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REPORT:

Surat Gas Project – Supplementary Report to the Environmental Impact Statement

Supplementary Surface Water Assessment Part A - Geomorphology and Hydrology

June 2013

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Executive Summary

Arrow Energy Pty Ltd (Arrow) is preparing a supplementary report to the Surat Gas Project Environmental Impact Statement (SREIS) to present information on updates to the project description, address issues identified in the Surat Gas Project Environmental Impact Statement (EIS) as requiring further consideration and/or information and to respond to stakeholder comments raised in the submissions on the EIS. This report builds upon the findings of the EIS and refines the geomorphology and hydrology assessments included in the EIS.

The main changes to the project description as presented in the EIS, which have the potential to affect the surface water impact assessment, include changes to the size of the project development area and the identification of sites to locate four central gas processing facilities (CGPFs) and two water treatment facilities. In addition, the updated project description proposes to potentially discharge treated or untreated coal seam gas water to Bottle Tree Creek and the Condamine River under normal operating conditions in the Maranoa-Balonne-Border River and Condamine-Macintyre River catchments, respectively. There have been no material changes to the project description for the Fitzroy River catchment since the EIS and as such, the assessment of impacts and mitigation measures to manage the potential impacts to geomorphology and hydrology in the Fitzroy River catchment remain as per the EIS.

E1 Environmental Values

Two overarching environmental values for each of the various types of watercourses and wetlands within the project development area were defined in the EIS (Alluvium 2011). These have been updated to include consideration of the option to release treated or untreated coal seam gas water to surface waters and updated wetlands mapping.

E2 Geomorphology

Geomorphic assessments were undertaken in the receiving environments of the five properties proposed to site infrastructure, the CGPF2, 7, 8 and 9 properties and the TWAF F property. Assessments were particularly focussed upon the receiving environments of the CGPF2 property and the CGPF9 property as these properties contain the two watercourses proposed to receive releases of treated or untreated coal seam gas water: Bottle Tree Creek and the Condamine River. Particular attention has been applied to assessing the geomorphic character, behaviour and condition of potentially affected watercourses in order to consider the sensitivity to change of those watercourses in the event of treated or untreated coal seam gas water discharges.

The assessment has included identification of potentially stable points most suited to the discharge of treated or untreated coal seam gas water and to the geomorphic character, behaviour and condition of downstream reaches along which the discharged water will flow.

E3 Hydrology

The assessment of hydrology comprised two principal components: Flood modelling to assess risks at the five properties identified to site proposed infrastructure (CGPF2, 7, 8, and 9 properties and the TWAF F property); and hydraulic modelling to determine the existing hydraulic parameters, which were then used to assess the impact of proposed water releases from the water treatment facilities co-located with CGPF2 and CGPF9.

Flood mapping for the 1% Annual Exceedance Probability (AEP) flood levels has been developed for each site to identify areas that remain flood free during this flood event, including consideration of potential changes through the project's lifespan due to climate change.

Hydraulic modelling was used in combination with the field assessment to determine the potential geomorphic impacts of proposed releases of treated and untreated coal seam gas water.

E4 Potential Impacts

Activities associated with project infrastructure at as yet unconfirmed locations are primarily the construction, operation and decommissioning of gathering lines, roads, tracks and well pads. Potential impacts may include: land disturbance and associated erosion and sedimentation; disturbance of watercourses at crossings; and changes to surface flows if there is above ground disturbance. As specific details of the location of these activities are not yet available, it is not possible to provide further assessment beyond that provided in the EIS.

A range of potential impacts have been identified for the following known sites and activities:

- CGPF2 property (construction of infrastructure and discharge of treated and untreated coal seam gas water);
- CGPF9 property (construction of infrastructure and discharge of treated and untreated coal seam gas water);
- CGPF7 property (construction of infrastructure);
- CGPF8 property (construction of infrastructure); and
- TWAF F property (construction of infrastructure).

Potential impacts include: changes to hydrology (direction and discharge points of surface flow paths); flood inundation; and changes to geomorphic character, behaviour and condition of waterways.

Potential impacts to surface water from subsidence have also been considered including flood levels and geomorphic impacts on low resilience waterways.

E5 Cumulative Impact Assessment

Geomorphic and hydrologic impacts are only two aspects of broader potential environmental impacts and as such have been considered within the context of a preliminary environmental flows assessment and strategy (provided as a separate report (Alluvium 2013)). Cumulative impacts due to all other planned developments also need to be considered within an environmental flows assessment, however, details of release regimes from other projects were not available at the time of preparing this report and therefore could not be considered as part of this assessment. It is expected that a further detailed assessment will be required with an Environmental Authority application that will include an assessment of the cumulative impacts of water discharges from other projects.

E6 Proposed Avoidance, Mitigation and Management

Mitigation and management measures for project activities with unconfirmed locations, including gathering lines, roads, tracks (and watercourse crossings) and well pads are provided in Section 6 of the EIS surface water technical report (Alluvium 2011) and are not repeated in the SREIS.

A range of site specific mitigation and management measures are recommended for each survey area. Common recommendations for all sites are:

- All major project infrastructure should be constructed above the 1% AEP flood levels as identified by the modelling detailed in this report.
- Avoid the concentration of overland flows discharging to watercourses where such flows could initiate erosion. Where this is not practical site specific erosion control measures should be developed which may include such options as: rock protected batter drains, energy dissipation structures; vegetated drainage lines and swales.

Site specific recommendations are provided for CGPF2 and CGPF9 properties, where treated and untreated coal seam gas water will potentially be discharged. Stable points for discharges have been identified and site specific erosion control measures may need to be developed at downstream locations where existing instabilities could be exacerbated.

E7 Conclusions

It has been determined that all potential adverse geomorphic impacts can be managed through the application of the management recommendations detailed in Section 7 and site specific management actions should be developed as part of detailed infrastructure design and planning.

The discharge of treated or untreated coal seam gas water will result in changed flow regimes at two locations: Bottle Tree Creek / Dogwood Creek; and in the Condamine River. Whilst it has been determined that this can be achieved within a range of flows without causing significant geomorphic impacts, a more in-depth preliminary environmental flows assessment further considers ecological impacts (provided as a separate report (Alluvium 2013)).

Flood modelling for the 1% AEP flood has been undertaken and flood extents have been mapped for all of the four known properties to locate central gas processing facilities (CGPF2, 7, 8, and 9 properties) and one site to locate a TWAF (TWAF F property). At each property there is sufficient land available above the mapped flood extents to locate project infrastructure, meaning sites can be selected so that there will be little impact from infrastructure on overland flow and flooding regimes if buildings are sited above the 1% AEP flood level. Where this is not practical, flood modelling can be used to determine any potential impacts and assist with designing alternatives layouts or mitigation measures to ensure that there are no adverse offsite impacts.

At the CGPF8 property, assessment is required at the detailed design stage of project infrastructure of any potential impacts to changed hydrology offsite that could reduce flows to Lake Broadwater. This may require the development of measures that prevent any potentially adverse impacts.

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Abbreviations

ACARP	Australian Coal Association Research Program
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
Alluvium	Alluvium Consulting Australia
ARI	Average Recurrence Interval
Arrow	Arrow Energy Pty Ltd
BoM	Bureau of Meteorology
CL	Continuing Loss
Coffey Environments	Coffey Environments Pty Ltd
CGPF	Central Gas Processing Facility
cumec	A measure of flow rate: Cubic metre per second, also can be written as m^3/s
DA	Discharge Area
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EHP	Department of Environment and Heritage Protection
EIS	Environmental Impact Statement
ESCP	Erosion and Sediment Control Plan
FFA	Flood Frequency Analysis
GEV method	Generalised Extreme Value distribution, a FFA method available in Flike
HEC-RAS	Hydraulic modelling software package
IL	Initial Loss
InSAR	Interferometric Synthetic Aperture Radar
JP2	JPEG 2000 imagery (an image compression standard and coding system)
k value	For RORB, empirical coefficient applicable to catchment
k_{en}	Entrance Loss Coefficient
LiDAR	Light Detection And Ranging
LH moment method	Generalisation of the L moment distribution, another FFA method available in Flike
ML/d	Megalitres per day
MODIS	Moderate Resolution Imaging Spectroradiometer
m value	For RORB, dimensionless exponent used in reach storage-discharge calculations
m/s	A measure of velocity: metres per second
m^3/s	A measure of flow rate: cubic metres per second (also written as cumecs)
m^3	A measure of volume: cubic metres
N/m^2	A measure of shear stress: Newtons per metres squared (metres squared = area)
$N/m\cdot s$	A measure of stream power: Newtons per metre per second
NRM	Department of Natural Resources and Mines
Origin	Australia Pacific LNG
QGC	Queensland Gas Company
RORB	Hydrological modelling software package
SEWPaC	Sustainability, Environment, Water, Population and Communities
SRTM	Shuttle Relay Topography Mission
SWMM	The 1D component of XPSWMM
TUFLOW	1D/2D Hydrodynamic modelling software package
TWAF	Temporary Workers Accommodation Facility
XPSWMM	1D/2D Hydrodynamic modelling software package

Glossary

aggradation	Filling and raising the bed of a stream by deposition of sediment.
alluvium	Material deposited by rivers.
anastomosing	Multiple channels that divide and reconnect.
avulsion	The sudden change in the course of a river, abandoning its former course by cutting a new channel.
chainage	A unit of measurement (in metres) to indicate the length along a centreline of a watercourse (nominally downstream is chainage zero in hydraulic analyses)
clasts	Rock fragments or grains resulting from the breakdown of larger rocks.
colluvium	Material deposited at the base of hillslopes by either rainwash, sheetwash, slow continuous downslope creep, or a variable combination of these processes.
conglomerate	A conglomerate is a rock consisting of individual clasts within a finer-grained matrix that have become cemented together.
fluvial geomorphology	The science that describes explains and predicts the shape and form of waterways.
hydraulic	The branch of science concerned with the conveyance of liquids through pipes and channels.
hydrograph	A graph showing changes in the discharge of a river over a period of time.
hydrology	The scientific study of the properties, distribution, and effects of water on the earth's surface.
pluviograph	An instrument for measuring the amount of water that has fallen (i.e. rain gauge), with a feature to register the data in real time to demonstrate rainfall over a short period of time.
sediment	Solid fragmented material, such as silt, sand and gravel, that is transported and deposited by water.
topography	The three-dimensional arrangement of a land surface.

1 Introduction

Arrow Energy Pty Ltd (Arrow) is required to prepare a supplementary report to the Environmental Impact Statement (SREIS) to present information on updates to the project description, address issues identified in the Environmental Impact Statement (EIS) as requiring further consideration and/or information, and to respond to comments raised in submissions on the EIS.

This report by Alluvium Consulting Australia (Alluvium) for Coffey Environments Pty Ltd (Coffey Environments) addresses requirements in regard to the geomorphology and hydrology aspects of surface water and is one of four reports covering aspects of surface water. These are as follows:

- Alluvium (2013). *Surat Gas Project – Supplementary Report to the Environmental Impact Statement: Supplementary Surface Water Assessment Part A – Geomorphology and Hydrology.* Alluvium Consulting Australia for Coffey Environments.
- NRA (2013). *Surat Gas Project – Supplementary Report to the Environmental Impact Statement: Supplementary Surface Water Assessment Part B – Water Quality*. NRA & Alluvium Consulting Australia for Coffey Environments.
- Alluvium (2013). *Surat Gas Project – Supplementary Report to the Environmental Impact Statement: Supplementary Surface Water Assessment Part C – Preliminary Environmental Flows Assessment.* Alluvium Consulting Australia for Coffey Environments.
- AMEC (2013) *Surat Gas Project – Supplementary Report to the Environmental Impact Statement: Supplementary Aquatic Ecology Assessment*. AMEC for Coffey Environments.

1.1 Overview of work completed to date

The EIS surface water impact assessment comprised a desktop study and field surveys to characterise the existing environment and was examined in two parts. The first part considered fluvial geomorphology and hydrology (Alluvium 2011) and the second part considered water quality (NRA 2011). The desktop assessment and subsequent targeted field investigations identified environmental values associated with wetlands, rivers and other water bodies in the study area to inform the assessment of impacts and the development of mitigation measures.

Environmental values were defined in accordance with the *Environmental Protection (Water) Policy* 2009 (EPP Water) and considered the following characteristics of surface water features within the project development area:

- Physical integrity.
- Fluvial processes, form and morphology.
- Hydrology.
- Spiritual and cultural values.
- Water quality and associated uses (for example, domestic, consumptive and productive, industrial and agricultural uses).

The desktop study component of the surface water impact assessment considered a conceptual layout of project infrastructure (including facilities, wells, access tracks and gathering lines) across the entire project development area to determine the magnitude of potential impacts on the environmental values identified. The desktop assessment also included a review of historical flood information, including extent, levels and frequency, undertaken for major waterways within the project development area using information available from the Bureau of Meteorology.

The field component of the surface water assessment involved an assessment of watercourse geomorphology and hydrology and a baseline surface water quality assessment. A total of 112 sites were visited to categorise geomorphology, hydrology of watercourses, and stream-order classification, during October and December 2009.

The assessment considered the impacts of project infrastructure on regional processes such as floods and a range of watercourse geomorphic categories and flow regimes. Site specific assessments were not possible because final infrastructure locations were not known. While site-specific impacts from project infrastructure on surface water values could not be determined, the EIS described the regional surface water system, and determined that through the implementation of standard mitigation measures, the potential impacts could be managed.

The following section describes changes to the project description since the EIS and identifies project components that could potentially have impacts upon the geomorphology and hydrology aspects of surface water.

2 Project Description Update

A summary of the differences in the project description between the EIS and the SREIS is provided below.

1.1 Project description update

The main updates to the project description as presented in the EIS, which have the potential to change or refine the EIS surface water impact assessment, include the identification of properties to locate central gas processing facilities (CGPFs), water treatment facilities and temporary workers accommodation facilities (TWAFs) and the possible discharge of treated or untreated coal seam gas water to watercourses under normal operations rather than only under emergency situations as stated in the EIS.

The EIS presented the sequence of the project's development in terms of 5 development regions. The SREIS now describes the development sequence in terms of 11 drainage areas. Each drainage area contains wells, a water and gas gathering network and a CGPF. They are identified by sequential numbering and correspond with the gas reserves that will be fed into the CGPF within each drainage area. This number of CGPFs has been reduced from 12 described in the EIS to 8. The number of water treatment facilities has been reduced from six described in the EIS to two. The water treatment facilities will be co-located with two of the CGPFs.

Arrow has identified four properties to locate the following CGPFs: CGPF2, CGPF7, CGPF8 and CGPF9. CGPFs are numbered according to which drainage area they will be located within. The northern water treatment facility, within drainage area (DA) 9, will be co-located with CGPF9 and the southern water treatment facility, within DA2, will be co-located with CGPF2. A fifth property has been identified by Arrow to locate a TWAF, TWAF F, and this property is located within DA9. For the purposes of this chapter, the properties are referred to as 'CGPF# property' or 'TWAF F property' (e.g., the property identified to locate CGPF2 is referred to as CGPF2 property). The exact locations of infrastructure within these properties have not been determined and the final positioning of infrastructure will be informed by detailed design which will include environmental constraints as well as technical constraints. Site-specific surface water assessments of geomorphology and hydrology, including flooding regimes were undertaken at the five properties.

The EIS stated that the modular water treatment capacity of water treatment facilities was 30 to 60 megalitres per day (ML/d). The northern water treatment facility, co-located with CGPF2, is planned to treat approximately 35 ML/d of coal seam gas water. The southern water treatment facility, co-located with the CGPF9, is expected to be rated at approximately 90 ML/d.

Coal seam gas water will be discharged from each water treatment facility to a nearby watercourse as required and within prescribed limits yet to be determined. Discharge to watercourses is a management option that provides water disposal security. This may not always be possible for other coal seam gas water management options given their variability (i.e. distribution to existing and new water users for beneficial use and injection to a suitable aquifer). The identification of properties for the location of water treatment facilities enabled site-specific assessments of the watercourses potentially affected by discharge of coal seam gas water.

Figure 2-1 shows the location of the properties identified to locate project facilities.

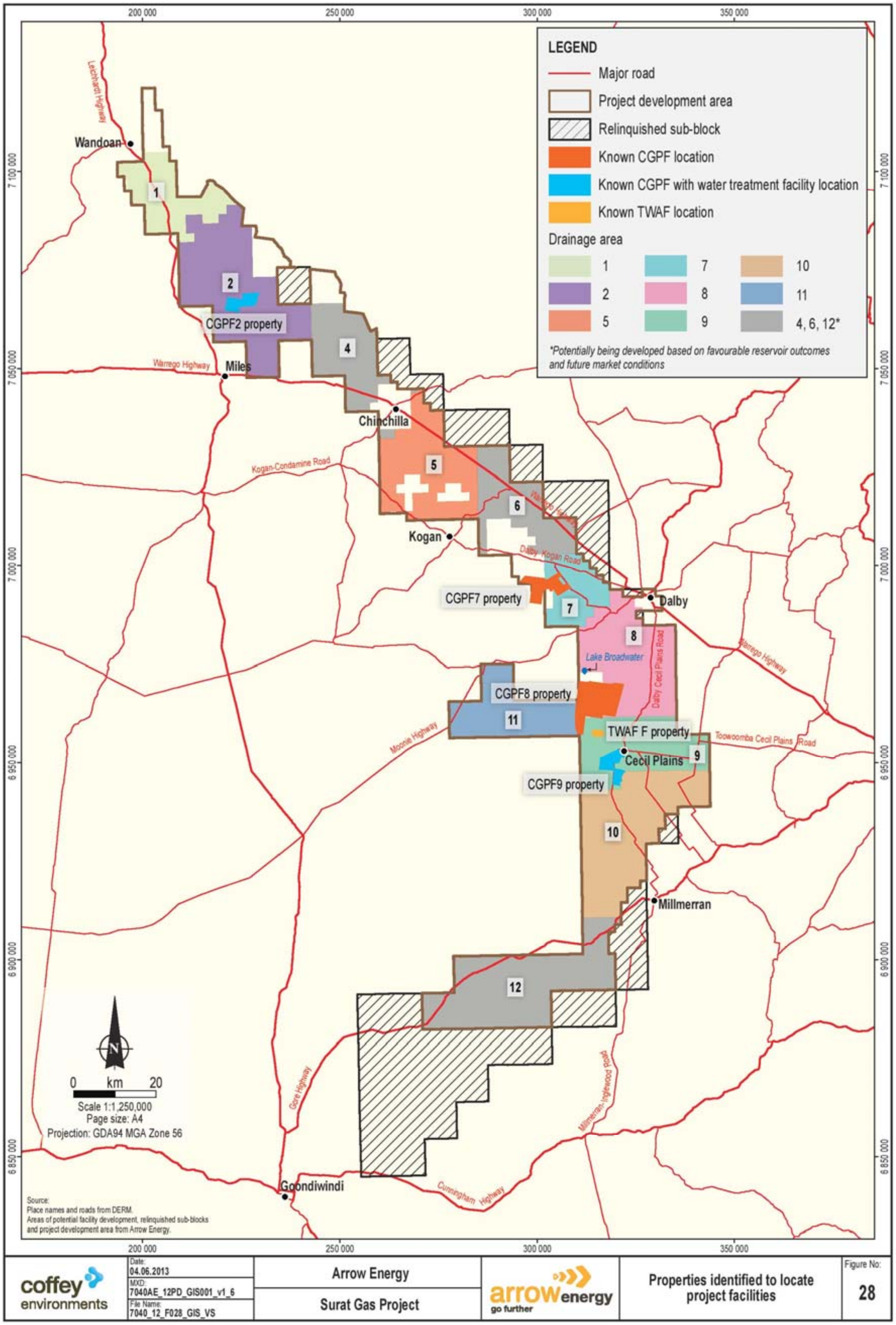

Figure 2-1. *Properties identified to locate project facilities* (figure by Coffey Environments)

3 Legislative Context

This section discusses changes to the administration of legislation and policies that have occurred since the EIS in 2011. It also includes reference to additional plans and policies not previously referenced in the EIS that are relevant to the assessment of geomorphology and hydrology of surface water.

3.1 Queensland Government departments

Following the election of the Queensland Government on 30 March 2012, the functions of the former Department of Environment and Resources Management (DERM) are now being delivered by the following departments:

- Department of Environment and Heritage Protection (DEHP).
- Department of Natural Resources and Mines (DNRM).
- Department of National Parks, Recreation, Sport and Racing (DNPRSR).
- Department of Energy and Water Supply (DEWS).

The fisheries responsibilities of the former Department Employment, Economic Development and Innovation (DEEDI) are now the responsibility of the Department of Agriculture, Fisheries and Forestry (DAFF).

Since the EIS the following changes of departmental responsibility have been made.

Table 3-1. Changes in departmental responsibility for required approvals relevant to surface water

Approval Source	Former Responsible Authority	Current Responsible Authority	Relevant Aspect of Project
Environmental Protection Act 1994 (Qld) (Schedule 5). Environmental authority (section s 426, and Schedule 5 Regulation).	DERM (formerly EPA).	DEHP	An environmental authority is required to carry out an environmentally relevant activity which includes petroleum activities. The environmental authority will also authorise other environmentally relevant activities to be carried out in the area of a petroleum authority granted under the *Petroleum and Gas (Production and Supply) Act, 2004* (PAG Act). If any environmentally relevant activities are undertaken on areas other than those subject to a petroleum authority, then a development approval under the SP Act may be required.
Sustainable Planning Act 2009 (Qld)	Department of Infrastructure and Planning	Unchanged	The new planning and development laws came into effect on 18 December 2009 with the *Sustainable Planning Act 2009 (Qld)* replacing the *Integrated Planning Act 1997 (Qld)*. The Project will require an approval under the SP Act for building works that are assessable under the Building Act 1975 (Qld) unless the works are within the petroleum tenure and categorised as incidental activities under the Petroleum and Gas (Production and Safety) Act. The Project may also require, depending on final

Approval Source	Former Responsible Authority	Current Responsible Authority	Relevant Aspect of Project
			project design and construction responsibilities, plumbing and drainage works approvals if the works are not authorised under the PAG Act or are located outside of the petroleum tenure. If operational works are required for waterway barrier works a development approval may be required.
Water Act 2000 (Qld), Sustainable Planning Act 2009 (Qld). Development permit for operational work (Schedule 8, Part 1, Table 4, Item 3(a) and Table 5, Item 3(c)(i).	DERM	DNRM	A development permit may be required to: • take or interfere with water from a water course; or • take or interfere with artesian water; or • take or interfere with overland flow water or sub artesian water.
Water Act 2000 (Qld), Sustainable Planning Act 2009 (Qld). Riverine protection permit (section s 266(1)).	DERM	DNRM	A riverine protection permit is required to do any or all of the following activities in a watercourse, lake or spring: • destroy vegetation; • excavate; and • place fill.
Water Act 2000 (Qld). Allocation notice for quarry material (section s 815)	DERM	DNRM	Quarry material includes stone, gravel, sand, rock, clay, earth and soil, unless it is removed from a watercourse as waste material. The need to obtain an allocation notice will only arise where there is an intention to re-use the material that is taken from a watercourse for another purpose (e.g. building up foundations). This will occur during certain project activities.
Water Supply (Safety and Reliability) Act 2008. *Sustainable Planning Act 2009 (Qld)*. Development permit for removing quarry material from a watercourse.	DERM	DEWS	The requirement to obtain the development permit will arise where there is an intention to re-use the material that is taken from a watercourse for another purpose (e.g. building up foundations). This will occur during certain project activities.
Water Supply (Safety and Reliability) Act 2008. *Sustainable Planning Act 2009 (Qld)*. Development permit for operational work being the construction of a referrable dam as defined under the *Water Supply (Safety and Reliability) Act 2008*.	DERM	DEWS	A development permit for operational work is required for the construction of a referrable dam as defined under the *Water Supply (Safety and Reliability) Act 2008*. This only applies to dams of a certain size and does not include dams that contain hazardous waste.
Fish Habitat Management Operational Policy FHMOP 008 (revised	DEEDI	DAFF	The construction or raising of a waterway barrier may require approvals under: • Fisheries Act 1994

Approval Source	Former Responsible Authority	Current Responsible Authority	Relevant Aspect of Project
September 2009).			• Water Act 2000 • Land Act 1994 A barrier may include any waterway crossing including tracks/roads that include culverts and or raised causeways.

3.2 Legislation, policies and plans

Coal seam gas Water Management Policy 2012
The main relevant change since the EIS in 2011 has been the introduction of the Coal Seam Gas Water Management Policy 2012, which replaces the Coal Seam Gas Water Management Policy 2010.

The Coal Seam Gas Water Management Policy 2012 policy deals with the management and use of coal seam gas water under the EP Act, and does not vary the requirements of the Water Act, such as a coal seam gas operator's 'make good' obligations. This policy encourages coal seam gas operators to consider the feasibility of using coal seam gas water to meet these obligations as part of developing their coal seam gas water management strategies and plans.

The objective of the policy is to encourage the beneficial use of coal seam gas water in a way that protects the environment and maximises its productive use of a valuable resource.

Coal seam gas water and saline waste is to be managed consistently with the prioritisation hierarchies described below:

Prioritisation hierarchy for managing coal seam gas water:
Priority 1 – Coal seam gas water is used for a purpose that is beneficial to one or more of the following: the environment, existing or new water users, and existing or new water-dependent industries.

Priority 2 – After feasible beneficial use options have been considered, treating and disposing coal seam gas water in a way that firstly avoids, and then minimises and mitigates, impacts on environmental values.

Prioritisation hierarchy for managing saline waste:
Priority 1 – Brine or salt residues are treated to create useable products wherever feasible.

Priority 2 – After assessing the feasibility of treating the brine or solid salt residues to create useable and saleable products, disposing of the brine and salt residues in accordance with strict standards that protect the environment.

The policy outlines management considerations for a range of water management options. It then provides an overview of the management considerations the government expects coal seam gas operators and the administering authority for the EP Act, to have taken into account when determining the coal seam gas water management and use options that best achieve the objective of this policy.

Arrow proposes to utilise treated or untreated coal seam gas water for the following purposes:

- Distribution to existing and new users for beneficial use.
- Injection into aquifers.
- Maintenance injection into aquifers.
- Discharge into watercourses at two sites: Survey area 9 (primary release point) and survey area 2 (secondary release point).

These proposed water uses align with the Coal Seam Gas Water Management Policy (2012).

Specific details on coal seam gas water and salt management will be provided in a separate management plan to be prepared by Arrow.

The *Environmental Protection (Greentape Reduction) and Other Legislation Amendment Act 2012* (the Greentape Reduction Act) was passed by parliament on 31 July 2012. It will amend the *Environmental Protection Act 1994* and takes effect on 31 March 2013.

The Greentape Reduction Act introduces an integrated approval process for environmentally relevant activities, which will allow for requirements to be proportional to the environmental risk of the activity. The main relevant change is expected to be the introduction of an integrated and modular approval process for all environmental authorities, which includes resource activities and prescribed environmentally relevant activities.

There are also a range of regional natural resource management (NRM) plans and policies that may have direct relevance to the project activities.

- ***Murray Darling Basin Authority – Water Act 2007 - Basin Plan (November 2012)***

The Basin Plan provides a coordinated approach to water use across the Basin's four States and the ACT. The Basin Plan was developed under the Water Act 2007. Relevant aspects that may need to be considered in relation to the project include Chapter 8 – Environmental watering plan; Chapter 9 – Water quality and salinity management plan.

- ***Queensland Murray Darling Committee (QMDC) policy and planning***

In 2004 QMDC developed its Regional NRM Plan. The Land and Soils, Riverine, Floodplains and Wetlands, and Vegetation and Biodiversity sections of this Plan were revised in 2006 and the Weeds and Pests section, and the Aboriginal and Cultural Heritage component, were also reviewed, in 2008-09. The Regional NRM Plan sets out the priorities, targets and milestones for NRM in the region.

Also of relevance is the Queensland Murray Darling Committee Policy Document: Mining and energy industry impacts on natural resources in the Queensland Murray-Darling Basin (2011). The policy's purpose is to: "address the impacts of the mining and energy industry on the Queensland Murray-Darling Basin's natural resources; and provide a framework for best practice and policy decision-making, risk management and responses to the specific and cumulative impacts of the mining and energy industry on the Queensland Murray-Darling Basin's natural resources" (Todd, L, Fletcher, K, and Penton, G. (2011)).

Condamine Alliance

The Condamine Alliance and its associated partners have developed the following relevant policies and plans that require consideration.

- ***Water Quality and Salinity Management Plan***

At the time of preparing this report, the Condamine Alliance was in the process of preparing a Water Quality and Salinity Management Plan (http://www.condaminealliance.com.au/water). This will need to be reviewed upon completion and relevant actions and targets considered.

- ***Condamine Catchment Natural Resource Management Plan (2010)***

There are a range of relevant Water Targets and related actions identified in the Condamine Catchment Natural Resource Management Plan (Condamine Alliance (2010a)). Relevant Targets include water use, water quality and monitoring, evaluation and reporting, all cognisant of economic social and ecosystem needs.

- ***CSG & Mining Policy***

The Condamine Alliance (Condamine Alliance (2010b)) recognises that Proposed coal mining and gas extraction developments in the Condamine catchment have the potential to make significant contributions to the state and regional economies but that there could be adverse impacts on natural resources which requires all development decisions to “give due weight to the scientific evidence and targets that have been set by the community, key government scientists, local government, industry and environmental groups as reflected in the Condamine Catchment Natural Resource Management Plan”.

- ***Floodplain management plans***

Land degradation, water quality and coordination of water flow have been recognised as significant natural resource management issues for the floodplains in the region and identified as priority community issues for many years. Dating back to 1998, the Upper Condamine Floodplain Management Project – Floodplain Strategy & Strategic Plan identified “uncoordinated runoff along with inappropriately sited development infrastructure has led to unnatural flow concentrations and extensive land degradation”. The risks associated with changes to flow paths and concentrations of overland flow are still a community priority in the upper Condamine area including the Brigalow-Jimbour Floodplains Group area. The “Report of the Upper Condamine Floodplain Management Project” (McLatchey, J. and Knowles-Jackson, C. 2002), also reinforces that “[o]ver-coming the issues resulting from infrastructure and the preservation of the natural flow patterns have been principal objectives of the Upper Condamine Floodplain Project” and that “[o]verland flow is of greater importance than river flooding in terms of impact on the open floodplains of the Upper Condamine Catchment”.

Potential impacts from the project on overland flows need to be appropriately considered and managed.

4 Method

This section describes the methods that have been applied to the assessment of potential impacts from the changed project components as described in Section 2 and from submissions made on the EIS. Methods are described for the assessment of:

1. Environmental values
2. Geomorphology
3. Hydrology
4. Subsidence impacts on surface water
5. Cumulative impacts

4.1 Environmental values

With consideration for the fact that the project development area extends across the Balonne, Condamine, Macintyre Brook, Macintyre and Weir Rivers, Moonie and Dawson River sub-basins (also known as catchments), the environmental values presented in the EIS were reviewed as follows:

- Values are now included as detailed and relevant to the Fitzroy Basin specified in Schedule 1 of *Environmental Protection (Water) Policy* 2009 (EPP Water) in September 2011 and the *Water Resource (Fitzroy) Plan* 2011. The Dawson River sub-basin forms part of the Fitzroy basin.
- The EPP Water does not nominate specific environmental values or water quality objectives for the Condamine-Macintyre and Maranoa-Balonne-Border Rivers.
- Environmental values with regard to geomorphology and hydrology are have been revised from the EIS to include the option of releasing treated or untreated coal seam gas water.

Updated environmental values are presented in this report in Section 5.1.

4.2 Geomorphology

The intent of the geomorphic study through desktop and field assessment was to:

1. Assess watercourses that are part of the receiving environment of the CGPF2 and CGPF9 properties and the sensitivity of the watercourses to change following potential discharge of treated or untreated coal seam gas water, and the placement of infrastructure. These watercourses (Bottle Tree Creek at the CGPF2 property and the Condamine River at the CGPF9 property) were assessed within the properties in February 2013. The downstream reaches (approximately 21km downstream from the CGPF2 property (Bottle Tree Creek and Dogwood Creek) and 14km of the Condamine River downstream from the CGPF9 property) were assessed in March 2013.
2. Assess watercourses running through the CGPF7, CGPF8 and TWAF F properties and their sensitivity to change during and following the placement of infrastructure.

3. Identify any wetlands as mapped in the Queensland Wetlands Programme (Version 3) that could be affected by project activities at the CGPF2, 7, 8 and 9 properties and the TWAF F property. There was a particular emphasis on locations where coal seam gas water may be discharged at the CGPF 2 and 9 properties with regard to their sensitivity to geomorphic or hydrologic change.

Desktop assessment

The geomorphic assessment prepared for the EIS was used as the basis for the SREIS. However, the watercourses that will potentially be affected by the updated project activities (as described in Section 2) were assessed in greater detail in the SREIS, coupled with the knowledge of the location of specific proposed infrastructure within the properties. The desktop study was undertaken using the following data provided by Arrow:

- Aerial imagery for the whole project area provided by Arrow (flown 2012 at a resolution of 0.3 m); and
- LiDAR derived contour data for the whole project area.

The aerial imagery was of a higher resolution than that available for the EIS and was used to confirm or modify the geomorphic categories mapped in the EIS and to pinpoint any potential areas of instability, which would require closer ground inspection.

Wetland characterisation

Wetlands need to be considered when planning facility locations. The data used to identify wetlands in the project development area is from the Queensland Wetlands Programme (version 3 – 2012), which has been updated since the EIS. The following wetland classifications are identified as occurring in the Surat Gas Project development area:

- **Riverine wetlands** describe all wetlands and deepwater habitats within a channel. The channels are naturally or artificially created; they periodically or continuously contain moving water, or form a connecting link between two bodies of standing water.
- **Lacustrine wetlands** are large, open, water-dominated systems (for example, lakes) larger than 8 hectares. This definition also applies to modified systems (for example, dams), which possess characteristics similar to lacustrine systems (for example, deep, standing or slow-moving waters).
- **Palustrine wetlands** are primarily vegetated non-channel environments of less than 8 hectares. They include billabongs, swamps, bogs, springs, soaks etc, and have more than 30 % emergent vegetation.
- **Artificial wetlands** which include such constructed features as dams, ring tanks and floodplain levees.

In addition to these wetland classifications, further information is provided including the degree to which these wetlands have been modified. The digital data layers are available to assist Arrow with planning. Wetland mapping is included in the results, Section 5.2.

Field assessment

All of the project activities being assessed in the SREIS will be occurring on Arrow owned properties, however field assessments were conducted on and off Arrow owned properties as impacts could potentially occur outside of Arrow owned properties with the greatest risk being downstream of the discharge points (in watercourses that are part of the receiving environment of the properties). To inform the geomorphic assessment, field inspections were undertaken as follows:

CGPF2 and CGPF9 properties – These properties are the locations for proposed surface water discharges of treated or untreated coal seam gas water and were therefore assessed in the greatest detail. Field assessments were undertaken for the main watercourses (Bottle Tree Creek in CGPF2 property and the Condamine River in the CGPF9 property) into which water discharges may occur. This was done from the upstream boundary of the properties to a downstream extent (outside properties) where access could be gained and downstream as far as a feature where geomorphic impacts are unlikely to occur from an increase in discharge. In most cases the downstream feature was a weir, or backpooling caused by a weir. These watercourses were then walked and assessed during two field trips in February and March 2013 by collecting data for the following parameters:

- Channel dimensions;
- Channel boundary material (bed, banks and floodplains);
- Geomorphic units;
- Riparian vegetation;
- Pre-existing instabilities and potential issues; and
- Overall stability under the current flow conditions.

These parameters were used to determine the resilience of the assessed watercourses and their potential response to changes in hydrological conditions. Tributary watercourses at the CGPF2 and CGPF9 properties and a mapped wetland at the CGPF2 property that may be disturbed by project activities were also assessed. The results of the assessment are presented in section 5.

CGPF7 and CGPF8 properties and TWAF F property – None of these properties are proposed to have surface water discharges of treated or untreated coal seam gas water. However, low levels of impact to these watercourses may occur through direct disturbance from construction of project infrastructure. These watercourses may also receive increased or decreased runoff from project infrastructure, which may cause geomorphic change. Following a desktop assessment, a high level field assessment was undertaken at representative locations to ground truth the desktop findings.

4.3 Hydrology

Since the EIS in 2011, a range of flood mapping for the project area has been collated and in particular the Queensland Reconstruction Authority flood mapping (http://qldreconstruction.org.au/). As input to this study, the available mapping was considered, however the Queensland Reconstruction Authority flood mapping is of a coarse scale, not suited to the site specific assessment required of the five properties in which infrastructure will be sited. Overland flow and flooding regimes that was conducted for the SREIS is described in detail below.

Overview

The assessment of hydrology comprised four main components:

1. Flood modelling (hydrologic and hydrodynamic modelling) to assess risks at the five properties which will contain proposed infrastructure (CGPF7, 8, 8 and 9 properties and TWAF F property)
2. Hydraulic analysis to determine the existing hydraulic parameters, which were then used to assess the impact of proposed water releases from the water treatment facility sites co-located with CGPF2 and CGPF9).
3. Development of stage discharge curves for the establishment of a gauging station on Bottle Tree Creek (which is currently ungauged) and on the Condamine River to enable continual monitoring of flows.
4. Collation and assessment of gauged daily flows at Gil Weir on Dogwood Creek (downstream from the CGPF2 property) and Cecil Weir on the Condamine River downstream of the CGPF9 property.

These four components were assessed by undertaking the following tasks:

1A: Hydrologic flood modelling

- Hydrologic modelling for two models: Dogwood Creek and Condamine River;
- Calibration of the two hydrologic models; and
- Flood frequency analysis.

The hydrologic modelling was undertaken as input to the hydrodynamic modelling.

1B: Hydrodynamic flood modelling

- 2D hydrodynamic model set-up;
- Consideration of hydraulic structures; and
- Mapping of flood extents and depths for the 1% AEP event.

1C: Comparison of Condamine River hydrodynamic model results and recorded satellite imagery of the December 2010 flood event.

2: Hydraulic analysis

A hydraulic analysis was undertaken for Bottle Tree Creek and the Condamine River in the area where water may be discharged from the water treatment facilities the CGPF2 and CGPF9 properties. This was undertaken to determine the existing hydraulic parameters, which were then used to assess the impact of proposed water releases from the water treatment facilities at the CGPF2 and CGPF9 properties through hydraulic modelling.

3: Development of stage discharge curves for the recommendation of establishment of potential gauging stations on Bottle Tree Creek and Condamine River.

- Identification of a potential suitable location for a gauging station; and
- Use of hydraulic modelling.

4: Gauged daily flows at Gil Weir on Dogwood Creek (downstream from the CGPF2 property) and Cecil Weir on the Condamine River below the CGPF9 property were assessed to determine the average number of low flow days per month from the available historical data.

Further details of the methods applied to these tasks are provided in the following sections.

Definitions of AEP and ARI

Throughout this report the acronyms AEP and ARI refer to the following:

AEP	Annual Exceedance Probability. The probability that a given rainfall total accumulated or peak flow rate for a given duration will be exceeded in any one year. According to Bureau of Meteorology guidelines (refer to http://www.bom.gov.au/water/designRainfalls/ifd/glossary.shtml) AEP has been used throughout this report in preference to ARI. See Table 4-1 for conversion to ARI.
ARI	Average Recurrence Interval. The average, or expected, value of the periods between exceedances of a given rainfall total accumulated or peak flow rate for a given duration. See Table 4-1 below for conversion to AEP. ARI has been used throughout the hydraulic analysis sections as the Australian Coal Association Research Program (ACARP) criteria used ARI.

Table 4-1. ARI to AEP conversion table

ARI (years)	AEP	AEP expressed as percentage (%)
1	0.632	63
2	0.393	39
5	0.181	18
10	0.095	10
20	0.049	5
50	0.020	2
75	0.013	1.3
100	0.010	1

Hydrologic modelling

Following a review of hydrologic data available for the Condamine catchment, two separate hydrologic models were developed for the study, refer to Figure 4-1. Details of these two catchment models, as delineated for the project, are as follows:

- Upstream of Dogwood Creek at Gil Weir gauging station 422202B (hereafter, "Dogwood Creek hydrologic model"). This catchment covers an area of approximately 3,000km^2 area (including the CGPF2 property).
- Upstream of Condamine River at Brigalow gauging station 422336A (hereafter, "Condamine River hydrologic model"). The catchment covers an area of approximately 18,000km^2 and includes the remaining four sites (including the CGPF2, 7, 8 and 9 properties and the TWAF F property).

The models were divided into subcatchments in order to provide inflow hydrographs for the 2D hydrodynamic flood models in all necessary locations.

Both catchment models were calibrated against values derived through Flood Frequency Analysis (FFA). Alluvium undertook FFA for streamflow gauges in the Condamine catchment and, in the case of the Dogwood Creek hydrologic model, Alluvium utilised the FFA undertaken by Water Technology (2011) for the Western Downs Regional Council Planning Scheme Review.

As per Arrow's commitment to "where practicable, site facilities above the 1 in 100 year average flood recurrence interval", flows were generated for the 1% AEP event (equal to the 1 in 100 year ARI event) and were based on existing conditions. Flows were later applied to the hydrodynamic model to determine the 1% AEP event flood envelope (see Section 4.4).

A review of appropriate streamflow and pluviograph data was also undertaken and assessed for relevance to the study which included: streamflow records; pluviograph records; and previous hydrologic studies. Results are presented in Section 5.3.

