SREIS

COMPARISON OF 1% AEP MAXIMUM FLOOD INUNDATION EXTENTS FOR WTF1 POTENTIAL LOCALITY

URS

HYDROLOGY AND GEOMORPHOLOGY

Figure: 9-2

File No: 42627140-g-1039b.mxd Drawn: RG Approved: DS Date: 22-04-2014 Rev.B A4

Area of Inundation	Major Drainage
Area of Inundation (Climate Change Impact)	Minor Drainage
Potential receiving environment for CSG discharge area for CSG water	

N W E S

0 0.5 1 2 3 km

1:125,000

Projection: Geographic (GDA94)

arrow energy go further

BOWEN GAS PROJECT SREIS

COMPARISON OF 1% AEP MAXIMUM FLOOD INUNDATION EXTENTS FOR WTF2 POTENTIAL LOCALITY

URS

HYDROLOGY AND GEOMORPHOLOGY

Figure: 9-3

File No: 42627140-g-1040b.mxd | Drawn: RG | Approved: DS | Date: 22-04-2014 | Rev. B | A4

9.3.3 Hydraulic Assessment for Possible CSG Water Releases

The flood impact assessment included consideration of potential impacts arising if CSG water was released during different periods within the hydrological regime, or even during a single flow event. It is important to also take into account potential impacts of introducing additional flows into the ecosystem during dry, baseflow, and high flow periods. The magnitude; frequency; duration; timing or predictability, and rate of change of flows (such as ‘flashiness’ and lag period following a high flow event) can all influence the “integrity” of an ecosystem (Poff *et al*., 1997).

This section provides an assessment of the various flow conditions under which CSG water may need to be released, to inform the impact assessment presented in Section 9.7. By assessing the estimated hydraulic conditions near the indicative WTF localities (where releases of CSG water to local watercourses may occur), an understanding of the assimilative capacity and sensitivity of the surface water environment to additional flows can be gained.

When a watercourse such as the Isaac River is at ‘bankfull discharge stage’, the channel is filled with water up to the crest of the bank, leaving no surface of the bank exposed. This condition is reached immediately prior to a flood event, when the floodplain adjacent to the channel becomes inundated. Bankfull discharge stage could be viewed as a ‘tipping point’ at which any added volume to the system would trigger the inundation of the floodplain. This increased incidence of flooding can then have adverse effects on riparian ecosystems and infrastructure within the inundation zone; it can also cause erosion of banks and floodplains and result in the transport of large volumes of sediment downstream. The significance of bankfull flows in relation to impacts from potential CSG water discharges is discussed further in Section 9.4.3.1.

Bankfull discharge was estimated for reaches of the Isaac River in the vicinity of potential discharge localities of CSG water for WTF1 and WTF2 to estimate potential impacts to the geomorphic conditions and flow conditions of the river.

The bankfull elevation at the assumed representative cross section location for the WTF1 potential receiving environment was estimated to be 269.0 mAHD. This estimate was developed using aerial photography, geometry data, and site photographs. From the site photographs, a bench could be seen below the major floodplain which generally indicates the bankfull location for the channel. The geometry data and aerial photography both indicated bankfull width of around 60 m, which corresponds to the bench seen in the site photograph.

For the assumed representative release location for WTF2, bankfull elevation was estimated to be 179.2 mAHD. This was estimated using channel geometry data at multiple cross sections upstream and downstream of the Deverill Gauge, which all showed a single bench leading from the main channel into the major floodplain, suggesting that the bankfull location was at the top of the main channel. The representative cross-section data indicated a bankfull width of approximately 110 m, which corresponds to estimates based upon the channel outline in aerial photographs.

Using the estimates of bankfull elevation along with the discharge rating curves, a bankfull discharge was estimated. This provides an indication of the watercourse’s assimilative capacity for potential CSG discharges without significantly impacting the flow and geomorphic characteristics of the Isaac River. A summary of the results is presented in Table 9-2.