Modelling was undertaken to test the impact that climate change will have on future storm events in the area. The Queensland Government document, *Increasing Queensland's resilience to inland flooding in a changing climate: Final Report on the Inland Flood Study*, provides practical guidance for modelling the impact of climate change. The project life is 35 years, the shortest time frame addressed in the document is the year 2050, just beyond the project life.

Catchment set-up

This section outlines the process taken to delineate the hydrologic catchments for Dogwood Creek and the Condamine River, and the steps taken to incorporate the delineation into the runoff routing model RORB Version 6.14, 2010.

Catchment delineation

Catchment delineation and subdivision was undertaken using the CatchmentSIM software program, which delineates subcatchments from a Digital Terrain Model (DTM), calculates their properties and creates output files for a range of hydrologic modelling packages including RORB.

For the hydrologic modelling, 1 arcsecond NASA Shuttle Relay Topography Mission (SRTM) 30m DEM grid tiles acquired by Alluvium on January 2013 from Geosciences Australia were used for generating the DTM. This data also covers the remainder of the catchment not covered by LiDAR data.

The catchment delineation and subdivision took account of most known diversions and waterways within the project area. Following delineation of the subcatchments, both CatchmentSIM models were exported as RORB catchment files using the CatchmentSIM – RORB macro (6.0 version 3). The catchment files were then modified to specify the locations where hydrograph outputs were required.

Calibration of the two hydrologic models

Calibration was undertaken for the two models, Dogwood Creek hydrologic model and Condamine River hydrologic model.

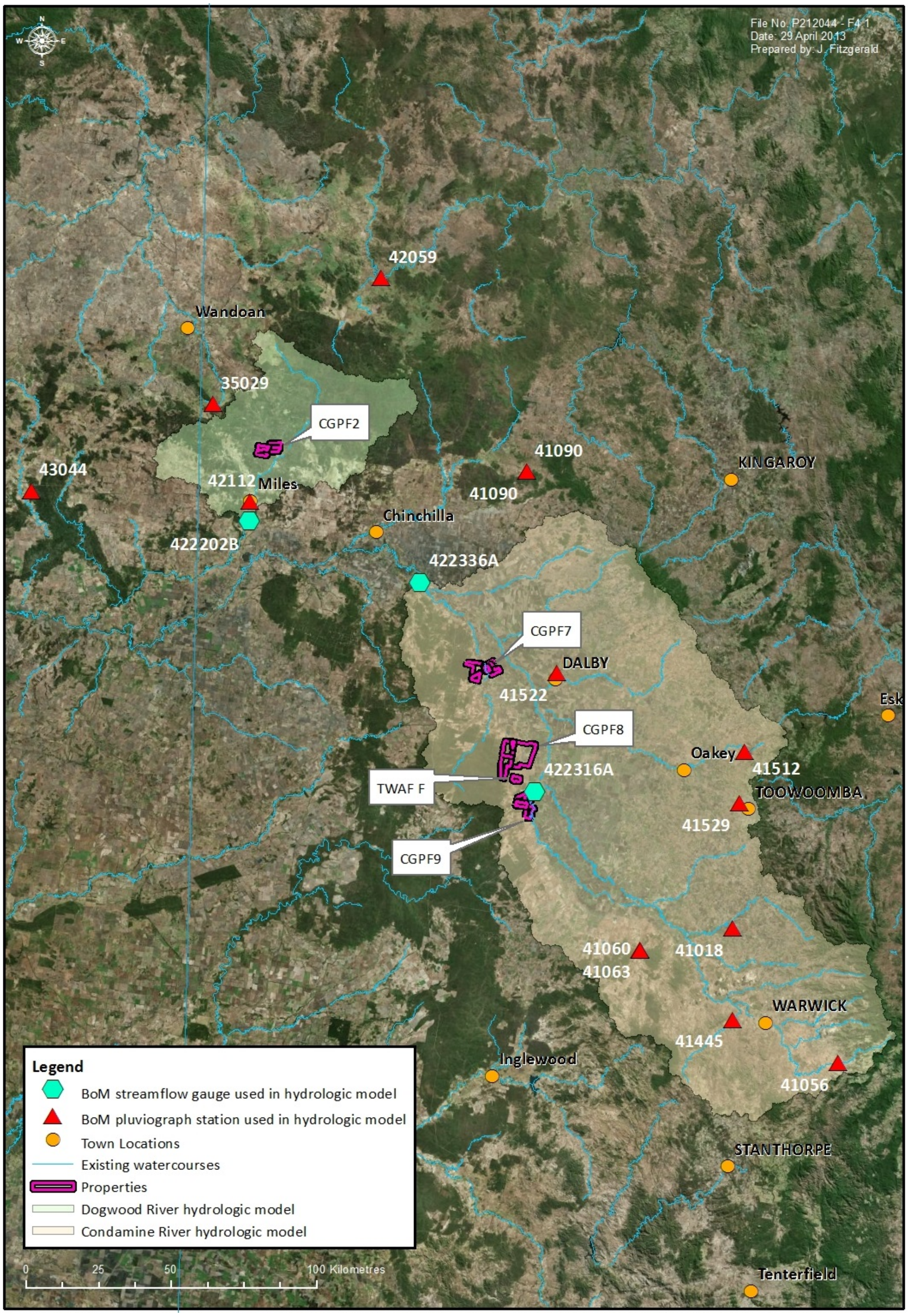

Figure 4-1. *Hydrological data stations surrounding the Dogwood Creek and Condamine River hydrologic models*

4.4 Hydrodynamic modelling

Dogwood Creek

Overview

Hydrodynamic modelling was undertaken for a reach of Dogwood Creek and Bottle Tree Creek to determine the 1% AEP event flood envelope through the CGPF2 property. This is referred to as the Dogwood Creek hydrodynamic modelling.

The topography was built exclusively from LiDAR survey data with design rainfall hydrology (as presented in Section 4.3) applied to the model to determine flood extents and depths in the area surrounding the proposed site. In order to model the overland flow through the site resulting from localised runoff, two direct rainfall models were developed to supplement the results from the riverine flood model.

Hydrodynamic model set-up

Flood modelling of Dogwood Creek was undertaken using the following three models:

- Dogwood Creek 2D hydrodynamic model including the reach of Bottle Tree Creek passing through the site.
- Dogwood East 2D direct rainfall model, covering the catchment of an unnamed tributary, to the east of Bottle Tree Creek .
- Dogwood West 2D direct rainfall model covering the Bottle Tree Creek catchment.

All three hydrodynamic models were built using XPSWMM, a hydrodynamic modelling software package, which couples together the SWMM 1D model and the 2D finite difference model TUFLOW.

The models outfall boundary conditions were sited at a sufficient distance downstream of the areas of interest to ensure that they did not have any impact on the water surface elevations through each property.

The Dogwood Creek 2D hydrodynamic model outfalls approximately 2.8 km downstream of the tributary with Bottle Tree Creek. The model is extended approximately 13.2 km upstream along Bottle Tree Creek (upstream of the CGPF2 property) and is approximately 2.5 km wide. See Figure 4-2.

The Dogwood East model covers the localised catchment for the tributary of Dogwood Creek passing through the east of the site approximately 3.5 km to the east of Bottle Tree Creek (see Figure 4-3). The model was built specifically to model the localised rainfall runoff in order to determine overland flow paths, which would not ordinarily be modelled using the traditional hydrologic approach. As the 1% AEP flood envelope for Dogwood Creek does not encroach on the eastern fringe of the site, the hydrology representing the creek flow has been fixed at the peak value. This is in order to present the peak flood extent from both riverine flooding and localised overland runoff using the one model.

The Dogwood West model focusses on the catchment contributing to Bottle Tree Creek at the CGPF2 property in order to determine the flood extent cause by localised rainfall runoff (see Figure 4-3).

The digital terrain model (DTM) used for all three models consists of LiDAR data supplied to Alluvium by Coffey Environments in late January 2013. The data used to generate the model and the source of the data is summarised in Table 4-2.

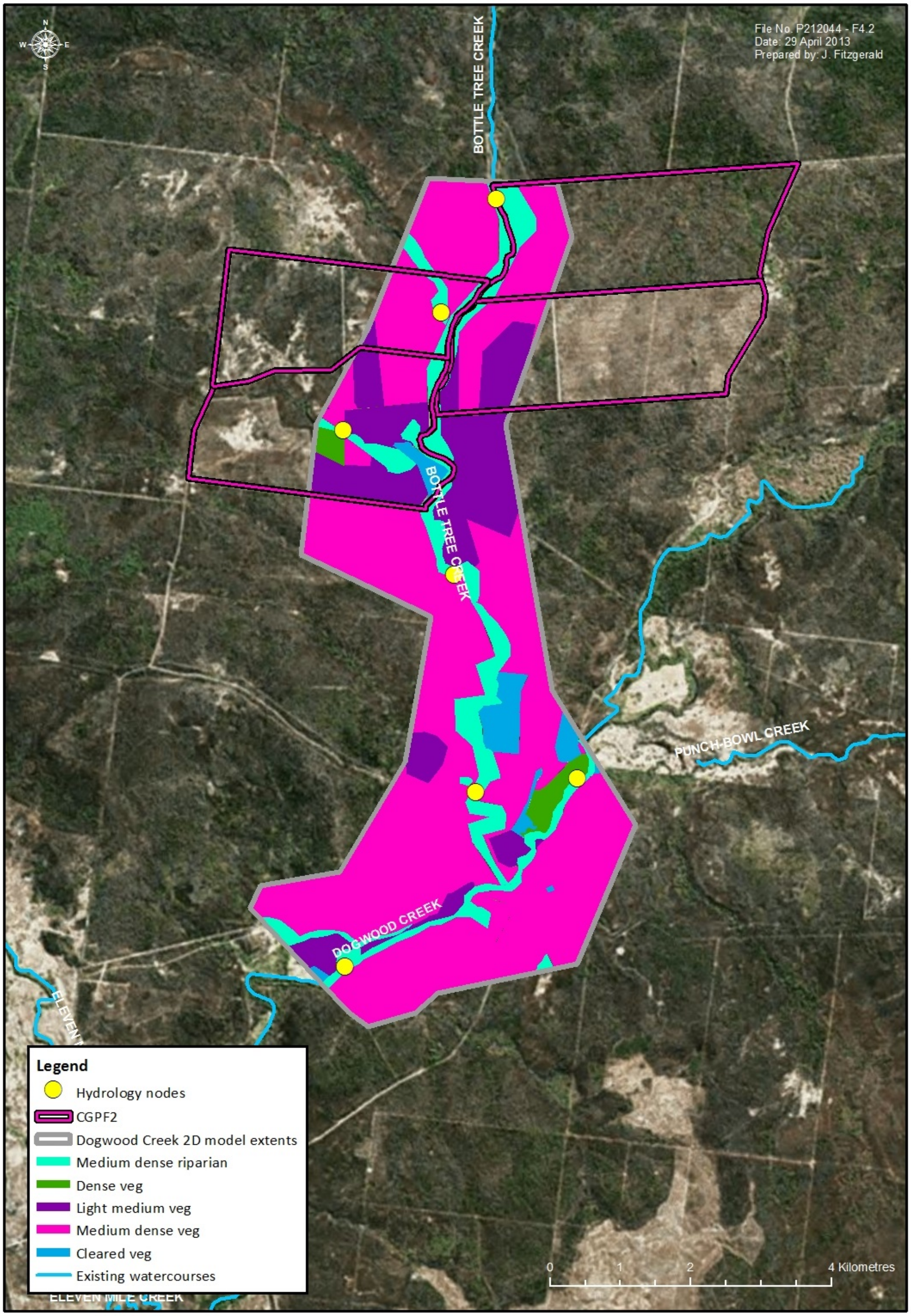

Figure 4-2. *XPSWMM Dogwood Creek 2D model set up*

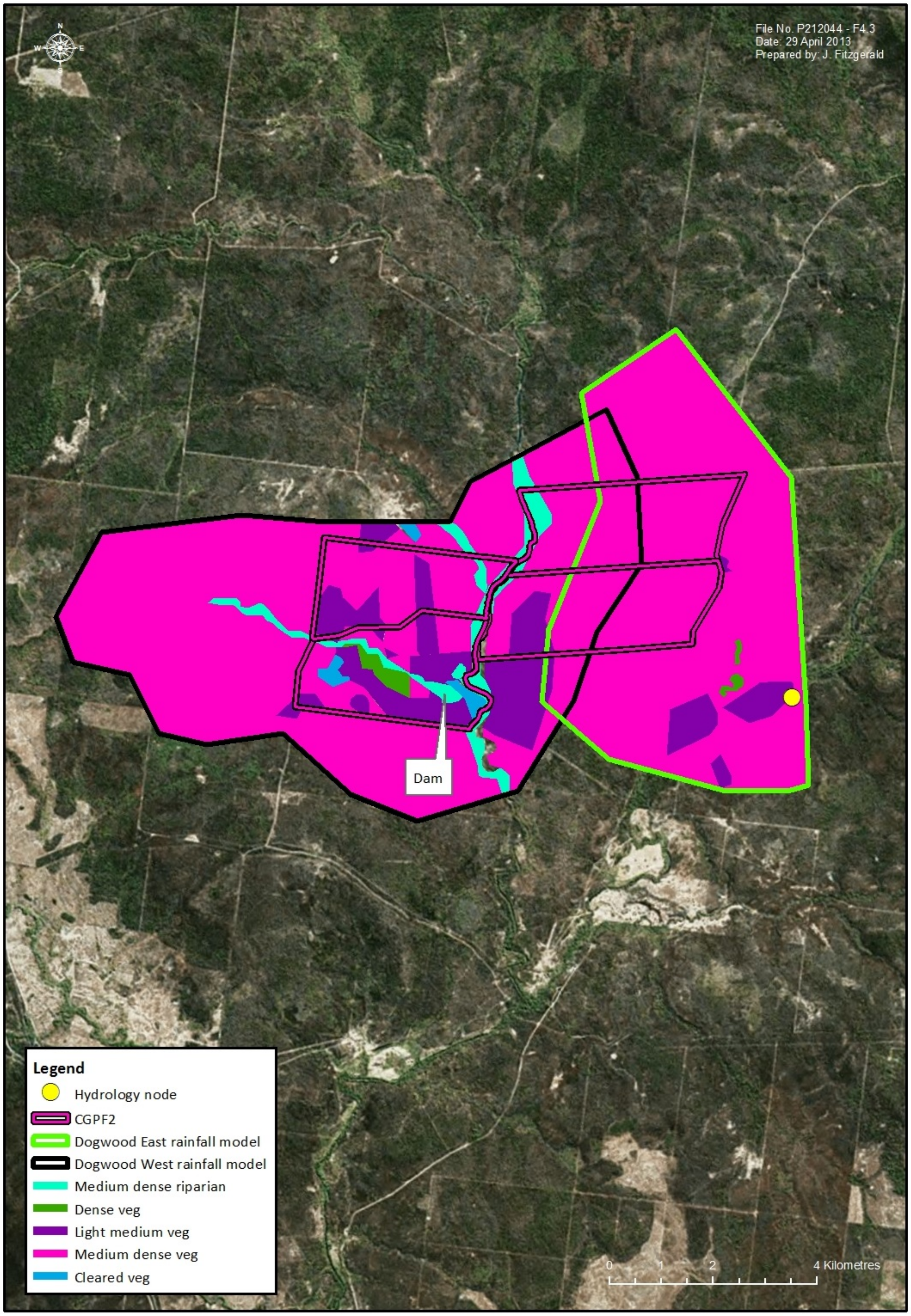

Figure 4-3. *XPSWMM Dogwood Creek East and Dogwood West direct rainfall models set up*

Table 4-2. Summary of data used in Dogwood Creek 2D model and Dogwood East direct rainfall model

Data	Provider	Comments
LiDAR DTM of proposed sites and surrounds	Coffey Environments	Provides full coverage of 2D model area. Supplied to Alluvium in January 2013.
Aerial of project sites and surrounds (JP2 format)	Coffey Environments	Provides full coverage. Supplied to Alluvium in January 2013.
Manning's delineation of site	Alluvium	Assessed from aerial image provided.
Catchment hydrology	Alluvium	Determined using RORB (see Attachment B) for riverine flooding and via the direct rainfall method for localised runoff flooding.

All three models were configured using a fixed cell size of 10m.

Manning's delineation of a site refers to how Manning's n coefficients were set for all models using polygons delineated from aerial imagery. Manning's coefficients are characterised by roughness; the higher the Manning's coefficient the greater the vegetation cover and the greater the roughness. The values adopted for the different polygons are presented in Table 4-3 with the delineation of the Manning's n polygons shown in Figure 4-2 and Figure 4-3.

Table 4-3. Manning's n roughness values adopted for Dogwood Creek XPSWMM models

Land use/Vegetation Type	Manning's n roughness coefficient
Medium dense riparian	0.055
Dense vegetation	0.080
Light medium vegetation	0.050
Medium dense vegetation	0.065
Cleared vegetation	0.025

As presented in Section 5.3, hydrologic inputs suitable for 2D modelling were developed for the 1% AEP event and applied to the hydrodynamic model in order to determine the 1% AEP event flood envelope.

Design hydrographs were used as inputs into the hydrodynamic models at the locations shown in Figure 4-2 and Figure 4-3 (as hydrology nodes) to represent inputs from both the catchments external to the area and runoff generated locally.

While the critical duration had been determined through hydrologic modelling, the hydrodynamic model was tested with this duration plus a number of storm durations either side of the hydrologic critical duration in order to determine that the duration yielded the greatest flood depth. The results are summarised in Table 4-4.

Table 4-4. Summary of critical durations for Dogwood Creek hydrodynamic modelling

Location	Critical duration
Bottle Tree Creek	18 hours
Dogwood Creek	24 hours
"Dogwood East" localised catchment	6 hours
"Dogwood West" localised catchment	2 hours

Hydraulic structures
Only one significant hydraulic structure exists within the model extent. One dam on the west side of Bottle Tree Creek, within CGPF2, was modelled as being full to maximise the flood envelope and assess its implications. The location of the dam is shown in Figure 4-3.

Minor structures including smaller culverts and bridges were not included in the model as they were not deemed large enough to impede flows.

Condamine River

2D hydrodynamic model set-up
Flood modelling of Condamine River was undertaken using the following seven models:

- Condamine River 2D hydrodynamic model, to inform the hydrology for the following three models:
    - CGPF7 property 2D hydrodynamic model
    - CGPF8 property 2D hydrodynamic model, and
    - CGPF9 property 2D hydrodynamic model.
- CGPF7 property East 2D direct rainfall model.
- CGPF7 property West 2D direct rainfall model.
- TWAF F property (also covering CGPF8 and 9 properties) 2D direct rainfall model.

All models were built using XPSWMM, a hydrodynamic modelling software package which couples together the SWMM 1D model and the 2D finite difference model TUFLOW.

The models have been extended far enough downstream along the relevant watercourses to eliminate the effect of backwater around the areas of interest and to have no impact on the water surface elevations.

The Condamine River 2D hydrodynamic model outfalls at approximately 3.5 km upstream of the Condamine at Brigalow streamflow gauge (422336A), approximately 33 km downstream of the CGPF7 property. The model extends approximately 22 km upstream of the CGPF 9 property and, in all, covers an area of approximately 2,500 km^2. Refer to Figure 4-4 for a depiction of the model setup.

The Condamine River 2D hydrodynamic model was configured using a 40 m fixed cell size and was built to develop an understanding of the broader Condamine catchment. The model was also developed to derive hydrology for the three finer resolution 15 m cell size models for the areas local to the CGPF7, 8 and 9 properties. See Figure 4-4 for a depiction of the model setup. Note that the model only covers the areas within the CGPF8 and 9 properties and the TWAF F property, which are vulnerable to flooding directly from the Condamine River. The flood risk to the balance of the sites has been addressed by the direct rainfall models, see below.

The three direct rainfall models were created using a 15 m cell size to focus on modelling the local rainfall catchment and the impact of rainfall runoff through each site. Figure 4-4 provides a depiction of the setup for all models.

The digital terrain model (DTM) used for all the hydrodynamic models consists primarily of the LiDAR data supplied to Alluvium by Coffey Environments in late January 2013. In addition to the LiDAR data, Geosciences Australia SRTM data was applied in two scenarios: 1) where there was no LiDAR data available, or 2) where there was little benefit in investing the substantial additional time required to process the LiDAR (eg. in areas far removed from the properties). While it would have been desirable to use LiDAR exclusively the SRTM data was used in areas that would not impact on the results at the survey areas. The data used to generate the model and the source of the data is summarised in Table 4-5.

Table 4-5. Summary of data used for all Condamine River hydrodynamic models

Data	Provider	Comments
LiDAR DTM of proposed sites and surrounds	Coffey Environments	Provides substantial coverage of 2D model area. Supplied to Alluvium in January 2013.
NASA SRTM 30m grid data (1 arcsecond)	Geosciences Australia	Provides full coverage of all areas of interest.
Aerial of project sites and surrounds (JP2 format)	Coffey Environments	Provides full coverage of project sites. Does not include some sections where hydrologic modelling was undertaken (outside sites). Acquisition date January 2013.
Aerial of project sites and surrounds (outside coverage of JP2 imagery)	Bing Maps	Provides full coverage of all areas of interest.
Manning's delineation of site	Alluvium	Assessed from aerial image provided.
Catchment hydrology	Alluvium	Determined using RORB for riverine flooding and via the direct rainfall method for localised runoff flooding.

Manning's n roughness coefficients for all models were set using polygons delineated from aerial imagery. Manning's n values adopted for the different polygons are presented in Table 4-6 with the delineation of the Manning's n polygons shown in Figure 4-4 and Figure 4-5.

Table 4-6. Manning's n roughness values adopted for Condamine River XPSWMM models

Land use/Vegetation Type	Roughness value
Structures	0.100
Water	0.020
Medium dense riparian	0.055
Light medium vegetation	0.050
Cleared vegetation	0.030
Dense vegetation	0.080
Agricultural land	0.040
Mine areas	0.025

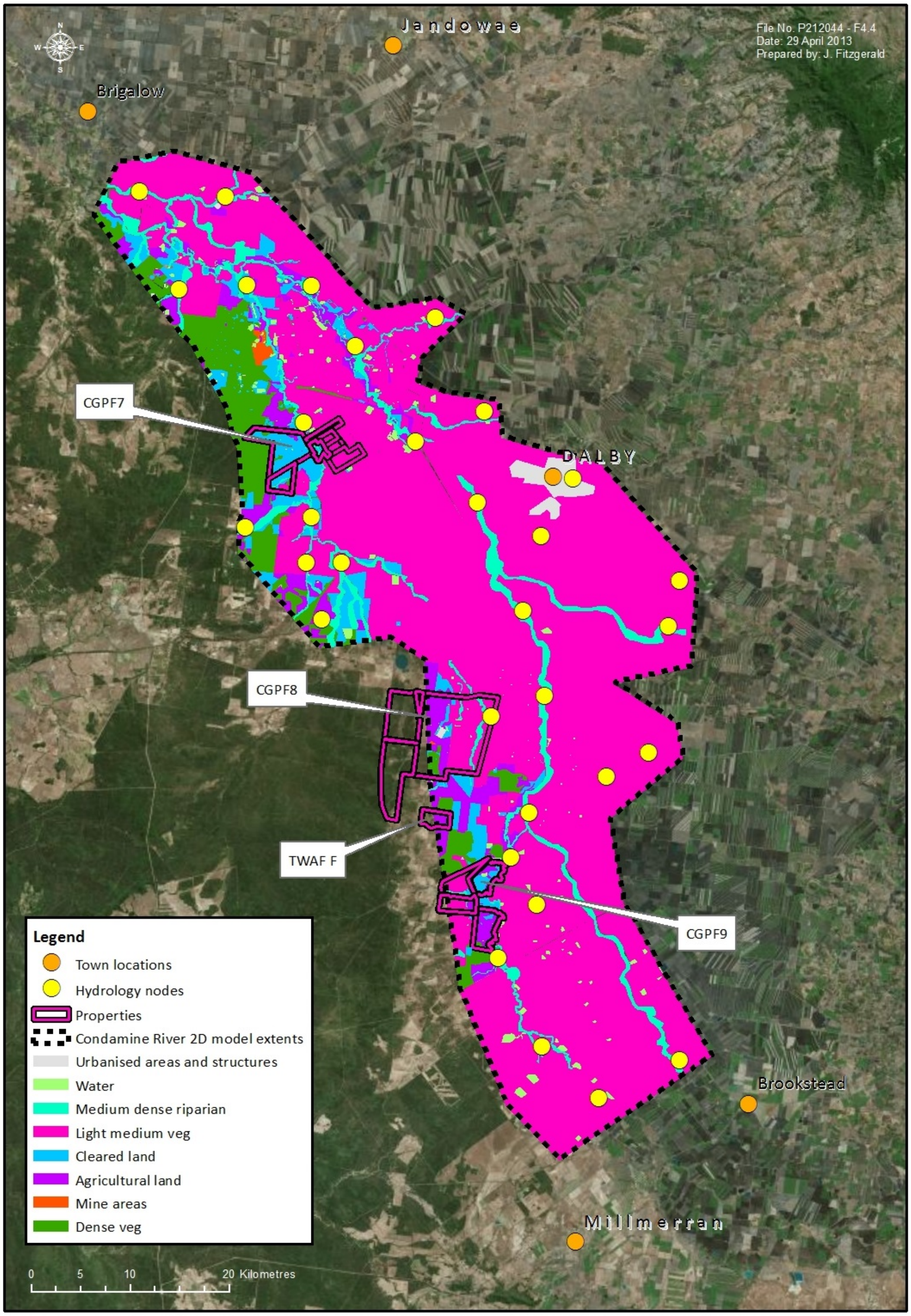

Figure 4-4. *XPSWMM Condamine River 2D model set up*

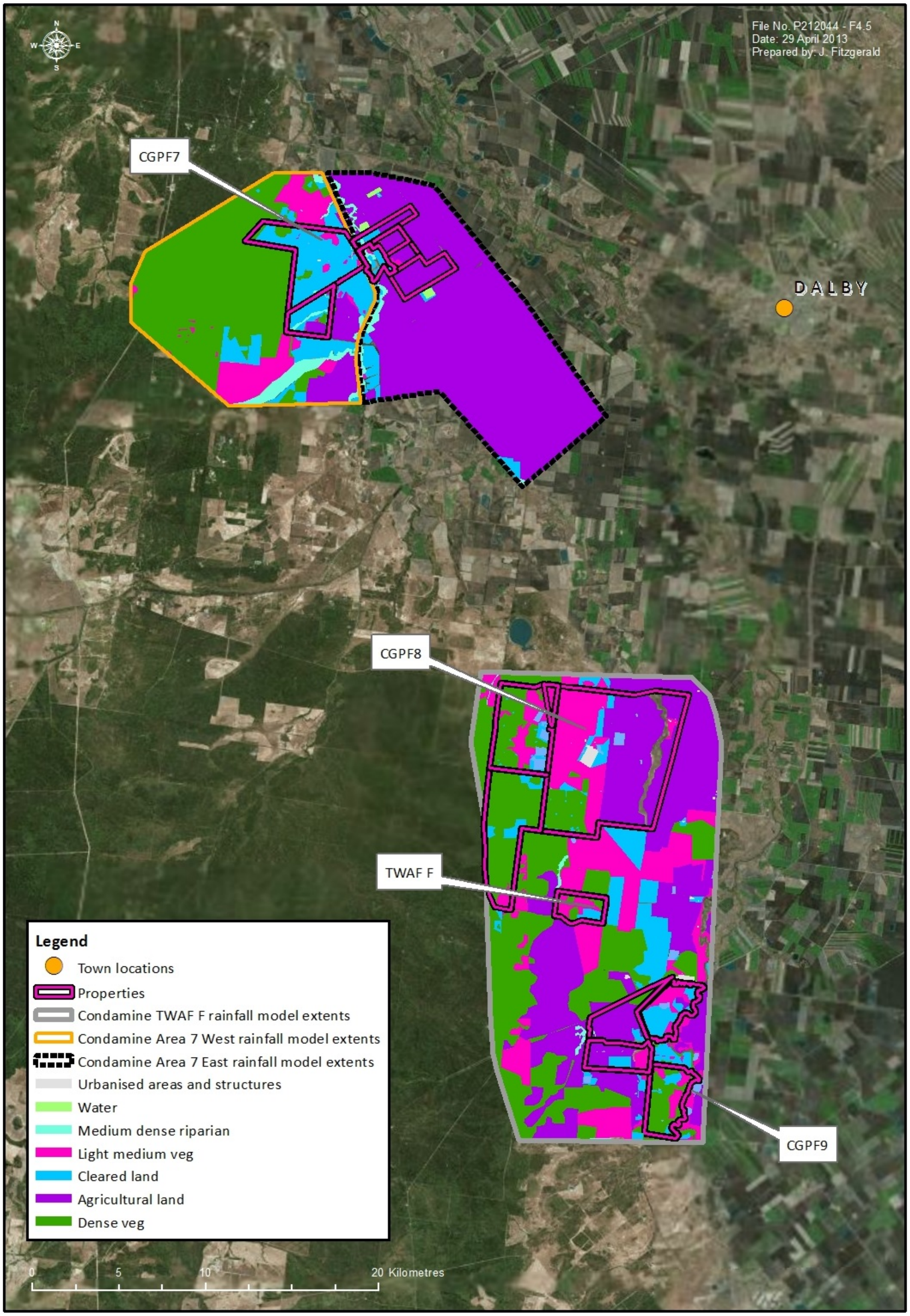

Figure 4-5. *XPSWMM Condamine River direct rainfall models setup*

Hydrologic inputs suitable for 2D modelling were developed for the 1% AEP event only in order to determine the 1% AEP event flood envelope.

For the Condamine River 2D hydrodynamic flood model, design hydrographs were used as inputs into the hydrodynamic model at the locations shown as hydrology nodes in Figure 4-4. This is to represent inputs from both the catchments external to the area and runoff generated locally.

The results from this model were used to generate hydrologic outputs, which were used for the higher resolution models developed for the CGPF7, 8 and 9 properties. These models used a mixture of hydrologic nodes and flow boundaries in order to generate flood extents through the sites. In the case of the direct rainfall models, rainfall was applied directly to the model in order to determine the flow paths and flood depths that would be caused by a localised storm event.

While the critical duration, the duration which yielded the highest peak flow rate, had been determined through hydrologic modelling, the hydrodynamic model was tested with this duration plus a number of storm durations either side of the hydrologic critical duration. This was to determine which duration yielded the greatest flood depth; in some cases, and depending on characteristics of the catchment, the critical durations can differ.

In some cases, particularly for the direct rainfall models, the critical duration varied across the sites so the critical duration was chosen based on the event which best represented the flood behaviour for the overall area. The results are summarised in Table 4-7.

Table 4-7. Summary of critical durations for Condamine River hydrodynamic modelling

Hydrodynamic model name	Critical duration
Condamine River 2D model	30 hours
CGPF7 property 2D model	30 hours
CGPF8 property 2D model	30 hours
CGPF9 property 2D model	30 hours
CGPF7 property East rainfall model	9 hours
CGPF7 property West rainfall model	4.5 hours
TWAF F property rainfall model	3 hours

Hydraulic structures

As input to the modelling, a field assessment was undertaken in February 2013 to inspect major bridge structures along the Condamine River. Field verification of these structures was required to ensure that these were modelled correctly in the sensitivity testing phase of the project. Sensitivity testing of the models was undertaken to test the impact that hydraulic structures have on the water surface elevation in the areas of interest. Minor structures including smaller culverts and smaller bridges were not included in the testing as they were not deemed large enough to impede flows.

Two bridges immediately north of the CGPF9 property, the Cecil Plains Rail Bridge and Toowoomba – Cecil Plains Road crossing, were modelled as complete blockages. However, as a substantial portion of the flow down the river was spread across the flood plain for the 1% AEP event, the change in water surface elevation was insignificant (approximately 0.02 m).

Figure 4-6 identifies the range of structures that were taken into consideration for testing.

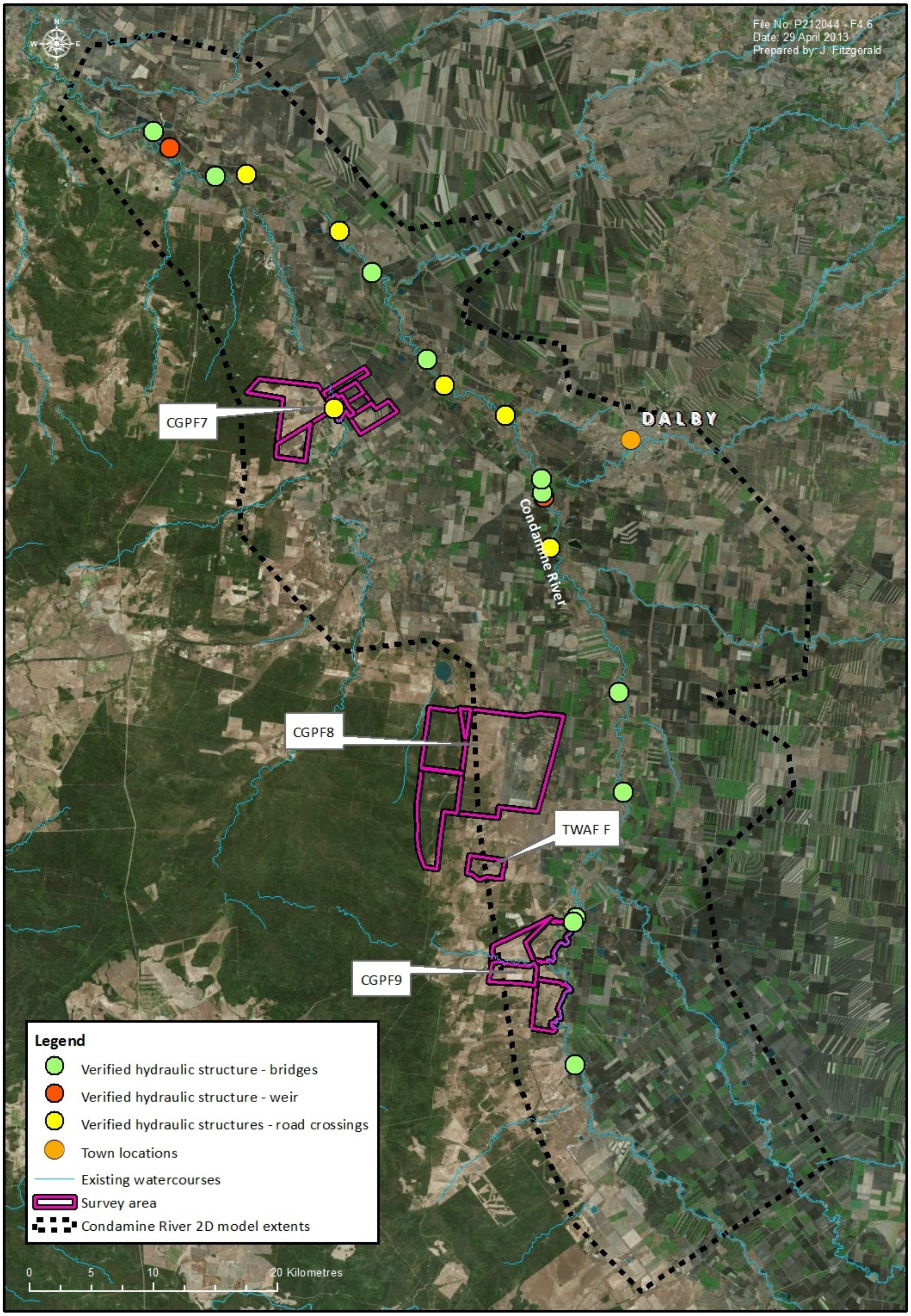

Figure 4-6. *Range of hydraulic structures considered for the Condamine River XPSWMM models*

Comparison of Condamine River hydrodynamic model results and recorded satellite imagery of the December 2010 flood event

The 1% AEP modelling results for the Condamine Catchment were overlaid on satellite imagery recorded during the late December 2010 flood event. This event was chosen as it was the largest magnitude event to have occurred in the last three years. This event is discussed in further detail in the original EIS submission in section 4.6 of Appendix H (Alluvium 2011).

Due to the lack of available satellite imagery, and the absence of data for the significant flow events in February and March 2013 in the Dogwood Creek catchment, a similar comparison could not be made for the Dogwood Creek 2D hydrodynamic model (pluviograph and stream flow data collected by the BoM is generally not made publically available for up to six months following collection of the data).

The results of the comparisons are presented in Section 5.2.4.

4.5 Hydraulic assessment for proposed surface water discharges

A hydraulic assessment was undertaken for the two proposed locations for treated or untreated coal seam gas water discharge: Bottle Tree Creek at the CGPF2 property and the Condamine River at the CGPF9 property.

During a hydraulic assessment of a watercourse, a number of key hydraulic parameters are analysed, which include stream power, velocity, and shear stress. These parameters allow for comparative assessment between waterways and against diversion design criteria established in ACARP (2002), which is considered industry best practice for assessing hydraulic conditions in a watercourse across Queensland. Given these ACARP parameters were derived using hydrology in ARI format, the hydrology used in the hydraulic assessment section of this project has also been derived in ARI format for comparative purposes.

The methods for undertaking the hydraulic assessments for each watercourse are outlined in the following section.

Bottle Tree Creek

Bottle Tree Creek is a watercourse within the CGPF2 property. The section of Bottle Tree Creek under investigation in this hydraulic analysis is 21,500 m long (hereafter “subject reach”). Figure 4-7 illustrates the location of this subject reach in relation to proposed project sites.

HEC RAS (Hydrologic Engineering Centers River Analysis System) modelling of the Bottle Tree Creek has been undertaken to determine the existing hydraulic parameters. These hydraulic parameters will be used as a baseline to assess the impact of proposed water releases from the CGPF2 property.

As outlined in section 5.5, modelling demonstrated that the impact of a range of discharge volumes on the 2 year ARI event was negligible. Modelling also investigated the impact of discharges volumes when there is no seasonal flow in the channel. As the peak flow rates for the 50 year ARI event would be significantly greater, discharge volumes would make up an even smaller proportion of the total flow down the watercourse and would therefore have an even smaller impact on the hydraulic parameters. Consequently, it was considered unnecessary to model the impact of the discharge volumes on the 50 year ARI event.

Hydraulic modelling overview

The key hydraulic parameters derived in this assessment were compared to diversion design criteria established by ACARP (2002).

The stream parameters established by ACARP (2002) are based on reach average parameter values of existing creeks within the Bowen Basin in Central Queensland and are detailed in Table 4-8. This design criterion can be used as threshold design levels for management and rehabilitation works.

Table 4-8. Bowen Basin diversion design criteria (reach average) (ACARP 2002)

Scenario	Stream Power (W/m^2)	Velocity (m/s)	Shear Stress (N/m^2)
2 year ARI event in channel with vegetation	20 to 60	1.0 to 1.5	<40

Model setup

One dimensional, steady state modelling has been undertaken using HEC-RAS.

The model was built for approximately 21,500 m of Bottle Tree Creek with cross sections at 100 m spacing except for the 7,000 m section of channel closest to the proposed gauging station, where 50m spacing was used for increased accuracy. In the absence of any specific stage/flow data, the boundary conditions were set to normal depth (slope of the channel in m/m (vertical metres/horizontal metres), as measured from the supplied DTM and as outlined in Table 4-9.

Table 4-9. Upstream and downstream settings adopted for the Bottle Tree Creek hydraulic model

Boundary	Adopted normal depths
Upstream	0.00089 m/m
Downstream	0.00047 m/m

Roughness, represented in the form of Manning's "n" values, was selected and applied to the model using an aerial image to determine vegetation cover and channel form, and supported by field observations. Identified vegetation types and corresponding roughness coefficients are detailed in Table 4-10.

Table 4-10. Vegetation types and adopted Manning's "n" values for Bottle Tree Creek HEC-RAS model

Vegetation Category	Description	Assigned Manning's "n" Value
Medium dense	Woodland with medium dense cover	0.065
Medium Density Riparian/Clean, Straight	Sections of natural creek with medium cover	0.040

Catchment hydrology

A detailed hydrologic assessment of Bottle Tree Creek catchment was undertaken and is presented in section 4.3. The estimated flow rates for the 2 year ARI event through Bottle Tree Creek are shown in Table 4-11.

Volumes of treated or untreated coal seam gas water discharged into the subject reach will be dependent on operational requirements and geomorphic conditions. As Arrow's water treatment facility will be designed to treat up to 35 ML/d (0.41 m^3/s) the assessment has assumed that the amount discharged per day is equal in volume. The impact of this discharge volume is also outlined in Table 4-11. As will be reported later in this section, higher flow discharges volumes were tested to understand the reach's sensitivity to flows larger than the design flow.

Table 4-11. Estimated flow rates for various flow events through Bottle Tree Creek

Flow Change Location	Chainage (m)	Discharge 35 ML/d (m^3/s)	Discharge 86 ML/d (m^3/s)	2 year ARI peak flow (m^3/s)	2 year ARI peak flow + Water release 35 ML/d (m^3/s)	2 year ARI peak flow + Water release 86 ML/d (m^3/s)
A	21,500	0.41	1.0	122.53	122.94	123.53
B	13,000	0.41	1.0	132.26	132.67	133.23

The extent of the Bottle Tree Creek hydraulic model and the flow change locations are illustrated in Figure 4-7.

Condamine River

Condamine River is a watercourse within the CGPF9 property. The section of the Condamine River under investigation in this hydraulic analysis is 5,900 m long (hereafter "subject reach"). Figure 4-8 illustrates the location of this subject reach in relation to proposed project sites.