Table 9-2 Estimates of Bankfull Elevation and Discharge of Isaac River at Assumed Representative Locations

Representative Location	Bankfull Elevation for Representative Cross-section (m)	Bankfull Discharge (m^3/s)	Bankfull Width for Representative Cross-section (m)
WTF1	269.0	270	60
WTF2	179.2	2,350	110

9.3.4 Geomorphology

Fluvial geomorphology describes the form of landscapes in relation to watercourses, and identifies key processes that have taken place historically, and in the present landscape, to develop that form. Key processes that contribute to the geomorphic character of a catchment, such as the Isaac River, may include movement of sediment through the system (via erosion, transport, and deposition processes); interaction between the hydraulic geometry of the river channel and changes in flow velocity and volume (such as scouring or incision of a deep channel at the bottom of slope), or the formation and/or influence of in-channel geomorphic features such as vegetated islands and lateral bars (sediment deposits on the inside bend of a channel).

The amount of energy and type of material (such as gravel, bedrock, sand, or fine sediments such as clay and silt) are the driving factors behind the physical form of a watercourse. If these factors fall out of balance, or are changed dramatically and intensively over a short time period (compared with the natural rate of change common to the study catchment), this can lead to the acceleration of processes that are detrimental to the long term condition of the watercourse’s natural geomorphic character. It is this imbalance, or potential for change that is outside of what appears to be the natural regime within the catchment, that would be considered an adverse impact on the system.

The following section provides a preliminary assessment of the geomorphic character of the Isaac River and local watercourses proximate to the currently preferred WTF localities, to inform the impact assessment contained in Section 9.4. Data from field investigations completed at sub-catchment level for the EIS assessment were combined with more site-specific data obtained from desktop sources, to provide a more local assessment of geomorphology for the SREIS. Secondary sources of information included the WetlandInfo database (EHP, 2013). The purpose of the wetlands characterisation is to identify those potentially sensitive areas within or proximate to the Project to inform the impact assessment.

While detailed site-specific studies will be undertaken prior to final selection of water discharge locations as part of the environmental authority (EA) application process, potential impacts from pipelines crossing local watercourses (i.e. ephemeral feeder creeks) to discharge CSG water into the Isaac River are expected to be minor.

It should be noted that the desktop geomorphic study described in this section (Section 9.3.4) assessed the baseline geomorphic conditions of the Isaac River in the general vicinity of, but not identical to, those reaches assessed as part of the hydraulic assessment described in Section 9.3.3 above.

9.3.4.1 Isaac River near WTF1 Area

The Isaac River is an ephemeral river with a sand bed that is largely alluvial downstream of the Burton Gorge dam and is terrace confined. The bankfull width varies from 20 m to 40 m. The floodplain varies from 150 m to 500 m in width, with an upper terrace approximately 2 m to 4 m higher than the floodplain. The condition of the Isaac River shows excess sediment inputs from changes in land use. The riparian vegetation along the reaches near the area of interest for WTF1 remains reasonably continuous at the overstory level but minimal at the understory level. Groundcover is variable but often dense with exotic grasses dominant. These provide conditions for deposition of a mud drape which enhances bank stability.

The channel of Skull Creek and the Isaac River near the indicative locality of WTF1 are classified as riverine systems (defined by EHP as wetlands and deepwater habitats within a channel which is naturally or artificially created, periodically or continuously contain moving water, or connect two bodies of standing water). An area surrounding the Isaac River channel in this locality is also classified as a remnant regional ecosystem (areas which may or may not include wetlands).

9.3.4.2 Isaac River near WTF2 Area

The field assessment of the Isaac River (undertaken as part of the EIS) upstream and downstream of the area of interest for WTF2 showed similar geomorphologic characteristics. The river was characterised as a low sinuosity, single channel (30 m to 40 m bankfull width), with floodplain up to 800 m in width. Similar to the upper reaches of the Isaac River, the river is ephemeral in nature and has a coarse sand bed. The riparian vegetation was described as semi-continuous along both banks with on average 50% of the trees greater than 10 m in height.

The channel of the Isaac River near the indicative locality of WTF2 is classified as a riverine system. Outside of the main channel, several areas are classified as palustrine wetland systems (primarily vegetated non-channel environments of less than eight hectares with more than 30% emergent vegetation). An area surrounding the Isaac River channel in this locality is also classified as a remnant regional ecosystem (areas which may or may not include wetlands).

9.4 Summary of Potential Impacts to Hydrology and Geomorphology

9.4.1 Changes to Potential Impacts

The assessment of potential impacts to the hydrology and geomorphology of the surface water environment associated with the Project was updated as part of the SREIS process, and includes an assessment of both the assimilative capacity and sensitivity of the receiving environment, as well as the magnitude of potential impacts that may arise as a result of the proposed development. Key changes to the proposed development since the EIS submission were also identified, along with any associated perceived changes to the type and extent of impact that may be incurred. Table 9-3 provides a summary of the key changes between the EIS and SREIS scenarios, and associated potential impacts that formed the basis of the revised impact assessment.

Table 9-3 Comparison of EIS and SREIS Scenarios: Revised Hydrology and Geomorphology Impact Assessment

Project component	EIS scenario (2012)	SREIS scenario (2014)	Associated potential impacts	Key changes in degree of potential impact	Applicable mitigation measures
Drainage areas	• 17 'drainage areas' of; and approximately 12 km radius.	• 33 'drainage areas' of approximately 6 km radius.	• Localised alteration of flows and flow paths; and • Erosion and sediment mobilisation.	• May result in increased *localised* impacts compared with EIS scenario.	• Mitigation measures outlined in Sections 9.2.1, 9.2.2 and 9.2.3 of the Surface Water Technical Report (Appendix N) of the EIS still apply.
Production wells	• 6,625 production wells; and • Single well pads only.	• Approximately 4,000 production wells; and • Multi-branch lateral (MBL) wells is base case, all wells located on multi well pads with up to 6 production wells on a pad.	• Ponding in subsided void areas; • Localised alteration of flows and flow paths; and • Erosion and sediment mobilisation.	• Reduced area of potential ponding of rainfall in subsided voids.	• Mitigation measures outlined in Sections 9.2.2.1, 9.2.2.2 and 9.2.2.3 of the Surface Water Technical Report (Appendix N) of the EIS still apply.
WTFs	• Maximum dam footprint 0.6 km^2; and • WTFs may have peak flows of between 15-30 ML/d of field produced water, allowing that some areas will produce more	• Water Transfer Stations in field (pumping and surge tanks); typically associated with an FCF; • One WTF associated with each CGPF. Feed water dams, treated water dams, and brine storage	• Controlled release of treated (and in certain instances untreated) CSG water to surface watercourses (potential adverse effects on surface water quantity); and • Uncontrolled release of treated or	• Reduction in number of WTFs, but retained a similar treatment capacity to that proposed for the EIS scenario; • Significant reduction in maximum area for WTF dams, potentially decreasing the overall impact of WTF	• Mitigation measures outlined in Sections 9.2.1.1 to 9.1.2.4, and 9.2.2 of the Surface Water Technical Report (Appendix N) of the EIS still apply; and • Section 9.2.2.4 of the Surface Water Technical Report (Appendix N) of the EIS specifically

Project component	EIS scenario (2012)	SREIS scenario (2014)	Associated potential impacts	Key changes in degree of potential impact	Applicable mitigation measures
	water than others.	facilities will be located at each WTF; • WTF1: Expected peak flow capacity of 12.9 ML/d; • WTF2: Expected peak flow capacity of 20 ML/d; • Raw water can be transferred between WTFs (current concept); • Water storage and pumping facilities at each FCF to move water to the WTFs; and • Possible third WTF in Blackwater area.	untreated CSG water, and contaminated process water to grade and/or watercourses due to flooding, dam failure or spills (from water gathering lines; trucks transporting wastewater and treated water from water transfer stations).	construction/operation; • Potentially lower risk of uncontrolled release to surface waters, due to reduced number of WTFs and discharge locations; and • No change in potential impacts associated with FCFs, as specific locations have not yet been identified (refer to impacts presented in EIS).	applies to any releases from WTFs to the receiving environment.
Project infrastructure	• Four integrated processing facilities with dams up to 1 km^2 in area; and • One compression facility per drainage area.	• Two CGPFs in the locality of Peak Downs and Red Hill (as well as close to the Isaac River); and • One FCF per drainage area.	• Flooding of Project infrastructure could cause contamination of floodwaters; and • Scour or sedimentation at watercourse crossings could impact geomorphology and	• Reduced footprint and number of gas processing facilities; • Larger footprint area for FCFs; and • Reduced watercourse crossings.	• Mitigation measures outlined in Sections 9.2.1.1 to 9.1.2.4, and 9.2.2 of the Surface Water Technical Report (Appendix N) of the EIS still apply.