HEC RAS modelling of the Condamine River has been undertaken to determine the existing hydraulic parameters. These hydraulic parameters will be used to assess the impact of planned water releases from the project site. Modelling was not undertaken for the 50 year ARI event as the impact of planned discharges on the 2 year ARI event was considered negligible and would have been even less significant for the larger 50 year ARI event.

Hydraulic modelling overview

The hydraulic modelling used for the Condamine River subject reach was similar to the modelling used for Bottle Tree Creek.

Model setup

One dimensional, steady state modelling has been undertaken using HEC-RAS.

The model was built for approximately 5,900 m of Condamine River with cross sections at 100 m spacing. In the absence of any specific stage/flow data, the boundary conditions were set to normal depth (slope of the channel in m/m (vertical metres/horizontal metres), as measured from the supplied DTM and as outlined in Table 4-12.

Table 4-12. Upstream and downstream settings adopted for the Condamine River rating curve hydraulic model

Boundary	Adopted normal depths
Upstream	0.00250 m/m
Downstream	0.00367 m/m

Roughness, represented in the form of Manning's "n" values, was selected and applied to the model using an aerial image to determine vegetation cover and channel form. Identified vegetation types and corresponding roughness coefficients are detailed below in Table 4-13.

Table 4-13. Vegetation types and adopted Manning's "n" values for Condamine River HEC-RAS model

Vegetation Category	Description	Assigned Manning's "n" Value
Medium dense	Woodland with medium dense cover	0.065
Medium Density Riparian/Clean, Straight	Sections of natural creek with medium cover	0.040

The reach assessed in this analysis did not include any road or culvert crossings.

Catchment hydrology

A detailed hydrologic assessment of Condamine River catchment was undertaken by Alluvium and is presented in section 4.3. The estimated flow rates for the 2 year ARI event through Condamine River are shown in Table 4-14.

Volumes of treated or untreated coal seam gas water discharged into the subject reach will be dependent on operational requirements and geomorphic conditions. As Arrow's water treatment facility will be designed to treat up to 90 ML/d (1.04 m^3/s) the assessment has assumed that the amount discharged per day is equal in volume. As will be reported later in this section, higher flow discharges volumes were tested to understand the reach's sensitivity to flows larger than the design flow.

Table 4-14. Estimated flow rates for 2 year ARI event through Condamine River

Flow Change Location	Chainage (m)	Discharge 90 ML/d (m^3/s)	Discharge 130 ML/d (m^3/s)	2 year ARI peak flow (m^3/s)	2 year ARI peak flow + Water release 90ML/d (m^3/s)	2 year ARI peak flow + Water release 130 ML/d (m^3/s)
A	14,000	1.04	1.50	271.60	272.64	273.10

The extent of the Condamine River hydraulic model and the flow change locations are illustrated in Figure 4-8.

4.6 Stage discharge curves for Bottle Tree Creek and the Condamine River

One of Arrow's proposed coal seam gas water management options involves the provision to discharge treated or untreated coal seam gas water into receiving watercourses: Bottle Tree Creek within the CGPF2 property and the Condamine River within the CGPF9 property.

As a part of this report, potential geomorphic impacts associated with potential controlled discharges to watercourses have been assessed. As input to that assessment, stage discharge curves have been developed to enable a comparison between natural flows and potential coal seam gas water discharges at a nominated location within the property.

This section of the report outlines the hydraulic modelling method adopted to assess the relationship between flow discharge and depth in the channel. In order to convert water depths into flow rate estimates, it is necessary to develop a stage discharge curve for the proposed locations.

Bottle Tree Creek

A specific point was identified for the location of a proposed gauging station to assess the impact of discharges on the water surface elevation within the channel. The most suitable location was identified to be in the section of bed rock along the channel banks, which is a stable point, suitable for the construction of a gauging weir and is outlined in Table 4-15 below and illustrated in Figure 4-7.

Table 4-15. Proposed flow gauging locations for treated or untreated discharge from the water treatment facility co-located with the CGPF2 property

Lease	Watercourse	Easting	Northing	Reason
CGPF2	Bottle Tree Creek	224343	7064497	Stable banks due to natural rock armour

Model setup

The HEC RAS model developed for the hydraulic assessment of Bottle Tree Creek (outlined in section 4.5) was also used to derive a stage discharge curve for the proposed Bottle Tree Creek gauging station.

Water levels were predicted by the model at the location of the gauging station for a range of flows, allowing a stage discharge curve to be defined.

As Arrow's northern water treatment facility (proposed to be sited in the CGPF2 property) will be designed to treat up to 35 ML/d (0.41 m^3/s), the assessment has assumed that the amount discharged per day is equal in volume. The model was assessed for a range of flows of up to 1 m^3/s (86 ML/d) to understand the reach's sensitivity to flows larger and smaller than the design flow.

Summary and limitations

The stage discharge curve developed during this analysis has been produced through 1D hydraulic modelling, based on the assumptions outlined in this report. This allows recorded depths to be converted into flow rate estimates using the equation provided. The curves were developed for flows between 0.1 and 1.0 m^3/s.

The selection of Manning's "n" values and other design coefficients are based on review of aerial photography. The reach assessed in this analysis did not include any road or culvert crossings.

It is essential that the stage discharge curve be updated following each substantial flow event which may change the channel form to ensure the validity of calculated flow data.

Condamine River

Two locations were identified for the location of a proposed gauging station on the Condamine River. One location is the existing Cecil Weir gauging station. The other suitable location is downstream of the Cecil Weir as shown in Figure 4-8.

If treated or untreated coal seam gas water is discharged into Cecil Weir, construction of a gauging station is not expected to be required. In this case, it is suggested that flows could be monitored through the existing Cecil Weir stream gauge, however, its suitability needs to be confirmed.

Both locations are outlined in Table 4-16 below and illustrated in Figure 4-8. The location of the most suitable location (due to its inherent stability at a rock bar) for the discharge point is also shown.

Table 4-16. Proposed flow gauging locations for treated or untreated discharge from the water treatment facility co-located with the CGPF9 property

Lease	Watercourse	Easting	Northing	Reason
CGPF9	Condamine River	322570	6953035	Discharge into Cecil weir pool.
CGPF9	Condamine River	322658	6954166	Discharge location downstream from Cecil weir.

Model setup

Water levels were predicted by the model at the location of the gauging station for a range of flows, allowing a stage discharge curve to be defined.

As Arrow's southern water treatment facility (proposed to be sited in the CGPF9 property) will be designed to treat up to 90 ML/d (1.04 m^3/s), the assessment has assumed that the amount discharged per day is equal in volume. The model was assessed for a range of flows of between 0.1 and 1.5 m^3/s (130 ML/d) to understand the reach's sensitivity to flows larger and smaller than the design flow.

Summary and limitations

The stage discharge curves developed during this analysis have been produced through 1D hydraulic modelling, based on the assumptions outlined in this report. This allows recorded depths to be converted into flow rate estimates using the equations provided. The curves were developed for flows between 0.1 and 1.5 m^3/s.

The selection of Manning's "n" values and other design coefficients are based on review of aerial photography. The reach assessed in this analysis did not include any road or culvert crossings.

It is essential that the stage discharge curve be updated following each substantial flow event which may change the channel form to ensure the validity of calculated flow data.

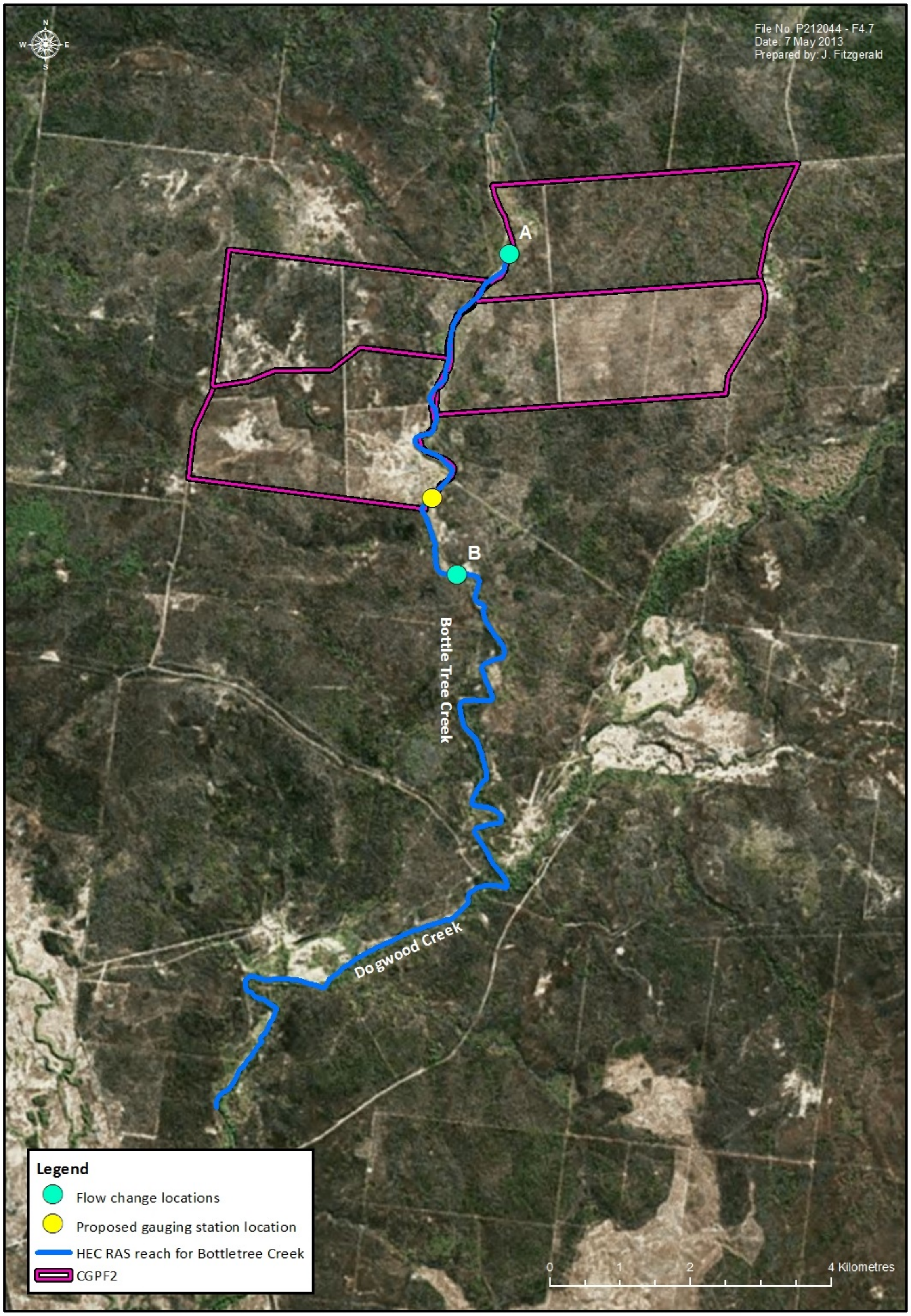

Figure 4-7. *Bottle Tree Creek flow recommended gauging station location map*

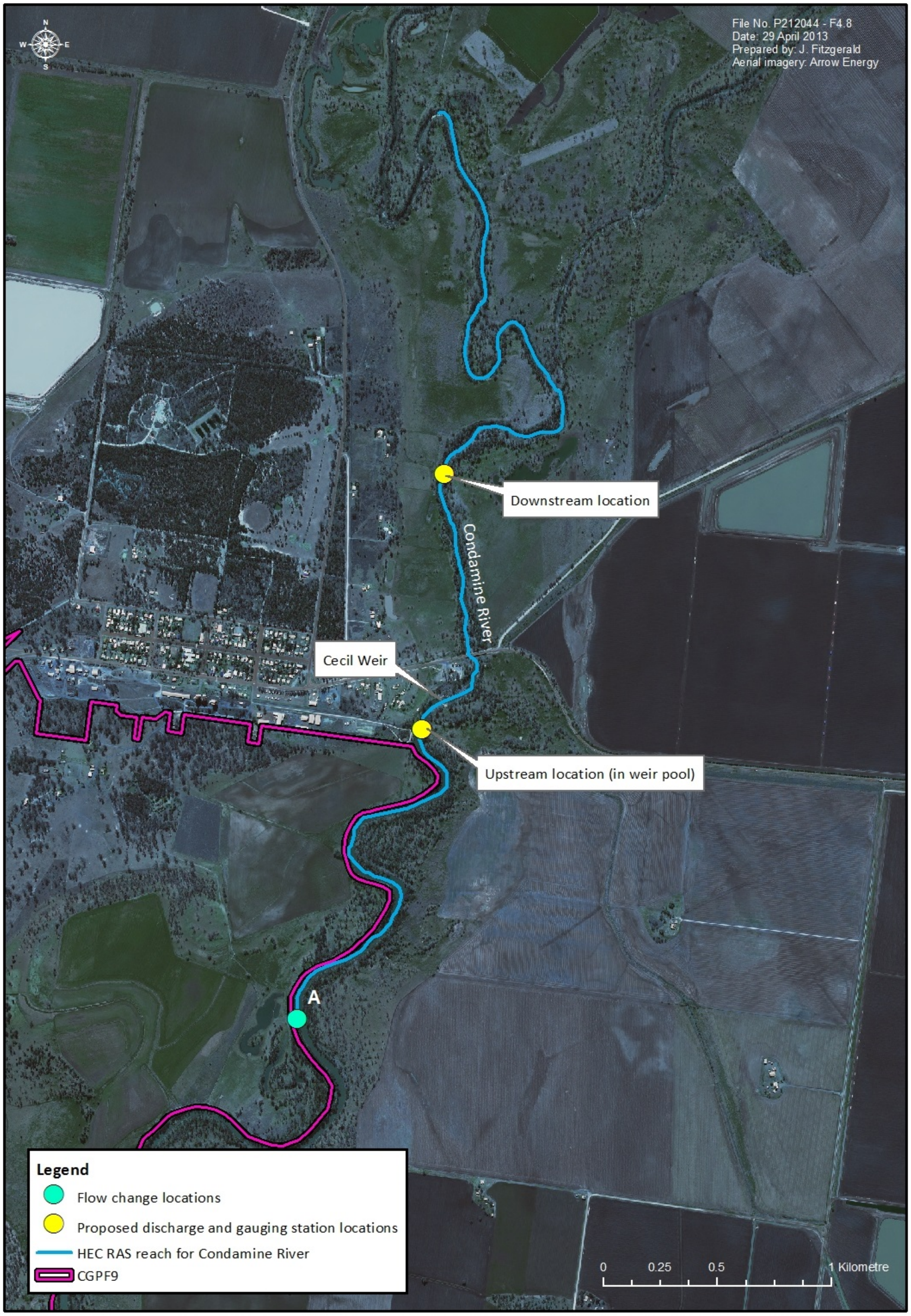

Figure 4-8. *Condamine River flow recommended gauging station location map*

Gauged daily flows at Dogwood Creek at Gil Weir (422202B) and Condamine River at Cecil Weir (422316A)

Gauged daily flows at Gil Weir on Dogwood Creek (downstream from the CGPF2 property) and Cecil Weir on the Condamine River downstream of the CGPF9 property were assessed to determine the average number of low flow days per month from the available historical data. This was done to assist with the surface water assessments of water quality (NRA 2013) and aquatic ecology (AMEC 2013). The results are presented in Section 5.3.

It must be noted that Bottle Tree Creek is ungauged. The closest available gauging weir (Gil Weir (422202B) below Miles) was therefore used to provide an indication of flows for Bottle Tree Creek. However, these results need to be treated with caution, as pointed out in Section 5.3.

The Cecil Weir gauging station was chosen for the Condamine River as it is the closest to the proposed discharge area.

4.7 Subsidence impacts on surface water

The assessment of potential impacts from subsidence on surface water was undertaken through a review of information available on the likely rates of regional subsidence as a result of coal seam gas extraction and consideration of the significance of any predicted impacts on overland flow. This assessment included a review of the baseline report on InSAR (Synthetic Aperture Interferometry) monitoring on the Surat – Bowen Basin which was conducted by Altamira in 2012.

4.8 Cumulative impacts

Cumulative impacts have been considered in regard to the discharge of treated or untreated coal seam gas water at the CGPF2 and 9 properties.

Chapter 28 of the EIS lists the planned developments that may discharge to the same drainage basins as the Surat Gas Project. The results of this study indicate that geomorphic and hydrologic impacts can be managed within a range of discharge regimes from this project. However, geomorphic and hydrologic impacts are only two aspects of broader potential environmental impacts and as such need to be considered with the context of a preliminary environmental flows assessment and strategy (provided as a separate report (Alluvium 2013)). Further assessment will be required, in order to consider cumulative impacts due to all other planned developments once details of those developments become available.

Details of release regimes from other projects were not available at the time of preparing this report and will therefore need to be considered as part of a recommended environmental flows assessment. This is considered further in Section 5.8.

5 Results

5.1 Environmental values

The EPP Water has nominated environmental values and water quality objectives for the Fitzroy Basin (Dawson) in *Dawson River Sub-basin Environmental Values and Water Quality Objectives*, published September 2011. The *Water Resource (Fitzroy) Plan* 2011 recognises the ecological values of Dawson sub-basin rivers by way of environmental flow provisions.

The EPP Water does not nominate specific environmental values or water quality objectives for the Condamine-Macintyre and Maranoa-Balonne-Border Rivers. For water quality objectives intended to protect the nominated environmental values, the EPP Water directs readers to the *Queensland Water Quality Guidelines* (DERM 2009a) and ANZECC 2000. In the absence of defined environmental values, ANZECC 2000 recommends that managers and practitioners take a conservative approach and assume that all appropriate environmental values apply to the resource.

The environmental values nominated for the Surat Gas Project area in regard to water quality are presented in Section 4.4 of Part B of this Surface Water report (NRA, 2013). For further details of environmental values related to water quality, readers are directed to that report.

Environmental values related to geomorphology and hydrology

Two overarching environmental values for each of the various types of watercourses and wetlands within the project development area were defined in the EIS (Alluvium 2011). These have been updated to include consideration of the option to release treated or untreated coal seam gas water to surface waters under normal operating conditions and updated wetlands mapping.

Environmental value 1: Physical integrity, fluvial processes, form and morphology of watercourses and wetlands.

Environmental value 1 objective: To maintain or enhance the physical integrity, fluvial processes, form and morphology of watercourses and wetlands as identified in the Queensland Wetlands Programme “Wetland mapping and classification for Queensland” (version 3 February 2012).

Environmental value 2: Hydrology of watercourses and wetlands in the catchment - quantity, duration and timing of stream flows.

Environmental value 2 objective: To manage impacts that may result from project activities on the hydrology of watercourses and wetlands (such as adverse increases or decreases in quantity, duration, rate or timing of stream flows). This includes: the management of surface water flows to protect and where practical enhance, existing beneficial downstream uses of those waters; and the minimisation of impacts on flooding levels and flood frequency both upstream and downstream of the project development area.

5.2 Geomorphology

The results are presented as follows:

1. Assessment of watercourses traversing and downstream of the CGPF2 and 9 properties.
2. Assessment of watercourses traversing the CGPF7 and CGPF8 properties and the TWAF F property.
3. Identification of wetlands mapped in the Queensland Wetlands Programme (V3)

Assessment of watercourses traversing the CGPF2 and 9 properties

As these two locations are proposed for the release of treated or untreated coal seam gas water, particular attention has been applied to assessing the geomorphic character, behaviour and condition of potentially affected watercourses.

This has been undertaken in order to consider the sensitivity to change of those watercourses in the event of coal seam gas water discharges.

The assessment has included identification of potentially stable points most suited to the discharge of coal seam gas water and to the geomorphic character, behaviour and condition of downstream reaches along which the discharged water will flow.

CGPF2 Property

As presented in Figure 5-1 (with an enlargement of the CGPF2 property shown as Figure 5-2), Bottle Tree Creek is the major watercourse running through the lease at the CGPF2 property, which joins with Dogwood Creek approximately 7 km downstream of the southern extent of the CGPF2 property boundary.

Overall, the watercourse is stable and is generally characterised by a single thread sand bed channel. Condition issues are generally associated with the upper bank and consist of some localised erosion of the sand banks either through slumping or removal of trees during floods, and some minor gullying on the downstream sections of Reach BC-R5.

The section of Bottle Tree creek traversing the CGPF2 property has been split into seven reaches based on geomorphic character and behaviour. This includes the two tributaries that run through the western lease blocks. The downstream sections of Bottle Tree Creek and Dogwood Creek that flow downstream from the CGPF2 property have been split into two reaches. Each reach is discussed below.

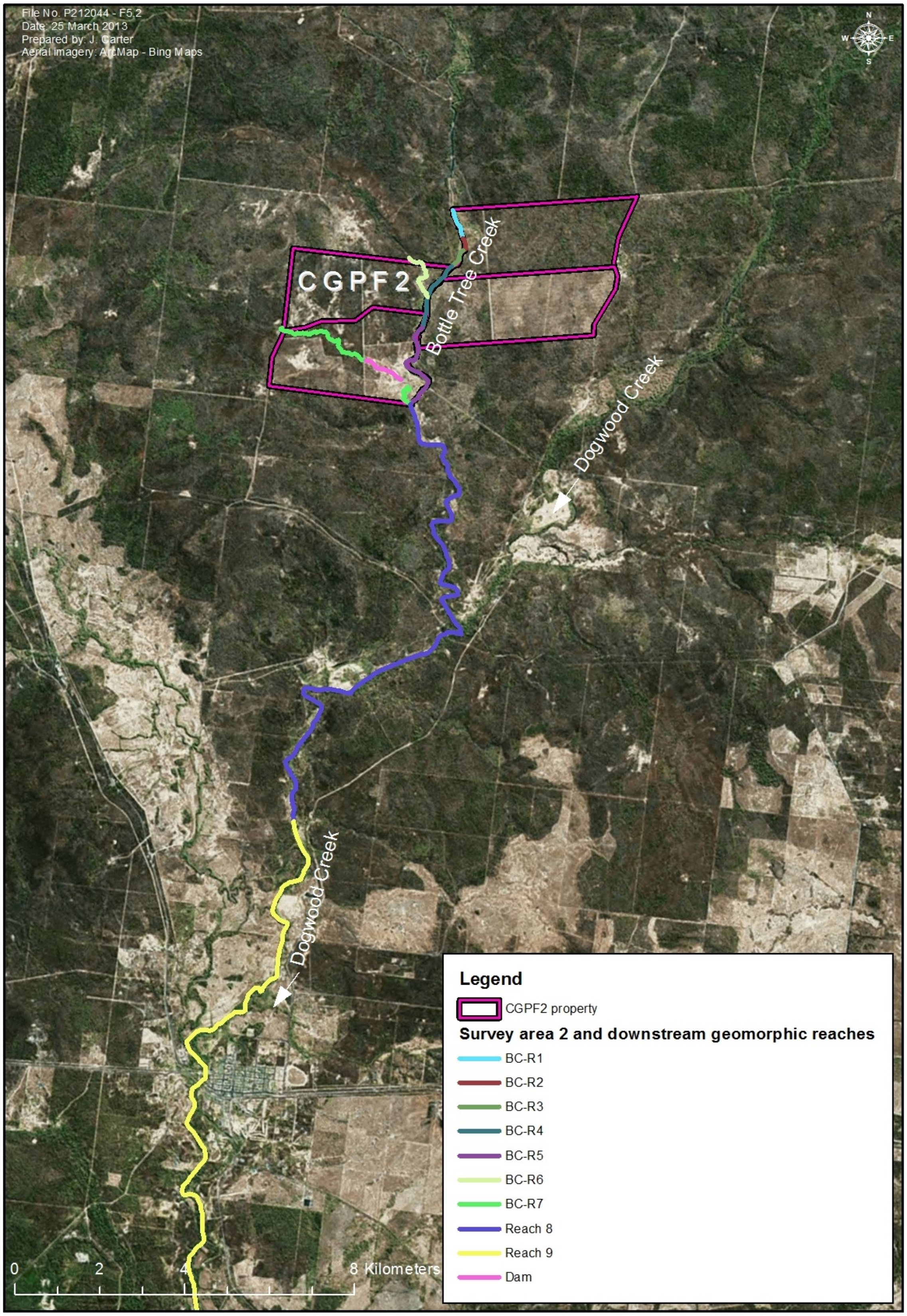

Figure 5-1. *Geomorphic reaches and mapped wetlands of watercourses traversing the CGPF2 property and downstream of the property.*

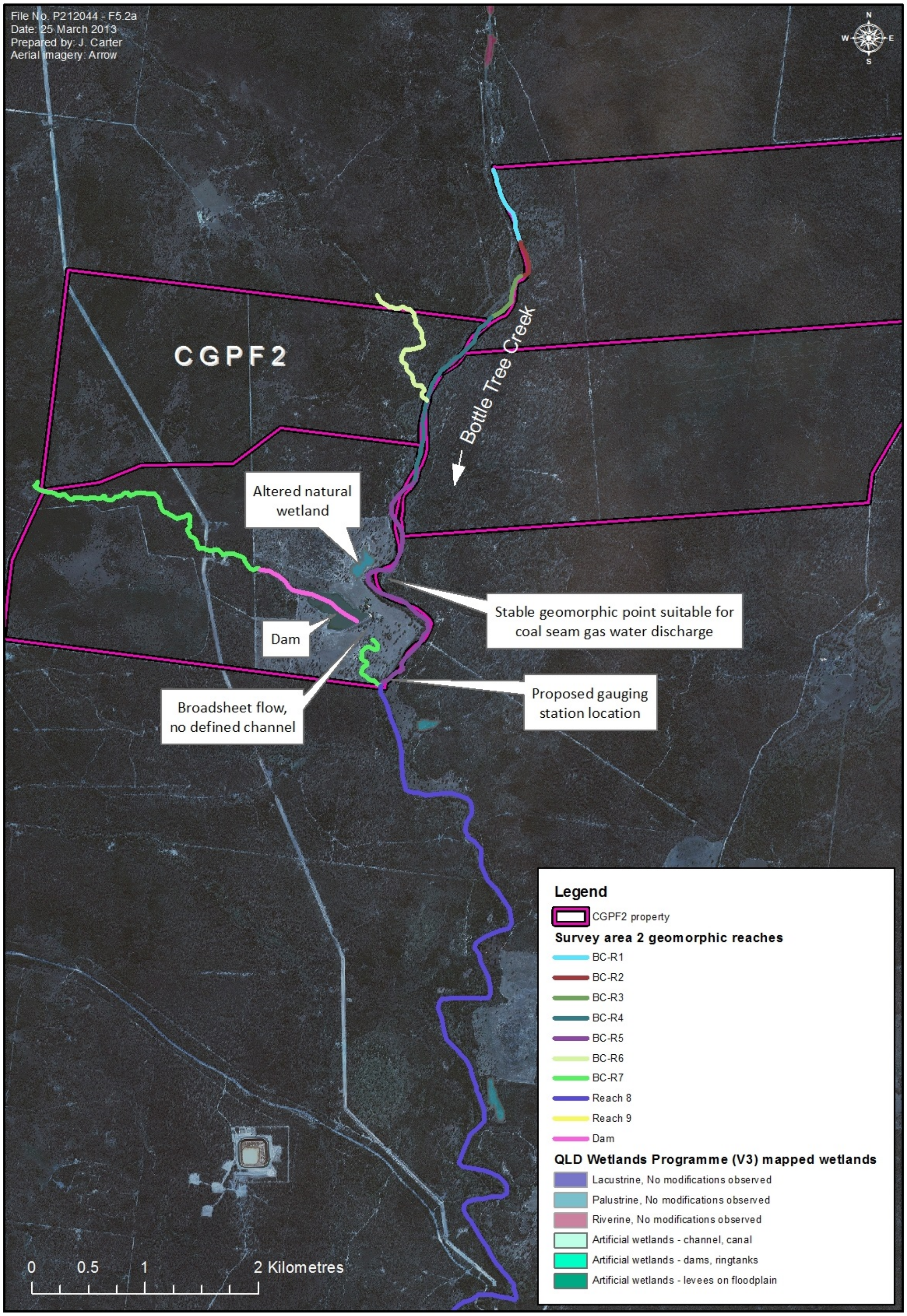

Figure 5-2. *Geomorphic reaches and mapped wetlands of watercourses traversing the CGPF2 property and downstream of the property*

Reach 1

The most upstream reach (BC-R1) is approximately 700 m long and is characterised by a single channel set in a partly confined valley setting. There are localised areas of bedrock abutting the channel margin, however otherwise the banks are high and steep, comprised predominantly of sands and silts.

There are several instances of localised bank erosion, most likely caused by toe of bank undermining and rapid wetting and drying of the banks during flood events. The channel bed form is comprised almost entirely of one long run.

Given the amount of water in the channel at the time of monitoring it is difficult to ascertain how deep the low flow channel is at this point, however it is likely that the water is back-pooling through this section due to a channel impingement further downstream. Overstorey vegetation was moderately dense through this reach, however the groundcover had been reduced due to recent flood impacts and grazing pressures. Images of the reach are shown in Figure 5-3.

Looking downstream from the left bank of BC-R1. Note the floodplain on the right bank.

Bank erosion and example of bank material in BC-R1. Note the depth of sand in the bank profile.

Looking upstream near the downstream end of BC-R1 from the top of a bedrock impingement on the left bank. Note the pooling in the channel.

Looking upstream from water level at the end of BC-R1.

Figure 5-3. *CGPF2 Property – Reach BC-R1*

Reach 2

A change in channel dimensions and overall processes prompted the change to a new reach through this section (BC-R2). Large amounts of sediment have been deposited previously in the channel, which has formed a bank-attached lateral sand bar. This, in combination with vegetation colonising the sediment, has forced the active channel towards the left bank thereby inducing bank erosion. The channel has aggraded and the low flow channel is narrow and meanders through thick sand deposits.

Further downstream, this slug has manifested as a bench on the right bank and a series of point bars at the very end of this reach. Whilst the sand slug has been colonised by regenerating woody species, there is potential for remobilisation of this sediment in the future, and a change in hydrological conditions could impact this reach. Images of the reach are shown in Figure 5-4.

Looking downstream from the beginning of BC-R2. Note the lateral bar in the channel.

Looking across stream in BC-R2. Note the vegetation of a similar age on the bar.

Looking downstream in BC-R2. Note the bank erosion from meander migration on the left bank. Also note the change in channel size from BC-R1.

Looking upstream from the end of BC-R2. Note the alternating point bars.

Figure 5-4. *CGPF2 property – Reach BC-R2*

Reach 3

BC-R3 is partly-confined to confined, with the valley margin abutting the channel on the left bank and hill slope present at places on the right bank. This reach appears to have a slightly higher sediment transport capacity, with the confined nature of the channel allowing slightly higher flow velocities.

Due to the confined nature of the channel, higher energy conditions exist, which provide for higher sediment transport capacity. As such, the upstream section of this reach displays an increase in sediment calibre with small gravels present in the channel. Mid-channel lobed sand bars are present at the downstream end of this reach indicating an abrupt widening of the channel and a reduction in sediment transport capacity leading into BC-R4. The right bank is predominantly sand with a high-set bench running for most of the length of the reach. A narrow low-set bench is also present on the left bank. This reach is relatively robust and resilient to change. Images of the reach are shown in Figure 5-5.

Looking upstream from the bed at the beginning of BC-R3. Note the narrow confined channel.

Gravel deposits on a lateral bar in BC-R3.

Looking downstream from the right bank, looking across to the valley margin on the left bank.

Looking upstream from the right bank in BC-R3.

Figure 5-5. *CGPF2 property – Reach BC-R3*

Reach 4

BC-R4 is the second longest reach in the study area on Bottle Tree Creek and is almost linear in its planform. The low width to depth channel returns, with a sand sheet on the bed, mud drapes on the toe of the bank and a thick sand veneer on the upper banks. The bed appears to be aggrading. Benches through this reach are prevalent, with alternating bench features on both banks.

There is a natural levee on the right bank, which has allowed backswamps to develop on the floodplains, indicating that the floodplain is regularly engaged in this system. This process has initiated the development of flood-channels draining the floodplain.

There is some minor bank erosion resulting from flows around obstructions and removal of large trees and the rapid drawdown of flood waters causing slumping. This reach has evolved to withstand overbank flows and is capable of both storing sediment and floodwaters on the floodplain. The channel could be susceptible to incision with increased flows, which may induce further bank erosion. Images of the reach are shown in

Looking downstream in BC-R4. Note the sand sheet on the bed and the more open channel profile.

Looking upstream from the top of bank in BC-R4. Note the levee and backswamp on the floodplain.

Bank erosion in BC-R4.

Looking upstream from the right bank in BC-R4.

Figure 5-6.

Looking downstream in BC-R4. Note the sand sheet on the bed and the more open channel profile.

Looking upstream from the top of bank in BC-R4. Note the levee and backswamp on the floodplain.

Bank erosion in BC-R4.

Looking upstream from the right bank in BC-R4.

Figure 5-6. *CGPF2 property – Reach BC-R4*

Reach 5

BC-R5 is the longest reach in the CGPF2 property. This reach was separated out from the others based on the more frequent alternating bedrock impingements throughout the reach, generally located on the outside of bends.

Channel morphology alternates between slightly narrower asymmetrical transfer zones where there is a bedrock impingement, to slightly wider symmetrical sand channels where bedrock is absent. The levee on the right bank is present where bedrock is not, and the valley margin abuts the channel on the left bank in the downstream section at several places.

The channel bed is covered with a mobile sandsheet, with localised bedrock exposure. This reach is relatively robust and would withstand an increase in discharge if required. There are several places in this reach with bedrock influences on the bed, which would be suitable for locating a discharge outfall. The two most suitable locations are identified in Figure 5-7 and summarised in Table 5-1. Due to the presence of bedrock on the bed throughout this reach, a gauging station can be located within this reach where necessary. It is recommended that the gauging station is located downstream of any potential discharge location.

Table 5-1. Stable locations suitable for coal seam gas water treated water discharge

Lease	Creek	Reach	Easting	Northing	Reason
CGPF DA2	Bottle Tree Creek	BC-R5	224396	7065624	Bedrock both banks and bed
CGPF DA2	Bottle Tree Creek	BC-R5	224382	7065592	Bedrock left bank and bed

Note that the two locations are approximately 40 m apart so have not been separately identified in Figure 5-2.

BC-R5 is resilient because of the prevalence and location of bedrock, however there are a few condition issues in the downstream section of BC-R5, namely, tunnel and gully erosion on the upper banks related to floodplain drainage. The earthen bund blocking the natural outlet point of the wetland on the right bank has tunnel erosion initiating. There is also a gully on the downstream end of the wetland which appears to have initiated from uncontrolled spilling when the wetland was full.

Both of these issues threaten the wetland in its current state and have the potential to reduce the condition of Bottle Tree Creek. There is also some minor gullying occurring on the upper banks of the right bank in front of the old farm house. This is likely from floodplain drainage during high rainfall events, but could also be related to stock access tracks concentrating overland flow.

As per Figure 5-2, the wetland is mapped in the Queensland Wetlands Programme (V3) as “palustrine wetland, no modifications observed”. However, it is significantly modified due to the construction of the earthen bund, which has resulted in the retention water within the wetland for extended periods compared to its natural condition.

Looking downstream at the beginning of BC-R5. Note the bedrock impingement on the left bank.

Looking downstream from the channel in a non-bedrock influenced section of BC-R5.

Potential discharge location in BC-R5. Note the dominance of bedrock (looking downstream).

Second potential discharge location in BC-R5. Note the bedrock valley margin on the left bank (looking upstream).

Tunnel erosion on the earthen bund built over the original wetland outflow point.

Example of some of the minor gully erosion in the downstream section of BC-R5.

Figure 5-7. *CGPF2 property – Reach BC-R5*

Reach 6

The unnamed tributary entering the CGPF2 property at the north western border was mapped as BC-R6. This reach is characterised by a relatively stable single thread low sinuosity, low capacity channel. The channel has low banks (0.5 m) comprised predominantly of mud drapes with a sand veneer in places and localised bedrock.

The terrace appears to be comprised of highly weathered sandstone and dispersive clays, and gully erosion has initiated where the vegetation has been cleared (predominantly near old tracks). This erosion has contributed a large pulse of sediment to the channel and has increased the risk of, or initiated avulsion in places. Images of the reach are shown in Figure 5-8.

Terrace erosion in BC-R6.

Looking downstream in BC-R6. Note the low capacity channel and low banks.

Looking downstream at BC-R6.

Localised thalweg shift has cut through sandy floodplain deposits.

Figure 5-8. *CGPF2 property – Reach BC-R6*

Reach 7

BC-R7 is the south-western tributary to Bottle Tree Creek in the CGPF2 property. This reach is a highly resilient series of bedrock forced pools and bars set in a partly confined valley setting. The floodplain is well vegetated and armoured with boulders. These boulders are likely to be colluvial as opposed to fluvially transported bedload, as it is unlikely this system would have the transport capacity to mobilise these. The terrace margin has eroded in some places and consists of a resilient conglomerate bedrock base, topped by erodible siltstone with loosely consolidated alluvium on the exposed surfaces.

The upstream section of this reach has good connectivity and geomorphic diversity with pools, regular floodplain engagement and good vegetation cover. The downstream section of this reach turns into a single thread low capacity mud lined channel which discharges into the farm dam.

Whilst the dam itself provides an additional level of resilience to this reach through flood attenuation, there is a large gully complex on the dam outlet, which is likely to progress upstream towards the dam embankment and threaten its stability. Images of the reach are shown in Figure 5-9.

Looking upstream at BC-R7. Note the bedrock bar at the far upstream extent.

Looking downstream at BC-R7. Note the eroded terrace margin on the right and the floodplain on the left.

Looking downstream at BC-R7 from the terrace. Note the boulders, and the slope to the channel on the left.

Gully at the outlet for the farm dam.

Figure 5-9. *CGPF2 property – Reach BC-R7*

Downstream of the CGPF2 property – Reach 8

Reach 8 comprises Bottle Tree Creek downstream from the CGPF2 property and Dogwood Creek from the confluence with Bottle Tree Creek to Reach 8. Bottle Tree Creek downstream from survey area 2 is similar in character and behaviour to reach BC-R5, with alternating bedrock valley intrusions along the bank.

However, the bedrock sections downstream from the CGPF2 property tended to be higher above bed level and had distinctly different vegetation communities than through the CGPF2 property section. The valley floor becomes wider in this section allowing the active channel to meander. This has initiated the formation of lateral, point and compound bars in localised areas.

Overall the riparian vegetation is in moderate condition, with grasses and sedges lining the lower bank. The vegetation in combination with the bedrock is providing stability and resilience to the bed and banks.

Several of the tributaries through this section are actively incising either in response to or in combination with potential historic change in base level or human disturbance.

A large gully is present on the right bank of Bottle Tree Creek approximately 700 metres upstream of the Myall Park Road crossing. At present the south-western arm of the gully is approximately 20 metres away from the recently constructed Origin energy-Santos gas pipeline corridor, and has the potential to continue to erode.

At the confluence with Dogwood Creek, Bottle Tree creek has intact mud drapes on the lower banks and a thick sand veneer on the upper banks. It is possible that the confluence with Dogwood Creek initiates backpooling in Bottle Tree Creek in some flow conditions. The confluence itself is stable. The left bank of Dogwood Creek opposite the confluence is bedrock, with a confluence bar at the toe of bank.

There were three crossings noted during the survey. One crossing was a private vehicle access track, which was a boulder armoured ford on Bottle Tree Creek. This was initiating minor bank erosion on the upstream side due to backpooling, however was otherwise having no other adverse effects. It should be noted that this crossing is at bed level, so increased flow may render the crossing unusable in its current state. The second crossing was the culverted causeway where Myall Park Road crosses over Dogwood Creek.

The above water structure appears to be stable, although the presence of bed level undermining could not be ascertained due to the amount of water in the channel at the time of the assessment. The third crossing is where the Origin energy-Santos pipeline crosses Dogwood Creek downstream of Myall Park Road.

There are gabion baskets (wire mesh boxes filled with rock) on the lower banks, and it was not ascertained if there was armouring on the bed to protect the pipe crossing. There is a gully forming on the right bank on the upstream end of the gabion basket.

This has exposed the flank of the basket potentially allowing this to be removed during a flood event. There is also a risk of failure of the baskets themselves, especially in a waterway dominated by sand as the bedload. Sand is capable of stripping any galvanising coating off the wire mesh enabling rust and ultimately failure to occur. Images of the reach are shown in Figure 5-10.

Example of a linear section of Bottle Tree Creek (downstream of the CGPF2 property) without bedrock influences. Note the lateral bar deposition.

Example of the higher bedrock margins in Bottle Tree Creek (downstream of the CGPF2 property). Note the wider valley floor and bifurcation of the channel at this point.

South-western arm of the gully threatening the Origin Energy-Santos gas pipeline. Note the bare earth of the pipeline corridor in the background.

Example of an actively incising tributary channel on the left bank of Bottle Tree Creek.

Confluence of Bottle Tree Creek (left of the photo) and Dogwood Creek. Note the bedrock on Dogwood Creek.

Private vehicle access track on Bottle Tree Creek. Note the pooling in the upstream section (left of the photo).

Myall Park Road causeway, looking upstream on Dogwood Creek.

Origin Energy-Santos gas pipeline crossing on Dogwood Creek. Note the gully on the right bank (bottom left of photo) and the constriction of the channel.