Project component	EIS scenario (2012)	SREIS scenario (2014)	Associated potential impacts	Key changes in degree of potential impact	Applicable mitigation measures
			potential wetlands.		
Linear Infrastructure (e.g. roads and pipelines)	• Network of roads and pipelines designed to cater for project layout.	• Updated linear infrastructure to be constructed as per refined project concept layout, i.e. less well pads require less linear infrastructure.	• Localised alteration of flows and flow paths; and • Erosion and sediment mobilisation.	• Extent of linear infrastructure required reflects updates to the project description under the SREIS scenario. The linear infrastructure required for the updated project description is considerably less, thereby minimising potential impacts.	• Mitigation measures outlined in Sections 9.2.1, 9.2.2 and 9.2.3 of the Surface Water Technical Report (Appendix N) of the EIS still apply.

9.4.2 Potential Impacts of Subsidence on Hydrology and Geomorphology

Review of available information from CSG proponents (Origin Energy, QGC and Santos) by Geoscience Australia and Habermehl (2010) in relation to the likely groundwater impacts of proposed CSG activities in the Surat and Bowen Basins, identified potential for subsidence to occur. Whilst Williams (2012) also identified the potential for land subsidence as a result of CSG extraction, on the basis of an assessment of CSG activities in similar environments, Geoscience Australia and Habermehl (2010) concluded that the risk of impacts to shallow groundwater systems was low.

In recognition of the identified potential for subsidence, albeit low, Altamira Information Ltd (Altamira) was engaged to complete a ground motion baseline study on behalf of Arrow Energy for their existing Moranbah Gas Project in the Bowen Basin (Altamira, 2013). The study involved analysing ground surface motion across the Moranbah Gas Project area to allow a comparison between known rates of CSG production and ground movement over the same time period. A review of the baseline assessment of subsidence undertaken by Altamira (2013) at the Moranbah Gas Project site was undertaken by Coffey (2013). The results showed that the vast majority of the area monitored was subject to movement of less than 8 mm/year over the monitoring period. Whilst isolated locations with greater rates of movement were identified, further interpretation was conducted and found consistent with site surface features. Details of selected individual movement locations showing greater than average movement presented in the Altamira report (2013) include:

- Swelling of reactive clay soils in response to changes in soil moisture;
- Localised settlement areas associated with areas of bare earth possibly associated with erosion;
- Settlement at an isolated location at a production well site over the period January 2007 to December 2010;
- Localised upward movement interpreted at a site which appears to be a gas processing site over the period January 2007 to December 2010, possibly related to swelling of reactive clay soils in an area which has been cleared of vegetation;
- Settlement interpreted on a circular embankment apparently constructed for a rail loop; and,
- Settlement interpreted at the embankment for a water storage pond associated with a racecourse.

Overall these findings indicate that the potential for subsidence resulting from CSG development in the Bowen Basin is low, and substantially less than that arising from longwall coal mining, where subsidence is typically greater than 1 m. Therefore on the basis of these reports the potential for any subsidence impacts on the surface water environment in the Bowen Basin as a result of CSG extraction activities is considered to be negligible. For further information please refer to Section 5.6 of the Supplementary Groundwater Assessment Report (Appendix E) of SREIS. Potential Impacts of CSG Water Discharge on Hydrology and Geomorphology.

Whilst Arrow will seek to beneficially reuse as much of its CSG water as possible, there may still be a requirement for the discharge of treated or untreated CSG water into the receiving environment. This report has examined the existing hydrological, hydraulic and geomorphic conditions of the receiving environment in order to ascertain the capacity of the Isaac River (in the vicinity of the two indicative WTF localities) to receive possible CSG water discharges, and if appropriate, to inform the Project's CSG water release strategy as to the volume, timing, frequency and duration of any releases. The impact assessments that have been undertaken in this section have also simultaneously considered the need to protect other environmental objectives related to the aquatic environment of the Isaac River, such as those related to stream water quality and protection of aquatic fauna and flora.

The potential impacts on the hydrology and geomorphology of the Isaac River associated with the discharge of CSG water into the Isaac River include:

- Increased bank erosion and changes in geomorphic character of banks due to increased flows;
- Changes in stream hydrological regime and perturbations to flow-dependent ecosystems; and
- Impacts on the receiving environment's water quality.

As indicated above, these impacts have been assessed in context of water quality and aquatic ecosystem protection. The Environmental Flow Analysis undertaken in this study indicates that the Isaac River in the vicinity of the indicative WTFs localities is highly ephemeral with a distinct dry season (from May to November) and a wet season (between December and April) characterised by periods of high flows. The high seasonal variability of flows means that opportunities for the release of CSG water will be linked to the ephemeral nature of the Isaac River.

9.4.2.1 Controlled CSG Water Releases

The bankfull flood typically has the greatest erosion potential and as such was assessed for the Isaac River for the potential release areas. The Isaac River channel has a bankfull capacity of 270 m^3/s (23.3 GL/d) in the reaches near the indicative WTF1 locality, and a bankfull capacity of 2,350 m^3/s (203 GL/d) in the vicinity of the indicative WTF2 locality. These relatively large volumes indicate that the Isaac River in flood has a high capacity to receive CSG water discharges without any significant impacts on its environment values (geomorphology, water quality, stream flow). Given that the WTF localities are indicative, the actual discharge conditions will need to be determined as part of the EA application process, and discharge rates adjusted accordingly to mitigate potential impacts.

Impacts to geomorphology as a result of localised disturbances of watercourses during construction activities or from subsidence, should any occur, could include localised erosion and sediment deposition. Works within watercourses should be conducted in the dry season as much as possible and in accordance with regulatory requirements for works conducted in watercourse channels. Monitoring and site specific erosion control measures should be developed at the design stage, including vegetation establishment or engineered erosion protection such as rock structures or energy dissipation structures.

Any potential wetland areas identified near the WTF1 and WTF2 potential localities will be better defined through field assessments in order to avoid inappropriate siting of infrastructure in relation to wetland areas where possible. At the construction phase of the Project, crossing of watercourses and floodplains near wetlands will be avoided as much as possible.

9.4.2.2 Uncontrolled Releases of CSG Water

Uncontrolled releases of treated or untreated CSG water may have significant impacts on the receiving environment depending on the timing, volumes and discharge rates of the release. The impact assessment of such uncontrolled releases on the hydrological, hydraulic and geomorphic environmental values, as well as that for controlled releases discussed above, are summarised in Table 9-7. Impacts on surface water quality are discussed in the Surface Water chapter (Section 8) and the Surface Water Technical Report (Appendix F) of the SREIS.

9.4.3 Cumulative Impacts

The Isaac River is known to be the receiving environment for discharges from a significant number of coal mines operating in the area. Likewise, Arrow may also choose to release CSG water into the Isaac River if beneficial use options for this water are insufficient. Releases of mine affected water or CSG water into the Isaac River will be regulated by conditions that stipulate the quality, volumes, timing and duration of the water that can be released under controlled conditions. Under these conditions, the river's environmental flow, geomorphic and water quality objectives are preserved and as such under periods of high flows, the cumulative impacts derived from the region's extractive industry on the environmental integrity of the Isaac River are deemed to be insignificant.

9.5 Mitigation Measures and Residual Impacts

The summary of impacts that potentially remain in association with the proposed Project activities, after application of suitable management and mitigation measures, are summarised in Table 9-5. The commitments pertaining to hydrology and geomorphology presented in the EIS are listed in Table 9-6.