Figure 5-10. *Bottle Tree Creek and Dogwood Creek downstream of the CGPF2 property*

Reach 9

Reach 9 is the most downstream section of Dogwood Creek that was assessed. This reach had a similar morphology to the upstream reaches; however flow conditions have been altered by the weirs downstream. The channel widened progressively downstream and mud drapes on the lower bank were common.

The upper banks were a mix of sand and bedrock. Groundcover was intact through this reach with dense grasses, rushes and sedges present, while the overstorey was moderately dense on the left bank, and less so on the right bank. There were several lateral gullies present on the left bank, one is on Pine Street and has compromised a small section of this road. The other terminates approximately 50 m from Pelham Road. Neither of these are likely to be detrimentally effected by any increase in discharge. Images of the reach are shown in Figure 5-11.

Looking downstream at Dogwood Creek at the end of Pine Street, Miles.

Looking upstream at Dogwood Creek from the bedrock valley margin, off Pelham Road.


Gully on a small tributary at the end of Pine Street, Miles.


Extensive gullying on the left bank of Dogwood Creek, terminating approximately 50 m from Pelham Road.

Figure 5-11. *Dogwood Creek, downstream from the CGPF2 property – Reach 8*

The CGPF9 property

The Condamine River is the major watercourse running south to north through the CGPF9 property. Overall the Condamine River is laterally active as it meanders across the broad floodplain. The Cecil Plains weir is at the downstream end of the CGPF9 property boundary, which provides some stability to Reach 3.

However, overall there is low stability, with extensive gullying through Reach 1 and active meander migration with several meander cut-offs through Reaches 2 and 4.

The on lease section of the Condamine River has been split into five reaches based on geomorphic character and behaviour. This includes the tributary that runs through the western blocks (Crawlers Creek). The downstream sections of the Condamine River that flow outside of the CGPF9 property were assessed as a single reach. Each reach is discussed below.

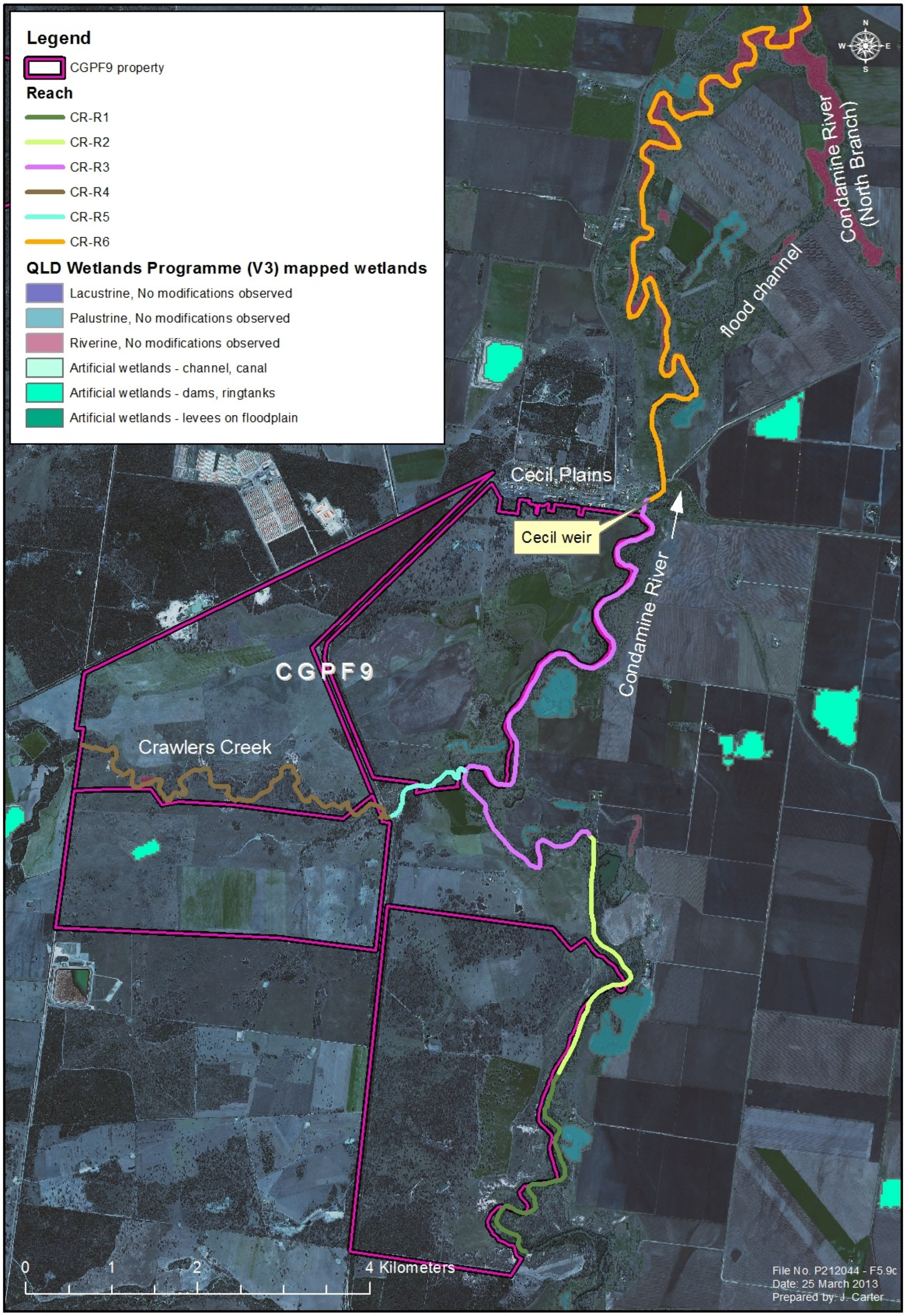

Figure 5-12. *Geomorphic reaches and mapped wetlands of watercourses traversing the CGPF9 property and downstream of the property*

Reach 1

CR-R1 is the most upstream reach of the CGPF9 property. It is a moderate sinuosity single thread channel set in a partly confined valley setting. The valley margin on the left bank is predominantly dispersive clays and highly weathered siltstones, which has led to extensive gullying through this reach. There is also an intact valley fill inset into the terrace on the left bank, which is a rare stream type due to its high sensitivity and low resilience to erosion.

The banks are comprised of clays and silts, with a thick veneer of sand from overbank flows. There are localised areas of bedrock, however this is highly weathered and also erodible. This reach is laterally and vertically active and is likely to continue to adjust under the current hydrological regime and is consequently not a suitable as a potential discharge location for coal seam gas water as discharges could significantly increase existing instabilities.. Images of the reach are shown in Figure 5-13.

Looking towards the river from the terrace of the left bank in CR-R1. This is one of the more advanced Gullies.

Looking downstream from the beginning of CR-R1 at the outlet of the Gully. Note the meander erosion and point bar deposition opposite.

Looking away from the river into the southern lobe of the first Gully (CR-R1).

Outlet of the intact Valley-Fill (CR-R1).

Looking downstream in CR-R1. Note the erodible clay banks.

Looking across stream in CR-R1. This is typical of meander migration and point bar deposition through CR-R1.

Looking downstream in CR-R1 towards the highly weathered bedrock intrusion.

Example of meander evolution and development of flood-channels on the convex bend through CR-R1.

Figure 5-13. *The CGPF9 property – Reach CR-R1*

Reach 2

CR-R2 is more linear than CR-R1 and is set in a broad floodplain comprised of black cracking clays. This has allowed a slightly more resilient channel with gently sloping mud-draped banks and sandy benches.

Back-swamps have developed on the floodplains often in association with previous channel alignments, which drain through small flood channels back into the Condamine River. Some of these have the potential to develop into meander cut offs.

There is a gully forming at the head and tail of one of the meander chute channels near the end of the CR-R2 on private property. Attempts to stabilise this gully with household debris was evident during the field survey. This gully may develop into a large meander cut off if the gully develops further. While there is some minor slumping of bank material in the downstream section of this reach, overall this reach is relatively stable. Images of the reach are shown in Figure 5-14.

Looking upstream through CR-R2. Note the reduced grade and increased stability of the banks.

Looking downstream in CR-R2. Note the mud-drapes and the bench feature on the left bank.

Looking across stream in CR-R2. Note the outlet from a back-swamp to the main Condamine Channel.

Gully erosion on the left bank in CR-R2. This goes quite a distance into the floodplain and could eventually cut off the meander.

Figure 5-14. *The CGPF9 property – Reach CR-R2*

Reach 3

The most downstream reach of the CGPF9 property is CR-R3 and is characterised by the back-pooling from the Cecil Plains weir. This reach has a similar morphology to CR-R2, however flow conditions have been altered due to the weir. Banks are mud draped with a sand veneer on the upper banks in some cases. Channel planform is more sinuous than CR-R2, but more laterally stable than CR-R1. The confluence with the western the CGPF9 property tributary (Crawlers Creek) is in this reach and is stable. The discharge of coal seam gas water in this reach is not expected to have any geomorphic impacts as this is stable due to backpooling from Cecil weir. Images of the reach are shown in Figure 5-15.

Looking upstream near the beginning of CR-R3.

Looking upstream from the middle of CR-R3.

Looking upstream towards the confluence with Crawlers Creek (CR-R3).

Looking upstream from the bottom end of CR-R3.

Figure 5-15. *The CGPF9 property – Reach CR-R3*

Reach 4

CR-R4 is the upstream reach of Crawlers Creek, running through the western side of the CGPF9 property from Duntroon Lee Steere Road to Millerran-Cecil Plains Road. This reach of Crawlers Creek has undergone significant adjustment in the recent past. The terrace and floodplains have been largely cleared of vegetation, and consist of dispersive clays. Large complex gullies have formed, and will most likely continue to erode, contributing large pulses of sediment to the system.

The creek has become laterally unstable with active meander migration and over widening of the channel occurring throughout the upstream section. The liberated gully and bank sediments are deposited on the point bars and in sediment slugs at the tail of the meander. This is causing localised bifurcation and in some cases, avulsion.

Continuing aggradation of the bed may exacerbate both meander erosion, and gully erosion. In its existing condition, this section of the creek is actively undergoing adjustment and it is likely these processes would be exacerbated if discharge was to be increased in Crawlers Creek. Images of the reach are shown in Figure 5-16.


Looking across stream in CR-R4 at meander erosion on the left bank. Note the lack of vegetation.


Looking upstream in CR-R4. Note the sediment slug in the bed and the bank erosion.


Looking south into one of the lateral gullies forming through the terrace.


Channel aggradation and over widening in CR-R4.

Figure 5-16. *The CGPF9 property – Reach CR-R4*

Reach 5

CR-R5 is the downstream section of Crawlers Creek from Millmerran-Cecil Plains Road to the confluence with the Condamine River in CR-R3. This reach has a large gully complex at the head, directly downstream of the road crossing, which is potentially endangering the road (18m at its closest point). The base material through this reach appears to be a weathered siltstone, prone to cracking and plucking.

The banks and floodplain appear to be comprised of dispersive clays, which have caused significant localised bank retreat. It is possible that the road is causing back-pooling upstream, which allows flow to spill over the road and onto the floodplain during flood events, potentially causing the floodplain erosion upon flow re-entry to the creek downstream of the road.

Downstream of this gully complex however, the creek is relatively stable but accreting laterally. The channel is a single thread channel with mud drape banks and small bench features on both banks. There is minimal erosion in this downstream section (other than the gully) and the confluence is stable. Images of the reach are shown in Figure 5-17.

Looking downstream from CR-R5 towards the confluence of Crawlers Creek and the Condamine River.

Looking upstream along CR-R5.

Looking upstream into the gully complex at the head of CR-R5. Note the weathered bedrock material on the bed.

Looking south to the furthermost arm of the gully complex. The main road is 30 m west of here.

Figure 5-17. *The CGPF9 property – Reach CR-R5*

Downstream of the CGPF9 property

Reach 6

The off tenure reaches of the Condamine River (downstream from the CGPF9 property) that were assessed were similar in morphology to CR-R2, however are referred to as CR-R6. Immediately downstream of the Cecil Plains weir to just downstream of the Toowoomba-Cecil Plains Road bridge there are strong bedrock influences on the lower banks.

Due to the stability of the active channel in this small section of CR-R6, it is likely that an increase in discharge on top of the baseflow would cause limited geomorphic change.

The upper banks are predominantly black clays, with a sand veneer in some places. CR-R6 is moderately laterally active with meander migration occurring in multiple places. Bank erosion was also present and generally associated with slump erosion and/or removal of trees during flood events.

Sand point bars and benches were often associated with areas of lateral bank movement. An historic weir was assessed as the most downstream point of CR-R6. However, due to limited property access a stretch of 7 km between the weir and the accessible properties upstream was not assessed.

A flood channel linking the Condamine River and the Condamine River (North Branch) is located on the right bank approximately 1.5 km downstream of the Toowoomba-Cecil Plains Road bridge. This channel is characterised by a series of pool features set within the floodplain. The take-off of this channel is characterised by a small entry channel and a large sand bar on the left bank. Immediately after the bar there is a large pool.

The entry channel bed invert is approximately 2.5 m above the bed level of the Condamine River, and it is considered unlikely that the proposed discharge of 90 ML/d on top of base flow will enable permanent engagement of the flood channel. It should be noted however, that the flood channel has some bank erosion issues, most likely due to the lack of riparian vegetation. Extended and prolonged engagement of flows in this channel could potentially exacerbate these processes.

Images of the reach are shown in Figure 5-18.

Looking upstream towards the Toowoomba-Cecil Plains Road bridge on the Condamine River.

Looking downstream in CR-R6 showing the typical channel geometry.

Looking downstream on the Condamine River, with the flood channel take-off on the right.

Looking upstream on the flood channel. Note the overstep banks and active erosion.

Example of active bank erosion on the Condamine River in CR-R6. Note the cracking at the top of the scarps.

Looking downstream at the historic weir on the Condamine River.

Meander migration of the Condamine River (left) endangering a waterbody on the floodplain (right). There is also a possibility of tunnel and gully erosion initiating.

Figure 5-18. *Downstream of the CGPF9 property – Reach CR-R6*

The CGPF9 property wetlands

There are a number of palustrine wetlands mapped within the CGPF9 property (see Figure 5-12), however, these are within the 1% AEP flood extent (see Section 5.3) and are not expected to be disturbed by project activities. Should infrastructure be required to be constructed within the 1% AEP flood extent then it is recommended that mapped wetlands not be disturbed.

There is a mapped palustrine wetland downstream from the CGPF9 property on the right floodplain of the Condamine River, approximately 600 m downstream from the Toowoomba-Cecil Plains Road bridge (see Figure 5-18). This is located in an area of the Condamine River undergoing active lateral adjustment, with significant bank erosion occurring near the downstream end of the wetland.

At this point, the current distance between the wetland and the Condamine River is approximately 25 m. There is a high potential for tunnelling to occur, initiating gully erosion and subsequent draining of the wetland. Alternatively, meander erosion could continue to proceed towards the wetland, again compromising the wetland. Any proposed discharge of coal seam gas water within this reach needs to ensure that appropriate management actions are applied to prevent any increased risk to this wetland.

The CGPF7 property

As can be seen in Figure 5-19, the CGPF7 property has two mapped watercourses running through the properties. One of them is a moderate sized watercourse called Wilkie Creek. This runs from south-east to north-west almost through the middle of the CGPF7 property and is a single thread moderately-sinuous channel, with multiple back-swamps and flood channels.

Riparian vegetation is largely intact and healthy with a continuous riparian strip running for most of the creeks length on the CGPF7 property.

The channel changes from wide and slow moving runs, to small low-flow channels passing through previously deposited sediment slugs. Being a laterally mobile channel, there is potential for bank erosion and meander migration, as well as further meander cut-offs. Some gully erosion was noted on the right bank on the outside of the meander, on the property boundary.

There are a two palustrine wetlands mapped within the CGPF7 property (see Figure 5-19), however, these are within the 1% AEP flood extent (see Section 5.3) and are not expected to be disturbed by project activities. Should infrastructure be required to be constructed within the 1% AEP flood extent then it is recommended that mapped wetlands not be disturbed.

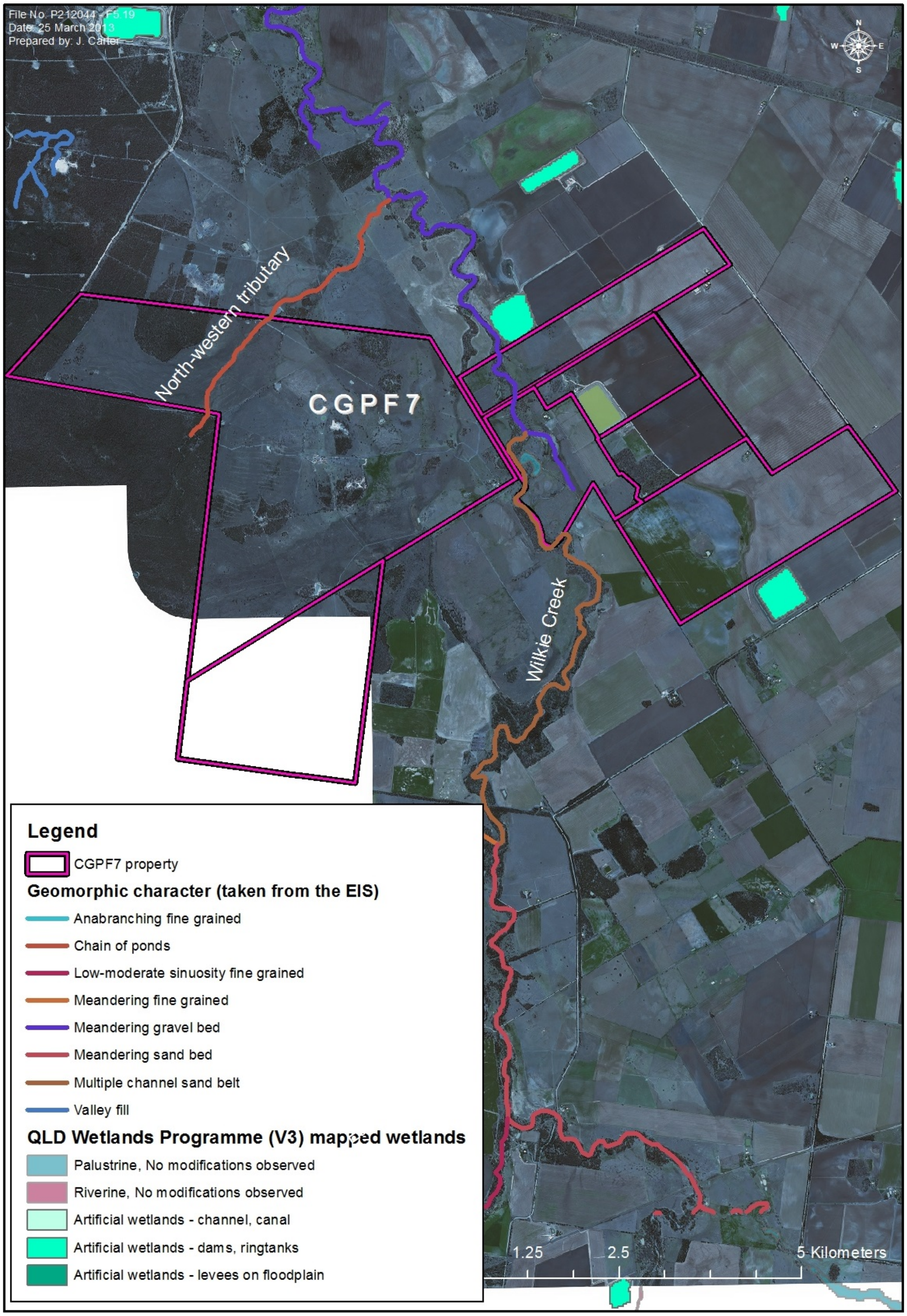

Figure 5-19. *The CGPF7 property – Geomorphic reaches and mapped*

Looking upstream on Wilkie Creek. Typical pool section with established vegetation.

Looking downstream on Wilkie Creek at meander erosion on the left bank.

Figure 5-20. *The CGPF7 property – Wilkie Creek*

The second watercourse is a small ephemeral low capacity chain of ponds on a broad low-feature floodplain. There were only small paired channels downstream of the road crossing visible at the time of the survey and some minor ponding upstream in no visible channel.

This watercourse feeds directly into an on-line dam which is not on Arrow owned property. Riparian vegetation is poor, with the majority of the creek cleared of canopy vegetation. There were no stability issues noted at the time of the survey. Images of the reach are shown in Figure 5-21.

Looking upstream at the undefined north-western watercourse. Note the ponded water.

Looking downstream on the north-western watercourse. Note the small low capacity channels.

Figure 5-21. *The CGPF7 property – north-western watercourse*

The CGPF8 property

The CGPF8 property has two watercourses running through the property (see Figure 5-24). The north western tributary runs south to north through the well field, is an intact valley fill and the main watercourse feeding Lake Broadwater (nationally important wetland, listed in the Directory of Important Wetlands in Australia (Environment Australia, (2001)), which is located downstream form the CGPF8 property. Riparian vegetation is intact with a dense stand of riparian canopy trees, and the infrequent pools are ringed with riparian sedges and grasses.

Flood debris across the immediate floodplain is testament to the regular engagement of this stream type with its floodplain. This stream type is highly susceptible to erosion, and an increase in flow, or removal of vegetation could initiate erosion and incision through this creek. Upstream propagation of an erosion head through this reach would endanger well and road infrastructure. Upstream of the access road has been completely cleared of vegetation.

Looking across stream on the north-western watercourse in survey area 8. Pond unit in regenerating vegetation.

Looking downstream on the north-western watercourse in survey area 8. The unchannelised section between ponds.

Figure 5-22. *The CGPF8 property – north-western tributary*

The Eastern watercourse is called ‘Longswamp’, and is an intact valley fill and runs south to north through the CGPF8 property for approximately 8 km. It is likely this is a previous channel of the Condamine River, and as can be seen in Figure 5-24 still functions as a flood flow path during larger Condamine River flood events. The land either side of the watercourse is intensive cropping land.

These stream types are prone to erosion and are important features on a floodplain, as they can convey and store large quantities of water during and after flood events. Images of the watercourse are shown in Figure 5-23.

Looking downstream from Percy Jergs Road on ‘Longswamp’. Note the unchannelised morphology and the cropping land either side of the corridor.

Looking upstream from Proposed Road. Note the unchannelised morphology and the regenerating vegetation.

Figure 5-23. *The CGPF8 property – Longswamp*

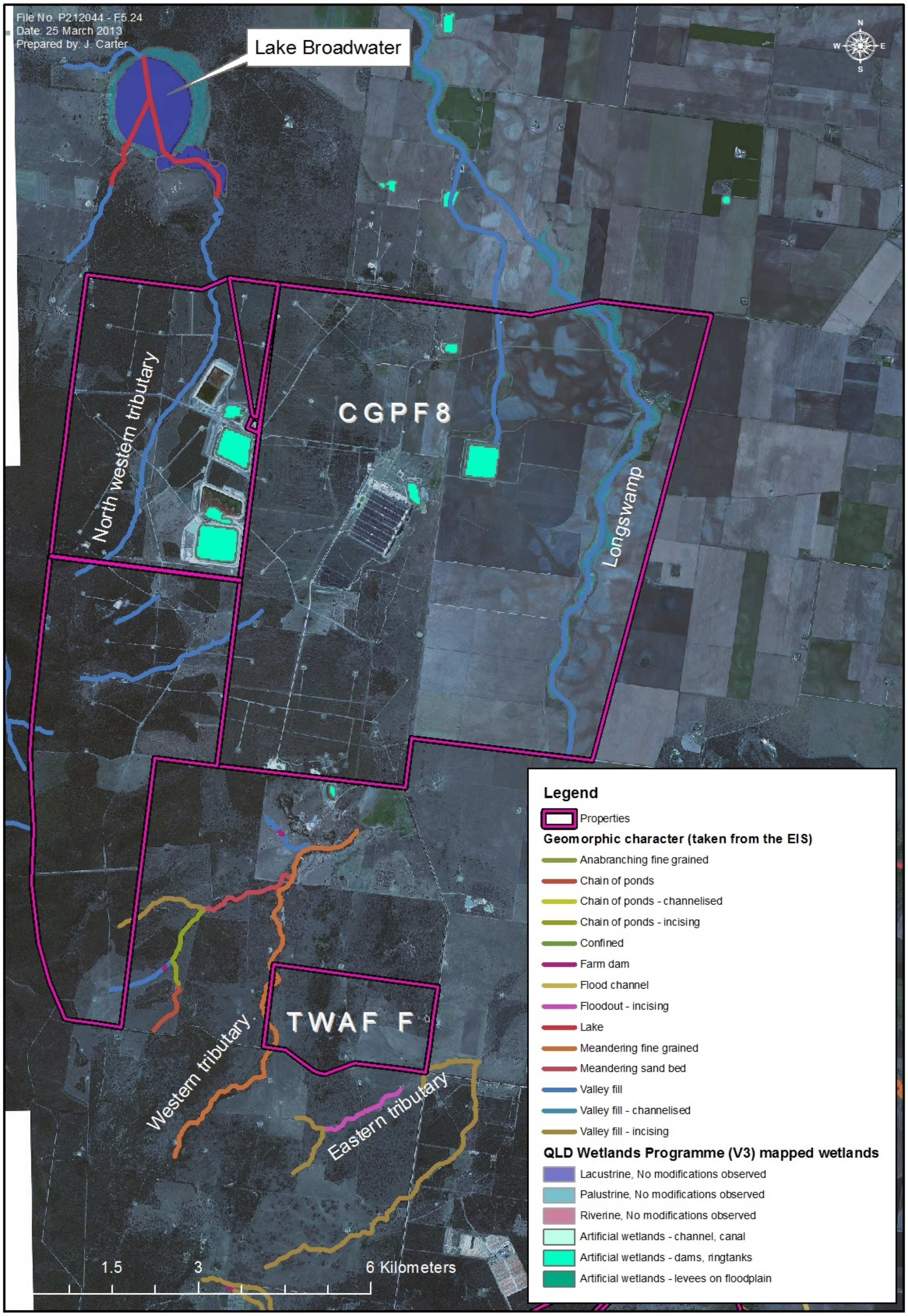

Figure 5-24. *The CGPF8 property and the TWAF F property – Geomorphic reaches and mapped wetlands*

Longswamp is the only mapped wetland within the CGPF8 property. It is mapped a palustrine wetland (see Figure 5-24). It is within the 1% AEP flood extent (see Section 5.3) and is not expected to be disturbed by project activities. Should infrastructure be required to be constructed within the 1% AEP flood extent then it is recommended that the mapped wetland is not disturbed.

Lake Broadwater is listed as a Nationally Important Wetland and is downstream from the CGPF8 property. All project activities need to be undertaken in a manner which ensures that there are no negative impacts on this wetland.

The TWAF F property

The TWAF F property has two small waterways passing through its southern boundary (see Figure 5-25). The eastern waterway is only on Arrow owned property for approximately 60 m, running along the eastern boundary, before passing under the road and heading east.

This creek is a low-capacity incised flood-out, with low banks and is currently relatively stable. The two road crossings have initiated back-pooling, which reduces flow velocities, and has created a wider channel planform. Images of the discussed watercourses are shown in Figure 5-25.

Looking upstream at the south-eastern tributary in survey area F.

Looking downstream at the south-eastern tributary in survey area F. Note the wider and deeper channel than upstream.

Figure 5-25. *The TWAF F property –Eastern tributary*

The western tributary passes in and out of the western boundary of the TWAF F property. The creek is an incised fine-grained meandering watercourse and has formed a small low-flow channel within high steep banks downstream of the road crossing.

On the upstream side of the road crossing (not on Arrow owned land) there is lateral terrace erosion, likely caused by back-pooling from the road crossing itself, but the channel appears less incised. The bed material appears to be a mobile sand sheet, and the banks loosely consolidated alluvium and sands. With the creek in its existing condition, any increase in flow could cause further bank erosion. Images of these tributaries are shown in Figure 5-26.

There are no mapped wetlands in the TWAF F property.

Looking upstream at the western tributary in the TWAF F property. Note the wider channel morphology.

Looking downstream at the western tributary in the TWAF F property. Note the erosion on the left bank.

Figure 5-26. *The TWAF F property – Western tributary*

5.3 Hydrology

A review of appropriate streamflow and pluviograph data was undertaken and assessed for relevance to the study and for use in the hydrologic models and is outlined in the following section.

Streamflow records

Dogwood Creek

The CGPF2 property is located adjacent to Bottle Tree Creek, approximately 7 km upstream of the confluence with Dogwood Creek. The Dogwood Creek project reach has one gauged location along its length, there are no gauging stations on Bottle Tree Creek. Details of this gauge are listed in Table 5-2.

Table 5-2. Streamflow gauge assessed for Dogwood Creek hydrologic model

Site	DERM number	Catchment Size (km^2)	Year start	Year end	Latitude	Longitude
Dogwood Creek at Gil Weir*	422202B	3010	1949	Ongoing	26.72 S	150.83 E

* The correct location name is *Gil Weir*. However, DERM have adopted the streamflow gauge name *Dogwood Creek at Gilweir*. The name *Gil Weir* has been adopted in this report for both the location name and gauging station name.

The Dogwood Creek at Gil Weir stream gauge is located approximately 14 km downstream of the confluence of Dogwood Creek and Bottle Tree Creek and is considered most relevant to this study for use in the Dogwood Creek hydrologic model. Its location is illustrated in Figure 5-30.

However, Water Technology (2011) found substantial errors in the DERM rating curve for the Gil Weir streamflow gauge. Based upon their derived results, a new rating curve was generated for the Gil Weir streamflow gauge and adopted by Water Technology and also by DERM (see page 18, Water Technology (2011)).

Figure 5-27 depicts the historical daily maximum flow through the streamflow gauge based on this revised assessment.

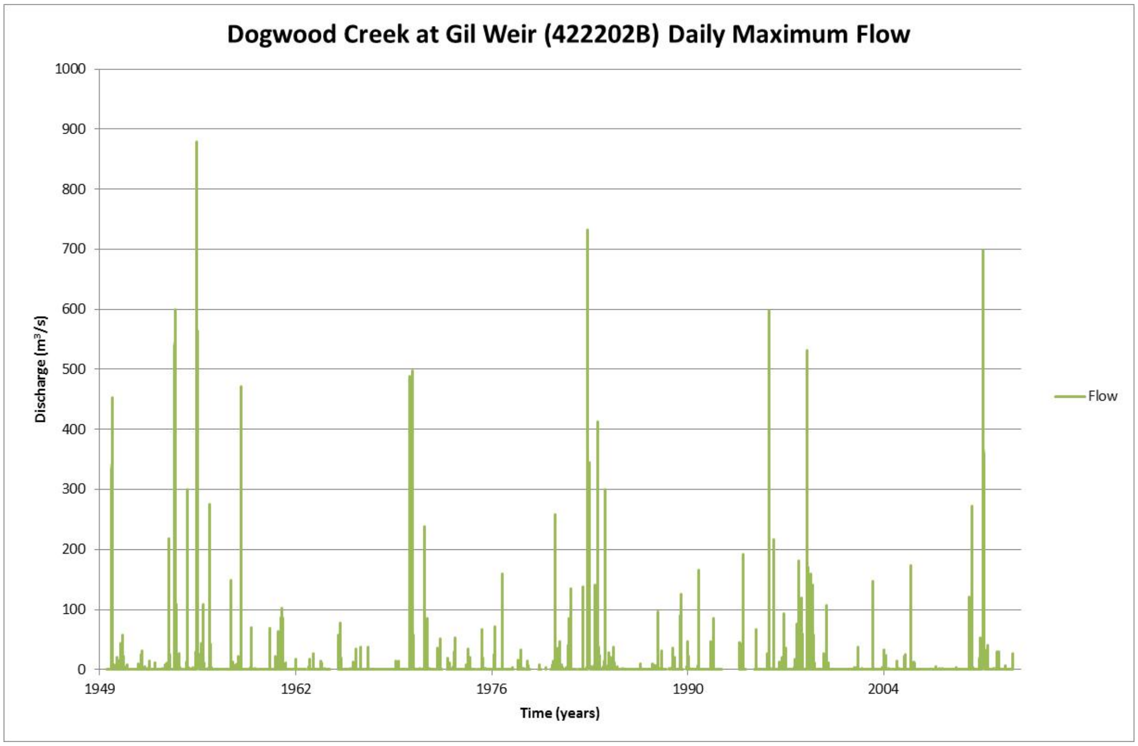

Figure 5-27. *Daily maximum flow through Dogwood Creek at Gil Weir (422202B) streamflow gauge*

Condamine River

While a number of streamflow gauges exist along the Condamine River, two particular gauges were considered for use in this hydrologic model. Details of the gauges are listed in Table 5-3.

Table 5-3. Streamflow gauges assessed for Condamine River hydrologic model

Site	DERM number	Catchment Size (km^2)	Year start	Year end	Latitude	Longitude
Condamine River at Cecil Weir	422316A	7,795	1947	Ongoing	27.53 S	151.20 E
Condamine River at Brigalow	422336A	18,000	1972	Ongoing	26.90 S	150.78 E

The Condamine River at Cecil Weir stream gauge is located adjacent to the CGPF9 property and as such its location is considered ideal for use in calibrating the model; see Figure 5-31 for a depiction of its locality. Figure 5-28 depicts the historical daily maximum flow through the streamflow gauge.

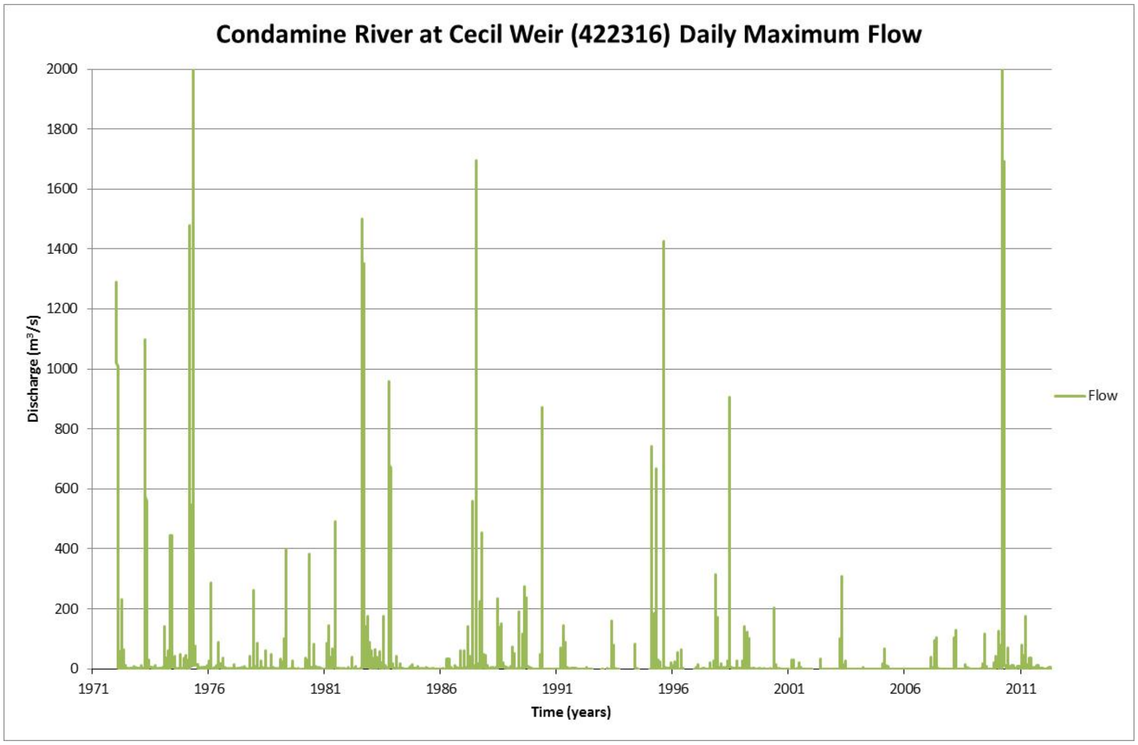

Figure 5-28. *Daily maximum flow through Condamine River at Cecil Weir (422316A) streamflow gauge*

The Condamine River at Brigalow stream gauge is located approximately 20 km south east of Chinchilla and its location is considered appropriate for use in calibrating the Condamine River hydrologic model as it is the next available stream flow gauge downstream of the CGPF7 property, the northern most survey area within the Condamine catchment (see Figure 5-31 for a depiction of its locality). Figure 5-29 depicts the historical daily maximum flow through the streamflow gauge.

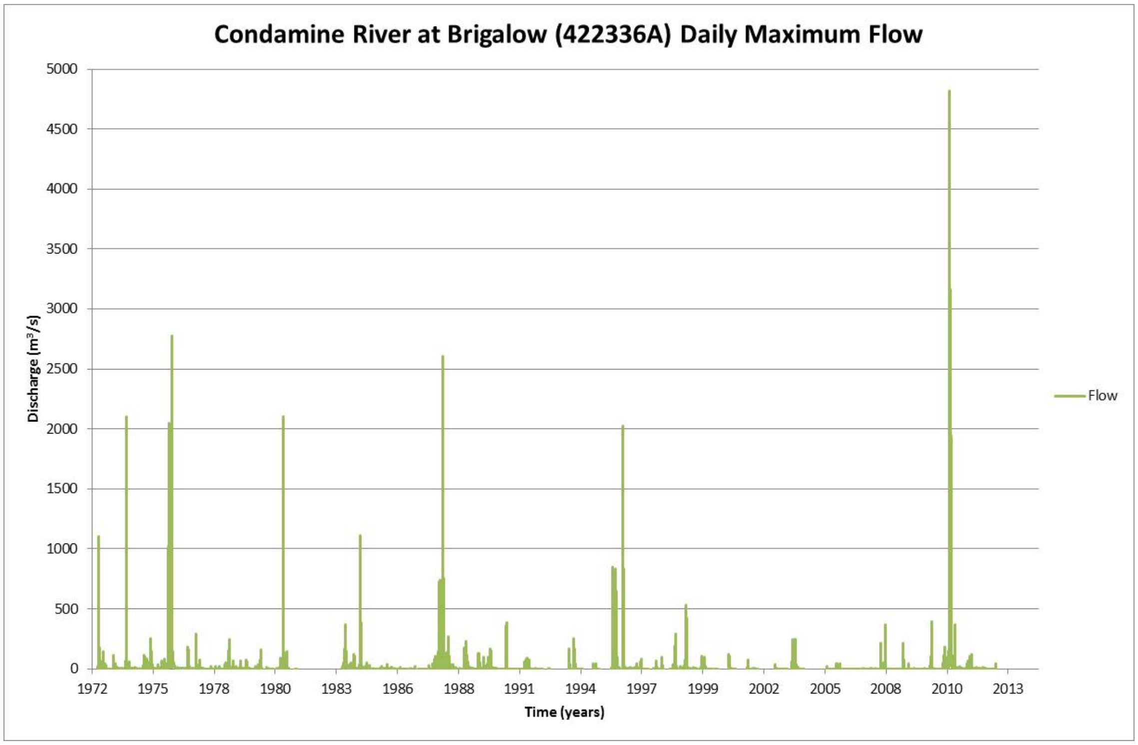

Figure 5-29. *Daily maximum flow through Condamine River at Brigalow (422336A) streamflow gauge*

Pluviograph records

Dogwood Creek

As part of the review of information to determine inputs to the Dogwood Creek hydrologic model, five pluviograph stations were chosen from the area within and surrounding the Dogwood Creek catchment on the basis of having been in reliable operation in recent years and yielding suitable data for calibration of the Dogwood Creek hydrologic model These five stations are listed in Table 5-4 and illustrated in Figure 5-30.

Table 5-4. BoM pluviograph stations relevant to Dogwood Creek catchment in model calibration

Site	Gauge number	Latitude	Longitude
Giligulgul	35029	26.3564 S	150.0464 E
Darr Creek TM	41090	26.5392 S	151.1347 E
Auburn	42059	25.9525 S	150.6142 E
Miles Constance Street	42112	26.6569 S	150.1819 E
Yuleba State Forest	43044	26.6383 S	149.4261 E

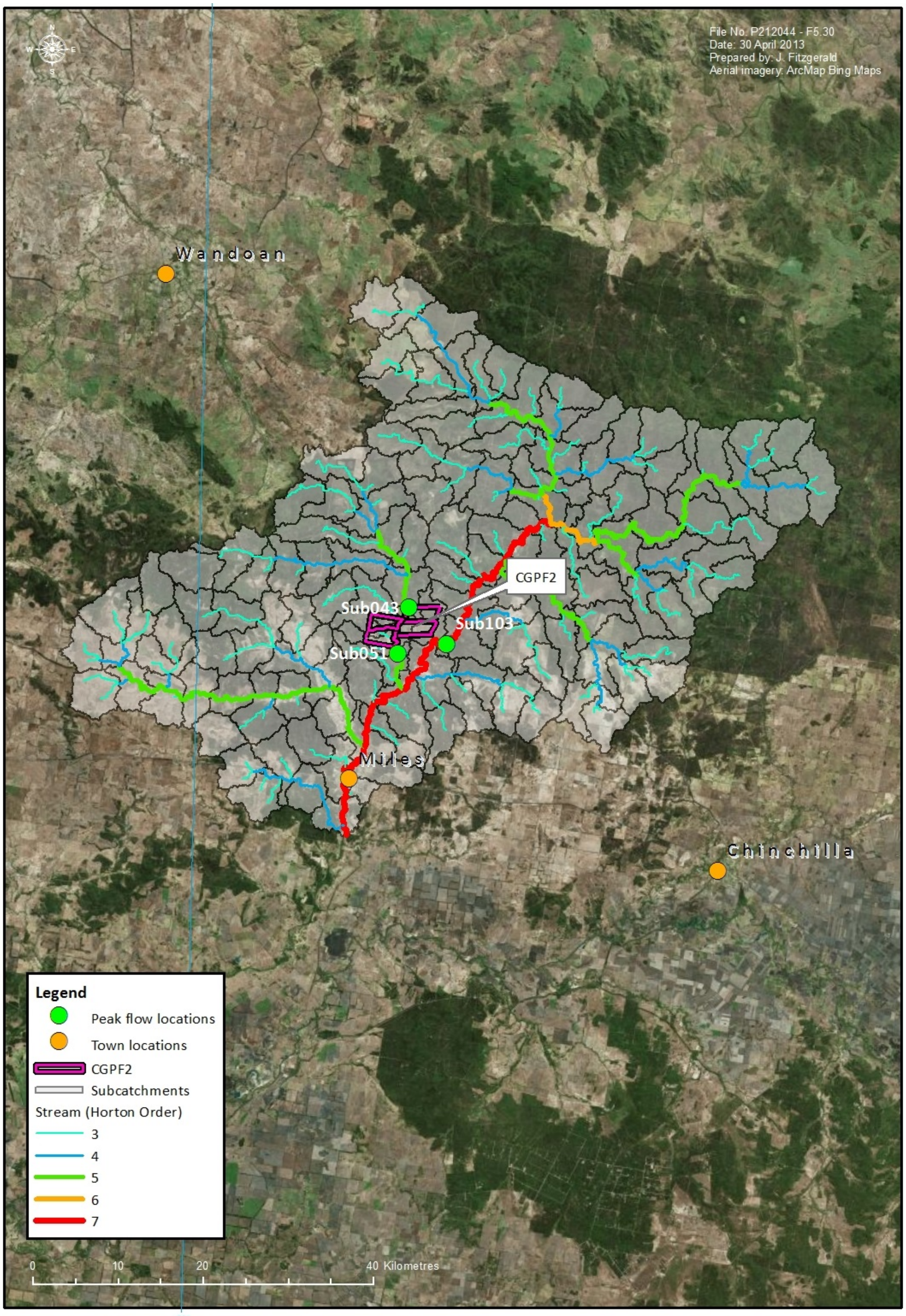

Figure 5-30. *Dogwood Creek hydrologic model catchment delineation and peak flow output locations*

Condamine River

Nine pluviograph stations were chosen from the area within and surrounding the Condamine River catchment on the basis of having been in reliable operation in recent years and yielding suitable data for calibration of the Condamine River hydrologic model. These nine stations are listed in Table 5-5 and illustrated in Figure 5-31.

Table 5-5. BoM pluviograph stations relevant to Condamine Creek catchment in model calibration

Site	Gauge number	Latitude	Longitude
Clifton Post Office	41018	27.9317 S	151.9058 E
Killarney Post Office	41056	28.3344 S	152.2953 E
Leyburn	41060	28.0092 S	151.5861 E
Leyburn Post Office	41063	28.0106 S	151.5856 E
Darr Creek TM	41090	26.5392 S	151.1347 E
Leslie Dam	41445	28.2144 S	151.9194 E
Cooby Creek Dam	41512	27.3825 S	151.9244 E
Dalby Airport	41522	27.1605 S	151.2634 E
Toowoomba Airport	41529	27.5425 S	151.9134 E

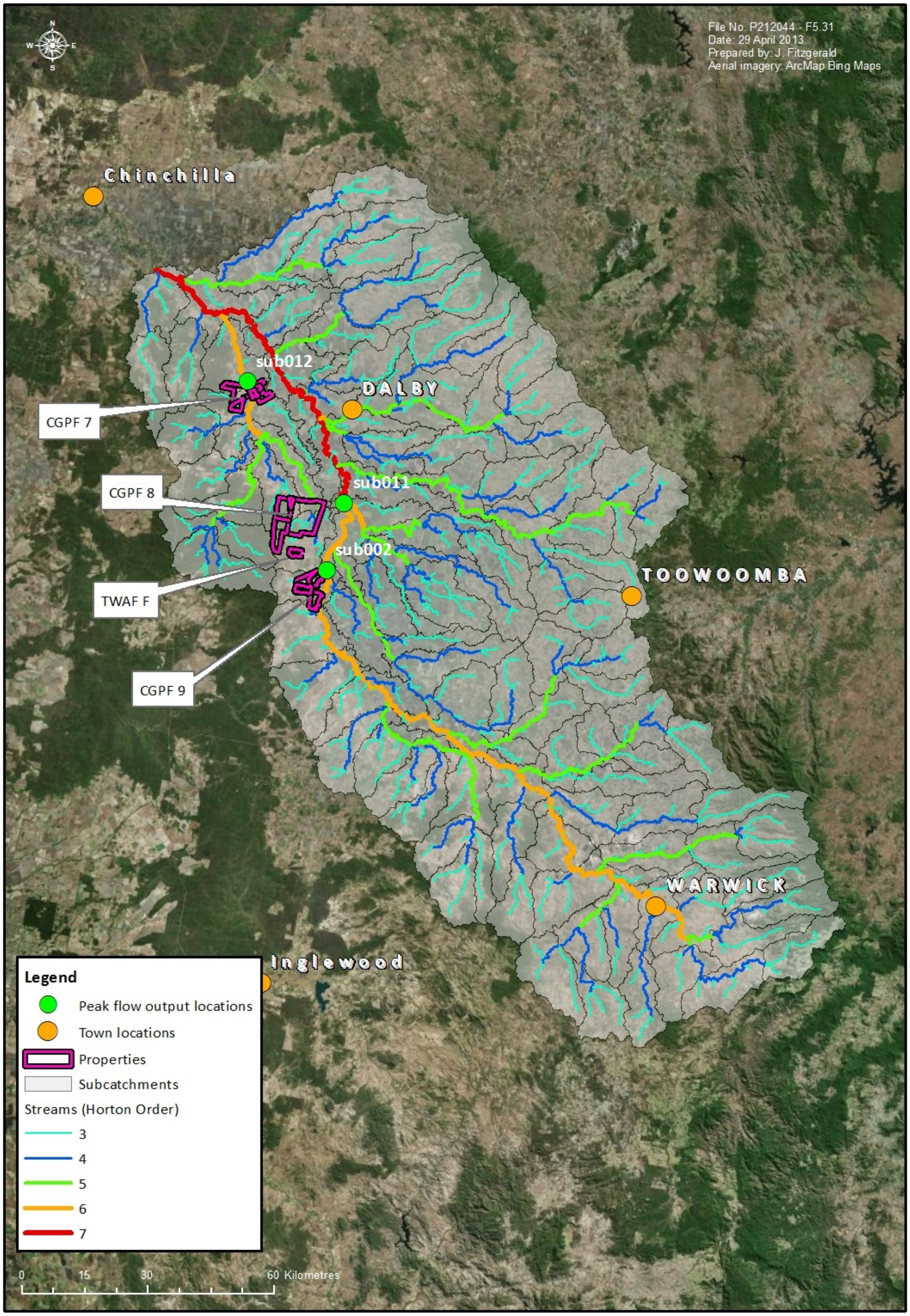

Figure 5-31. *Condamine River hydrologic model catchment delineation and flow peak output locations*

Previous hydrologic studies

The peak flows derived in the FFA developed by Water Technology (2011, p29) were adopted for input into this assessment. This was because the data for the Gil Weir gauging station was demonstrated, by Water Technology (2011), to be unreliable. The reason for requiring this information is explained in further detail below. The peak flows are summarised in Table 5-6.

Table 5-6. Peak flows 10 to 1% AEP for Gil Weir streamflow gauge (Water Technology 2011, p29)

AEP	Peak flow (m^3/s)
10%	947
5%	1,523
2%	2,599
1%	3,725

For more details of the derivation of these peak flows, refer to Water Technology (2011).

Hydrologic modelling for two models, Dogwood Creek and Condamine River

The Dogwood Creek hydrologic model has 130 subcatchments while the Condamine River hydrologic model has 106 subcatchments. The resulting layout of subcatchments and reaches is shown in Figure 5-30 and Figure 5-31 respectively. Each figure also indicates the peak flow output locations selected for reporting (see Table 5-8 and Table 5-11 for a summary of these values).

Dogwood Creek hydrologic model calibration and design model

Individual event calibration

Using the plot shown in
Figure 5-27, Alluvium selected a range of different events to calibrate the Dogwood Creek hydrologic model. Through the process of collecting and analysing pluviograph and streamflow data, it was found that only four flood events yielded sufficient data to calibrate the model.

Each of these four events was calibrated separately for a range of m values (dimensionless exponent used in reach storage-discharge calculations). Figure 5-32 shows the parameter interaction curve developed using this method.

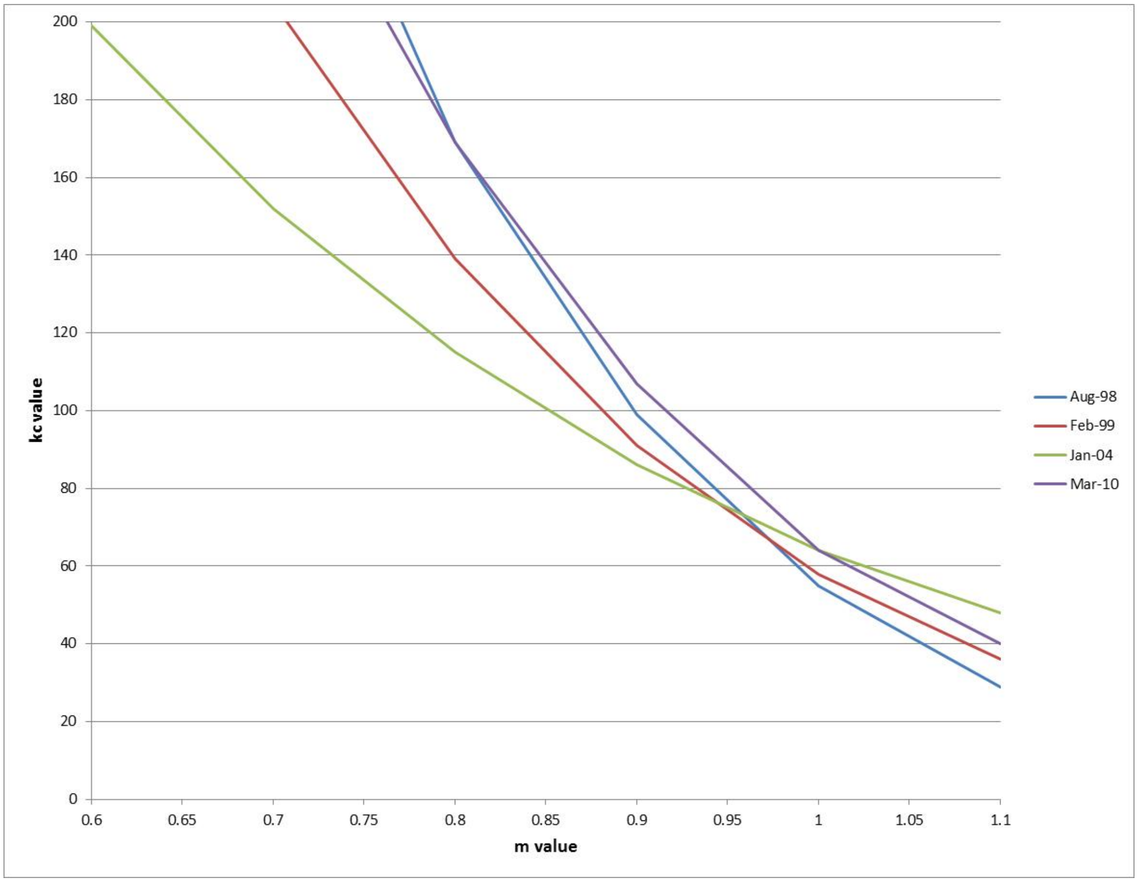

Figure 5-32. *Parameter interaction curve Dogwood Creek model at Gil Weir*

Although the method did indicate that the m value would most likely reside between 0.9 and 1.0, it was evident that calibrating the model against Water Technology's FFA would be more appropriate given the unreliability of the recorded flow data at the Gil Weir streamflow gauge.

Calibration using Flood Frequency Analysis

Using RORB to generate a number of curves for a range of m values, the results were compared to the peak flows derived by Water Technology (2011, p29). The results are presented in Figure 5-33.

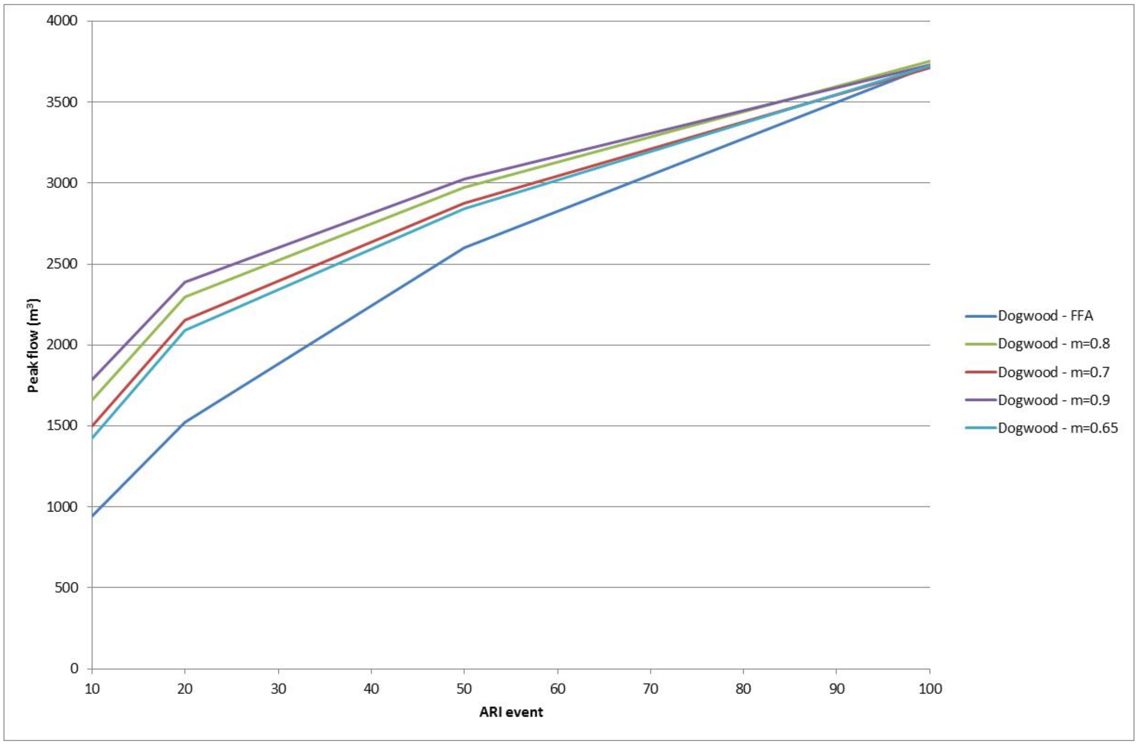

Figure 5-33. *Calibration of Dogwood Creek model and compared to Water Technology (2011) Flood Frequency Analysis peak flows*

Based on these results, it was clear that in this case reducing the m value would obtain a better fit. However, an m value of 0.65 was considered the lowest acceptable value to use for this region (Weeks, 1986). As this was in contrast to the preliminary findings from the direct event calibration, which suggested an m value approaching 1, it was considered appropriate to adopt a middle ground approach and use an m value of 0.8. While the adoption of m = 0.8 yielded a less satisfactory result at a lower AEP, it did provide an appropriate match for the 1% AEP event, which is the focus of this study.

Adopted model parameters

With an m value fixed at 0.8, the k_c value for the model was adjusted to match the peak flow for the 1% AEP event derived in Walton (2011) FFA. It was found that when k_c = 65, the peak flows corresponded. For comparison, the Weeks' value is slightly more conservative with k_c = 61.06. The adopted k_c and m values are listed in Table 5-7.

As the FFA was used to calibrate the modelled peaks, as opposed to the losses, it was necessary to fix the losses to those typically used for uncalibrated design models in Queensland which is also outlined in Table 5-7.

Table 5-7. Adopted parameters in the Dogwood Creek hydrologic model

Parameter name	Adopted number
k_c value (Weeks k_c value for comparison)	65 (61.06)
m value	0.80
Initial losses (IL)	25mm
Continuing losses (CL)	2.5 mm/hr

Hydrologic model design outputs

Presented in Table 5-8 are the RORB model outputs for existing conditions for the Dogwood Creek catchment. The peak flow output locations are depicted in Figure 5-30 and have been chosen to facilitate reporting. Note that the design discharges at the peak flow locations did not all coincide on the same duration storm event; these are also highlighted in Table 5-8.

Table 5-8. 1% AEP design discharges (at peak locations) generated from hydrologic modelling, Dogwood Creek model

	Sub043	Sub051	Sub103
Upstream catchment (km^2)	338	415	1,600
Critical duration (hours)	18	18	24
Peak Discharge (m^3/s)	751.2	821.3	2466.0

Condamine River hydrologic model calibration and design model

Individual event calibration

Using two streamflow gauges along the Condamine River reach, Cecil Weir and Brigalow gauges respectively, Alluvium selected a range of different events to calibrate the Condamine River hydrologic model. Using a combination of pluviograph and streamflow data, four flood events were selected based on the appropriateness of available data. Each of these four events was calibrated separately to find the unique set of parameters that provided the best fit. Figure 5-34 and Figure 5-35 show the parameter interaction curves using this method for calibration.

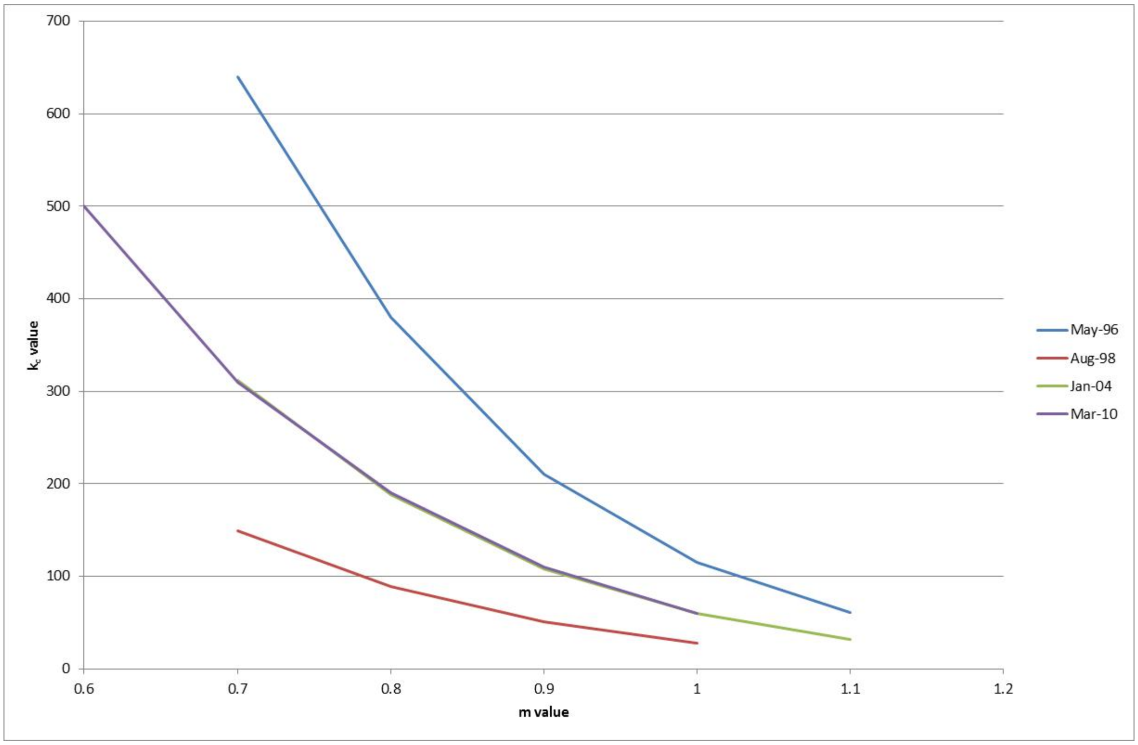

Figure 5-34. *Parameter interaction curve Condamine River model at Cecil Weir*

As demonstrated in both Figure 5-34 and Figure 5-35, this method of calibration failed to yield an appropriate calibration for k_c and m and also failed to provide an approximate range of values. Based on these results, it was determined that it would be necessary to calibrate the Condamine River hydrologic model against a FFA.

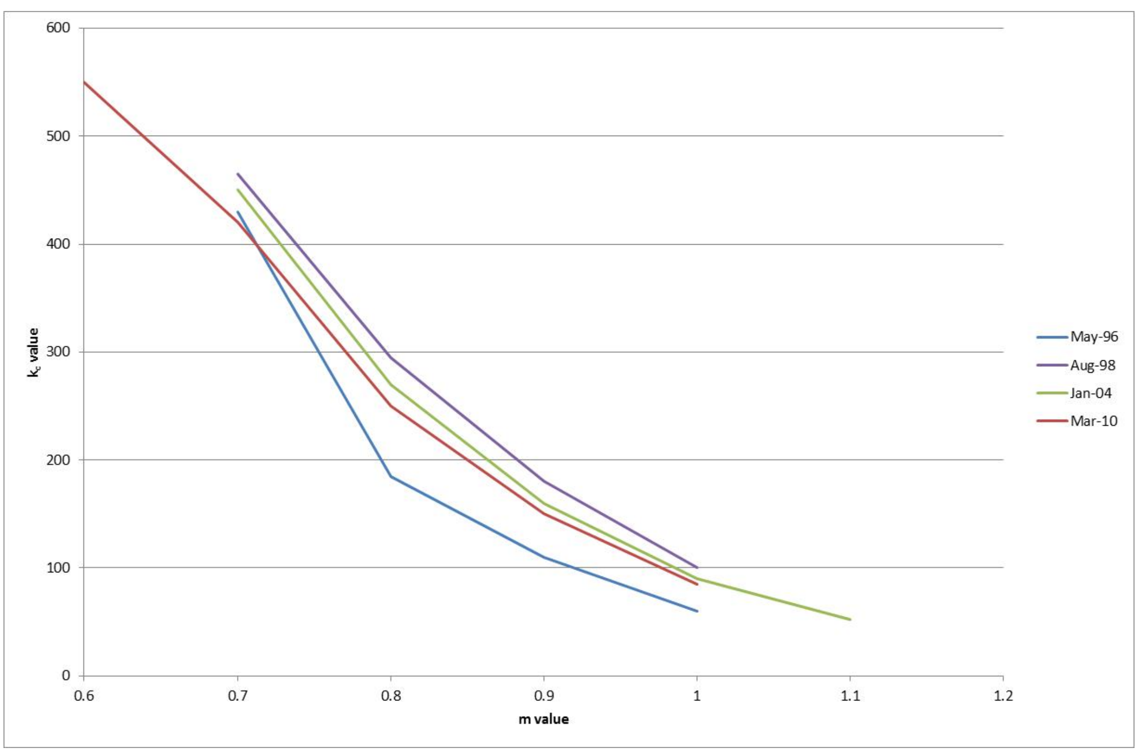

Figure 5-35. *Parameter interaction curve Condamine River model at Brigalow*

Flood Frequency Analysis

In order to use the flood frequency analysis approach to calibrate the Condamine River hydrologic model, annual maxima streamflow values were derived for both Cecil Weir and Brigalow streamflow gauges, see Figure 5-36 and Figure 5-37, respectively.

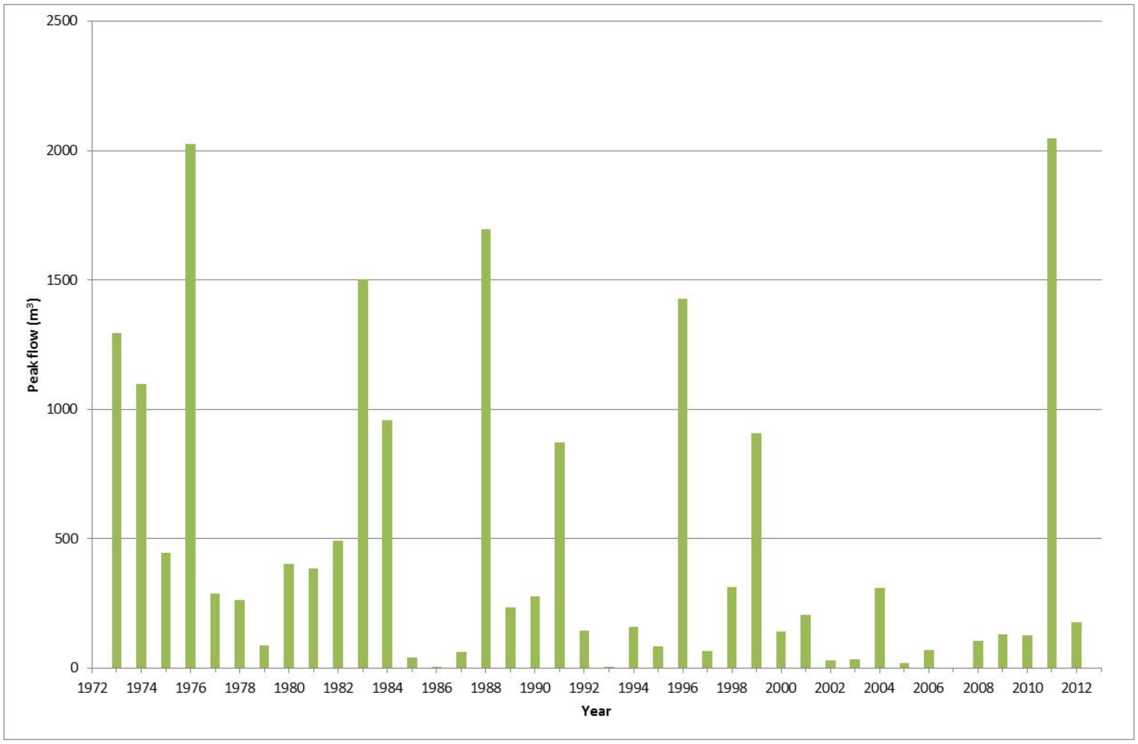

Figure 5-36. *Annual maxima peak flows at the Condamine River at Cecil Weir streamflow gauge*

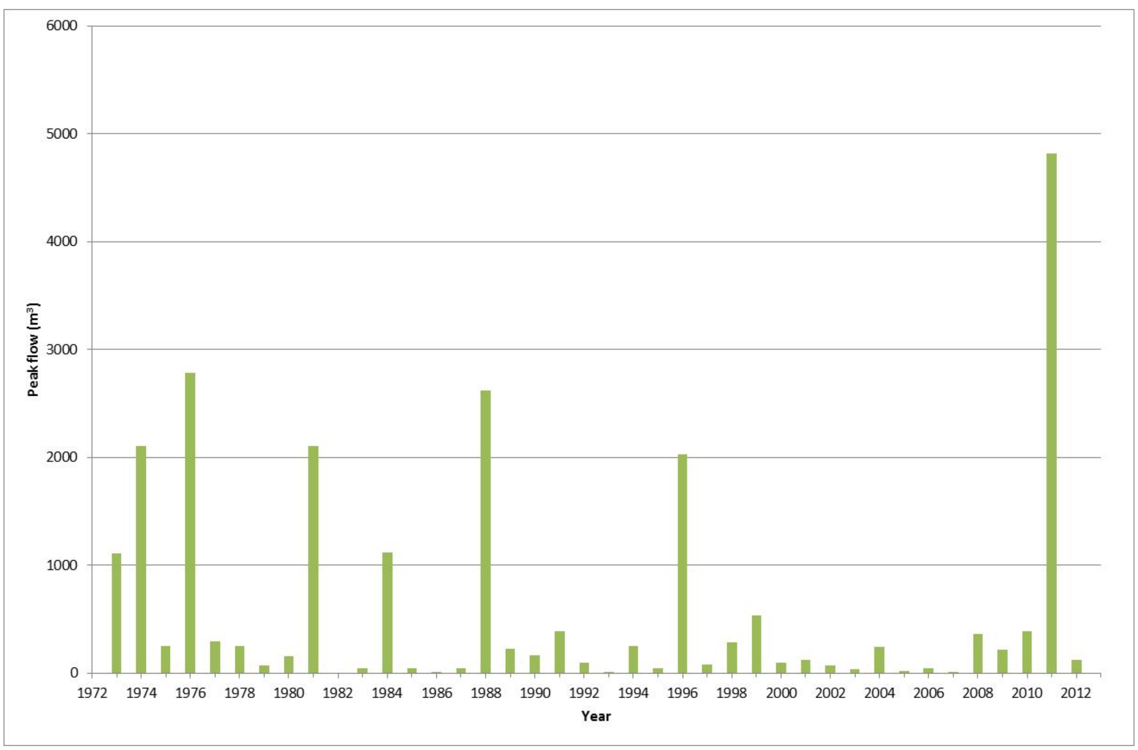

Figure 5-37. *Annual maxima peak flows at the Condamine River at Brigalow streamflow gauge*

The annual maxima peak flows were used as inputs into Flike, a statistical analysis program for working with streamflow data. Using the LH moment and generalised extreme value (GEV) statistical methods – which provided the best fit for both streamflow gauges – peak flows were derived up to the 1% AEP event (GEV distribution and Generalisation of the L moment distribution statistical method respectively, are FFA methods used in Flike). The resulting FFA curves for both streamflow gauges are illustrated in Figure 5-38 and Figure 5-39, respectively. Note that "cumec" is equivalent to m^3/s.

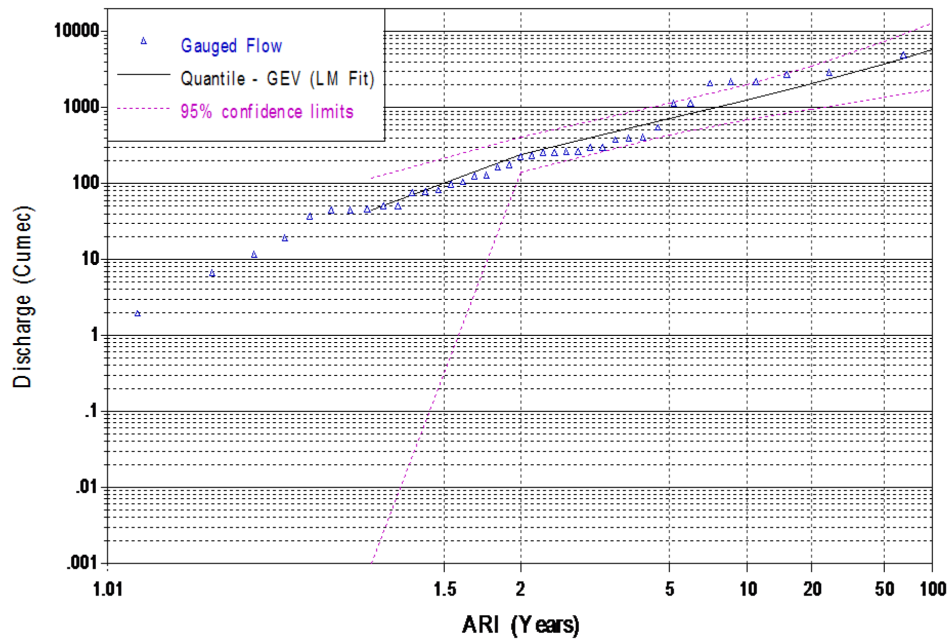

Figure 5-38. *Annual maxima FFA using Condamine River at Brigalow streamflow gauge data*

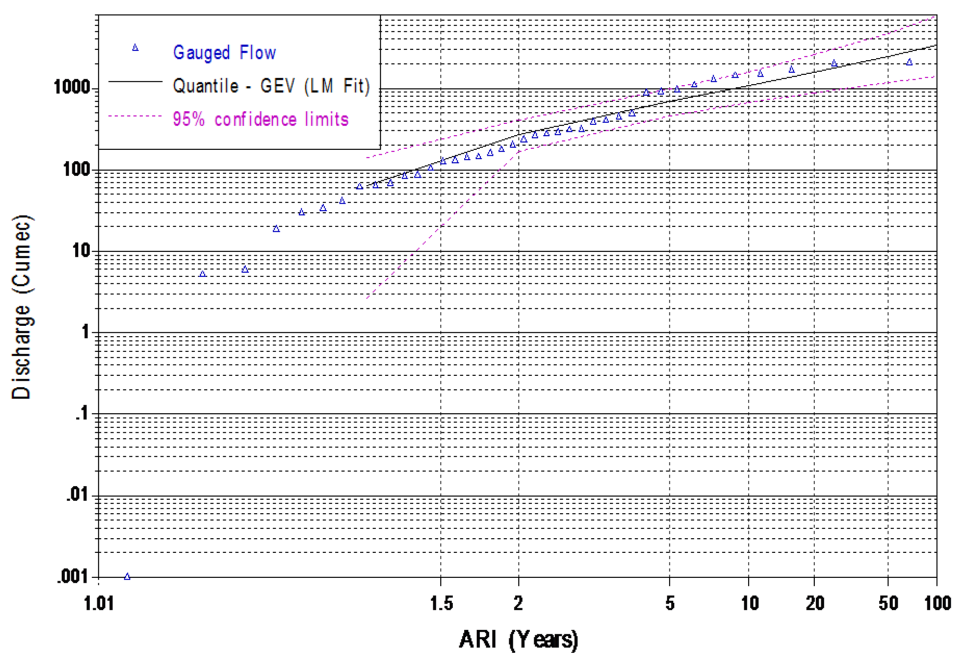

Figure 5-39. *Annual maxima FFA using Condamine River at Cecil Weir streamflow gauge data*

The resulting peak flow rates adopted for the 1% AEP event for both the Brigalow and Cecil Weir streamflow gauges are presented in Table 5-9.

Table 5-9. Summary of annual maxima FFA 1% AEP peak flow rates at Brigalow and Cecil Weir streamflow gauges

Streamflow gauge name	Adopted 1% AEP peak flow (m^3/s)
Condamine River at Brigalow	5,759.9
Condamine River at Cecil Weir	3,395.5

Calibration using FFA

Using RORB to generate a number of curves for a range of m values, the results were compared to the peak flow rates generated from Flike (shown in both Figure 5-38 and Figure 5-39). The results of this assessment are illustrated in Figure 5-40 and Figure 5-41, for the Cecil Weir and Brigalow streamflow gauges, respectively.

Based on these results, an m value of 0.60 generated the closest fit to the FFA for both the Cecil and Brigalow streamflow gauges. Given that 0.60 was considered too low for calibrating the model, an m value of 0.8 was adopted.

While the adoption of m = 0.8 yielded a less satisfactory result at lower AEP it did provide an appropriate match for the 1% AEP event which is the focus of this study. Testing demonstrated that the magnitude of difference in water surface elevations between m=0.6 and m=0.8 is for a 1% AEP event is minimal. A summary of the adopted values is outlined in Table 5-10.

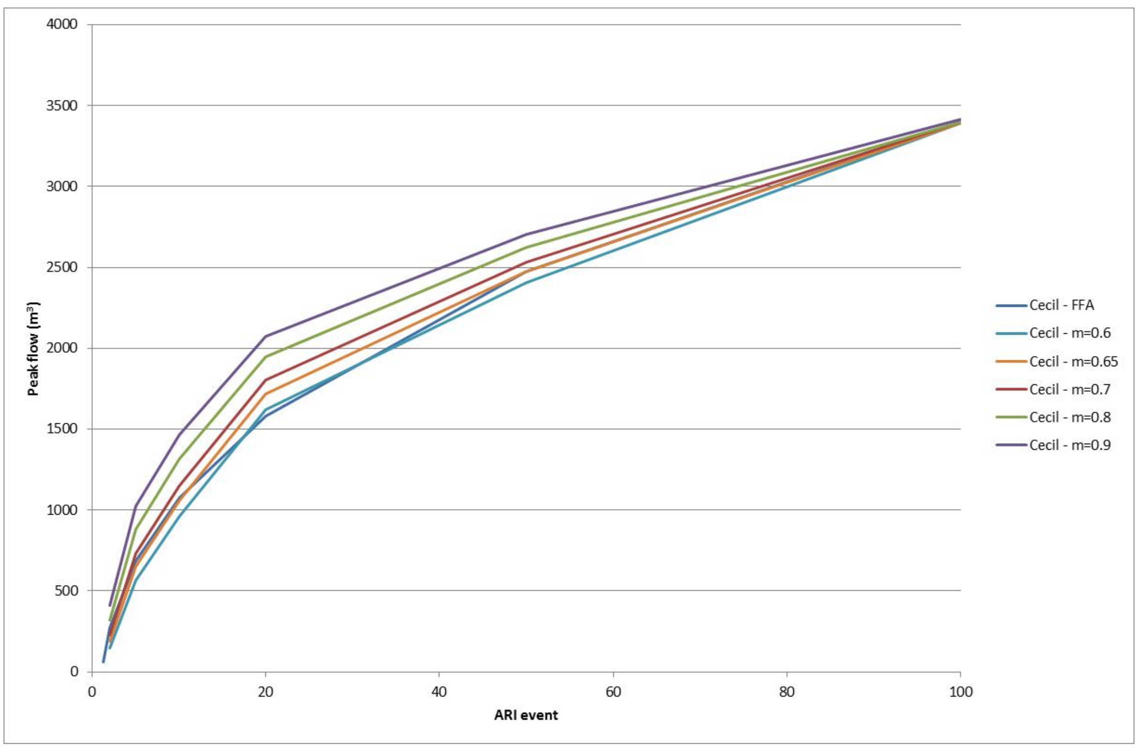

Figure 5-40. *Calibration of Condamine River model comparing against derived FFA, at Cecil Weir streamflow gauge using IL=25mm, CL=2.5 mm/hr*

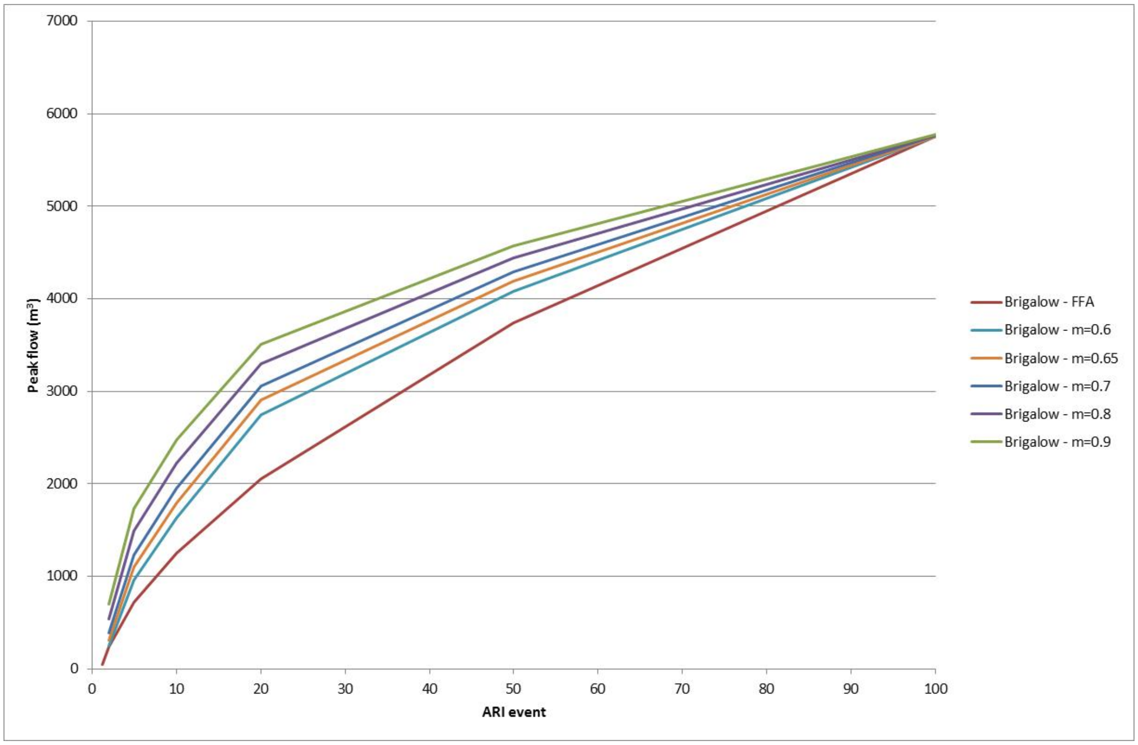

Figure 5-41. *Calibration of Condamine River model comparing against derived FFA, at Brigalow gauge using IL=25mm, CL=2.5 mm/hr*

Adopted model parameters

With an m value fixed at 0.8, the k_c value for the model was adjusted to match the peak flows for the 1% AEP event for each gauging station derived from the FFA. The resulting k_c values are presented in Table 5-10.

As the FFA was used to calibrate the modelled peaks, as opposed to the losses, it was necessary to fix the losses to those typically used for uncalibrated design models in Queensland, which is also outlined in Table 5-10.