Providing that all further planned developments are managed with sufficient mitigation measures and with discharge strategies having the same objectives as that of the Project, significant cumulative impacts on the river's flow regime, geomorphic character and water quality should not occur.

Table 9-4 Assessment of Potential Impacts on Hydrology and Geomorphology of the Isaac River Resulting from CSG Water Release

CSG Water Release Scenario	Contributing factor	Potential impacts	Magnitude of Impact	Significance of Impact
Uncontrolled release of *untreated* CSG water	Flooding (dams over capacity; inundation of infrastructure) , dam failure, WTF operational emergency- Dry Season	• During periods of low flow, sudden release of large volumes of moderately saline water could result in potential inundation of riparian margins and floodplain areas not usually inundated during dry season; and • Transport of large quantities of sediment and large woody debris downstream.	High	High
	Flooding (dams over capacity; inundation of infrastructure) and dam failure- Wet Season	• During periods of high flow, sudden release of large volumes of moderately saline water will have a minimal impact on the natural low flow regime and may cause limited erosion to stream banks; • Transport of large quantities of sediment and large woody debris downstream; and • During periods of high flow, there may be a slight increase in stream water level and impacts on stream physical integrity.	Low	Low
Uncontrolled release of *treated* CSG water	Flooding (dams over capacity; inundation of infrastructure) , dam failure, WTF operational emergency- Dry Season	• During periods of low flow, sudden release of large volumes of treated CSG water could result in potential inundation of riparian margins and floodplain areas not usually inundated during dry season; and • Transport of large quantities of sediment and large woody debris downstream.	Moderate	Moderate
	Flooding (dams over capacity; inundation of infrastructure) and dam failure- Wet Season	• During periods of high flow, sudden release of large volumes of water will have a minimal impact on the natural low flow regime and may cause limited erosion to stream banks; • Transport of large quantities of sediment and large woody debris downstream; and • During periods of high flow, there may be a slight increase in stream water level and impacts on stream physical integrity.	Low	Low

CSG Water Release Scenario	Contributing factor	Potential impacts	Magnitude of Impact	Significance of Impact
Controlled release of treated and untreated CSG water	Release according to EA conditions (where beneficial use is not appropriate/available)	Treated CSG water is released at a volume and water quality that does not cause a significant impact on the receiving environment, based on findings of site-specific baseline assessments.	Low	Low to negligible

Table 9-5 Residual Impacts to the Isaac River's Flow Regime and Geomorphic Character Arising from Project Activities Following Implementation of Mitigation Measures

Project Component	Associated potential impacts	Applicable Mitigation Measures	Residual Impact	Magnitude of Residual Impact	Significance of Residual Impact
Drainage areas	• Alteration of flows and flow paths; • Erosion and sediment mobilisation; • Improper disposal of wastes from construction and operations activities; and • Potential release of contaminants to watercourses (adverse effects on surface water quality).	Mitigation measures outlined in Sections 9.2.1, 9.2.2 and 9.2.3 of the Surface Water Technical Report (Appendix N) of the EIS still apply.	Potential release of sediment and contaminated water to overland flows paths if management controls fail (for example, sediment fence is washed away or vandalised).	Low	Low
Production wells	• Alteration of flows and flow paths; and • Erosion and sediment mobilisation.	Mitigation measures outlined in Sections 9.2.2.1, 9.2.2.2 and 9.2.2.3 of the Surface Water Technical Report (Appendix N) of the EIS still apply.	Potential localised impact to river geomorphology if engineering/management control options fail (potential for larger volume of sediment to be mobilised from multi-well pads, on a local scale only).	Low	Low to negligible