Table 5-10. Adopted parameters in the Condamine River hydrologic model

Parameter name	Adopted number
k_c value, Cecil gauge (Weeks' k_c value for comparison)	206.50 (158.4)
k_c value, Brigalow gauge (Weeks' k_c value for comparison)	167.50 (101.6)
m value, Cecil gauge	0.80
m value, Brigalow gauge	0.80
Initial losses (IL), all models	25 mm
Continuing losses (CL), all models	2.5 mm/hr

Hydrologic model outputs

Presented in Table 5-11 are the RORB model outputs for existing conditions for the Condamine River catchment. The peak flow output locations are also depicted in Figure 5-31 and have been chosen to facilitate reporting. Note that the design discharges at the peak flow locations did not all coincide on the same duration storm event; these are also highlighted in Table 5-11.

Table 5-11. 1% AEP design discharges (at peak flow locations) generated from hydrologic modelling, Condamine River model

	Sub002	Sub011	Sub012
Upstream catchment(km^2)	7,734	9,651	1,560
Critical duration (hours)	30	30	30
Peak Discharge (m^3/s)	3,399	3,645	1,668

5.4 2D hydrodynamic modelling

Dogwood Creek

Modelling demonstrated that the CGPF2 property is vulnerable to flooding in a 1% AEP event. This is a direct result of riverine flood modelling arising from Bottle Tree Creek and areas of channelised flow and sheet flow from localised runoff.

Figure 5-42 illustrates the entire 1% AEP event flood extents and depth for all Dogwood Creek models. Figure 5-43 focuses on the CGPF2 property only.

Other than the flood extent as a direct result of flow within Bottle Tree Creek, the only other significant form of flooding is due to the watercourse passing through with southwest parcel of land, in a west to east direction.

Overall, the balance of land unaffected by flooding due to the 1% AEP event comes to approximately 1,500 ha. Should development be required in the entire south-western parcel of land, it is highly likely that a satisfactory localised drainage option could be developed to mitigate any impact on neighbouring land.

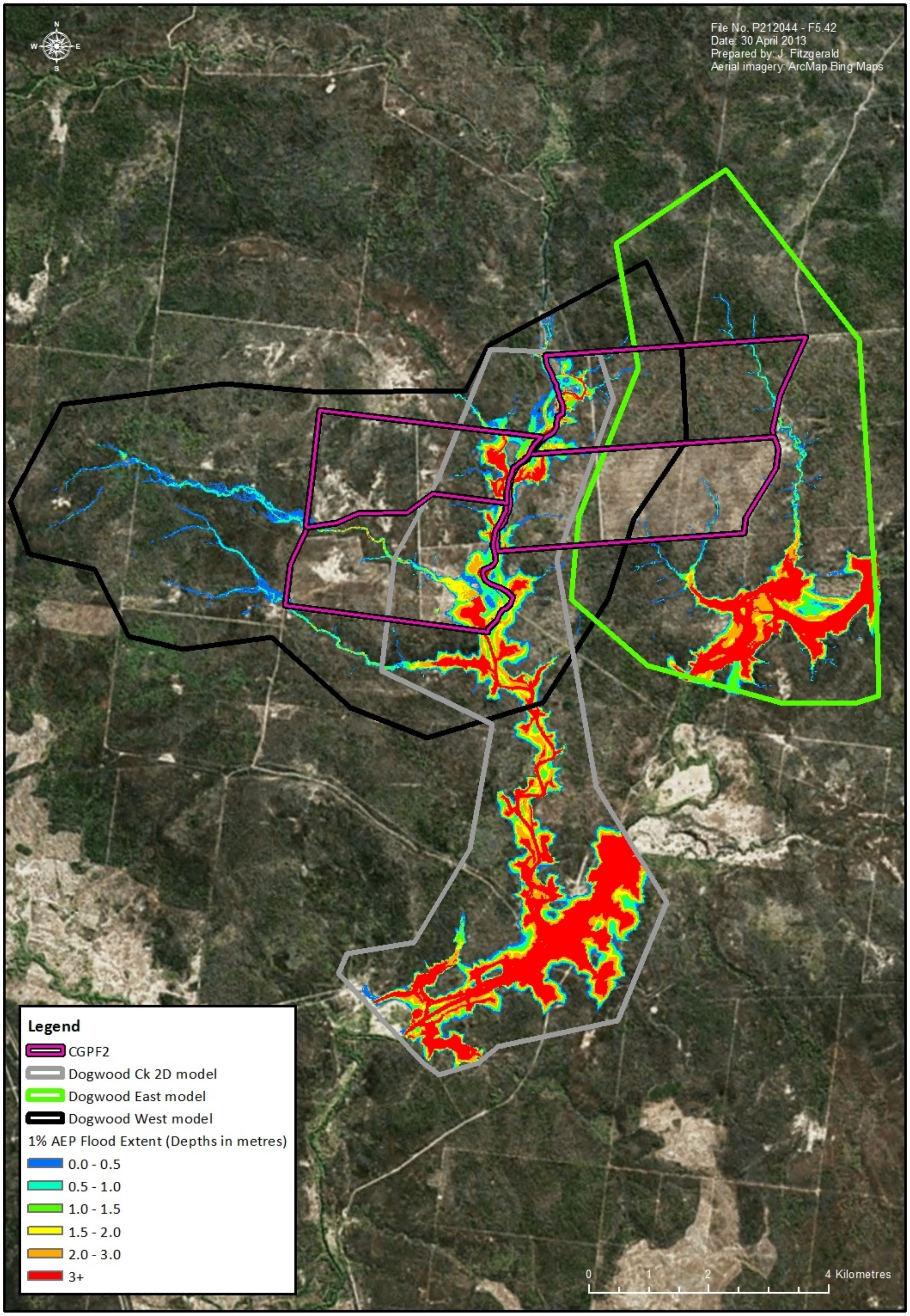

Figure 5-42. *1% AEP event flood extents and depth for all Dogwood Creek models*

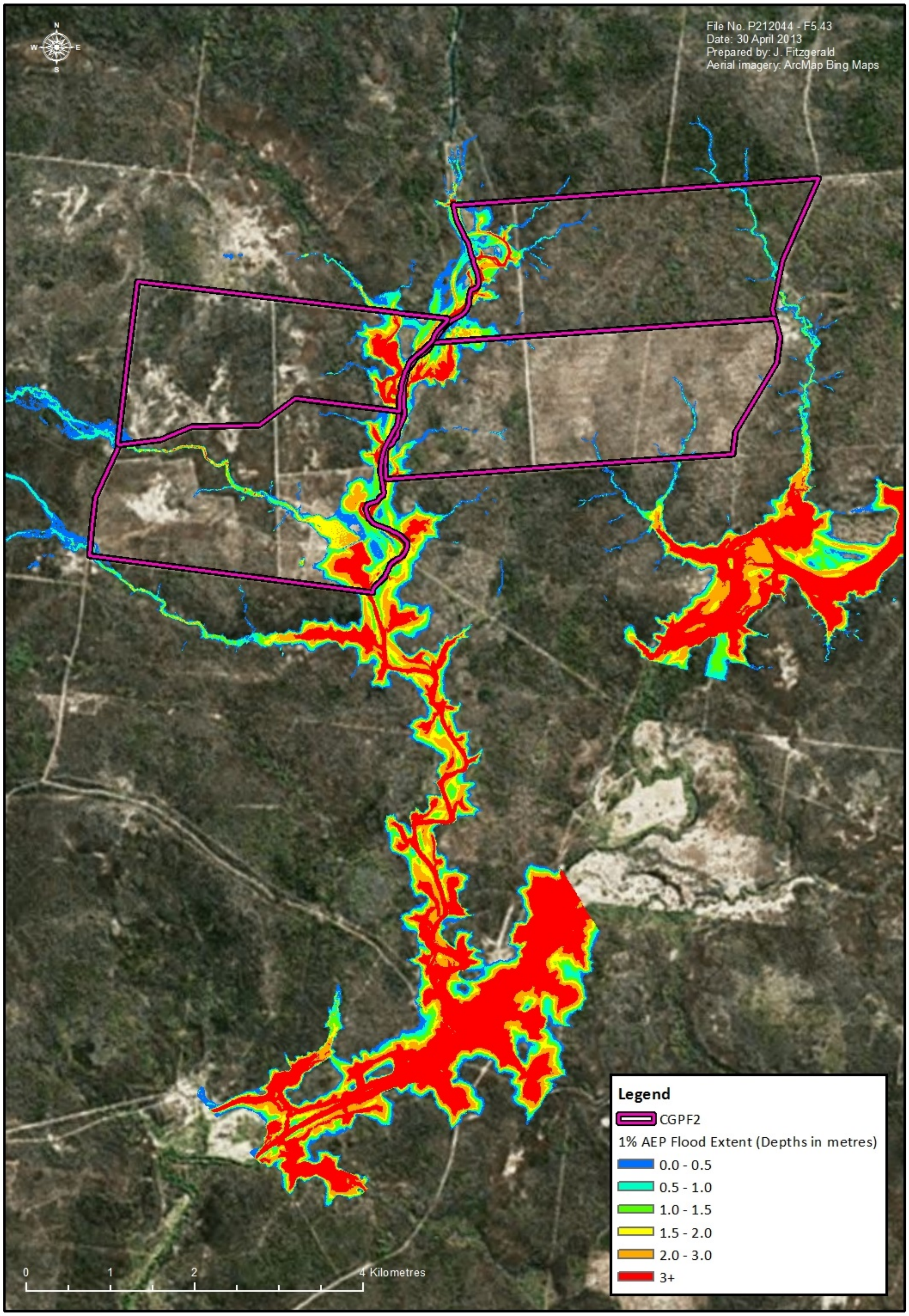

Figure 5-43. *1% AEP event flood extents and depth for the CGPF2 property only*

Condamine River

Modelling demonstrated that all properties analysed in this hydrodynamic assessment, the CGPF7, 8 and 9 properties and the TWAF F property, are vulnerable to flooding in a 1% AEP event. This is a direct result of a combination of riverine flooding and areas of channelised flow and sheet flow from localised rainfall runoff.

Figure 5-44 provides an overview of the 1% AEP event flood extents and depths for all Condamine River models. As this model was developed specifically to generate hydrology for the finer resolution models, the outputs have been provided in each figure only in order to help better understand the flood behaviour of the catchment. Also note that the NASA SRTM data used in some sections of the model contains some artefacts (e.g. man-made structures) and has resulted in coarse flood results in those areas.

Jimbour floodplain

The Jimbour floodplain is in the area of Jimbour Creek, Cooranga Creek and Myall Creek. Detailed flood modelling has not been undertaken for that area, although it is partially covered by the model. To model overland flows in the Jimbour floodplain for the purpose of assessing erosion related to solely wells, tracks and gathering lines was considered unnecessary as the recommendations for erosion management strategies will not change.

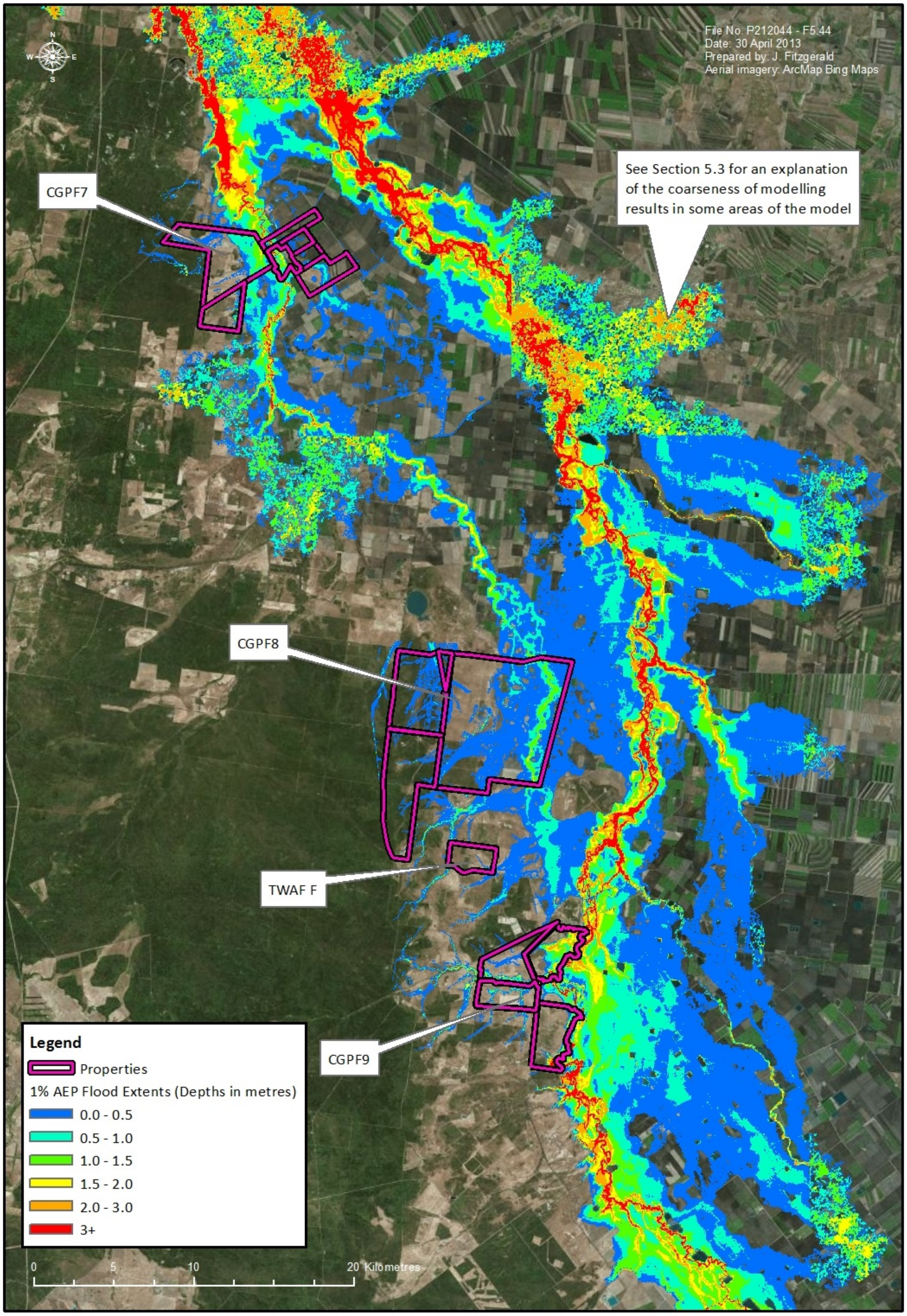

Figure 5-44. *1% AEP event flood extents and depth for all Condamine River models*

Figure 5-45 to Figure 5-48 illustrates the 1% AEP event flood extents and depths for the respective project sites (from north to south).

The CGPF7 property

Project site the CGPF7 property straddles Wilkie Creek. The parcels of land on the west side of the Creek experience significant inundation in the area immediately adjacent to the creek, and some shallow depth overland flow crossing the site from west to east.

The parcels of land on the east side of Wilkie Creek are also heavily inundated immediately adjacent the Creek, however away from the watercourse the majority of the land lies outside the flood extent. There is a flood flow path entering the site from the south and bisects the southern end of the land parcels.

Overall, a significant portion of the land lies outside the 1% AEP flood extent, particularly on the west side of Wilkie Creek. See Figure 5-45 for an illustration of the flood modelling for this site.

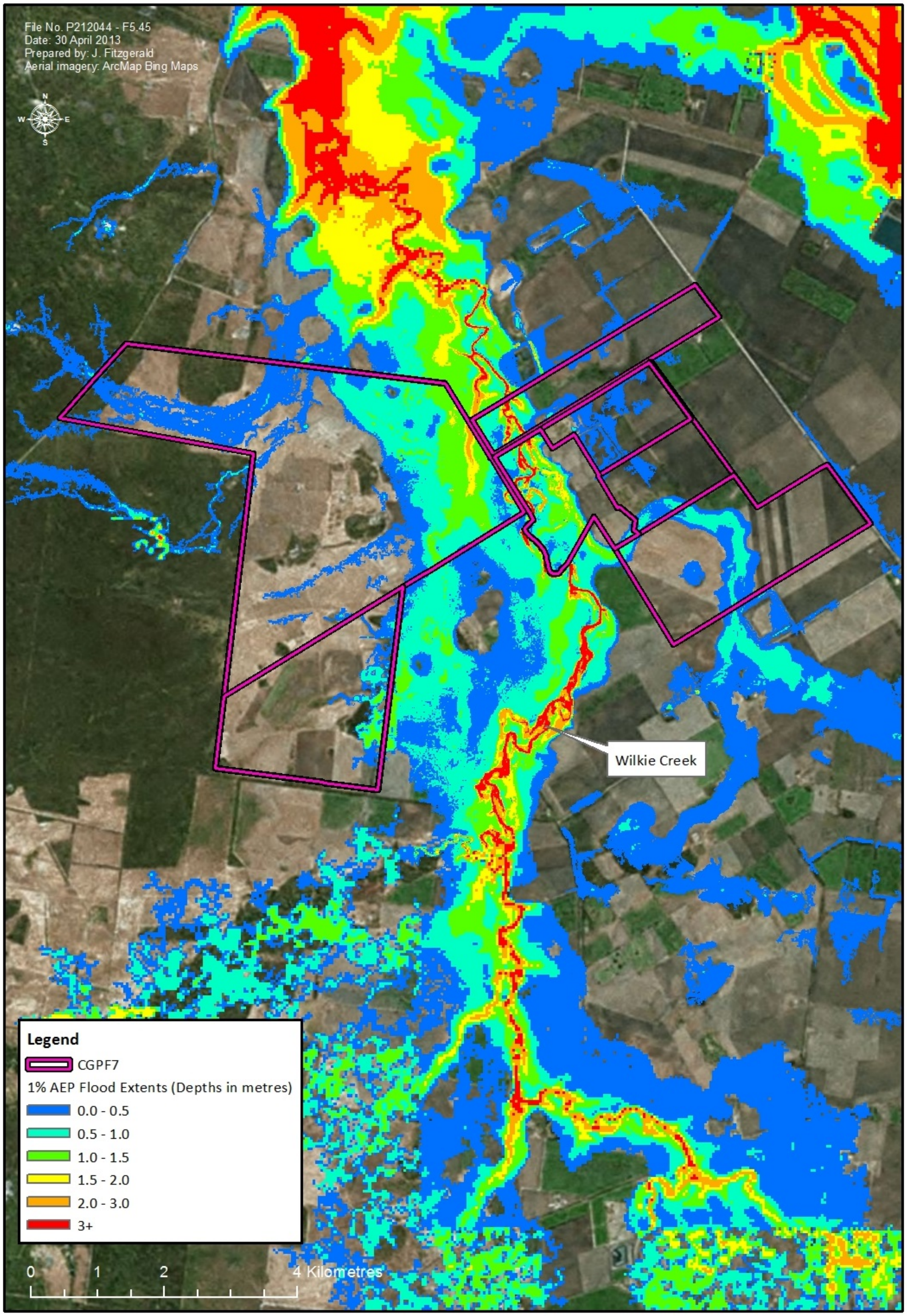

Figure 5-45. *1% AEP event flood extents and depth for the CGPF7 property*

The CGPF8 property

The CGPF8 property experiences significant flooding across a large portion of the site, particularly in the north and east. The eastern sector lies directly within the flood extents from the Condamine River. The majority of the site experiences significant, albeit shallow overland flow resulting from localised rainfall runoff.

Despite the broad inundation of flooding across the CGPF8 property, there is an area of land in the centre of the site (approximately 1,200ha), which remains mostly flood free for the 1% AEP event as shown in Figure 5-46. As the majority of the flow across the site is shallow, it may be managed on site through adequate natural resource management techniques with minimal impact on neighbouring properties.

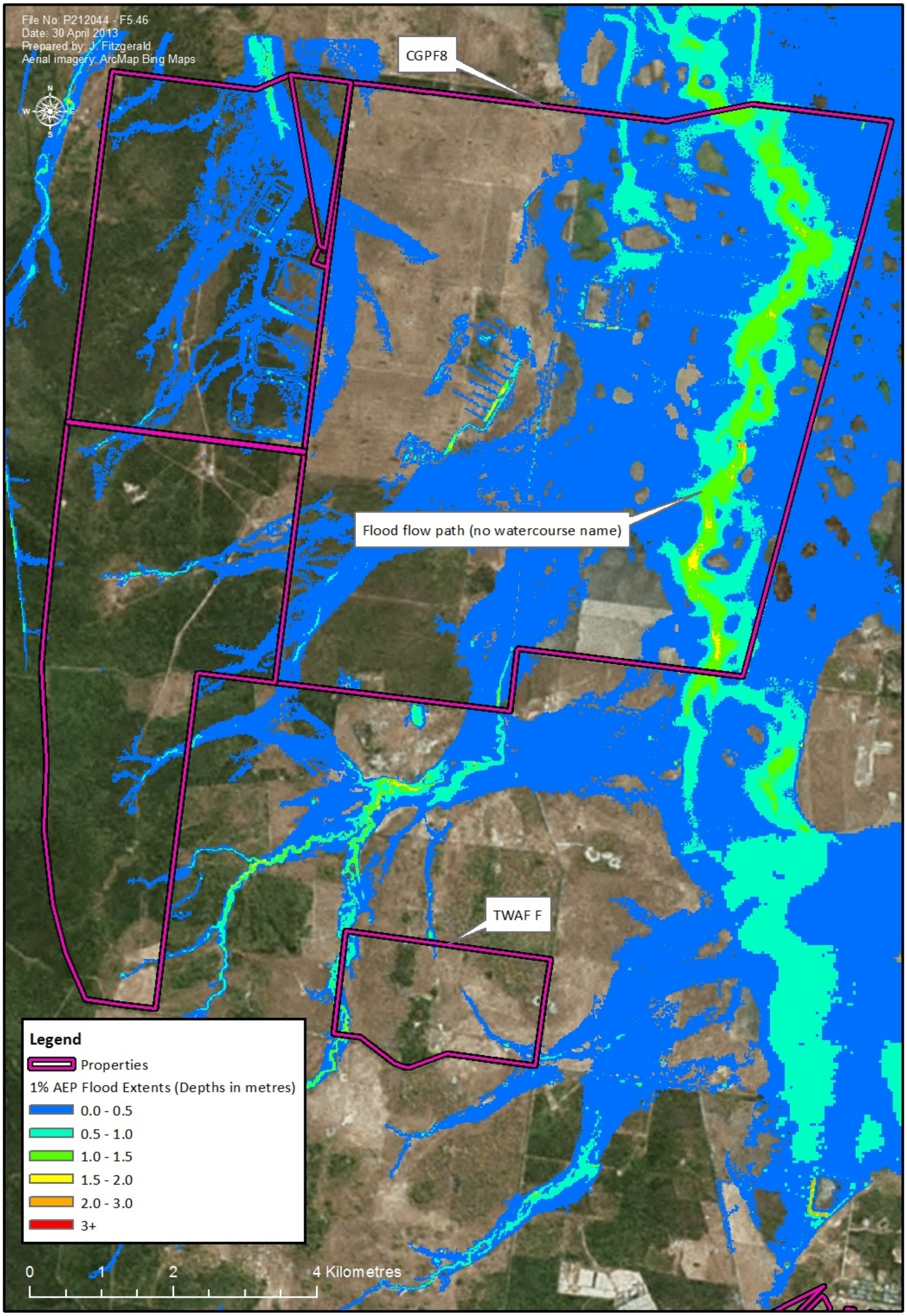

Figure 5-46. *1% AEP event flood extents and depth for the CGPF8 property*

The TWAF F property

As shown in Figure 5-47, the TWAF F property is completely devoid of riverine flooding and generally free of localised rainfall runoff. Channelised flow straddles the western boundary of the site with flow coming from south and heading north.

A small section of channelised flow also intersects the site in the southeast corner with localised runoff contributing to this flow. As the majority of the flow lies within the boundary extents, these areas of channelised flow could probably be managed on site through adequate natural resource management techniques.

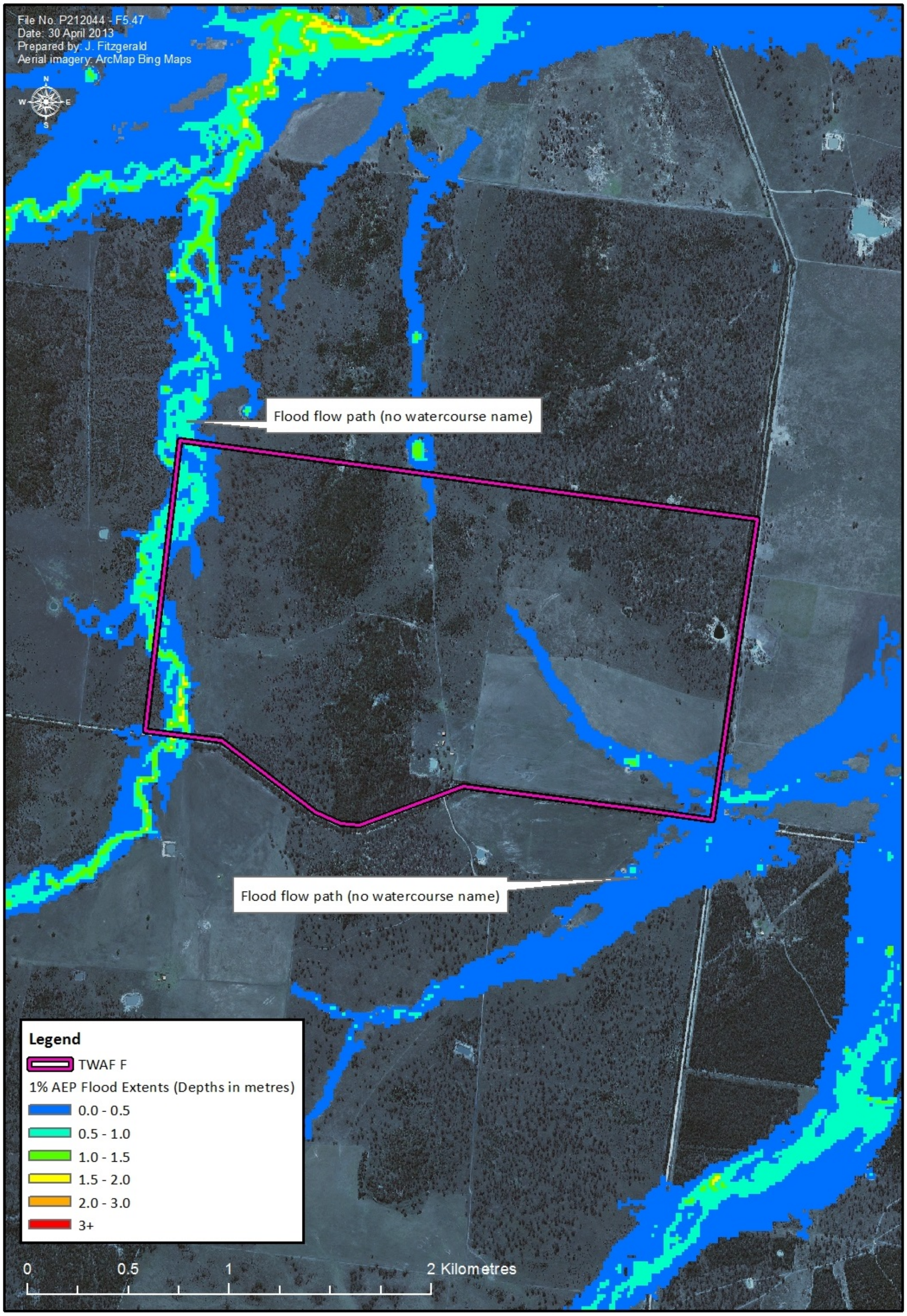

Figure 5-47. *1% AEP event flood extents and depth for the TWAF F property*

The CGPF9 property

Figure 5-48 demonstrates that eastern sections of the parcels of land, adjacent to the Condamine River, are vulnerable to riverine flooding with flood depths often exceeding 3 m.

Channelised flow bisects the northwest of the site from west to east along with two smaller flood channels, due to localised rainfall runoff, and converges with the riverine flooding at the east extent of the project site.

Despite this, there are approximately 500 ha of land in the south that is not vulnerable to 1% AEP flooding. There is also a 700 ha section of land in the north which could probably be managed on site through adequate natural resource management techniques, and providing the flood path in the north of the site was diverted around development.

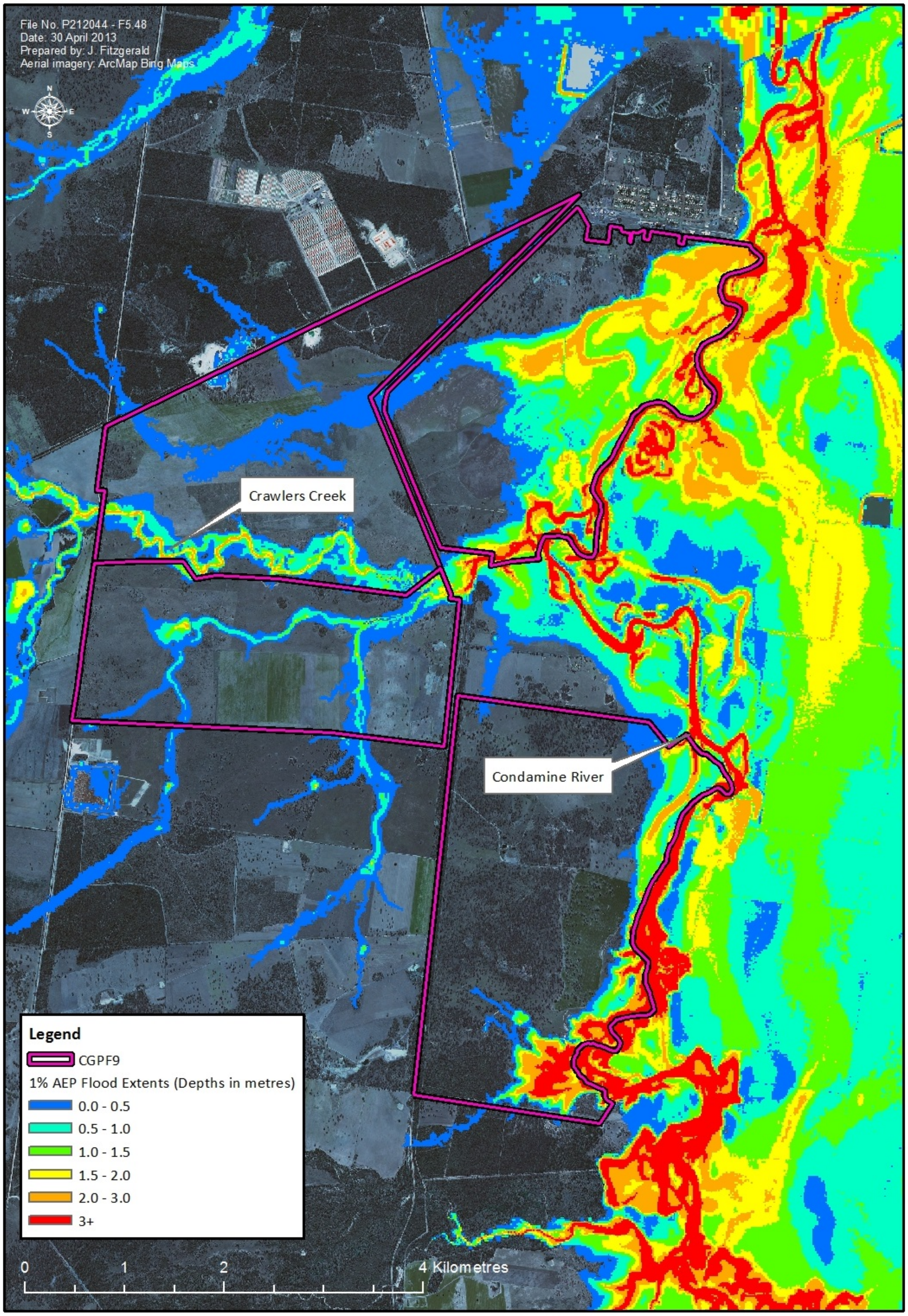

Figure 5-48. *1% AEP event flood extents and depth for the CGPF9 property*

Hydraulic structures
Two bridges immediately north of the project site the CGPF9 property, the Cecil Plains Rail Bridge and Toowoomba – Cecil Plains Road crossing, were modelled in the hydrodynamic models as complete blockages. However, due to substantial engagement of the flood plain for the 1% AEP event, the change in water surface elevation was insignificant (approximately 0.02 m).

Figure 5-49 identifies the range of structures that were taken into consideration for testing. The images from Figure 5-50 to Figure 5-55 show some of the bridges that were assessed during the site assessment. The locations and names of these photos are also marked in Figure 5-49.

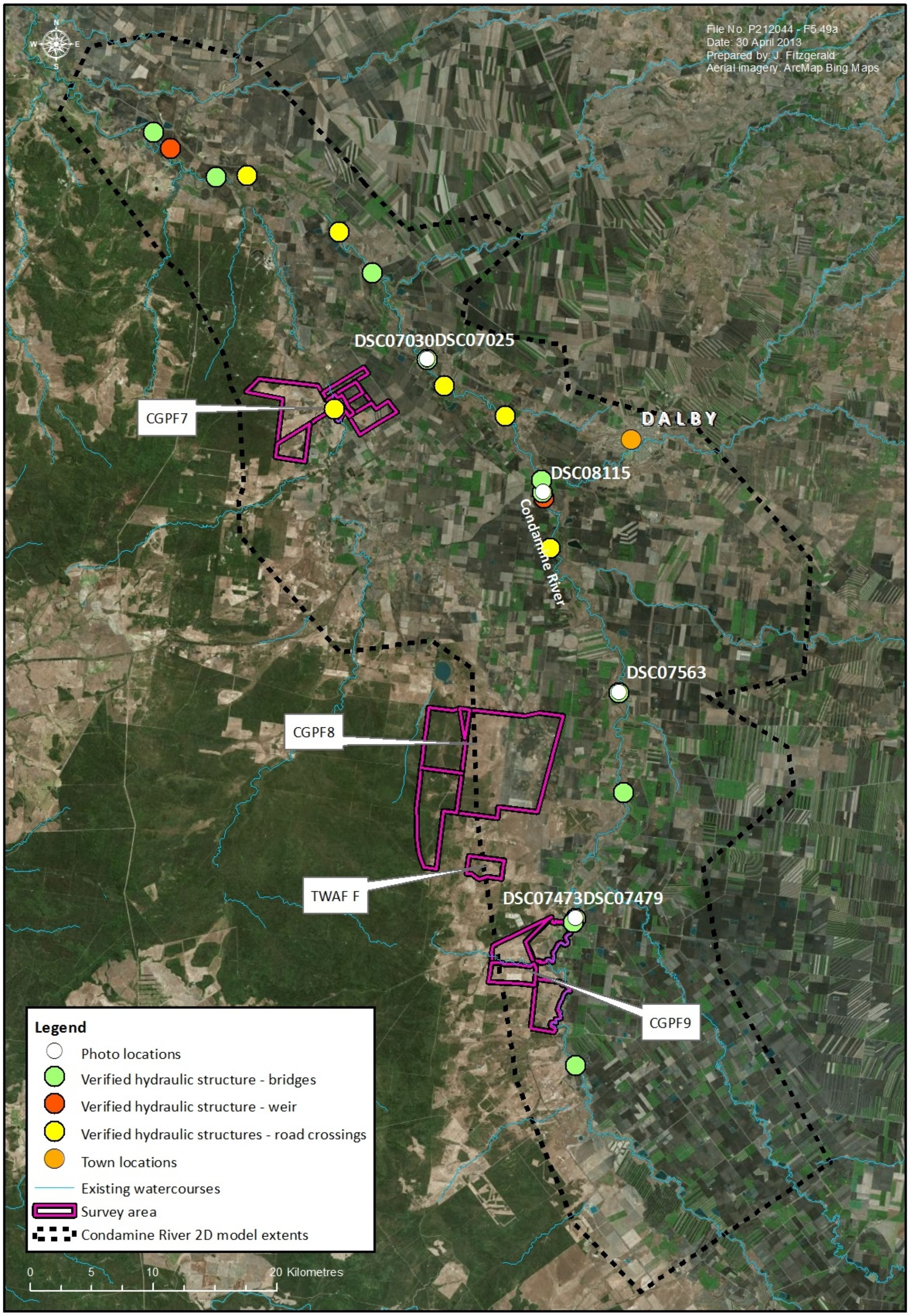

Figure 5-49. *Hydraulic structures considered for the Condamine River XPSWMM models*

Figure 5-50. *Assessment of bridges along Condamine River, photo DSC07030*

Figure 5-51. *Assessment of bridges along Condamine River, photo DSC07025*

Figure 5-52. *Assessment of bridges along Condamine River, photo DSC07473*

Figure 5-53. *Assessment of bridges along Condamine River, photo DSC07479*

Figure 5-54. *Assessment of bridges along Condamine River, photo DSC07563*

Figure 5-55. *Assessment of bridges along Condamine River, photo DSC08115*

Comparison of Condamine River hydrodynamic model results and recorded satellite imagery of the December 2010 flood event

Alluvium obtained satellite imagery of the December 2010 flood event, recorded by MODIS (Moderate Resolution Imaging Spectroradiometer), which is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites, and Landsat 5, NASA's last originally mandated satellite. This flood event was chosen as it is well known to local communities and landholders and because it is a large flood.

The imagery covers the CGPF7 property, the CGPF8 property, the TWAF F property, and the CGPF9 property. The extent of the imagery did not cover the CGPF2 property and so a comparison of the Dogwood Creek hydrodynamic model with such imagery could not be made.

Figure 5-56 presents a comparison of the modelled flood extents through the CGPF7 property overlaid on the Landsat5 image collected on 30 December 2010. The peak flow rate through the Brigalow streamflow gauge (approximately 33km downstream of the CGPF7 property) occurred on the same day as the image was recorded. This corresponded approximately to a 1-1.33% AEP flow event, which is of a similar magnitude as modelled for this project. The modelled flood extents overlaid on the satellite imagery excluded the direct rainfall results as the majority of localised rainfall would have fallen prior to the peak occurring in the Condamine River and would have mostly drained away in the meantime.

The satellite image indicates a flood envelope of a smaller extent compared to the flood envelope generated through hydrodynamic modelling. However, the difference in the two envelopes is minor and may be accounted for by the satellite imagery not having been recorded during the specific peak of the event. It may also be possible that the event may be slightly less than a 1% AEP event in which case the flood extent would not be as broad.

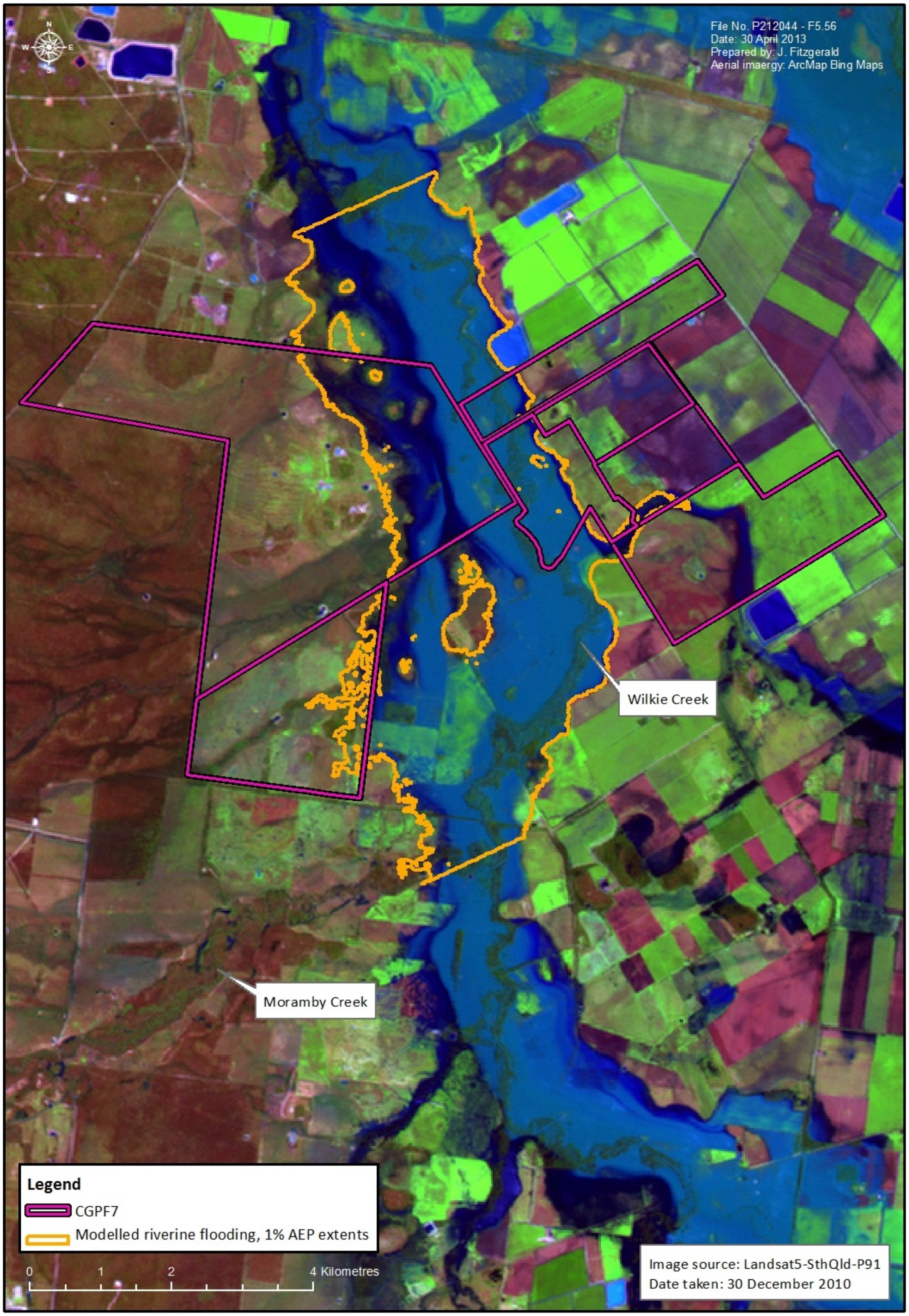

Figure 5-56. *1% AEP event flood extents compared to recorded satellite imagery for the CGPF7 property*

Figure 5-57 presents a comparison of the modelled flood extents through sites the CGPF8 property, the CGPF9 property and the TWAF F property (excluding the direct rainfall results) overlaid on the satellite imagery recorded by MODIS (and also the Landsat5 imagery where it covers part of the CGPF DA8 site). The recorded data through the Cecil Weir flow gauge, nearby to the CGPF9 property indicated the event as being in the range of 3.33 to 2% AEP. However, the satellite imagery was acquired on 31 December 2010, approximately three days after the peak, by which time the flow rate through the gauging station was approximately half, corresponding to a 10% AEP.