Project Component	Associated potential impacts	Applicable Mitigation Measures	Residual Impact	Magnitude of Residual Impact	Significance of Residual Impact
Gas compression infrastructure	• Alteration of flows and flow paths; and • Erosion and sediment mobilisation.	Mitigation measures outlined in Sections 9.2.1.1 to 9.1.2.4, and 9.2.2 of the Surface Water Technical Report (Appendix N) of the EIS still apply.	Potential localised impact to stream geomorphology in surface water catchments containing FCFs, if engineering/management control options fail (potential for larger volume of sediment to be mobilised from FCFs with increased area).	Low	Low to negligible
Water treatment facilities	• Release of treated and untreated CSG water to surface watercourses (potential adverse effects on stream flows and geomorphology); • Uncontrolled release of contaminated water to grade and/or watercourses due to spills (from water gathering lines; trucks transporting wastewater and treated water from water transfer stations); and • Reduced risk of adverse impacts to water quality, with fewer discharge points (a function of having fewer WTFs).	Mitigation measures outlined in Sections 9.2.1.1 to 9.1.2.4, and 9.2.2 of the Surface Water Technical Report (Appendix N) of the EIS still apply. Section 9.2.2.4 (Discharge of CSG Water to Waterways) of the Surface Water Technical Report (Appendix N) of the EIS specifically applies to any releases from WTFs to the receiving environment, along with information outlined in Sections 9.1 and 9.2 of the same report.	Potential impact to surface water hydrology and geomorphology in the event of uncontrolled releases (where it is not possible to control the volume released, such as in an emergency). Impact to surface water hydrology and geomorphology is dependent on the actual rate and water quality of release. Magnitude of impact depends on size of flow in the Isaac River main channel (see table above)	Moderate	Moderate
Linear infrastructure (e.g. roads and pipelines)	• Alteration of flows and flow paths; and • Erosion and sediment mobilisation.	Mitigation measures outlined in Sections 9.2.2.1, 9.2.2.2 and 9.2.2.3 of the Surface Water Technical Report (Appendix N) of the EIS still apply.	Potential localised impact to stream hydrology and geomorphology if engineering/management control options fail.	Low	Low to negligible

Arrow committed to implement a number of avoidance, mitigation and management measures to reduce impacts on values in the project development area. The commitments pertaining to hydrology and geomorphology presented in the EIS are listed in Table 9-6.

New and revised commitments are also presented below in Table 9-7. This update has resulted from changes made to the project description since the EIS was finalised and the decision to further clarify the intent of a commitment (e.g., through the consolidation of similar commitments to avoid inconsistent wording).

A full list of all project commitments, including those that remain unchanged from the EIS, and details of those that have changed, are included in the Commitments Update (Appendix O) of the SREIS.

Table 9-6 Hydrology and Geomorphology Commitments Presented in the EIS (2012)

Commitment Number	Commitment
B286	Watercourse crossings to be designed to minimise impacts on geomorphology and river flows
B287	Where practical major facilities will be constructed above the 1:100 year flood level
B290	Develop an Erosion and Sediment Control Plan to include: • Erosion and sediment control • Stabilise exposed areas
B298	Regular inspections of pipeline and roads alignments will be undertaken to ensure that disturbed surfaces are stable and not subject to concentration of flows or erosion. Repair works will be undertaken proactively to prevent erosion from occurring or worsening
B300	Minimise potential impacts on surface waters through implementation of the following measures during construction of watercourse crossings: • Watercourse crossings should be timed to occur during the dry season during periods of low flow, where possible; • Construction of watercourse crossings will be conducted in the shortest possible time and in accordance with the NRM (2012) guideline Activities in a watercourse, lake or spring carried out by an entity. • Avoid disrupting overland natural flow paths and, where avoidance is not practicable, maintain connectivity of flow in watercourses • Delay clearance of stream banks until the watercourse crossing is due to be constructed, to the greatest extent practicable. Implement appropriate erosion and sediment control measures on watercourse approaches and banks and ensure prompt completion of construction • Check for flood warnings or subscribe to flood warning services where relevant during construction of watercourse crossings • Construct watercourse crossings in a manner that minimises sediment release to watercourses, stream bed scouring (e.g., the crossing location will be at low-velocity, straight sections, with the pipeline or road orientated as near to perpendicular to water flow as practicable), obstruction of water flows and disturbance of stream banks and riparian vegetation (i.e., the crossing location will be at a point of low velocity, and straight sections will be targeted, with the pipeline or road orientated as near to perpendicular to water flow as practicable). Avoid, where practicable, the use of rock gabions, as they are unsuited to watercourses of the region • All crossings will be constructed and reinstated to ensure that flows are not impeded and water is not ponded by the crossing. Where the temporary damming of flows is necessary during construction then flow will be diverted where required to maintain flows and allow for fish movement