It was not possible to obtain and verify satellite imagery of a 1% AEP event without access to the extensive archive of imagery recorded by MODIS and Landsat 5.

The satellite image indicates a significantly reduced flood extent when compared to the flood envelope generated through hydrodynamic modelling. However, this is a reasonable expectation, given the order of magnitude difference in the probability of the two events.

Overall, the correlation between modelled flood extents and recorded flood extents are considered strong enough to validate the model and its suitability for this study.

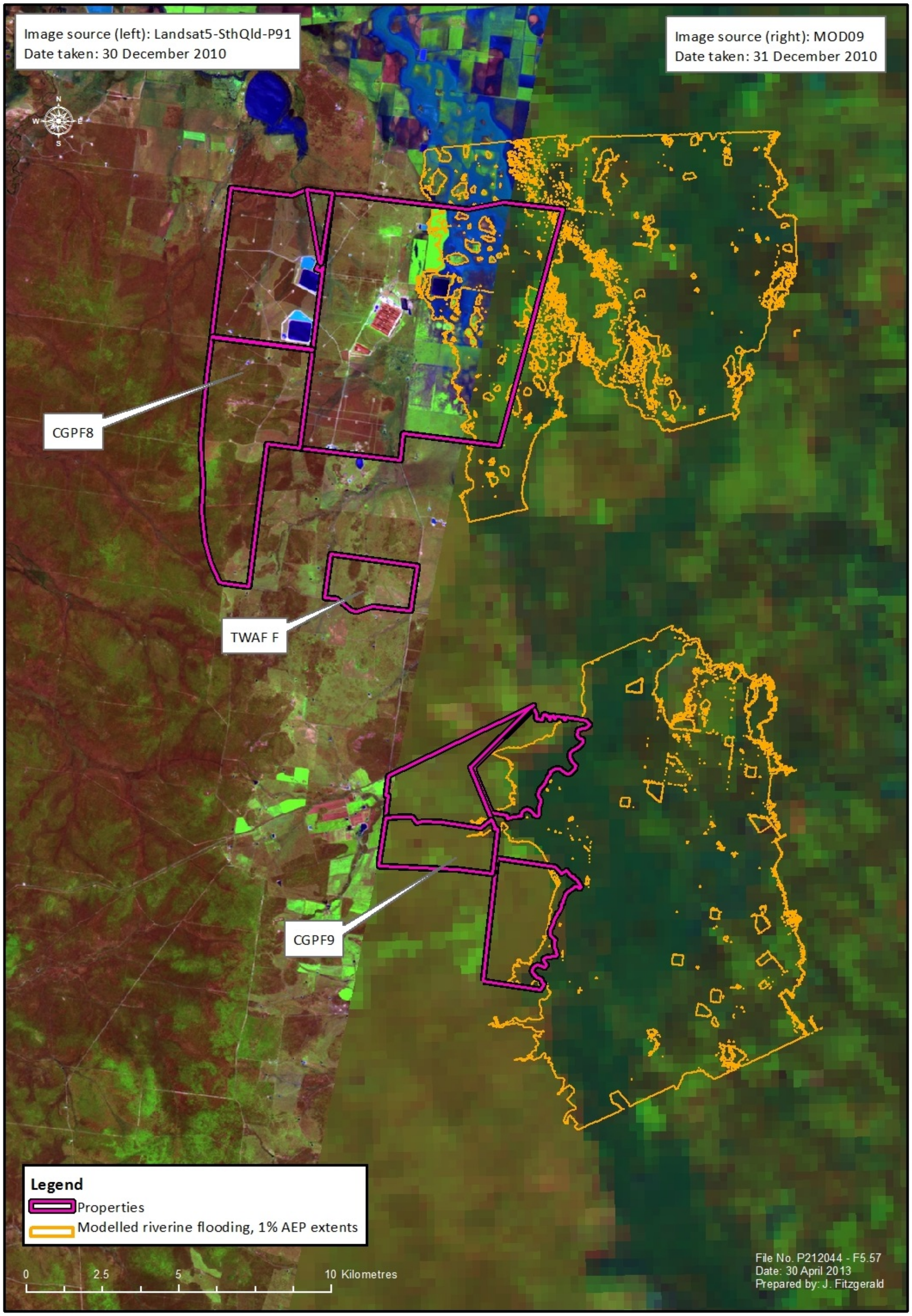

Figure 5-57. *1% AEP event flood extents compared to recorded satellite imagery for the CGPF8 property, the CGPF9 property and the TWAF F property*

Impact of Climate Change on flooding of the Condamine River and Dogwood Creek systems

Modelling was undertaken to test the impact that climate change will have on future storm events in the area and the effect this will have on flood depths and extents.

The Queensland Government document, *Increasing Queensland's resilience to inland flooding in a changing climate: Final Report on the Inland Flood Study*, provides practical guidance for modelling the impact of climate change.

While the project life is expected to be only 25 years, the shortest time frame addressed in the document is the year 2050, 37 years from 2013. While conservative, the longer horizon was adopted for climate change modelling in the absence of guidance for short timeframes.

The document recommends adopting a 2 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.

Overall, while the increased flows due to climate change did increase flooding through the catchment as a whole the areas specific to this project exhibited only slight sensitivity to the increases and in all cases the flood extents increased by an amount too small to affect the siting of infrastructure. This is demonstrated in Table 5-12 and Figure 5-58 and Figure 5-59. Both figures depict the worst increases within each respective catchment which were observed in the CGPF2 and 8 properties. Note that neither figure presents localised runoff and instead focuses on the flooding from the major watercourses, as this is where the most significant change occurred.

Table 5-12. Magnitude of flood depth increases due to climate change for the properties

Site	Approximate range of depth increase	Comments
The CGPF2 property	Up to 0.3 m, typically less	Negligible increase in flood extent
The CGPF7 property	Up to 0.15 m, typically less	Negligible increase in flood extent
The CGPF8 property	Up to 0.25 m, typically less	Showed the greatest variation in flood extents of all the sites
The CGPF9 property	Up to 0.2 m,	Negligible increase in flood extent
The TWAF F property	Up to 0.05 m	This site is almost completely unaffected by climate change

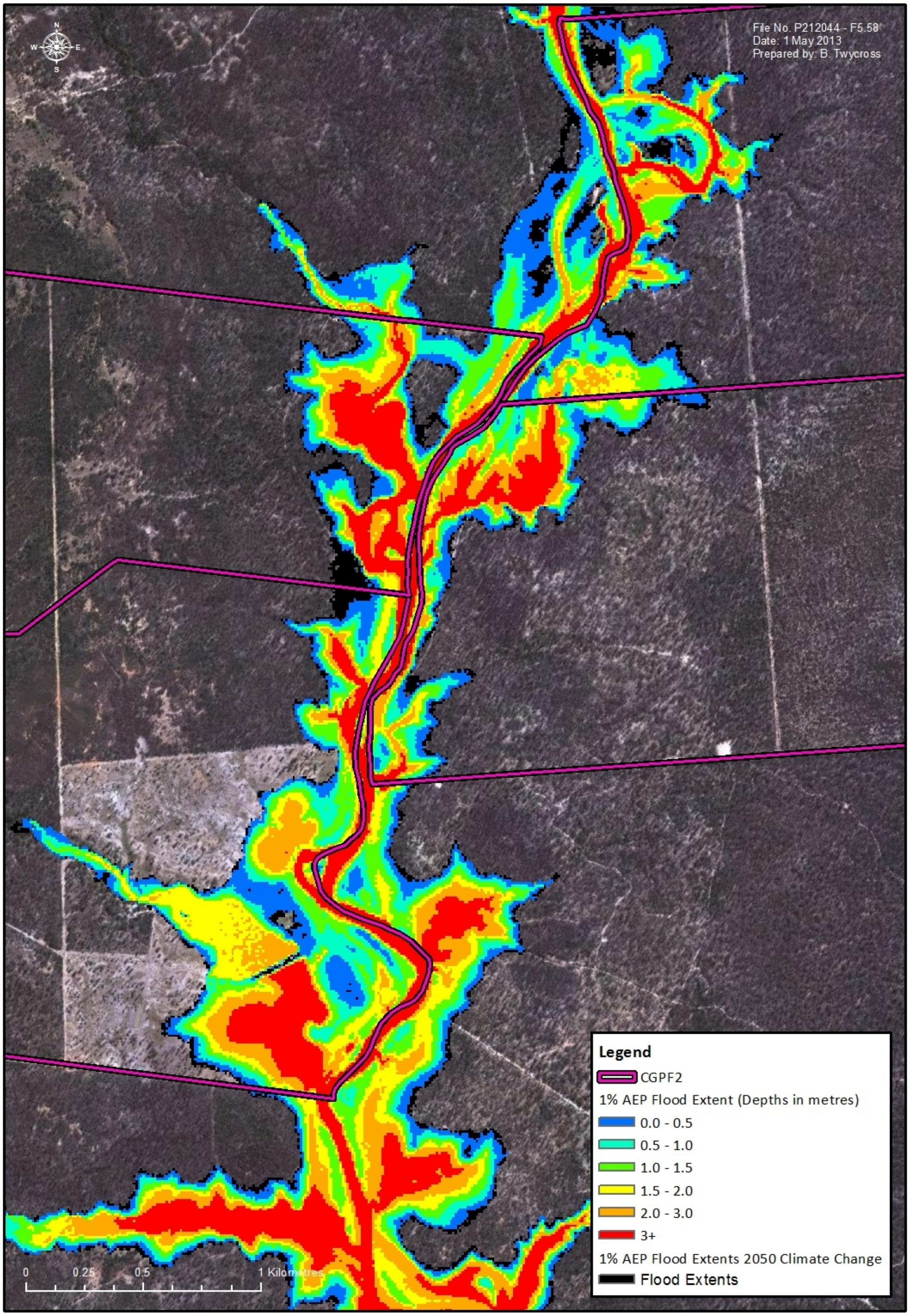

Figure 5-58. *Comparison of 1% AEP event flood extents through the CGPF2 property when accounting for climate change*

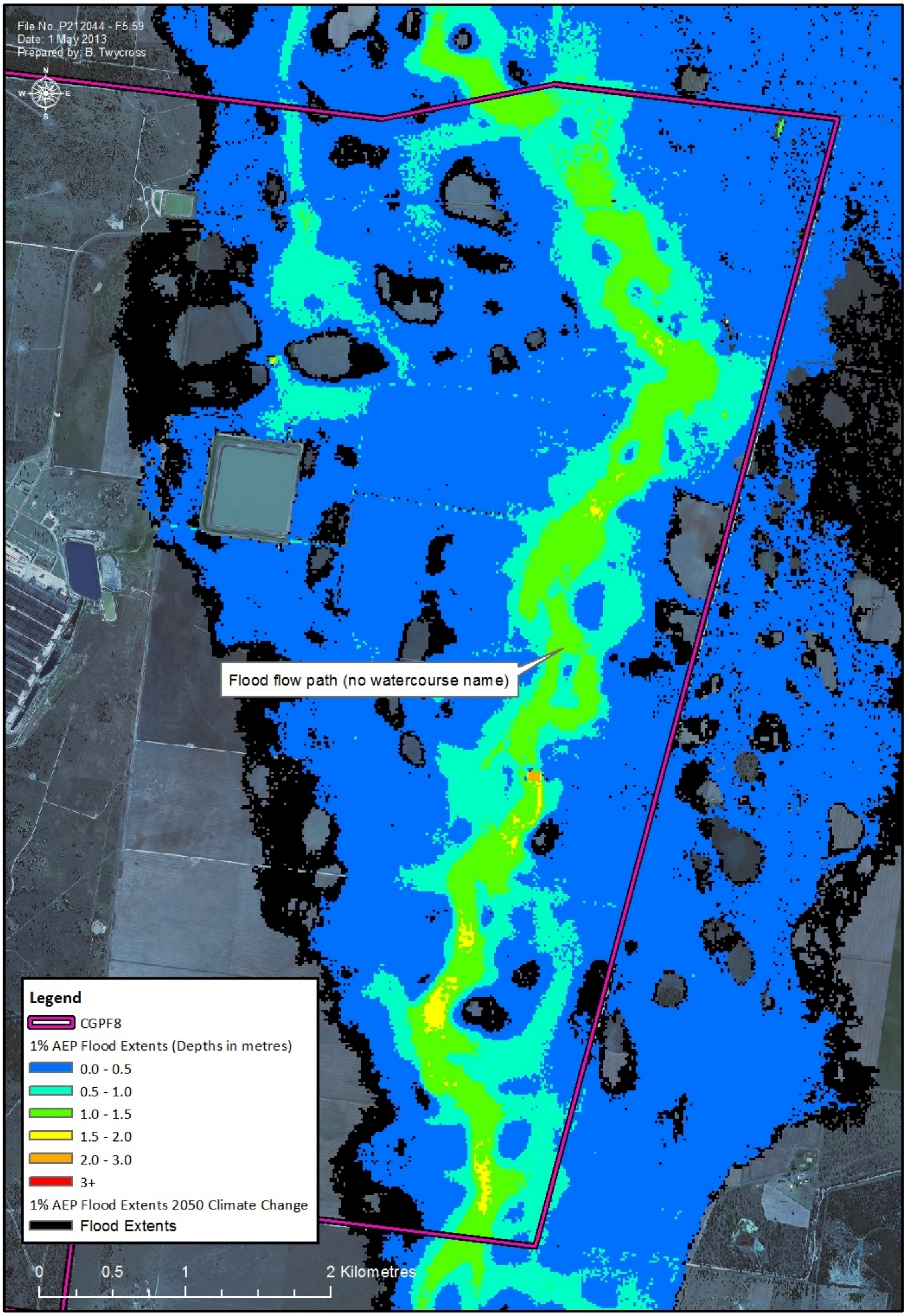

Figure 5-59. *Comparison of 1% AEP event flood extents through the CGPF8 property when accounting for climate change*

5.5 Hydraulic assessment for proposed surface water discharges

Bottle Tree Creek

The hydraulic models were run to compare the ACARP criteria with the hydraulic parameters estimated for Bottle Tree Creek under the following scenarios:

- no seasonal flow (and an additional 35 ML/d);
- no seasonal flow (and an additional 86 ML/d);
- the 1-in-2 year ARI flow (no discharge);
- the 1-in-2 year ARI flow (and an additional 35 ML/d);
- the 1-in-2 year ARI flow (and an additional 86 ML/d.

A tabulated summary of the results for each of these scenarios is provided in Table 5-13.

The graphs for two of these scenarios are illustrated in

Figure 5-60 and Figure 5-61. Firstly, a hydraulic parameter plot for the entire subject reach for the 2 year ARI event is presented in Figure 5-60. Secondly, Figure 5-61 illustrates what impact the discharges will have on stream parameters when 86 ML/d of treated or untreated coal seam gas water is released into the system when there is no existing flow in the reach (86 ML/d was chosen as it corresponds with 1.0 m^3/s which is the highest flow modelled for the stage discharge curve in Table 5-15).

Given the scenario of no seasonal flow and an additional 86 ML/d had negligible average stream parameters across the entire reach, the graph for the scenario of no seasonal flow and an additional 35 ML/d is not presented.

Similarly, given the additional 86 ML/d during a 1-in-2 year ARI flow event had negligible impact on the average stream parameters across the entire reach, the graph for the scenario of the 1-in2 year ARI flow event with an additional 35ML/d is not presented.

The graph of each parameter must be understood in context of local and reach scale geomorphic characteristics due to the dramatic appearance of spikes that exceed threshold levels. If these spikes are localised and not in consecutive cross sections then they do not necessarily represent an area of instability.

Table 5-13. Bottle Tree Creek reach existing hydraulic characteristics, various scenarios

Parameter	Units	Bowen Basin diversion design criteria (reach average)	Event	Modelled parameters		
				Minimum	Maximum	Average
Stream power	N/m.s	with vegetation <60	86 ML/d release only	0.00	124.21	4.27
			2 year ARI only (no discharge)	0.02	419.33	19.82
			2 year ARI + 35 ML/d release	0.02	418.86	19.84
			2 year ARI + 86 ML/d release	0.02	417.17	19.87
Velocity	m/s	with vegetation<1.5	86 ML/d release only	0.01	1.43	0.29
			2 year ARI only (no discharge)	0.10	2.43	0.96
			2 year ARI + 35 ML/d release	0.10	2.43	0.96
			2 year ARI + 86 ML/d release	0.10	2.43	0.96
Shear stress	N/m^2	<40	86 ML/d release only	0.00	86.69	5.40
			2 year ARI only (no discharge)	0.16	172.23	17.82
			2 year ARI + 35 ML/d release	0.16	172.06	17.84
			2 year ARI + 86 ML/d release	0.16	171.52	17.86

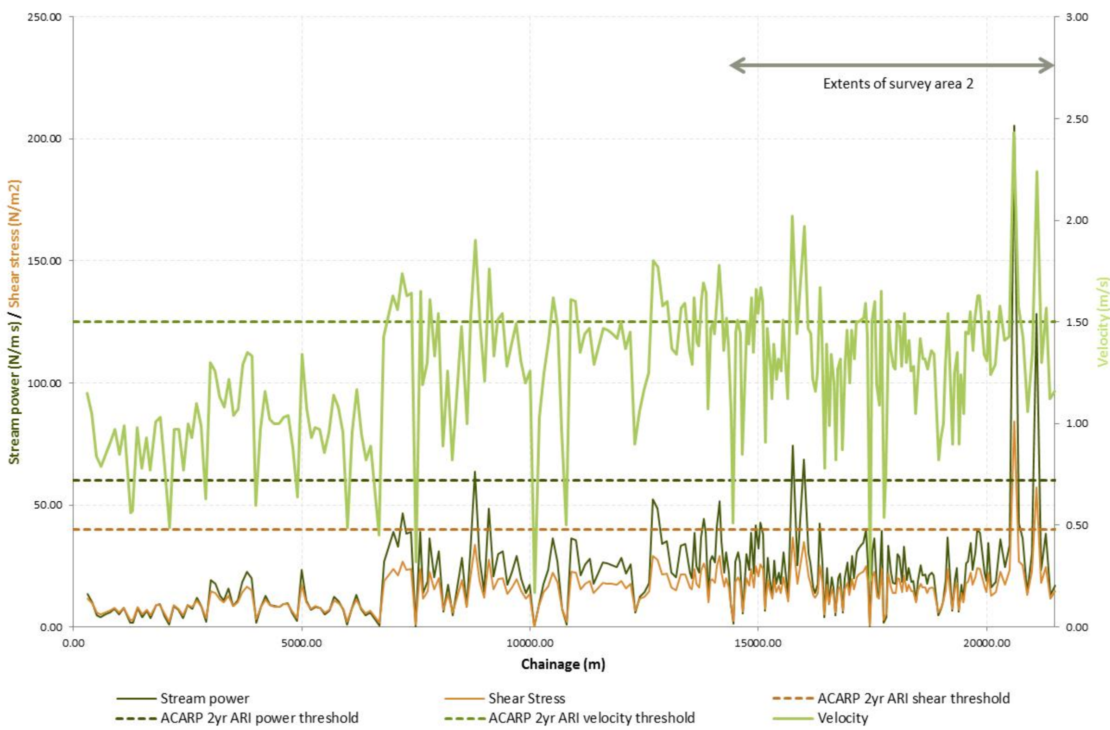

Figure 5-60. *Modelled 2 year ARI event hydraulic parameters for Bottle Tree Creek subject reach*

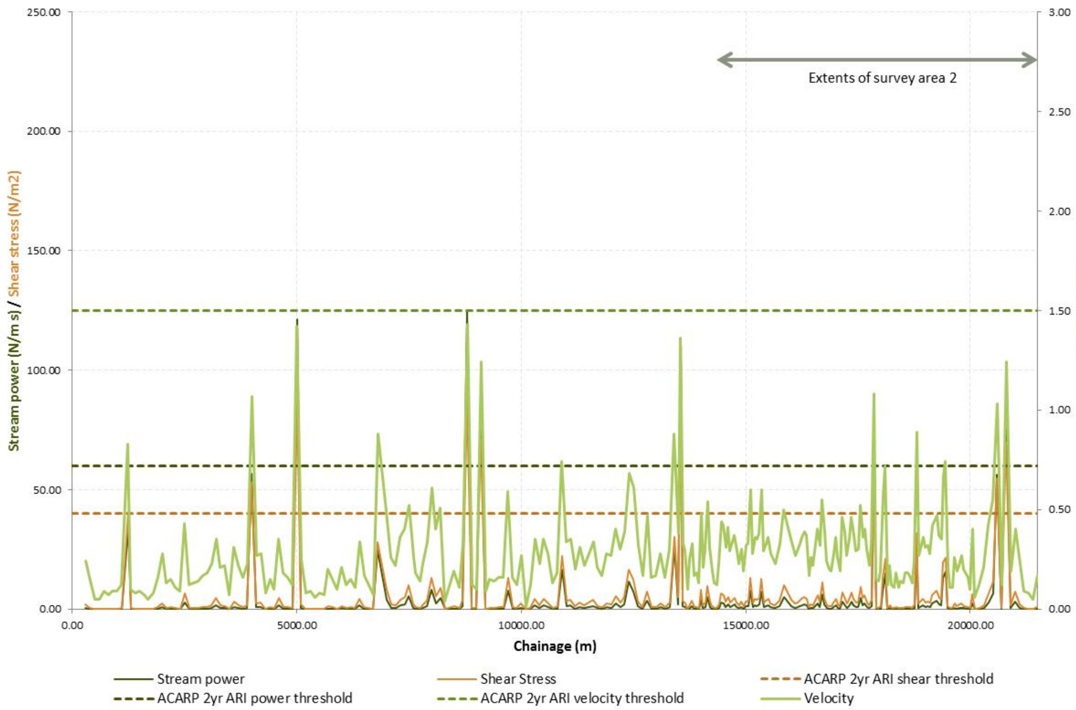

Figure 5-61. *Modelled hydraulic parameters for Bottle Tree Creek subject reach, when 86 ML/d is released when the reach is dry*

A plot of the cross section at chainage 14,600 in Figure 5-62 shows the depth of flow for a 2 year ARI, and also a 2 year ARI flow with a 35 ML/d release. The image in Figure 5-63 shows the approximate location of the cross section plot.

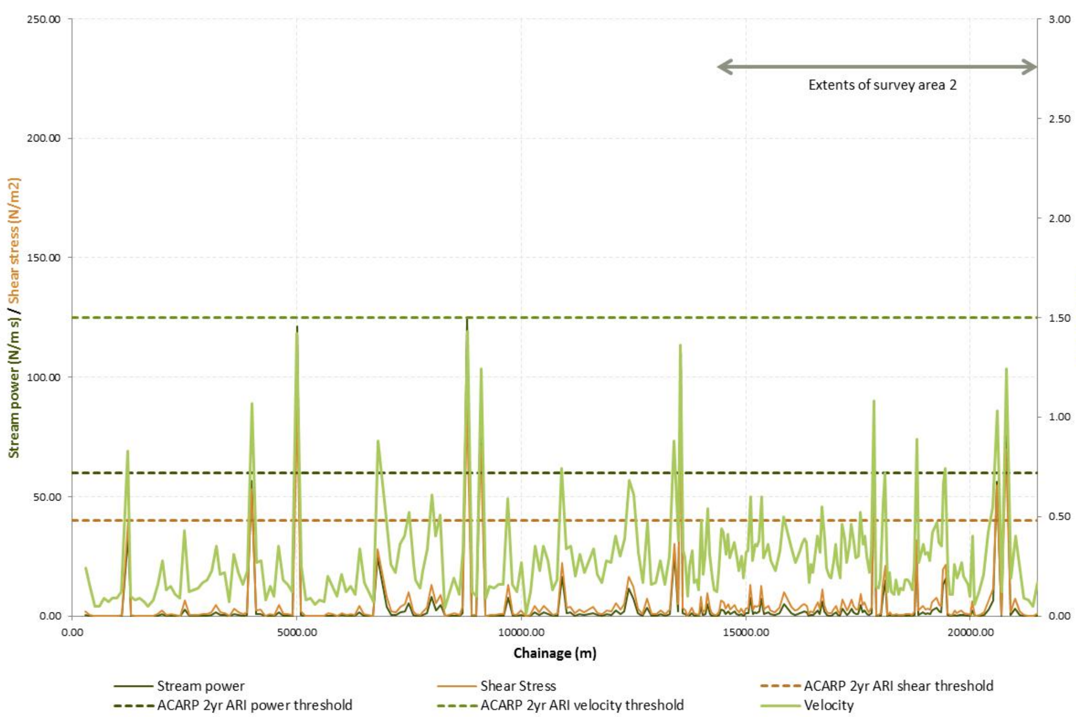

Figure 5-62. *Plot of cross section on Bottle Tree Creek at chainage 14,600 for 2 year ARI plus 35 ML/d release*

Figure 5-63. *Image of cross section on Bottle Tree Creek at approximate chainage14,600*

Figure 5-60 and Table 5-13 demonstrate that the average hydraulics of Bottle Tree Creek subject reach are well below the recommended ACARP parameters. Modelling indicates that with a combination of a 2 year ARI flow event, with an additional 35 ML/d discharge into the watercourse, the modelled parameters remained unchanged across the subject reach. Similarly, modelling indicates that with a combination of a 2 year ARI flow event, with an additional 86 ML/d discharge into the watercourse, the modelled parameters remained unchanged across the subject reach.

Based on the assumption that discharge per day is equal to processing rate of the water treatment facility, these results suggest that geomorphic change is unlikely to occur within the subject reach based on the proposed volume of treated or untreated coal seam gas water to be discharged, based on the assumption that discharge per day is equal to processing rate of the water treatment facility.

Given that the impact from the planned discharges on the 2 year ARI event was considered negligible, modelling was not undertaken for the 50 year ARI event.

Condamine River
The hydraulic models were run to compare the ACARP criteria with the hydraulic parameters estimated for Condamine River under the following scenarios:

- no seasonal flow (and an additional 90 ML/d);

- no seasonal flow (and an additional 130 ML/d);
- the 1-in-2 year ARI flow (no discharge);
- the 1-in-2 year ARI flow (and an additional 90 ML/d);
- the 1-in-2 year ARI flow (and an additional 130 ML/d.

A tabulated summary of the results for each of these scenarios is provided in Table 5-14.

The graphs for two of these scenarios are illustrated in Figure 5-64 and Figure 5-65. Firstly, a hydraulic parameter plot for the entire subject reach for the 2 year ARI event is presented in Figure 5-64. Secondly,

Figure 5-65 illustrates what impact the discharges will have on stream parameters when 130 ML/d of treated or untreated coal seam gas water is released into the system when there is no existing flow in the reach (130 ML/d was chosen as it corresponds with 1.5 m^3/s which is the highest flow modelled for the stage discharge curve in Table 5-16).

Given the scenario of no seasonal flow and an additional 130 ML/d had negligible average stream parameters across the entire reach, the graph for the scenario of no seasonal flow and an additional 90 ML/d is not presented. Similarly, given the additional 130 ML/d during a 1-in-2 year ARI flow event had negligible impact on the average stream parameters across the entire reach, the graph for the scenario of the 1-in2 year ARI flow event with an additional 90ML/d is not presented.

The graph of each parameter must be understood in context of local and reach scale geomorphic characteristics due to the dramatic appearance of spikes that exceed threshold levels. If these spikes are localised and not in consecutive cross sections then they do not necessarily represent an area of instability.

Table 5-14. Condamine River subject reach existing hydraulic characteristics, various scenarios

Parameter	**Units**	**Bowen Basin diversion design criteria (reach average)**	**Event**	**Modelled parameters**		
				Minimum	**Maximum**	**Average**
Stream power	N/m.s	with vegetation <60	130 ML/d release only	0.00	92.94	6.07
			2 year ARI	0.39	326.15	39.24
			2 year ARI + 90 ML/d release	0.39	322.45	39.15
			2 year ARI + 130ML/d release	0.38	320.25	39.10
Velocity	m/s	with vegetation<1.5	130 ML/d release only	0.03	1.39	0.26
			2 year ARI	0.30	2.71	1.14
			2 year ARI + 90 ML/d release	0.29	2.70	1.14
			2 year ARI + 130ML/d release	0.29	2.69	1.14
Shear stress	N/m^2	<40	130 ML/d release only	0.02	66.99	6.13
			2 year ARI	1.32	120.56	23.29
			2 year ARI + 90 ML/d release	1.31	119.60	23.26
			2 year ARI + 130ML/d release	1.30	119.01	23.25

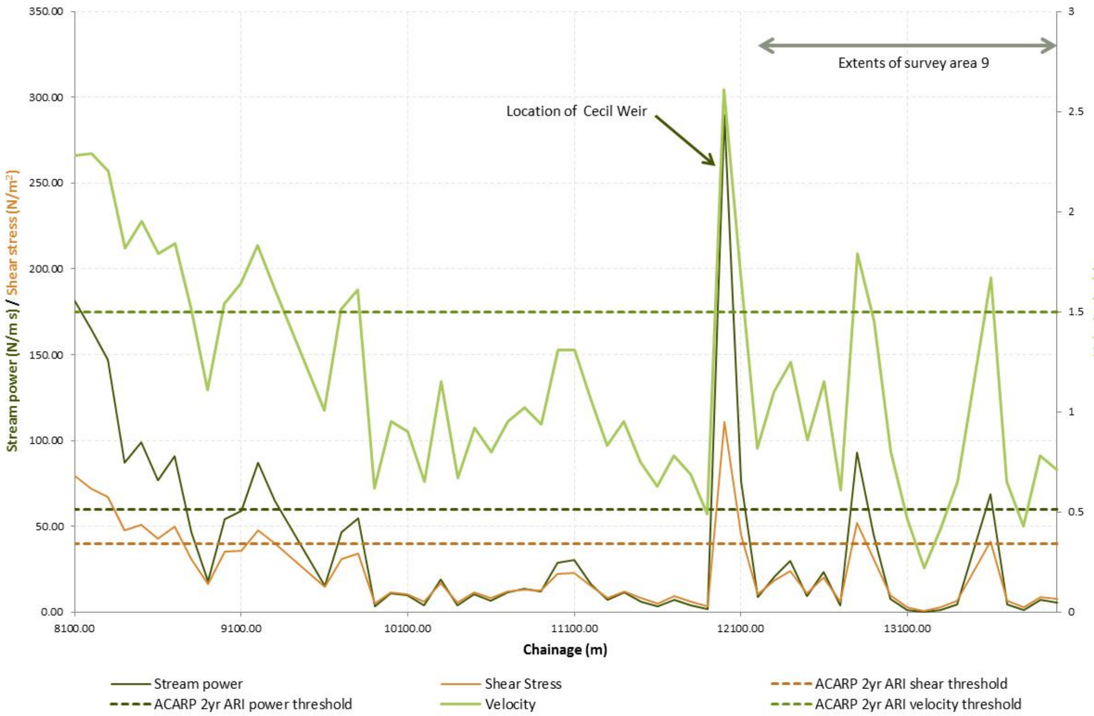

Figure 5-64. *Modelled 2 year ARI event hydraulic parameters for Condamine River subject reach*

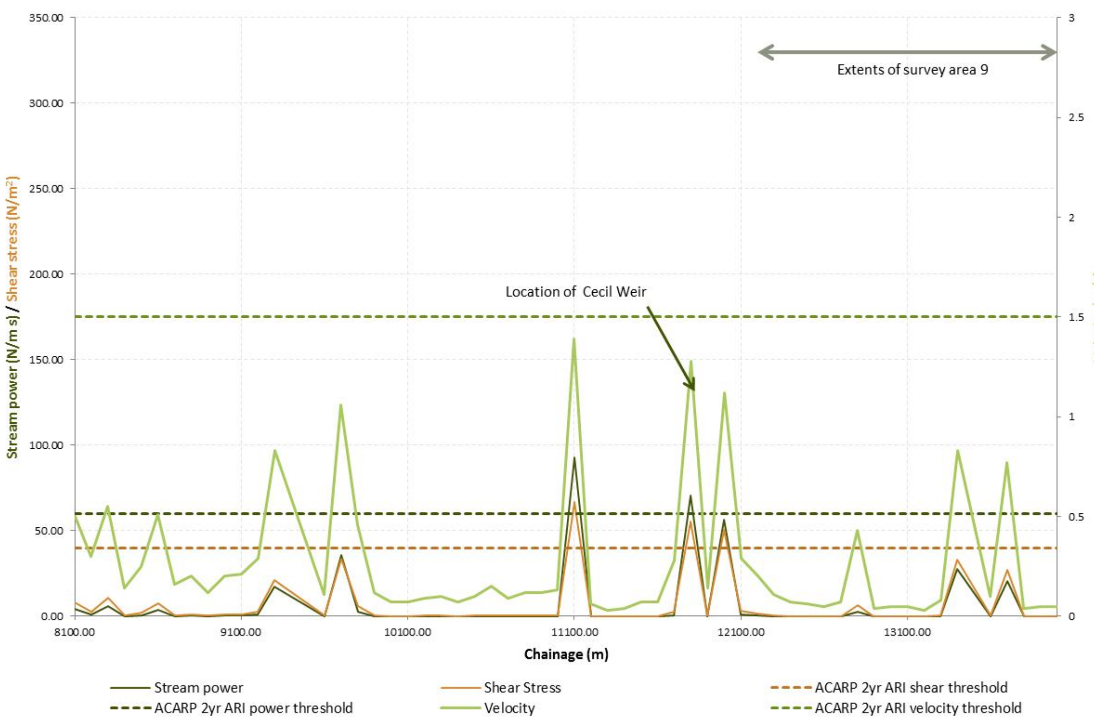

Figure 5-65. *Modelled hydraulic parameters for Condamine River subject reach, when 130 ML/d is released when the reach is dry*

A plot of the cross section at chainage 12,200 in Figure 5-66 shows the depth of flow for a 2 year ARI and also a 2 year ARI flow with a 90 ML/d release. The image in Figure 5-67 shows the location of the cross section plot.

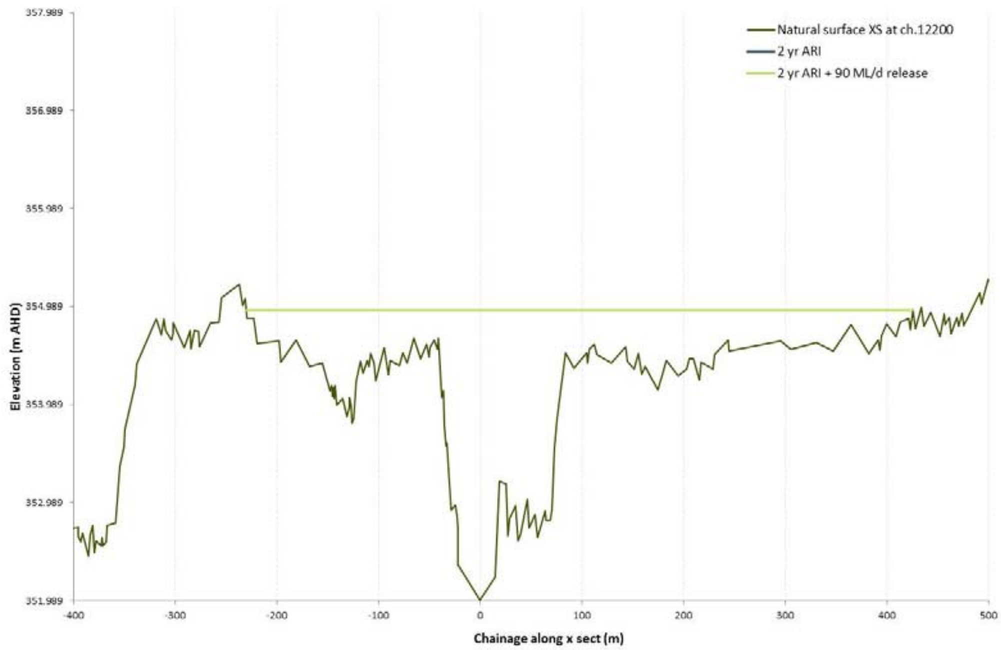

Figure 5-66. *Plot of cross section on Condamine River at chainage 12,200 for 2 year ARI plus 90 ML/d release*

Figure 5-67. *Image of cross section on Condamine River at approximate chainage 12,200*

Figure 5-64 and Table 5-14 demonstrate that the average hydraulics of the existing Condamine River subject reach are well below the recommended ACARP parameters. Modelling indicates that with a combination of a 2 year ARI flow event, and a 130 ML/d discharge into the watercourse, the modelled parameters remained unchanged across the subject reach. Similarly, modelling indicates that with a combination of a 2 year ARI flow event, with an additional 90 ML/d discharge into the watercourse, the modelled parameters remained unchanged across the subject reach.

Based on the assumption that discharge per day is equal to processing rate of the water treatment facility, these results suggests that geomorphic change is unlikely to occur within the subject reach based on the proposed volume of treated or untreated coal seam gas water to be discharged provided flows are released at an ecologically appropriate time.

Given that the impact from the planned discharges on the 2 year ARI event was considered negligible, modelling was not undertaken for the 50 year ARI event.

5.6 Stage discharge curves for the establishment of a gauging stations

Bottletree Creek

Based on the assumption that Arrow will discharge approximately 35 ML/d (equal to 0.41 m^3/s) into the channel at either of the two locations outlined in Table 5-1, flows ranging from 0.1 to 1 m^3/s were applied to the constructed model to allow for variability in the discharge rate. Refer to Figure 5-68 for the stage discharge curve.

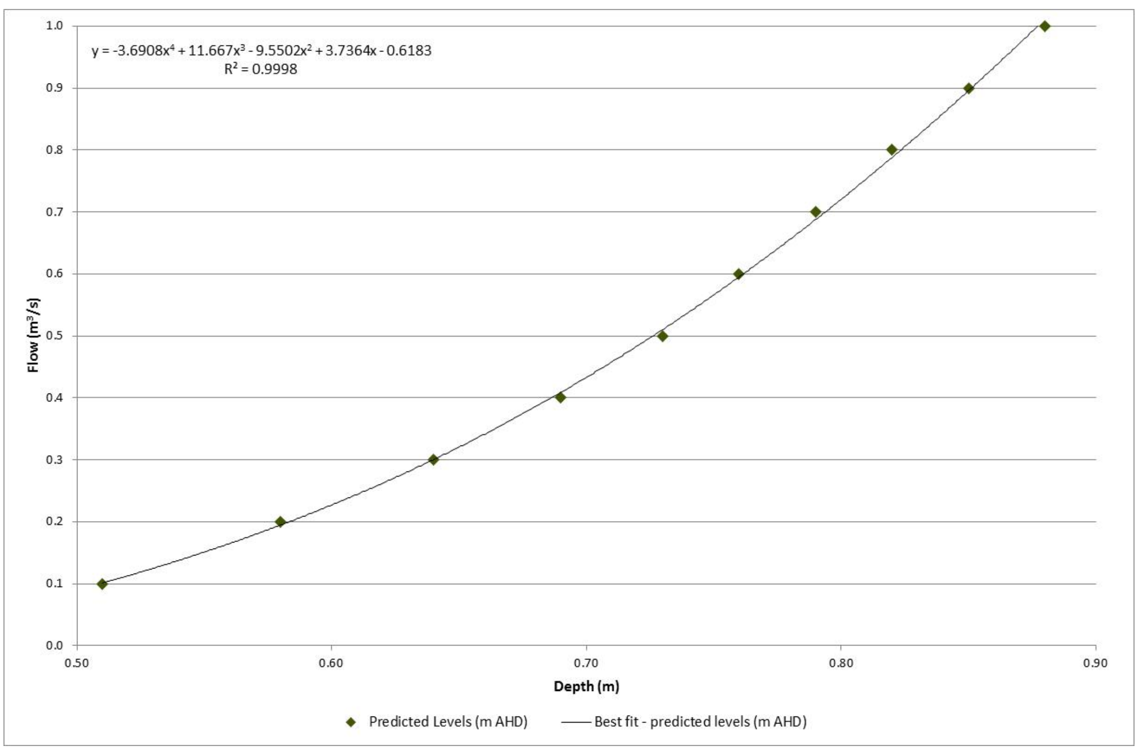

Figure 5-68. *Bottle Tree Creek stage discharge curve, 0.1 – 1 m^3/s*

The polynomial equation used to define the stage discharge curve for the Bottle Tree Creek gauging station is presented in Table 5-15. To obtain a more accurate fit for the curve, it was necessary to use a fourth order polynomial for the channel.