Commitment Number	Commitment
	• Minimise the number of channels to be crossed • Avoid permanent pools • Avoid mid-channel alluvial bars and islands • Stockpile watercourse bed material in the watercourse channel adjacent to the construction ROW only when the watercourse is dry, and site the stockpile to avoid impacts on riparian vegetation and in-stream features • Retain coarse alluvial material from watercourse crossings for backfill armouring over the finer unconsolidated material • Stabilise watercourse crossings as soon as possible using bedrock where available Rehabilitate and revegetate banks as soon as possible after construction
B316	Design surface flows from unsealed areas to flow to adjacent grassed areas at low velocities
B326	Design and construction supervision of regulated dam embankments undertaken by a suitably qualified and experience engineer (as defined by EHP)
B327	Rapid stabilisation of constructed regulated dam embankments through the implementation of suitable erosion controls
B334	Water or storm water contaminated by sewage treatment activities must not be released to any waters or the bed and banks of any waters (i.e. effluent irrigation must not occur during rainfall events)
B337	Rapid stabilisation of constructed regulated dam embankments through the implementation of suitable erosion controls
B339	Develop and implement a rehabilitation management plan for decommissioning which includes monitoring and maintenance of rehabilitated areas until rehabilitation is complete
B340	Locate Project infrastructure with consideration of downstream values.
B342	Identify strategies to minimise CSG water surface storage and to promote increased efficiency
B344	Develop and continually maintain the CSG water management plan throughout the Project life to optimise the investigation and implementation of the potential CSG water management options in alignment with the overall Project development
B345	Incorporate into an emergency response plan or water management plan procedures for the controlled discharge of CSG water

Table 9-7 Revised Hydrology and Geomorphology Commitments

No.	Revised / New Commitment	Rationale
B316	Design surface flows from unsealed areas to flow to any existing adjacent grassed areas at low velocities	Amended to clarify intent
B327	Maintain stabilisation of constructed regulated dam embankments through the implementation of suitable erosion controls and/or maintenance	Amended to clarify intent
B339	Develop and implement a rehabilitation management plan for decommissioning which includes monitoring and maintenance of rehabilitated areas until rehabilitation sign off criteria is met.	Amended to clarify intent
B344	Develop and maintain the CSG water management plan throughout the Project life	Amended to clarify intent

9.6 Conclusions

The hydrology and geomorphology assessment undertaken for the SREIS has provided information on the likely impacts with activities included in the updated project description, and informs the CSG water and salt management strategy for the Project.

A detailed Environmental Flows Analysis describes the Isaac River at the reaches proximate to the areas being considered for the proposed WTFs as highly ephemeral with flows occurring only for short duration between December and April. For the remainder of the year the river is dry or is limited to a series of isolated pools. The hydrological nature of the Isaac River therefore links the release rates of CSG water to flow conditions. The CSG water discharge strategy needs to be tailored so as to provide a framework for CSG water releases at rates which will avoid a significant impact to the receiving environment (including water quality, hydrological regime, and geomorphic characteristics). The findings of this assessment as well as those presented in the Surface Water Quality Technical Report (Appendix F) of the SREIS document ultimately will enable the proponent to develop the discharge strategy according to the variable water quality and stream flow conditions within the Project area as part of the EA application process.

The hydraulic assessment presented in this report indicates that the Isaac River supports very significant flows during the wet season; flows that are considered to be large enough to more than cater for the release of CSG water without causing any environmental flows or geomorphic impacts.

A modelled estimate of flood inundation that would occur as a result of a 1% AEP flood event indicates that the two indicative WTF localities have substantial areas which are flood free; these areas are orders of magnitude larger than the minimum area required for the gas compression and water treatment infrastructure associated with these two infrastructure hubs. This is typical for the catchment, even under scenarios of increased rainfall intensity and duration as a result of climate change. As such, it can be concluded that the gas compression and water treatment infrastructure for these two infrastructure hubs can be located outside of the modelled 1% AEP flood inundation level.