Table 5-15. Bottle Tree Creek stage discharge curve equation and associated R^2 value

Curve	Equation (based on 300.07m AHD invert)	R^2 Value
0.1 – 1 m^3/s	$y = -3.6908x^4 + 11.667x^3 - 9.5502x^2 + 3.7364x - 0.6183$	0.9998

Results show that for the stage discharge curve, the depth of water ranges from 0.51m for a 0.1 m^3/s flow to 0.88m deep for a 1.0 m^3/s flow.

Condamine River

Based on the assumption that Arrow will discharge approximately 90 ML/d (equal to 1.04 m^3/s) into the channel, either into the Cecil Weir pool or downstream of the Cecil Weir, flows ranging from 0.1 to 1.5 m^3/s were applied to the model. Refer to Figure 5-69 for the stage discharge curve at the proposed location in the Cecil Weir pool, and refer to Figure 5-70 for the stage discharge curve at the proposed location downstream of the Cecil Weir.

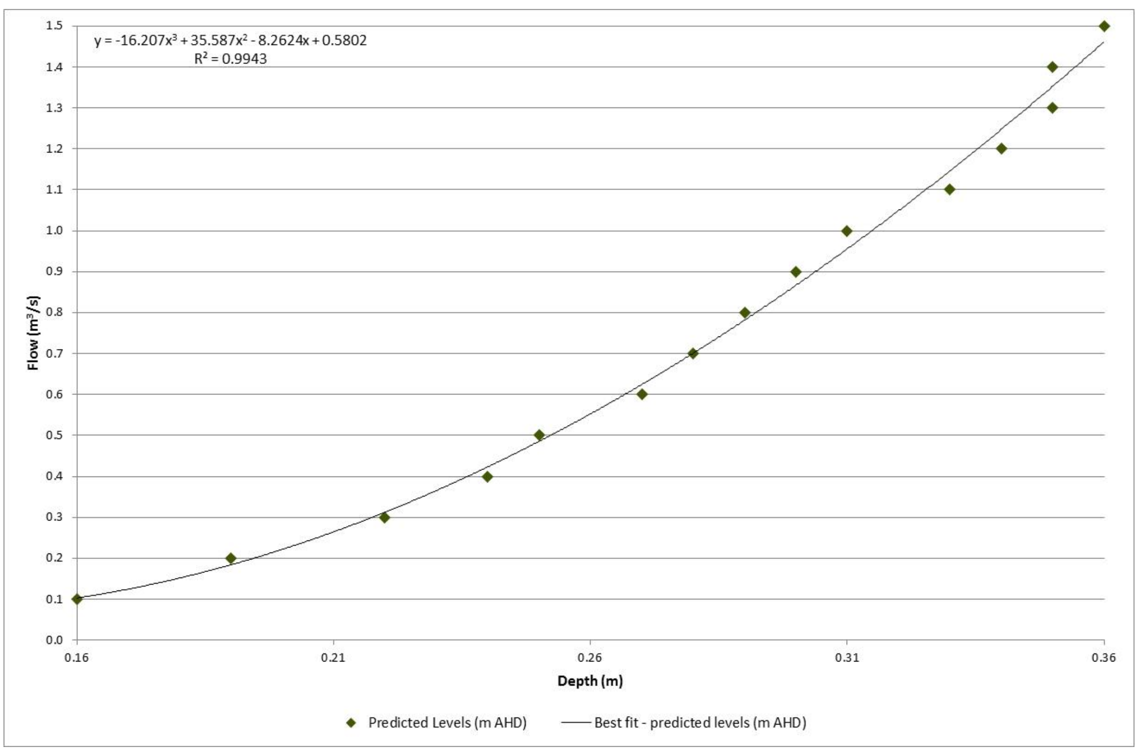

Figure 5-69. *Condamine River stage discharge curve in Cecil Weir pool, 0.1 – 1.5 m^3/s*

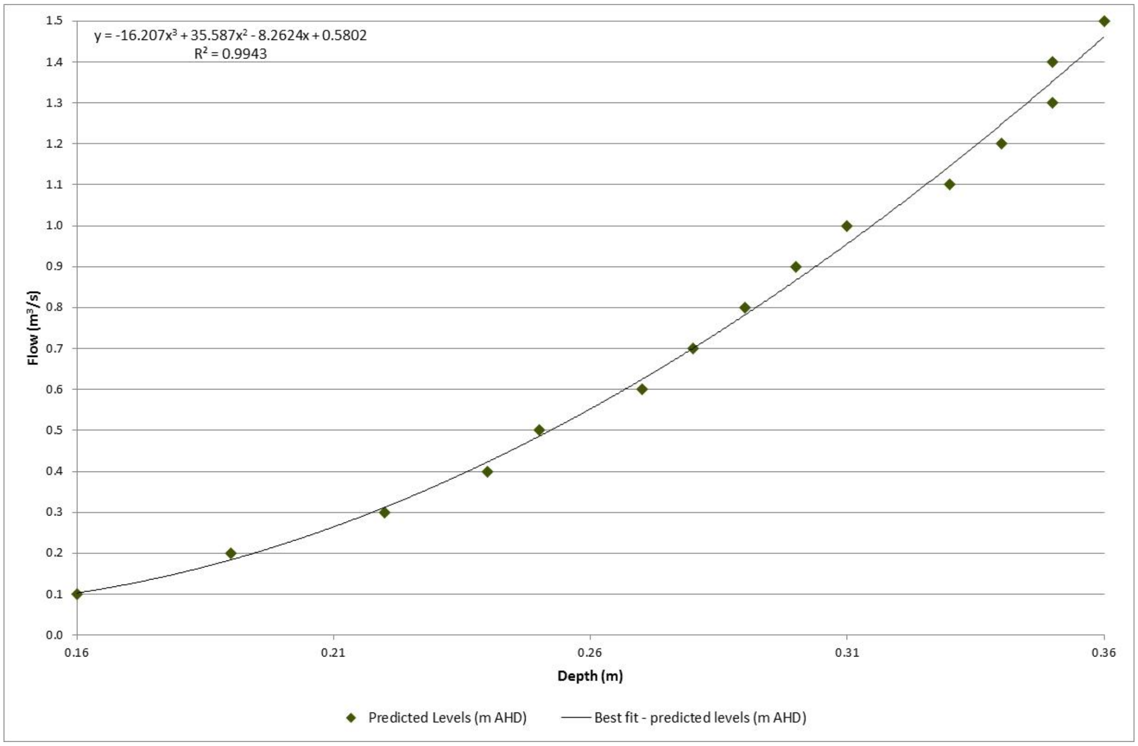

Figure 5-70. *Condamine River stage discharge curve downstream of Cecil Weir, 0.1 – 1.5 m³/s*

The polynomial equations used to define the stage discharge curves for the Condamine River gauging stations are presented in Table 5-16.

Table 5-16. Condamine River stage discharge curve equation and associated R^2 value

Curve	Based on AHD invert (m)	Equation	R^2 Value	Applicable range (m^3/s)
Cecil Weir pool	351.99	$y = -16.207x^3 + 35.587x^2 - 8.2624x + 0.5802$	0.9943	0.1 – 1.5
Downstream of Cecil Weir	347.03	$y = -1.0287x^3 + 5.848x^2 - 2.8747x + 0.4501$	0.9995	0.1 – 1.5

Results show that for the stage discharge curve in the Cecil Weir (upstream of Cecil Weir), the depth of water ranges from 0.16 m for a 0.1 m^3/s flow to 0.36 m deep for a 1.5 m^3/s flow. Results also show that for the stage discharge curve downstream of Cecil Weir, the depth of water ranges from 0.33 m for a 0.1 m^3/s flow to 0.83 m deep for a 1.5 m^3/s flow.

5.7 Gauged daily flows at Gil Weir on Dogwood Creek and Cecil Weir on Condamine River

Gil Weir Dogwood Creek (includes Bottle Tree Creek catchment)

For the Gil Weir data, the total catchment is approximately 3000 km^2. The Bottletree Creek catchment is approximately 435 km^2 (14.5% of the overall catchment). The average days with flows exceeding various low flow thresholds (in m^3/s) calculated from the flow data available since 1949 are provided in Figure 5-63.

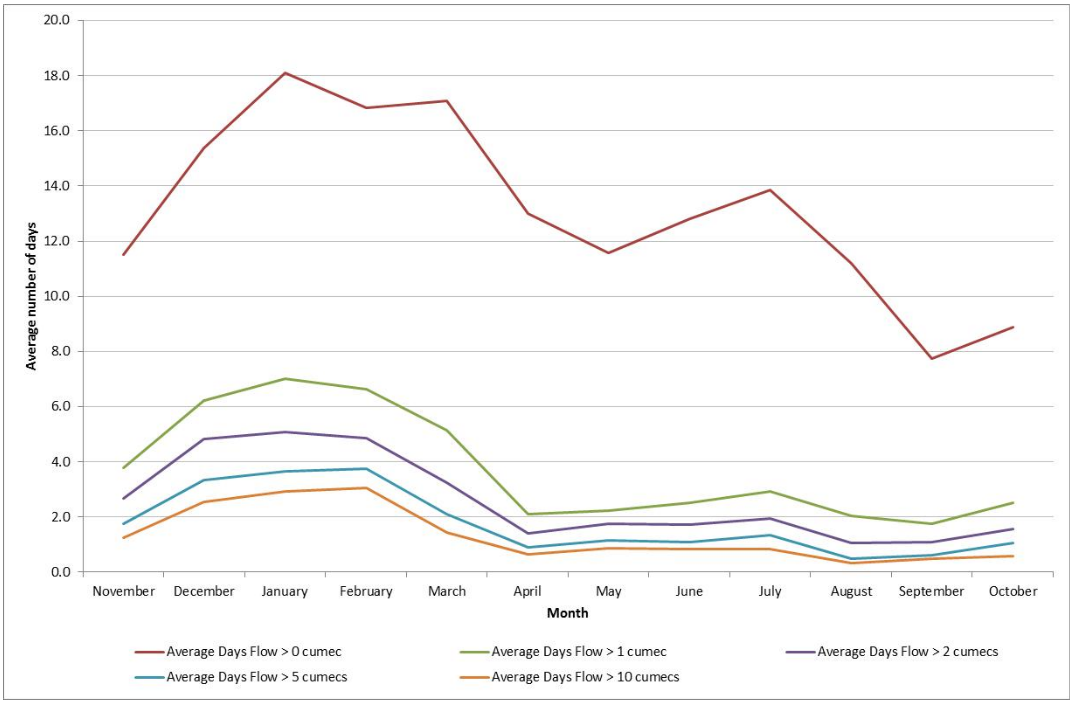

Figure 5-71. *Dogwood Creek at Gil Weir (422202B), average number of days exceeding flow thresholds*

Condamine River

The average number of days with flows exceeding various low flow thresholds (in m^3/s) calculated from flow data since 1972 are provided in Figure 5-72.

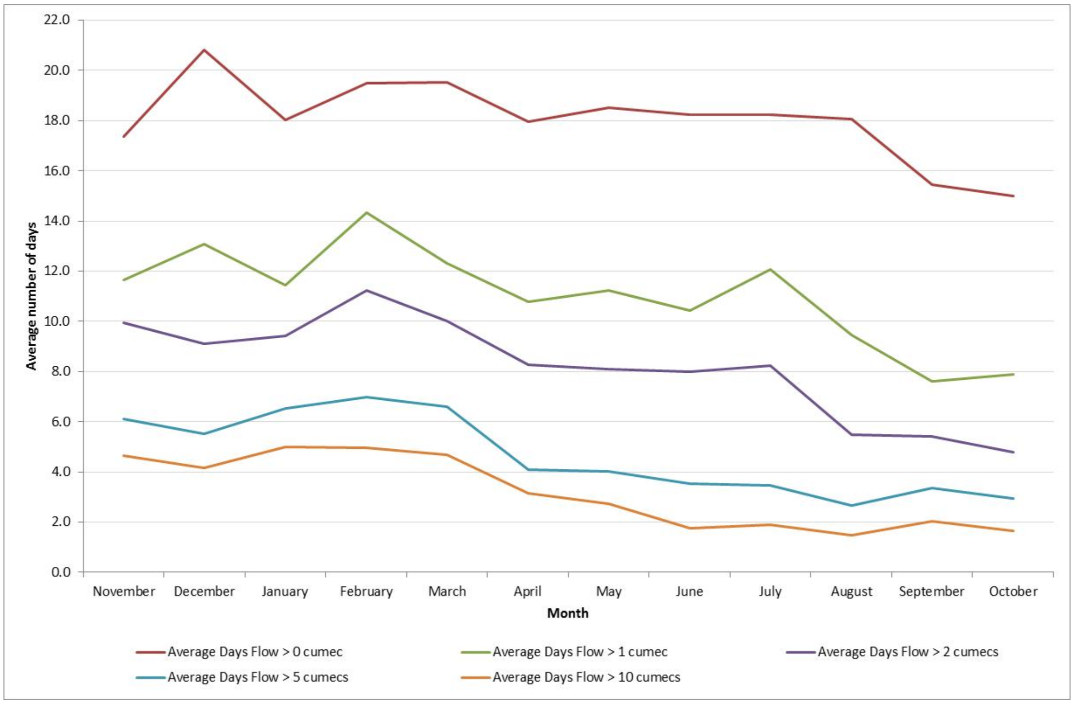

Figure 5-72. *Condamine River at Cecil Weir (422316A), average number of days exceeding flow thresholds*

5.8 Cumulative impacts

Geomorphic and hydrologic impacts are only two aspects of broader potential environmental impacts and as such have been considered within the context of a preliminary environmental flows assessment and strategy (provided as a separate report (Alluvium 2013)). Cumulative impacts due to all other planned developments will require further assessment once details of those developments become available. Details of release regimes from other projects were not available at the time of preparing this report and therefore could not be considered as part of the geomorphology and hydrology assessment. It is expected that a further detailed assessment will be required that will include an assessment of the cumulative impacts of water discharges from other projects.

Arrow has an Environmental Authority for the discharge of coal seam gas water to an unnamed tributary of Wilkie Creek (a tributary of the Condamine River). A condition of the Authority is that releases to waters must be undertaken so as not to cause erosion of the bed and banks of the receiving waters, or cause a material build-up of sediment in such waters. As such any cumulative impacts can be expected to be negligible but further investigations should be undertaken where necessary at a later date once details of all other project discharges are known.

Beneficial use

It should be noted that the Condamine River system is heavily altered from its pre-European settlement condition including extraction for irrigation, land clearance, dams and drains. The opportunity for the release of treated and untreated coal seam gas water to more closely mimic its pre-European flows could be explored as a potential beneficial use.

6 Assessment of impacts and risks

6.1 Potential impacts to surface water from subsidence

Coffey Environments completed a Groundwater Impact Assessment (included as Appendix G in the EIS) of the proposed Surat Gas Project in February 2012. This report found that as the depressurisation of the wells occurs over a vast spatial area of the Surat Basin, and the layer of the coal bearing formations is deep, 'the likely effects of any subsidence are considered unlikely to have significant impacts on structures at the surface' (Coffey Environments, 2012, p77). This section provides an overview of the available information and literature relating to subsidence in Queensland since publication of the EIS and, based on the literature review, identifies the potential impacts to surface water systems.

There are a number of works which have addressed a range of natural resource and environmental matters, in juxtaposition with overviews of economic and social issues associated with exploration and production of coal seam gas in Australia. Given the high level of technical proficiency required to assess these issues, coupled with the multi-disciplinary and multi-layered requirements, these reports tend not to be exhaustive. However, three of these types of reports were useful in the development of this section. In addition to the available literature discussed, the Office of Water Science (a group within SEWPaC) is currently undertaking investigations into subsidence across Queensland. Arrow Energy will consider this information when it becomes available.

Firstly, Williams (2012) prepared a report for the Australian Council of Environmental Deans and Directors in October 2012, which provides an analysis of coal seam gas production and natural resource management in Australia. The report suggests that it is generally understood across the industry that subsidence within a landscape will occur to some degree when groundwater aquifers are dewatered (Williams, 2012).

Secondly, a report commissioned by the Australian Government Department of Sustainability, Environment, Water, Population and Communities (SEWPaC), and undertaken by Geosciences Australia in 2010, has recognised these multi-layered issues and attempted to provide some recommendations for cumulative impacts. It has also provided some key recommendations for a staged process of adaptive management of coal seam gas development, which can be accessed at Geosciences Australia (2010). The report has suggested that the structural integrity of aquifers in relation to groundwater transmission is unlikely to be significantly impacted by the proposed groundwater extraction in coal seam gas activities. It is noted that groundwater extraction may cause some aquifer compaction that is likely to result in a degree of subsidence (2010, p2). The review suggests that the overriding issue in coal seam gas development is 'the uncertainty surrounding the potential cumulative, regional scale impacts of multiple developments' (Geosciences Australia, 2010; Williams, 2012, p53).

In addressing the uncertainty surrounding cumulative impacts, Arrow Energy, in collaboration with Australia Pacific LNG (Origin), Queensland Gas Company (QGC) and Santos Limited, commissioned Altamira to undertake an InSAR Baseline Ground Motion Study (Altamira Information, 2012). The study was commissioned as part of conditions provided from SEWPaC to the three coal seam gas projects approved in Queensland.

The Altamira study was completed in 2012 and involved analysis of ground motion between December 2006 and February 2011 using InSAR (Interferometric Synthetic Aperture Radar) satellite imagery technology in the Surat and Bowen Basins. The use of high resolution and wide swath SAR data provides an accurate and detailed solution to measure local ground motion on a regional scale. Within the timeframe of the baseline monitoring, coal seam gas development was underway in the Surat basin, including Arrow's Dalby Expansion Project.

Based on the results of this study, Alluvium concludes that:

- In terms of flood risk, the observed changes in ground elevation that occurred during the baseline monitoring timeframe are substantially smaller than the tolerances allowed for when configuring the 2D hydrodynamic models. In essence, the vertical accuracy of the terrain data or the tolerances used in configuring the hydrologic and hydrodynamic models is greater than the observed changes in ground elevation that have been observed to date.
- The broad flood plain across the Condamine River catchment suggests that changes to the topography would have minimal if any impact on flood levels.

In summary, historical monitoring of subsidence shows the area to be stable and does not provide evidence of significant enough changes to surface topography between 2006 and 2011 to be able to identify significant risks to surface hydrologic or geomorphologic processes. However, if further investigations provide a greater level of accuracy or indicate greater levels of subsidence than indicated in the reviewed literature to date then the risks should be reassessed.

Alluvium suggests that the impact to surface water systems, and in particular geomorphic values, are expected to be minor in terms of risk of adverse geomorphic impacts. In a worst case scenario, if there is differential subsidence at a local scale in low resilience waterways there could theoretically be some induced geomorphic impacts or alteration in flood behaviour or flows in anabranching or anastomosing systems, which may influence geomorphic processes.

If this was to occur then management intervention to increase erosion resistance or mitigate changes in flow distribution may be required. However, the large areas involved and the lack of possible detailed modelling makes a site specific assessment impossible. The impact on waterways over broader scales, and on steeper and more resilient waterways, is not expected to be discernible. The mitigation and management measures for addressing these impacts are outlined in Section 7.

6.2 Potential impacts of site specific project activities

A range of potential impacts have been identified for the following sites and activities:

- The CGPF2 property (construction of infrastructure and discharge of coal seam gas water);
- The CGPF9 property (construction of infrastructure and discharge of coal seam gas water);
- The CGPF7 property (construction of infrastructure);
- The CGPF8 property (construction of infrastructure); and
- The TWAF F property (construction of infrastructure).

The CGPF2 property Bottle Tree Creek and Dogwood Creek

Potential impacts from proposed activities

Generic impacts have been identified previously in the EIS (Alluvium, 2011) and while specific infrastructure plans have not yet been developed for the properties, it is possible to provide an assessment of potential site specific risks. Depending upon the final infrastructure design, the risks associated with the current condition as identified above could be exacerbated by construction, operation and decommissioning activities. Impacts are outlined below.

Bottle Tree Creek within the CGPF2 property

- Concentration of stormwater runoff leading to overbank flows and bank erosion
- Failure of the bund covering the original outlet point of the natural wetland in BC-R5 leading to dewatering.
- Exacerbated gullying of the farm dam spillway and associated downstream flow path.
- Erosion and sedimentation resulting from construction activities.
- Flooding of project infrastructure if located below at least the 1% AEP flood level as shown in Figure 5-43.
- Disturbance of mapped wetlands by encroachment of project infrastructure.
- Hydrology (flow regime) changed in Bottle Tree Creek and downstream into Dogwood Creek due to increased flows from the discharge of treated coal seam gas water.
- Bed and bank erosion in Bottle Tree Creek and downstream into Dogwood Creek increased above current levels due to increased flows from the discharge of treated and untreated coal seam gas water.

Bottle Tree Creek and Dogwood Creek downstream from the CGPF2 property:

- Hydrology (flow regime) changed in Bottle Tree Creek and downstream into Dogwood Creek due to increased flows from the discharge of coal seam gas water.
- Reduced access across Bottle Tree Creek and Dogwood Creek due to extended flows from discharge of coal seam gas water.
- Bed and bank erosion in Bottle Tree Creek and downstream into Dogwood Creek increased above current levels due to increased flows from the discharge of treated and untreated coal seam gas water. The sudden decrease of flows if discharges are immediately terminated could also initiate slumping at the toe of banks in sandy soils and requires consideration in flow management.

The CGPF9 property

Potential impacts from proposed activities

Generic impacts have been identified previously in the EIS (Alluvium, 2011) and whilst specific infrastructure plans have not yet been developed for this site it is possible to provide an assessment of potential site specific risks as follows:

Condamine River at the CGPF9 property

- Proposed infrastructure at this location could have negative impacts upon reach CR-R1 if it results in increased run-off, which could exacerbate the tunnel and gully erosion already occurring extensively on the left bank. Whilst a lower risk than CR-R1, reach CR-R2 also has some current erosion issues and will require consideration of the impacts of runoff from proposed infrastructure.
- If coal seam gas water were discharged at either CR-R1 or CR-R2, it would most likely increase bank erosion, with even an increase in low flows potentially destabilising the toe of the banks through these reaches.
- Any infrastructure proposed which may impact upon reach CR-R4, Crawlers Creek, needs to consider the risk of increased run-off, which could exacerbate existing instabilities. As this creek is currently undergoing geomorphic adjustment in response to current land condition and flood flows it is inherently unstable. Concentration of overland flows from project infrastructure or the discharge of treated or untreated coal seam gas water could exacerbate existing erosion unless significant erosion control management works were implemented.
- Flooding of project infrastructure could occur if it is located below at least the 1% AEP flood level as shown in Figure 5-48.

Condamine River downstream from the CGPF9 property

- Increased and prolonged increases in current flows from the discharge of coal seam gas water could increase already occurring erosion at a number of locations downstream from the CGPF9 property.
- The flood channel linking the Condamine River and the Condamine River (North Branch) could experience increased bank erosion if flows in this channel are increased due to increases in current flows from the discharge of coal seam gas water.
- The mapped palustrine wetland downstream from the CGPF9 property is located in an area of the Condamine River undergoing active lateral adjustment, with significant bank erosion occurring near the downstream end of the wetland. Erosion could continue to proceed towards the wetland, compromising the wetland. This process could be exacerbated by prolonged increases in current flows from the discharge of coal seam gas water.

The CGPF7 property

At this site (as described in Section 5.2) there are two mapped watercourses and one unmapped watercourse. The unmapped watercourse is included in this assessment because it is a chain of ponds geomorphic type, which is particularly susceptible to erosion if disturbed.

On both watercourses there are some relatively minor current instabilities. These instabilities will require monitoring and could be exacerbated if project activities cause disturbance or if there is a concentration of flows from runoff due to drainage from project infrastructure. The discharge of coal seam gas water is not being considered at this site and is consequently not considered as a risk. Overall risks are assessed as being:

- The initiation of erosion in the watercourse if it is disturbed by pipeline or track crossings or by the concentration of flows from project infrastructure.
- Flooding of project infrastructure if located below at least the 1% AEP flood level as shown in Figure 5-45.

The CGPF8 property

The CGPF8 property has two watercourses running through the property (as described in Section 5.2). The north western tributary running south to north through the existing well field is an intact valley fill and the main watercourse feeding the nationally important wetland (listed in the Directory of Important Wetlands in Australia (Environment Australia, (2001)), Lake Broadwater (off tenure). This stream type is highly susceptible to erosion, and concentration of overland flows from project infrastructure or removal of vegetation could initiate erosion and incision through this waterway. Upstream propagation of an erosion head through this reach could endanger wells, pipelines and road infrastructure.

The Eastern watercourse, 'Longswamp', is an intact valley fill and runs south to north through the CGPF8 property for approximately 8 km and is not in the catchment of Lake Broadwater. This type of watercourse is also prone to erosion if disturbed. If disturbed, erosion can lead to incision, which can propagate upstream for long distances.

The discharge of coal seam gas water is not being considered at this site and is consequently not considered as a risk.

Overall risks are assessed as being:

- The initiation of erosion in watercourses if they are disturbed by pipeline or track crossings or by the concentration of flows from runoff from project infrastructure.
- Project infrastructure could be flooded if located below at least the 1% AEP flood level as mapped in Figure 5-46.

If the development of the CGPF at this site was to include significant areas of new water storages within the catchment of Lake Broadwater it could reduce the catchment area for runoff into the lake. Whilst in wet years this may not have any impact, in drier years any decrease in catchment area could have an adverse impact on inflows to the Lake. However, only limited water storage is proposed at this location with water to be transferred to one of the two water treatment facilities at the CGPF2 and 9 properties.

The TWAF F property - TWAF F

This site is only being considered for the location of a TWAF. It has two watercourses within the fringes of the property, each with minor current instabilities. The topography of the site is relatively high and flood risk for the 1% AEP flood level is low as shown in Figure 5-47. The relatively minor current instabilities on these watercourses will require monitoring and could be exacerbated if project activities cause disturbance or the concentration of flows due to drainage from project infrastructure.

7 Mitigation and management measures

7.1 Overview

As per the identified risks, project activities are considered by the site specific areas where potential infrastructure may be constructed and if there is the potential for discharge of coal seam gas water. The following sections identify recommended management measures for each of these.

7.2 Mitigation and management measures for site specific project activities

A range of mitigation and management measures (in addition to the generic recommendations identified in Section 6 of the EIS surface water technical report (Alluvium 2011)) are recommended for the following sites and activities:

- The CGPF2 property (construction of infrastructure and discharge of coal seam gas water)
- The CGPF9 property (construction of infrastructure and discharge of coal seam gas water)
- The CGPF7 property (construction of infrastructure)
- The CGPF8 property (construction of infrastructure)
- The TWAF F property - TWAF F (construction of infrastructure)

Common recommendations for all sites are:

- All major project infrastructure should be constructed above the 1% AEP flood levels as identified by the modelling detailed in this report. It is recognised that some infrastructure may need to extend into the flood envelope; in such cases the design of that infrastructure should include incorporation of the flood modelling to consider any potential off site impacts to overland flow and flooding regimes or impacts to that infrastructure.
- Avoid the concentration of overland flows discharging to watercourses where such flows could initiate erosion. Where this is not practical, site specific erosion control measures should be developed which may include such options as: rock protected batter drains, energy dissipation structures; vegetated drainage lines and swales.

Site specific recommendations

In regard to the discharge of treated coal seam gas water at the CGPF2 property (Bottle Tree Creek) and the CGPF9 property (Condamine River), a range of alternative uses are being considered by Arrow including use for irrigation and injection to aquifers, however, should the discharge of treated or untreated coal seam gas water be undertaken this report assumes the potential to discharge is up to the full range of produced treated water, which is approximately 35 ML/d at the CGPF2 property (Bottle Tree Creek) and approximately 90 ML/d at the CGPF9 property (Condamine River Include sentence stating that, however, to be thorough the models were tested up to a maximum discharge of 86 ML/d at the CGPF2 property and 130 ML/d at the CGPF9 property and discuss the mitigation measures of this below as well.

The CGPF2 property

This site is one of two where treated or untreated coal seam gas water is proposed to be discharged. This report has assumed that the discharge will be up to approximately 35 ML/d into Bottle Tree Creek, which is a tributary of Dogwood Creek. Within the Arrow owned property, two recommended locations suitable for the discharge of water have been identified from desktop hydraulic and field assessments. Those locations are at the downstream end of the property at points of good channel stability (rock bars) and are identified in Table 5-1. A flow of 35 ML/d (assumed to be a constant rate of flow) was modelled to ascertain channel stability and has been determined to not be an erosion risk. The discharges will alter the hydrology of Bottle Tree and Dogwood Creeks, and this has been considered as part of a preliminary environmental flows assessment (provided as a separate report (Alluvium 2013)). However, it is not considered to be a management issue for channel geomorphic stability unless proposed releases exceed those assessed within this report. A possible exception is the sudden decrease of flows if discharges are immediately terminated, which could initiate slumping at the toe of banks in sandy soils. However, this can be managed by gradual flow reduction to allow draining of saturated banks. In addition to the proposed discharge rate of approximately 35 ML/d (which is equivalent to 0.4 m^3/s) a range up to 1 m^3/s (86 ML/d) was also assessed as a margin of safety. This discharge rate was also determined to not be an erosion risk providing that gradual flow reduction is applied.

Downstream from the CGPF2 property, increased flow levels or durations above current conditions due to discharges of treated or untreated coal seam gas water could reduce crossing accesses on private properties and whilst not directly a geomorphic issue, will never-the-less require consideration. Where access crossings are required, discussions with landholders and site specific designs will be required.

Bottle Tree Creek is an ungauged watercourse and as such any recommendations in regard to the potential to vary discharges rates to account for seasonal variability have been considered in regard to flows as gauged at Gil Weir below Miles. This is not sufficiently close to the discharge point to provide accurate data to determine suitable timing of discharges. It is therefore recommended that a gauging station be established on Bottle Tree Creek in association with the discharge location specifically to gauge flows in Bottle Tree Creek and as input to determining an appropriate discharge regime for treated or untreated coal seam gas water.

In addition to the management of coal seam gas water discharges there are a number of site specific issues that require management. These would most appropriately be contained within the context of a site specific property management plan or ESCP and will be determined or influenced by the final infrastructure design. These management measures should consider the following:

- Rates of change of discharge should be varied gradually and not rapidly pulsed, to ensure that rapid drawdown of flow does not occur in the channel, as this will potentially exacerbate bank erosion by causing slumping.
- Erosion risk to the bund that contributes to the retention of water within the mapped wetland (see Figure 5-7) requires treatment to achieve stabilisation.
- Erosion risk to the existing farm dam spillway (see Figure 5-9) requires treatment to achieve stabilisation
- Existing bank erosion, which is considered to be partially a natural geomorphic process but also exacerbated by reduced vegetation cover from stock access and requires stabilisation to natural rates by managing stock access and encouraging increased riparian vegetation
- Any pipeline or track crossings of watercourses should consider at the design stages the most appropriate locations to minimise erosion risk and incorporate site specific erosion control management measures (e.g. perpendicular crossing on straight section of channel, bed level crossings, rock protection).

The CGPF9 property

This site is the second of two where treated or untreated coal seam gas water is proposed to be discharged. This report has assumed that the discharge will be potentially up to approximately 90 ML/d into the Condamine River. Two suitable discharge point locations (from a geomorphic consideration) have been identified. This has been done by desktop hydraulic analysis and supported by field assessments. Those locations are: into the existing weir pool created by Cecil Weir, which is the most stable reach; and downstream from the Cecil Weir at a point of good channel stability.

A flow of approximately 90 ML/d (assumed to be a constant rate of flow) was modelled to ascertain channel stability. The assessment has determined there is not an erosion risk from discharge at this location. However, current existing instabilities in the reach downstream from the discharge point could be exacerbated without some management intervention. In addition to the proposed discharge rate of approximately 90 ML/d (which is equivalent to 1.04 m^3/s), a range up to 1.5 m^3/s (130 ML/d) was also assessed as a margin of safety. This discharge rate was also determined to not be an erosion risk.

The discharge will alter the hydrology of the Condamine River, and this has been considered as part of a preliminary environmental flows assessment (provided as a separate report (Alluvium 2013)). It is expected that some management intervention will be required to ensure that current channel instabilities are not exacerbated by the discharge. Site specific management measures will be required to be developed based upon the final discharge regime.

Crawlers Creek is not a suitable discharge location for treated and untreated coal seam gas water due to its inherent instability. If it was determined for operational reasons that Crawlers Creek would be a preferred discharge location then substantive erosion control measure would be required to stabilise existing erosion and to prevent further erosion due to increased and extended flows.

The Condamine River at Cecil Plains Weir is gauged, which is expected to be suitable as the gauging point for the determination of suitable timing for the discharge of treated or untreated coal seam gas water.

In addition to the management of treated or untreated coal seam gas water discharges there are a number of site-specific issues that may require management. These management measures would most appropriately be within the context of a site specific property management plan or ESCP and will be determined or influenced by the final infrastructure design. These management measures should include the following:

- Avoiding any unnecessary disturbance of watercourses including trenching and track crossings during flow conditions and concentration of overland flows.
- Excluding or managing stock access to watercourses.
- Managing existing erosion in reach CR-R4, Crawlers Creek (see Figure 5-16), which may include site specific gully erosion (manage overland flows into gullies, rock protection and revegetation. Gullies should be stabilised before project activities are undertaken. Halting gully erosion will reduce the amount of sediment entering the creek, and therefore reduce the likelihood of avulsion and continued bank erosion.

- Managing existing erosion in reach CR-R1 of the Condamine River, which is upstream from the Gil Weir pool and is currently unstable and even increased discharges at low flows could increase existing bank instabilities. Management measures should include stock exclusion and revegetation.
- At the design stage, for all pipeline or track crossings of watercourses, consideration needs to be applied to the most appropriate locations to minimise erosion risk and incorporate site specific erosion control management measures (e.g. perpendicular crossing on straight section of channel, bed level crossings, rock protection).

The CGPF7 property

Additional recommendations for this site are limited to:

- At the design stage, for all pipeline or track crossings of watercourses, consideration needs to be applied to the most appropriate locations to minimise erosion risk and incorporate site specific erosion control management measures (e.g. perpendicular crossing on straight section of channel, bed level crossings, rock protection).

The CGPF8 property

Site specific recommendations:

- Undertake an assessment at the design stage to assess potential negative impacts that could change the hydrology of flows to Lake Broadwater. If any negative impacts are identified, develop measures to prevent such impacts.
- At the design stage, for all pipeline or track crossings of watercourses, consideration needs to be applied to the most appropriate locations to minimise erosion risk and incorporate site specific erosion control management measures (e.g. perpendicular crossing on straight section of channel, bed level crossings, rock protection).

The TWAF F property

Site specific recommendations:

- At the design stage, for all pipeline or track crossings of watercourses, consideration needs to be applied to the most appropriate locations to minimise erosion risk and incorporate site specific erosion control management measures (e.g. perpendicular crossing on straight section of channel, bed level crossings, rock protection).

8 Inspection and Monitoring

Inspection and monitoring recommendations have been presented in the EIS and are not repeated here. Site specific monitoring will be required to be developed for the discharge of treated and untreated coal seam gas water at the two proposed discharge points and associated reaches of watercourses at the CGPF2 and 9 properties.

An effective monitoring program will provide a mechanism to identify any management issues at an early stage and allow for appropriate management intervention. The following recommendations are based upon recognised waterway monitoring standards (*"Monitoring and Evaluation Program for Bowen Basin Diversions"* (ID&A 2001) undertaken for the Australian Coal Association Research Program (ACARP)) and have been adapted as a recommendation for this specific project.

Table 8-1. Monitoring package components

Monitoring package components	**Objective and timeframe**
1: Baseline monitoring	To establish a baseline data set that can be used for comparison with operations and relinquishment monitoring. To be undertaken prior to construction works. The geomorphic assessment undertaken for the SREIS can be used as the basis for the baseline together with the associated aerial imagery and survey data already held by Arrow.
2: Operations monitoring	To maintain channel condition and assist to identify issues that may arise. To be undertaken initially at 3 month intervals for twelve months and then if no significant management issues are identified, annually during the operational lifetime of the project (25 years).
3: Relinquishment monitoring	To demonstrate that the watercourses have not been adversely impacted by the discharges. To be undertaken annually post-decommissioning until such time as monitoring can demonstrate that the watercourses are operating without adverse impacts from the cessation of the discharges. If operations monitoring does not identify any recurring management issues it can be expected that relinquishment monitoring will only be required for a short number of years.

Table 8-2. Recommended monitoring program

Performance criteria	**Monitoring requirements**
Survival of Works	The survival of instream structural and rehabilitation works should be assessed during this phase of monitoring. Early detection of failure is likely to increase the options for remedial action. This will include any erosion control measures that may be required and crossing (if any) that may be required on Bottle Tree Creek or Dogwood Creek.
Index of Waterway Condition	Index of Waterway Condition (IWC) is a method of recording and monitoring the condition of waterways and adjacent upstream and downstream reaches. (Originally developed for diversions in the Bowen Basin as part of the ACARP program "*Monitoring and Evaluation Program for Bowen Basin Diversions"* (ID&A 2000)). IWC provides a rapid assessment of the condition of diversions and adjoining rivers or streams. It has been adapted to suit the particular circumstances for the project. The purpose of the IWC is to flag potential management issues rather than provide a scientific assessment. It is an integrated suite of indicators that measures the geomorphic and riparian condition of a waterway and its upstream control and downstream reaches.

Performance criteria	Monitoring requirements
	The geomorphic and riparian condition (index) of a reach is given a score out of 10 and the sum of these provides the IWC score. The IWC can be undertaken for each identified reach. As part of the IWC assessment, photographs will be taken to record the condition of each reach. The photographs will be taken from fixed points along the upstream and downstream reaches to allow future comparisons. The photographs will be added to a monitoring database.
Aerial Photographs	The most recently available aerial photographs should be used to assess the condition of the waterways over time. These photographs should be added to the monitoring database.
Survey	For each assessment reach, a cross-section survey and long-section survey can be prepared from digital topographic data, Lidar or photogrammetry and included as part of the monitoring database. This information will be used to monitor the performance of the waterways during operations and contribute to relinquishment monitoring to demonstrate that operations have had no adverse impacts on reaches. The cross-section surveys will include all changes in bed height and bank shape. The survey data will be added to the monitoring database. This task should not be onerous. Onground assessments by an experienced waterway professional will readily identify any significant erosion issues. Periodic survey (can be less than annual if the onground assessments do not identify any significant issues) will help to inform the onground assessment.
Vegetation	The species, abundance and diversity of vegetation in the waterways and control reaches will be recorded and added to the monitoring database.
Flow events	Flows from the discharges will need to be monitored. Recommended locations are as follows: • Gauging weir at discharge outfall on Bottle Tree Creek. • Existing Cecil Weir gauging station (If suitable and if the discharge outfall is located here. Requires assessment).

9 Conclusions

Geomorphic impacts at the CGPF2, 7, 8 and 9 properties and the TWAF F property

Desktop and field geomorphic assessments have been undertaken for all of the four known sites to locate central gas processing facilities (CGPF2, 7, 8 and 9 properties) and one site to locate a TWAF (the TWAF F property). It has been determined that all potential adverse geomorphic impacts can be managed through the application of the management recommendations detailed in Section 7. However, further detailed management actions will be required to be developed as part of site specific ESCPs and as part of detailed infrastructure design.

Flood risk

Flood modelling for the 1% AEP flood has been undertaken and flood extents have been mapped for all of the four known sites to locate central gas processing facilities (CGPF2, 7, 8 and 9 properties) and one site to locate a TWAF (the TWAF F property). At each site there is sufficient land available above the predicted flood extents to locate project infrastructure. Where this is not practical, flood modelling can be used to determine any potential impacts and assist with designing alternative layouts or developing mitigation measures to ensure that there are no adverse offsite impacts to overland flow and flooding regimes.

Changed hydrology

At the CGPF8 property, assessment is required at the detailed design stage of project infrastructure of any potential impacts to changed hydrology offsite that could reduce flows to Lake Broadwater. This may require the development of measures that prevent any potentially adverse impacts.

Discharge of coal seam gas water

The discharge of coal seam gas water will result in changed flow regimes in Bottle Tree Creek and Dogwood Creek at the CGPF2 property and in the Condamine River at the CGPF9 property. Whilst it has been determined that this can be achieved within a range of flows without causing significant geomorphic impacts it will never-the-less require assessment as part of potential ecological impacts. Flows will need to be gauged on Bottle Tree Creek, which will require the installation of a gauging weir and on the Condamine River, where the use of the Cecil weir gauging station is expected to be suitable. The determination of appropriate discharge volumes and frequencies to account for seasonal variations will need to be determined by potential ecological impacts rather than geomorphic impacts.

Beneficial use

The Condamine River system is heavily altered from its pre-European settlement condition including extraction for irrigation, land clearance, dams and drains. The opportunity for the release of coal seam gas water to more closely mimic its pre-European flows could be explored as a potential beneficial use. This has been considered as part of a preliminary environmental flows assessment (provided as a separate report (Alluvium 2013)). Further assessment of potential cumulative releases from other coal seam gas proponents will be required once details of those projects are available.

Potential impacts to surface water from subsidence

Historical baseline subsidence monitoring undertaken to date does not provide evidence of significant enough changes to surface topography to be able to identify significant risks to surface hydrologic or geomorphologic processes. Available relevant literature does not indicate that there are likely to be significant subsidence impacts related to coal seam gas extraction. However, if further investigations indicate greater levels of subsidence than estimated, and a more definitive link between coal seam gas extraction and surface subsidence than presented in the reviewed literature to date, then the risks should be reassessed.

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